TONGJI UNIVERSITY

博士学位论文

混凝土本构关系试验研究与细观随机断裂模型参数识别

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Experimental Research on Constitutive Law and Parameter Identification on Mesoscopic Stochastic Fracture Model for Concrete

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摘要

本文在课题组对混凝土本构关系理论研究的基础上，采用大样本本构试验研究、细观单元本构理论分析和宏观结构数值分析相结合的方法，研究了混凝土材料受力行为的损伤机理和发展过程。通过对比试验结果和理论分析结果，验证了弹塑性随机损伤模型的合理性。

论文的主要内容如下：

（1）混凝土单轴受压应力-应变全曲线试验。采用 MTS815 力学性能试验系统，针对强度等级为 C30-C60 的商品混凝土材料进行了大样本单轴受压静力加载和动力加载试验。累计完成混凝土基本力学性能试验 32 次、混凝土单轴受压应力-应变全曲线静力试验 60 次、混凝土单轴受压应力-应变全曲线动力试验 358 次、混凝土单轴受压加卸载试验 3 次，共计 453 次试验。基于大样本试验进行分析研究，着重阐明了混凝土单轴受压全过程的随机性特征和非线性行为；

（2）系统介绍了基于细观随机断裂模型的混凝土随机损伤本构关系理论。并基于试验得到的应力均值和标准差曲线，采用优化算法和分阶段识别方法，对混凝土细观随机断裂模型中部分参数进行识别，获得了弹性模量 E_0，受压断裂应变随机场参数 λ^-、ζ^-、ω^- 和受压塑性应变参数 ξ^{p-}、η^{p-}。所得参数为本构模型的实际应用提供了可靠的实用数据；

（3）识别混凝土细观随机动力模型中的应变迟滞因子 α_{st}，并提出经验计算公式，通过数值计算得到动力加载条件下（$10^{-8}s^{-1} < \dot{\varepsilon} < 10^{3}s^{-1}$）混凝土强度提高系数的均值和标准差。通过与已有试验结果进行对比，证明混凝土动力损伤模型可以正确反映动力作用下强度的平均提高效应和变异性。

（4）混凝土结构数值分析——预制装配式型钢混凝土框架梁柱节点有限元分析。结合混凝土材料本构试验结果，利用本课题组提出的混凝土弹塑性随机损伤本构模型，对有限元软件 ABAQUS 本构模型的二次开发，针对 6 个不同的预制装配式型钢混凝土框架梁柱节点进行了系统的有限元分析。通过与已有的梁柱节点拟静力试验结果进行对比，验证了弹塑性随机损伤本构理论模型的合理性和有效性，为该模型在复杂的结构设计中的实际应用提供了依据。

关键词：混凝土，弹塑性，损伤，本构关系，随机性，大样本试验，数值模拟

ABSTRACT

Based on the research results of the constitutive law for concrete from our group, a framework of concrete material research is developed. Based on the framework which is formed with large-sample experimental research, mesoscopic theoretical study on constitutive law and concrete structure numerical analysis, the damage mechanism of concrete is studied. The agreement between the theoretical results and experimental data indicates reliability of the present model.

The major works of the present thesis are summarized as follows:

(1) Experimental study on complete stress-strain curves of concrete under uniaxial compression. An experimental research is performed to investigate the behavior of concrete with static and dynamic loading using the MTS testing system. The strength grade of 453 concrete prism specimens are range from C30 to C60. The randomness and nonlinearty of concrete are studied based on the analysis of test results of 32 cube strengths, 60 complete stress-strain curves with static strain rate, 3 uniaxial cyclic loading and unloading curves and 358 complete stress-strain curves with high strain rate.

(2) Based on the mesoscopic stochastic fracture model (MSFM), the stochastic damage model of concrete is systematically introduced. Material parameters such as the elastic modulus (E_0), random field parameters ($\lambda^-, \zeta^-, \omega^-$) and plastic strain parameters(ξ^{p-}, η^{p-}) are identified according to the experimental results. The identified parameters provide reliable datas for the practical application of the constitutive model.

(3) Strain lag factor α_{st} in dynamic damage model of concrete is identified according to the experimental results. Then the mean value and standard deviation of DIF is provided by using empirical formula of α_{st}. The simulation results are in great agreement with the experimental data under the strain rate from $10^{-8}s^{-1}$ to $10^{3}s^{-1}$, which indicates that the dynamic damage model could correctly describe the variability and increasing rule of concrete strength under dynamic loadings.

(4) Numerical analysis of concrete structure——Numerical simulation of fabricated concrete beam-column joints. Based on the secondary development with the FEA software ABAQUS interface, the nonlinear behavior of 6 types of fabricated

concrete beam-column joints under cyclic loading are simulated by numerical models. The numerical results agree well with the test results, which verify the valid of the theoretical model.

Key Words: concrete, elasto-plasticity, damage, constitutive law, randomness, large-sample experiments, numerical simulation

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