Featured at the proceedings FIB-symposium "Concrete and environment" in Berlin, October 2001

Environmentally “Green” Concrete Structures

Dr.-Ing. Carola Edvardsen
COWI Consulting Engineers and Planner AS
Lyngby, Denmark

M.Sc. Karsten Tølløse
Concrete Centre, Danish Technological Institute
Taastrup, Denmark

Summary

A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. One important issue is the use of environmental-friendly concrete (“green”) concrete to enable world-wide infrastructure-growth without increase in CO_2-emission. Another, probably even more important issue, is the use of more environmental-friendly structural designs incorporating more environmental-friendly maintenance/repair strategies which requires less use of resources, reduce energy and CO_2-emissions at all phases during the entire service life of a concrete structure. One promising more environmental-friendly design strategy includes the use of stainless steel, both as normal reinforcement and as cladding system, to assure a more durable, less maintenance and repair intensive concrete structure.

Introduction

With the increasing interest of the public, industry and government in sustainable development, environmental assessment in construction is becoming more important. Society and the social changes that have occurred in the world have placed insatiable demands on the construction industry in terms of the world's material and energy resources. The construction industry must address certain consequential issues in the process of achieving sustainable development as it consumes considerable resources and has a significant impact on the environment.

In this scenario, sustainable development of concrete and concrete design has to be the foundation of all construction activity in the next millennium. Concrete is the most important construction material of the world.

An essential step toward achieving sustainable development of concrete is taken by establishing a large Danish research project called "Resource Saving Concrete Structures" (colloquially "Green Concrete") running from 1998-2002 /1/. The project involves partners from all sectors related to concrete production, i.e. cement and aggregate producers, a contractor, a ready mix plant, a consultant, building owners, the Danish Technological Institute and two technical universities. The 4-year, 2.8 Mio. Euro project comprises five development projects (U1 ... U5), six technical activities, and a demonstration project (demo-bridge).

The purpose of the project is based on a holistic approach, integrating material characteristics and structural performance with the following tasks: (see Table 1):

- To develop green cement and green concrete types; e.g. concrete with less cement, i. e. high amounts of cement replacement materials, such as fly ash, silica fume and other natural pozzolans and concrete with waste materials such as stone dust, crushed concrete, concrete slurry, cement stabilised foundations with waste incineration and other inorganic residual products (Development project U1, U2, U3)
- To develop green design strategies which require less maintenance and repair activities using for example stainless steel instead of black reinforcement. This is of particular interest since it is very well known that in concrete structures located in aggressive

environment the highest environmental loads result from maintenance and repair activities during the service life of the structure (Development project U4).

- To develop green structural designs and structural solutions for green concrete e.g.: optimised structural detailing by minimising the structural dimensions using for example CRC® (Development projects U5).

	Traditional concrete	Green concrete
Traditional structure	Concrete with restricted amount of fly ash and micro silica	High amount of fly ash and micro silica Green types of cement Use of stone dust, slurry, waste incineration
Green structure	Cladding with stainless steel Stainless steel reinforcement	Green concrete (see above) plus stainless steel cladding or stainless steel reinforcement

Table 1: Combination of traditional and green concrete/concrete structures

The technical activities include transverse activities, combining research and development with focus on the environmental aspects, and the mechanical, fire, durability, performance, and physical/ thermodynamic related concrete properties.

The present paper presents some investigations from the development project U4. Information about the durability investigations of the different concrete types are given in the paper from M. T. Jepsen, D. Mathiesen et al. /2/ likewise presented at this symposium.

Background and purpose of development project U4

Traditionally, design of concrete structures has concentrated on the construction phase, optimising the construction costs and short-term performance. Sustainable developments raise a strong need for integrated life-cycle design, where all phases during the entire service life of the structure have to be considered, see Fig. 1.

