Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Biaxial Loading Test for Steel Containment Vessel

Takuya Miyagawa[1], David J. Wright[2] and Shoji Arai[3]

1) Nuclear Power Engineering Corporation, Japan
2) AEA Technology Energy, United Kingdom
3) Toshiba Corporation, Japan

ABSTRACT

The Nuclear Power Engineering Corporation (NUPEC) has conducted a 1/10 scale of the steel containment vessel (SCV) test for the understanding of ultimate structural behavior beyond the design pressure condition.

Biaxial Loading Tests were supporting tests for the 1/10 scale SCV model to evaluate the method of estimating failure conditions of thin steel plates under biaxial loading conditions.

The tentative material models of SGV480 and SPV490 were obtained. And the behavior of SGV480 and SPV490 thin steel plates under biaxial loading conditions could be well simulated by FE-Analyses with the tentative material models and Mises constitutive law.

This paper describes the results and the evaluations of these tests.

1. Introduction

NUPEC has conducted a test for the understanding of ultimate structural behavior of the 1/10 scale SCV model beyond the design pressure. In order to establish the method of estimating failure conditions of the SCV test, Biaxial Loading Tests were performed.

The objectives are to study the behavior of the thin steel plates used for an actual SCV under biaxial loading conditions and to develop material specific constitutive models and failure criteria as shown in Fig.1.

This test program consisted of three tests. The first tests were Small Scale Tests which were conducted to obtain material models to be used in FE-Analyses. The second tests were Medium Scale Biaxial Tests which were conducted by using 34 pieces of 8mm thickness SGV480 and SPV490 steel (which are the main material of SCV) cruciform plate with loading ratios between 1:1 and 1:0. The third test was Large Scale Biaxial Test which was conducted by using the 32 mm thickness SGV480 steel cruciform plate with a loading ratio at 1:1. The material models of FE-Analyses to simulate the behavior of SGV480 and SPV490 thin plate under biaxial loading condition were verified by comparing test results with FE-Analyses using ABAQUS.

2. Small Scale Tests

Small Scale Tests were conducted using uniaxial round and notched tensile bars. An uniaxial round bar test was performed in accordance with BS EN10 002 test standard in order to evaluate yield and flow behavior of SGV480 and SPV490 materials and to develop material models used for FE-Analyses of biaxial tests.

Notched tensile bar test was conducted in order to validate the material model of SGV480 and the tentative material model was used in the analyses. It was based on the results of the plain tensile bar tests, however the data only provided data up to 16% true strain, so that the data were extrapolated to higher strains; SGV480FE-data1 (elastic perfectly plastic behavior) and SGV480FE-data2 (elastic hardening plastic behavior).

The tentative material model of SGV480 was validated by comparing notched tensile bar tests result with FEM analysis and SGV480FE-Data2 model was selected.

3. Biaxial Tests

3.1 Medium Scale Biaxial Tests

Medium Scale Biaxial Tests were conducted to evaluate the effect of load ratio on the behavior of thin steel plates under biaxial loading conditions by using 34 pieces of 8mm thickness SGV480 and SPV490 steel cruciform plate with loading ratios between 1:1 and 1:0. Test model configuration, test facility and instrumentation of Medium Scale Biaxial Tests are shown in Figs.2 to 4.

FE-Analysis result of 1:0 load case shows the highest strain point located at the edge of gauge area, which in the other cases showed that the highest strain point located at the corner of gauge area. That is the locations where the test specimens finally cracked were well simulated by FE-analyses. The actuator load strain carves derived by SGV480 plain tests and FE-Analyses in 1:1 load case are shown in Fig.5 and 6. The average load at the yield point were 294 kN in the test result and 296 kN in the analytical result, respectively. The average maximum load were 540 kN in the test result and 534 kN in the analytical result, respectively.

In these analyses, material model was modified from SGV480FE-Data2 (which had been calibrated in Small Scale Tests) to SGV480FE-Data3 and Mises constitutive law was used. Comparison of applied loads at yield and at the maximum load between measured and predicted results using FE-Analysis showed good agreement. So the material model SGV480FE-Data3 and Mises constitutive law were confirmed to be applicable to plastic region of SGV480 under biaxial condition.

The actuator load strain carves derived by SPV490 plain tests and FE-Analyses in 1:1 load case are similar to SGV480 plain tests. The average load at the yield point were 392 kN in the test result and 386 kN in the analytical result, respectively. The average maximum load were 622 kN in the test result and 606 kN in the analytical result, respectively.

In these analyses, the material model SPV490FE-Data2 (elastic hardening plastic behavior) and Mises constitutive law were used. Comparison of applied load at yield and at the maximum load between measured and predicted results using FE-Analysis showed good agreement. So the material model SPV490FE-Data2 and Mises constitutive law were confirmed to be applicable to plastic region of SPV490 under biaxial condition.

