12.3 –
Integrity as a Novel Paradigm for Safe/Aware Design

Giuseppe Rega

Department of Structural and Geotechnical Engineering
Sapienza University of Rome, Italy
Giuseppe.Rega@uniroma1.it

Coworker: S. Lenci

DAY	TIME	LECTURE
Monday 05/11	14.00 -14.45	Historical Framework - A Global Dynamics Perspective in the Nonlinear Analysis of Systems/Structures
	15.00 -15.45	Achieving Load Carrying Capacity: Theoretical and Practical Stability
	16.00 -16.45	Dynamical Integrity: Concepts and Tools_1
Wednesday 07/11	14.00 -14.45	Dynamical Integrity: Concepts and Tools_2
	15.00 -15.45	Global Dynamics of Engineering Systems
	16.00 -16.45	Dynamical integrity: Interpreting/Predicting Experimental Response
Monday 12/11	14.00 -14.45	Techniques for Control of Chaos
	15.00 -15.45	A Unified Framework for Controlling Global Dynamics
	16.00 -16.45	Response of Uncontrolled/Controlled Systems in Macro- and Micro-mechanics
Wednesday 14/11	14.00 -14.45	A Noncontact AFM: (a) Nonlinear Dynamics and Feedback Control (b) Global Effects of a Locally-tailored Control
	15.00 -15.45	Exploiting Global Dynamics to Control AFM Robustness
	16.00 -16.45	**Dynamical Integrity as a Novel Paradigm for Safe/Aware Design**

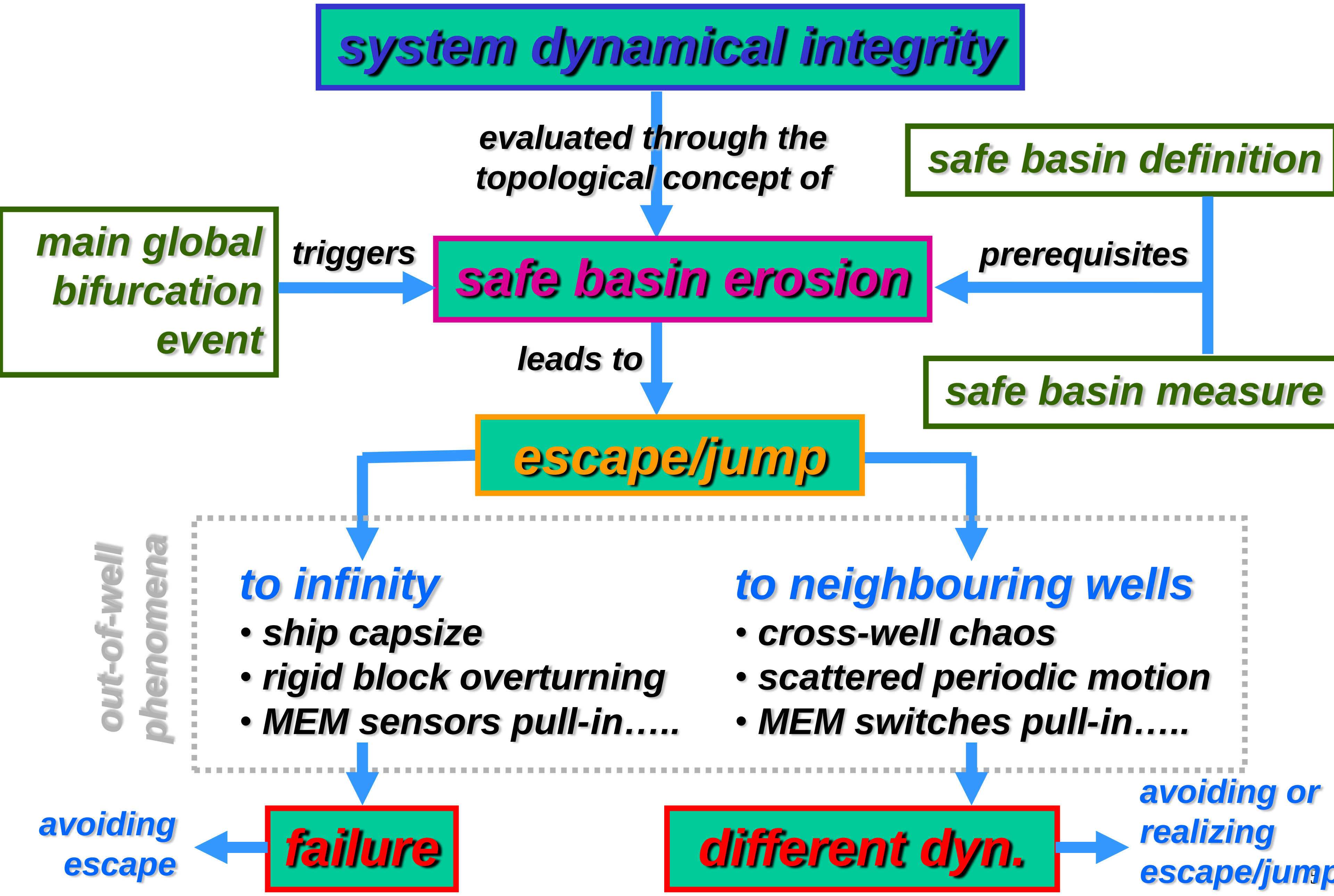
From a local to global perspective

- **Stability:** a **local** property of the attractor
- **Dynamic integrity:** a **global** characterization of system behaviour

from **local** to **global** dynamics

- more difficult (demanding theoretical concepts, heavy numerical simulations, involved topological description)
- but …..more information, more knowledge of the system, more usefulness