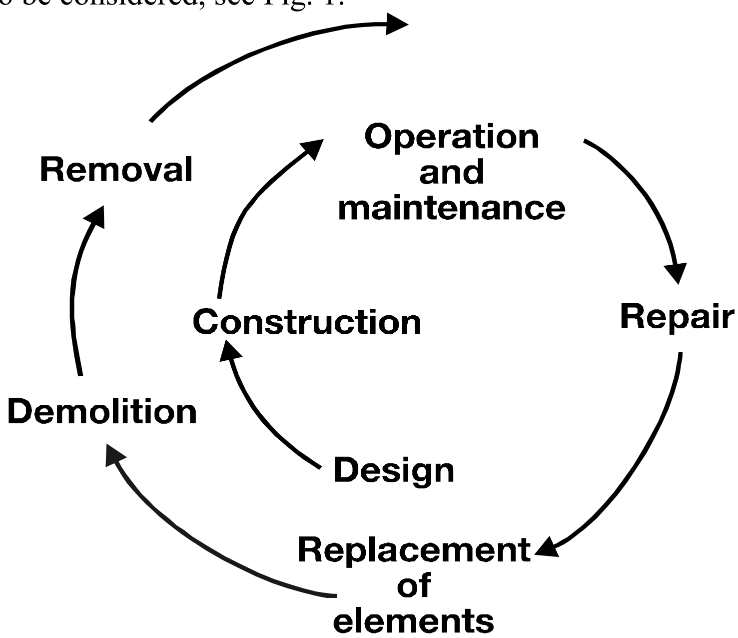


Fig. 1 Phases in the life cycle of a concrete structure to be considered in the life cycle inventory

It is a fact that concrete structures exposed to aggressive environment involves major maintenance and repair activities. The environmental loads associated with maintenance and repair are very often the dominant sources occurring during the entire service life of the structures. Thus, it was decided within U4 to select a concrete bridge as a typical example of a structure exposed to aggressive environment. e. g. bridges in marine environment or exposed to de-icing salt.

One primary purpose of U4 is to quantify the environmental impact (including cost related) caused during maintenance/repair. Further purpose is to elaborate more environmental-friendly maintenance/repair strategies, which require less maintenance/repair activities and thus lower environment loads compared to traditional maintenance/repair. The evaluation of the selected environmental-friendly maintenance/repair strategies, which themselves imply different design alternatives, is based on life-cycle inventories.

The ecological goals regarding the consumption of non-renewable natural resources and energy, and the degree of atmospheric pollution, which accounts for all tasks of the project, are as follows (more information see /2/):

- Reduction of the concrete industry's CO_2-emmision by 21% (Kyoto obligation)
- Increased concrete industry's use of waste products by 20%
- Reduction of the concrete industry's use of non-renewal fuels
- No use of constituents listed as unwanted by the Danish Environmental Protection Agency
- The recycling quality of green concrete must not be less compared to existing concrete types
- The production of green concrete must not reduce the recycling applicability of the discharged water
- No increased noise and dust emissions

Alternative design and green maintenance and repair strategies

One important purpose of the project is to elaborate different maintenance/repair strategies that are based on different alternative designs. In principle two main design principles exit which reflect different maintenance/repair strategies (other intermediate solutions possible), see Table 2:

Design principle	Construction stage	Maintenance/ repair stage
1	cheep	expensive
2	expensive	cheep

Table 2: Different design principles and maintenance/repair strategies

- the first design principle assumes the construction of a cheep, less robust and less durable structure which requires repeating, environmentally and financially speaking, extensive maintenance/repair (for example: a structure with reduced concrete cover: low construction costs, however substantial repair costs due to deterioration of concrete caused by e.g. corrosion of reinforcement at an early stage)
- the second design principle assumes the construction of a expensive, yet more robust and durable structure which requires minimum maintenance/repair which itself is more environmental and cost friendly (for example: use of stainless steel instead of traditional black reinforcement: almost no need for maintenance/repair during the entire service life)

For a typical Danish motorway bridge a scenario of alternative designs which requires different maintenance/repair activities has been elaborated, see Table 3. The structural bridge elements that have been selected for this case study are a bridge deck, a column and an edge beam.

Structural element	Concrete type	Design	Expected service life	Maintenance/ repair
Bridge deck	Green concrete	Waterproofing membrane (traditional design)	25 years	extensive, expensive
		Top layer of DENSIT 1) *)	Min. 30 years (may be 75 years)	limited, moderate
		Top layer of steel fibre reinforced concrete *)	Min. 30 years	limited, moderate
Column	CRC 2)	None	Min. 75 years	negligible, very cheep
	Green concrete	Traditional design (column A)**)	50 years	limited, moderate
		Stainless steel reinforcement (column B)**)	Min. 75 years	negligible, very cheep
		Cladding of stainless steel (column C)**)	Min. 75 years	negligible, very cheep
Edge beam	Green concrete	Stainless steel reinforcement	Min. 75 years	negligible, very cheep

1): DENSIT® = Cement and micro silica based material providing high density and high compressive strength (150-300 MPa)