3.2 Large Scale Biaxial Test

Large Scale Biaxial Test was conducted to evaluate the effect of the thickness on the behavior of thin steel plates under biaxial loading conditions by using the 32 mm thickness SGV480 steel cruciform plate with a loading ratio at 1:1. Test model configuration and instrumentation of Large Scale Biaxial Test are shown in Fig.7.

The maximum total load was 12.38 MN on the horizontal axis and 12.44 MN at the vertical axis. Similar to SGV480 1:1 load case of Medium Scale Biaxial Tests, the final crack location was the corner of gauge area.

The actuator load-strain curves measured by displacement transducers D1 to D4 are shown in Fig.8. The transducers D1 toD4 at the central region of the plate gave final true strain measurements just prior specimen failure of 15.9%, 16.7%, 15.9% and 16.5% respectively.

The actuator load-strain curves measured with clip gauges 1 and 2 at the center of the gauge area is shown in Fig.9. The clip gauges 1 and 2 gave final true strain readings just before specimen failure of 18.8% and 19.3% gave on the vertical and horizontal axes respectively, and this result showed good agreement with the results of Medium Scale Biaxial Tests.

4 Conclusion

Two conclusions were drawn from these tests. Firstly, the tentative material models of SGV480 and SPV490 were obtained by comparing Medium Scale Biaxial Tests results with FE-Analyses. Secondly, the behavior of SGV480 and SPV490 thin steel plates under biaxial loading conditions could be well simulated by FE-Analyses with the tentative material models and Mises constitutive law.

References

D J Wright et al. "Supporting programme for containment vessel tests – Final Report (May 1997)".AEAT-1349, SPD/GD/0662

D J Wright et al. "A programme to determine the deformation and fracture behaviour of containment vessel steel in biaxial stress fields". International Conference on Nuclear Containment, Cambridge, England, September 23-25, 1996

H W Swift, "Plastic instability under plane stress", J. of Mesh. Phys. of Solids, Vol.1, 1-18, 1952.