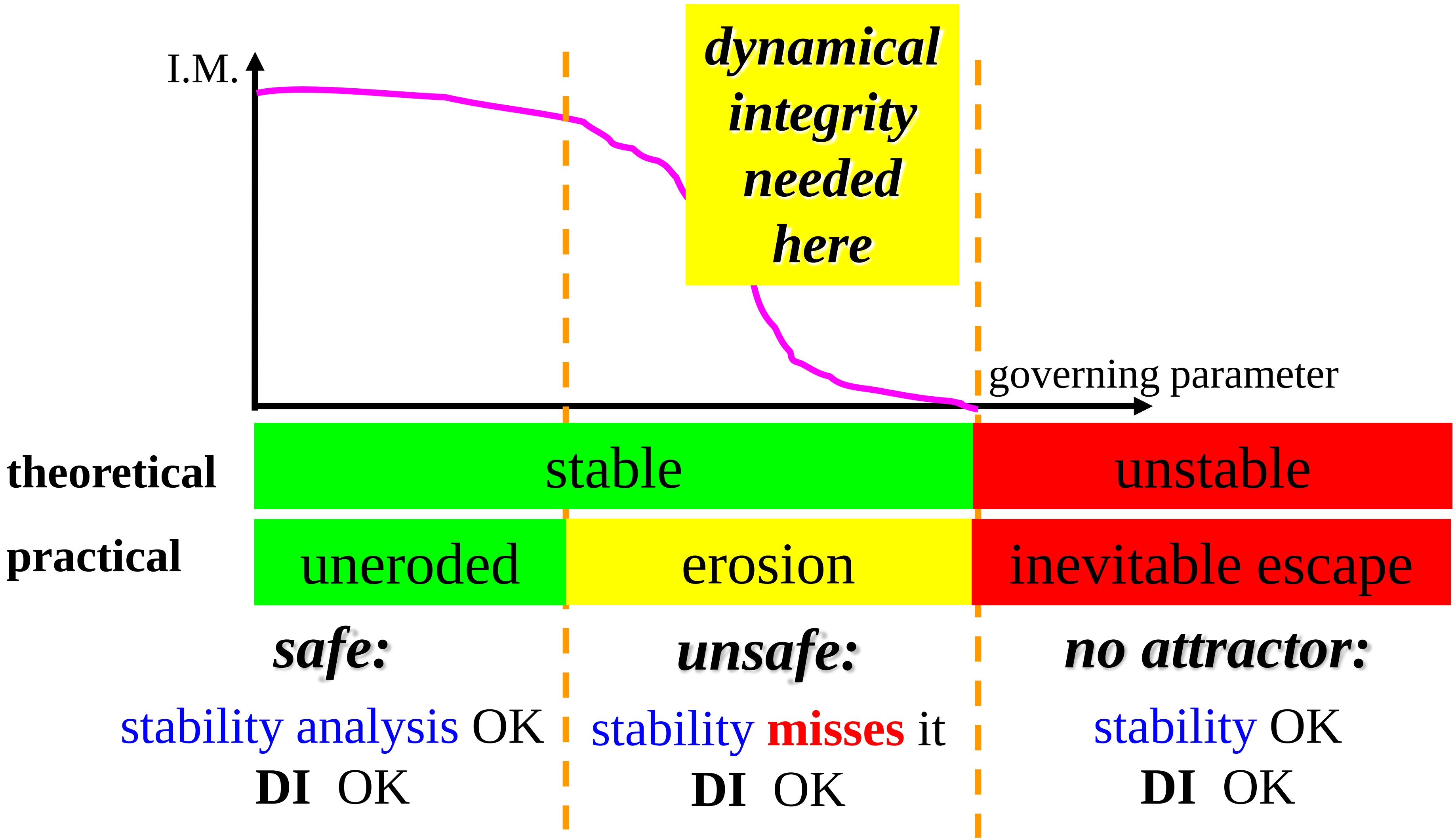
System Integrity (Erosion) Scenario



Lyapunov Stability versus **Dynamical Integrity**

final outcome – **escape** – entailing **loss of stability**;

intermediate features – **erosion** – entailing **loss of robustness**



DI as a criterion for load carrying capacity (1)

Non-small imperfections of the real world to be considered by referring to perturbations in **phase space** and in **control space**

---

1. Initial conditions in phase space:

may directly **drive the response out of safe basin** towards a different, more robust, attractor (bounded or unbounded)

high DI = attractor in **large and compact** basin

low DI = attractor in **small and/or eroded** basin

In terms of **practical stability** (at given values of control parameters):

- fixing the **minimum acceptable value of DI**, i.e. the **maximum allowed change of initial conditions** which can be **safely supported by the system** w.r.t. the **desired static or dynamical solution**

DI as a criterion for load carrying capacity (2)

2. System parameters in control space:

may indirectly **prevent from actually realizing the desired response**, owing to the reduction of DI entailed by also ***small*** parameter variations

(reduction may **not involve** / **involve** compactness)

robust attractor = **smooth** **reduction of basin size** / **basin erosion**

unsafe attractor = **sudden** **reduction of basin size** / **basin erosion**

In view of system **load carrying capacity**:

- verifying whether the **minimum acceptable value of DI** – which governs the practical stability of a solution/attractor – is actually **kept** when **varying other control parameters**, in such a way to guarantee a **satisfactorily uniform system safety**

