FIBRE CONCRETE 2007
Prague, 12th – 13th September 2007

ENVIRONMENTAL ASPECTS OF CONCRETE STRUCTURES DESIGN

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Abstract

Basics of environmental design of concrete structures are introduced. Main environmental indicators for concrete structures design are specified. For new fibre reinforced material named engineered cementitious composite (as a member of FRC family) the life cost analysis on bridge deck slab retrofitting example is described.

Keywords: fibre reinforced concrete, engineered cementitious composite, life cost analysis, environmental aspects, environmental impact indicators

1 Introduction

Environmental impact assessment involves the integrated examination of all important environmental assets (relating to human welfare, animals, plants, soils, water, landscapes etc.) and is based on the precautionary principle.

Environmental impact assessment examines the influence of projects (plans) on the major categories of environmental problems: forestry, biodiversity, land quality, air and water pollution, global environmental concerns (specifically greenhouse gas emissions and protection of the ozone layer). If we speak about a "project" or "plan" we mean a problem which is connected to the civil engineering design of a concrete mixture or of a structure made from concrete.

The functions of the environmental impact indicators (EII) are *descriptive* in nature, for example:

- to describe and diagnose the existing situation as regards sustainability, and
- to forecast future trends relating to sustainable development;

and *normative*, for example:

- to assess the existing situation and trends against the background of qualitative and quantitative objectives for sustainable development
- to assist with formulating objectives of sustainability more precisely and quantifying them
- to facilitate policy decision-making
- to monitor the success of sustainability-related measures (What does this mean?) for example: it would be possible to monitor the influence of some standards on sustainability
- to contribute to public awareness and communication.

The method of assessing the environmental impact of a designed structure is connected with the life cycle of the whole structure – Fig. 1. A Life Cycle Assessment (LCA) can be used in two ways:

- To determine the total environmental impact of structure or its design alternatives with the aim of comparing them. For a designer, an LCA can provide information if he/she has to choose among design alternatives or among different components or materials.
- To determine the most important causes of a product's environmental impact. A designer can concentrate on achieving improvements based on LCA

A designer wishing to use LCA in the design process is faced with two major problems:

- It is difficult to interpret the result of LCA. Within an LCA, it is possible to determine the environmental impact of a product to the greenhouse effect, acidification and other environmental problems in the life cycle, while the total environmental impact remains unknown. The reason is the lack of mutual weighting method for environmental effects (indicators).
- In general, the careful collection of all environmental data in a life cycle of product/plan is complex, expensive and time consuming.

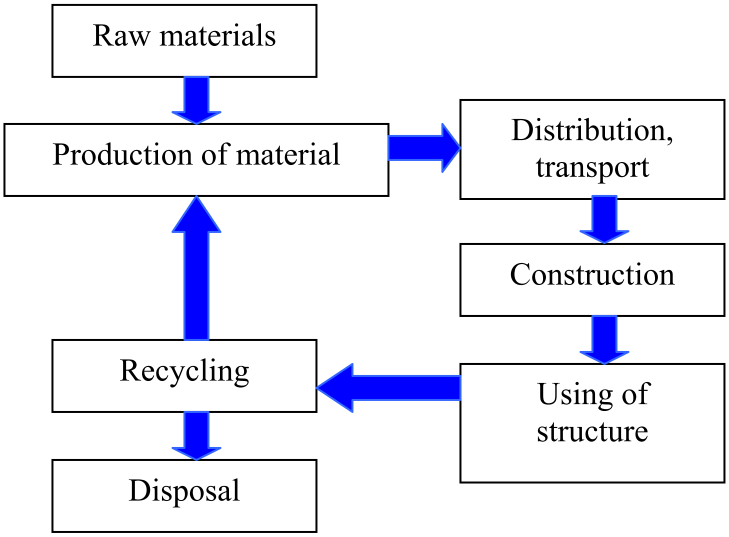

Fig. 1: Life cycle of concrete structure, [1]

2 Main EIIs connected to concrete

It is not possible to define all EIIs for concrete and/or concrete structures. The division of EIIs into several groups could be based on different principles. We can define a lot of EIIs. Some of them can be mutually transferred. In the following tex`t the main EIIs are described.

2.1 Raw Material Resource Consumption

Consumption of raw material resources is one group of EIIs. It is possible to define the main raw materials for concrete production and execution of a concrete structure: limestone, sand, water, admixtures.

