Robustness of Structures

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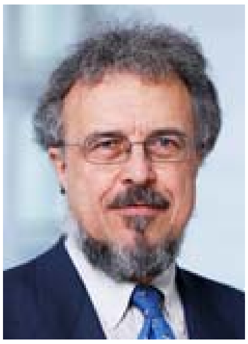

Thomas Vogel received his diploma from ETH Zurich in 1980. He worked for 11 years in consulting and since 1992 as professor of Structural Engineering at ETH. His fields of interest cover the evaluation of existing structures, non-destructive testing methods, ductile design with brittle materials as well as structures designed for and protecting from natural hazards.

Summary

Robustness has become an important general requirement for both, design of new and evaluation of existing structures, to reduce the global risk caused by structures. Methods to achieve robustness are presented in a systematic order and illustrated by examples. Some important issues to get robust structures are addressed like strength, stiffness, ductility, strain hardening, and continuity. Different definitions of robustness are presented, showing that they slowly converge. Some proposed metrics are discussed, although they are not yet practically applicable. With a example of a bolted steel splice, it can be shown that even in a simple detail robustness as a design criterion may be ambiguous. Finally, the implicit and explicit treatment of robustness in former and actual codes is covered and developments for the future are sketched.

Keywords: Alternative load path, continuity, ductility, event control, progressive collapse, redundancy, segmentation, specific load resistance, strain hardening, vulnerability.

1. Introduction

Robustness can be defined as the ability of a structure and its members to keep the amount of deterioration or failure within reasonable limits in relation to the cause [1]. In the past, the issue was raised periodically, triggered by events like the progressive collapse of one corner of a 23 storey block at Ronan Point in east London in 1968 due to a gas explosion in the 18th floor, or the car bomb attack to the Alfred P. Murrah Federal Building, Oklahoma City, USA in 1995, which led to the almost complete collapse of its northern façade. Robustness has again become a major theme of structural engineering by the incidents of September 11, 2001. Research has been intensified to look for suitable concepts for all different types of structures and building materials and to quantify robustness. This would be a precondition to cover robustness more precisely by structural codes in the long term. A comprehensive overview on the state of the art is given by the final report of COST action TU0601, consisting of three parts [2], [3], [4].

2. Estimating risks

2.1 Risk analysis in a perfect world

Risk analysis provides tools to assess the global risk of a structure, for instance by applying the general equation given in EN 1991-1-7 [5]:

$$R = \sum_{i=1}^{N_H} P(H_i) \sum_{j=1}^{N_D} \sum_{k=1}^{N_S} P(D_j \mid H_i) P(S_k \mid D_j) C(S_k) \tag{1}$$

where:

N_H	number of hazards H_i
N_D	number of direct (local) damages D_j
N_S	number of types of follow-up behaviour S_k
$P(H_i)$	probability of occurrence of hazard H_i

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