DI as a criterion for load carrying capacity (3)

System load carrying capacity robustly achieved if:

(i) attractor is ***practically stable***, namely it has a ***non-residually integer*** (i.e., suitably large and compact) ***basin***, which allows to sustain effects of *finite* changes in ***initial conditions***

(ii) such a non-residually integer basin is ***robust*** with respect to also *small* changes in ***control parameters values***

- This corresponds to fixing a '**safety factor**' w.r.t. unwanted (static or dynamical) events, under given values of other control parameters
- But the context is now totally new because of **clear identification, comprehensive knowledge, and controllability** of the factors which govern the **system behavior**, with the beneficial consequence of **exploiting the system resources in a much more effective way**

...... but **Global Dynamics still currently overlooked** !!

- Meaningfully affects **discrepancy between theoretical and practical stability** limits always occurring due to real world disturbances, which **does not allow to fully exploit stability ranges**

- One **main constraint in the operational life of engineering systems**, presently faced by the technical community via the introduction of **too large safety factors in the design stage**

- An **approach** to system safety which **overlooks the dynamics** behind the problem, and **does not provide** the designer with **a capability to overcome it** and **go beyond the practical barriers**

Global dynamics for safe/aware design

In contrast:

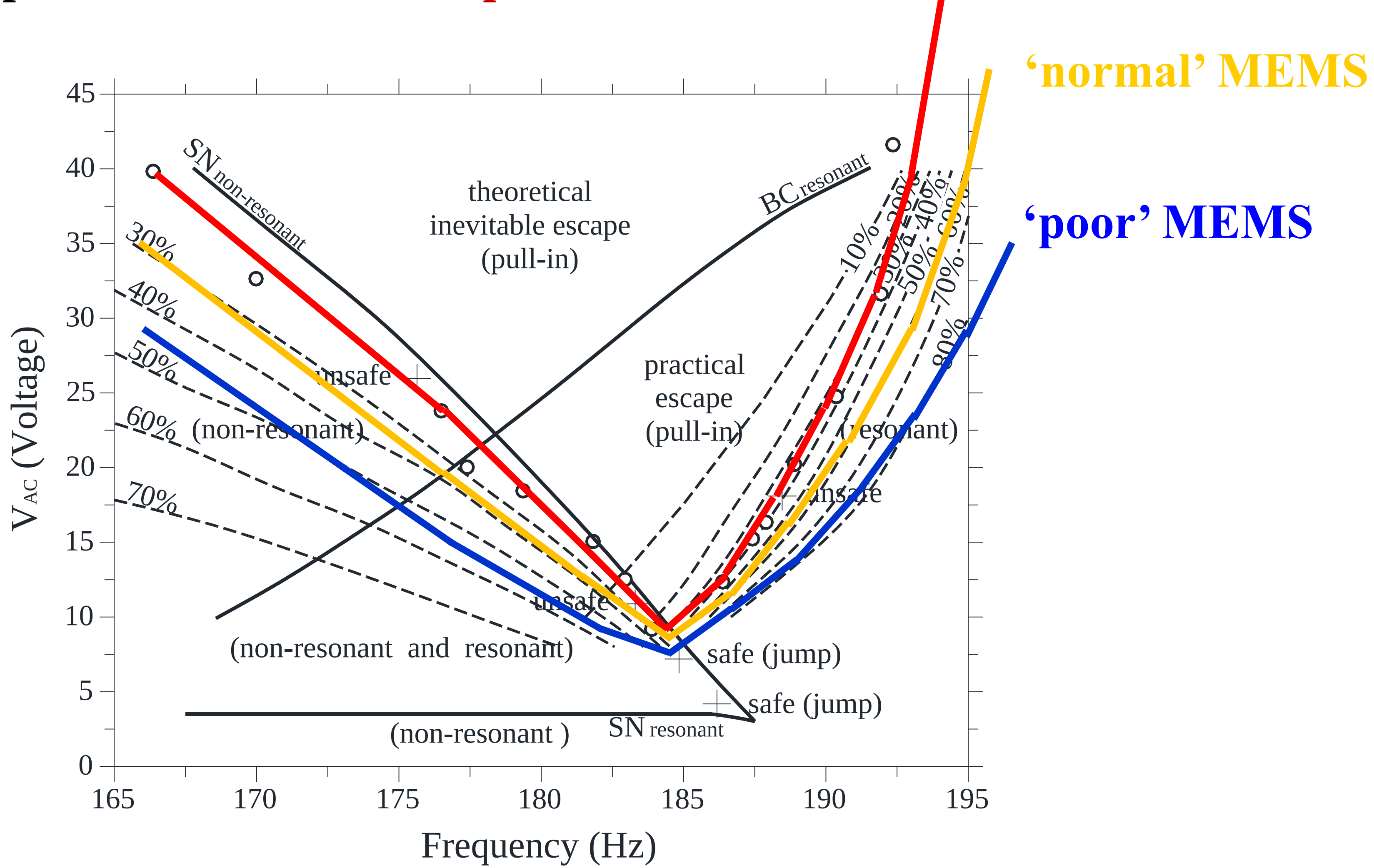
- **DI allows** us to understand/explain the matter, giving hints towards a completely different**, knowledge-based criterion for system design**, where the researcher/engineer is provided with the **level of perturbations the system can support**
- **Integrity charts** are useful **guidelines for aware/safe design** as regards predicting boundaries of **disappearance** of attractors and understanding how **perturbations, imperfections** and even **control** may **enlarge/reduce** their range of **practical existence**