2.2 Energy Consumption

The energy consumption of concrete (concrete structure) during the life cycle is made up of the phases visible on the Fig. 1: material production, transport related energy, construction phase, use (maintenance) phase, and end of life phase (demolition, transport, land filling or recycling).

2.3 Greenhouse Gas Production

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

2.4 Other EIIs

Into group of other EIIs is possible to include: other air pollutant gas emissions (e.g. nitrogen oxides NOx, sulfur oxides SOx, nonmethane hydrocarbons NMHCs), water pollutant discharges (emissions into water at each life cycle stage of concrete or concrete structure), particulate air emissions, visual landscape destruction, solid waste production, traffic congestion, noise and adverse health effects.

3 ECC as a member of FRC family

Traditionally, materials engineering has focused on the interplay between material microstructure, physical properties, processing and performance. Li successfully developed a fiber reinforced concrete (FRC) with special properties; [2]. The result is ductile fiber reinforced engineered cementitious composite (ECC). ECC is a composite reinforced usually with polymer fibers. ECC is a micromechanically designed material; on the other hand, the common FRC is a macro-mechanically designed material. The amount of fiber (e.g., polyvinyl alcohol and polyethylene) in ECC is generally 2% or less by volume.

By ECC design the mechanical interactions between fiber, matrix and its interface are taken into account by a micromechanical model which calculates these constituent properties to a composite response. The micromechanics is used as the analytical tool to guide microstructure tailoring of ECC. As a result, guidelines for selection of fiber, matrix and interface characteristics advantageous for composite properties are made available.

Unlike other concrete materials, ECC strain-hardens after first cracking, similar to a ductile metal, and demonstrates a strain capacity 500-600 times greater than normal concrete or mortar (Fig. 2). Other characteristics of ECC include fracture toughness like that of aluminum alloys, extreme ductility under severe shear loading conditions (Fig. 3a).

Potential infrastructure applications of ECC include building frames (Fig. 3b), bridge piers, bridge deck repair, extruded pipes and roadway repairs.

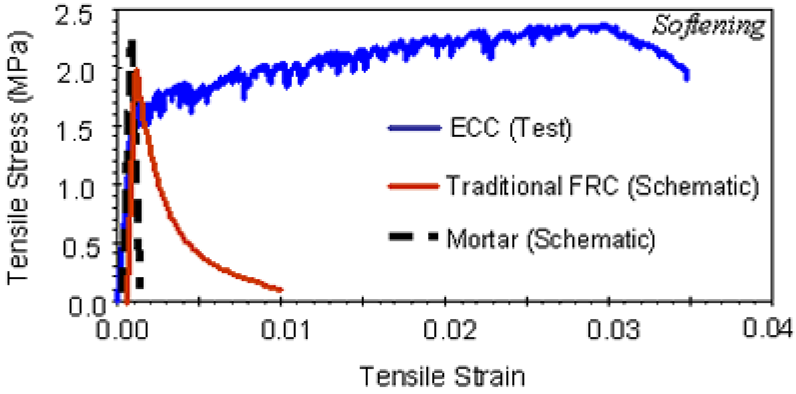

Fig. 2: Working diagram of ECC, FRC and cement mortar, [4]

