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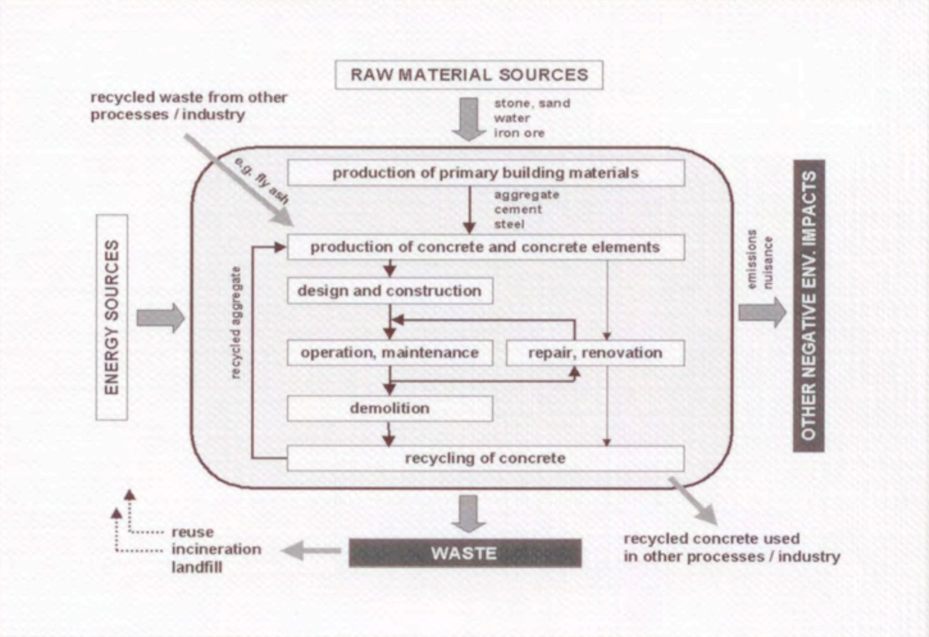

Environmental design

state-of-art report

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CEB•FIP

Environmental design

State-of-art report prepared by

Task Group 3.3

February 2004

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Cover picture: Life cycle of concrete structure – material and energy flows and consequent environmental impacts (see Fig. 5.3-1)

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Preface

The 20th century is the century in which material prosperity was intensely pursued by utilizing science and technology. As a consequence, the deterioration of the earth has become obvious to a great extent. Considering the future of developing countries, it is obvious that the 21st century needs to establish a system in which environmental conservation and restoration take precedence. In this meaning, there is no exception in human activities. Construction activities have been consuming almost 50% of natural resources and energy used in all industries in the world, and an indispensable construction material, concrete, has played a great role to provide a comfortable living, working, and productive environment. Concrete may be the ultimate environmental material because the eco-rucksack of concrete is comparatively light, although the production of carbon dioxide is large. However, it is estimated that more than a ton of concrete is produced each year for every human being on the planet – some 6 billion tons a year. The construction boom in developing countries and the reconstruction of infrastructures in developed countries will cause environmental impacts in the near future.

The design of concrete structures has been focused on safety for a long time. As a result, durability problems become more and more serious. It is easily understandable that a long lifespan of a structure will greatly reduce environmental impact. Energy consumption, CO_2 emission, and other environmental impacts are also important. In other words, environmental aspects should be incorporated into the conventional design process. TG3.3 aimed to make the framework of so-called environmental design, to document "Best Available Technology (BAT)" for concrete structures from an environmental point of view and to summarize methodologies for environmental impact evaluation and optimization of concrete structures. Although the authors of this state-of-the-art report were from Europe and Japan, it was attempted to collect information as widely as possible.

Finally, I would like to thank all members of TG3.3 for their devoted efforts and all members of Commission 3 for their constructive suggestions during the drafting of the report.

Takamatsu, January 2004

Koji SAKAI
Convenor of TG3.3
Chairman of Commission 3

Contents

1 Introduction

1.1 General

The global environment is a life-support system for human society. Human activities in the 20th century have not necessarily taken this fact into account. As a result, serious problems that concern the fate of mankind have emerged. Our main task in the 21st century can be summarized as how to understand and maintain complex systems of the global environment. This task must be accomplished without fail.

The changes in energy consumption all over the world are summarized in Fig.1-1. In developing countries, the energy consumption is dramatically increasing year by year. In order to maintain sustainable development, urgent improvement will be needed through technical assistance from industrialized countries. It should also be pointed out that the energy consumption per capita in OECD countries far exceeds that in non-OECD countries as shown in Table 1-1. As a result, emission of CO_2 (the most important greenhouse gas) shows almost the same trend.

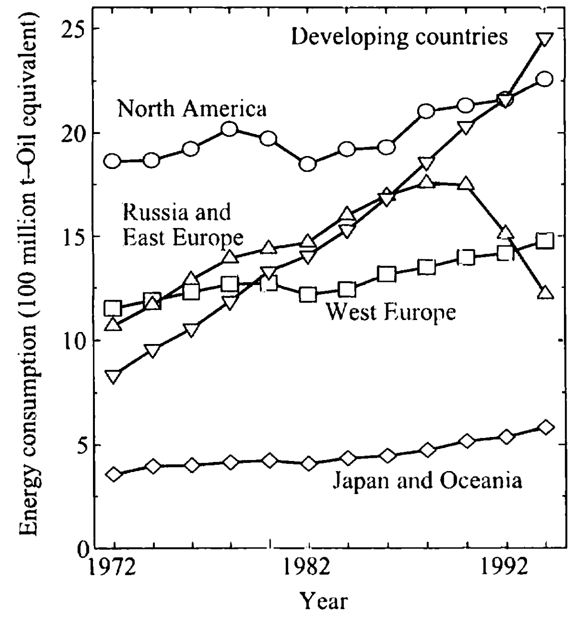


Fig.1-1: Energy consumption[1-1]

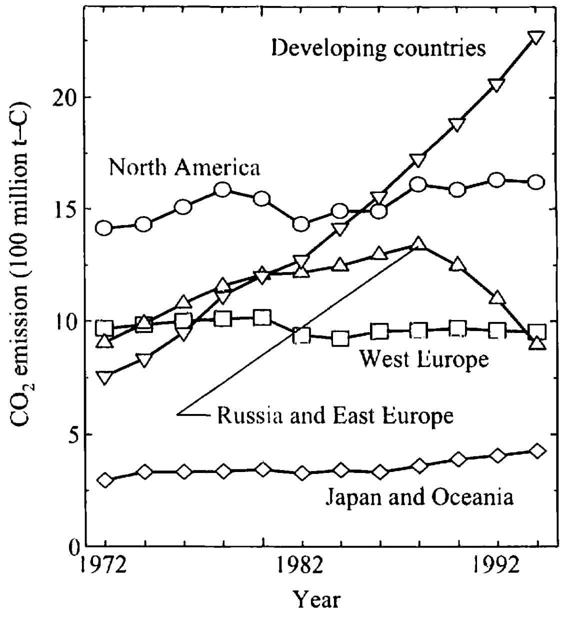


Fig.1-2: CO_2 emission[1-1]

The 20th century was the era when the relations between the construction of infrastructure and economic activities were pursued to the utmost degree. It is said that, at present, 20% of the total global population is using 80% of resources. The construction industry, in which large quantities of concrete are being used, is a resource-dependent industry. Large amounts of energy are also consumed in buildings. It is estimated that the construction industry and built environment are responsible for approx. 40% of energy consumption and greenhouse gas emissions. Moreover, construction and demolition activities produce the largest waste stream. Construction activities impose burdens on nature, and construction noise and the release and diffusion of toxic substances after its completion may cause serious problems. Considering such circumstances, the construction industry faces an environmental challenge and therefore it is extremely important for the construction industry to establish systems taking into account resource circulation and energy efficiency as in the household electrical and automobile industries. While it is obvious that the "establishment of circulative society" is a key to

	Energy consumption (ton)	CO_2 emission (ton)
Canada	7.85	5.12
U.S.A.	7.81	6.20
Australia	5.34	5.00
Germany	4.13	3.32
Japan	3.86	2.95
U.K.	3.77	2.92
OECD countries (Av.)	4.58	3.47
Non-OECD countries (Av.)	0.78	0.64

IEA Energy Balance of OECD countries 1993-94
IEA Energy Balance of Non-OECD countries 1993-94

Table 1-1: Energy consumption and CO_2 emission/person/year in selected countries (1994) [1-1]

"sustainable development," infrastructure with its long service life requires different ideas and design systems from those for household electric appliances, automobiles and other articles that have a relatively short service life.

According to the Brundtland Report[1-2], "Sustainable Development" is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". There are two important points for accomplishing sustainable development. One is the construction of institutional infrastructure and the other is the reexamination of the technical framework and the associated technical development. Institutional infrastructure refers to legal restrictions and international agreements concerning resource circulation, energy efficiency, CO_2 emissions and other environmental issues. CO_2 emissions represent currently one of the most important environmental factors. As shown in Fig. 1-2, the trend of CO_2 emission all over the world is similar to that of energy consumption. Also the similar trend is shown regarding CO_2 emission of each country per capita in Table 1-1. The Kyoto Protocol adopted at the International Conference for the Prevention of Global Warming (COP3) in 1997 required Japan, the U.S.A. and the E.U. to reduce by 2010 their emissions of greenhouse gas by 6, 7 and 8%, respectively, compared to 1990 levels.

As a reflection to the Kyoto Protocol some countries have already started to implement legal steps to support achievement of this goal. For example, the Japanese government established the "Law Concerning the Promotion of the Measures to Cope with Global Warming" in 1998, as well as other laws concerning recycling and environmental assessment. The E.U. initiated and supports several international projects like IPPC (Integrated Pollution Prevention Control), etc. However, the general agreement of the Kyoto Protocol has not been achieved yet and the amount of CO_2 emissions released is still increasing.

The essential importance of the evaluation of structure's sustainability has been increased during the last 10 years. The traditional design and evaluation approach was based on three basic and competitive factors: quality, cost and time. As stated in the General Agenda 21 (Rio 1992) and Agenda 21 on Sustainable Construction[1-3] the three principal areas (pillars) of sustainability,

- environmental issues
- economic constraints
- cultural-social aspects

should be considered in the design, construction, use and other life-cycle phases of any product.

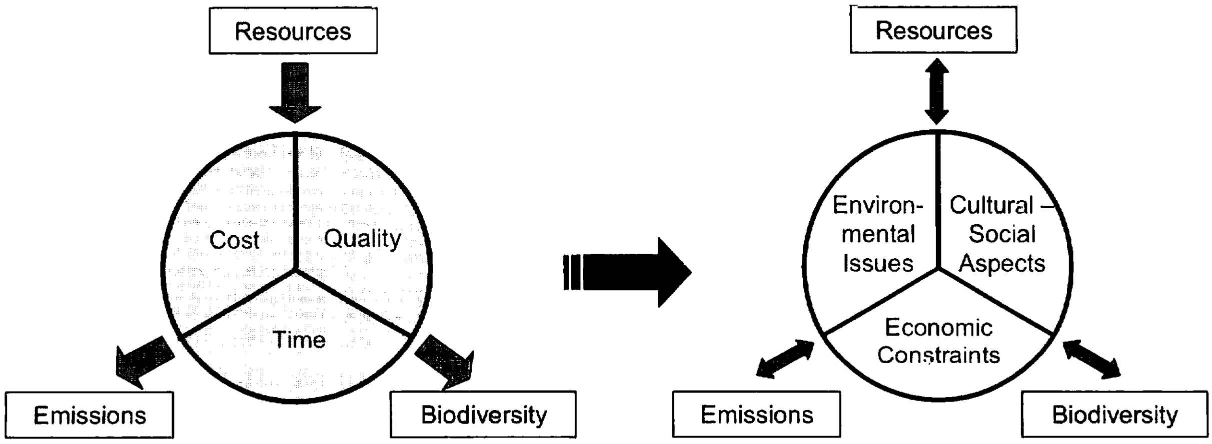
While the traditional approach is based on the principle of maximization of economy efficiency without major consideration of environmental impacts, the new approach, "sustainable construction," emphasizes the importance of reduction of the environmental impact of buildings and civil engineering structures. However, all other criterions (economic, cultural and social) are considered and balanced in the design as well as in the assessment processes. The traditional factors (quality, cost and time) are coherently included in the above mentioned three sustainability pillars.

Thus, the construction industry, including the concrete industry, faces the transformation process from the traditional building process to the new approach, "sustainable construction" (Fig.1-3). The environmental aspects represent a key role in this process. The principal importance of the environmental impact evaluation of concrete structures follows from the high amount of concrete structures built around the world every year.

Even if our target could be determined by the construction of the environmental infrastructure, there is no point in doing so if it is not effective. It is therefore very important to reexamine the conventional technical framework thoroughly and establish a new framework in the next step. Until recently consideration of the environment had not been given high priority in almost all economic activities. Today, people recognize the importance of the environment and make efforts to incorporate the environment into their own activities. In this sense, international standard ISO 14000 (Environmental Management) [1-4] may be playing an important role. However, the extent of its role is of course limited. It means it cannot transcend the framework of the current system. That is why it is essential to establish a new framework. By setting a new framework, positions of tasks that should be carried out can be identified in the whole picture and, as a result, necessary technological development will be promoted.

The field of concrete is also unexceptional. Concrete is produced using natural resources, which exist abundantly in the earth. Concrete is one of the cheapest construction materials to keep the comfortable living and working environment. It seems that there will be no feasible and effective alternative in the near future. It means that we have to continue to use limestone for cement production and aggregates in large quantities. The aggregates occupy approximately 70 % of concrete. Consequently the use of recycled concrete as an aggregate in new concrete may have crucial importance.

Considering the volume of produced concrete and number of built concrete structures, the problem of their environmental impact forms a significant part of the whole global problem of sustainable development. The specific amount of harmful impacts embodied in concrete unit is, in comparison with other building materials, relatively small. However, due to the high production of concrete, the final negative environmental impact of concrete structures is significant. Any improvement of concrete design principles, methodologies of assessment, construction and demolition technologies, and management of operation and use of concrete structures thus provides a very significant contribution to the general goal: the achievement of a



Traditional construction process **Sustainable Construction**

Fig. 1-3: Transformation from traditional construction process to new sustainable construction approach.

development process in the sustainable way.

The main aim of the work of TG3.3 in the *fib* Commission 3 is to present a framework of "environmental design", to document "Best Availability Technology (BAT)" for concrete structures from an environmental point of view, and to summarize methodologies for environmental impact evaluation and optimization of concrete structures. The term "Best Available Technologies" is defined as the most effective and advanced stage in the development of activities and their methods of operation to prevent and to reduce emissions and the impact on the environment as a whole.

1.2 Terms and definitions

Acidification

Environmental issue related to pollution. Acidification is defined as the quantity of SO2 (in kg) that causes acidification comparable to that of the substance emitted. (Hendriks 2000)

Agenda 21

Document adopted by the United Nations Conference for Environment and Development (UNCED) in Rio de Janeiro, Brazil, 1992

Design working life

Duration of the period during which a structure or a structural element, when designed, is assumed to perform for its intended purpose with expected maintenance but without major repair being necessary. (ISO 8930 – draft 2001)

Durability

Ability of a structure or a structural element to maintain adequate performance for a given time under expected actions and environmental influences. (ISO 8930 – draft 2001)

Elementary flow

Material or energy entering the system being studied, which has been drawn from the environment without previous human transformation. (ISO 14040)

Emission

Discharge from a system of chemical or physical entities (substances, heat, noise, etc.) into the environment. (Hendriks 2000)

Energy depletion

A variant of abiotic depletion relating to the relatively rapid consumption of energy at a rate exceeding that of creation, resulting in decreasing global supplies. This may result in scarcity. (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 interrelations.

Note: Surroundings in this context extend from within an organization to the global system. (ISO 14050)

Environmental aspect

Element of an organization's activities, products or services which can interact with the environment. (ISO 14040, ISO 14050)

Environmental audit

Systematic, documented verification process of objective obtaining and evaluating audit evidence to determine whether specified environmental activities, events, conditions, management systems, or information about these matters conform with audit criteria, and communicating the results of this process to the client. (ISO 14050)

Environmental impact

Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services. (ISO 14050)

Environmental influences

Chemical, biological, or physical influences on a structure. They may deteriorate the materials constituting the structure, which in turn may affect its reliability in an unfavourable way. (ISO 8930 – draft 2001)

Environmental management system - EMS

Part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy. (ISO 14050)

Environmental objective

Overall environmental goal, arising from the environmental policy, that an organization sets itself to achieve, and which is quantified where practicable. (ISO 14050)

Environmental performance

Measurable results of the environmental management system, related to the organization's control of its environmental aspects based on its environmental policy, objectives and targets. (ISO 14050)

Environmental performance indicator - EPI

Specific expression that provides information about an organization's environmental performance. (ISO 14031)

Environmental policy

Statement by the organization of its intentions and principles in relation to its overall environmental performance which provides a framework for action and for the setting of its environmental objectives and targets. (ISO 14050)

Environmental profile (environmental balance, eco-profile, eco-balance)

List of effect scores for all environmental issues included in the life cycle of a system under investigation. (Hendriks 2000)

Environmental target

Detailed performance requirement, quantified where practicable, applicable to the organization of parts thereof, that arises from the environmental objectives and that needs to be set and met in order to achieve those objectives. (ISO 14050)

Eutrophication

Environmental issue related to pollution. Eutrophication is defined as the quantity of PO43- (in kg) causing the same eutrophication as the substance emitted. (Hendriks 2000)

Fly ash

Particles formed by combustion, which due to their very small dimensions are carried away in the flue gases, from which they are separated out by means of filters of flue gas scrubbers. (Hendriks 2000)

Functional unit

Qualified performance of a product system for use as a reference unit in a life cycle assessment study. (ISO 14040)

Greenhouse effect

Environmental issue related to pollution. The greenhouse effect is defined as the amount of CO_2 (in kg) that reinforces the greenhouse effect to the same degree as the substance emitted. CO_2 emissions as a result of fuel combustion and CH4 emissions are mainly responsible for the greenhouse effect. (Hendriks 2000)

Impact category

Class representing environmental issues of concern to which LCI results may be assigned. (ISO 14040)

Life cycle

1) Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal. (ISO 14040)
2) Total period of time during which the execution and use of a construction works takes place. (ISO 8930 – draft 2001)

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)

Life cycle impact assessment - LCIA

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. (ISO 14040)

Life cycle interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations. (ISO 14040)

Life cycle inventory analysis - LCI

Phase of life cycle assessment involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle. (ISO 14040)

Maintenance

The set of activities to be performed during the working life of the 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)

Ozone layer depletion

Environmental issue relating to pollution. Ozone layer depletion is defined as the quantity of CFC-11 (in kg) that causes the same ozone layer depletion as the substance emitted. (Hendriks 2000)

Pollution

Result of non-degradable substances emissions into the environment. (Hendriks 2000)

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 14050)

Raw material

Primary or secondary material that is used to produce a product. (ISO 14040)

Recycling

The collection or processing of waste from a system, which results in a useful application in the same or a different system. (Hendriks 2000)

Reliability

Ability of a structure or a structural member to fulfill the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms. (CEN/TC250)

Sensitivity analysis

1) Systematic procedure for estimating the effects on the outcome of a study of the chosen methods and data. (ISO 14041)
2) Analysis to determine the sensitivity of a calculation result to small changes in the assumptions or variations of, for example, process data. (Hendriks 2000)

Sensitivity check

Process of verifying that the information obtained from a sensitivity analysis is relevant for reaching the conclusions and giving recommendations. (ISO 14043)

Structural failure

Failure exceeding any specified performance criterion. (ISO 8930 – draft 2001)

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.

Transport

Relocation of materials or energy between operations at different locations. (Hendriks 2000)

UNCED

United Nations Conference for Environment and Development (UNCED) in Rio de Janeiro, Brazil, 1992, 167 countries represented. Main results of UNCED conference: The Rio Declaration on Environment and Development, adoption of Agenda 21, creation of the Commission for Sustainable Development, adoption of the Convention on Biological Diversity, adoption of the UN Framework Convention on Climate Change.

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)

Unit process

Smallest portion of a product system for which data are collected when performing a life cycle assessment. (ISO 14040)

Waste

1) Any output from the product system which is disposed of. (ISO 14040)

2) Materials without any positive commercial value and produced in an economic process. A low-value by-product is occasionally also considered waste. A distinction can be made between waste processed within an economic system, resulting in emissions, and end waste, which ends up in the environment. (Hendriks 2000)

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)

References

1-1 Environment-Chronological Table '98/'99, supervised by Yoichi Kaya, Ohmsha (in Japanese).

1-2 Our Common Future, The World Commission on Environment and Development (WCED), Oxford U.P., 1987

1-3 Agenda 21 on Sustainable Construction, CIB Report Publication No. 237, ISBN 90-6363-015-8, 1999, Rotterdam

1-4 EN ISO 14001 – 14049 Environmental Management, set of International Standards, CEN 1997-2001

2 Framework of environmental design

2.1 Scope and objective

Although the existing design methodology for concrete structures has been formed based on technical information accumulated for a long time, the limits have been pointed out in recent years. Extended service life of structures is a key point in considering environmental issues. In many actual cases, however, design is not handled as a time function from a long-term viewpoint. Durability design of concrete structures, in particular, is so-called "prescribed design." If durability is taken into account, design of a structure should be "performance-based design" to deal with the behavior of the structure as a time function, and there is an increasing tendency towards this type of design. In addition, CO_2 generated from construction materials, energy consumption, recycling and other issues must be considered appropriately in the design frame. By clarifying the direction of technical development, it will be promoted.

For the above context, TG3.3 (Environmental Design) of *fib* Commission 3 firstly considered the framework of environmental design and clarify the future direction of rational environmental design. Then, the current condition of the best available technology (BAT system) is summarized as an element technology of environmental design. Furthermore, the information on evaluation indexes for taking account of environmental impact, the maintenance systems and the life cycle environmental assessment are sought out, and an environmental design guideline will be suggested in the next step.

"Environmental design" is a new term introduced for symbolic representation of a new concept that includes environmental aspects in the design activity. Environmental design is thus a design that integrates environmental aspects into safety, serviceability and durability, which were taken into consideration in conventional design. These aspects are interrelated in multi-criterion approach and cannot be considered separately. What we must do now, therefore, is to find a new direction by reviewing all knowledge and technology we currently have from the environmental point of view and to re-arrange them in the environmental design framework.

2.2 Environmental design

When a construction project is planned, the planner will select the type of structure from some feasibility studies in which functional requirements are satisfied. Based on the type of structure and its functions, performance requirements which may include "environmental performance" and "structural performance" will be set. There are various options in setting environmental and structural performance requirements for the structures. A clear process is needed to establish performance requirements. The owner and designer should agree on structural concept, environmental aspects, location, cost, construction term, and performance requirements. This process can be defined as conceptual design. Figure 2-1 shows an example of an environmental design system for concrete structures, which is feasible at present. This framework is based on the idea of performance-based design. Performance-based design is basically composed of setting of the "required performance" and "performance verification." Because performance verification is conducted under certain preconditions concerning materials, components, structure as a whole and other matters, "inspection" is necessary to confirm that such preconditions are actually satisfied. A system for effective use of "monitoring" information during the service life is also necessary.

Although there has been no established index concerning environmental performance, CO_2

emission, consumption of energy, nature, safety (e.g. leaching), landscape, etc. or combinations of these factors can possibly be introduced. Structural performance includes safety, serviceability and durability. If safety and serviceability can be dealt with as a function of time, the problem of durability can be included in them and the extension of service life of a structure is accordingly determined by setting of required performance concerning its durability. The technology to evaluate its long-term performance is necessary.

Although it is not so easy to set environmental performance requirements because many aspects have to be considered, it will be possible if appropriate indices are developed to evaluate environmental impacts. One approach that we can introduce may be to set target criteria on emission reduction (CO_2, SO_x, NO_x and others), natural resource savings, energy consumption reduction, waste reduction and/or environmental safety as a limit value of environmental performance requirement. The most important aspect is not a current feasibility, but an acceleration of necessary technological development by clarifying the future direction.

After setting the required performance of a structure, its shape, size and reinforcement arrangement will then be determined. Consequently, types and proportions of materials and/or types of components, i.e. precast concrete or in-situ concrete will be selected. Environmental impacts imposed by the use of resources and other factors will also be taken into account when selecting materials and/or components. A maintenance plan will be developed in connection with these procedures. In other words, basic ideas concerning repair and strengthening during the design service life will be clarified. Then a construction method will be chosen. Environmental impacts during execution will also be taken into consideration.

Under these preconditions, structural performance and execution performance will be simulated using various models and methods. The execution performance is considered as a performance concerning concreting, formworks, machinery and others. If the results of these simulations satisfy the required performance, an environmental impact simulation will then be conducted. In the environmental impact simulation, factors during life cycle will be considered comprehensively in addition to those that impose direct impact on the environment. If the results of the environmental impact simulation satisfy the required performance, the verification is accomplished. The establishment of concrete methods for the simulation is a major task to be accomplished in the future.

After the setting and verification of required performance are completed on paper, the next step is the execution of structures. After the completion of execution, an inspection will be conducted to confirm that the preconditions of verification are met. If no problems are found in the inspection, the structure will be put into service. When there is a problem, reconstruction will be examined. If reconstruction is not conducted, the structure will be put into service and a new maintenance plan and monitoring will also be developed. What is important here is to establish a system in which monitoring and maintenance data will be fed back to simulation models. Lack of consideration of such a system in the past made it difficult to evaluate the service life of structures.

If monitoring shows that re-evaluation of performance is necessary, actual performance will be verified again. If there is a problem, the effectiveness of repair/strengthening will be evaluated. After considering costs, environmental impact and other factors, it will be decided either to use the structure with repair/strengthening it or to demolish and remove it. In order to decide on re-use/recycle or disposal of the waste from demolished structures, the comprehensive evaluation of costs and environmental impact is also needed.