Disturbances the structure is **expected** to undergo during its life are to be assessed by also referring to the **uncertainty quantification** issue, and **compared with the admissible** ones provided by **DI analysis**

Integrity charts for safe/aware design (1)

- **MEMS device:**

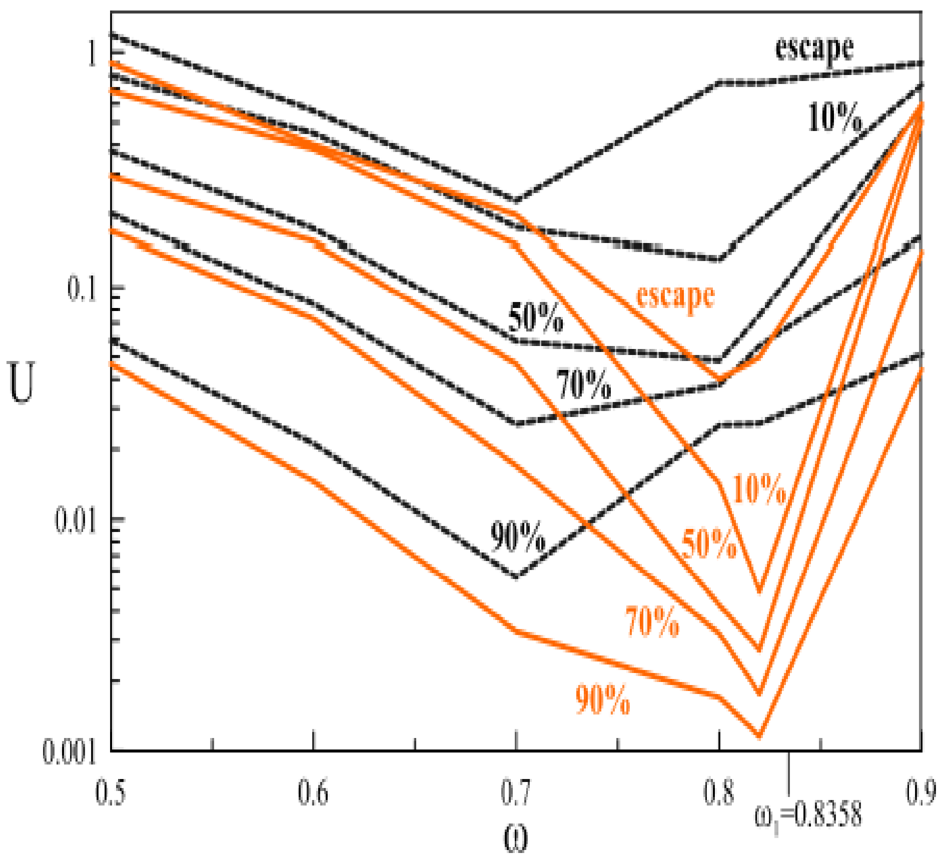
practical threshold for pull-in



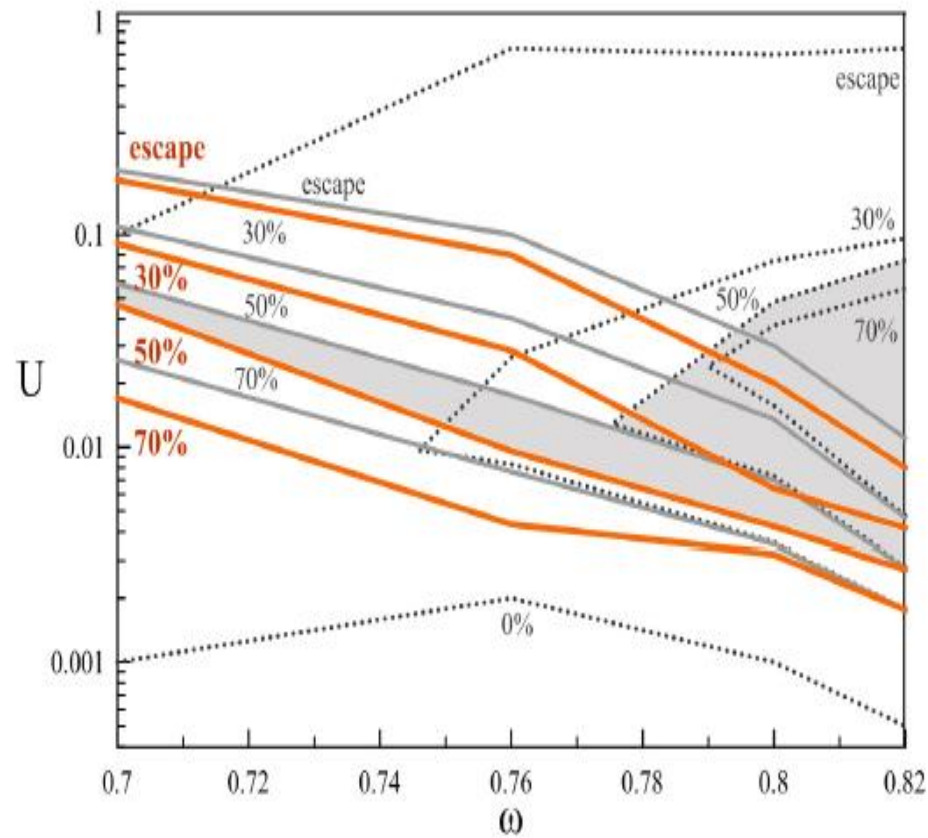
Integrity charts for safe/aware design (3)

