# Quantifying Redundancy and Robustness of Structures

**Eduardo Cavaco**
Assistant Researcher
UNIC; Universidade Nova de Lisbon, Portugal
*e.cavaco@fct.unl.pt*

Eduardo Cavaco received his civil engineering and Masters degree from Lisbon Technical University. His research work focus on robustness of deteriorating concrete structures.

**Joan R. Casas**
Professor
Tech. University of Catalonia, Barcelona
*joan.ramon.casas@upc.edu*

Received his civil engineering and PhD degree from the Technical University of Catalonia (UPC). He is professor of Bridge Engineering at UPC and Secretary General of IABMAS (International Association for Bridge Maintenance And Safety) and Chairman of IABSE-WC1.

**Luis Neves**
Assistant Professor
UNIC, Universidade Nova de Lisboa, Portugal
*lacn@fct.unl.pt*

Luis Neves, born in 1974, received his civil engineering degree from Lisbon Technical University and his PhD from Minho University. He is a member of IABSE-WC1 and his research interest focus on structural robustness and asset management.

## Summary

The paper presents the different definitions proposed for structural robustness and redundancy, as well as the different measures to quantify them, according to the proposed definition. From this review, it is emphasized that almost all proposed definitions are related to sudden damages (impacts, explosions, ...) and unforeseen events. For this reason, in the present paper a new approach to robustness is defined in terms of the ability of the structure to respond to continuous deteriorating processess as corrosion. The paper also shows how most of the proposed measures of robustness are relative, in the sense that they may help identify which structure is more or less robust than another. However, a target or threshold value that defines the border between what is robust or not, normally does not exist. Finally, an example of application of the new proposed measure of robustness to an existing reinforced concrete bridge, in advanced state of deterioration due to corrosion attack, is presented.

**Keywords**: robustness, redundancy, bridges, corrosion, deterioration, reliability, risk.

## 1. Introduction

The occurrence of catastrophic consequences due to extreme events in buildings and bridges has increased the interest of the engineering community in structural robustness. Robustness first received attention about 40 years ago, just after the partial collapse of the Ronan Point building in London in 1968. After this, many other events, such as the collapses of the Alfred P. Murrah Federal Building in Oklahoma City (1995), the World Trade Center in New York (2001), the Windsor Tower in Madrid (2005) and the I-35W Mississippi River bridge in Minneapolis (2007) among others, have awaken the interest of engineers to this concept. Although the referred collapses had different causes, such as the occurrence of a fire, a terrorist attack, or component failure, among others, the fact is that in all the cases the consequences resulting from collapse were considered disproportionate in relation to the initial damage. This concept became particularly clear specially after the 9/11, as the consequences due to structural failure largely supersede the mere rebuilding costs.

On the other hand, the need for a robustness framework has also derived from the fact that structural design codes are mainly based on the design of structural members individually, neglecting, in most cases, the overall structural performance. Robustness is commonly related, and sometimes misunderstood, with some structural properties such as redundancy, ductility, flexibility

https://doi.org/10.2749/222137813807018971