The introduction of a performance-based design system means to eliminate the vagueness in design as much as possible. It will also lead to accountability for the construction of infrastructure. The essence of global environmental problems is that everyone is both causing and suffering from the problems. To solve these serious problems in the 21st century, each industry needs to make an effort to enhance resource efficiency. In our industry, it is necessary for designers and engineers to go beyond the conventional framework of design and to promote

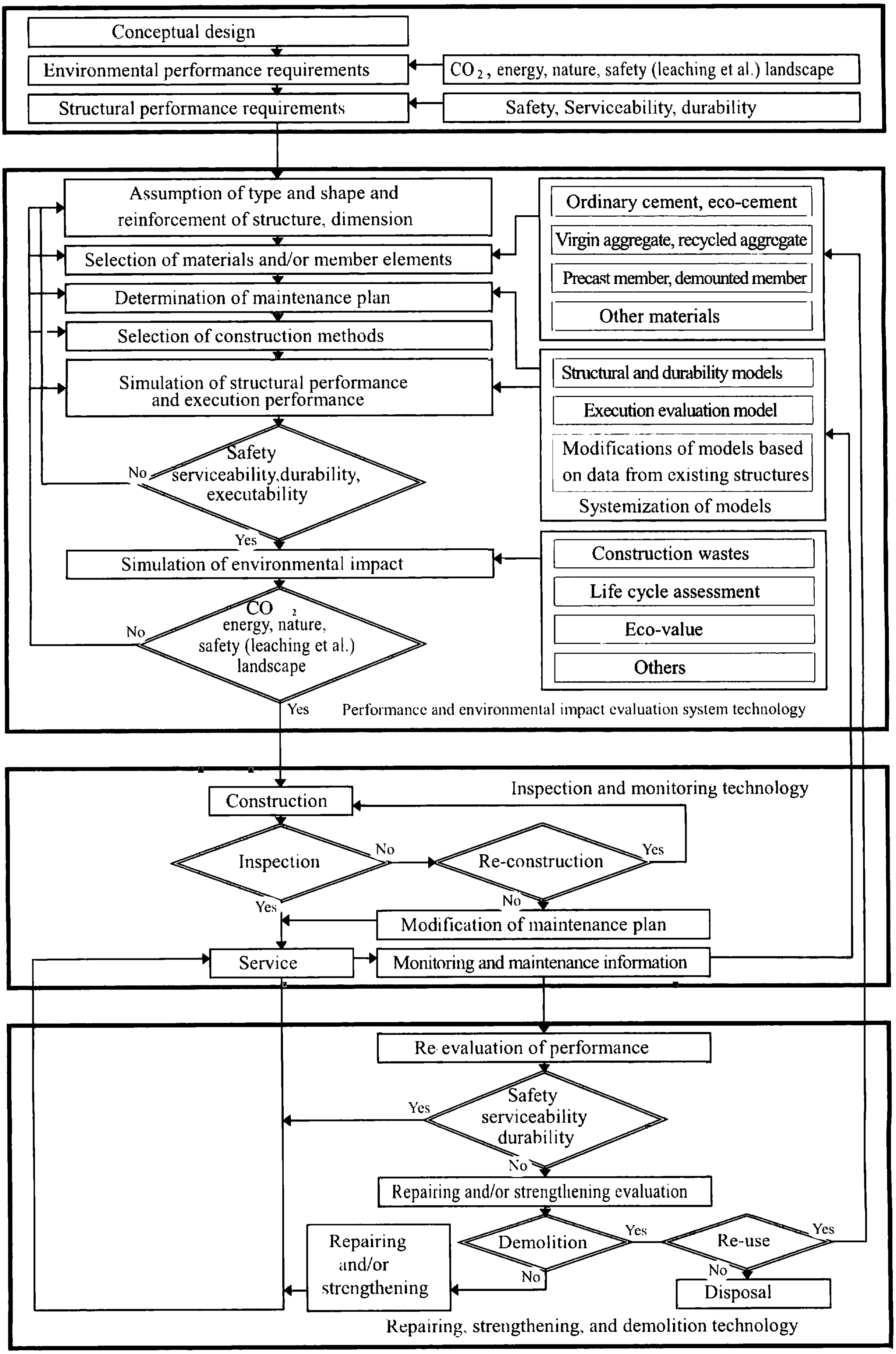


Fig.2-1: An example of environmental design systems for concrete structures.

research on environmental performances, which makes it possible to select various options. The proposed framework for environmental design may be the first step.

3 BAT system in concrete technology

3.1 Environmental aspects in concrete industries

The consumption of natural resources and energy by the construction industry, which produces heavy products such as roads, bridges, dams and buildings, equals almost half of that of industry as a whole. Since concrete, among all construction materials, is used in great volume, environmental aspects should be considered during design, construction, utilization and demolition of concrete and concrete structures.

In order to establish guidelines for the environmental design of concrete structures on the basis of the framework proposed in the former chapter, it is necessary to understand the state-of-the-art of both the environmental impacts caused by concrete throughout its life and the best available technologies (BAT) to reduce them. BAT, however, is time-dependent and may be easily changed. The life of concrete is composed of the following stages.

- Cement production
- Aggregate production
- Admixture production
- Concrete production
- Reinforcement production
- Prestressing steel production
- Formwork production
- Execution of concrete structures
- Operation of concrete structures
- Maintenance of concrete structures
- Demounting of concrete components
- Demolition of concrete structures
- Re-use and recycling of concrete
- Recycling of reinforcement and prestressing steel
- Disposal of concrete and constituent materials
- Disposal of reinforcement and prestressing steel

The scope of this Chapter 3 covers the environmental aspects in cement production, aggregate production, concrete production, execution of concrete structures, reuse, recycling and disposal of concrete. Environmental aspects resulting from the demolition of concrete structures are not covered in this report because of a lack of sufficient information. Since the environmental effects resulting from the utilization of concrete structures, which contain for instance the following aspects, are dependent not only on the design of structures but mostly on how they are used, this is not discussed in the life of concrete in this chapter.

- Utilization of high-strength concrete leading to a sectional and/or a partial reduction of concrete components, which adversely increases a rentable space but affects the increase of cement consumption
- Utilization of autoclaved lightweight concrete (ALC) or lightweight concrete for the improvement of insulation of walls leading to lower energy consumption
- Utilization of ribbed and waffle slab leading to a reduction in the use of concrete and steel

Environmental aspects during production and transportation of construction machinery are not considered in this chapter.

The environmental impacts that have to be considered are categorized and the substances relevant to each impact are given in the following.

- Global warming (Carbon dioxide [CO2], Methane [CH4], Nitrous oxide [N2O])
- Ozone depletion (Halon, Chlorofluorocarbon [CFC], Hydrochlorofluorocarbon [HCFC], etc.)
- Acidification (Sulfur oxides [SOx], Nitrogen oxides [NOx], Ammonia [NH3], Hydrogen fluoride [HF], Hydrogen chloride [HCl])
- Natural resource depletion (Oil, Natural gas, Coal, Bauxite, Copper, Iron, Zinc, etc.)
- Eutrophication (Phosphates [PO4], Nitrogen oxides [NOx], Ammonia [NH3], Nitrogenous matter, Nitrates [NO3-], Phosphorous, Chemical oxygen demand)
- Air pollution
- Water pollution
- Soil pollution
- Solid waste leading to the rapid solidification of landfill
- Noise and dust
- Indoor air quality (Volatile organic compound)

The impacts related to global environment include global warming, ozone depletion, acidification and natural resource depletion, while those related to the local environment are eutrophication, air pollution, water pollution, soil pollution, solid waste, noise and dust. Indoor air quality is related to the indoor environment of buildings.

This chapter presents the environmental impacts caused during each stage in the life of concrete, the best available technologies (BAT) being used in practice or studied in laboratory for the reduction of environmental impact, and the relevant codes and standards enforced in various countries.

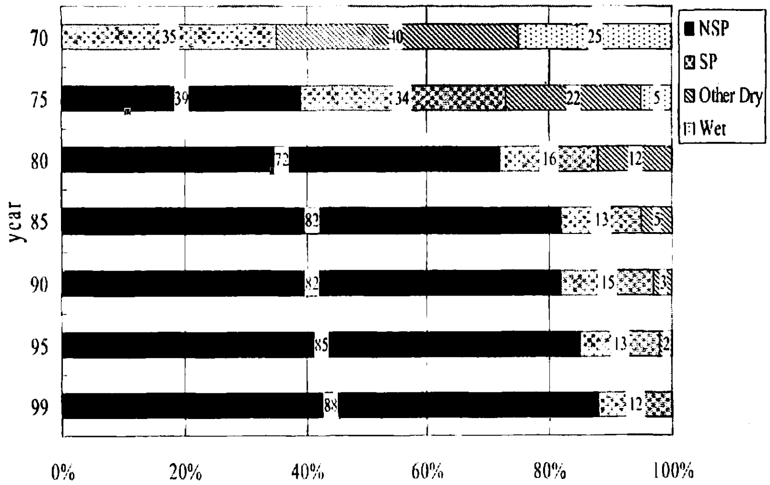
3.2 Cement production

3.2.1 General

The origin of material with hydraulicity dates back to 7000 B.C., while modern cement was developed by J. Aspdin in 1824 [3.2-1]. Industrial production began in 1825, with worldwide production at present being more than 15 hundred million tons per year [3.2-2]. The consumption of each area in 1997 is shown in Table 3.2-1. Cement is produced by heating raw materials composed of limestone, clay and various wastes etc., which are previously mixed and ground, to a temperature higher than 1,450□ in a rotary kiln. The semi-product (so called "Clinker") from the kiln is cooled and ground with other constituents such as gypsum. The manufacturing processes have remained unchanged but the facilities and technologies have advanced dramatically in order to increase both energy saving and production. Fig. 3.2-1[3.2-2] shows the changes in the type of kilns running in Japan from 1970 to 1999. With the changes in kiln-type

	Area						Total
	North America	Latin America	Europe	Asia-Pacific	India, Middle East	Africa, etc.	
Demand (million t/year)	104	106	280	774	156	80	1500
Ratio (%)	6.9	7.1	18.7	51.6	10.4	5.3	100.0

Table 3.2-1: Cement demand in the world (1997)



Note: NSP=Precalciner-type SP kiln, SP=Suspension Preheater type kiln

Fig. 3.2-1: Production ratio by kiln type [3.2-2]

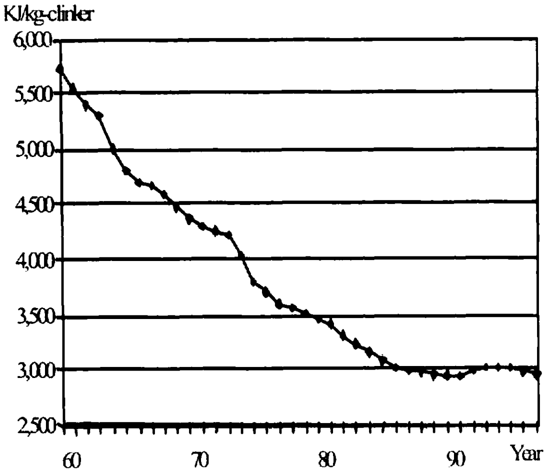


Fig. 3.2-2: Specific fuel consumption [3.2-2]

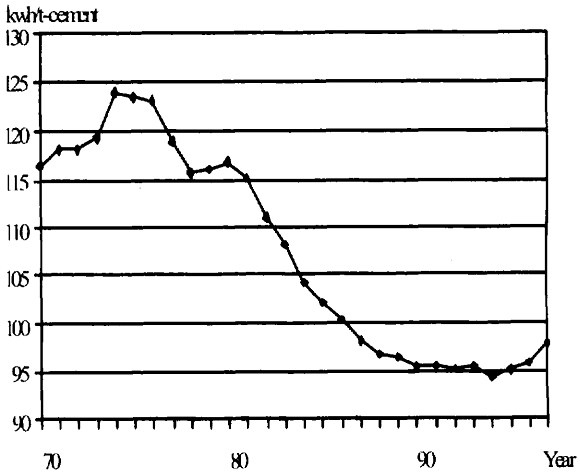


Fig. 3.2-3: Specific power consumption [3.2-2]

and other technological advances, specific heat consumption continuously decreases as shown in Fig. 3.2-2 [3.2-2]. Power consumption also decreases as shown in Fig. 3.2-3 [3.2-2] mainly due to the introduction of the classifier to the ball mill grinding system and replacement of the ball mill by the vertical mill as a grinder of raw mixes and/or a pregrinder of clinker.

3.2.2 Environmental impacts

An inventory analysis of portland cement in the system boundary shown in Fig. 3.2-4 was carried out by the Japan Cement Association in 1998 [3.2-3]. This data was collected from 26 plants in which more than 80% of the cement consumed in Japan was produced. Table 3.2-5 shows the results of inventory in each substance and process. 90% of total CO_2 emissions were caused by the decarbonation of limestone (60%) and fuel combustion (30%) in the process of clinker production. Clinker production is also the main process which emits NOx and dust. In the case of SOx, the main source of emission resulted from the power generation in private plants. The ratio of the power generated in private plants to the total power consumption in cement plants was approximately 60%.

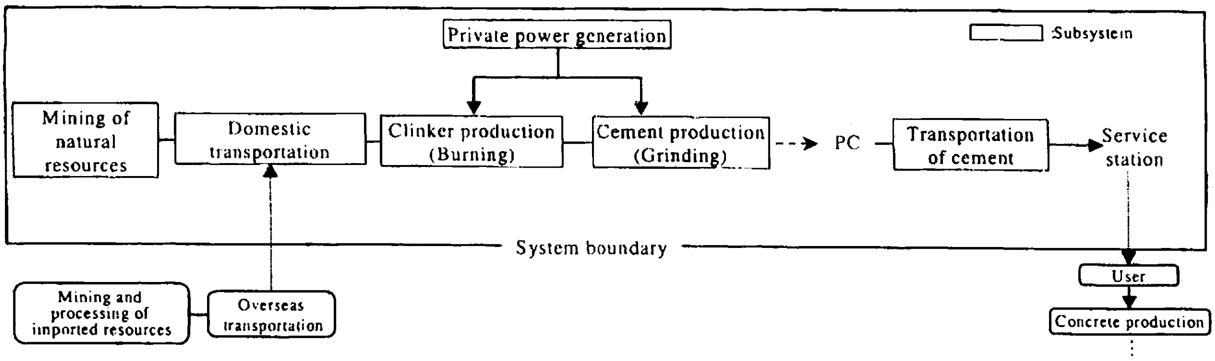


Fig. 3.2-4: System boundary

CO_2 emission: 749.5 kg/t-cement

Decarbonation (clinker production)	59.9 %
Fuel combustion (clinker production)	30.1 %
Transportation of raw material and fuel	0.2 %
Mining of raw materials and pre-processing	0.3 %
Transportation of cement (to SS)	0.6 %
Purchase electric power (clinker and cement production)	1.8 %
Private power generation	7.0%

SOx emission: 155 g/t-cement

Clinker production	13.8 %
Transportation of raw material and fuel	1.0 %
Transportation of cement (to SS)	3.5 %
Purchase electric power (clinker and cement production)	7.2 %
Private power generation	74.6 %

NOx emission: 1.68 kg/t-cement

Clinker production	84.6 %
Transportation of raw material and fuel	0.2 %
Transportation of cement (to SS)	0.9 %
Purchase electric power (clinker and cement production)	0.7 %
Private power generation	13.6 %

Dust emission: 60 g/t-cement

Clinker production	74.8 %
Transportation of raw material and fuel	2.2 %
Transportation of cement (to SS)	8.4 %
Purchase electric power (clinker and cement production)	1.2 %
Private power generation	13.4 %

Table 3.2-5: Inventory of portland cement produced in 1998 [3.2-3]

3.2.3 Environmental contribution

The energy savings shown in Fig. 3.2-2 and Fig. 3.2-3 contribute to a decrease in environmental load. However, it is true that improvement in efficiency is approaching the limit. As a new trend many cement companies are focusing on recycling activities. Fig. 3.2-6 shows the use of wastes and byproducts in the Japanese cement industry [3.2-3]. Fig. 3.2-7 shows the ratio of the amounts of commonly used wastes and byproducts in cement production to the total amounts generated. These activities consequently contribute to prolonging the life of natural resources and landfill space. According to a trial evaluation, the environmental load of portland cement production is reduced to 60% by recycling activities [3.2-3].

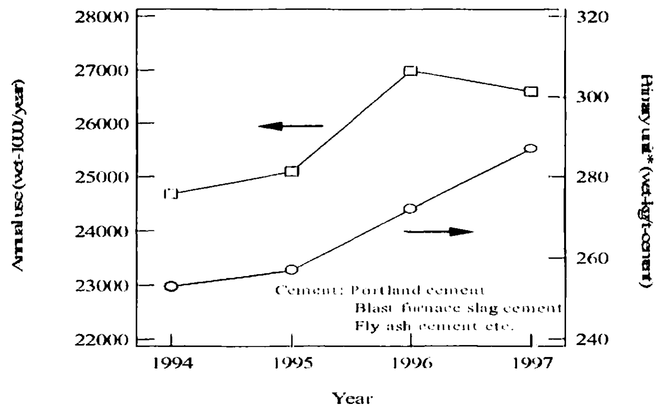


Fig. 3.2-6: Use of waste and byproducts in Japanese cement industry
** Amount per ton cement*

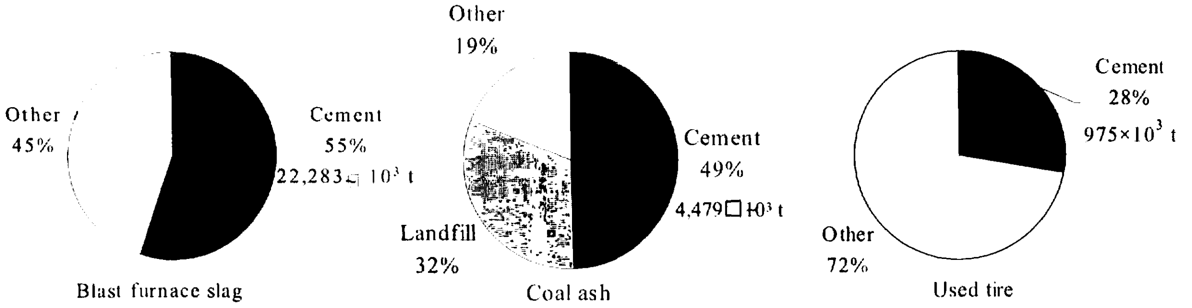


Fig. 3.2-7: The rate of practical use of the industrial waste and byproduct in cement industry

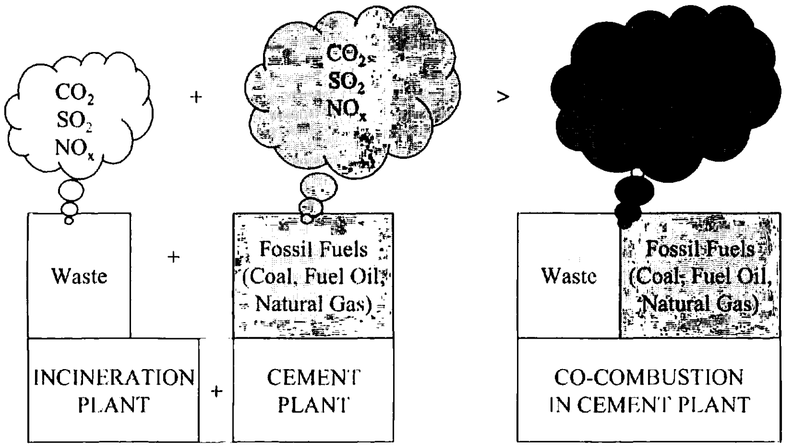


Fig. 3.2-8: Mechanism of reduction in emission [3.2-5]

wastes such as plastic and sludge with organic components in cement production [3.2-4]. The benefits are quantitatively examined by LCA under three headings: (1) CO_2 reduction, (2) disposal versus recovery in cement kilns and (3) recovery in cement kiln system versus other systems. The results suggest that by using alternative fuels in cement production, overall CO_2 emission decreases to a considerable extent compared with incineration without recycling because of the mechanism shown in Fig. 3.2-8. When various environmental loads are taken into account and are evaluated with the "Distance to Target method", environmental impact significantly decreases. The utilization of plastic wastes in cement plant as alternative fuels is more competitive even when it is compared to recovery technologies such as the conversion of plastics into gaseous and liquid products.

3.2.4 **BAT system** [3.2-6]

As mentioned above, the cement industry emits not a little CO_2, SO_x, NO_x and dust into the atmosphere. Otherwise, it contributes to prolonging the life of landfill space by utilizing waste materials. The schemes for reducing the former and for promoting the latter are presented in this chapter.

(1) Reduction of CO_2 emission

Energy saving and cement design are primary measures for not only reducing CO_2 but also other environmental loads.

a. Energy saving

The emission of CO_2 is estimated at 800 to 1,000 kg/ton clinker. This is related to the specific heat demand of approximately 3,000 to 5,000 MJ/tonne clinker, but also depends on the type of fuel. Approximately 60-70% originates in the calcining process of limestone, while the remaining 30-40% is related to fuel combustion. CO_2 emissions resulting from combustion of the carbon content of the fuel is directly proportional to the specific heat demand as well as the ratio of carbon content to the calorific value of the fuel. Emissions from the combustion of CO_2 have been progressively reduced; a reduction of about 30% in the last 25 years has been accomplished mainly by the adoption of more fuel efficient kiln processes.

Energy demand is an important source of CO_2 emissions as indicated above. The dominant use of energy in cement manufacture is as fuel for the kiln. The main users of electricity are the mills (finish grinding and raw grinding) and the exhaust fans (kiln/raw mill and cement mill) which together account for more than 80% of electrical energy use. On average, energy costs in the form of fuel and electricity represent 50% of the total production cost involved in producing a ton of cement.

Fuel energy use for different kiln systems is in the following ranges (MJ/tonne clinker). Further replacement to higher efficiency processes is expected.

About 3,000	for dry process, multi-stage cyclone preheater and precalciner kilns,
3,100-4,200	for dry process rotary kilns equipped with cyclone preheaters,
3,300-4,500	for semi-dry/semi-wet processes (Lepol-kiln),
Up to 5,000	for dry process long kilns,
5,000-6,000	for wet processing kilns, and
3,100-4,200	for shaft kilns.

Present electricity demand is also decreased to about 90 to 130 kwh/ton cement mainly by adopting a new grinding system: a highly efficient separator and vertical roller mill and pre-grinder etc.

b. Design and selection of cement

Many types of cement have been prepared to match the various requirements of concrete. They are roughly divided into Portland cement and blended cement. The initial environmental load of concrete can be reduced by using blended cement [3.2-7]. The amount of utilized wastes which cannot be disposed of as landfill or in cement plants is superior in the production of Portland cement. Further the performance of concrete, for example durability, depend on the type of cement used; concrete using blast furnace slag cement shows a high resistance against chloride and sulfate attack but low resistance against carbonation. The difference in durability varies the life cycle environmental load according to time. Therefore cement should be designed and/or chosen depending on many parameters regarding various factors. A balance must also be achieved between the initial environmental load and the life cycle environmental load.

(2) Reduction of SO_2 emission

SO_2 emissions from cement clinker kilns are due to the volatile sulphur compounds in raw materials and fuels. The emission concentration in stack depends on the concentration of those sulphur components in the site specific raw material resource. However, the major part of sulphur is retained as a clinker constituent component. Furthermore, utilization of the gypsum form smoke desulfurization process during cement production will be helpful in spreading this process.

The BAT associated emission level for SO_2 given in the European BAT reference document is 200 to 400 mg SO_2 per 1 m^3 clinker production. The different techniques described may be applied at a different unabated SO_2 emission concentration. The BAT document refers to the dry additive technique for unabated SO_2 concentration of 400-1,200 mg/m^3. Some cement plants with higher starting levels exist. In these cases above 1,200 mg/m^3 wet scrubbers or circulating fluidized bed absorbers using dry absorbents may be applied. The cost of these techniques is rather high and it will be a local decision whether the environmental benefits justify them.

(3) Reduction of NO_x emission

On an average, the European cement kiln emits 1,300 mg NO_x/m^3 (as NO_2, dry gas, 273K, 101.3 kPa and 10% O_2). The European BAT reference document refers to primary measures, such as staged combustion and the SNCR technique (selective non-catalytic reduction) as BAT. The primary measures are flame cooling and low NO_x-burner. The staged combustion is BAT only for kilns with existing calciners because retrofitting an existing kiln with a calciner would require completely redesigning the plant.

For SNCR the BAT emission level is 200–500 mg/m^3. There are only very limited experiences with high efficiency SNCR techniques at these low emission concentrations. It is questionable whether such experience can be transferred to other kilns. First trials have shown that these concentrations can only be achieved under certain favourable site specific circumstances (raw material, unabated NO_x level). All tests have shown a strong increase in NH_3 emissions when high rates of ammonia water have to be injected as a reducing agent.

(4) Reduction of dust emission

The cement industry uses electrostatic and bag filters for dust precipitation. Both filter types have proved reliable for gas cleaning at kilns, clinker coolers and cement mills. Electrical energy consumption strongly increases when increasing the precipitation efficiency of the filters: lower dust concentrations require higher power consumption for electrostatic precipitators or result in a higher pressure drop across a bag filter which increases energy consumption by the exhaust gas fan.

Specific costs for dust precipitators are site specific, especially for existing plants. In many cases an enlargement of the filter device requires additional modifications to the existing process. The BAT emission level is 20–30 mg/m^3.