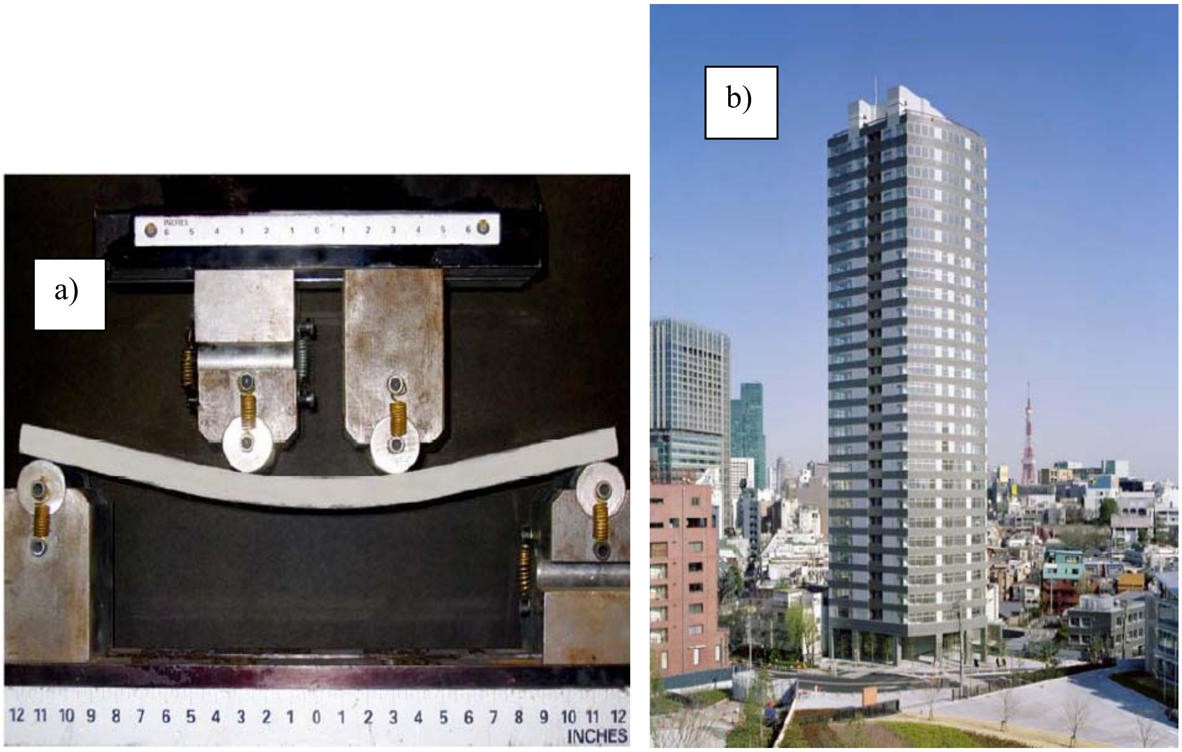

Fig. 3: a) ECC subjected to flexural loading, b) Glorio Roppongi (Tokyo, Japan) high-rise residential building uses ECC coupling beams in core for seismic resistance (height: 27-stories, 95m high` completed 2006); [6]

4 Environmental design of concrete structures

The magnitude of the environmental impact of the structure E_{tot} may be expressed

$$E_{tot} = \sum p_i \; E_i \tag{1}$$

where p_i is the probability of incidence of i-th environmental impact E_i. (1) may be explicated as

$$E_{tot} = E_{ini} + E_{oper} + E_m + \sum p_f\, E_{repair} + \sum p_{renov} E_{renov} + E_{demol} + E_{recycl} \quad , \qquad (2)$$

where the individual environmental impacts represent: E_{ini} the impact connected with the materials and members production and to the design and realisation of the construction, E_{oper} the impact connected with the operation of the construction, E_m the impact connected with maintenance, E_{repair} the impact connected with the repair of failures, E_{renov} the impact connected with the reconstruction, E_{demol} the impact connected with the demolition, E_{recycl} the impact connected with the recycling and p_f , p_{renov} are the referring probabilities of possible failures origin and reconstructing interventions.

The quantity cost of construction C_{tot} is expressed as a function expressing the construction cost during its life cycle, i.e.

$$C_{tot} = \sum r_i \; C_i \qquad (3)$$

or in the more detailed form as:

$$C_{tot} = C_{ini} + C_{oper} + C_m + \sum r_f\, C_{repair} + \sum r_{renov} C_{renov} + C_{demol} + C_{recycl} \quad , \qquad (4)$$

where C_{ini} is the construction initial cost (i.e. a sum of the costs of materials, transport, design and construction), C_{oper} is the operating cost, C_m is the maintenance cost, C_{repair} is the repairs cost, E_{renov} is the accidental reconstruction (renovation) cost, C_{demol} is the demolition cost, C_{recycl} is the recycling cost and r_f , r_{renov} are probabilities of the possible failures origin and reconstructing interventions.

The specification of social and cultural quality of designed concrete structure represents very soft problem. It is possible that its introducing could lead to the confusion and devaluation of the optimisation results.

The life cycle analysis (LCA) for 2 alternatives of bridge deck retrofitting of continuous bridge deck according to Fig. 4 was done [7]. ECC material was used for 2nd alternative to make a continuous deck instead 2 simply supported decks because of its good ductility - Fig. 4.

