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混凝土类材料破坏机理及宏细观损伤本构模型研究

Study on Failure Mechanism and Macro-meso Damage Constitutive Model of Concrete-like Materials

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摘 要

混凝土、岩石材料是由颗粒组成的一类脆性材料，都先天带有微裂隙（裂纹）等缺陷以及不均质性等特点，因此它们具有相近的力学性质。混凝土类材料破坏机理及本构模型的研究一直是土木工程学科最为重要的问题之一，最近发展起来的损伤力学理论为该研究提供了一种新的研究思路和方法。利用连续损伤理论分析混凝土类材料破坏的损伤机理，并结合统计强度理论建立混凝土类材料受压破坏全过程的损伤本构模型成为研究热点。本文以混凝土和岩石材料为研究对象，从室内试验出发，利用连续损伤理论分析混凝土类材料破坏的损伤机理，并结合统计强度理论建立混凝土类材料受压破坏全过程的损伤本构模型。在建立损伤本构模型的过程中，通过混凝土类材料破坏过程的应力应变全曲线的几何边界条件具体推导了本构模型的参数表达式，通过与混凝土类材料压缩试验实测结果对比，证明模型可以很好的反映混凝土类材料受压状态下的应力-应变关系。并在此基础上，根据混凝土类材料受压破坏过程中的不同阶段特性，重点进行了损伤本构模型的改进研究。首先根据不同围压条件下岩石破坏后还存在残余强度的特性，引入损伤修正参数，建立了能够反映残余强度的不同围压条件下岩石损伤本构模型，并探讨了围压与损伤修正参数的关系；其次根据混凝土类材料在低应力水平或变形较小时的线弹性变形特性，引入损伤阀值（位置）参数，建立了可考虑损伤阀值影响的混凝土类材料损伤本构模型，并探讨了损伤阀值参数的大小。

基于连续损伤理论的损伤本构模型着重考察损伤对材料宏观力学性质的影响以及材料和结构损伤演化过程和规律，注重研究损伤的宏观后果；而不细查损伤的细观物理背景和材料内部的细观结构变化。该模型是建立在材料处于均匀弱损伤状态假设的基础上的，因此该类模型不适合描述局部破坏阶段材料的损伤突变机制。运用先进的试验方法和手段，将混凝土细观损伤机理与宏观破坏现象联系起来，是从本质上认识和解决混凝土等结构灾害的一条正确途径，这也成为一种必然的发展趋势。声发射是材料或结构在外力或内力作用下，在产生变形或损伤的同时，以弹性波的形式释放出部分应变能的一种自然现象。因此声发射是粒状脆性材料在受载过程中的伴生现象，而且在不同的受力条件下，会表现出不同

的声发射特征。一次声发射代表材料的一次微损伤，声发射事件表征着材料的细观破裂，因此声发射参量（声发射事件数、能量等）可以用来表征材料的损伤程度，那么同应力、应变参量一样，声发射参量也应该属于一个本构参量。因此运用声发射试验对混凝土类材料损伤演化过程进行跟踪和分析，从微观上研究混凝土类材料损伤过程，分析混凝土类材料损伤的细观机理，探讨声发射参数与损伤变量的定量关系，继续研究应力、应变、声发射这几种信息参量的本构耦合关系，不仅是对基于损伤力学的损伤本构模型研究的进一步发展和完善，而且对于实际工程的稳定性监测与评价，都有很重要的实际价值。但是声发射技术是一门理论落后实际的学科，迄今尚未建立起完善的声发射参数与力学参数间的本构耦合关系，因而在实际应用上缺少理论依据。本文在室内试验本身试验特性下，基于 Dai 和 Labuz 提出的应力水平V与声发射事件累积数N之间的关系式，探讨了声发射概率密度的表达式及声发射参数N和力学参数D的关系表达式；最后基于损伤力学的观点，利用上文建立了基于 Weibull 分布基础的损伤本构模型及损伤变量D与累积声发射数N一致的关系，推导出应力、应变参量与声发射数参量的损伤本构耦合模型，为利用声发射技术定量的评价混凝土类材料的损伤及结构可靠性提供了理论依据。