(5) Promotion of wastes use

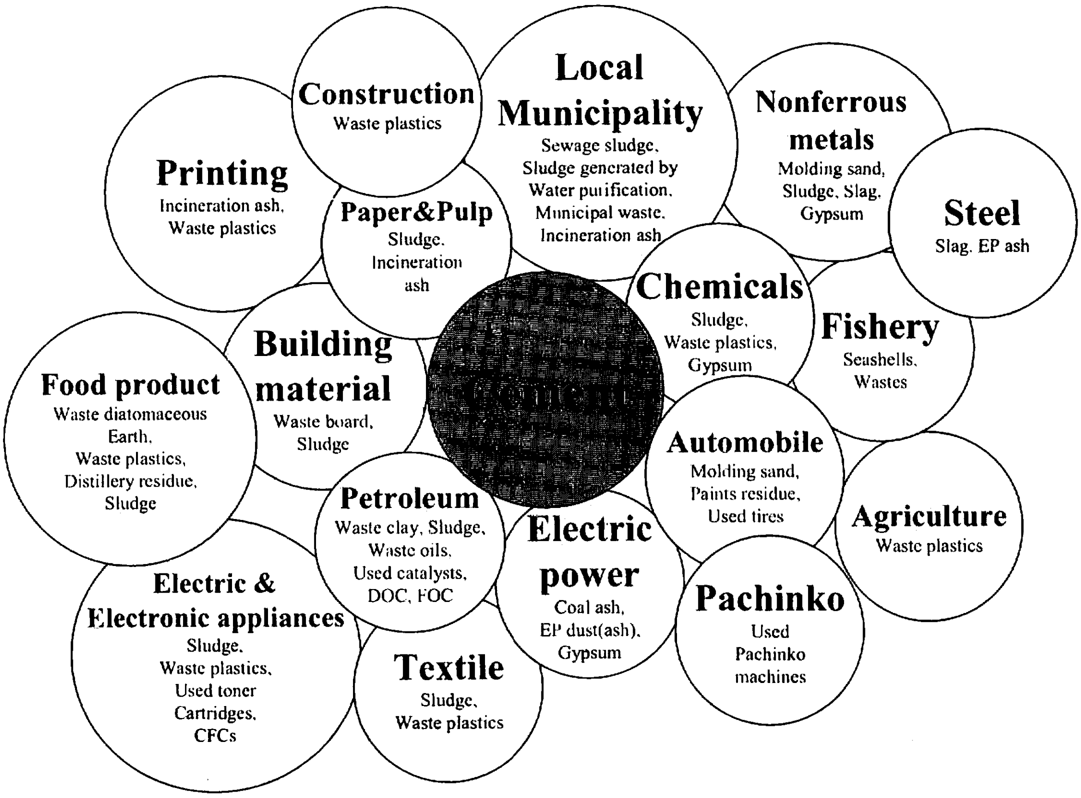


Fig. 3.2-9: Recycling ecosystem

Many cement works use alternative materials and fuels in cement manufacture. By utilizing alternatives cement plants improve the cost-effectiveness of the production process. The use of alternatives in the cement industry simultaneously contributes to the environmentally compatible disposal of a variety of waste materials.

However, constituents of the waste must comply with strict quality requirements to be met by the product. It is important that environmentally relevant trace elements do not have any adverse effects on emissions during the cement production process and on the environmental compatibility of the product. For that reason, trace element levels in waste materials have to meet tough requirements. It might become necessary to strictly limit trace element levels in individual cases.

The use of alternatives in the clinker burning process considerably lessens the impact on the environment. Integrated assessments show that this allows the reduction of energy consumption and thus CO_2 emissions. In addition, the quantity of waste is reduced significantly.

(6) Advanced challenge

The shortage of landfill space in Japan, especially in urban areas, is very serious. In order to resolve this situation Ecocement was developed through the collaboration of NEDO (New Energy and Industrial Technology Development Organization) and several companies in Japan [3.2-8], and through the recently standardized certification concerning quality and safety (JIS: Japanese Industrial Standard R 5214). It is defined in the standard as cement which utilizes more than 500kg/t-cem of municipal waste such as incineration ash. Industrial production began in May 2001 at a newly established plant in Chiba prefecture. The establishment of an Ecocement plant has been also scheduled in Metropolitan Tokyo. An accessory recovery plant of heavy metals which are extracted during the burning process is found beside the main plant and the products are returned to the smelters.

Systems for promoting the use of various wastes in existing cement plants have also been developed: (1) a chlorine bypass system and desalination system [3.2-9] for the use of wastes with high chlorine content (2) systems for using municipal wastes without incineration [3.2-9], (3) a system for decomposing CFCs (Chlorofluorocarbons) [3.2-10] and (4) a process for supplying power generated from exhausted heat energy to an area near the cement plant [3.2-11] etc. Further systems will be developed in response to the society's demands for environmental conservation.

The cement industry is a powerful waste management route because of its capacity and the possibility of using various wastes from other industries. This means that the cement industry can be located at the core of the "Recycling Eco-system" as in Fig. 3.2-9. The maintenance of safety and quality must be established as a principle of cement industry. Further voluntary agreements are required and understanding by the society will support the growth of recycling activities.

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3.3 Aggregate production

3.3.1 Environmental impacts

a. Amount of aggregate production

The origin of concrete aggregates is rock which covers the surface of the earth. And rock is the material we use most except water and soil.

Aggregates are usually very stable both chemically and physically. Basically, aggregates are not hazardous materials, so they rarely affect the environment, however the problem lies in amount used in construction. Because of its great amount, aggregate produces an environmental impact through its production, transportation and dumping.

For example, the production of aggregates in Japan has been huge. Rock materials are used as concrete aggregates as well as for sub-base material, railway ballast, foundation material, etc. The amount of aggregate production has been closely related to economic conditions, because infrastructure was the base of economic activity. Fig. 3.3-1 shows the aggregate production (not only for concrete but also other applications) in Japan for the last half century. It increased very rapidly during the period of steady economic growth, and after the "oil shock" of 1973 it was almost constant with small ups and downs.

Annual production of 800 million tons corresponds to six or seven tons per person a year.

Aggregate production per capita varies considerably in Europe from one country to another. An estimate of the production (not only for concrete but also other applications) in 1999 is indicated in Table 3.3-1 for most countries of Central and Western Europe.

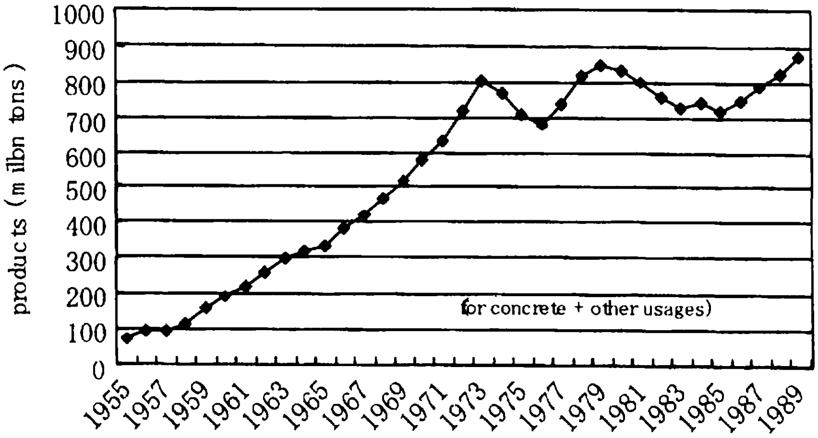

Fig. 3.3-1: Aggregate production in Japan

Country	Population 1998, in 1000	Aggregate production 1999, in 1,000 tons	Aggregate production Per capita, in kg approximately
Austria	8,075	93,000	11,500
Belgium	10,192	57,000	5,600
Denmark	5,295	26,000	4,900
Finland	5,147	80,000	15,500
France	58,727	381,000	6,500
Germany	82,057	645,000	7,900
Great Britain	59,090	256,000	4,300
Hungary	10,300	70,000	6,800
Ireland	3,694	41,000	11,100
Italy	57,563	350,000	6,100
Netherlands	15,654	47,000	3,000
Norway	4,418	61,000	13,800
Portugal	9,957	125,000	12,600
Spain	39,348	315,000	8,000
Sweden	8,848	81,000	9,200
Switzerland	7,069	33,000	4,700
Total	385,434	2,661,000	6,900

Source: QPA, Quarry Products Association, London

Table 3.3-1: Aggregate production in Europe (for concrete + other usage)

b. Environmental issues due to aggregate production

When we look at the environmental influence of aggregate use, we have to observe both the aspects of negative impact and positive influence. In this section, we review the former.

Figure 3.3-2 shows the ratio of aggregate taken from rivers to total aggregate production in 1963 and 1995 in Japan. River sand and gravel are ideal aggregates for concrete because of their round shape and appropriate grading. In addition, the production of aggregates from river sand and gravel is very easy. Therefore, before 1970 rivers were the main suppliers of concrete aggregates. Japan is such a steep mountainous country that sand and gravel are brought to the rivers every year. However when construction work became very active, the amount of sand and gravel taken from some areas in Japan, exceeded the amount that was newly supplied naturally. Consequently, aggregate production caused problem regarding river environments and flood control. Therefore the Japanese government established a new law to control the digging and dredging of river sand and gravel, following which sand supply shifted from rivers to the ocean. Recently, environmental influence on the seabed became so obvious that many local governments now plan to ban the digging of the sea sand.

Figure 3.3-2 shows that crushed stone is the main constituent of concrete aggregate today. Crushed stone is usually quarried by cutting hills, and after production is finished, the land has been used to dispose of waste. Nowadays, however, it is obligatory to replant the land once quarrying has ceased.

Around 1970, lorries for transporting aggregates became a social problem, because they brought not only environmental problems such as air pollution, ground vibration and noise but also represented a danger to residents along the roads. Improvement of road networks has relieved this problem, but in some areas it is still serious.

Recently, the transporting distance of aggregates has become longer and longer, and in the vicinity of big cities especially, it is very difficult to obtain good aggregates from near-by sites. Extension of transporting distance means an increase in the use of fuel, and CO_2 emissions, as well as problems due to the transport of machinery.

In Europe too, areas with good quality aggregates near to the places of use are becoming scarce. The Netherlands and the Flemish region in Belgium have implemented a gradual slowdown in river gravel production until coming to a complete stop (in Belgium production stops in 2006 – in the Netherlands mineral resources planning is provided to last until 2030 because of the risk of the flooding). The most important reason for this is that river gravel extraction has a tremendous impact on the landscape. Due to high population densities, it is quite clear that this environmental problem leads to considerable political pressure. Scenarios

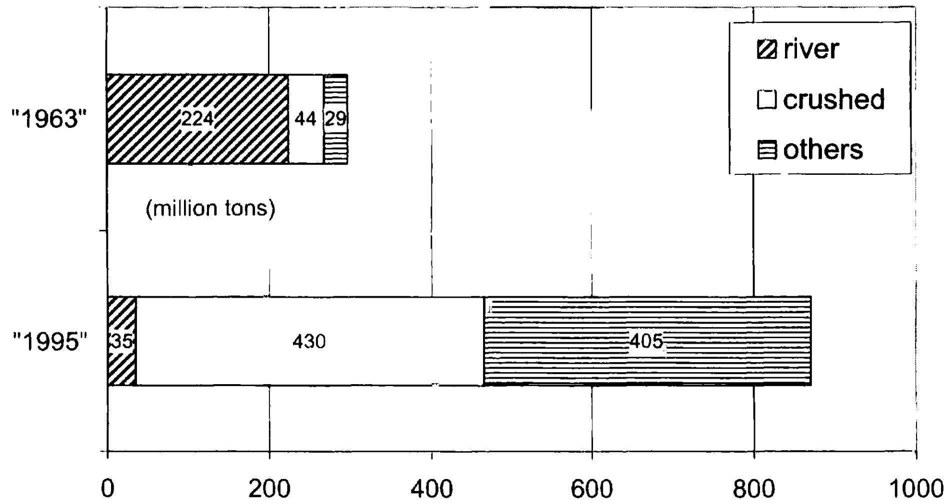

Fig. 3.3-2: Ratio of river origin aggregate and crushed stone

have been and are being developed to provide for alternatives. For the moment, it is thought that river gravel will be replaced by crushed aggregates, sea gravel and, if available, artificial or recycled aggregates. A lot is also expected from future imports from the so-called super-quarries, i.e. quarries situated near the sea in amongst others Scandinavian countries and Scotland. However, the success of these super-quarries has been rather limited until now. Also other countries within Europe, such as Germany, United Kingdom and France, are confronted with shifts in aggregate production and use. Over the past three decades transport distances have become longer, and environmental and social impact associated with transport is growing. According to CEMBUREAU, on average 89% of all transport of cement in 1998 was by road, 5% by rail and 6% by water, with large variations in proportion from one country to another. The peak values are 43% by water in the Netherlands and 52% by rail in Switzerland. It can be expected that the proportions are similar for the transport of aggregates. The refilling and re-cultivation of areas is governed by national or regional legislation, and in general requirements have become more severe recently.

c. Contribution to the environment through the use of by-products

As a positive influence concerning aggregates, the recycling and/or re-use of many kinds of by-products becomes important.

Concrete has accepted many kinds of by-products as aggregate so far, from the construction industry as well as other industries. That means concrete has been contributing to environment in this respect.

Most typical materials for by-products used for aggregates are slag from metals melting and refining. These materials have been used as aggregates for concrete as well as raw materials for cement production. Blast furnace slag is a by-product of iron smelting, and annual production is more than 20 million tons in Japan. Having been used as reclaimed material, a steel company tried to use it as an aggregate in the construction of their factory. Blast furnace slag coarse aggregate for concrete was standardized as JIS in 1997, and fine aggregate in 1981. But approximately only one million tons of blast furnace slag aggregate is used for concrete every year, because ground granulated blast furnace slag as cementitous materials brings more benefit to steel companies.

The fine aggregate of ferro-nickel slag was standardized as JIS in 1992 and the fine aggregate of copper slag in 1997. Annual use for concrete is two million tons for each slag.

Recently it is planned to standardize the slag aggregate from other metals refining and melted slag of burned ash from domestic waste. There is a requirement to develop technologies to use other wastes, for example, glass from bottles, brick and pottery waste. In addition to these inorganic materials, even some organic materials such as plastics and rubber are on the waiting list.

1997	Blast furnace slag coarse aggregate
1981	Blast furnace slag fine aggregate
1992	Ferro-Nickel slag fine aggregate
1997	Copper slag fine aggregate
2002	Electric furnace oxidized slag
200?	Melted slag from burned ash of garbage

Table 3.3-2: Standardization of by-product aggregates for concrete in Japan

However, some questions have been raised by concrete engineers. While concrete has accepted many kinds of waste materials, some materials in the waiting list do not improve, but lower concrete quality. So recently concrete engineers tend to think that concrete is not a dustbin and materials like glass should be recycled in their own closed circuit. Another concern is that if concrete easily accepts glass as an aggregate, its own closed circuit will be broken. There is also concern that concrete with these kinds of aggregate is not as durable as normal concrete and that the life span of structures will be shortened. When they are demolished in the future, what will happen? Can these concretes be treated in the same way as normal concrete? What will their environmental impact be?

Therefore, when by-product materials are used for concrete aggregate, the total life span of the concrete structures has to be considered.

In Europe, about 46 million tons of coal combustion products (CCP), such as fly ashes, bottom ashes etc. were produced in 1999, with 24 million tons being used for cement and/or concrete and 18 million tons as landfill, according to ECOBA (European Coal Combustion Products Association). Of about 35 million tons of blast furnace slag produced, some 20 million tons were used in cement and sub-base construction. Compared to the total amount of about 2,600 million tons of aggregates required per annum this is a small contribution and is not likely to increase.

A bigger potential lies in the use of mineral materials from recycled construction and demolition waste. According to a study by a consulting company, the contribution of recycled mineral materials to the total amount of aggregates in Germany is expected to increase from 50 million tons or 7% in 1997 to 13% in 2010. In Switzerland 3 million tons of recycled mineral materials were used as aggregates in the year 2000 (corresponding to 10% of total aggregate consumption), with 20% being used in concrete and 10% in road surface construction. The use of recycled aggregates is currently also widely spread in the Netherlands, Denmark, Belgium and some densely populated areas of Germany and France. A report in EU– the so-called Symonds report – showed that in these areas 85% or more of the construction and demolition waste was recycled. However, most of the construction and demolition waste recycling takes place in low-grade applications, such as sub-base material or in foundations. Although in some countries standards do allow it, recycling in concrete remains limited to less than 1% of the amount of aggregates used in concrete.

3.3.2 BAT system

While continuing to use huge amounts of aggregate resources, the following issues have to be considered:

1) The average quality of aggregate will decrease because due to environmental restriction it will become more difficult to use only good quality aggregate.
2) The performance required of concrete will diversify, therefore the quality of aggregate may diversify also.
3) The recycling of demolished concrete and reuse of by-products will be accelerated by social demands.

Regarding the first issue, this has happened already in dam construction. The condition of dam construction sites has been deteriorated and in many cases relatively low quality aggregates have to be used. In large scale dam construction concrete, the aggregate is usually taken from newly developed quarries close to the dam site. But it has become difficult to develop good quarries due to transporting routes and environmental conservation. The recent requirement to reduce construction costs has lead to using as much aggregate as possible from quarries and to reduce the waste of rock. Therefore, aggregates which do not satisfy the conventional standards on required quality have been used in many dam constructions. These kinds of aggregate for general concrete other than dam concrete may have to be used in the future.

Concerning the second issue, high strength concrete requires stronger aggregate and self compacting concrete requires more strict quality control of the aggregate, because the slight scattering of grading and surface water of fine aggregate results in large scattering of fresh concrete properties.

From these backgrounds, aggregates have to be used based on the required performance of concrete. A policy of "Right material in the right place" must be introduced in order to conserve resources and minimize the environmental impact.

An example of "Right material in the right place" can be seen in the use of recycled aggregate. There are many technical approaches to the use of recycled aggregate from demolished concrete, while new aggregate with good quality is still being used as sub-base material for paving where high quality is not required. When recycled aggregate is used for concrete, if high durability is required, much energy is consumed to produce recycled aggregate with good quality, and if energy is saved, concrete durability is lowered. Therefore, using recycled aggregate for sub-base and new aggregate for concrete is rational.

3.3.3 Standards and recommendations

An example of a trial in Japan is given below. Generally speaking, standards or specifications are important for construction works. Almost all concrete cast in-situ is supplied as ready-mixed concrete, and ready-mixed concrete is standardized as JIS A 5308. JIS A 5308 has enabled many unspecified constructors to buy ready-mixed concrete with assured quality almost anywhere in Japan and to build quality concrete structures at reasonable cost. This fact shows that the supply system is appropriate so far. But this system is not flexible, because it is not easy to buy ready-mixed concrete other than that specified in JIS A 5308 nor ready-mixed concrete with non-standardized materials.

Under the current JIS it is difficult to use various aggregate in concrete according to its quality and/or characteristics. Therefore, we have to revise the standard regarding ready-mixed concrete as well as that of concrete aggregate in order to realize the "Right material in the right place". And more, it is also required to reform the supply systems of aggregate and ready-mixed concrete which have been adapted to the current JIS.

In order to make the acceptance of new standards smooth, understanding and recognition on the part of the users of concrete and/or owners of structures is indispensable. Because the users and/or owners tend to make a safer and easier choice, it is important to create an atmosphere in which they have to consider the environmental aspect even when choosing ready-mixed concrete. Otherwise, revised standards will be good for nothing.

To allow free trade in Europe, work began decades ago in the CEN (European Committee for Standardization) to create common European standards in many fields. With regard to construction products this work acquired a form of legal basis with the European Construction Products Directive (CPD), which was issued as long ago as 1989. This CPD is now generating the first concrete results. The Directive states that construction products which are intended for use in structures and constructions may only be placed on the market if they are of such a nature that the structures in which they are incorporated, assembled, applied or installed satisfy six essential requirements, namely:

- Mechanical resistance and stability.
- Safety in case of fire.
- Hygiene, health and the environment
- Safety in use

- Protection against noise
- Energy economy and heat retention.

In the near future (for some product categories, such as cement, this can already be seen) the fact that construction products satisfy this regulation will be indicated by the CE mark. In fact, it will no longer be possible to market products without this mark. For the attribution of the CE mark one works with harmonized standards issued by CEN (see http://www.cenorm.be) and converted by the national standardization institutes, or with European Technical Approvals drafted within EOTA (see http://www.eota.be).

By now several standards have already been elaborated and/or published. With regard to concrete, one can refer to EN 206-1 for concrete including additives, EN 197-1 for cement, EN 450-1 for fly ash, EN 13263-1 for silica fume, EN 12620 for aggregates for concrete, EN13055-1 for lightweight aggregates for concrete and mortar, EN 934-2 for concrete admixtures and EN 1008 for mixing water.

The consequence of harmonized standards is that if the properties of a product, e.g. additive, deviate from the standard requirements, the CE mark will not be attributed to the product and the product may no longer be placed on the market. However, for some products for instance innovative ones, harmonized standards are not available. For such products all alternative roads exist through the European Technical Approval. Such approvals are issued following the usual EOTA procedures to guarantee that the essential requirements are fulfilled.

One main principle of the above mentioned CPD and the associated standards is that it is not the origin of the materials that is important, but the properties. By the introduction of EN 12620, requirements for primary and secondary materials from natural or industrial origin will be covered. However, CEN TC154 realizes that this ideal will not be reached by the first generation of standards. At its meeting in November 2002, it was decided that standards will be amended in the next few years to cover recycled waste aggregates. In a later phase standards will be reviewed in order to cover the complete range of alternative aggregates. At that stage the way will be open to use recycled aggregates as much as possible. It may however be clear that this process is a slow one involving a lot of lobbying.

Until now mainly technical aspects, such as mechanical properties, durability etc. are dealt within the standards. Within the next five to ten years, environmental requirements will be included. The 3rd essential requirement of the CPD already covers environmental properties in a way, but in reality the CPD defines environment in a particular way. Only the internal and immediate environment of the construction is covered. Global environmental issues, such as global warming or waste, are not included in the CPD. Studies to see if and how these global issues can be taken up in European standardization have been commissioned. The CEPMC – the Council of European Construction Products Manufacturers – expects a lot from European Environmental Product Declarations. Such declarations have already been put in place in several European member countries (Finland, Sweden, the UK, Netherlands, France...).

The use of recycled materials is promoted by national and regional regulations and, indirectly, by fees levied for waste disposal on dump sites. Two examples within Europe which demonstrate this are presented below (others may be found in almost all Member States of the EU).

Finland for example has had a waste management law since 1993. Treatment of construction waste is more closely regulated by government decisions regarding construction wastes which states the goal that by the year 2000 50% of construction waste will be recycled (soil materials, aggregates and dredging waste not included). The decision is to be followed on construction sites of a certain size. Construction work must be planned and performed in such a way that waste materials are separated and classified.

In 1997 the Swiss government for example issued a directive concerning the utilization of mineral construction waste. It defines the requirements for six classes of recycled construction materials (asphalt granulate, recycling sand-gravel type P, A and B, concrete granulate and mixed waste granulate) and clearly defines their fields of application. On this basis the interested industry represented by ARV (the Swiss Demolition, Excavation and Recycling Association) along with the Government Agency for the Environment jointly undertake information campaigns and sponsor education programs on how to reuse to the greatest extent mineral materials from construction and demolition waste, ultimately for the purpose of promoting "The right material in the right place".

3.4 Production of reinforcement and prestressing steel

The steel industry is a major consumer of energy, especially fossil fuels. In 2001, 846.9 million tons of crude steel was produced worldwide (Table 3.4-1). Therefore many steel products have been used for concrete constructions, although the environmental impact analysis has not been developed in this field yet.

The International Iron and Steel Institute, IISI is pressing on with the LCA project taking part in 55 sites in 37 countries in order to develop a world standard method of life cycle inventory analysis for steel producing processes.

In Japan, the LCA-national project started in 1995 with the support of the Ministry of Economy, Trade and Industry. In this project, transparent and reliable inventory data will be constructed within the year of 2002 for some industries including petroleum chemical, chemical, iron and steel, electric machine/device and paper industries. Based on statistics and input-output analysis, the carbon dioxide emissions for shapes are shown to be 1,250kg-CO_2/t, 1,210kg-CO_2/t for bars and 1,320kg-CO_2/t for wire rods as inventory data [3.4-2]. Another reference shows that the carbon dioxide emissions for basic oxygen furnace hot-rolled steel are 1,507kg-CO_2/t [3.4-3]. The system boundary for these data is defined as "cradle to gate".

China	Japan	U.S.A.	Russia	Germany	S. Korea	Ukraine	India	Brazil	Italy	World
148.9	102.9	90.1	59.0	44.8	43.9	33.1	27.3	26.7	26.7	846.9

Table 3.4-1: Steel production in the world (million ton, 2001) [3.4-1]

References

3.4-1 International Iron and Steel Institute, World Steel in Figures 2002 Edition, 2002
3.4-2 Practice LCA – ISO 14040, Science Forum, 1999 (in Japanese)
3.4-3 Proceedings of the Research Committee on LCA in Construction, Japan Society of Civil Engineers, 1997 (in Japanese)

3.5 Concrete production and transportation

This section contains the environmental aspects that have to be considered during concrete manufacturing, i.e. during production of concrete in ready-mixed concrete plants and transportation of fresh concrete from the plants to construction sites. The upstream profile of the transportation of constituent materials to concrete plants is, however, excluded from the concrete manufacturing boundary. In this section the environmental impacts, which are caused in concrete manufacturing, are described. BAT, which have already been used in practice and are being developed, codes and standards for the reduction of environmental impacts in concrete production are introduced.

3.5.1 Environmental impact

Among the various environmental impacts described in 3.1, the following impacts are closely related to concrete production.

- Global warming due to electricity consumption
- Air pollution due to combustion of fossil fuels
- Water pollution due to used washing water for equipment
- Solid waste due to returned concrete
- Noise and dust at receipt of constituent materials.

(1) Global warming

Global warming gas is emitted during the following processes in concrete production and transportation.

- Electricity consumption in conveying constituent materials to silos
- Electricity consumption and fossil fuel combustion in heating and cooling constituent materials and concrete
- Electricity consumption in mixing concrete
- Fossil fuel combustion in delivering concrete to construction sites

According to the Forintek report [3.5-1], the average energy consumption used in the production of 1m^3 of concrete at ready-mixed concrete plants in Canada consists of 3.90kWh (15.7MJ) electricity, of 5.95 liter (210.6MJ) diesel fuel and of 1.09m^3 (45.8MJ) natural gas. Accordingly, the total amount of energy consumption and CO_2 emission from production of 1m^3 of concrete are 272.1MJ and 14.2kg respectively in Canada.

