Comparison of Analysis Results with Experimental Results for ENEA and CRIEPI Rubber Bearings

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Abstract

In this paper, the preliminary structural analyses of ENEA HDRB and CRIEPI NRB were performed by using computer code ABAQUS, and the analysis results were compared with the test results provided by Italy and Japan thru IAEA. The test data for the rubbers used for the fabrication of bearings were also provided thru IAEA, and were utilized for the formulation of the rubber models for the analyses. The analyses performed for the rubber bearings are for the combined compression and shear and for the compression. The analysis results show a good agreement in shear strains when compared with the test results of HDRB and NRB for the combined compression and shear and for the compression benchmarks, but show relatively smaller responses in displacements for the compression with offsets benchmarks.

1. INTRODUCTION

As part of the IAEA/IWGFR coordinated research program on "Intercomparison of analysis methods for seismically isolated nuclear structures", three test data sets are provided for the benchmark problems by Italy, Japan and Russian Federation[1~3]. They are HDRB(High Damping Rubber Bearing), NRB(Natural Rubber Bearing) and 3-D Isolator, respectively.

Among them, KAERI have conducted the analyses for HDRB and NRB by using computer code ABAQUS[4] to compare the analysis results with the test results.

In this paper, test data, FEM analysis modelling and analysis results are briefly described and evaluated.

2. TEST DATA

Test data of HDRB and NRB provided are as follows.

2.1 ENEA HDRB Test Data

-Rubber material, G=0.4MPa (soft compound)

-Compound tests

· uniaxial
· biaxial
· planar
· volumetric

-HDRB tests
· combined compression and shear tests(shear strain, 50, 100, 200, 400%, break)
· compression tests(design vertical load, 150, 500, 800, 1100%)

Geometry of ENEA HDRB is shown in Fig.1 and compound test data are shown in Fig.2~5, and some HDRB test results are shown in Fig.6 and Fig.7.

2.2 CRIEPI NRB Test Data

-Rubber material, natural rubber
-Compound test
· strip-biaxial test
· coefficients of derivatives of strain energy function
-NRB tests
· combined compression and shear test
  · shear strain at 20, 50, 100, 200, 300, 400%, break
· compression tests
  · design vertical load 200tonf
  · loading tests with different shear strain offsets(offsets, 0, 50, 100, 200%)

Geometry of CRIEPI NRB is given in Fig.8. Strip biaxial test result and coefficients of strain energy function are given in Fig.9 and Fig.10, respectively, and NRB test results are also shown in Fig.11 and Fig.12.

3. FEM ANALYSES FOR RUBBER BEARINGS

Two kinds of the structural analyses for ENEA HDRB with soft compound and for CRIEPI NRB; one of which is for the combined compression and shear, and the other is for the compression, have been carried out by using computer code ABAQUS. In modeling of ENEA rubber, Mooney-Rivlin model, polynomial model(N=2), and Ogden model(N=3) are used from the rubber test data of uniaxial, biaxial, planar and volumetric tests. In modeling of CRIEPI rubber, the derivatives of strain energy density function which are formed by strip-biaxial test data are inputted by using subroutine UHYPER of ABAQUS.

3.1 FEM Analysis for ENEA HDRB

For the vertical and shear strain analyses of ENEA bearing, the ABAQUS code, version 5.5 is used. The models to follow the hyperelastic material behavior of rubber compound are Mooney-Rivlin, polynomial with N=2, and Ogden with N=3, which all are supported in ABAQUS. The rubber properties used in analyses are the uniaxial, the biaxial, the planar and the volumetric test data. The Young's modulus and Poisson ratio of the steel plates are assumed as 200 GPa and 0.3 respectively.

For combined compression and shear analyses, a design vertical load(50KN) is first applied by using the equivalent pressure, and then horizontal loads are increasingly applied to top elements by using nonaxisymmetric harmonic loads which are equivalent to the test displacements.

The dimension of ENEA bearing is as follow;the diameter is 120mm excluding coated rubber, the thicknesses of rubber and steel shim plates are 2.5mm and 1.0mm, respectively, and the number of rubber layers are 12. The types of element are an axisymmetric with nonaxisymmetric loads, CAXA41 for a combined compression and shear, and an axisymmetric, CAX41 for a compression loading only.