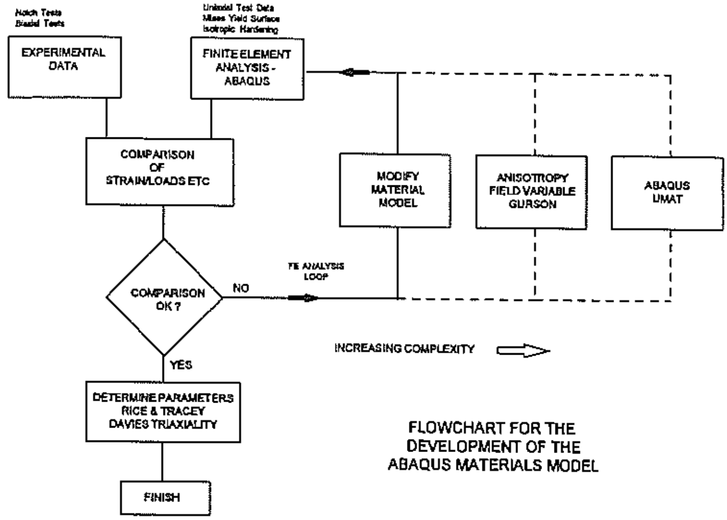

Fig.1 Flow of Biaxial Loading Test

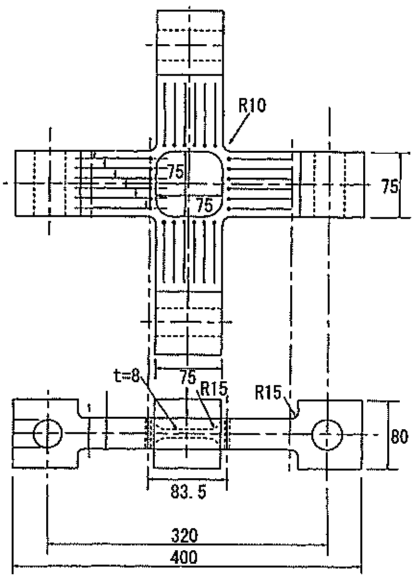

Fig.2 Test model configuration of Medium Scale Tests

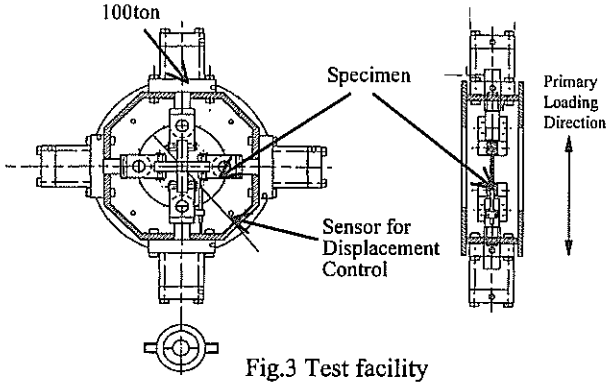

Fig.3 Test facility

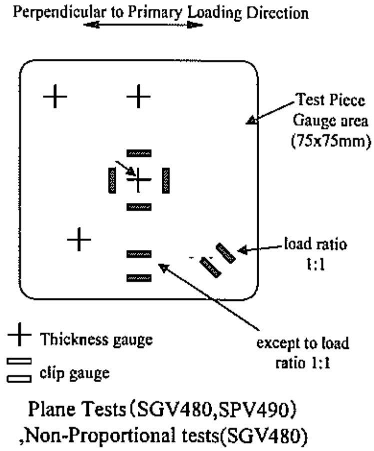

Fig.4 Instrumentation of Medium Scale Tests

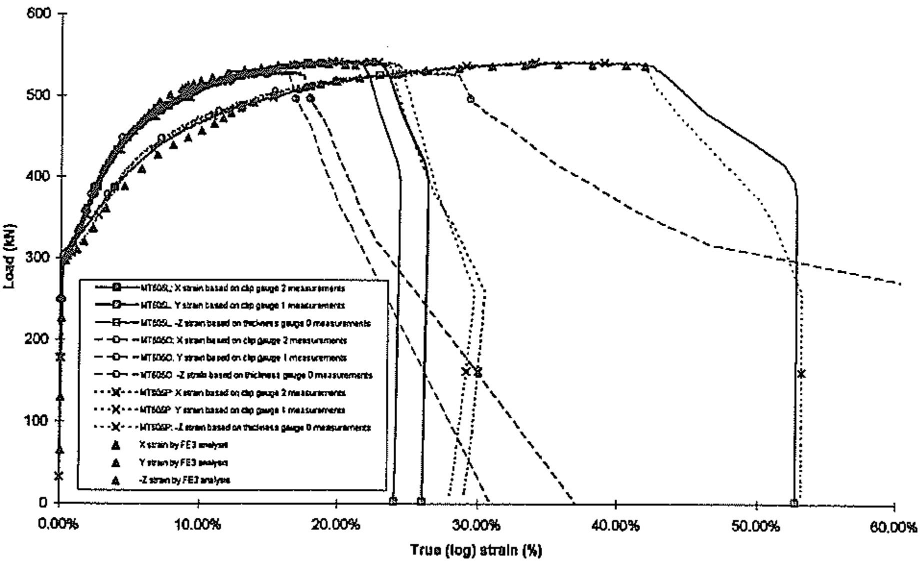

Fig.5 Relationship between load and strain in the center of the specimen (SGV480)
(Medium scale biaxial tests)

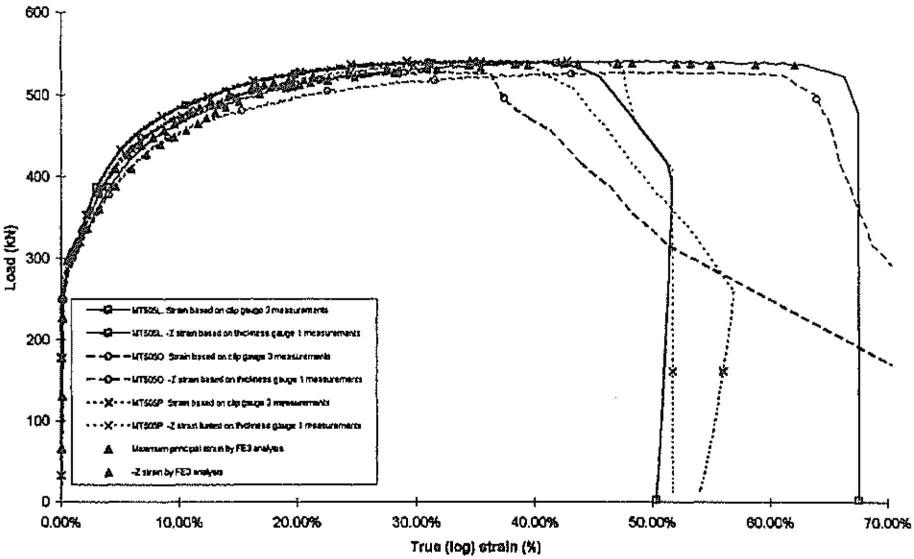

Fig.6 Relationship between load and strain at the hotspot of the specimen (SGV480) (Medium scale biaxial tests)

