METHODOLOGY OF LIFE-CYCLE ASSESSMENT OF RC STRUCTURES USING HIGH PERFORMANCE CONCRETE

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Summary

A third version of a tool for Life Cycle Assessment (LCA) of reinforced concrete structures was developed based on general methodology (standards) and tested for implementation in Czech regional conditions in the previous two years. The Tool enables to compare objectively and evaluate various types of structures from various kinds of concrete from the perspective of impacts on environment within the whole life cycle of the structure. A LCA approach from cradle to the gate is presented in environmental analysis of three alternatives of experimentally verified subtle columns. Relevant LCA is based on local environmental data collected within the inventory phase of the LCA procedure.

Keywords: LCA, high performance concrete, subtle column, environmental efficiency

1 Life-Cycle Assessment of concrete structures

1.1 Application of LCA methodology to concrete structures

The LCA methods and models should consider all important environmental impacts within the whole life (from "cradle to grave") of a concrete product (element, structure, etc.). The typical life cycle of a concrete product should cover all life stages from raw material acquisition, through construction and operation, up to demolition and reuse of materials or waste disposal. The quality level of performance of a concrete structure in a specific life cycle stage is determined by the initial quality of the structure achieved during the construction process. A higher initial investment to the higher quality could result in lower operational costs and lower total environmental or economy costs at the end of the life cycle of the concrete structure.

A methodology for Life-cycle assessment of RC structures considering Czech regional specifics and conditions has been published by authors in [1] and [2]. This methodology is based on principles defined in ISO 14040 and corresponding set of international standards.

1.2 Environmental profiles of concrete components and specifics of HPC

A set of environmental information data of concrete components and related processes has been collected and determined within the research performed at the CIDEAS centre of the Czech Technical University in Prague (CTU) and within other following research projects. These data are based on regionally available materials and are based on source data provided by companies producing and/or selling their products mainly on the Czech market. The data have been stored and organized in ICF concrete LCA$^{\text{Tool 3.0 CZ}}$ developed by C. Fiala at the Czech Technical University in Prague.

In the inventory analysis of LCA there are parts of balance processes organized into modules. All the material and energy flows (inputs and outputs) are balanced and quantified in these modules, i.e. consumption of raw materials, products and by-products, auxiliary materials, energy, water and transport, emissions, by-products and waste from manufacturing processes. Impact data collection and calculations were done for cement, aggregates, admixtures, water, steel reinforcement, for concrete production processes, transport, for repair of the concrete surface and demolition. Energy data and emission factors used in the assessment are from GEMIS (Global Emission Model for Integrated Systems) Version 4.6 [3]. The impact data for fine admixtures usually used in mixture of high-performance concrete was supplemented in ICF concrete LCA$^{\text{Tool 3.0 CZ}}$ in 2012. Commonly used types of admixtures in high performance concrete are mainly silica fume, fly ash and slag.

2 Environmental comparison of subtle columns

Environmental assessment was evaluated for three selected alternatives of subtle columns. The columns are experimentally verified (Fig. 1 and Fig. 2) at the CTU within the research of subtle prefabricated RC frame for energy-efficient buildings.

The environmental analysis covers transport of the raw material to the concrete plant and production of prefabricated elements in the plant (cradle to the gate approach). The subtle column's alternatives are as follows:

- V1 *column HPC SL + R*: length 2500 mm, cross-section of the column 100/200 mm, concrete: High-Performance Concrete SL mixture was designed as fine-grained with 13 mm long steel microfibres. The tensile strength of these fibres is 2400 MPa. The amount of steel fibres was 1% by volume. HPC SL has compressive strength of 155 MPa (measured on 100 mm cubes), reinforcement: main reinforcement 4 profile R10, stirrups R6 ā 800 mm only structurally.
- V2 *column HPC SL*: length 2500 mm, cross-section of the column 100/200 mm, concrete: HPC SL mixture as V1, reinforcement: only dispersed steel fibres.
- V3 *column C30/37 + R*: length 2500 mm, cross-section of the column 100/200 mm, concrete: C30/37 XC1, reinforcement: main reinforcement 4 profile R10, stirrups R6 ā 800 mm only structurally.

Fig. 1 *Subtle column before the test (V1)*

Fig. 2 *Subtle column after the test (V1)*

Table 1 shows the balance of input data for one column of construction life phase. The freight traffic is expressed in tonnes kilometres (tkm) that cover the amount of material and transported distance.

Tab. 1 *Balance of input data of construction life phase*

Balance of input data of assessment variants	**unit**	**V1 column HPC SL + R**	**V2 column HPC SL**	**V3 column C30/37 + R**
ordinary concrete C30/37	m^3	0	0	0.0492
high performance concrete HPC SL	m^3	0.0492	0.0500	0
cement CEM II 32.5 R	MJ	0	0	17.2
cement CEM I 42.5 R	kg	33.4	34.0	0
sand | gravel	kg	47.2	48.0	51.6
crushed gravel	kg	0	0	38.0
silica fume	kg	8.6	8.8	0
micro milled sand	kg	16.0	16.3	2.5
steel fibres	kg	3.9	4.0	0
admixture (PCE) superplasticizer	kg	1.4	1.5	0.2
water	kg	8.4	8.5	9.6
reinforcing bars R10505	kg	6.5	0	6.5
freight traffic	tkm	23.1	23.5	8.5

Aggregated impact data for specific life cycle construction phase (from cradle to gate) are presented in Table 2. The values in the table are also impact data for one column.