The boundaries are fixed at the bottom of the bearing, and vertically coupled and horizontally freed at the top of the bearing. The applied horizontal displacements vary from 50% to 400% of the total rubber height. Fig.13 represents analysis model and some deformed shapes of rubber bearing under the combined compression and shear loads.

The number of element layers used for a rubber layer(2.5mm) is changed from one to four to investigate the solution accuracy using Ogden model. But one layer element mesh type is excluded because the results of using one element layer for one rubber layer are poor.

3.2 FEM Analysis for CRIEPI NRB

In modeling of CRIEPI rubber to follow the hyperelastic material behavior of rubber compound, the derivatives of strain energy density function which are formed by strip-biaxial test are inputted by using the subroutine UHYPER of ABAQUS. The types of element are an axisymmetric with nonaxisymmetric loads, CAXA8H1 for a combined compression and shear, and an axisymmetric with 8 nodes, CAX8H1 for a compression loading only. The finite element mesh of the rubber bearing is shown in Fig.14, of which the diameter is 1012mm excluding coated rubber, the thicknesses of a rubber layer and a steel shim plate are 5.7mm and 3.1mm respectively, and the number of rubber layers are 25.

4. ANALYSIS RESULTS AND DISCUSSION

4.1 Analysis Results for ENEA HDRB

The variation of the number of layers greater than two affects a little on the displacement results in combined test as shown in Fig.15.

The calculated horizontal forces according to different rubber models in case of three element layers for a rubber layer are represented with experimental ones in

Fig.16. Analysis results using Ogden model agree better with the test results than those using other models in the strain range upto 150%, but those using polynomial model fit better in the higher strain range above 200%. The calculated horizontal forces are smaller than experimental ones for all models except Mooney Rivlin model. The force differences in high strain region become larger. And when the vertical design load increases to the several times of original one to evaluate the effects of the vertical loads, the difference of the calculated forces is less than 5%.

The vertical displacements to the vertical loads are shown in the Fig.17 to Fig.19. The displacement results for polynomial(N=2) and Ogden(N=3) models agree very well with test results, but the results for Mooney Rivlin model are smaller than those for tests. Displacement results for increasing the number of element layers per rubber layer in Mooney Rivlin fit better to test results. But when the number of elements for one layer becomes four, a convergence problem is occurred over 200% of the design vertical load as shown in Fig.19.

4.2 Analysis Results for CRIEPI NRB

In the combined compression and shear analysis, the analysis results as shown in Fig.20 follow the test results well until 140% shear strain above which the convergence problem is occurred. In the compression analysis of rubber bearing with no shear strain offset, the analysis results agree well with test results up to 400% design vertical load as shown in Fig.21. However in the compression with offsets as shown in Fig.22, the displacements corresponding to the values obtained by the combined compression and shear analyses are smaller than those by tests.

5. CONCLUSIONS

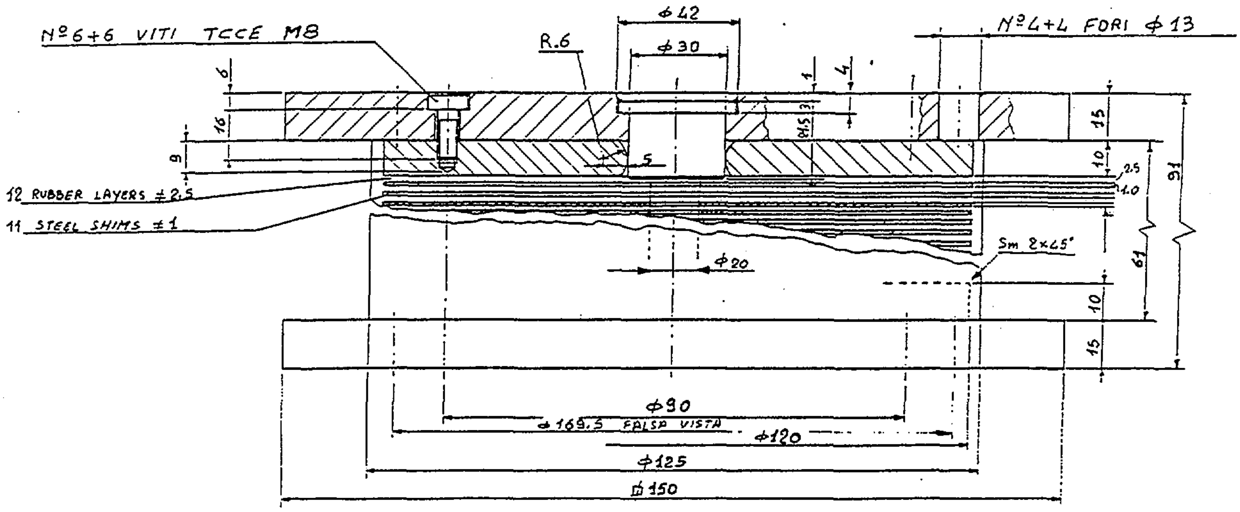
In this paper for ENEA HDRB and CRIEPI NRB, FEM analyses using ABAQUS in combined compression and shear and in compression have been performed and compared with test results to verify the analysis procedures used valid and powerful. For ENEA HDRB benchmarks three different rubber modellings, Mooney Rivlin, Ogden and polynomial methods used for the computation are evaluated and Ogden and polynomial models can be recommended for the analysis validation with test results. For CRIEPI NRB benchmarks, analysis results using coefficients of the derivatives of strain energy function show good agreements with the test results.