NONCONTACT AFM with LOCALLY-TAYLORED CONTROL

severe worsening of practical stability around resonance frequency



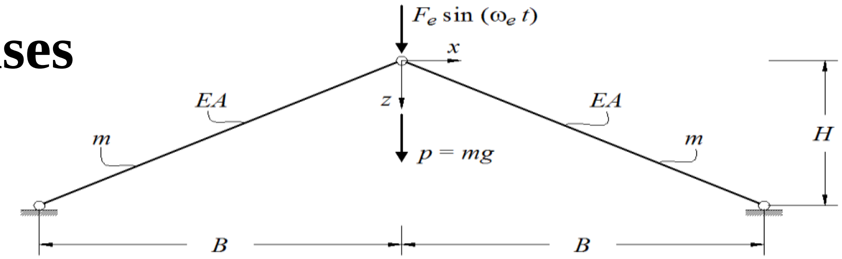
loss of stability for given (50%) iso-integrity curves



Systems with uncertainty: Basins of attraction

Elastic von Mises truss model

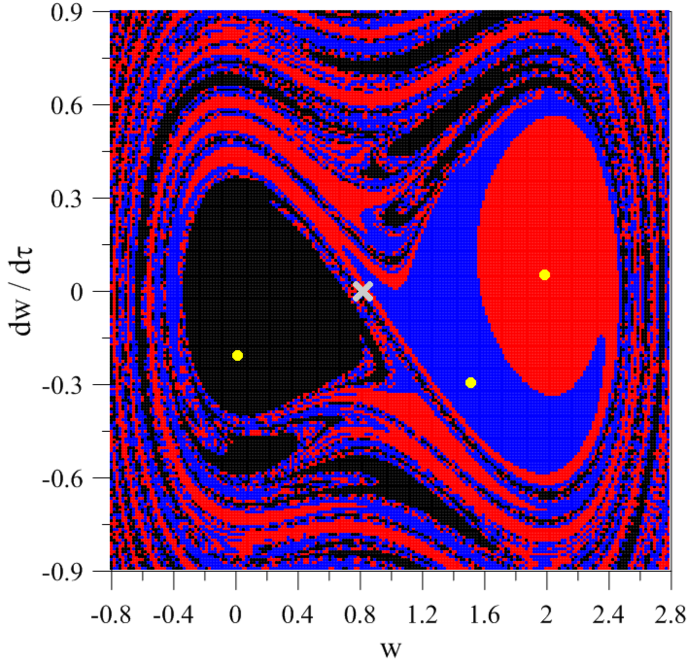
(Orlando et al, 2018)



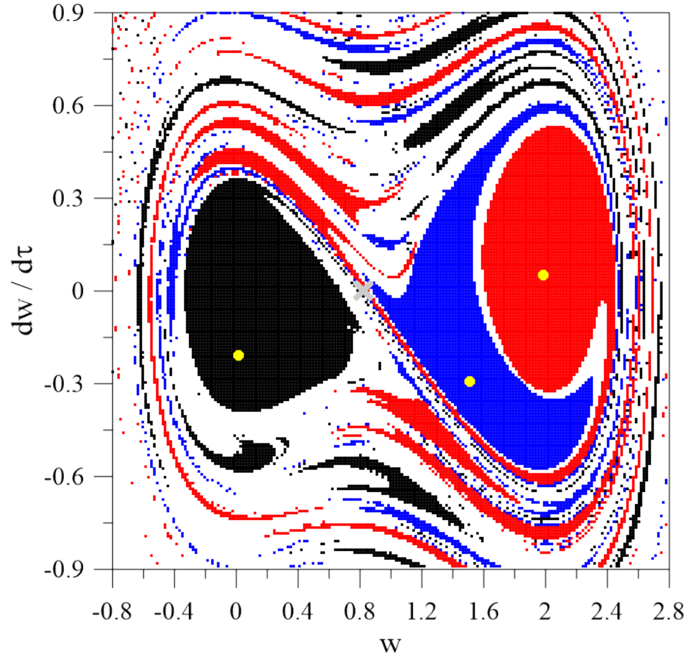
$$Q = F_e \sin(\omega_e t) + G(t; F_e, \omega_e)$$

load random noise

Deterministic



Non-deterministic

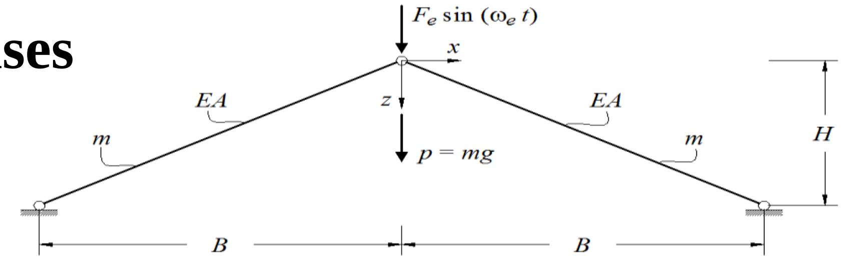


- White region: initial conditions for which the final outcome is uncertain
- **Noise influence on the compact region surrounding each attractor not significant**

