香港科技大學
THE HONG KONG
UNIVERSITY OF SCIENCE
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土木及環境工程學系
DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

SEMINAR

FRACTURE AND COMPLEXITY: SCALE EFFECTS ON THE DUCTILE-TO-BRITTLE TRANSITION IN PLAIN AND REINFORCED MATERIALS

Speaker

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Biography

Alberto Carpinteri received his Doctoral Degrees in Nuclear Engineering cum Laude (1976) and in Mathematics cum Laude (1981) from the University of Bologna (Italy). After two years at the Consiglio Nazionale delle Ricerche, he was appointed Assistant Professor at the University of Bologna in 1980.

He moved to the Politecnico di Torino in 1986 as a full professor, and became the Chair Professor of Solid and Structural Mechanics, as well as the Director of the Fracture Mechanics Laboratory. During this period, he has held different positions of responsibility, among which: Head of the Department of Structural Engineering (1989-1995), and Founding Director of the Post-graduate School of Structural Engineering (1990-2014). After his retirement from Politecnico di Torino in 2023, he became Chair Professor of Structural mechanics at Shantou University, Shantou-Guangdong, China.

Prof. Carpinteri was a Visiting Scientist at Lehigh University, Pennsylvania, USA (1982-1983), and was appointed as a Fellow of several Academies and Professional Institutions, among which: the European Academy of Sciences (2009-), the International Academy of Engineering (2010-), the Turin Academy of Sciences (2005-), the American Society of Civil Engineers (1995-). He was the Head of the Engineering Division in the European Academy of Sciences (2016-2023).

Prof. Carpinteri was the President of several Scientific Associations and Research Institutions: the International Congress on Fracture, ICF (2009-2013), the European Structural Integrity Society, ESIS (2002-2006), the International Association of Fracture Mechanics for Concrete and Concrete Structures, IA-FraMCoS (2004-2007), the Italian Group of Fracture, IGF (1998-2005), the National Research Institute of Metrology, INRIM (2011-2013).

Prof. Carpinteri was appointed as a Member of the Congress Committee of the International Union of Theoretical and Applied Mechanics, IUTAM (2004-2012), a Member of the Executive Board of the Society for Experimental Mechanics, SEM (2012-2014), a Member of the Editorial Board of eleven international journals, the Editor-in-Chief of the International Journal “Meccanica” (Springer, IF=1.949), the Honorary Editor of the International Journal “Smart Construction & Sustainable Cities”. He is the author or editor of over 1,000 publications, of which more than 500 are papers in refereed international journals (Google-Scholar H-Index=90, more than 32,000 Citations; Scopus H-Index=66, more than 16,000 Citations) and 58 are books or journal special issues.

Prof. Carpinteri received numerous international Honours and Awards: the Robert L'Hermite Medal from RILEM (1982), the Griffith Medal from ESIS (2008), the Swedlow Memorial Lecture Award from ASTM (2011), the Inaugural Paul Paris Gold Medal from ICF (2013), the Doctorate Honoris Causa in Engineering from the Russian Academy of Sciences (2016), the Frocht Award from SEM (2017), the Honorary Professorship from Tianjin University (2017), the Founding Fellowship from the Indian Structural Integrity Society (2018), the “Pearl River” Professorship from Guangdong Province, Shantou University (2019), the Giuliano Preparata Medal from the International Society for Condensed Matter Nuclear Science (2022), and the George Irwin Medal from ASTM (2023).

26 March 2024
Tuesday

3:30 pm - 4:30 pm

Civil Engineering
Conference Room
Room 3574 (Lift 27/28)
HKUST

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Abstract

Brittle solids often show an unstable structural behaviour represented by a negative slope in the load-displacement softening response. This means that the load must decrease to obtain a stable crack propagation. In extremely brittle cases, crack propagation occurs suddenly with a catastrophic drop in the load carrying capacity, and the load-displacement softening branch assumes a virtual positive slope. If the loading process is controlled by the displacement, the curve presents a discontinuity, and the representative point drops onto the lower branch with negative slope. In this case, both load and displacement must decrease to obtain a controlled crack propagation. Such a phenomenon, the so-called snap-back instability, was deeply investigated with reference to crack growth in quasi-brittle materials (Carpinteri, 1984; 1989). In the framework of Linear Elastic Fracture Mechanics, the cusp catastrophe represents the classical Griffith instability for very brittle systems.

Part I deals with Nonlinear Fracture Mechanics models (in particular, the Cohesive Crack Model to describe strain-localization both in tension and in compression) and their peculiar consequences: fold catastrophes (post-peak strain-softening and snap-through instabilities) or cusp catastrophes (snap-back instabilities) in plain or reinforced structural elements. How can a relatively simple nonlinear constitutive law, which is scale-independent, generate a size-scale dependent ductile-to-brittle transition? Constant reference is made to Dimensional Analysis and to the definition of suitable nondimensional brittleness numbers that govern the transition. These numbers can be defined in different ways, according to the selected theoretical model. The simplest way is that of directly comparing critical LEFM conditions and plastic limit analysis results. This is an equivalent way –although more effective for finite-sized cracked plates– to describe the ductile-to-brittle size-scale transition, if compared to the traditional evaluation of the crack tip plastic-zone extension in an infinite plate. In extremely brittle cases, the plastic zone or process zone tends to disappear and the cusp catastrophe conditions prevail over the strain-softening ones and tend to coincide with the LEFM critical conditions in the case of initially cracked plates.

