1

2

Cambridge University Press 978-1-107-15170-3 — Probabilistic Mechanics of Quasibrittle Structures Zdenek P. Bazant , Jia-Liang Le Table of Contents <u>More Information</u>

Contents

Fore	word	page
Preja	ace	
Intro	duction	
1.1	The Problem of Tail of Probability Distribution	
1.2	History in Brief	
	1.2.1 Classical History	
	1.2.2 Recent Developments	
1.3	Safety Specifications in Concrete Design Codes and Embedded	
	Obstacles to Probabilistic Analysis	
1.4	Importance of Size Effect for Strength Statistics	
1.5	Power-Law Scaling in the Absence of Characteristic Length	
	1.5.1 Nominal Strength of Structure and Size Effect	
1.6	Statistical and Deterministic Size Effects	
1.7	Simple Models for Deterministic Size Effects	
	1.7.1 Type 1 Size Effect for Failures at Crack Initiation	
	1.7.2 Type 2 Size Effect for Structures with Deep Cracks	
	or Notches	
1.8	Probability Distributions of Strength of Ductile and Brittle	
	Structures	
Revie	ew of Classical Statistical Theory of Structural Strength and Structural	
Safe	ty, and of Statistics Fundamentals	
2.1	Weakest-Link Model	
2.2	Weibull Theory	
2.3	Scaling of Weibull Theory and Pure Statistical Size Effect	
2.4	Equivalent Number of Elements	
2.5	Stability Postulate of Extreme Value Statistics	
2.6	Distributions Ensuing from Stability Postulate	
2.7	Central Limit Theorem and Strength Distribution of	
	Ductile Structures	
2.8	Failure Probability When Both the Strength and Load Are Random,	
	and Freudenthal Integral	

viii	Contents				
3	Revie Quasi	w of Fracture Mechanics and Deterministic Size Effect in ibrittle Structures	35		
	2 1	Linger Electic Freeture Machanics	25		
	3.1	Cohesive Crack Model	33		
	3.3	Crack Band Model	40		
	3.4	Nonlocal Damage Models and Lattice-Particle Model	44		
	3.5	Overcoming Instability of Tests of Post-Peak Softening			
		of Fiber–Polymer Composites	46		
	3.6	Dimensional Analysis of Asymptotic Size Effects	47		
	3.7	Second-Order Asymptotic Properties of Cohesive Crack or Crack			
		Band Models	50		
	3.8	Types of Size Effect Distinguished by Asymptotic Properties	51		
	3.9	Derivation of Quasibrittle Deterministic Size Effect from			
		Equivalent LEFM	52		
		3.9.1 Type 2 Size Effect	53		
	3 10	3.9.2 Type I Size Effect Nonlocal Waibull Theory for Mean Personase	54		
	3.10	Combined Energetic-Statistical Size Effect Law and Bridging of	50		
	5.11	Type 1 and 2 Size Effects	57		
4	Failur	re Statistics of Nanoscale Structures	59		
	4.1	Background of Modeling of Nanoscale Fracture	59		
	4.2	Stress-Driven Fracture of Nanoscale Structures	60		
	4.3	Probability Distribution of Fatigue Strength at Nanoscale	65		
	4.4	Random Walk Aspect of Failure of Nanoscale Structures	66		
5	Nano	-Macroscale Bridging of Probability Distributions of Static	- 1		
	and F	atigue Strengths	/1		
	5.1	Chain Model	72		
	5.2	Fiber-Bundle Model for Static Strength	73		
		5.2.1 Brittle Bundle	74		
		5.2.2 Plastic Bundle	79		
		5.2.3 Softening Bundle with Linear Softening Behavior	81		
		5.2.4 Bundle with General Softening Behavior and Nonlocal	0.4		
	5 2	Interaction Fiber Pundla Model for Fatigue Strength	84		
	5.5 5.4	Hierarchical Model for Static Strength	00		
	5.5	Hierarchical Model for Fatigue Strength	92 97		
6	Multiscale Modeling of Fracture Kinetics and Size Effect under Static				
	and C	Syclic Fatigue	100		
	6.1	Previous Studies of Fracture Kinetics	100		
	6.2	Fracture Kinetics at Nanoscale	102		

		Contents	ix		
	6.3	Multiscale Transition of Fracture Kinetics for Static Fatigue	103		
	6.4	Size Effect on Fracture Kinetics under Static Fatigue	106		
	6.5	Multiscale Transition of Fracture Kinetics under Cyclic Fatigue	108		
	6.6	Size Effect on Fatigue Crack Growth Rate and Experimental			
		Evidence	112		
	0.7	General Loading	117		
7	Size	Effect on Probability Distributions of Strength and			
	Lifeti	ime of Quasibrittle Structures	119		
	7.1	Probability Distribution of Structural Strength	119		
	7.2	Probability Distribution of Structural Lifetime	122		
		7.2.1 Creep Lifetime	122		
		7.2.2 Fatigue Lifetime	127		
	7.3	Size Effect on Mean Structural Strength	129		
	7.4	Size Effects on Mean Structural Lifetimes and Stress-Life Curves	133		
	7.5	Effect of Temperature on Strength and Lifetime Distributions	136		
8	Computation of Probability Distributions of Structural Strength and Lifetime				
	8.1	Nonlocal Boundary Layer Model for Strength and Lifetime	120		
	8 2	Distributions Computation by Pseudo random Placing of PVFs	139		
	0.2 8 3	Approximate Closed Form Expression for Strength	144		
	0.5	and Lifetime Distributions	146		
	84	Analysis of Strength Statistics of Beams under Flexural Loading	140		
	8.5	Ontimum Fits of Strength and Lifetime Histograms	152		
	0.0	8.5.1 Optimum Fits of Strength Histograms	154		
		8.5.2 Optimum Fits of Histograms of Creep Lifetime	157		
		8.5.3 Optimum Fits of Histograms of Fatigue Lifetime	159		
9	Indir	ect Determination of Strength Statistics of Quasibrittle Structures	161		
	9.1	Relation between Mean Size Effect Curve and Probability			
		Distribution of RVE Strength	161		
	9.2	Experimental Verification	164		
		9.2.1 Description of Experiments	164		
		9.2.2 Analysis of Test Results	166		
	9.3	Determination of Large-Size Asymptotic Properties of			
	0.4	the Size Effect Curve	169		
	9.4	Comparison with the Histogram Testing Method	170		
	9.5	0.5.1 Theoretical Argument	1/1		
		7.5.1 Fuidence from Histogram Testing	1/1		
		9.5.2 Deficience from thistogram resulting 9.5.3 Mean Size Effect Analysis	172		
		7.5.5 Inteall Size Effect Milarysis	175		