Systems with uncertainty: Integrity profile

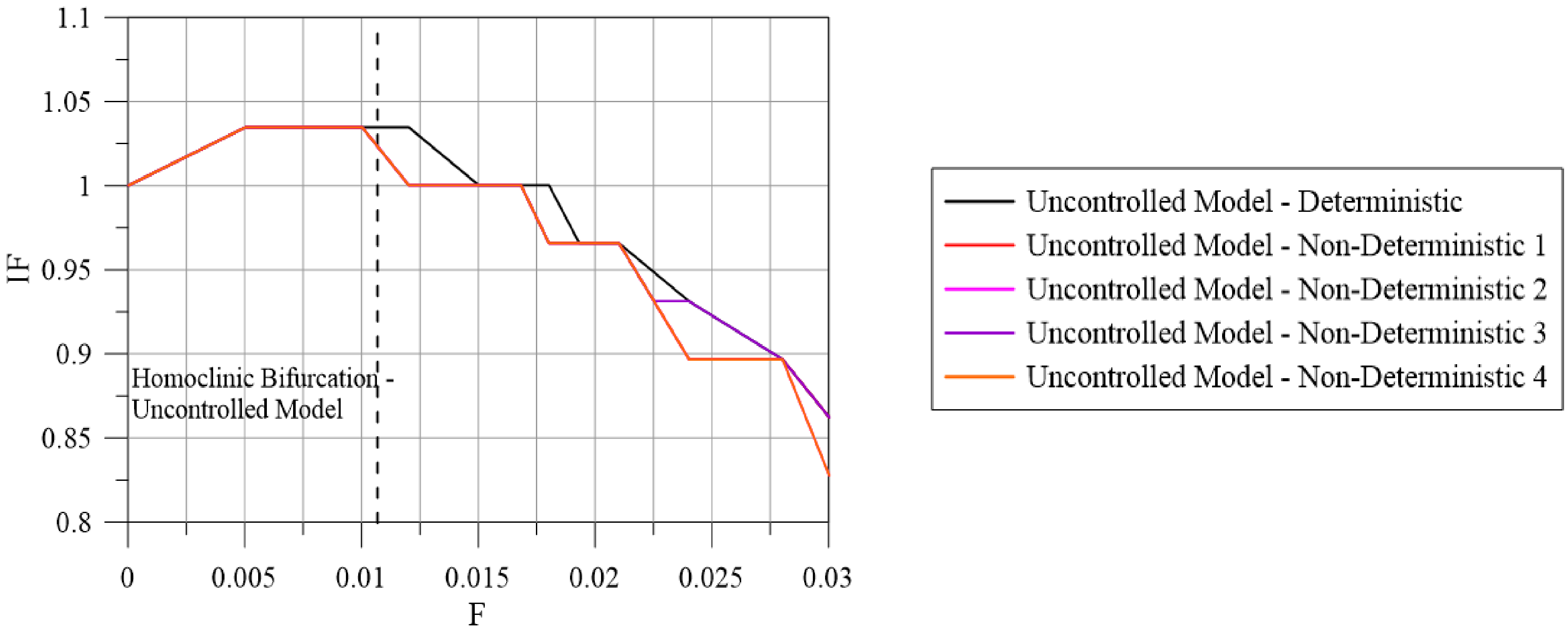
Elastic von Mises truss model

(Orlando et al, 2018)