关键词：混凝土；岩石；声发射；损伤；本构模型；耦合模型

ABSTRACT

Concrete and rock materials, a class of brittle materials composed of grain, which are both inherent with defects (such as micro-cracks) and non-homogeneous characteristics have similar mechanical properties.The research for failure mechanism and constitutive model of concrete-like materials has been one of the most important issues of Civil Engineering all along and a recently developed damage mechanics theory provides a new thinking and method for the study .Using continuum damage theory to analysis damage mechanism of failure in concrete-like materails and combining the statistical approaches of strength to develop a statistical damage constitutive model reflecting the compression destruction full process of concrete-like materials becomes the hotspot .Taking Concrete and rock materials as research objects, based on large number of domestic and foreign scholars studying the damage constitutive model , starting from the laboratory tests, using the continuum damage theory and statistical approaches of strength, this paper developed a statistical damage constitutive model reflecting the full process of compressed destruction of concrete-like materials. In the procession of establishing the constitutive model, by using the geometrical boundary conditions of the stress-strain curve of the concrete-like materials samples to establish the equation of the constitutive model parameter and through with concrete-like materials compression test results of contrast prove that models can well reflect the state of concrete-like materials under compression stress - strain relationship. And based on the compression failure process of concrete-like materials in different stages of characteristics, I conducted a focus on damage constitutive model of improvement. First according to characteristics of still exist the residual strength after the destruction of the rock under different confining pressures, I introduce damage amendment parameters, establish a statistical constitutive damage model for rock under different pressure, which can reflect the residual strength of rock. Then according to characteristics of the liner-elastic characteristics of concrete-like materials deformation in low stress level or small

deformation, I introduce damage threshold (location) parameters, establish a statistical constitutive damage model for concrete-like materials, which can reflect the liner-elastic characteristics of concrete-like materials deformation in low stress level or small deformation, and discuss the value size of the damage threshold.

The damage constitutive model based on the continuous damage theory focus the study, which is on the effect of damage to macroscopic properties of materials and the process and law of the damage evolution in materials and structure,paying attention to the macro-consequences of damage instead of examining the micro-physical background of damage and the micro-structural changes of the internal materials. The model is based on material which is hypothetically in a uniform state of weak damage,therefore the type of this model is not suitable to describe damage mutation mechanism of material in local failure stage. Using advanced methods and means of test to Link the microsopic damage mechanism and macroscopic failure phenomena of concete,is essentially a correct way to understand and solve the disaster of the concrete structue,is also becomed an inevitable trend of development.Acoustic emission is a natural phenomenon which a mateial or structure will release part of strain energy as the form of elastic waves,produce deformation or damage in the same time under external or internal forces .Therefore,AE is a granular brittle materials loaded in the process of associated phenomena,and in the different stress conditions,will show different emission characteristics. An AE event represents a macro-damage of material. Since AE events mean material fracture, damage degree can be represented by AE parameters (AE count and energy), So with the stress and strain parameters,acoustic emission parameters should also be part of a constitutive parameters. Therefore acoustic emission test is used to trace and analysis the the damage evolution of concrete-like material,studying the process of damage in concrete-like material from the microscopic,analysising the damage mechnism of concrete-like material from mesoscopic, investigating the quantitative relationship between acoustic emission parameter and the damage variable,continuously researching coupled constitutive relationship of these types of information as stress、

strain、acoustic emission,not only is the further development and improvement for the damage constitutive model based on the damage mechanics,but also have very important pratical value to monitor and evaluate the stability of the actual project. But the acoustic emission technology is a theory of actual behind, for a perfect coupling model of the acoustic emission parameter versus stress and strain has not been established , thus causing the lack of theoretical basis for practical application. With the characteristics of their own tests in the indoor experiment, based on the relationship of the stress level V and the cumulative number of acoustic emission events which is proposed by Dai and Labuz,discuss the probability density of the expression of AE and the relationship of AE parameter and mechanical parameter D. Last, point of view based on damage mechanics, based on the damage constitutive model which is based on the Weibull probabilistic density function and the empirical formula about the relationship of the damage variable versus the number of acoustic emission, in the theory of damage mechanics ,the coupling damage models of the acoustic emission parameter versus stress and strain are formulated, which provide a theoretical basis for using acoustic emission technology quantitative evaluation of the damage of concrete-like materials and structural reliability.

Key Words: concrete; rock; acoustic emission; damage; constitutive model; coupling model

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