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Load carrying capacity of systems within a global safety perspective. Part II. Attractor/basin integrity under dynamic excitations

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ABSTRACT

The effects of the dynamic excitation on the load carrying capacity of mechanical systems are investigated with reference to the archetypal model addressed in Part I, which permits to highlight the main ideas without spurious mechanical complexities. First, the effects of the excitation on periodic solutions are analyzed, focusing on bifurcations entailing their disappearance and playing the role of Koiter critical thresholds. Then, attractor robustness (i.e., large magnitude of the safe basin) is shown to be necessary but not sufficient to have global safety under dynamic excitation. In fact, the excitation strongly modifies the topology of the safe basins, and a dynamical integrity perspective accounting for the magnitude of the solely *compact* part of the safe basin must be considered. By means of extensive numerical simulations, robustness/erosion profiles of dynamic solutions/basins for varying axial load and dynamic amplitude are built, respectively. These curves permit to appreciate the practical reduction of system load carrying capacity and, upon choosing the value of residual integrity admissible for engineering design, the Thompson practical stability. Dwelling on the effects of the interaction between axial load and lateral dynamic excitation, this paper supports and, indeed, extends the conclusions of the companion one, highlighting the fundamental role played by global dynamics as regards a reliable estimation of the actual load carrying capacity of mechanical systems.

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1. Introduction

In the companion paper [1] we put the main contributions to the determination of the practical load carrying capacity of structures into a historical perspective, with the aim of showing how it is reduced by the loss of robustness of stable equilibria. In summary, we have recalled the works of Euler [2], who discovered branching (pitchfork and transcritical) bifurcations in elastic systems (talking in modern language, of course); of Koiter [3], who discovered the structural instability of those bifurcations, i.e. how model imperfections can lower the critical load or, equivalently, how pitchfork and transcritical (branching) bifurcations become saddle-node (snap) bifurcations; and, finally, of Thompson [4–6], who realized that classical stability, based on infinitesimal perturbations of initial conditions, is not enough for practical purposes.

We have mainly focused on Thompson's contribution, which is the last one and which, in the authors' opinion, is the decisive step toward the final understanding of the problem. Implicitly referring to a *global safety* approach, Thompson had a double intuition:

(i) If the basin of attraction of a given attractor is not 'large' enough there will be no hope to observe it in real world applications. This can be reformulated by saying that classical local stability refers to *infinitesimal* changes in initial conditions, while global safety refers to *finite* changes in initial conditions. Thus, local stability must be complemented by robustness towards variations of initial conditions. In other words, safe basins must have a large enough *magnitude.*
(ii) Basins of attraction must be topologically 'uncorrupted,' or dynamically *integer*, i.e., non-fractal. More precisely, for a reliable estimation of the load carrying capacity we have to thrust only on the compact part of the safe basin, ruling out fractality, squeezing and other topological effects which reduce safety without appreciably affecting the magnitude of the safe basin.

Of course, the overall transition from a local stability perspective to a global safety concept has also major implications as regards the involved kinds of global bifurcation events playing a

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