Further analyses for the case of the compression with offsets and for the resolution of convergence problem being occurred when the number of layers becomes four will be given to have better agreement between analyses and tests.

REFERENCES

1. A.Martelli and M.Forni, ENEA experimental data concerning high damping rubber

bearings with soft compound, April 16, '96(Received)
2. K.Hirata, CRIEPI experimental data on Natural Rubber Bearing, 1996. 4. 30(Received)
3. V.S.Belyaev, Test data on viscous dampers and pneumatic isolators, IAEA Letter 622-I3-RC-624, 1996-03-26.
4. ABAQUS V.5.5, Hibbitt, Karlsson & Sorenson, Inc.



Diameter of HDRB(mm)	125
Rubber Thickness(mm)	2.5
No. of Rubber Layers	12
Total Rubber Height(mm)	30
Shim Plate Thickness(mm)	1.0
No. of Shim Plates	11
Shape Factor	12

Fig.1 Geometrical Data for ENEA HDRB

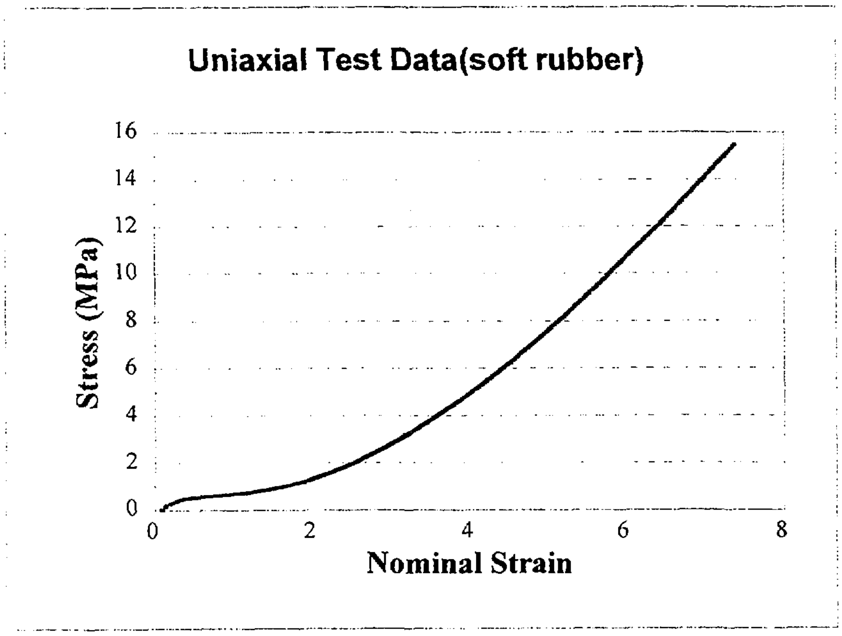


Fig.2 Uniaxial Test Data for ENEA HDRB(Soft Compound)

