Design optimization of progressive collapse-resistant structural systems

Dimos C. Charmpis

Department of Civil and Environmental Engineering, University of Cyprus,
75 Kallipoleos Str., P.O. Box 20537, 1678 Nicosia, Cyprus,
charmpis@ucy.ac.cy

ABSTRACT

Structural design optimization has progressed over the last decades to a valuable computational tool, which assists the engineer in making good use of structural material, in order to detect feasible and cost-effective designs satisfying certain pre-specified constraints. Typically, the aim is to minimize the cost (or weight/material volume) of the structure under consideration subject to the satisfaction of behavioural constraints, which are mainly based on provisions imposed by design codes (e.g. the Eurocodes). Such constraints are formulated at the structural component/element level ('local' level) and are expressed as functions e.g. of member stresses. Overall structural safety (both at 'local' and 'global' levels) is pursued with the aid of calibrated 'local' requirements implicitly addressing structural system performance (e.g. 'strong column-weak beam' concept).

A 'global' structural property that needs explicit treatment in the design process is progressive collapse resistance. This property is associated mainly with critical structural systems and refers to their safety against local failure. Progressive collapse is initiated by a local damage or failure (e.g. loss of certain bearing components of the system) that propagates within the structural system by triggering a chain of failures in a 'domino-like' manner until, eventually, partial or full collapse of the system occurs. Progressive collapse is characterized by a final extent of failure in the structural system that is disproportionally large compared to the initial local failure. Insensitivity to local failure is an important structural property, therefore the issue of progressive collapse is actively investigated by researchers and engineers in recent years and some first related design guidelines have already appeared.

The present work presents design optimization approaches for progressive collapse-resistant structures. The aim of the optimization algorithm employed is to minimize the structural weight subject to 'local' constraints involving standard Eurocode member checks, as well as to 'global' constraints explicitly treating structural system performance and progressive collapse resistance. The 'global' constraints focus on the system resistance not only of an intact structure, as is often the case in optimization applications, but also of the same structure suffering assumed local failure. The term 'assumed local failure' refers to failure scenarios, which are defined by notionally removing certain key-members of the structure. Such failure scenarios are used to direct the optimizer towards identifying structural designs, which provide adequate alternate load paths (and therefore sufficient progressive collapse resistance) when local failure occurs in the structure. The optimization applications presented include cases with deterministic constraints, as well as cases with reliability-based constraints accounting for randomness in structural properties and loads.

Of particular importance is also the investigation of the variation in the structural cost when progressive collapse resistance constraints are incorporated in the design process. By enforcing the satisfaction of additional design requirements on system resistance and safety against local failure, the structural cost is inevitably increased due to the need for extra material. This increase is quantitatively explored by detecting optimal designs for the constraints imposed in each case considered. The optimization results reveal how progressive collapse resistance can be achieved with minimum structural cost.

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