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Concrete: Limit States and Sustainability

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1 Introduction

Limit state design is a common approach in civil engineering practice; the issue of service life is important. Also, new types of engineering tasks have emerged, concerning sustainability and resilience, which also need relevant definition of limit states. (LS).

2 Traditional LS

The traditional ultimate limit state (ULS) and serviceability limit state (SLS) were presented in the nineties in standards. The ULS concerns the safety of people and/or structures. The SLS concerns the functioning of the structure, the comfort of people and the appearance of construction work. For material degradation, the serviceability limit state can be defined.

3 The durability Concept

The durability of reinforced concrete components or structures was included in connection with the reinforcement corrosion: (i) an initiation and (ii) a propagation period. Broadly accepted models (carbonation and chloride effect) were included in the Model Code for Service Life Design (2008) and later in fib Model Code 2010 (2012).

4 The Limit State Concept from the Perspective of Sustainability

Sustainable target value design can be expressed as the comparison of sustainable capacity vs. sustainable impacts. This may require a new class of limit state - sustainability limit states: the environmental performance of a concrete structure shall be verified by confirming that the retained performance or barrier (R) with regard to the environment is larger (or smaller) than the set value or effect of the action (S) of the relevant performance requirement. The relevant limit states are not being identified at the present time; it has to be based on the probabilistic approach combined with the life cycle approach together with service life and/or financial factors. Authors of the present contribution have developed a sustainability LS formulation at material level using the sustainability potential indicator k_{SB}, Eq. (1), which is a normalized form of the Building Material Sustainability Potential (BMSP) defined previously by Müller (2013). The ranking of k_{SB} values is the resulting information enabling thus the comparison of concrete mixture sustainability levels within a group of analysed compositions under a given degradation effect.

$$k_{SB} = \frac{\frac{R}{R_{ref}} \cdot \frac{L}{L_{ref}}}{\frac{E}{E_{ref}}} \tag{1}$$

Eq. (1) can be further enhanced by considering the costs, C, of concrete leading to a modified indicator - see Hrabová *et al.* (2019). Additionally, for any individual concrete composition using k_{SB} as an action and the limiting value of indicator $k_{SB,lim}$ as a barrier, the general limit state condition is:

$$P_{SB} = \left[\left(k_{SB} - k_{SB,lim}\right) \leq 0\right] \geq P_{d.SB} \tag{2}$$

This equation enables the evaluation of the probability P_{SB}, with which a certain limit value $k_{SB,lim}$ can be exceeded for the concrete mixture in question. However, this value has not yet been discussed and no experience or recommendations are known in this respect. Note that $k_{SB,lim}$ depends on three involved factors. A less complicated option can be formulated utilizing the individual limit values R_{lim}, L_{lim} and E_{lim} of quantities R, L and E, respectively, or in other words to determine the $k_{SB,lim}$ value as follows:

$$\boldsymbol{k_{SB,lim}} = \frac{\frac{\boldsymbol{R_{lim}}}{\boldsymbol{R_{ref}}} \cdot \frac{\boldsymbol{L_{lim}}}{\boldsymbol{L_{ref}}}}{\frac{\boldsymbol{E_{lim}}}{\boldsymbol{E_{ref}}}} \tag{3}$$

A major obstacle for the effective utilization of the limit state condition (4) is the choice of a suitable value for target reliability $P_{d,SB}$, which is not yet available in any recommendation or standard. Some suggestions are mentioned in the full text.

5 Numerical Demonstration of the Presented Approach

A simple example of the sustainability limit state assessment of concrete composition is illustrated on an ad-hoc case - concrete suffering from carbonation in the full text of this contribution.

6 Concluding Remarks

The paper concentrates on the description and formulation of limit states for sustainability.

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