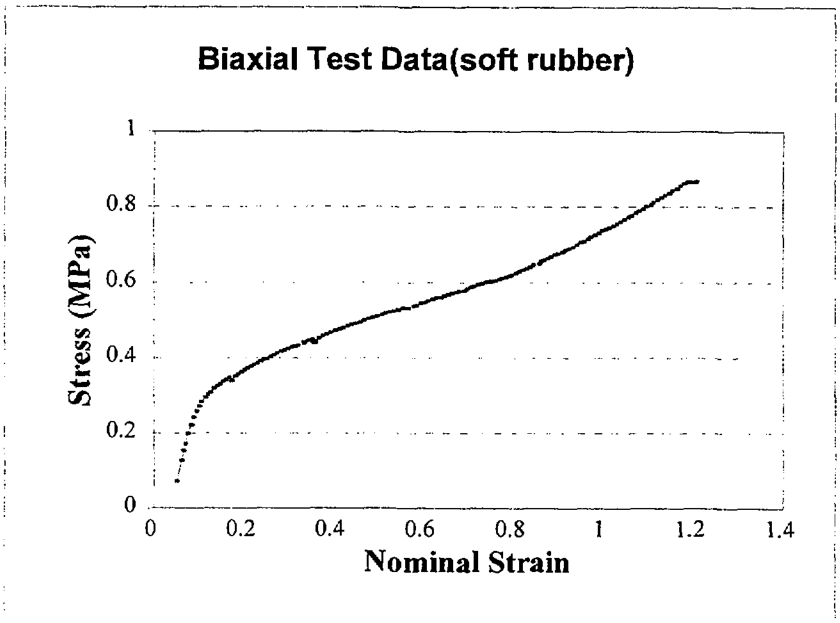


Fig.3 Biaxial Test Data for ENEA HDRB(Soft Compound)

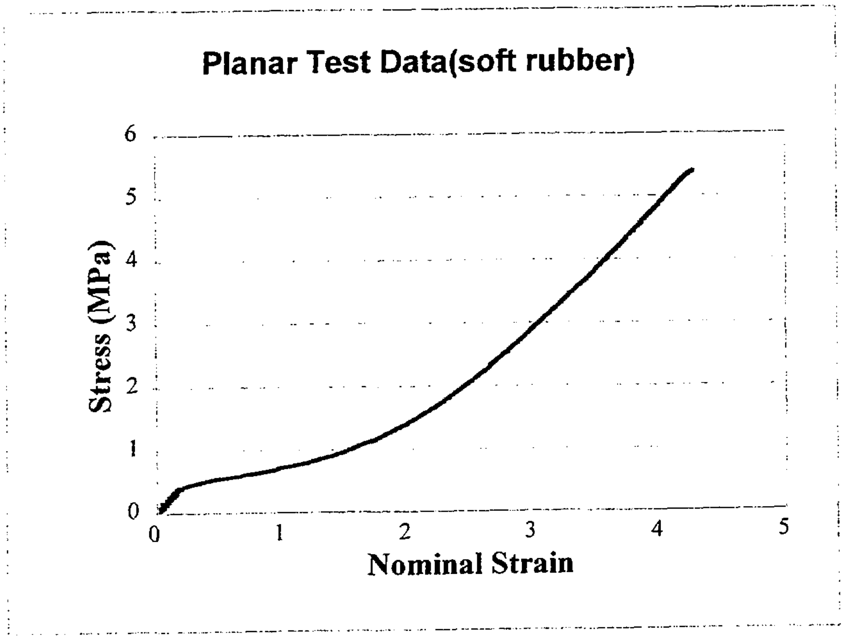


Fig.4 Planar Test Data for ENEA HDRB(Soft Compound)