On the other hand, the JTCCM (Japan Testing Center for Construction Materials) reported that energy consumption in the production of 1m^3 of concrete at a ready-mixed concrete plant in Japan consisted of 4.71kWh (19.0MJ) electricity and 1.57 liters (55.57MJ) diesel fuel [3.5-2]. Accordingly, 5.94kg of CO_2 is emitted from the production of 1m^3 of concrete at a plant in Japan. Another report [3.5-3] made by BCS (Building Contractors Society in Japan) shows electricity consumption of 4.18kWh and diesel fuel consumption of 2.97 liters at a ready-mixed concrete plant in Japan. Energy consumption in concrete transportation depends on the distance from concrete plant to construction site. In the "LCA Guideline for Buildings [3.5-4]" established by AIJ (Architectural Institute of Japan), average CO_2 emission in the transportation of 1m^3 of concrete to the construction site is estimated to be 10.4kg, which contains CO_2 emission caused by the manufacturing truck mixer, based on an Input-Output Analysis

	C 20/25	C 30/37	Mortar (Mg IIa)
Primary energy, non renewable (MJ/m^3)	1350	1792	1080
Global warming potential, GWP (CO_2-eq)	241.7	329.4	194.4
Ozone depletion potential, ODP (R11-eq.)	0.0	0.0	0.0
Acidifiation potential, AP (SO_2-eq.)	0.560	0.734	0.443
Nutrification potential, NP (PO_4-eq.)	0.071	0.091	0.056
Photochem. ozone creation potential, POCP (C_2H_4-eq.)	0.035	0.042	0.027

Table 3.5-1: Building materials profiles for ready-mixed concrete and mortar [3.5-5]

C 20/25 : Water 185 kg/m^3, Cement 260 kg/m^3, Fly ash 80kg/m^3, Aggregates 1840 kg/m^3
C 30/37 : Water 180 kg/m^3, Cement 360 kg/m^3, Aggregates 1824 kg/m^3
Mortar : Water 200 kg/m^3, Cement 210 kg/m^3, Aggregates 1300 kg/m^3
Data in Table 3.5-1 include the contribution of all pre-stages.

In Germany as in many other European countries, LCA investigations on the production of concrete and its constituents were performed. As a result, so-called building materials profiles shown in Table 3.5-1 [3.5-5] were published which contain the main parameters of a life cycle impact assessment such as primary energy, global warming potential or acidification potential with regard to $1m^3$ of concrete. However, these data include not only the impacts related to concrete manufacture itself but also the contribution of all pre-stages, i.e., the impact of the production of the concrete constituents as well as the supply using fossil fuels and electricity.

(2) Acidification

Substances causing acidification contain SO_2 and NO_x. From the report of the U.S. Environmental Protection Agency, emission of SO_2 and NO_x from concrete production is 0.0837kg and 0.0143kg, respectively.

(3) Water pollution

Used washing water is generated when extracting aggregate from the water used for the washing of equipment and concrete returned from the construction site. As the used washing water demonstrates pH of more than 13, it cannot be drained to the river as it is. In order to re-use the used washing water, it is usually separated into sludge water and top clear water in a mechanical condensing tank or a natural settling tank. Sludge water contains a large amount of unhydrated cement particles, cement hydrates and very fine aggregate particles.

According to the Forintek report [3.5-1], washing water used in the production of $1m^3$ of concrete at a ready-mixed concrete plant in Canada ranges widely from 41.6 to 618.4 liters, depending on the type of plant and on the distance to the construction site. The type of plant is a central mix plant in which a wet product is loaded into the truck mixer or a transit mixer operation in which dry material is loaded out. The smaller amount of washing water is needed at plants in urban areas because of the shorter distance to the construction sites and the central mixing applied. From the result of an investigation [3.5-6] by the National Ready-mixed Concrete Industry Association in Japan, the average amount of washing water used in producing $1m^3$ concrete at a ready-mixed concrete plant in Japan is 200 liters.

(4) Solid waste

The following solid wastes are most likely to be generated at a ready-mixed concrete plant.

- Returned concrete
- Concrete attached to production equipment
- Aggregate extracted from the returned concrete
- Aggregate extracted from the used washing water for equipment
- Sludge cake generated from dehydration of sludge water
- Dry sludge generated from dehydration of sludge water

From the result of investigations [3.5-6] by the National Ready-mixed Concrete Industry Association in Japan, the average amounts of returned concrete, concrete attached to equipment and sludge cake are 9.82 liters, 1.96 liters and 5.88kg, respectively when producing $1m^3$ concrete at a ready-mixed concrete plant in Japan. The returned concrete results mainly from overestimation of the amount of concrete placed at the construction site.

(5) Noise and dust

The noise causing trouble at ready-mixed concrete plants is mainly generated by the receipt of aggregates and in loading concrete from the mixer into the truck mixers.

At a ready-mixed concrete plant, dust is mostly generated from cement silos and sometimes from aggregate silos in the case that aggregates are stored in a dry condition. Unburnt carbon and dust are emitted from the diesel engines of truck mixers.

3.5.2 BAT system

Various technologies and measures are being used in practice and are being developed in laboratories to reduce the environmental impact of concrete production and its transportation. Technologies and measures for the reduction of environmental impact are outlined below.

(1) Global warming and acidification

Preventive measures to reduce emission of CO_2, SO_2 and NO_x include ordering concrete to decrease the number of truck mixers waiting to load concrete at a concrete plant and unloading it at a construction site, and to prohibit waiting truck mixers from idling.

(2) Water pollution

The top clear water, which is obtained from the used washing water in the natural setting tank after a certain number of hours, is used mostly for the following purposes.

- Mixing water for concrete
- Washing water for returned concrete and equipment

Inorganic admixtures for condensation, by which such harmful substances as Cr^{6+}, Cu, Zn, etc. are easily precipitated and removed from the sludge water, are newly developed in order both to increase the amount of top clear water and to decrease the amount of new water added to washing water. The top clear water is discharged after neutralization unless other measures can be taken.

The sludge water is sometimes added to mixing water for concrete after decreasing the solid concentration in the sludge water under the specified value, e.g. 2% or 3 % on average.

In some countries the reuse of used washing water is still restrained for mixing water for high strength concrete and air-entrained concrete due to lack of experience, though recent investigations show that air-entrained concrete can be safely manufactured with recycled water [3.5-7]. For instance, the re-use of recycled water from the recycling of unset concrete as mixing water for concrete, which is regulated by the "Guidelines for the Production of Concrete using Recycled Water, Recycled Concrete and Recycled Mortar (Recycled Water Guidelines)" issued by the German Committee for Reinforced Concrete (DAfStb), is common practice in virtually all ready-mixed concrete plants in Germany. In the future, parts of the guideline will be included in the European Standard EN 1008 "Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete". Though the use of recycled concrete by application of long-time retarder had been allowed by national technical approval in Germany, its validity expired and was not extended by the producer of the long-time retarder.

(3) Solid waste

In order to reduce the amount of returned generated concrete, it is important for concrete producers to make a previous arrangement in detail and make close contact with purchasers and users during construction. The returned concrete and the concrete attached to equipment are used as they are for the following purposes.

- Concrete products
- Materials for road sub-bases after being treated with consolidation

The mortar attached to truck mixers, the setting of which is sometimes retarded by means of the addition of a chemical admixture, is mixed into concrete that is loaded into truck mixers on the next day.

Aggregates extracted from the used washing water are used for the following purposes.

- Materials for road sub-bases
- Aggregates for concrete

The average amount of fine aggregates recollected from 1m^3 of concrete at a ready-mixed concrete plant in Japan ranged from 7.08 to 10.3 kg and that of coarse aggregates from 7.53 to 9.44 kg.

Sludge cake, which is generated from sludge water after being treated with dehydration such as mechanical dehydration, natural dehydration, and precipitation and condensation, is used for the following purposes.

- Materials for road sub-bases after being treated with consolidation
- Raw materials for cement
- Neutralizing materials for hydrogen chloride generated from the combustion of municipal wastes
- Raw materials for concrete products

Fine powders of dry sludge obtained from sludge cake through the process of drying and grinding are used for the following purposes.

- Addition for concrete
- Materials for hardening soft ground

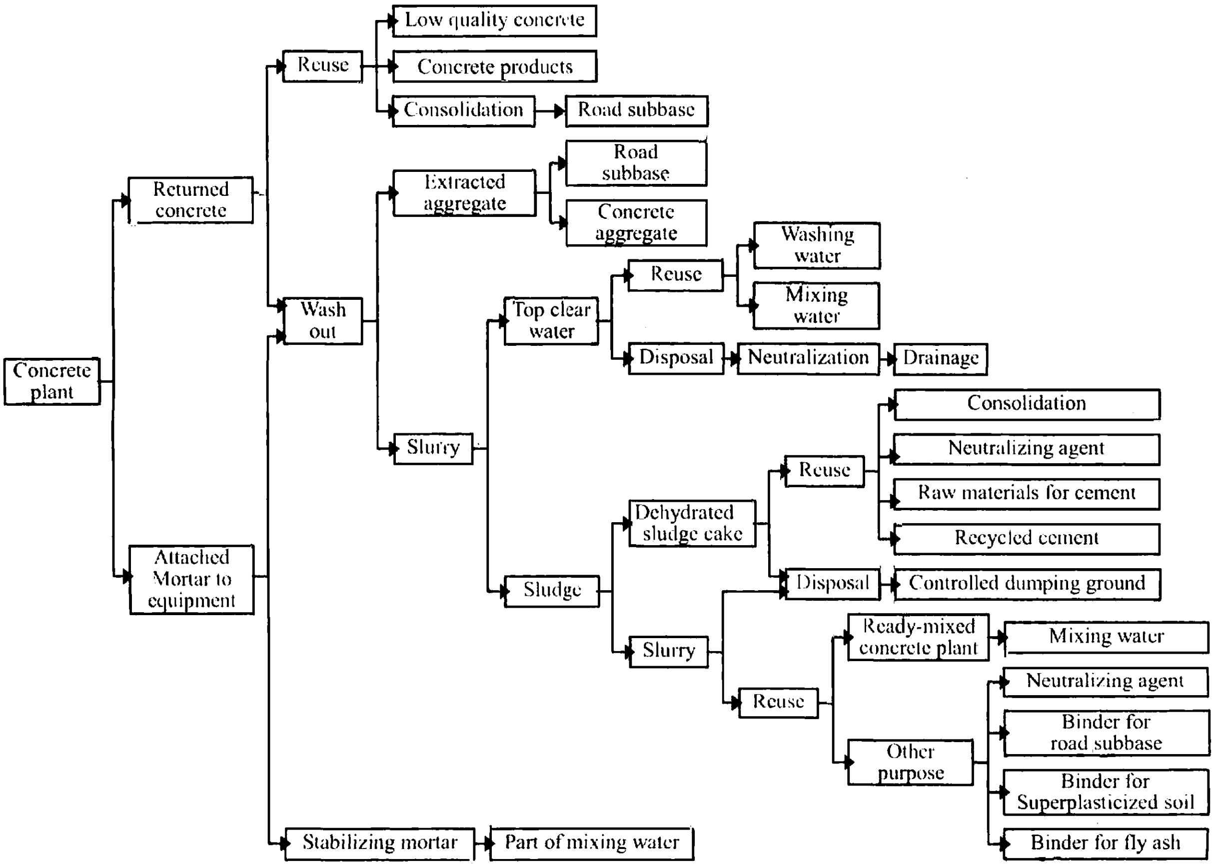

Fig. 3.5-1: Flowchart of re-use and recycle of solid waste at a ready-mixed concrete plant

Plant	ig. loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	Water content (%)
A	18.1	22.6	5.04	2.80	46.3	1.96	1.50	0.28	0.41	0.014	39.1
B	26.7	19.2	5.12	2.10	43.1	1.65	1.34	0.27	0.27	0.007	45.3
C	19.2	23.1	6.57	2.40	43.2	2.57	1.82	0.40	0.38	0.007	23.4

Table 3.5-2: Chemical composition (%)

- Materials for deoxidizing acid soil
- Neutralizing materials for hydrogen chloride generated from the combustion of municipal wastes

Figure 3.5-1 shows the flowchart of reuse and recycle of solid wastes at a ready-mixed concrete plant. Table 3.5-2 shows an example of the chemical compositions of concrete sludge.

(4) Noise and dust

In order to decrease the noise generated at a ready-mixed concrete plant, various measures are taken, e.g. receiving aggregates during a time when the noise causes less trouble, equipping a rubber sheet on the surface of the hopper of the truck mixer, etc. The traffic noise can be reduced by the use of low-noise truck mixers.

In order to reduce the dust generated from silos for cement and aggregate at a ready-mixed concrete plant, the silos are usually sealed hermetically. According to the DAfStb-Sachstandbericht "Nachhaltig Bauen mit Beton" [3.5-8], dust emissions during the loading of the trucks can be avoided to a large extent since the concrete constituents in Germany are usually premixed with water.

3.5.3 Standards

The following regulations regarding environmental aspects are established for ready-mixed concrete plants and regulations in Japan.

Regarding plant location,

- Law concerning location of factories
- Building standard law regarding drainage
- Water pollution control law
- Law concerning sewage
- Agricultural land soil pollutant prevention law
- Environmental quality standards for water pollution
- Environmental quality standards for ground water pollution
- Regarding dust emission, environmental quality standards for soil pollution
- Air pollution control law
- Regulatory measures against air pollutants emitted from factories and business sites and the outline of regulation
- Noise regulation law
- Regarding vibration
- Environmental quality standards for noise
- Regarding industrial waste
- Vibration regulation law
- Regarding the drawing of ground water
- Waste disposal law
- Law concerning industrial water

According to the Waste Disposal Law in Japan, concrete sludge, which has been properly cured after dehydration and consolidation, can be disposed of as glass waste and ceramic waste in Japan if it has equivalent properties to hardened mortar such as a compressive strength of not less than 8 N/mm^2.

Considering the preservation of the local and global environment as a part of business activities, ready-mixed concrete plants which have obtained ISO 14000, Environmental Management System are increasing these days.

References

3.5-1 Portland Cement Association: Environmental Life Cycle Inventory of Portland Cement Concrete, PCA R&D Serial No.2137, 2000

3.5-2 Japan Testing Center for Construction Materials: Report of the Investigation on Standard Assessment for Environment Regarding New Power Generating System, 1998 (in Japanese)

3.5-3 Building Contractors Society: Toward Utilization of LCA in Building Industry, 2001 (in Japanese)

3.5-4 Architectural Institute of Japan: Draft Guideline for Life Cycle Assessment for Building – $LCCO_2$ Assessment for Protection of Global Warming, 1999 (in Japanese)

3.5-5 P. Eyerer and H. W. Reinhardt: Okologische Bilanzierung von Baustoffen und Gebauden, 2000

3.5-6 National Ready-mixed Concrete Industry Association in Japan: Report on the State of the Ready-mixed Concrete Sludge in Japan, 1999 (in Japanese)

3.5-7 Verein Deutscher Zementwerke e.V.: Activity Report 1999-2001

3.5-8 H. W. Reinhardt : DAfStb-Sachstandbericht “Nachhaltig Bauen mit Beton”

3.6 Execution

This section contains the environmental aspects that have to be considered during execution of concrete structures, especially during concreting, i.e. during transportation, placing and consolidation of fresh concrete on construction sites, and the curing of concrete in structures until development of the required strength. In this section the environmental impacts, which are caused in concreting, are firstly explained. Not only available technologies, which have already been used in practice and are being developed, but also codes and standards for the reduction of environmental impacts are introduced.

3.6.1 Environmental impact

Among the various environmental impacts described in 3.1, the following are closely related to concreting.

- Global warming and air pollution due to the combustion of fossil fuels
- Solid waste produced from temporary formwork
- Vibration and noise due to concrete vibrating

(1) Global warming and air pollution

Global warming gas, SO_2 and NO_x are emitted during the following processes in concreting.

- Fossil fuel combustion in erecting metal formwork systems

- Fossil fuel combustion in the pumping of fresh concrete
- Electricity consumption in vibrating fresh concrete
- Fossil fuel combustion in heating concrete for curing in cold weather

According to the report [3.6-1] by the Japan Society for Civil Engineers (JSCE), the average energy consumption of equipment used in concreting is demonstrated in Table 3.6-1, which also contains the CO_2 emission calculated from the energy consumption. When a concrete structure of which the volume is 100 m^3 is constructed, the total working periods for generator, crane, stick-type vibrator and jet heater are 9.6, 9.6, 1.0 and 310 hours, respectively. Consequently energy of approximately 60 GJ is consumed and 3.8 t-CO_2 is emitted during concreting, which corresponds to 7.7 % and 5.7 % of the total life cycle energy consumption and $LCCO_2$ emission for civil engineering concrete structures. For residential reinforced concrete buildings, another report shows that energy of 787 MJ is consumed and the corresponding CO_2 of 20.5 kg is emitted during the construction of 1m^2 of floor [3.6-2].

Equipment	Energy		CO_2 emission
	Type	Consumption	
Generator (45 kVA)	Gas oil	7.2 liter/hour	20.33 kg-CO_2/hour
Truck Crane (Maximum load : 15-16 t)	Gas oil	6.3 liter/hour	17.78 kg-CO_2/hour
Concrete pump (Boom type, 40-45 m^3/hour)	Gas oil	0.233 liter/m^3	0.66 kg-CO_2/m^3
Concrete pump (Oil pressure type, 40-45 m^3/hour)	Electricity	0.49 kwh/m^3	0.18 kg-CO_2/m^3
Flexible stick-type vibrator	Electricity	0.29 kwh/m^3	0.11 kg-CO_2/m^3
Vibrator attached to formwork	Electricity	0.05 kwh/m^3	0.02 kg-CO_2/m^3
Jet heater	Kerosene	4.0 liter/hour	10.66 kg-CO_2/hour

Table 3.6-1: Examples of energy consumption and CO_2 emission in construction equipment [3.6-1]

In Germany the profile for the execution of concrete structures on environmental impact has been taken into account within "GaBi" report [3.6-3] shown in Table 3.6-2. This profile however, includes the influence of pre-stages, i.e. the impacts of the production and delivery of concrete constituents and concrete.

Primary energy, non renewable (MJ/m^3)	25
Primary energy, water-power (MJ/m^3)	0.2
Global warming potential, GWP (CO_2-eq)	15.5
Ozone depletion potential, ODP (R11-eq.)	0.0
Acidifiation potential, AP (SO_2-eq.)	0.012
Nutrification potential, NP (PO_4-eq.)	0.002
Photochem. ozone creation potential, POCP (C_2H_4-eq.)	0.001

Table 3.6-2: Concreting profile [3.6-3]

(2) Solid waste

The following solid wastes are most likely to be generated during concreting on construction sites.

- Panels and supports for formwork made of wood

- Pumping mortar preceding concrete

Panels and supports for formwork have been made of plywood. Panels of $3.929m^2$ are necessary on average for the construction of a floor area of $1m^2$ in reinforced concrete buildings in Japan [3.6-4]. As the panels and supports are usually reused approximately five times on the same and/or other construction site, wood waste of $0.8m^2$ is generated from a floor area of $1m^2$.

Mortar of approximately $0.5m^3$ is usually used for smooth pumping before concreting at the beginning. As mortar is usually of a lower quality and demonstrates higher shrinkage than concrete, it is not placed into formwork and disposed of.

(3) Vibration and noise

Noise and vibration is generated during consolidating concrete.

3.6.2 BAT system

Various technologies and measures are being used in practice and being developed in laboratories to reduce environmental impact during concreting. Technologies and measures for the reduction of environmental impact are outlined below.

(1) Solid waste

Preventive measures to reduce solid waste, i.e. wood waste from formwork on construction sites include the following reusable or recyclable materials for formwork.

- Precast concrete formwork that needs no conventional formwork and also functions as finished material
- Steel formwork system that can be reused many times
- Plastic panels that can be recycled after being used ten to twenty times

(2) Vibration and noise

Self-compacting concrete (SCC) was developed to produce high quality concrete in structures independent of the laborers' skill and has been investigated for practical application throughout the world. As SCC needs no consolidation, it contributes to the reduction of noise and vibration on construction site.

References

3.6-1 JSCE Committee: Draft of Report, 2001 (in Japanese)
3.6-2 AIJ Committee on Global Environment: Present and Future Tasks for Global Environment in Building Structure, Proceedings of Panel Discussion on Global Environment in Annual Meeting in AIJ, 2000 (in Japanese)
3.6-3 P. Eyerer and H. W. Reinhardt: Okologische Bilanzierung von Baustoffen und Gebauden, 2000

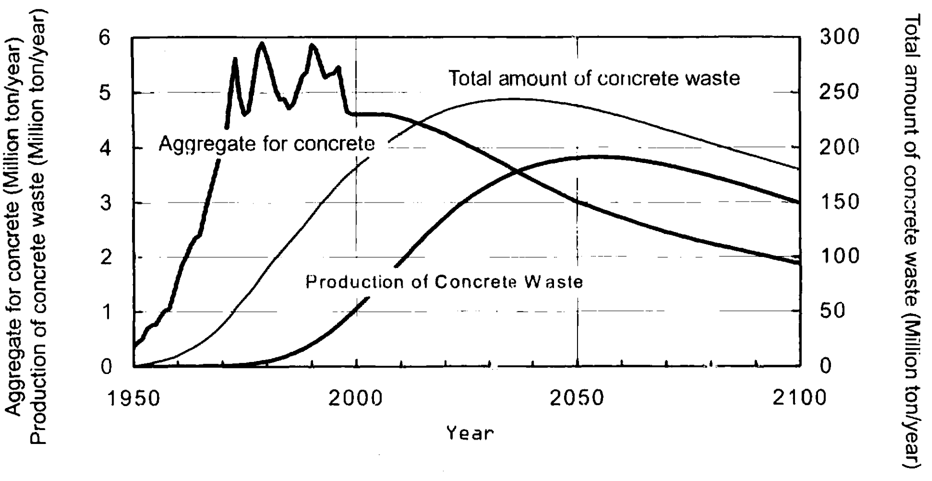

Fig. 3.7-1: Future estimation of the production/stock of concrete in Japan [3.7-1]

3.7 Recycling of concrete

3.7.1 Environmental impact

Recently, people have been dramatically faced with the worldwide problem of how to conserve our limited natural resources. Not only engineers in the construction industry but most engineers are now thinking about and discussing this severe problem.

For example, Fig. 3.7-1 shows an estimate of future production of concrete waste in Japan [3.7-1]. This figure shows that if Japan continues to use natural resources as it did in the 20th century, it will have to store hundreds of millions of tons of concrete waste, even though its population is estimated to decrease. From this inspection, it can be clearly seen that, if we continue to consume our remaining natural resources in the same way as in the 20th century, we must face the problem of dealing with a huge amount of construction waste in the near future. Therefore, it can be quite naturally thought that we have to solve these waste problems as responsible engineers.

One design concept to solve such problems is that if we construct more durable concrete structures, or maintain existing structures more carefully, we will not have a large amount of construction waste as shown in Fig. 3.7-1. However, these solutions may not be agreed upon, because of economic or political requirements. So, we have to make efforts to recycle these construction wastes.

The amount of concrete waste, percentage of recycling at present and the use of recycled waste are briefly summarized as follows.

Australia [3.7-2, 3.7-3]

In 1997, the total amount of construction waste was reported as 15 million tons/year (831 kg/year/person). Fifty-five percent of total concrete waste and 40% of total clay bricks was included in this estimation. Because of the Olympic Games in 2000, construction materials especially were required. As a result, 40 million tons of demolished construction waste was mainly used for base materials. However, cases of using these materials for concrete construction were limited.

The Czech Republic [3.7-4, 3.7-5]

The Czech Environmental Institute maintains a database of waste materials (classification according ISO standards). The database is accessible to everybody through the Internet.

Kind of waste	Outline of production [kt]		Recycling amount [kt]	
	year 1998	year 1999	year 1998	year 1999
Concrete, coarse and fine ceramics, plaster and asbestos products	1241	1536	199	279
Wood, glass, plastic	34	40	0.5	0.6
Products from asphalt and tar	115	94	36	61
Metals and metal alloys	1289	1880	38	30
Excavated earth	4907	4174	84	57
Mixed building and demolition waste	130	151	1	3

Table 3.7-1: Produced and recycled amount of building wastes

Kind of waste	Amount of waste [kt]	
	year 1999	year 2000
Masonry rubble	488.3	589.4
Concrete rubble	466.9	384.6
Bitumen	247.7	317.9
Mixed building waste	166.3	79
Stones	476.8	704
Soils	103.8	261
Others	109.6	249.6

Table 3.7-2: Characterization of recycled building wastes

A summary of the results concerning production of waste in the Czech Republic is presented in Table 3.7-1. The level of recycling in the Czech Republic is characterized by data from the years 1999 and 2000 obtained from the Czech Association for building material development – Table 3.7-2.

The total volume of gravel sand and structural stone exploitation is 50.196 million tons in the year 2000. The recycling of structural rubble is 1.371 million tons and the recycling of stones is 0.704 million tons.

The proportion of recycled materials as part of the total amount of building materials is 3.5 %. Of this amount, 62% belongs to filling non-compacted materials (slopes and rock fills), 30% to non-load bearing structures (e.g. concrete), 8% to load bearing structures (mostly foundations).

Denmark [3.7-2, 3.7-6]

Denmark, as one of the advanced recycling countries, has provided a great contribution to international activities, for example, RILEM research work. The total amount of construction waste was reported as 2.4 million tons/year (459 kg/year/person) in 1993, while the percentage of concrete recycling has improved greatly from 12% in 1986 to 83% in 1993. At present, more than 90% of recycling is expected in Denmark by the systemizing of classification.

However, the on-going cases of applying these recycled materials to construction are only about 10 projects, although many useful specifications have been established in Denmark. The main reasons of this condition are,

(1) There is only a small economic advantage even when recycled materials are used

(2) Many unknown factors regarding the effects or influences of using recycled materials on the properties of concrete still remain.

For these reasons, there are only a few plants in service which can provide demolished concrete aggregate in Denmark.

In 1990, guidelines for using recycled concrete aggregate were published by the Denmark Concrete Institute, and updated in 1995.

France [3.7-7]

In France, the total amount of construction waste has been reported as 24 million tons/year (417 kg/year/person), and the percentage of concrete recycling is 20%. Concrete waste of 15.6 million tons/year (271 kg/year/person) was estimated. About 30 concrete recycling plants are already in service near the big cities.

Although laboratory research on recycling technologies or the use of these materials has been well developed, no guidelines regarding their application to the construction industry have been established.

Germany [3.7-8]

The total amount of construction waste has been reported as 97 million tons/year (1,191 kg/year/person) in 1995, and the percentage of concrete recycling is 73% (1995). About 1,000 concrete recycling plants and 100 classification plants have been in service since 1995. Most of the recycled concrete is provided as base material or back filling material.

With respect to recycling materials, a government level research project has started, while setting domestic specifications which are independent from the DIN.

Italy [3.7-9]

The total amount of construction waste has been reported as 15-30 million tons/year (261-522 kg/year/person), while the percentage of concrete recycling has reached 10%.