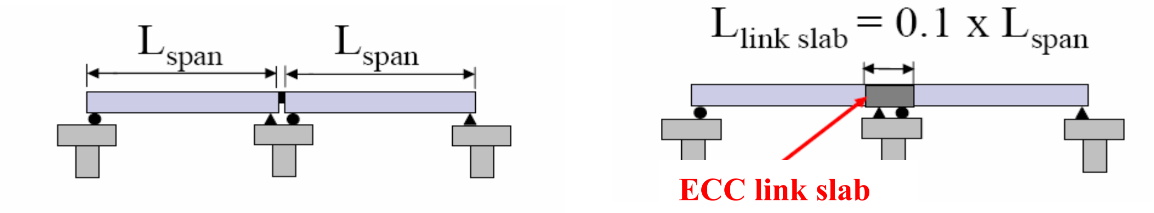

Fig. 4: Design idea of bridge deck link slab retrofitting (Michigan, 2005, [7])

Results of LCA are shown on the Fig. 5 for 2 EIIs: total primary energy and global warming potential.

5 Conclusions

It is necessary to prepare tools for the integrated life cycle design framework of FRC and ECC. For this apparatus we have to

- collect the data for *Alternative Infrastructure Materials* ECC and FRC and compare them to conventional steel-reinforced concrete,
- make a microscale research activities for obtaining guidelines for selection of fiber, matrix and interface characteristics advantageous for composite properties

- provide structural testing and End-of-Life Studies of FRC and ECC structures and materials.

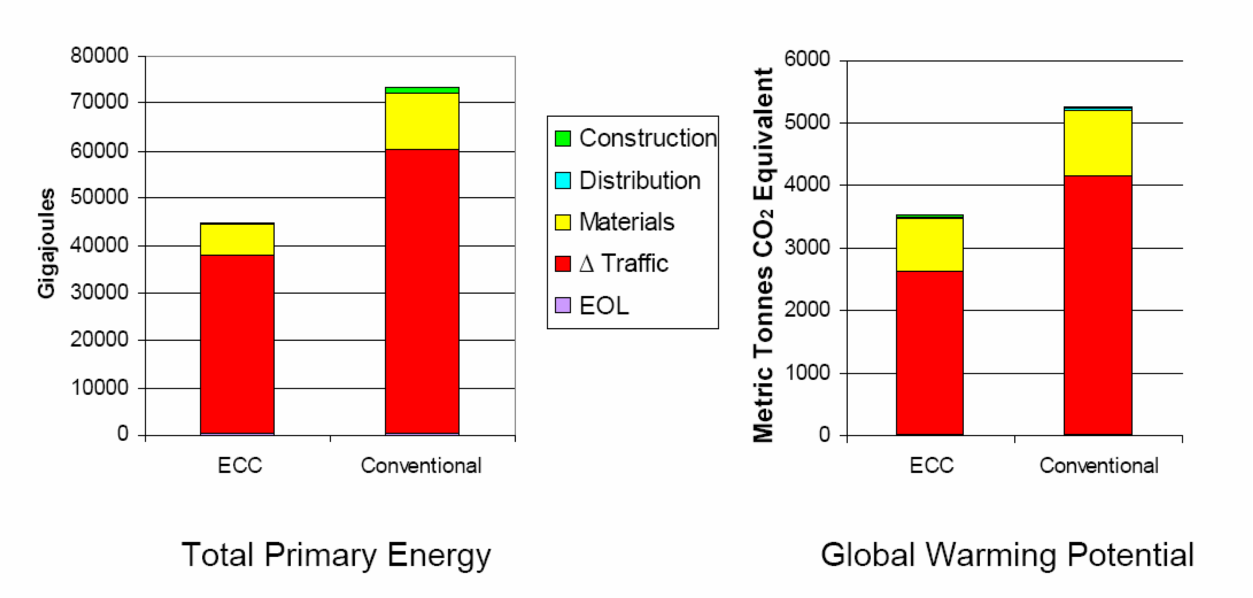

Fig. 5: Results of LCA of bridge deck retrofit; [7]

Aknowledgements

This outcome has been achieved with the financial support of grant GAČR 103070400 and project of Czech ministry of industry 1M06005/09/2006.

References

[1] www.worldbank.org
[2] http://en.wikipedia.org/wiki/Fiber_reinforced_concrete
[3] Li, V.: Li, V. C., Fischer, G.: Reinforced ECC – An evolution from materials to structures, 105 – 122 . Sborník FIB Osaka 2002
[4] http://blume.stanford.edu/Blume/Newsletters/Winter2005.htm
[5] Štěpánek. P.: Kompozitní konstrukce. Poznatky z kongresu FIB Osaka 2002. ČBS, 2003
[6] Construction Innovation Forum, NOVA AWARDS 2007 nomination for ECC “bendable” concrete, www.CIF.org
[7] Li, V.: Engineered Cementitious Composites (ECC). CONMAT’05, Vancouver, Canada, August 22-24, 2005