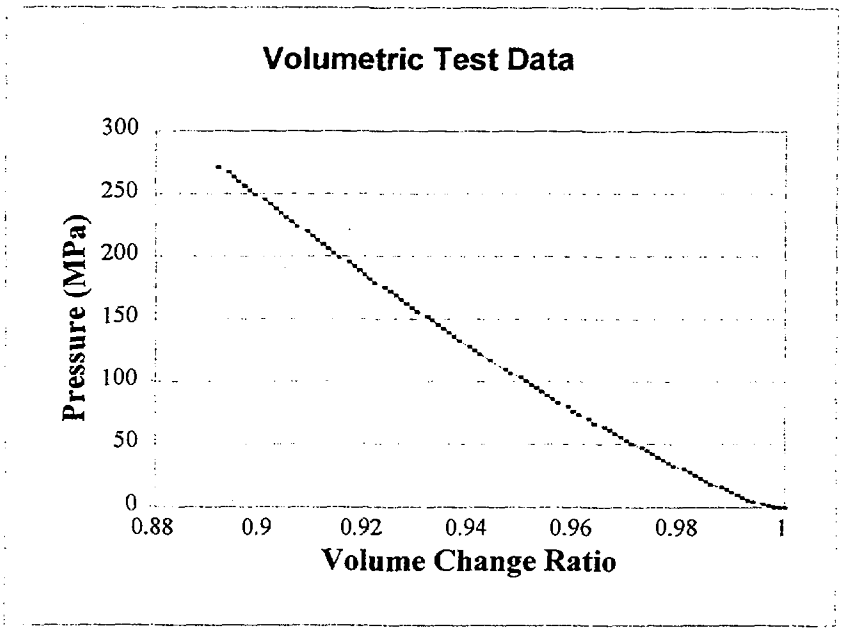


Fig.5 Volumetric Test Data for ENEA HDRB(Soft Compound)

Test BQ062: combined compression (50 kN) & shear (50% - 100% - 150% - 200% - 300% - 400% shear strain) loads

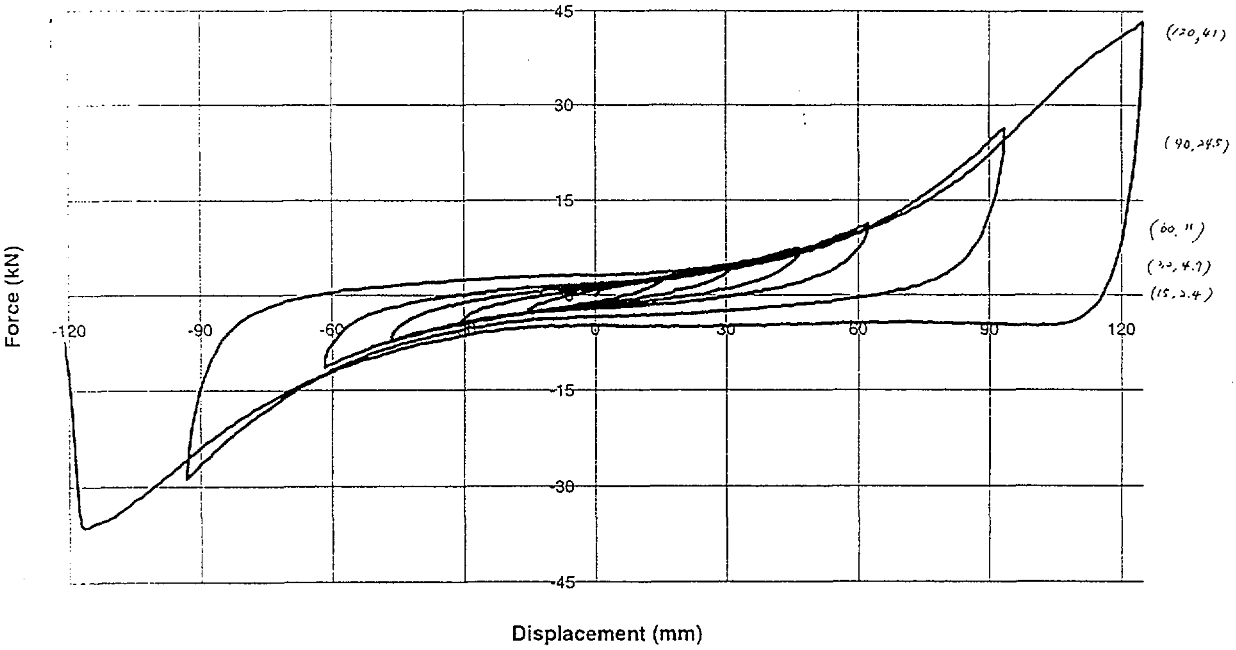


Fig.6 Combined Compression and Shear Test for ENEA HDRB(Soft Compound)