At present, the total amount of construction waste at the middle of the 21st century is estimated as 60 million tons. Therefore, the recognition concerning the importance of recycling has increased in these years. However, there is no official application report or guideline for the use of recycled materials.

Japan [3.7-10, 3.7-11]

According to an official report by the Japanese Ministry of Health and Welfare, the total amount of industrial waste produced in Japan annually has been nearly 400 million tons since 1990. Of this amount, 37% has been designated for recycling, while 18%, 69 million tons, has been disposed of. Under these circumstances, 19% of the total amount of waste has been discharged by the construction industry. This percentage is one of the biggest among all industries.

Figure 3.7-2 shows the amount of construction by-products as summarized by the Japanese Ministry of Construction (MOC). In this figure, the amount of concrete waste, 25 million tons

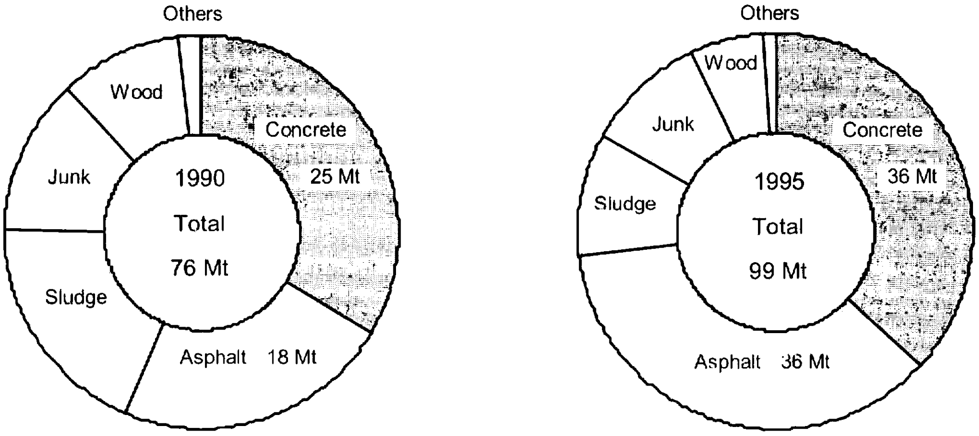

Fig. 3.7-2: Amount of construction by-products
(Summarized by the Japanese ministry of construction at 1990 and 1995)

(34%) in 1990 and 36 million tons (37%) in 1995, shows the largest percentage of total waste. It can be calculated from this summary that, in Japan, people dispose of 788 kg/year/person of construction waste, and 287 kg/year/person of concrete waste.

According to an MOC report of 1995, 65% of concrete waste was recycled and re-used in Japan. This result was higher than the average recycling percentage of all industrial waste. However, compared to the recycling percentage of asphalt (81%), the concrete recycling level of 65% was not considered as a satisfactory. In addition, in the case of concrete waste, the percentage which is finally disposed of is 37%.

In Japan, about 1,200 concrete recycling plants have already been in service since 1995. In most of these plants, the recycling level is low because base materials or back filler materials are produced at the moment. As for recycling plants for concrete materials, there are only a few mainly in Tokyo and Osaka, where a large amount of concrete waste can be collected. These recycled concrete materials, including fine and coarse aggregate, are used mainly for the production of retaining walls or pre-cast concrete. However, in recent years, they have been applied to trial construction.

The Netherlands [3.7-12, 3.7-13]

Like Denmark, the Netherlands has been making a great contribution to RILEM research activities as one of the advanced recycling countries. The total amount of construction waste has been reported as 14 million tons/year (910 kg/year/person). The percentage of concrete recycling had already reached 75% in 1995, while a level of 90% was expected by 2000.

As in the case of other countries, most of their recycled concrete is used as base or back filler materials.

Belgium [3.7-2, 3.7-16]

The production of construction and demolition waste is estimated at eight to eight and a half million tons per year, of which, according to the Symons study, about 85% is recycled. There are however quite important differences within the country. In the South, i.e. the Walloon Region, recycling reaches at the moment lower percentages due to the richness in natural resources. On the other hand, the Brussels Capital Region as well as the Flemish regions are confronted with a higher population density and nearly no natural resources. In those regions the competitiveness of the recycling industry is of course positively influenced by these conditions.

Belgium is a federal state and environmental matters fall under the authority of the regions, therefore waste and recycling issues are regulated and planned at the regional level. All three regions have developed waste management plans and regulations addressing construction and demolition waste. As such, clear objectives with regard to the recycling of construction and demolition waste have been put in place:

- The Brussels Capital Region aimed for a recycling level of 95% in 2002.
- In its C&D waste management plan, the Flemish Region aimed for a recycling level of 75% by 2000, which is now already above 80%.
- In its Horizon 201- waste management plan, the Walloon Region defined its recycling target for construction and demolition waste as 81% by 2005 and 87% by 2010.

Poland [3.7-14, 3.7-15]

In Poland, the average amount of construction waste was assessed at over 650 kg/year/person in the period 1995-1999. The utilisation of rubble aggregate obtained from the demolition of reinforced concrete or pre-stressed concrete structures has become an important problem in Poland since the new highway program was made

Research work on the properties of recycled aggregates and structural concretes with such aggregates was seriously undertaken on a relatively large scale in Poland in the early 1990's. Unfortunately, the early tests were carried out with use of weak concretes or concretes of unknown initial properties. In general, very few tests described with full information about the initial material, compositions of recycled concrete, workability and development of strength, or deformability and shrinkage in early age. Since 1995, research efforts in Poland have been concentrated on high-strength/high-performance concrete manufacturing with the use of recycled aggregate (RAC) and mainly coarse aggregate.

Spain [3.7-16, 3.7-17]

The total amount of construction waste in 1997, has been reported as 17 million tons/year (380 kg/year/person), however, the percentage of concrete recycling has not been reported. These construction wastes include 54% of clay bricks and 12% of concrete waste. 5-10% of wastes have been used as concrete materials.

In Spain, 12 on-site (removable) recycling plants are in service, and the recycled materials are mainly used as base materials. The use of recycled concrete materials is only permitted as blending with natural materials. Concrete made by using only recycled materials is not allowed, since the water adsorption of recycled concrete materials is higher than its specification.

United Kingdom [3.7-18]

In 1991, the UK reported the total amount of construction waste as 24 million tons/year (411 kg/year/person), while the percentage of concrete recycling has reached 60%. Although three to four million tons of concrete waste has been treated as recycled materials every year, only 50% of it can be satisfactorily used as concrete aggregate. In producing recycled concrete materials, both the source concrete and application are well controlled by their domestic specifications. For example, only old road pavement and airport pavement can be used as source concrete for recycling, and these recycled materials can only be used as base materials.

United States [3.7-19]

Basically, the United States does not have serious problems regarding a shortage of natural resources. However, research work on the recycling of construction materials and technologies started in the 1970's, with the main area of concern being the reuse of construction waste as base material.

3.7.2 BAT system

It is recognized that the amount of demolished concrete will increase. Currently the uses for waste concrete are mostly limited to down-cycling, such as for road sub-base materials, while the enormous amount remaining is still being dumped. Meanwhile, there is a serious depletion of aggregate resources around the world. In other words, it will become difficult to expect any sustainable development of construction activities while maintaining the present system of disposal and use of concrete.

Unless the problems of concrete waste disposal and recycling are solved by developing a high-performance and economical method for recycling waste concrete, the environment will deteriorate, with piles of concrete debris discharged into people's living area.

In the following, BAT systems for the utilization of recycled aggregate from road sub-base material to structural concrete are introduced.

(1) Use as sub-base materials

Recycled aggregates for back-filling or road sub-base materials are produced by a simple compressive-type crushing machine such as a Jaw Crusher. However, it is difficult to use such recycled aggregates for structural concrete because of its low quality. A large amount of research has been conducted on recycled aggregate, with the publication of proposed guidelines and specifications [3.7-11, 3.7-24]. However, many difficult problems remain unsolved concerning the utilization of recycled aggregate as a material for ready-mixed concrete. Therefore, most of the recycled concrete is being used as back-fill or road sub-base materials (Table 3.7-3, (6)).

(2) Use as recycled aggregate for non-structural concrete

Low-quality recycled aggregates from concrete are generally produced by a combination of compressive-type and impact-type crushers such as the Jaw Crusher and Impact Crusher. Such concrete materials are basically used as aggregate for non-structural concrete [3.7-10, 3.7-11, 3.7-24]. The quality of recycled aggregates has been classified in terms of absorption. A high content of cement hydrate adhering to the surface gives a high absorption. It has been clarified that concrete made using such aggregate exhibits lower strength, lower modulus of elasticity, larger drying shrinkage, and lower freezing and thawing resistance. Low-quality recycled aggregates have limitations regarding the maximum design strength and the applicable structural components. Therefore, it will be difficult to commercialize them. This is the reason why down-cycling-type recycling is being conducted. (Table 3.7-3, (3) to (5)).

On the other hand, advanced methods of recycling aggregate concrete have been proposed. For example, virgin and recycled aggregates are combined or additives such as silica fume or fly ash are mixed in concrete to enhance the mechanical properties, durability and homogeneity of concrete. The concrete, in which such mixing methodologies are applied, is often called high-performance concrete with recycled aggregate [3.7-15].

(3) Use as recycled aggregate for structural concrete

High-quality recycled aggregates which can be applied to structural concrete, such as virgin aggregate can be produced by using advanced technology. Such recycling technology is not similar to those used for low-quality recycled aggregate, and is regarded as a new technique for producing high-quality recycled aggregate that causes no reduction in the values of the resulting products (Table 3.7-3, (1) and (2)).

It should be noted here that the techniques extract recycled aggregates or materials, having the same quality as natural aggregate, from waste concrete. Though a significant amount of energy may be input at the treatment stage of the production system, recycled aggregate is produced in a condition usable as a component for the same product or for other products for which the same or higher performance is required. When this condition is ensured, the material is in a condition that can be circulated in a closed system. In methods for the recycling of waste concrete, it should be made clear that some of the methods can be operated in a closed system while the others cannot. For example, two techniques for producing high quality recycled aggregates are introduced as follows:

1) Technology 1

This technology is called mechanical scrubbing [3.7-20], in which concrete lumps are crushed using an eccentric tubular vertical mill to produce recycled coarse aggregate by removing adhering cement paste. Fine aggregate is then similarly produced from the recycled aggregate that is smaller than the specified size. A recycled aggregate conforming to general quality standards is thus obtained. On the other hand, the percentage of recovery varies widely depending on the type of original aggregate, and there is a slight difficulty in producing fine aggregate. Virgin fine aggregate is therefore mixed when applying recycled aggregate produced

Type of circulation	Type of application	Type of recycled concrete	Quality of recycled aggregate		Application of recycled aggregate / recycled concrete				
			Coarse	Fine	Main frame	Sub frame	Back filling	Special treatment	Examples
Loop1	Structural concrete	(1) High quality 1	High	High	o	o		Production system for high quality aggregate must be utilized	Ordinary reinforced concrete structure
		(2) High quality 2	High	(Virgin)	o	o		Production system for high quality aggregate must be utilized	Ordinary reinforced concrete structure
Loop2	Non-structural concrete	(3) Low quality 1	High	Low	×	o		Cement paste must be strengthened	Concrete in contact with ground, Foundation, Cast-in-place concrete piles
		(4) Low quality 2	Low	(Virgin)	×	o		---	Foundation slabs, Earthen floor slabs
		(5) Low quality 3	Low	Low	×	o		---	Subslab concrete, Back filling concrete, Leveling concrete
Loop3	Sub-base Materials	(6) No use	Low	Low	×	×	o	---	Paving stone, Earthen floor stone

Table 3.7-3: Type of recycling of concrete and suggested uses in structure

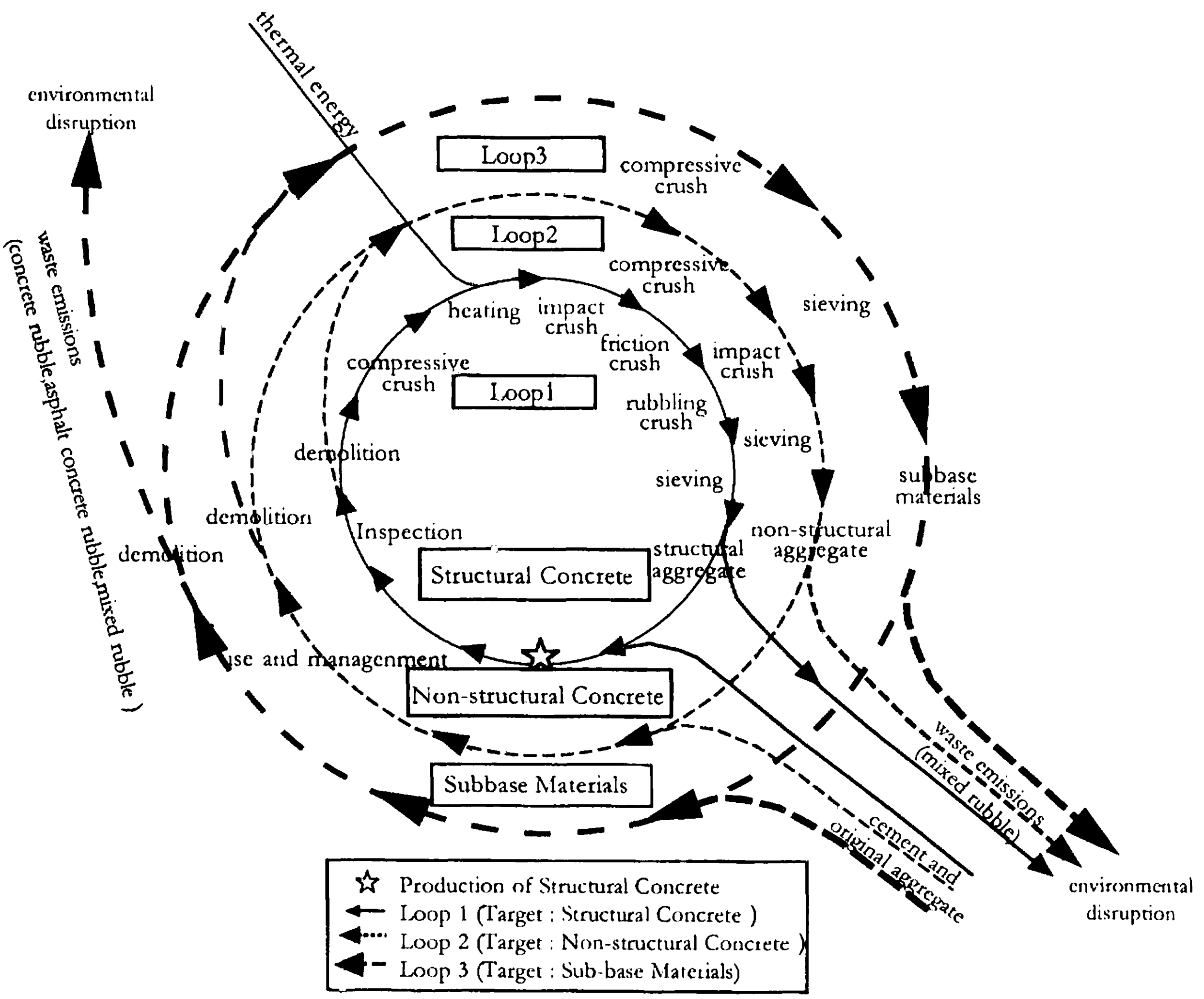

Fig. 3.7-3: Material flow of recycling of concrete

by this method to structural concrete. The use of recycled coarse aggregate produced by this method is not classified as down-cycling, because the quality of structural concrete is assured. However, it is designated as (2) in Table 3.7-3, since the use of virgin fine aggregate opens the loop of resource circulation.

2) Technology 2

This technology is called heated scrubbing [3.7-21], in which concrete crushed beforehand into 50-mm lumps is charged in a vertical heating furnace and subjected to hot air from below to make the cement paste brittle and weak. It is then scrubbed in a tube mill to separate cement paste from the aggregate. The heating temperature is approximately 300°C. The quality of recycled aggregate is the same as the original one, while the percentage of recovery is sufficiently high. The qualities of concrete made using this aggregate are virtually the same as the original concrete. This technology assures the quality of structural concrete, avoiding down-cycling, while forming a closed loop in terms of the resource circulation of concrete materials. Accordingly, this technique is designated as (1) given in Table 3.7-3.

It requires the availability of infrastructures that economically provide the sources necessary for heating. In addition, the superiority of this technique from the standpoint of the life-cycle load on the environment and life-cycle cost has to be socially recognized.

3.7.3 Research, development and standard of concrete demolition and recycling

As noted before, the present state of research and development activities on concrete recycling and as a consequence the development state of standards or specifications differs widely in each country and area. In the following, the situation in Europe and Japan are briefly introduced.

European Area [3.7-24, 3.7-25]

Most of the early European recommendations were rather conservative compared with other areas. Such was the general assessment of RILEM TC 121-DRC Specifications [3.7-25]. Forerunners in the areas of research and national technical specifications, recommendations and/or standards were no doubt Denmark, the Netherlands and Belgium.

Since the European area strongly recognizes the importance of environmental sustainability, tasks concerning the treatment of demolished waste and recycling technologies began in the 1970's, mainly in RILEM and CEN. The RILEM technical Committee 37-DRC on Demolition and Reuse of Concrete was formed in 1976. In 1978 the first RILEM TC 37-DRC state-of-the-art report was published on recycled concrete as an aggregate for concrete. On the other hand, two CEN technical committees, CEN/TC-154 and CEN/TC-227, have started as special task groups for recycling concrete. The draft specification of recycling concrete was published in 1998 by RILEM.

The first international symposium on demolition and recycling of concrete was held in Rotterdam in 1985 in co-operation with the European Demolition Association (EDA). This symposium gave valuable input to the work of the committee from an industrial point of view. Developments were fast, and it was soon decided to hold a second international RILEM symposium on demolition and reuse of concrete in 1988 in Tokyo in order once more to scientifically and practically enlighten people from all over the world.

Another research committee on "Demolition and Removal Methods" started at that time and the first technical book in this field; "Demolition Method for Concrete Structures" was published in 1970. In 1971 the Building Contractors Society (BCS) started the "Committee on Demolition of Reinforced Concrete Structures" which drew its members from the research and engineering staff of major contractors along with academics from various universities. This committee conducted research and development work into a variety of demolition techniques such as jacking, explosives, and rebar heating methods by either direct or induced current.

In 1978 the committee published the "Standard of Public Nuisanceless Demolition Method of Reinforced Concrete Structures", and in 1987 also published a "Recommended Proposal of Demolition Method of Underground Reinforced Concrete Structures". These two recommendations were in principle based on the guidelines of the Netherlands, Denmark and Belgium which were advanced in recycling techniques. Also, in Germany, the specification of DIN4226-100, which includes recommendations for the use of recycled fine and coarse aggregate as concrete materials, was published in 2000.

The UK has had some approaches to recycling which is different from other countries. They introduced a "Landfill Tax" to cover the cost gaps between recycling materials and natural resources in 1996. Additionally, the UK government supports economically plant construction and research projects for recycling construction materials. Furthermore, the BS 6543 for the use of industrial by-products and construction wastes was introduced in 1985.

Japan [3.7-10, 3.7-11]

Studies of the demolished concrete of the Japan Power Demonstration Reactor (JPDR) by the Japan Atomic Energy Research Institute (JAERI), which started in 1979, resulted in many useful developments for the demolition of reinforced concrete structures. In 1981, the diamond wire saw for cutting reinforced concrete was introduced and it is expected that this method will be the subject of further developments over the coming years.

In this way, methods for the demolishing of concrete structures have developed rapidly in Japan in order to meet the strict requirements for demolition methods imposed by its citizens. The successful development of these methods is the result of the efforts of the demolition related industries, academic institutions and public authorities which have joined forces to ensure that these requirements are met. Indeed the reason for holding the Symposium in Tokyo is that the RILEM Committee 37-DRC considered that the development of demolition methods and use of modern demolition techniques was well advanced in Japan.

Japan has a relatively long experience in conducting research and development on the reuse of demolished concrete. About 95% of demolished concrete is being reused in construction projects, but almost entirely as a sub-base material for road pavement.

Study of the reuse of concrete waste in Japan started in about 1971. The "Committee on Disposal and Reuse of Construction Waste", which was formed by the BCS in 1974, conducted many successful experiments on the production of recycled concrete aggregate and the study of recycled concrete. In 1977 this body published the Proposed Standard for the Use of Recycled Aggregate and Recycled Aggregate Concrete. Later on, during the period 1981-1985, the Ministry of Construction (MOC) conducted a study to encourage the reuse of construction waste for new construction work and introduced a standard for the reuse of demolished concrete.

In 1991, the Japanese government established the Recycling Law, which required relevant ministries to nominate materials that they must control and to encourage reuse and recycling of those materials under their responsibility. The Ministry of Construction (MOC) specified demolished concrete, soil, asphalt concrete, and wood as construction by-products.

In 1994, the MOC announced "Tentative quality standards for reusing materials from demolished concrete", which defined the quality of recycled aggregate, recycled sub-base material and filling material. The tentative standard classified recycled aggregate into several classes according to quality as shown in Table 3.7-4.

With this background, the draft JIS Technical Report (JIS/TR) for recycled concrete was published in 2000, which includes the following policies.

- A new JIS is to be created for recycled concrete, but not recycled aggregate.
- Recycled concrete must be standardized independently from JIS A 5308.

Coarse Aggregate			Fine Aggregate		
Class	Absorption	Soundness	Class	Absorption	Soundness
I	< 3%	< 12%	I	< 5%	< 10%
II	< 3% and or < 5% and	< 40% < 12%	II	< 10%	
III	< 7%				

Table 3.7-4: Quality recommendation for recycled aggregate (1994, Ministry of construction, Japan)

Class	Nominal Strength (N/mm^2)	Gmax (mm)	Slump (cm)	Chloride Content (kg/m^3)
Normal	12	20 or 25	< 15	---
Chloride Controlled	12	20 or 25	< 15	< 0.6
Flexible Use	< 18	as required	as required	as required

Table 3.7-5: Specification of recycled concrete (Japan industrial standard, technical report, JIS/TR 0006, 2000)

- Applicable sections in structures where recycled concrete can be used are limited.
- In order to facilitate quality control, the number of classes of recycled concrete should be minimized.
- Considering the variety of recycled concrete, an adequate margin of quality for designated uses must be allowed, which will also simplify quality control.
- When skilled engineers use recycled concrete, they can extend its scope of application.

The specification of recycled concrete is shown in Table 3.7-5.

"Completely recyclable concrete (CRC) [3.7-23]" a kind of concrete that permits complete recycling, is defined as "concrete whose binders, additives and aggregates are all made of cement or cement materials, all of which can be used as raw materials for cement or recyclable aggregate after hardening". CRC was employed for the first time in the construction of an actual structure in the autumn of 2000 in Japan.

Under these circumstances, conventional recycling, which depends too much on reactive, nosotropic technology with an emphasis on down-cycling inhibits the ensuring of circulatability to establish sustainable development by continuing construction activities that are economically feasible in industrial ecosystems. It is necessary to put into practice proactive technology involving material-selection and material-design techniques that permit complete recycling on the material level. It should be noted that both proactive and reactive technologies [3.7-22] should be put into practice. In order for the construction industry to seriously consider sustainability of construction activities, it is important to formulate at a certain stage a new operation system for primary materials, or basic materials constituting the earth, by selecting and designing them to achieve their complete return to materials after use.

3.7.4 Standards and recommendations

For example, the following regulations regarding concrete recycling are established.
DIN4226-100 (Germany)
BS 6543 (UK)JIS/TR 0006, Specification of Recycled Concrete, 2000 (Japan)

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4 Maintenance systems of concrete structures in environmental design

4.1 General

The purpose of maintaining of concrete structures is to retain their required performance throughout their service lives. The original meaning of "design" is to devise a logical program to achieve the expected purpose of an act. Therefore, the maintenance system of concrete structures is a part of the design of concrete structures.

In the conventional maintenance systems of concrete structures, the strategy from the viewpoint of environmental impact is not clear, while methodologies for assessing the environmental impact during maintenance are not provided, in the current standards and recommendations. The required performance and maintenance method at the initial design stage should be changed by the adopted maintenance strategy or the maintenance systems for concrete structures.

As global environmental conditions are becoming worse, there is an increasingly strong desire to minimize environmental impact during the service life and demolition of concrete structures. Therefore, a maintenance system for concrete structures should be developed to minimize the total environmental impact. These maintenance systems should include an environmental strategy that covers both the lifetime and demolition of concrete structures. It is necessary to develop a quantitative evaluation method regarding the environmental impact for the stage of maintenance of concrete structures through their service life and its demolition.

However, many important problems have not been solved concerning environmental impact resulting from the maintenance of concrete structures as follows:

- Method and strategy of maintenance to reduce environmental impact
- Quantitative environmental impact during service life of concrete structures
- Performance requirement of concrete structures, such as safety, serviceability, hazards to third parties, aesthetic appearance, landscape and durability from the view point of reduction of environmental impact
- Mechanism of deterioration and prediction of the deterioration progress of concrete structures caused by factors such as carbonation, chlorides, freezing and thawing, chemical attack, alkali-silica (alkali-aggregate) reaction, fatigue etc.
- Evaluation method regarding the degree of deterioration of concrete structures
- Monitoring method of deterioration degree of concrete structures
- Quantitative evaluation method regarding the environmental impact of maintaining a concrete structure for its life cycle using a LCA based on Life Cycle Management (LCC), such as LCE, $LCCO_2$, etc.

In the following part of this chapter, present maintenance methods for concrete structures are described together with consideration of environmental impact through their life cycle in the form of published principal standards or recommendations. However, these methods could not evaluate the environmental impact using quantitative indexes.

4.2 BAT of maintenance method of concrete structures

Concrete structures that are designed and constructed according to codes should be inspected and maintained as frequently and carefully as possible, so that they continuously fulfill all requirements related to their intended serviceability and safety. Particularly, structures of major importance or under severe service conditions should necessarily be inspected periodically, adopting appropriate in-situ testing and monitoring.

For conventional concrete structures under normal service conditions, the following time periods between successive component inspections is suggested in CEB-FIP Model code 1990 [4-1],

• For houses, offices, etc.	10 years
• For industrial buildings	5-10 years
• For highway bridges	4 years
• For railway bridges	2 years
• For road bridges	6 years

All non-structural minor defects or light damage impairing the performance of elements or parts of the structure should be systematically rehabilitated. If serious damage is observed or major defects are suspected with possible structural consequences, an appropriate assessment and redesign procedure should be followed.