$$Q = F_e \sin(\omega_e t) + \mathrm{G}(t; F_e, \omega_e)$$

load random noise

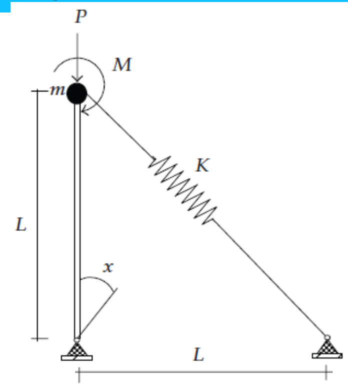


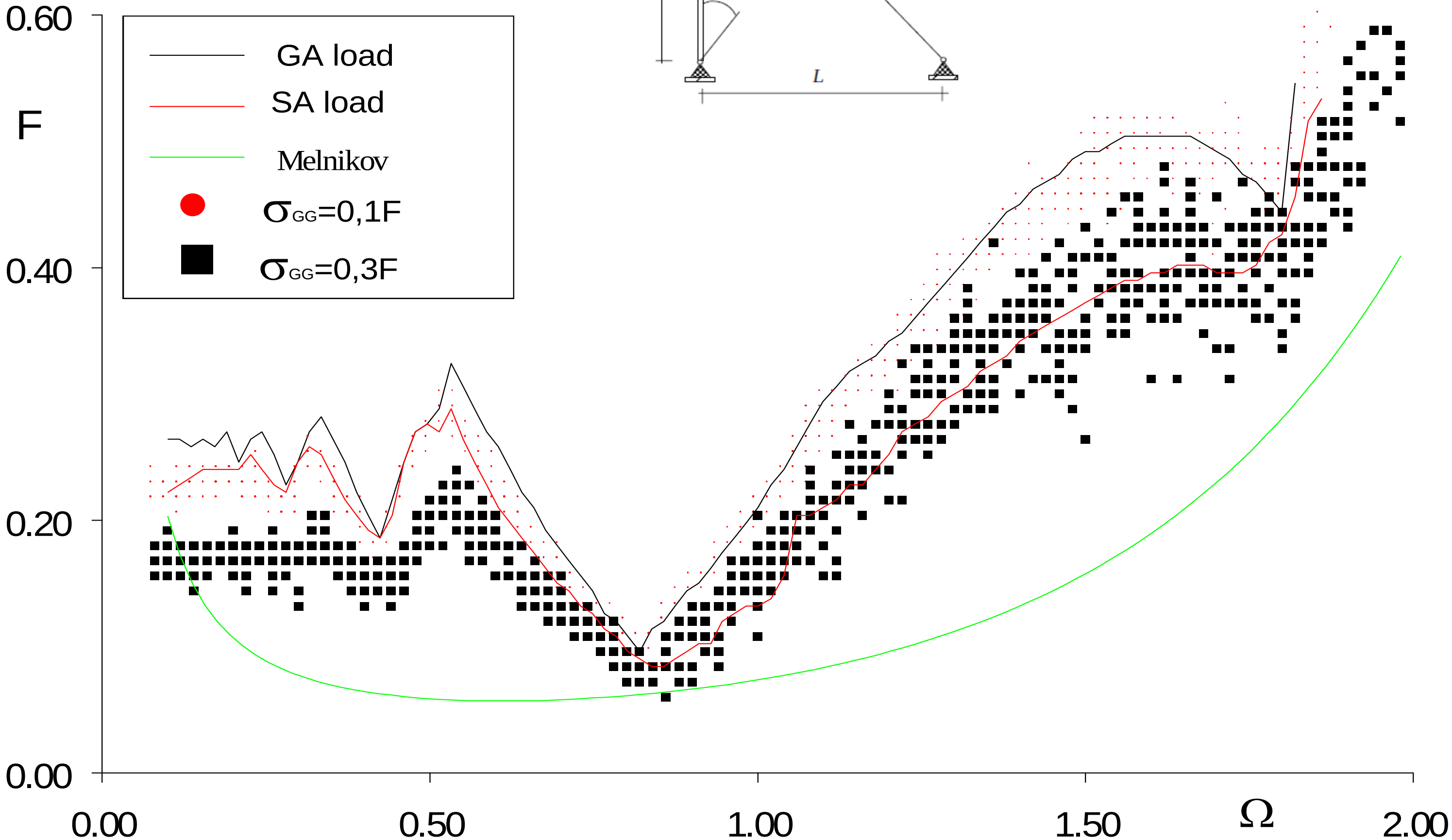
- **The random noise does not significantly influence the IF, since the IF only takes into consideration the compact region around the attractor**

Systems with uncertainty: Escape in integrity chart

Structure Liable to
Asymmetric Postbuckling Behavior

(Goncalves, Santee, 2008)





Scatter of dynamic buckling load:

Within the (unacceptable !!) low range of residual integrity

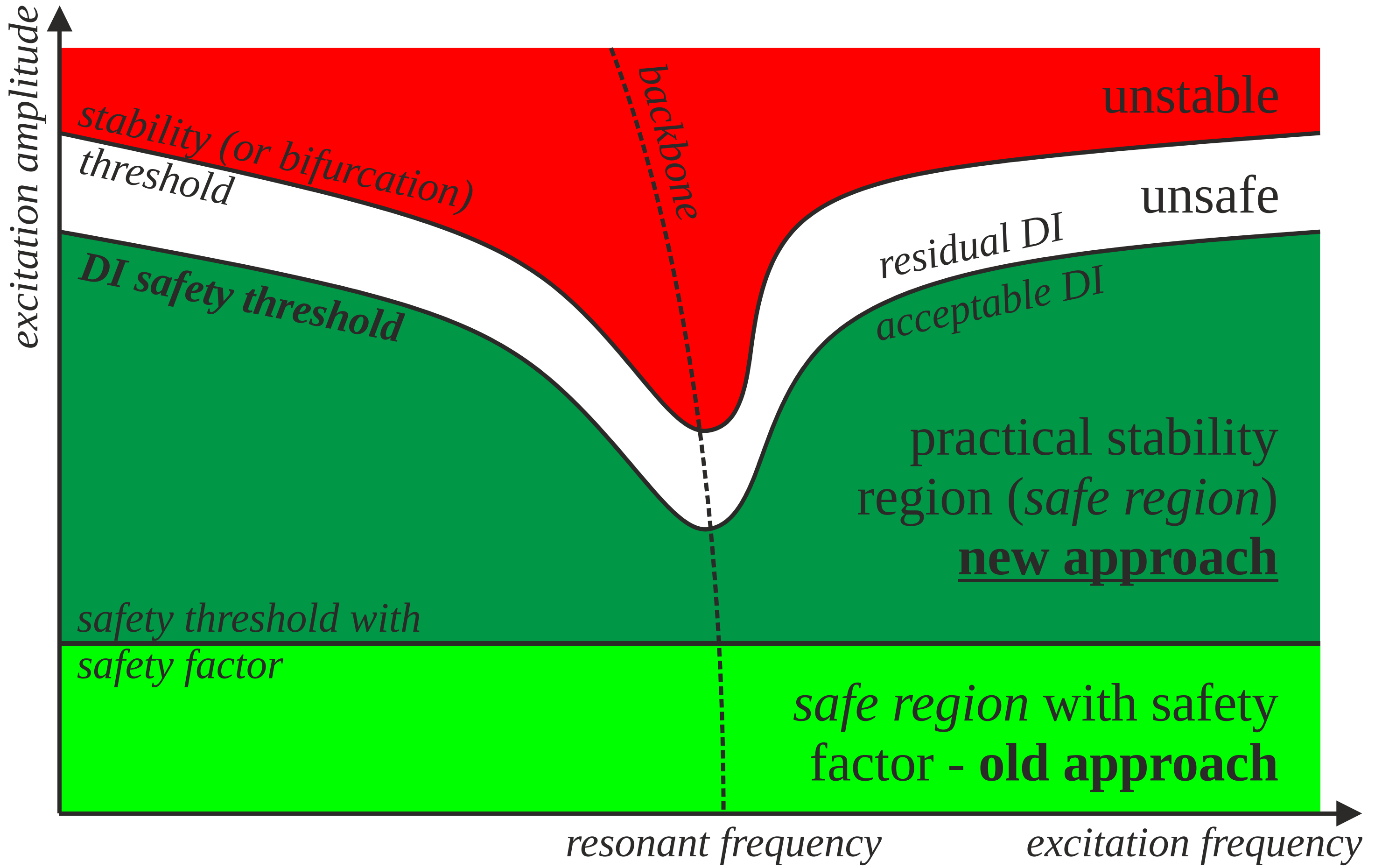
Dynamic integrity for engineering design (1)