Test BQ811: compression at 1100% design vertical load

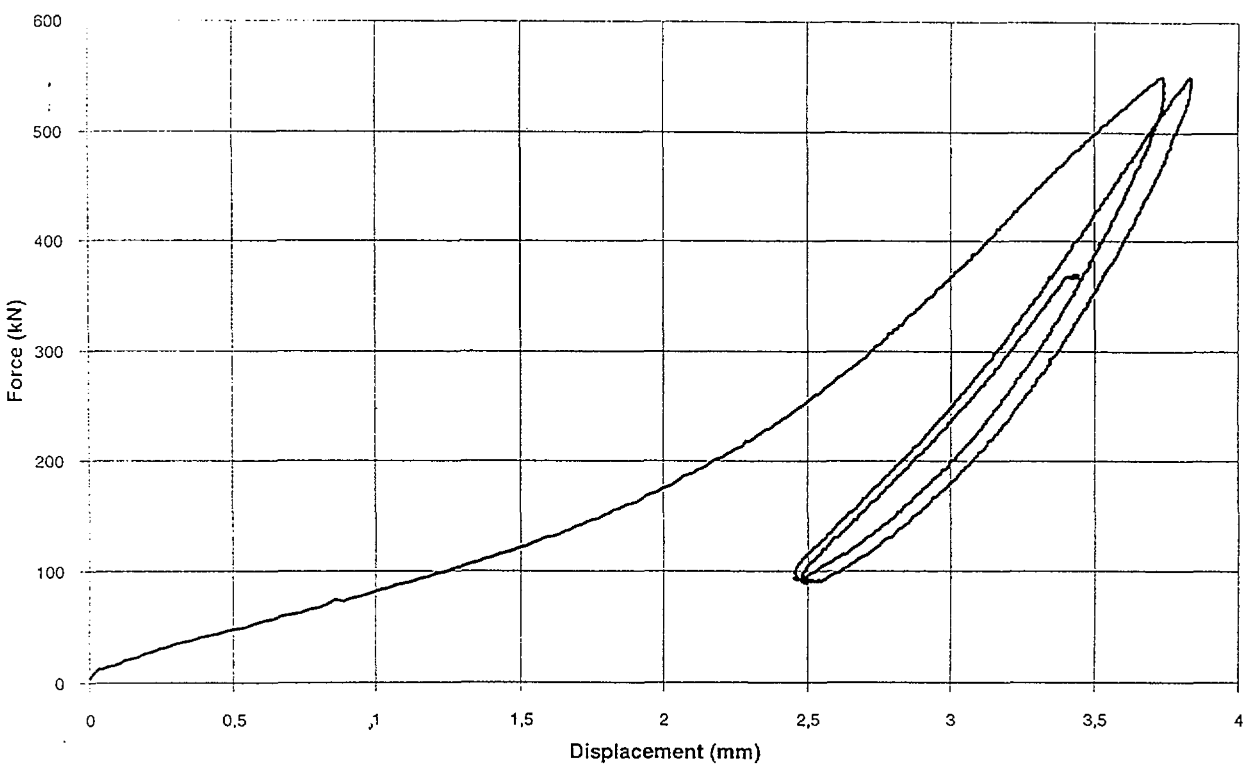
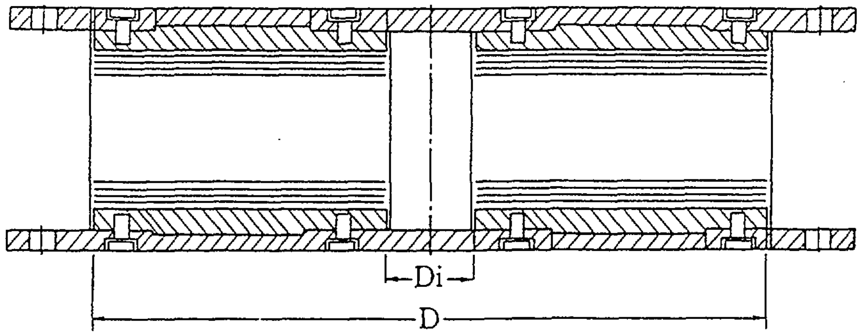


Fig.7 Compression Test for ENEA HDRB(Soft Compound)