ACI Committee [4-2] reported the time of repair or rehabilitation of a damaged concrete structure to predict the service life of a bridge by combining field data and theoretical models (Cady and Weyers 1984; Weyars et al. 1993,1994 [4-3]). The actual calculation of the service life was made by breaking down the entire process into several independent phenomena, such as corrosion initiation, visible corrosion damage requiring maintenance, and subsequent damage requiring rehabilitation. The time to initiate repair or patching of the structure *Tm* can be calculated by determining the time of corrosion initiation *Ti* and the time after the initiation of corrosion to significant corrosion *Tcor*

$$Tm = Ti + Tcor$$

In addition, the time for rehabilitation, or resurfacing of the structure, *Trehab*, can be calculated using the value *Tm* by determining the time after significant corrosion occurrence to deterioration *Tdet* and the equation as follows:

$$Trehab = Ti + Tcor + Tdet$$

To estimate the time between initial cracking and effective functional service life (*EFLS*), the following equation was used:

$$T = EFSL - (ID/DR)$$

where

ID = noticeable initial surface damage resulting from the initiation of corrosion; and
DR = deterioration time.

And this report gives the estimating method of chloride concentration at the given point of a concrete structure.

However, this method is not provided to evaluate the total environmental impact for its life cycle including maintenance.

According to the AASHTO Maintenance Manual "The Maintenance and Management of Roadways and Bridges 1999" [4-4], an integrated management system will be needed to examine each maintenance activity, considering the merit of moving from a reactive ("fix it when it's broken") maintenance approach to preventive ("a stitch in time saves nine") maintenance approach with anticipated costs and long-term infrastructure consequences.

To initiate or extend a preventive maintenance philosophy to any maintenance activity requires an assessment of why an activity is done and when. To complete the transition from a reactive maintenance philosophy for an activity requires that some definitive threshold be established at which the planned maintenance activity is programmed, scheduled, performed, and subjected to review for quality, productivity, efficiency, and cost-effectiveness. An activity must be reviewed to determine if it is being performed "on demand" or "on schedule".

In these maintenance systems it is not easy to evaluate the environmental impact of the adopted maintenance system or method, although it is necessary to evaluate or assess the environmental impact of the adopted system or method using a quantitative assessment method, such as LCE, $LCCO_2$, etc., based on LCA (Life Cycle Assessment).

On the other hand, in designing a new concrete structure, an integrated designing method or system is necessary, which is based on safety, durability, cost and maintenance for concrete structures. However, adequate quantitative evaluation methods based on the LCA method, such as LCE, $LCCO_2$ etc., in concrete structure design including maintenance have not been developed. Therefore, a suitable period and countermeasure which includes demolition or reconstruction, relevant repair or strengthening of a damaged concrete structure to minimize the environmental impact for its entire service life can not be decided.

The JSCE (Japan Society of Civil Engineering) Standard Specification "Maintenance of Concrete Structures 2001" [4-5] provides the method of maintenance including maintenance strategy, method of inspection, testing and monitoring methods, estimation of the mechanism of deterioration, evaluation of degree of deterioration, prediction of deterioration progress, method for judging the necessity of countermeasures and general countermeasure methods for damaged concrete structures. The prediction of deterioration progress in this standard specification is performed using the deterioration rate and degree for each attack factor, such as carbonation, chlorides, freezing and thawing, chemical attack, alkali-silica (alkali-aggregate) reaction and fatigue over time and under defined conditions for concrete structures.

An example of maintenance systems for concrete structures by the JSCE [4-5] is shown in Fig.4-1.

Computer aided technologies are very helpful in estimating the environmental impact of the service life and demolition of concrete structures. An example of such computer-aided technology was developed by the JSCE [4-6]. In this technology, the LCC of particular concrete bridge can be estimated based on the BMS (Bridge Management System).

4.3 Standards and recommendations

The list of published standards and recommendations for maintenance systems of concrete structures is as follows:

- Highways and Traffic Departmental Standard (BD27/86)-Materials for the repair of concrete highway structures- (Department of Transport, UK) (1986)
- Highways and Traffic Departmental Advice Note (BD23/86)-The investigation and repair of concrete highway structures (Department of Transport, UK) (1986)
- CEB-FIP Model Code 1990 (1990) Part III 13. Maintenance 13.1 Maintenance 13.2 Inspection 13.3 Repair
- Causes, Evaluation, and Repair of Cracks in Concrete Structures (ACI224.1R-93, USA) (1993)
- Draft Recommendation for Repair Strategies for Concrete Structures Damaged by Reinforcement Corrosion (RILEM124-SRC) (1994)
- Compendium of Case Histories on Repair of Erosion-Damaged Concrete in Hydraulic Structures (ACI210.1R-94, USA) (1994)
- Draft Recommendation for Repair Strategies for Concrete Structures Damaged by Reinforcement Corrosion (RILEM) (1994)
- Draft Recommendation for Maintenance Systems for Concrete Structures (JSCE) (1995)
- Guide for Service Life Design of Buildings Part 1-Genaral Principles ISO Draft Number 2 (ISO) (1995)

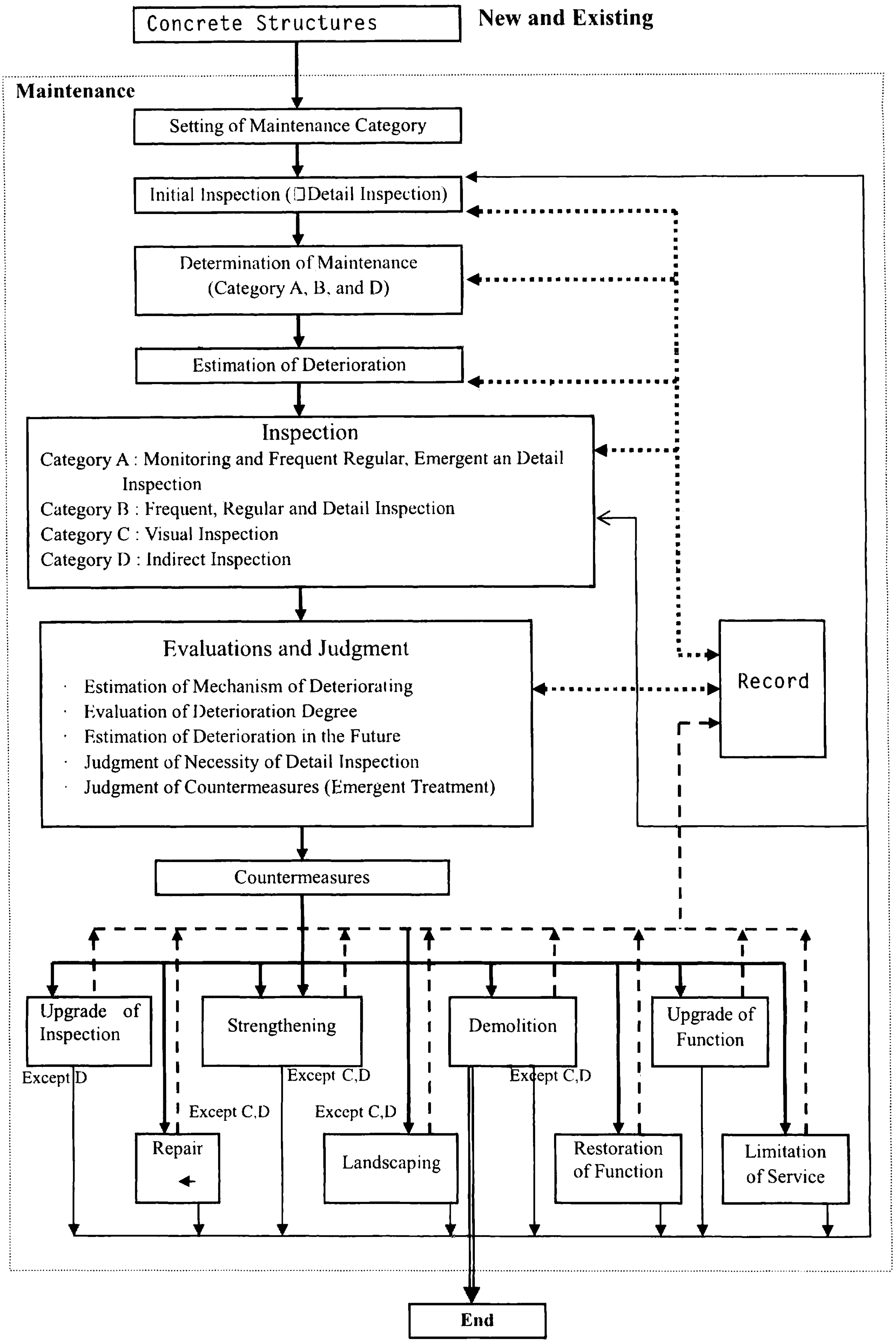


Fig.4-1: An example of countermeasures in maintenance (JSCE 2001)

- Guide to Concrete Repair and Protection (Standards Australia, Standards New Zealand) (1996)
- Recommendation for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures (AIJ) (1997)
- EN1504 Products and Systems for the Protection and Repair of Concrete Structures - Definitions, Requirements, Quality Control and Evaluation of Conformity - (CEN/TC104) (1998)
- EN1504-1 Part1: General scope and definitions
- prEN1504-2 Part2: Surface protection systems
- prEN1504-3 Part3: Structural and non structural repair
- prEN1504-4 Part4: Structural bonding
- prEN1504-5 Part5: Concrete injection
- prEN1504-6 Part6: Grouting to anchor reinforcement or to fill external voids
- prEN1504-7 Part7: Reinforcement corrosion prevention
- prEN1504-8 Part8: Quality control and evaluation of conformity
- ENV1504-9 Part9: Genaral principles for the use of products and systems
- prEN1504-10 Part10: Site application of products and systems and quality control of the works
- Committee Report on Rehabilitation Method for Damaged Concrete Structures (JCI) (1998) (in Japanese)
- AASHTO Maintenance Manual: The maintenance and Management of Roadways and Bridge (AASHTO) (2000)
- Standard Specification for Maintenance of Concrete Structures (JSCE) (2001) (in Japanese)

References

4-1 CEB-FIP Model Code 1990 (1990) Part III 13. Maintenance 13.1 Maintenance, 13.2 Inspections, 13.3 Repairs, 1990

4-2 Service-Life Prediction – State-of-the-Art-Report (ACI 365. 1R-00), ACI, 2000.

4-3 AASHTO Maintenance Manual: The maintenance and Management of Roadways and Bridge, 2000

4-4 Service-Life Prediction – State-of-the-Art-Report (ACI 365. 1R-00), ACI, 2000.

4-5 JSCE (Japan Society of Civil Engineers): Standard Specification for Maintenance of Concrete Structures, 2001(in Japanese)

4-6 JSCE(Japan Society of Civil Engineers): Concrete Library, No.104, Date for Standard Specification for Maintenance of Concrete Structures, pp.123-143, 2001(in Japanese)

5 Methodologies for environmental impact evaluation and optimization of concrete structures

Environmental performance represents one of the principal areas of sustainability. The three essential pillars of sustainability should be considered in the design, construction, use and other life-cycle phases of any concrete structure:

- Environmental issues
- Economic constraints
- Cultural-social aspects

This chapter deals mainly with the first group of aspects related to environmental impact evaluation of concrete structures. However, some examples of more complex methods with evaluation methodologies covering other sustainability areas are also mentioned.

The environmental impact evaluation is an essential part of Life Cycle Assessment (LCA) methodology defined in the ISO 14000 standards. The LCA includes a technique for assessing environmental aspects and potential impacts associated with the existence of a product within the whole life cycle. In this sense any concrete structure – e.g. concrete building structure, concrete bridge, concrete structural element or any other concrete engineering structure has to be considered as a product and thus should be assessed from the point of view of all its environmental impacts within the whole life cycle.

The environment-based optimization is an active process targeting reduction (minimization) of negative environmental impacts of the product – concrete structure - and according to the basic principles of LCA should cover its entire life.

5.1 Context and principles

The goal and scope of environmental impact evaluation and optimization shall be consistent with the intended application in the design process. The recognition level of the evaluation and optimization model should be sufficiently well defined to ensure that the results of the study are compatible, relevant and sufficient to address the pre-defined goals.

The global character of the problem, being significant by the complexity of relations among the elements of the analyzed system, requires consideration of its multicriterial character. The use of multicriterion evaluation methodology and multicriterion optimization techniques respecting the significance of the system's interrelationships is thus essential and necessary.

The evaluation and optimization methodologies have to be complex, considering all relevant flows (material, energy and other), thus covering the corresponding essential environmental criteria. However, admissible simplifications of the model are usually needed.

Taking into account the relatively high variance of available environmental data used in environmental impact evaluation and optimization, the implementation of the stochastic approach, including sensitivity and reliability analysis can be suitable and/or necessary.

The evaluation and optimization methods and models should preferably be based on the following characteristics and essential qualities:

- Complexity - the methods and models should be complex and should cover the most important environmental criterions; a multicriterion approach incorporating weighting method and corresponding sensitivity analysis is in many cases desirable or necessary,
- Time dependency - the methods and models should consider the entire life cycle of a concrete product (element, structure etc.). The typical life cycle of concrete product should cover the following stages: raw material acquisition, production of concrete and structural components, design and construction, operation and maintenance, repair,

renovation, demolition, recycling and waste disposal (Fig. 5.1-1).

- Probability - the evaluation methods and models should respect the probability feature of the time dependent problem; implementation of the stochastic approach including reliability analysis is valuable and/or necessary.

The complex life-cycle assessment covering the evaluation of material, energy, pollution, waste, and other harmful impact flows throughout the whole life cycle of the concrete product should become an essential part of the quality design approach. The basic principles of LCA methodology are further described in chapter 5.4.

The quality of performance of the structure throughout its whole life is essentially determined in the initial conceptual design stage. Correspondingly the best opportunity to influence the total value of the environmental impact of the structure is in the initial phase of the structural design – in the conceptual design stage (Fig. 5.1-2). The second opportunity is at the beginning of the construction phase – when the technology concept is being adjusted and detailed.

The level of environmental impact of a concrete structure in the utilization phase is strongly

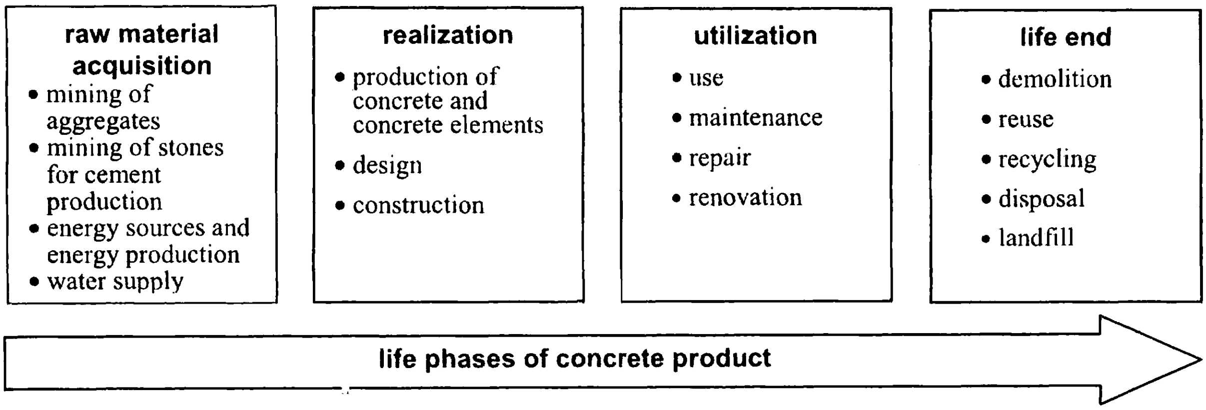


Fig. 5.1-1: Typical life phases of the concrete product / concrete structure with possible life stages

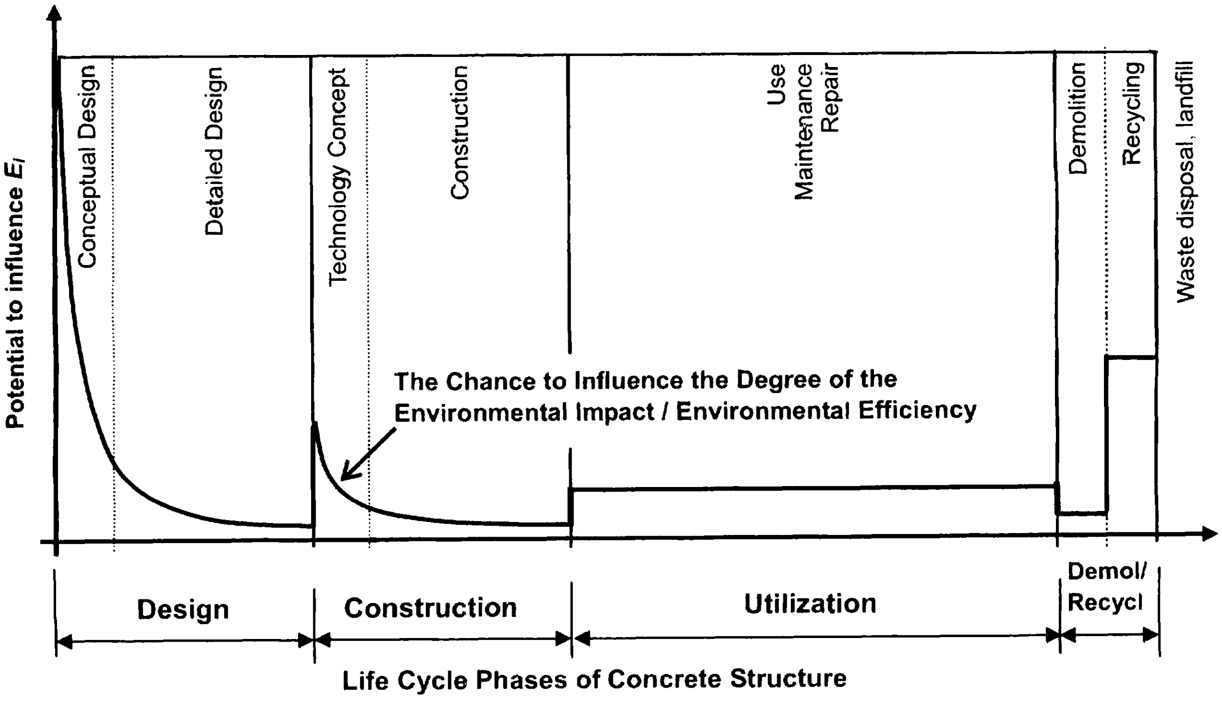


Fig. 5.1-2: The potential chance to influence the degree of the environmental impact E_i throughout the whole life cycle of the concrete structure

pre-determined by the design and construction concepts and can be influenced during the utilization phase only to a relatively small extent – particularly during maintenance or repair of a concrete structure. There is a relatively high chance to influence the degree of environmental impact at the very end of the life cycle – in the recycling phase – when elements, parts and materials can be converted and prepared for new use in another material cycle.

Considering the above-described feature of the life cycle, it is extremely important to concentrate optimization efforts at the beginning conceptual steps of both the design and construction phases.

5.2 Evaluation criteria and data

5.2.1 General

A large number of various behavior aspects and parameters of a concrete structure have to be considered when design, optimization and evaluation respecting environmental issues are carried out. In general, the parameters can have a technical as well as non-technical feature. The definition of essential evaluation criteria and the collection of relevant data needed for environmental impact evaluation are targets of two phases of the LCA – goal and scope definition and Life Cycle Inventory (LCI) as defined in ISO 14041 (see also 5.4.2).

The important environmental aspects are: (i) non-renewable raw materials depletion, (ii) non-renewable energy source depletion, (iii) non-controlled water consumption and contamination, (iv) use of renewable resources at a rate faster than their regeneration ability, (v) harmful emissions, (vi) harmful waste, (vii) nuisance and health risk, (viii) durability, (ix) repairability, (x) reusability and (xi) recyclability. Detailed description of the main environmental aspects and corresponding criteria are described in Chapter 3.

The environmental impact categories essential and frequently used for evaluation of environmental performance of structures are e.g.:

- Global Warming Potential - GWP (global view),
- Ozone Depletion Potential - ODP (global view)
- Acidification Potential - AP (regional view),
- Eutrophication Potential - EP (regional view)
- Natural Resource Depletion
- Waste Disposal, Landfill
- Air Pollution - Indoor and Outdoor
- Toxicity ...etc.

The corresponding environmental criteria essential for an assessment of environmental impact and/or environment-based optimization of the concrete construction are for example:

- Embodied CO2 ,
- Embodied SO2 ,
- Embodied energy,
- Non-renewable resources use (material and energy),
- Water consumption and contamination,
- Waste disposal,
- Reuse and recyclability potential.

However, other environmental criteria could also be important in specific evaluation tasks of concrete structures (see Chapter 3).

5.2.2 Materials and energy flows

The typical material flows related to construction, utilization, maintenance, repair, demolition and recycling of concrete structure with corresponding environmental impacts are shown in Fig. 5.2.1.

5.2.3 LCA databases

The process of environmental impact evaluation requires input of environmental data associated with structural materials and technology processes used in construction. The needed environmental data are mostly based on the statistical evaluation of environmental damages associated with the existence of product – e.g. embodied energy, embodied CO_2, embodied SO_2 etc. The environmental material characteristics are implemented in different tools for assessment of environmental impact like: (i) printed catalogue sheets [5-1], [5-2], (ii) digital database [5-3] or (iii) complex assessment tools with internal database [5-4], [5-5]. Two examples from many others follow:

- An essential part of the GEMIS system [5-3] (see also chapter 5.5.6) is a database containing environmental and economic data for energy, material and transport systems through the whole life cycle. The GEMIS database offers environmental data on fossil fuels, renewables, nuclear, biomass, hydrogen, processes for electricity and heat, raw materials and transportation. Available environmental data contain information about emissions of harmful gases, liquid and solid wastes and land use.

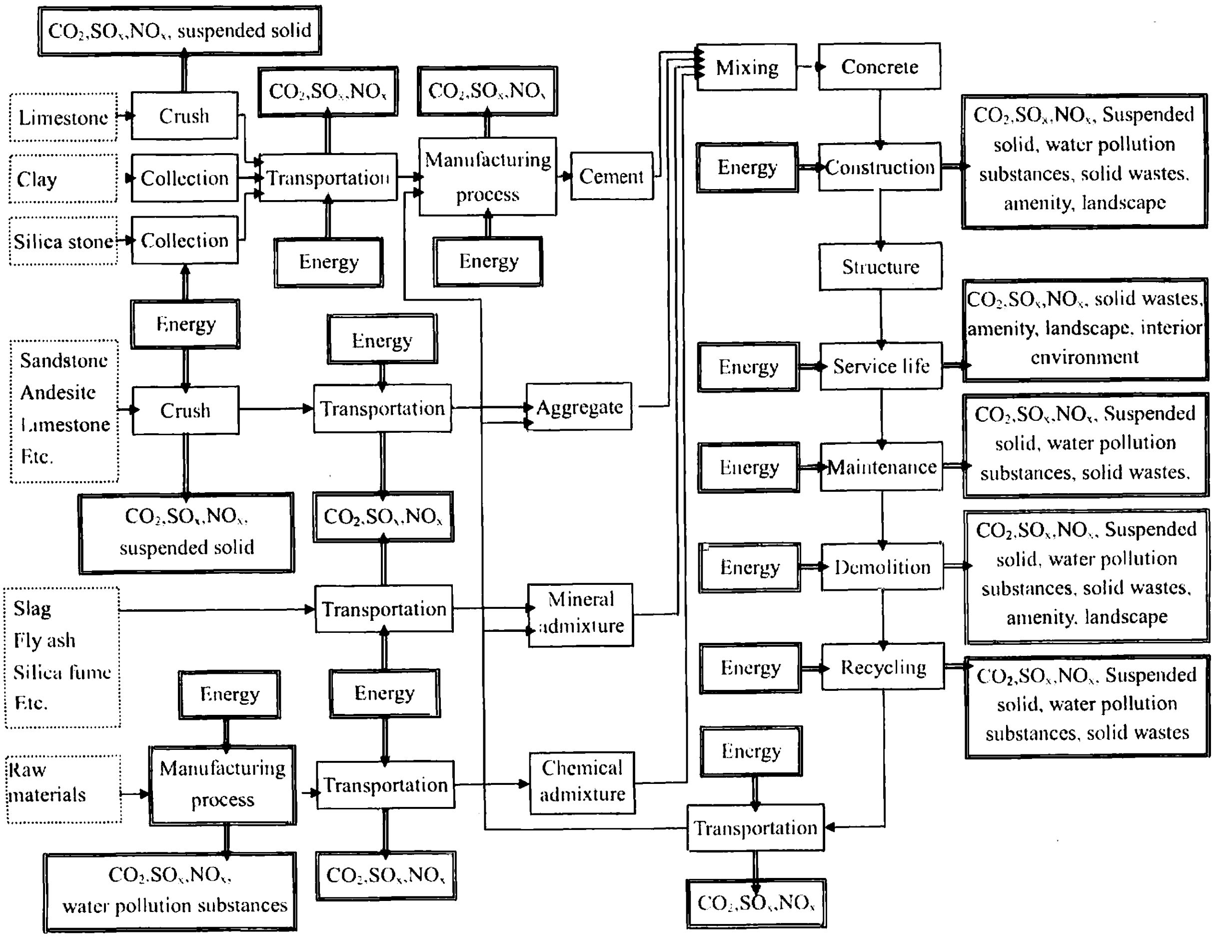
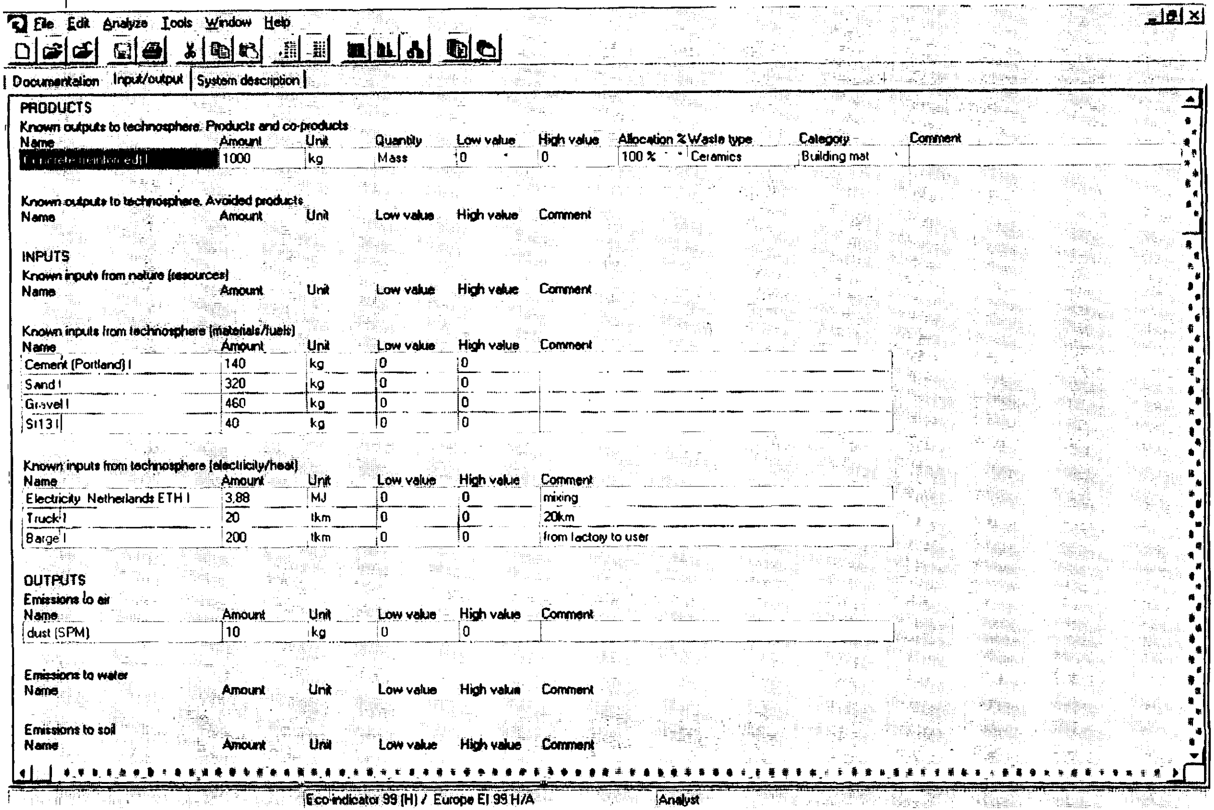


Fig. 5.2-1: Material and energy flows associated with construction of concrete structures



PRODUCTS

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Waste type	Category	Comment
Concrete reinforced I	1000	kg	Mass	0	0	100 %	Ceramics	Building mat	

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

INPUTS

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
Cement (Portland) I	140	kg	0	0	
Sand I	320	kg	0	0	
Gravel I	460	kg	0	0	
St13 I	40	kg	0	0	

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity Netherlands ETH I	3,88	MJ	0	0	mixing
Truck I	20	tkm	0	0	20km
Barge I	200	tkm	0	0	from factory to user

OUTPUTS

Emissions to air

Name	Amount	Unit	Low value	High value	Comment
dust (SPM)	10	kg	0	0	

Emissions to water

Name	Amount	Unit	Low value	High value	Comment

Emissions to soil

Name	Amount	Unit	Low value	High value	Comment

Eco-indicator 99 (H) / Europe EI 99 H/A

Analyst

Fig. 5.2-2: An example of product environmental data sheet (reinforced concrete) from SimaPro 5 database

- Assessment tools SimaPro [5-5] and Eco-indicator 99 [5-4] (see also chapter 5.5.4) are connected with a large inventory database containing environmental data related to different materials and processes (Fig. 5.2-2).