2): CRC® = Compact Reinforced Concrete which contains a high amount of steel fibre providing high ductility and compressive strength (150-400 MPa)

*) : without traditional waterproofing membrane

**) : designation used for the environmental screening

Table 3 Alternative designs with requires different maintenance/repair used for the assessment of environmental effects of concrete bridges

Environmental screening – case study

Within the U4-tasks an environmental screening has been performed for a column presenting the different design principles as described in Table 3 (green concrete columns defined as A, B, C). For comparison, the same environmental screening has been performed for a reference column (traditional concrete column defined as R), which is similar to column A, except that the green concrete type being substituted by a traditional concrete suitable for aggressive environment (detailed information about the green concrete types is given in /2/). The objective of the screening is to identify significant resource consumption and environmental loads of traditional concrete/design compared to green concrete/design occurring during the entire service life, this includes the environmentally viewed most critical maintenance/repair stage.

The performed lifecycle screenings quantify material usage (consumption of concrete) as well as CO_2-emissions generated at the involved stages during the lifecycle of the columns. The input data for this comparison are given in Table A1, Appendix A. In order to limit the analysis to a minimum, the environmental screening comprises only those issues where the environmental impacts of the green concrete columns differ from those of the traditional one (see Table A1).

The environmental parameters related to the working environment have not been included.

The results of the environmental screening for the 3 green concrete columns (A, B, C) and the traditional concrete column (R) is presented in Table 4 with regard to the CO_2-emission and in Table 5 with regard to the consumption of concrete.

Design solution	Column R	Column A	Column B	Column C
	Traditional design + traditional concrete	Increased concrete cover + green concrete	Stainless steel reinforcement + green concrete	Stainless steel cladding + green concrete
kg CO_2 per year	300	200	86	80

Table 4 CO_2-emissions for different designs of concrete columns

Design solution	Column R	Column A	Column B	Column C
kg concrete for construction	5102	5733	5102	5102
kg concrete for maintenance/repair	1533	2442	0	0
kg concrete, total	6635	8175	5102	5102

Table 5 Consumption of concrete for different designs of concrete columns

This comparison demonstrates that column B (stainless steel reinforcement) and column C (stainless steel cladding) present the most environmental-friendly design solutions both with regard to the CO_2-emissions and the consumption of concrete. An even more environmental-friendly solution is if the selected concrete at column C would be substituted by a more environmental-friendly (greener) concrete type (e.g. concrete suitable for passive environment, see /2/) provided that the steel cladding assures the long-term protection of the reinforced concrete. It should be noted that the results stated above are strongly related to the assumed service life expectations as defined in Table 3. As a next step the financial analysis of this scenario will be performed.

Acknowledgement

The following companies, educational and research institutions participated in the Centre for Resource Saving Concrete Structures:

Aalborg Portland A/S, Unicon Beton A/S, COWI Consulting Engineers and Planners AS, Højgaard & Schultz a/s, AB Sydsten, the Concrete Centre (Danish Technological Institute), Department of Buildings and Energy (the Technical University of Denmark), Department of Building Technology and Structural Engineering (Aalborg University), and the Danish Road Directorate.

The Centre is co-financed by the Danish Agency for Industry and Trade.

Literature

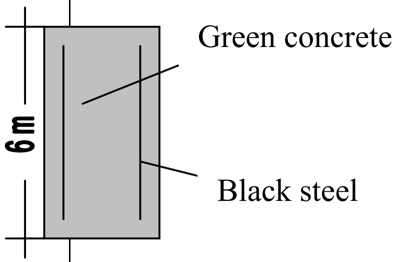
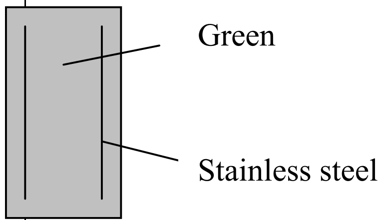
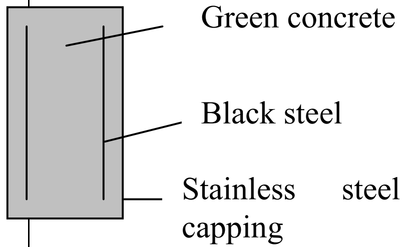
[1] RESOURCE SAVING CONCRETE STRUCTURES (colloquially “Green Concrete”), Danish Research Project, 1998-2002