X	Conte	ents			
	9.6	Alternative Proof of Strength Distribution of an RVE Based on Stability Postulate and Atomistic Analysis	176		
10	Statistical Distribution and Size Effect on Residual Strength				
	after Sustained Load				
	10.1	Nanomechanics Based Relation between Monotonic Strength and			
		Residual Strength of One RVE	178		
	10.2	Analysis of Residual Strength Degradation for One RVE	180		
	10.3	Probability Distribution of Residual Strength	181		
		10.3.1 Formulation of Statistics of Residual Strength for One RVE10.3.2 Formulation of Residual Strength cdf of Geometrically	181		
	10.4	Similar Structures of Different Sizes	182		
	10.4	Comparison among Strength, Residual Strength, and Lifetime	102		
	10.5	Experimental Validation	103		
	10.5	10.5.1 Ontimum Fits of Strength and Residual Strength Histograms	104		
		of Borosilicate Glass	184		
		10.5.2 Optimum Fits of Strength Histograms and Prediction of			
		Lifetime and Mean Residual Strength for Unidirectional			
		Glass/Epoxy Composites	186		
		10.5.3 Prediction of Strength Degradation Curve for Soda-Lime			
		Silicate Glasses	188		
	10.6	Comparison of Size Effects on Mean Strength, Residual Strength,	100		
		and Lifetime	189		
11	Size I	Effect on Reliability Indices and Safety Factors	193		
	11.1	Size Effect on the Cornell Reliability Index	194		
	11.2	Size Effect on the Hasofer-Lind Reliability Index	197		
	11.3	Approximate Equation for Scaling of Safety Factors	199		
	11.4	Analysis of Failure Statistics of the Malpasset Arch Dam	202		
		11.4.1 Model Description	203		
		11.4.2 Discussion of Cornell and Hasofer–Lind Indices	204		
		11.4.3 Discussion of Central and Nominal Safety Factors	207		
12	Crack	K Length Effect on Scaling of Structural Strength and Type 1			
	to 2 1	ransition	210		
	12.1	Type 1 Size Effect in Terms of Boundary Strain Gradient	211		
	12.2	Universal Size Effect Law	213		
	12.3	Verification of the Universal Size Effect Law by Comprehensive			
		Fracture Tests	215		
13	Effec	t of Stress Singularities on Scaling of Structural Strength	218		
	13.1	Strength Scaling of Structures with a V-Notch under			
		Mode I Loading	218		

		Contents	xi
		13.1.1 Energetic Scaling of Strength of Structures with Strong	• • •
		Stress Singularities	219
	12.0	13.1.2 Generalized Finite Weakest-Link Model	220
	13.2	Numerical Simulation of Mode I Fracture of Beams with a V-Notch	223
		13.2.2 Results and Discussion	223
	13.3	Scaling of Fracture of Bimaterial Hybrid Structures	224
	15.5	13.3.1 Energetic Scaling with Superposed Multiple Stress	220
		Singularities	229
		13.3.2 Finite Weakest-Link Model for Failure of Bimaterial	
		Interface	232
	13.4	Numerical Analysis of Bimaterial Fracture	234
		13.4.1 Description of Analysis	234
		13.4.2 Results and Discussion	236
14	Lifetim	e of High-k Gate Dielectrics and Analogy with Failure Statistics	
	of Quas	sibrittle Structures	239
	14.1	Deviation of Lifetime Histograms of High-k Dielectrics from the	
		Weibull Distribution	239
	14.2	Breakdown Probability	242
		14.2.1 Analogy with Strength of Quasibrittle Structures	242
		14.2.2 Application to Dielectric Breakdown	244
		14.2.3 Microscopic Statistical Models	245
		14.2.4 Breakdown Voltage Distribution	248
	14.3	Breakdown Lifetime under Constant Voltage	249
		14.3.1 Relation between Lifetime and Breakdown Voltage	249
		14.3.2 Microscopic Physics	250
		14.3.3 Probability Distribution of Breakdown Lifetime	251
	14.4	Breakdown Lifetime under Unipolar AC Voltage	251
	14.5	Experimental Validation	252
		14.5.1 Breakdown under Constant Gate Voltage Stress	252
	14.6	14.5.2 Breakdown under Unipolar AC Voltage Stress	255
	14.6	Size Effect on Mean Breakdown Lifetime	255
	Append	tix A: Power-Law Scaling of Boundary Value Problems	257
	Append	lix B: Proof of Transitional Size Effects of Types 1 and 2 by	2(0
	Dimens	sional Analysis and Asymptotic Matching up to Second Order	260
	Append	lix C: Proof of Small-Size Asymptotics of Cohesive Crack Model	264
	up to S		204
	Referen	nces	269
	Author	Index	291
	Subject	t Index	297