Similitude Ratio	1/1.58
Diameter of NRB(mm), D	1012
Inner Diameter(mm), Di	126
Rubber Thickness(mm)	5.7
No. of Rubber Layers	25
Total Rubber Height(mm)	142.5
Shim Plate Thickness(mm)	3.1
No. of Shim Plates	24
Primary Shape Factor	38.9
Secondary Shape Factor	7.1

Fig.8 Geometric Data for CRIEPI NRB(200tonf)

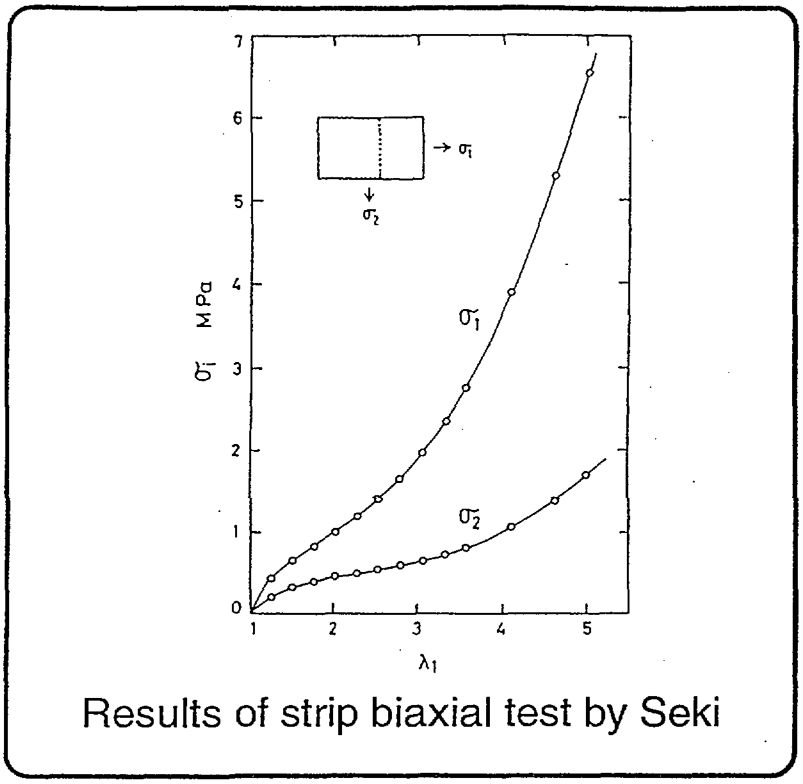