- **Abandoning** the merely **local perspective** traditionally assumed in analysis/design, and **moving to** a **global** one where the whole system dynamical behaviour is considered, even if interested in only a small (but finite) neighbourhood of solution

- A **paramount enhancement**, while conceptually simple, with tremendous implications for systems with **large number of d.o.f.** → **strong research effort**
  - theoretically addressing **MDOF global bifurcations** and their effects
  - developing numerical tools able to perform **MDOF global analysis**

1. A **change of perspective** in **analysis/control** of mechanical/structural systems,
2. A great potential to enhance **performance, effectiveness, reliability** and **safety** of systems via **novel design criteria**

Dynamic integrity for engineering design (2)



Safe region associated with an **acceptable residual dynamical integrity**:

- **larger than** that provided by **conventional safety factors**
- **does not overlook** specific **dangerous** situations (**resonances**)
- **consciously exploits** the whole safe region in parameters space, defining a **safe – *but not too conservative* – lower bound for design**

Dynamic integrity for engineering design (3)

- **Overcoming conventional** design approach through **safety factor**
- **Establishing a new design paradigm** in which system reliability analysis is performed with also **stochastic arguments** needed to **determine the average amplitude of expected perturbations**, to be **less than the admissible ones** furnished by **DI**
- **DI** as a way of **dealing with imperfections in a substantially deterministic framework**, owed to the increased level of knowledge and understanding of system behavior that it provides
- Affecting the **awareness of practitioners of mechanics** about the **importance of global analysis** for an **improved and modern** use of systems and structures in **engineering**

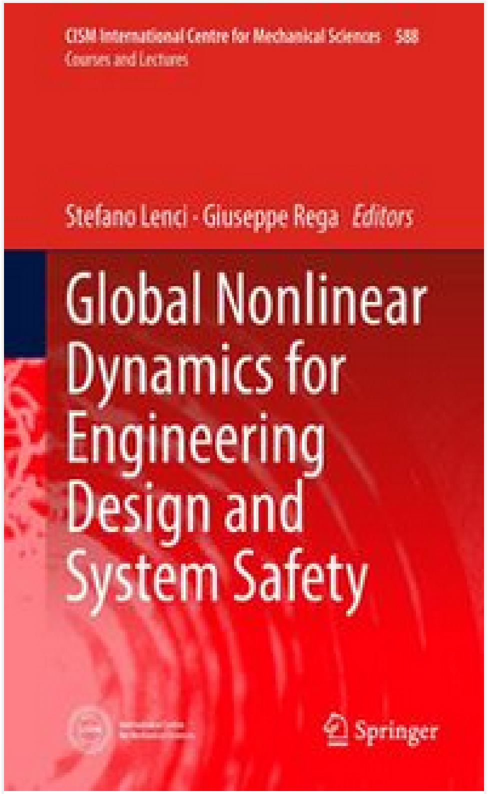
DI for Engineering Design (4)

In a longer term perspective:

- ***Paving the way*** to ***technical recommendations*** fully **accounting** and possibly **exploiting nonlinear and global behavior of systems**, within a ***new generation of Standards and Code Regulations***

- ***Widening*** the range of ***applicability and reliability*** of engineering dynamical systems

- Improving **aware use of existing structures/devices** in **larger ranges** of parameters, and **design of new structures/devices**, with expected ***technological improvements*** (performance, cost reduction, novel conception/development)



BOOK

Global Nonlinear Dynamics for Engineering Design and System Safety - 2019

Editors: Prof. Stefano Lenci · Prof. Giuseppe Rega

This is the first book which exploits concepts and tools of global nonlinear dynamics for bridging the gap between theoretical and practical stability of systems/structures, and for possibly enhancing the engineering design in ma

Italy

Stefano Lenci
(Ancona)

Valeria Settimi
(Sapienza)

Eduardo Saetta
(Sapienza)

Laura Ruzziconi
(eCampus)

U.K.

- Michael Thompson (Cambridge)

Brazil

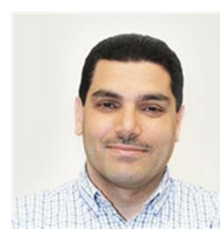
- Paulo Goncalves (PUC-Rio)
- Frederico Silva (Goyania)
- Diego Orlando (UERJ)

Israel

- Oded Gottlieb (Technion)

USA – Saudi Arabia

- Mohammed Younis (Binghamton; KAUST)



Thank you very much for your attention !!