5.3 Principles of environmental impact evaluation

5.3.1 General

Evaluation of the environmental impact of concrete structures is based on several basic principles. Most of these principles represent key elements of a variety of evaluation methods. Representatives of evaluation methods are presented in chapter 5.5.

5.3.2 Life cycle concept

The total environmental impact of a product (i.e. concrete structure) should be considered throughout its whole life, from raw material acquisition, through production, use and disposal. The characteristic life cycle of a concrete structure with its typical material and energy flows and consequent environmental impacts is presented in Fig. 5.3-1.

It is essential that the goal of optimization efforts should be to keep structural materials in the closed material cycle (the gray area) as long as possible. The high importance of maintenance and repair processes, which can increase the durability of a concrete structure, is thus evident. Equally, the significance of renovation and recycling phases on the total environmental impact of a concrete structure is considerable.

The environmental impact of the entire structure can be expressed in two principal forms:

- Environmental profile - environmental profile is composed from a set of values of different criterions

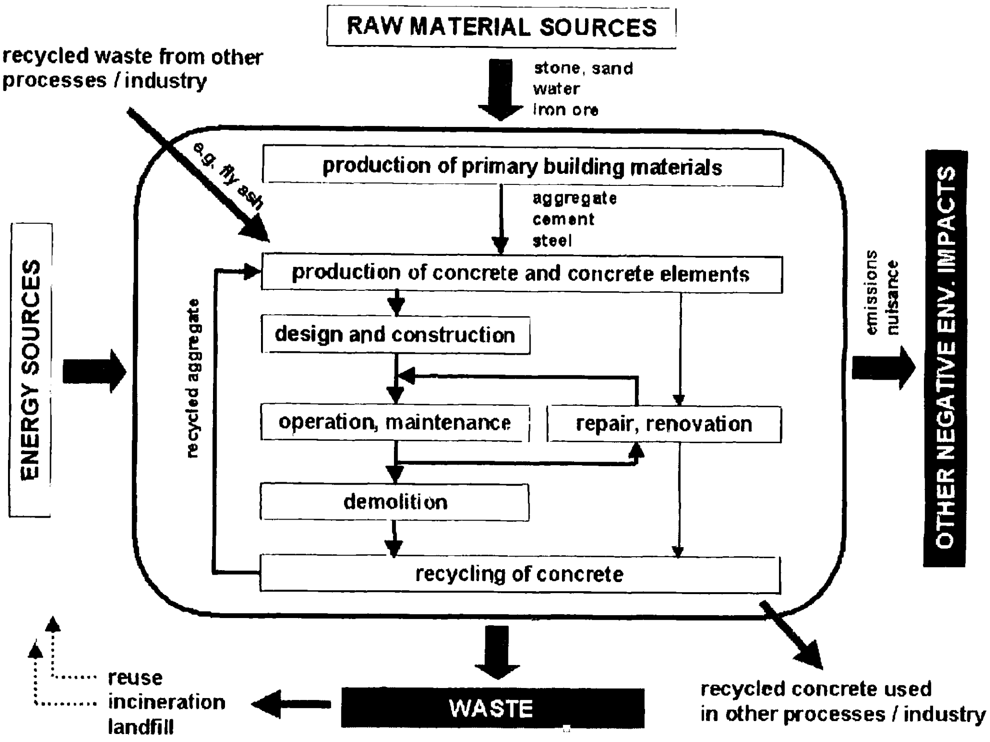


Fig. 5.3-1: Life cycle of concrete structure – material and energy flows and consequent environmental impacts

- Environmental impact expressed by a single characteristic value (weighted sum of values of different criterions)

Taking into account the whole life cycle of the product, the environmental impact associated with particular criterion can be expressed as the sum of partial environmental impacts E_i as follows:

$$E_{tot} = \sum E_i$$

The value of environmental impact of the product and/or process can be expressed as an environmental cost – eco-cost or in normalized amounts of points.

In the case of most concrete structures the general equation can be expressed in a more detailed form as:

$$E_{tot} = E_{ini} + E_{oper} + E_m + \sum E_{repair} + \sum E_{renov} + E_{demol} + E_{recycl}$$

where E_{ini} represents the initial environmental impact covering production, design and construction phases defined as:

$$E_{ini} = E_{pbm} + E_{pc} + E_{constr}$$

Particular environmental impacts within particular life-cycle steps are:

E_{oper} ...	environmental impact associated with operation of the structure,
E_m	environmental impact associated with its maintenance,
E_{repair} ...	environmental impact associated with the repair of failure,
E_{renov} ...	environmental impact associated with renovation,
E_{demol} ...	environmental impact associated with demolition,
E_{recycl} ...	environmental impact associated with recycling and waste disposal,

E_{pbm} ... environmental impact associated with the production of primary building materials,

E_{pc} environmental impact associated with the production of concrete and concrete elements,

E_{constr} environmental impact associated with the design and construction of the structure.

Partial environmental impact E_i, related to a particular step of the life cycle should incorporate all environmental damages, which correspond to all essential environmental criterions:

$$E_i = \sum w_j \; Q_j$$

where $\{w_j\} = (w_1 \ldots w_m)^T$ is the vector of weights representing the importance of individual criteria, m is the number of essential environmental criteria and $\{Q_j\} = (Q_1 \ldots Q_m)^T$ is the vector of embodied values of environmental criteria.

Considering the particular environmental criteria, the environmental impact in each phase of the life cycle can be written in the form:

$$E_i = w_1 Q_{CO2} + w_2 Q_{SO2} + \ldots + w_m Q_m$$

where Q_{CO2}, Q_{SO2} and Q_m are total values of embodied CO_2, SO_2, and embodied value of other environmental criteria, respectively.

This equation should be determined for every particular phase of the life cycle in order to analyze the environmental impact of the structure within the entire life cycle.

In some cases the independent evaluation of environmental impact of a single criterion could be important and useful:

$E_i = Q_{CO2}$ ... for Life Cycle CO_2 ($LCCO_2$) evaluation

$E_i = Q_{en}$ ... for Life Cycle Energy (LCE) evaluation

5.3.3 Probability of environmental impact

The evaluation methods should consider the probability character of the time dependent problem. Implementation of the stochastic approach including reliability analysis is thus valuable and/or needed. The pre-setting of various probable life-cycle strategies is one of the useful approaches.

Risk of environmental damage caused by product (e.g. concrete structure) and/or process can be expressed by general equation

$$R = p \; C_{env}$$

where p represents the probability of environmental damage caused by a particular impact and C_{env} corresponds to environmental damage.

With respect to the probability of the environmental impact caused in individual phases of the whole life cycle of the structure, the total environmental impact can be expressed as:

$$E_{tot} = \sum p_i \; E_i$$

In the case of most concrete structures this equation can be written in the form:

$$E_{tot} = E_{in} + E_m + \sum p_f E_{rep} + \sum p_{mod} E_{mod} + E_{dem} + E_{rec} + \ldots\ldots + E_{op}$$

where p_f ... probability of failure,
p_{mod} ... probability of modernization/reconstruction.

5.3.4 Weighting

Evaluation of the multicriterion assessment problem can be performed by determination of the environmental profile (a set of values of different criterions) or by use of the weighting approach. The weighting approach requires determination of weighting factors representing the significance of particular criterions. It is possible to work with weighting factors decided at the national level, regional level or local level (within a group of concerned people - experts). In some countries it may be possible in the near future to come to a national "political" decision regarding weighting factors.

The weighting process represents the most critical and often controversial step in the Life-Cycle Assessment process. The reliability of obtainable results is highly dependent on the quality of determination of weighting factors. The process of determination of weighting factors is very complex and should cover specific conditions, boundary limitations and preferences associated with the particular case. However, this process is very often subjective due to a variety of criterions with different characteristic features (the problem of "mixing apples and oranges"). Sensitivity analysis of the multicriterion problem is thus essential.

It is recommended to reduce the number of environmental aspects to be weighted, in order to keep the specific evaluation task to a manageable and transparent form. The recommended number of weighted aspects is about 4 to 7. This requires selection of the most important and significant environmental aspects for the specific evaluation problem. In some cases the number of weighted aspects can be reduced using aggregated indicators obtained by the following transformation: one environmental aggregated indicator covers more particular criterions (e.g. environmental aspect: GWP, aggregated indicator: CO_2 equivalent, criterions: CO_2 emission, CH_4 emission, N_2O emission, etc.).

It is recommended to set specific weighting factors for different countries and/or regions, because natural, climatic and industrial conditions and the resulting preferences of environmental criteria can be significantly different and each country can have different environmental targets in their government policy.

Weighting factors could be determined using different weighing approaches and methods such as [5-6]:

- EPS method – Environmental Priority Strategies in Product Design (developed by the Institute for Environmental Research, Sweden): The model covers environmental, cost and other aspects. The weight of the particular aspect is based on the price that has to be paid by society to prevent the corresponding environmental impact. The method has been used in the car industry.
- Panel method - Expert-based determination of weighing factors: An expert makes a professional judgment of weights among different environmental aspects. A single expert judgment represents a rather subjective view. However, by the use of a higher number of experts (panel of experts) the subjectivity of determination of weights can be reduced.
- NEL method – No-effect level method: The method is based on quantitative analysis of the relation between the no-effect level and current level of a particular environmental aspect. The difference between the current environmental load and NEL level called sustainability indicator is used to determine weighting factors.
- Combined Panel-NEL method: The combined method consists of the following steps: (1) criteria selection by a panel of experts, (2) effect – criterion relation score using the NEL method, (3) criteria weighting – weighting factors determined by a panel of experts, (4) calculation of environmental standards.

- Dominant weighting method [5-7] : The method represents a weighting method with implemented sensitivity analysis. The method is based on sequential increasing or decreasing of pre-determined weights (e.g. using the panel method) by means of multiplication by factor of dominance. This is done step by step for all environmental impacts considered in the evaluation process. Sensitivity analysis using dominant weighting simulation can be used as a tool for the increasing of decision quality.

5.3.5 Sensitivity analysis

Sensitivity analysis (sensitivity check) related to the different criterions is one of the approaches that can help to show the reliability and stability of the results of environmental evaluation, while changing the importance of different criterions. The basic principle of sensitivity analysis is a comparison of evaluation results based on certain assumptions, methods and data with the results obtained using altered assumptions, methods and data. This approach can help the designer to decrease the level of subjectivity in the decision process based on multicriterion assessment. Nevertheless, it cannot rule out the risk of assessment conflict due to weighting of different criterions. However, the results of the sensitivity analysis can support the quality of the final decision significantly.

The sensitivity check represents one of the essential parts of the interpretation phase in the Life Cycle Assessment framework (see Chapter 5.4.2).

5.3.6 Eco-value

In value engineering, the performance of a product is evaluated with its function and cost. At that time, the concept of value is used. In general the value of a product is defined as follows:

$$Value = \frac{Function}{Cost}$$

A product with many functions may be good in a sense. This product, however, may be over-functional. Therefore when the function of a product is evaluated, minimum function requirement should be assessed in spite of all functions of a product. That is to say, the value for a product should be defined as follows:

$$Value = \frac{Minimum\ function\ requirement}{Cost}$$

This concept must be reasonable in terms of performance-based design methods. Based on this explanation, the concepts of eco-cost and eco-value are introduced. The eco-cost of a product is defined as the cost equivalent to environmental impact of the product. The eco-cost is calculated from the burdens of environmental impact factors. The eco-value of a product is the value considering the eco-cost of the product as follows:

$$Eco \cdot Value = \frac{Optimum\ function\ requirement}{Cost + Eco \cdot cost}$$

For example, the eco-cost of carbon dioxide emission should be determined by costs for the collection, isolation and treatment of carbon dioxide. But feasible technologies for these processes have not been developed yet. Therefore an alternative criterion is used for the calculation.

5.4 Life cycle assessment

5.4.1 General

The general methodology of LCA is defined in the International Standard ISO 14040:1997 Environmental management – Life cycle assessment – Principles and framework and in the complementary International Standards ISO 14041, ISO 14042 and ISO 14043 concerning various phases of LCA[1] [5-9]. There is no single method for conducting LCA studies. Results from LCA studies may be useful inputs to different evaluation, optimization and other decision-making processes. The LCA technique includes the phase of evaluating the potential environmental impacts associated with the whole life cycle of the product.

5.4.2 Life cycle assessment – implementation of ISO 14040 principles

Life cycle assessment methodology defined in ISO 14040 is an iterative assessment method. It includes several steps covering (i) definition of goal and scope, (ii) inventory analysis, (iii) impact assessment and (iv) interpretation of results, while these particular steps are in the state of mutual interaction (Fig. 5.4-1).

The goal and scope of an LCA study must be both clearly defined and consistent with the intended application. The scope must consider all relevant aspects and criterions and should be sufficiently well defined to ensure that the definition of the evaluation model and specification of assessment data sets are compatible and sufficient to address the stated goal.

The inventory analysis (LCI – Life cycle inventory analysis) involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system e.g. concrete element, concrete structure, whole building or other civil engineering structure etc. through the whole life cycle.

The target of the impact assessment phase (LCIA – Life cycle impact assessment) is to examine the product system from an environmental point of view using impact categories and category indicators connected with the inventory analysis results.

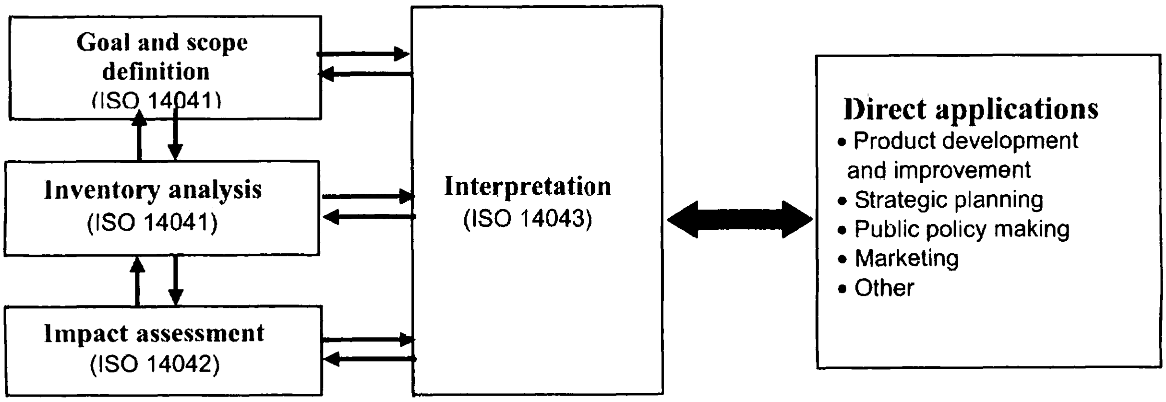


Fig. 5.4-1: Phases of LCA and corresponding ISO Standards

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[1] The International Standard ISO 14040:1997 was approved by CEN as a European Standard. According to CEN/CENELEC Internal Regulations, the following countries are bound to implement this Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The final phase of LCA is interpretation in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations.

5.4.3 LCA of concrete structure - An example of the assessment model

When an assessment for environmental impact is carried out, the most difficult issue is how environmental factors are expressed as mentioned above. Since the environmental factors such as energy consumption, carbon dioxide emissions and waste emissions have different units, it is not easy to compare the magnitude of the factors. One approach is to apply weighting methods; however determination of weights is usually a very difficult and sensitive task (see Chapter 5.3.4). Another way is to determine environmental profiles based on LCA data (see Chapter 5.2.3). Different approaches can be used in different countries based on national preferences and political decision.

The environmental impact of concrete structures should be evaluated within the framework of the Life Cycle Assessment (LCA) where manufacture of materials, construction, maintenance, demolition and disposal are comprehensively taken into account. Figure 5.4-2 shows an example of the verification and inspection flow of environmental design. Each stage throughout the life span of concrete structures comprises planning and verification in pair and an action with respective inspections.

During a planning stage before construction, the manufacture of materials will play an important role for the evaluation of the environmental impact since large amounts of raw material are consumed and used to make concrete at manufacturing plants. These materials are also transported between service stations and plants. In addition, environmental impact associated with construction periods can be relatively large depending on the nature of the construction site and its magnitude. The environmental impact of construction needs to be evaluated at the construction planning stage. The environmental assessment applied for a local region must also be separately met according to the environmental law.

The life-span of concrete structures is normally much longer than other products such as cars and electrical machines. This makes it difficult to evaluate the environmental impact of maintenance during a service period and demolition and disposal. The establishment of a life cycle design for concrete structures can lead to the correct prediction of these impacts. Therefore, these environmental impacts may be evaluated during the maintenance planning stage and a demolition and disposal planning stage after construction.

Figure 5.4-3 shows an example of verification in environmental design during construction planning stage. A standard or conventional construction method is compared with an alternative method with respect to environmental impact. The alternative method is planned to reduce environmental impact so that its method will be employed if the reduction requirement is achieved. The reduction requirement may be provided with an achieved percentage on given factors related to the goal of environmental design.

5.5 Environmental impact evaluation

5.5.1 General

A wide range of methods for environmental impact evaluation has been developed in the last ten years. Most of the methods are based on basic principles of the LCA methodology. The main differences among evaluation methods and models used in corresponding computer programs 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 are

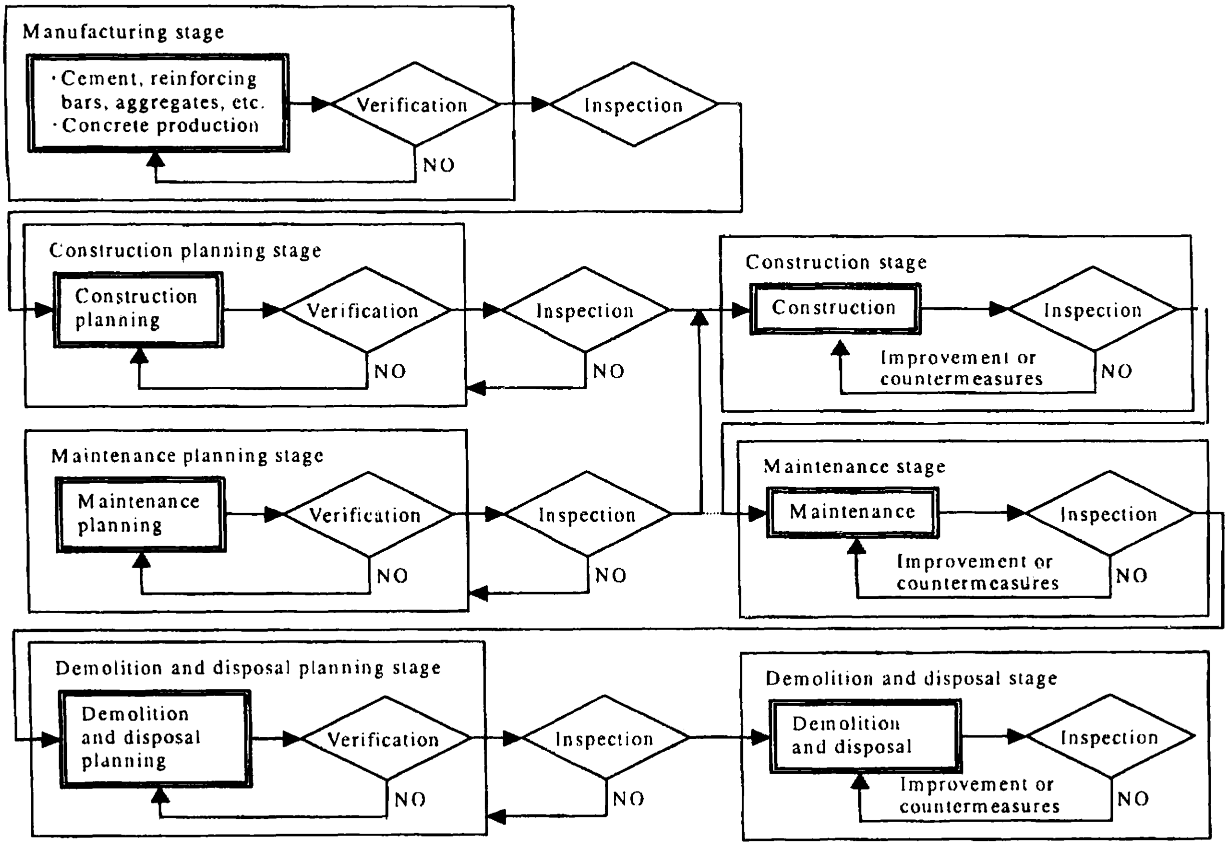


Fig. 5.4-2: Verification and inspection flow of environmental design

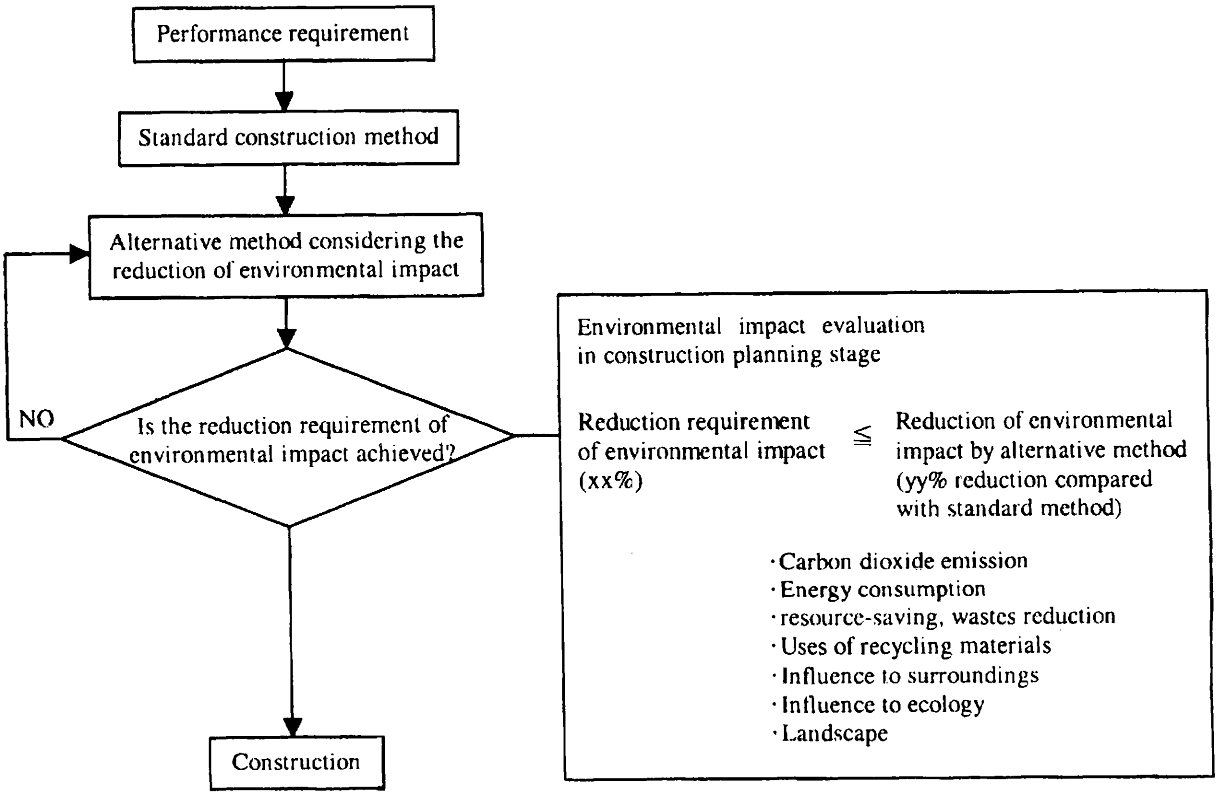


Fig. 5.4-3: Example of vwrification in environmental design (Construction planning stage)

focused on the environmental evaluation of the construction based upon the materials and structural elements used (e.g. BEES, ENVEST, ECOQUANTUM ...), some on the evaluation of different industrial processes (e.g. GEMIS, SimaPro), some are focused on more general aspects of the sustainability of structural components and buildings (e.g. GBTool, BREEAM and LEED). The latter (GBTool and BREEAM) are not based upon the LCA methodology, but may use LCA data when evaluating construction materials with regard to environmental impacts.