[2] TANGE JEPSEN, M., MATHIESEN, D. ET AL., “Durability of Resource Saving “Green” Types of Concrete” (proceeding fib Symposium 2001, Berlin)

[3] CONCRETE CENTRE, DANISH TECHNOLOGICAL INSTITUTE, “Miljømæssig screening af grønbetonsøjler” (in Danish), private communication

Appendix A

Table A1: Environmental screening – Case study- Columns

Design solution	Column A	Column B	Column C
Specifications	 Height: 6 m Diameter: 74 cm Concrete cover: 50 mm (increased compared to traditional concrete structures exposed to aggressive environment: 30 mm) Black steel: ø 25 mm, 150 kg/m^3 Construction: Traditional, in-situ casting Maintenance and repair: - Cleaning/washing: every year – Surface treatment: every 13. year – Repair: after 25 years – Removal (lifetime): after 50 years	 Height: 6 m Diameter: 70 cm Concrete cover: 30 mm Stainless steel: ø 25 mm,150 kg/m^3 Construction: traditional, in-situ casting Maintenance and repair: - Cleaning/washing: ·/· - Surface treatment: ·/· - Repair: ·/· - Removal (lifetime): after 50 years	 Height: 6 m Diameter : 70 cm Concrete cover: 30 mm Black steel: ø 25 mm, 150 kg/m^3 Construction: Cladding with stainless steel that replaces traditional shuttering, in-situ casting Maintenance and repair: - Cleaning/washing: ·/· - Surface treatment: ·/· - Repair: ·/· - Removal (lifetime): after 75 years

Concrete recipe	Green concrete type A1 [1)]	Green concrete type A1 [1)]	Green concrete type A1 [1)]
Concrete quantity changes compared to traditional column (ø70 cm)	Increased concrete quantity (due to increased cover) *Quantities see input data (below)*	-	-
New materials for construction compared to traditional column	-	Stainless steel	Stainless steel cladding
Process- and material savings for construction compared to traditional column	-	-	No establishment of traditional wood shuttering. *Quantities see input data (below)*
Process- and material savings for operation and maintenance compared to traditional column	-	No cleaning/washing or reparation *Quantities see input data (below)*	No cleaning/washing or reparation *Quantities see input data (below)*
Material savings/increasing for demolition and deposition compared to traditional column	Increased concrete quantity (due to increased cover) *Quantities see input data (below)*	Difference between deposition of stainless steel and black steel	Stainless steel cladding as extra residual product *Quantities see input data (below)*

1): Green concrete type A1: concrete with high amount of fly ash (40% of powder b.w.) ; more details on the concrete mix are given in /2/

Input data for the 3 design solutions:

Design solution A:

- New materials /change of material amounts

Increased concrete quantity: 0,27 m^3 (relevant for construction + deposition)

Design solution B:

- New materials /change of material amounts

Stainless steel: AISI 304 (steel quantity: 150 kg/m^3 x π x $0,70^2$ x 6 /4 = 346 kg)

(plus materials for process changes, see mentioned below)

- Process changes (savings):

Cleaning/washing with high water pressure (cold water): every spring after winter duty (the entire column):
Quantity: surface: π x 0,74/2 x (0,74 + 2x 6,0) = 14,8 m^2

Surface treatment every 13. years (the entire column) (e.g.: Monosilan-product, Conservado 70 (0,31 litre/m^2, 2 gang), from Sika-Beton)
Quantity: 9 litre

Reparation after 25 years (the first two meters of the column above terrain):

3.1 Removal of concrete with compressed air hammer up to 10 mm behind the corroded reinforcement (total = 50 + 25 + 10 = 85 mm)
Quantity of concrete that needs removal: 0,35 m^3

3.2 Sand-blasting of reinforcement
Quantity of concrete that needs cleaning: 130 kg

3.3 Shotcreting with green concrete
Quantity of concrete: 0,35 m^3

3.4 Mortar (e.g.: Sikatop 120, 5 mm thick coating)
Quantity: 0.03 m^3

Design solution C:

- New materials/change of material amount

Stainless steel cladding: 2 mm thick. Area: π x 0,70/2 x (0,70 + 2x 6,0) = 14 m^2

(plus materials for process changes, see mentioned below)

- Process changes (savings):

1. Establishment of traditional wood shuttering: Wood shuttering: The boards have to be bevelled (75 mm wide, 30 mm thick)
   Total wood area: ca.: 15 m^2
2. see design solution B