Tab. 2 *Aggregated impact data of construction life phase*

Aggregated data of assessment variants	unit	V1 column HPC SL + R	V2 column HPC SL	V3 column C30/37 + R
consumption of primary raw materials	kg	178	169	144
water consumption	m^3	0.1	0.1	0.1
primary energy consumption[1)]	MJ	579	409	313
global warming potential | GWP	kg	64	49	32
acidification potential | AP	g	298	200	151
photochemical ozone creation potential | POCP	g	12	8	6
Note: [1)] non-renewable primary energy				

Figures 3 present the environmental indicator primary energy consumption. The influence of individual components such as cement, aggregate, water, admixtures, etc., is displayed. It is apparent that the main environmental impact is due to cement and steel reinforcement.

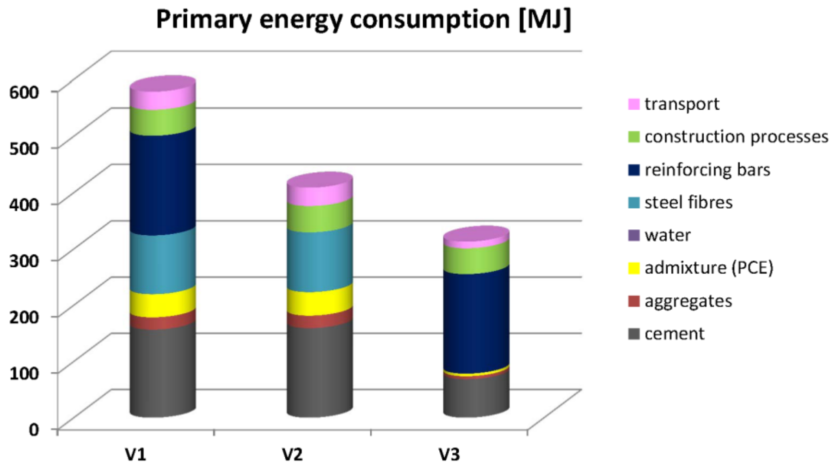

Fig. 3 *Aggregated data – primary energy consumption per one column of all options*

It is obvious from Table 2 that impact values are logically higher for columns from high performance concrete. Environmental efficiency of material utilization (EE) is inversely proportional to the share of the environmental impact (EI) per unit power (P): (P): $EE = (EI/P)^{-1}$. Smaller number of environmental impact per unit of power means more environmental efficiency of material utilization for the consideration of environmental impact.

Tab. 3 *Evaluation of experiments and environmental efficiency*

variant	total horizontal displacement f_{max} [mm]	F_{max} [kN]	$F_{L/300}$ [kN]	primary energy consumption | EE [MJ/column]	global warming potential | GWP [kg $CO_{2,equiv.}$/column]	$EE/F_{L/300}$ [MJ/kN]	$GWP/F_{L/300}$ [kg $CO_{2,equiv.}$/kN]
V1	15.4	900.9	749.8	579	64	0.772	0.085
V2	17.0	1167.9	1033.0	409	49	0.396	0.047
V3	8.1[*)]	650.1[*)]	648.9[*)]	313	32	0.482	0.049

Note *) The values for the column from ordinary concrete V3 are values related to the testing sample No. 1, not the average of three testing samples. The reason is early failure of testing samples No. 2 and 3 due to incorrectly assembled reinforcement in cross-section and subsequent damage of testing samples to transverse tensile.

The proportion of experimentally achieved load capacity in buckling pressure (max. force that is proportional to the load capacity of the column – i.e. its mechanical performance) was quantified in the case of evaluated columns for selected environmental impacts (embodied primary energy, embodied emissions $CO_{2,equiv.}$).

Table 3 shows for individual variations of columns achieved environmental impacts, and the average value of the horizontal displacement, maximum force and force on the limit of application (column buckling L/300) and its ratio. A higher environmental efficiency of HPC SL columns is evident, although amount of embodied emissions and energy consumption related to column V1 is worse than that of normal concrete column.

3 Conclusions

The results show that the high quality of mechanical and environmental performance creates the potential for wider application of High Performance Concrete in building construction in the future. The effective application and quality of results of LCA are dependent on the availability of relevant input data obtained using a detailed inventory analysis, based on specific regional data sources. The next step in evaluation of the complex quality of concrete structures is integrated life-cycle assessment (ILCA) covering all three pillars of sustainability – environmental, social and economic.

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References

[1] HÁJEK, P., FIALA, C. & KYNČLOVÁ, M. 2011. *Life Cycle Assessment of Concrete Structures – Step towards Environmental Savings*, Structural Concrete, Journal of the fib, Volume 12, Number 1, 2011, ISSN 1464-4177.

[2] HÁJEK, P., FIALA, C., KYNČLOVÁ, M.: *Life-cycle assessment of RC structures in Czech regional conditions*, IALCCE 2012, Wien, Austria, 2012, p. 197, ISBN 978-0-415-62126-7 (eBook 978-0-203-10336-4).

[3] *GEMIS (Global Emission Model for Integrated Systems) – version 4.6*, database CZ, D 2010, *www.oeko.de/service/gemis/,* 2010.