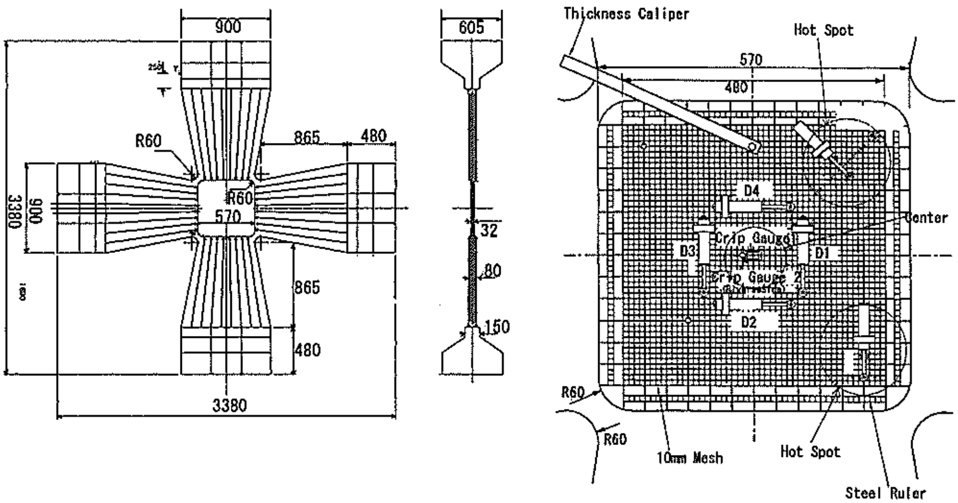

Fig.7 Test model configuration of Large Scale Biaxial Test

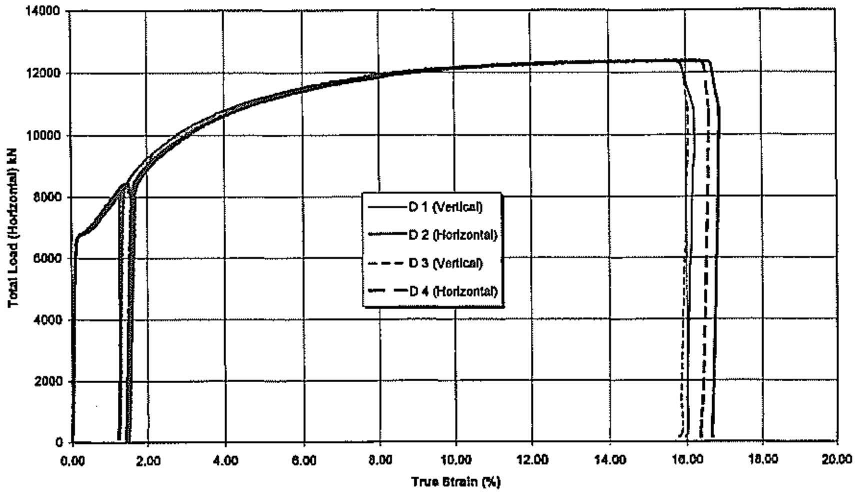

Fig.8 Relationship between load and strain
(Large scale biaxial tests)

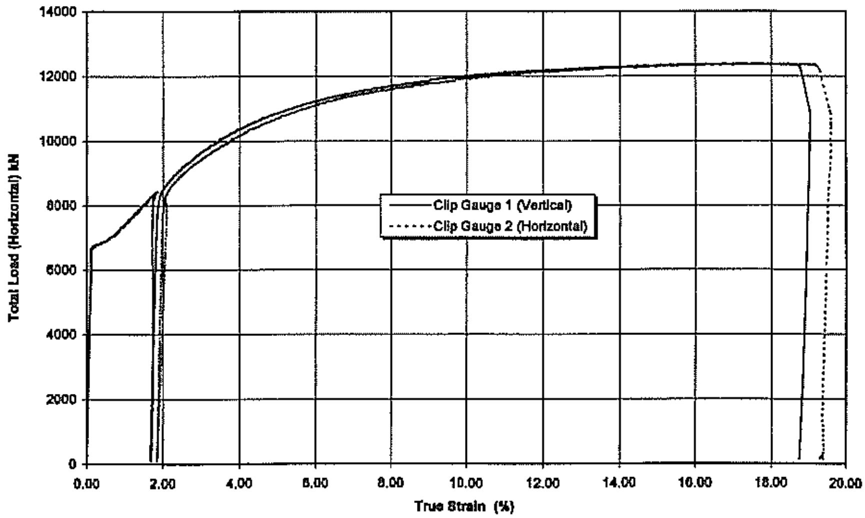

Fig.9 Relationship between load and strain
(Large scale biaxial tests)