Part II deals with the unstable mechanical behaviour of fibre-reinforced materials with a linear elastic matrix and the analogy with weakened materials.

Let us consider a tension test specimen where reinforcing fibres are embedded in the matrix, as illustrated in Figure 1a. In addition, let us consider the case of a specimen containing a distribution of collinear micro-cracks, as illustrated in Figure 1b. A load P is applied, opening the faces of an edge crack that propagates through the fibres or the collinear micro-cracks. Propagation will occur alternately within the matrix and through the heterogeneities (Carpinteri and Accornero, 2018; 2019). The loading process is controlled by the monotonically increasing crack length.

In both cases, the structural response presents a discrete number of snap-back instabilities with related peaks and valleys (Fig.1c). After each single peak, the crack starts growing in the matrix. Thus, the descending branches after peaks describe the crack growth between a fibre and the next, or between a micro-crack tip and the next. The crack arrests at the minimum of each valley, which represents the achievement of the next fibre or crack tip (Fig. 1a,b). The analogy between strengthened and weakened zones consists therefore in a multiple snap-back mechanical response, where descending branches of propagating cracks alternate with ascending (linear) branches of arrested cracks.

References

Carpinteri, A. (1984) "Interpretation of the Griffith instability as a bifurcation of the global equilibrium", Proceedings of the N.A.T.O. Advanced Research Workshop on Application of Fracture Mechanics to Cementitious Composites, 287-316.

Carpinteri, A. (1989) "Cusp catastrophe interpretation of fracture instability", Journal of the Mechanics and Physics of Solids, 37:567-582.

Carpinteri A., Accornero F. (2018) "Multiple snap-back instabilities in progressive microcracking coalescence", Engineering Fracture Mechanics, 187:272-281.

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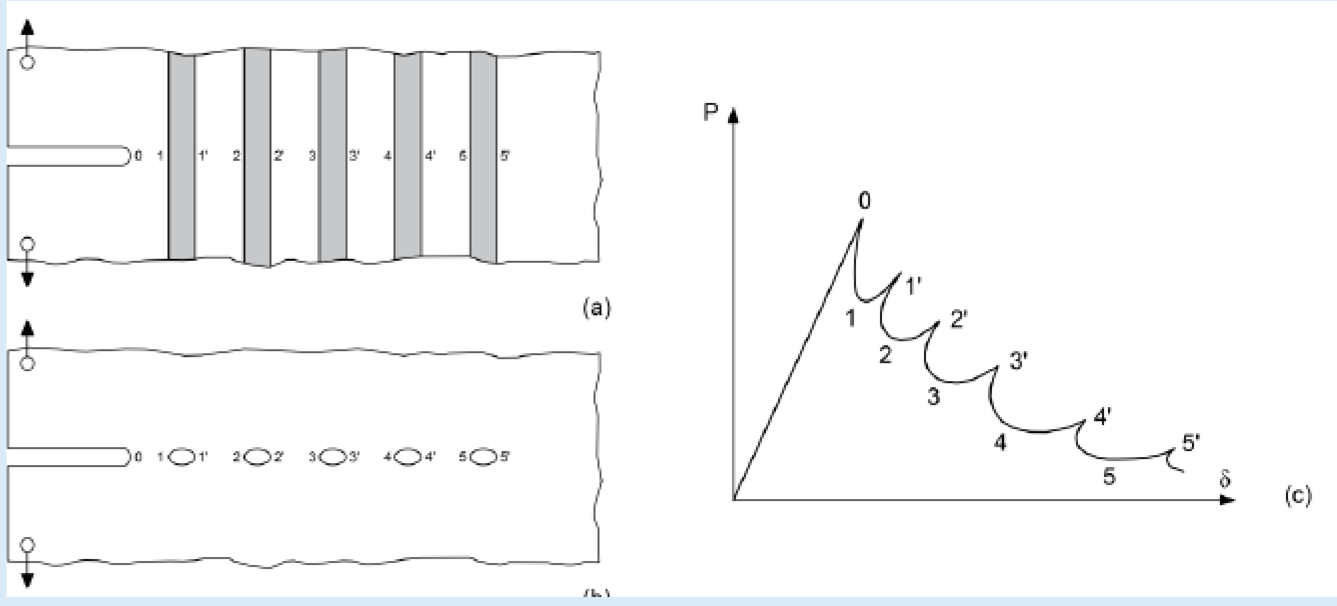

Figure 1. Regular distribution of reinforcing fibers in a brittle-matrix specimen with an edge crack (a); Brittle specimen with an edge crack and collinear micro-cracks (b); Load-displacement response diagram (c).