論 文 の 内 容 の 要 旨

論文題目　Ductile Fracture of Structural Steels under Cyclic Large Strain Loading
（繰返し大ひずみ負荷による構造用鋼材の延性破壊）

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Ductile fracture of steel structures has been observed in huge earthquakes, e.g., Northridge earthquake in 1994 and Kobe earthquake in 1995. During a severe earthquake event, local or global buckling may first occur in some steel structural members such as bracings and corner columns, and large plastic strain will occur in some localized regions, and fracture may happen after suffering several cyclic large strain loading cycles. During an earthquake event, structures commonly suffered from large plastic loading less than 20 cycles, and the fracture mode should be classified as ductile fracture but not low cycle fatigue. The mechanisms and evaluation approaches for the two fracture modes are distinguished. Ductile fracture has a typical dimple fracture surface under fractographic obsevations with scanning electron microscope (SEM), and it is possible to predict ductile fracture with only small-scale monotonic tensile coupon tests. However, typical SEM fractography of low cycle fatigue is striations. And it may be impossible to predict the life of low cycle fatigue from a monotonic tensile coupon tests. To distinguish the loading history of ductile fracture from that of low cycle fatigue which is concerned with small strain amplitudes, the loading history concerned with ductile fracture under seismic loading is herein named as cyclic large strain loading (CLSL).

This thesis is aimed to investigate the mechanisms of ductile fracture under CLSL, and establish a straightforward procedure to predict ductile fracture of structural steels and members. This thesis firstly studies the cyclic plastic behaviors of structural steels at large plastic strain ranges till fracture of the materials, and constructs proper plasticity models based on cyclic coupon test results of structural steels. Secondly, the mechanisms of ductile fracture of structural steels under monotonic and CLSL are studied, and proper fracture models with simple formations are established. Moreover, all of the model parameters of the plasticity models and the fracture models can be simply obtained from monotonic tensile coupon tests. Finally, the plasticity model and fracture model are validated by cyclic tests on stub box columns under various loading histories. The corresponding finite element analyses are carried out, where the

predicted fracture initiation locations and crack propagation agree well with the experimental results.

This thesis has three major parts. The first part built on Chapters 2 and 3 is devoted to study the behaviors of structural steels at large plastic strain ranges till fracture, and to find or construct proper plasticity models. The approach is characterized by calibrating the plasticity model parameters only from a simple tensile coupon test, which has never been done before. The second part of this thesis is assigned to Chapters 4 and 5, in that the mechanisms of ductile fracture of structural steels under monotonic and CLSL are studied, and proper fracture models with simple formations are established, to meet the requirement that the fracture model parameters can be easily calibrated from a tensile coupon test. The proposed fracture models are validated by monotonic tensile tests as well as tensile and compressive cyclic tests of smooth and notched coupons. The final part, i.e. Chapter 6, is devoted to demonstrate that the plasticity model and fracture model proposed in Chapters 2 to 5 are applicable to the post-buckling fracture of steel columns subjected to large plastic strain reversals which are anticipated during a hit of severe earthquake. The content of each chapter is detailed as follows.

Chapter 1 gives the background, aims, methods and structure of the thesis.

Chapter 2 describes true stress-true strain behavior of structural steels at large plastic strain ranges after necking initiates. Monotonic coupon tests are carried out and a simple method to obtain the true stress and true strain after necking initiates is proposed.

Chapter 3 describes cyclic coupon tests on structural steels using hourglass-type specimens, and the capacities and limitations of several classical plasticity models for metals are studied. Proper refinements are carried out for a selected plasticity model to well simulate the cyclic plasticity of structural steel till fracture. The relationship between plasticity behaviors under monotonic and cyclic loading is also studied to calibrate the model parameters of the plasticity models with only a simple tensile coupon test.

Chapter 4 covers ductile fracture mechanism of structural steels under monotonic loading. A simple fracture model with simple formation is established, and the model is also calibrated by available monotonic test results of notched coupons of several structural steels. A simple approach to calibrate the model parameter for the monotonic fracture model using only tensile coupon tests is also given.

Chapter 5 describes the mechanism of ductile fracture of structural steels under CLSL, and a cyclic fracture model is proposed to evaluate ductile fracture of structural steels under CLSL, which is also coincident with the monotonic fracture model for the case of monotonic loading. The cyclic fracture model is then validated by comparison between the cyclic coupon tests carried out in Chapter 2, and the corresponding numerical simulations. The model parameters of the plasticity models and the cyclic fracture model are all calibrated using tensile coupon tests.

Chapter 6 gives an application of the plasticity model and the cyclic fracture model to structural members under CLSL. Experimental tests on steel stub box columns with and without heat-treatment under different loading protocols are carried out. The effects of heat-treatment, width-to-thickness ratio, and loading history on the ductile fracture of the columns are studied. The failure processes of the different specimens are concluded. The effects of heat-treatment, width-to-thickness ratio, and loading history on the dissipated plastic energy of the box columns are also studied. Moreover, numerical simulations using the plastic model and the cyclic fracture model are carried out for the experiments. The mechanisms of the ductile fracture of the various specimens are studied in detail based on the numerical simulation results. The numerical results validate the applicability of the plasticity model and the cyclic fracture model to the prediction of post-buckling fracture of steel structural members.

Finally, Chapter 7 describes the main conclusions obtained in this thesis and future work of ductile fracture under CLSL.

Appendices A and B give the design drawings and test results of the hourglass-type specimens in Chapter 3, respectively.

Appendix C gives the fracture surfaces of coupons and hourglass-type specimens using a scanning electron microscope in Chapters 2 and 3.

Appendix D gives the design drawings of the box columns in Chapter 6, respectively.

Appendix E gives the monotonic tensile coupon test results of the box columns in Chapter 6, respectively.

Appendices F and G give the test results of the box columns with and without heat-treatment in Chapter 6, respectively.