5.5.2 Environmental labels and declarations for construction products

The ISO standard 14020 "Environmental Labels and Declarations" establishes the general principles for environmental labels and declarations. The ISO standards 14021 and 14024 and the ISO/TR technical report 14025 describe the different types of declarations. According to ISO 14020, an environmental label or declaration is a type of claim which indicates what environmental aspects are associated with a product or service. Several general principles and requirements with regard to such environmental labels or declarations are also established: e.g. they must be accurate, verifiable, relevant, and not misleading [5-10], [5-11], [5-12].

Type I: Environmental labels

According to ISO 14021, Type I environmental labels 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. However, it is not necessarily the LCA methodology, which is used in order to attribute the label.

Labels can be attributed by government authorities or by private, non-commercial organisations. Familiar examples of such labels are the European Ecolabel, the Scandinavian "Swan" and the German "Blauer Engel". The advantage of such labels is that they clearly illustrate the good environmental performances of a specific product without going into too much detail. Because of this they are quite often applied for relatively inexpensive consumer goods, where the decision to purchase is made quickly. With regard to the building industry, for example, they have been used for paints and hard floor coverings.

Nevertheless, such labels have the disadvantage that they are unsuitable for developing products or managing the product life cycle. After all, the criteria and the background information, which belong to the label, are not always known to the producer or user. Moreover, this is a black/white system, and it is not always clear where the dividing line between black and white lies.

Type II: Claims

ISO 14024 establishes the requirements, in which Type II declarations must satisfy. In fact these involve environmental claims, which are made by the manufacturer or distributor. In most cases these claims relate to only one environmental aspect. There are many examples of such declarations, one of the most familiar will presumably be "produced with x % recycled materials".

The standard describes a number of terms, which are frequently used in such claims. Compostable, degradable, designed for disassembly, extended life, recovered energy, recyclable, recycled content, reduced energy consumption, reduced resource use, reduced water consumption, reusable, refillable, renewable, waste reduction, etc. are defined and it is also indicated in which cases they may be used.

Because it involves declarations, which are made by the manufacturer or distributor, and there is no certification or verification by third parties, such declarations have only a low credibility. Moreover, they do not actually offer all that much information, because they focus on only one environmental aspect.

Type III : Environmental declarations or information sheets

ISO/TR 14025 describes environmental declarations as quantitative information on the environmental impact of products associated with their entire life cycle. The information is furnished by the producer or distributor, but must be verified by an independent third party. The information provided is generally based on LCAs, but can also include aspects which do not really derive from an LCA. For example, it can involve specific precautions which must be taken with regard to dangerous components, or information about the ingredients of the product.

The information is presented in a form which permits comparison between (technically equivalent) products vis-à-vis a set of parameters. However, the comparison does not form part of the declaration - it is up to the user himself to draw conclusions on the basis of the information provided.

A well-known example of such a declaration is the "MRPI" developed in the Netherlands (MRPI stands for environmentally relevant product information). Similar examples can be found in Great Britain (BRE Environmental Profiles), Denmark (Environmental Product Declarations for Building Products - MVDB), Norway (MVD), Finland (RT) and France.

The advantage of such declarations is that all products come into consideration, even those which do not perform so well on the environmental level. End users, that can be both industrial customers and consumers, can compare the environmental performances of different products with one another, and can then choose on the basis of their own set of criteria, whereby for example not only environmental, but also technical performances and economic aspects can play a role. An additional benefit of such quantitative information is that it - certainly if it involves components of a final product (for example, the parts of a car or the elements of a house) - can be used in the environmental evaluation of this final product.

The fact that value judgments about the significance of certain environmental impacts can be regarded as subjective is a disadvantage of some declarations. Some systems add together, by means of weighting factors, certain environmental effects in order to form a limited number of "environmental measures".

5.5.3 Eco-indicator method

An eco-indicator method [5-4] can be used for more complex environmental impact evaluation. The method represents a complex weighting method for evaluation of environmental effects damaging ecosystems and human health. The eco-indicator of a material or process represents a single score expressing 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 damages caused by flows to three damage categories (human health, ecosystem and resources).
3. Weighting of normalized scores of three damage categories (panel method).

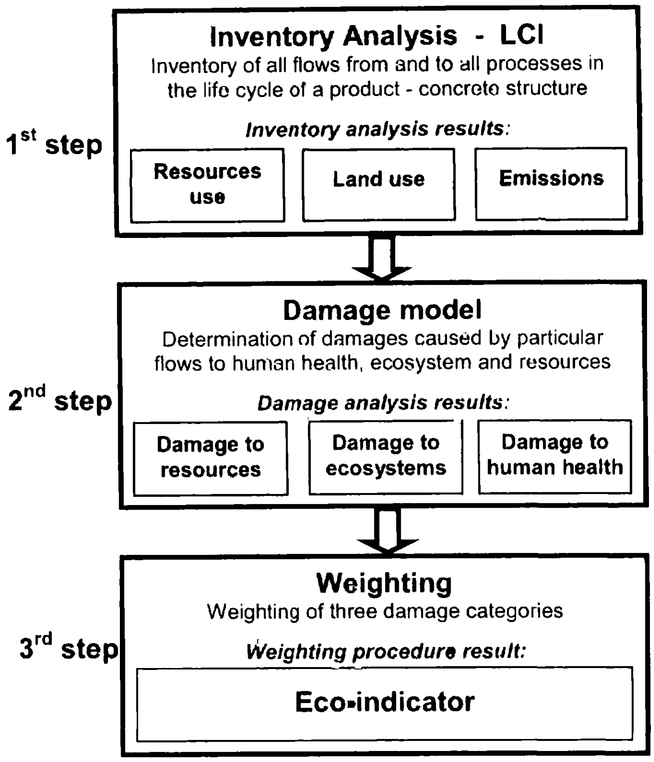


Fig. 5.5-1: The three-stage core concept of the Eco-indicator 99 methodology

The basic concept of the eco-indicator method implemented in Eco-indicator 99 methodology [5-4] is shown in the Fig. 5.5-1.

The system contains eco-indicators for important materials and processes. The values of eco-indicators are available for (i) materials, (ii) processing aspects, (iii) transport processes, (iv) energy generation processes and (v) 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 or to the ecosystem.

5.5.4 Complex LCA of products and processes using SimaPro software

SimaPro Life Cycle Assessment software [5-5] represents a complex tool for collection, analysis and monitoring of environmental information about products and services. It makes it possible to model and analyze 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 (see also Chapter 5.2.3).

The SimaPro 5 system contains several impact assessment methods: the Eco-indicator method (see Chapter 5.2.2), 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 the theme or damage approach.

Based upon SimaPro the EcoQuantum software has been developed. In contrast to SimaPro, EcoQuantum represents a software developed specifically for the building industry.

5.5.5 Environmental / economic performance balance – BEES model

The BEES model (Building for Environmental and Economic Sustainability) is based on Life Cycle Assessment and Life Cycle Cost approaches applied to the comparison process of generic building product alternatives. The method uses selected inventory flows and

Category of environmental impact	**Pre-defined weights**			**User – Defined weights**
	EPA Scientific Advisory Board	Harvard University study	Equal weights	
GWP – Global Warming Potential	27	28	17	
AP – Acidification Potential	13	17	17	
EP – Eutrophication Potential	13	17	17	
Natural Resource Depletion	13	15	17	
Indoor Air Quality	27	12	16	
Solid Waste	7	10	16	

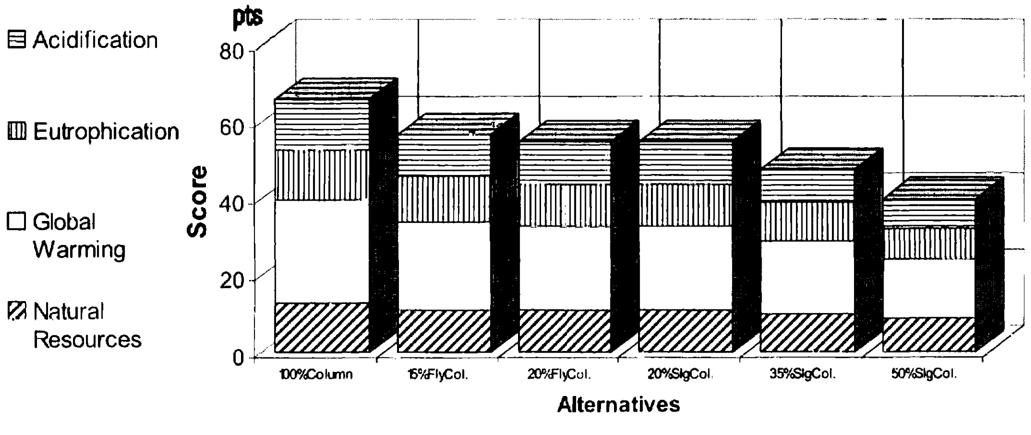
Table 5.5-1: Categories of environmental impacts and corresponding pre-defined weights according to BEES 2.0 tool

consequent environmental impacts for evaluation of the corresponding environmental performance within a particular Life Cycle stage. The method uses the weighting approach to combine environmental and economic performance measures into a single performance score. The importance of different environmental impacts is also expressed using pre-defined or user-defined weights. The resulting environmental scores represent relative environmental impacts (damage), among competing alternatives.

There are six basic environmental impact categories included in the BEES model (see Table 5.5-1).

For a selected group of products the BEES 2.0 model includes the following additional environmental impacts: ecological toxicity, human toxicity, ozone depletion and smog. It is possible to use three sets of pre-defined weights for the weighting of environmental impacts. The model also enables 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 2.0 is shown in Figs. 5.5-2 and 5.5-3.

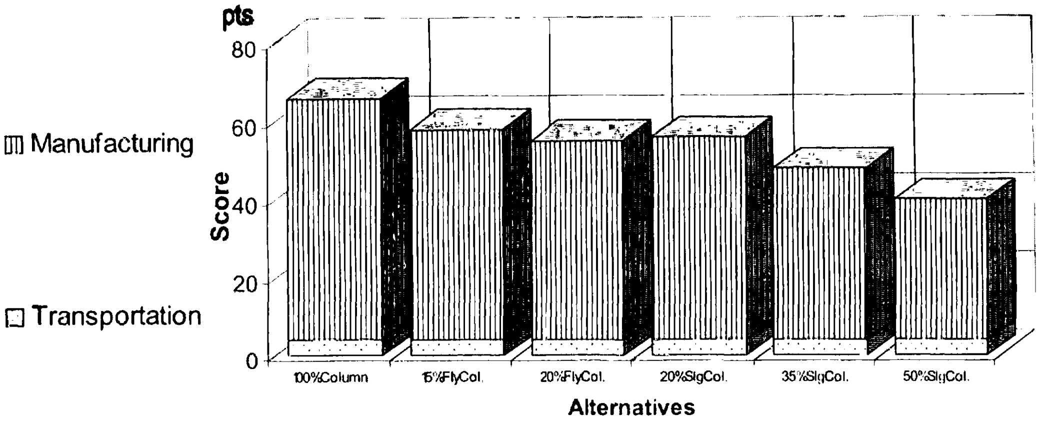
5.5.6 Global emission model for integrated systems - GEMIS



Note: Lower values are better

Category	**100%Column**	**15%FlyCol.**	**20%FlyCol.**	**20%SlgCol.**	**35%SlgCol.**	**50%SlgCol.**
Acidification--13%	13	11	11	11	9	8
Eutrophication--13%	13	12	11	11	10	8
Global Warming--27%	27	23	22	22	19	15
Indoor Air--27%	0	0	0	0	0	0
Natural Resources--13%	13	11	11	11	10	9
Solid Waste--7%	0	0	0	0	0	0
Sum	66	57	55	55	48	40

Fig. 5.5-2: Comparison of environmental (by impact) of 6 alternatives of RC columns from different types of concrete (results from BEES 2.0)



Note: Lower values are better

Category	100%Column	15%FlyCol.	20%FlyCol.	20%SlgCol.	35%SlgCol.	50%SlgCol.
1. Raw Materials	0	0	0	0	0	0
2. Manufacturing	62	54	51	52	44	36
3. Transportation	4	4	4	4	4	4
4. Use	0	0	0	0	0	0
5. End of Live	0	0	0	0	0	0
Sum	66	58	55	56	48	40

Fig. 5.5-3: *Comparison of environmental performance (by life cycle stages) of alternatives of RC columns from different types of concrete (results from BEES 2.0 tool)*

The system GEMIS [5-3] was developed as a tool for the comparative assessment of environmental effects such as production of harmful emissions, wastes, and cost analysis based on LCA methodology. The system contains an extensive database of environmental data exceeding 4,500 processes collected from more than 30 countries. It is possible using system GEMIS to evaluate the environmental impact of energy, transport and other material processes. The method is based on summarizing total amount of (i) greenhouse-gas emissions (CO_2, CH_4, N_2O, SF_6, etc.), (ii) direct air pollutants (SO_2, NO_x, halogens, CO, NMVOC, particilates, etc.), (iii) production of solid and liquid wastes, and (iv) land use. The evaluation of impacts using GEMIS system covers the total life-cycle including fuel delivery, use of construction materials, waste treatment, transport etc. GEMIS allows evaluation of results using the 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.

5.5.7 LCA software at the building level

In several countries, work has been carried out on software packages, which make it possible to calculate an LCA at the level of the building. Obviously the objective is to acquire insights into the potential environmental effects at the design stage, so that possible adjustments can be made. Examples of such packages include Eco-Quantum and GreenCalc from the Netherlands, ENVEST from England and ATHENA from Canada [12], [13], [14].

The information derived from the environmental declarations seems to be of ever-increasing usefulness. This appears to be the case in both the Netherlands and England, where the environmental profiles of MRPI and Environmental Profiles are increasingly used as basic data of the respective software packages. After all, earlier software designers had to draft the environmental profiles for the different building materials all on their own.

The user of an LCA software package can generally use standard components, which are included in the packages. This allows the input of data regarding the design and the re-billing to be somewhat reduced. However, it is also possible to diverge from the standard components, but this obviously requires more time.

5.5.8 Environmental audits of buildings

LCA software at the building level can thus deliver a great deal of information regarding ecological performance [5-12], [5-13], [5-14]. However, ecology is only a single element, which will play a role in the decision-making process of a contractor, principal or architect. Technical, economic and social criteria are at least equally important elements. This is why a number of organizations have worked out evaluation and qualification systems to assess the (environmental) quality of buildings. The most familiar, and until now also most successful, system is undoubtedly BREEAM, which stands for "BRE Environmental Assessment Method". 30 % of the new office buildings in the United Kingdom are evaluated on the basis of BREEAM for Office Buildings (i.e. the version developed specifically for the latter).The first version of BREEAM was developed in 1990 by the BRE in collaboration with ECD Partnership. This first version was initially intended for office buildings. Since then it has been supplemented and further developed step by step to take account of technological progress and the experience acquired using the evaluation in practice. Today there exist several methods, depending on the building type. The distinction between the different building types is necessary, given that the various environmental requirements, which one imposes on the building, for example concerning wastes, can differ by type. Currently, four types of building can be analysed according to their own specific method: besides office buildings, these are supermarkets, factories and residential buildings. The last-mentioned version is better known under the name "EcoHomes".

Several methods for sustainability evaluation of buildings were developed since the late 90s. Most of the available methods are based on regional conditions and data sets. In the Table 5.5.2 there is a brief overview of some available tools. The GBTool, LEED and BREEAM

Tool	Country	Comments
GBTool	Canada/International	Criteria-based comprehensive framework to assess new & retrofit buildings – offices, multi-unit residential and schools
BREEM	United Kingdom	Criteria-based assessment method for office buildings
LEED	U.S.A.	Criteria-based assessment method for existing buildings
PromisE	Finland	Criteria-based environmental classification system for buildings – evaluation of the major environment effects with simple but dependable indicators.
CASBEE-J	Japan	Criteria-based assessment system of building environmental efficiency
SBAT	South Africa	Assessment method for buildings – environmental, social and economic aspects are equally important.
NABERS	Australia	Criteria-based assessment method for new & existing buildings.

Table 5.5-2: Some available sustainability evaluation tools
GB Tool - tool for assessing the level of sustainability in a building

GBTool - Tool for Assessing the Level of Sustainability in a Building

Score	Performance level
-2	performance below the acceptable level (for specific region and specific occupancies)
-1	
0	minimum level of acceptable performance (for specific region and specific occupancies)
3	Best Practice
5	best technically achievable solution, without consideration of cost

Table 5.5-3: GB Tool scores

program tools have been widely used in building practice. The most successful until now is BREEAM. About 30% of new office buildings constructed in the UK are evaluated using the BREEAM methodology.

GB Tool (Green Building Tool) [5-8] developed by an international team under the leadership of Natural Resources Canada represents a very comprehensive framework implemented and tested in many different countries all over the world. The tool is presently undergoing permanent development, updating and evaluations. GB Tool can be customized to suit specific assessment needs, taking into account regional differences, contextual settings, different technologies, building traditions and cultural values that exist in various regions and countries.

GB Tool is suitable for the approximate complex assessment 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 -2 to +5 (Table 5.5-3).

There are four levels of parameters included in the GB Tool: *Issues, Categories, Criteria* and *Sub-Criteria*. The weighting of Issues and Category parameters is made by experts in the Vote worksheet, while the weighting of Criteria and Sub-Criteria parameters is made

Issues		Categories		GB Tool default weights
R	RESOURCE CONSUMPTION	R1	Life-Cycle net primary energy use	20
		R2	Use of land and change in quality of land	25
		R3	Net consumption of potable water	20
		R4	Re-use of existing structure or materials and/or recycling of materials	15
		R5	Amount and quality of off-site materials used	20
L	LOADINGS	L1	Emission of greenhouse gases	25
		L2	Emission of ozone-depleting substances	15
		L3	Emission of gases leading to acidification	10
		L4	Emissions leading to formation of photo-oxidants	15
		L6	Solid wastes	10
		L7	Liquid Effluents	10
		L8	Hazardous wastes	5
		L9	Environmental impacts on site and adjacent properties	10
Q	INDOOR ENVIRONMENTAL QUALITY	Q1	Air Quality and Ventilation	30
		Q2	Thermal Comfort	25
		Q3	Daylighting and Illumination	25
		Q4	Noise and Acoustics	15
		Q5	Electro-Magnetic Pollution	5
S	SERVICE QUALITY	S1	Flexibility and adaptability	25
		S2	Controllability of systems	25
		S3	Maintenance of performance	20
		S4	Privacy and access to sunlight and views	20
		S5	Quality of amenities and site development	5
		S6	Impact on quality of service of site and adjacent properties	5
E	ECONOMICS	E1	Economic Performance	100
M	PRE-OPERATIONS MANAGEMENT	M1	Construction Process Planning	35
		M2	Performance Tuning	35
		M3	Building Operations Planning	30
T	COMMUTING TRANSPORT	T1,T2, T3	Associated emissions – *not yet finished*	100

Table 5.5-4: GB Tool 2000 issues and main categories with default weights

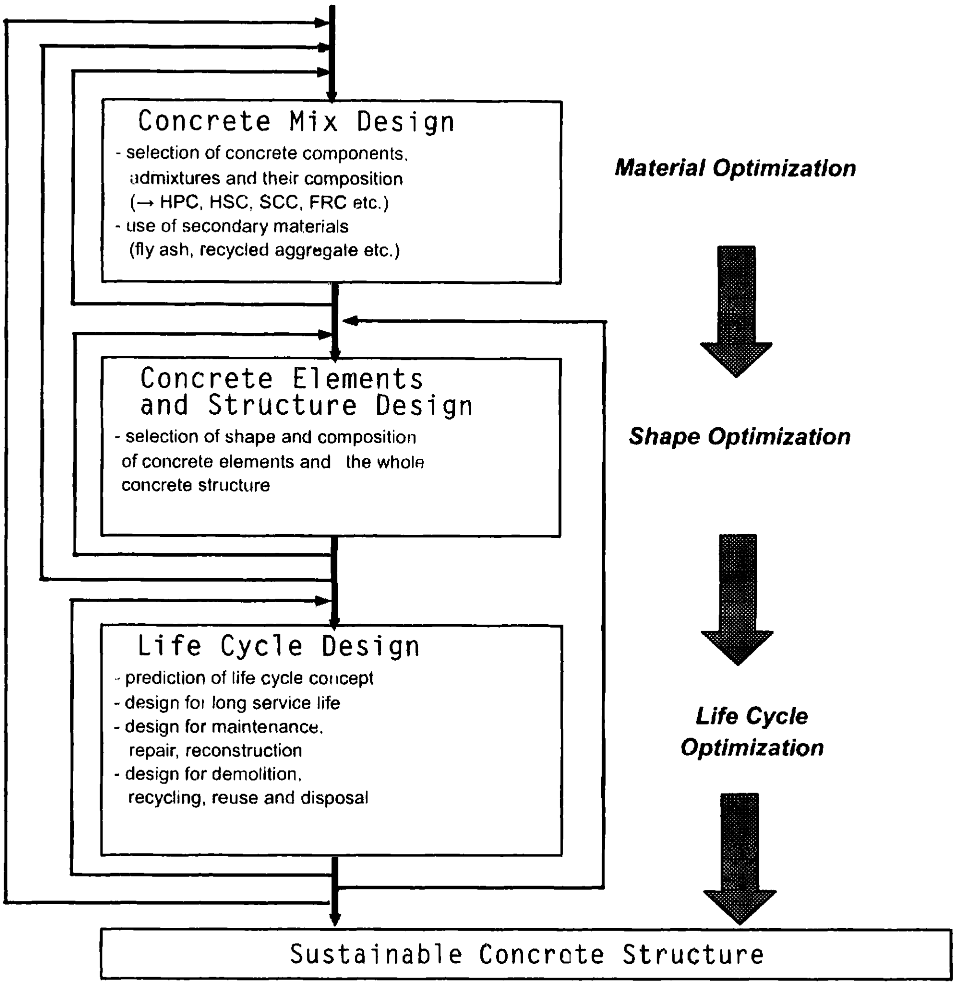


Fig. 5.6-1: Concept of environment-based optimization of concrete structure

automatically by system in the Weight worksheet. Scores are multiplied by the weights and the weighted scores are shown in the Results worksheet.

The main categories, which are used in the GB Tool, are shown in Table 5.5-4. These categories are used to structure a number of detailed building related indicators

The results of GB Tool assessment obtained using scores and defined weights are presented in two forms: Environmental Sustainability Indicators (ESI) - absolute numbers; and barcharts showing weighted scores (-2 to +5) relative to the benchmarks.

5.6 Environment-based optimization

Environment-based optimization is an active process targeting the reduction (minimization) of negative environmental impacts of product – concrete structure.

The problem concerning the environmental quality of structures is very complex and includes a large number of parameters and criterions from different areas of technical as well as non-technical sciences. In general, the environmentally based optimization of structures is, therefore, dependent on many different criteria: physical, chemical, biological, economic and others. The complex formulation of such multicriterion problems is thus very complicated. The definition and solution of the exact model is practically impossible, and it is necessary to search for an acceptable approximation in the form of the *simplified environmental structural model*. The creation process of the simplified environmental structural model covers:

- *Decomposition* of the system into subsystems or elements with a definition of mutual interfaces,
- *Detachment* of subsystems or elements with an admissible low mutual influence (only in cases where it is relevant to consider independent behavior from the view point of environmental impact) ,
- *Selection* of parameters and criterions essential for environmental impact assessment.
- The complex optimization model of the concrete structure can be simplified by breaking it down into three optimization steps:
- 1st step: material optimization,
- 2nd step: shape optimization,
- 3rd step: life cycle optimization.

The optimization process has a complex and iterative character and should thus cover all relevant interactions and repeated iterations within all the above specified optimization steps. The basic concept of environment-based optimization of concrete structure presents a flow chart in Fig. 5.6.1. However, with respect to the potential possibility of influencing the degree of environmental impact (see Fig. 5.1-2) the first two optimization steps have decisive importance.

Minimization of the negative environmental impact can be formulated as follows:

$$\min E_{tot}(\{x_k\}) \quad \text{such that} \quad f > f_0$$

where E_{tot} : the total environmental impact (it can be expressed as eco-cost)
f : reliability of the structure
f_0 : the design value of reliability
$\{x_k\} = (x_1 \ldots x_p)^T$: the vector of design variables

The objective function E_{tot} is in general a multicriterion function and can be derived from equations specified in chapter 5.3.2.

The reliability of obtainable results using such complex multicriterion formulation is very dependent on the quality of determination of the weights. Sensitivity analysis of the multicriterion problem is thus essential.

The independent single-criterion optimization using formulations like: min $Q_{CO2}(\{x_k\})$, min $Q_{SO2}(\{x_k\})$, min $Q_{em}(\{x_k\})$, or others can in some specific target studies be valuable and effective.

The optimization process according to the general flow chart shown in Fig. 5.6-1 can be performed using common models for environmental impact evaluation in successive iterative steps. This discrete optimization approach is in many cases very effective – especially when feasible structural alternatives vary in a significant manner.

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Environmental design

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fédération internationale du béton
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