Fig.9 Strip Bi-axial Test Data for CRIEPI NRB

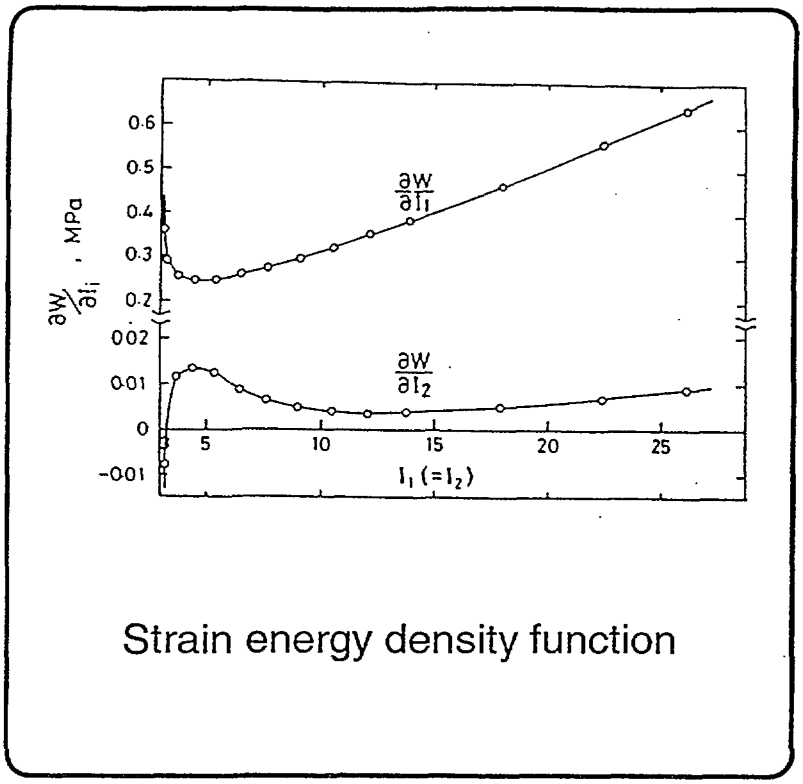


Fig.10 Coefficients of Strain Energy Function for CRIEPI NRB

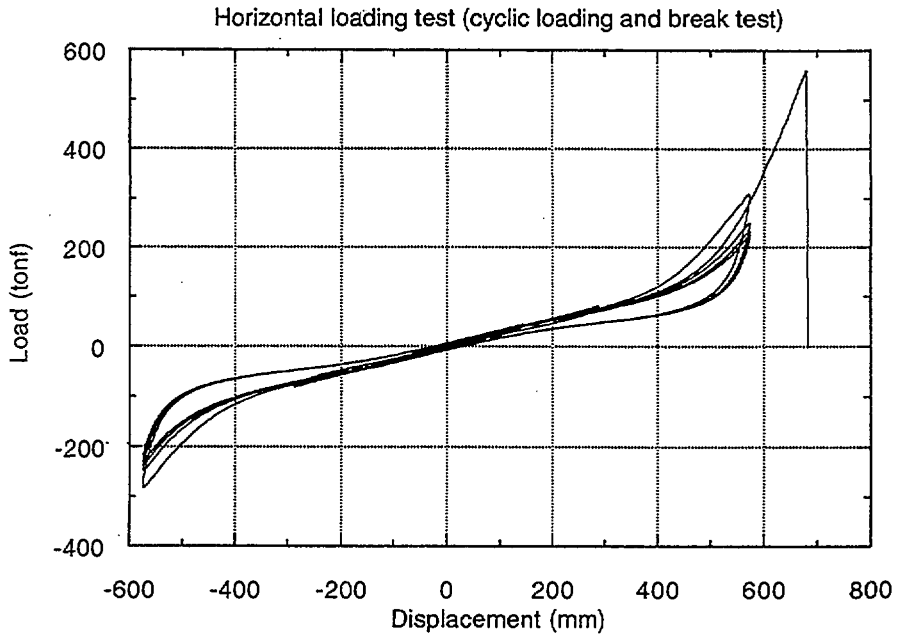


Fig.11 Combined Compression and Shear Test for CRIEPI NRB

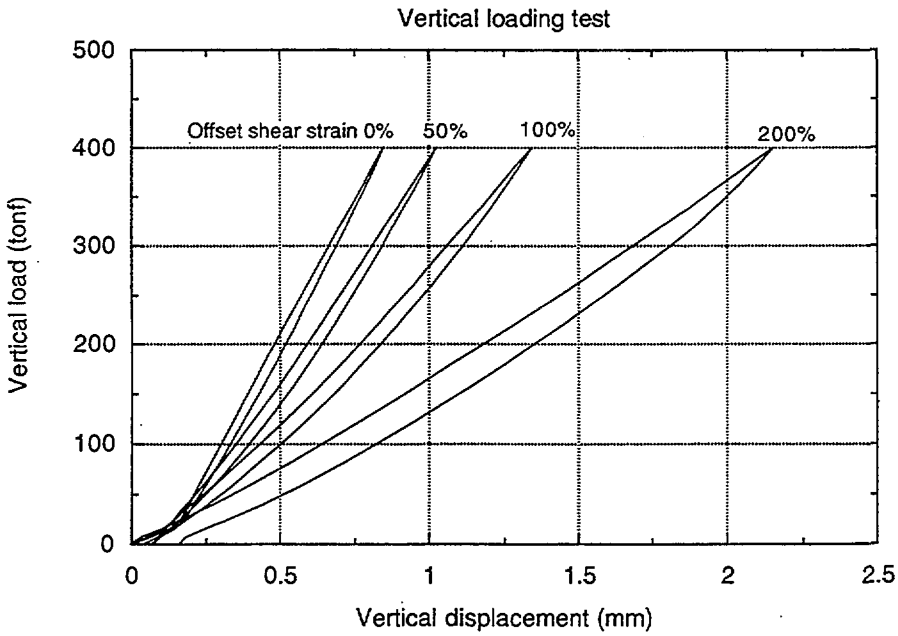


Fig.12 Compression Test for CRIEPI NRB

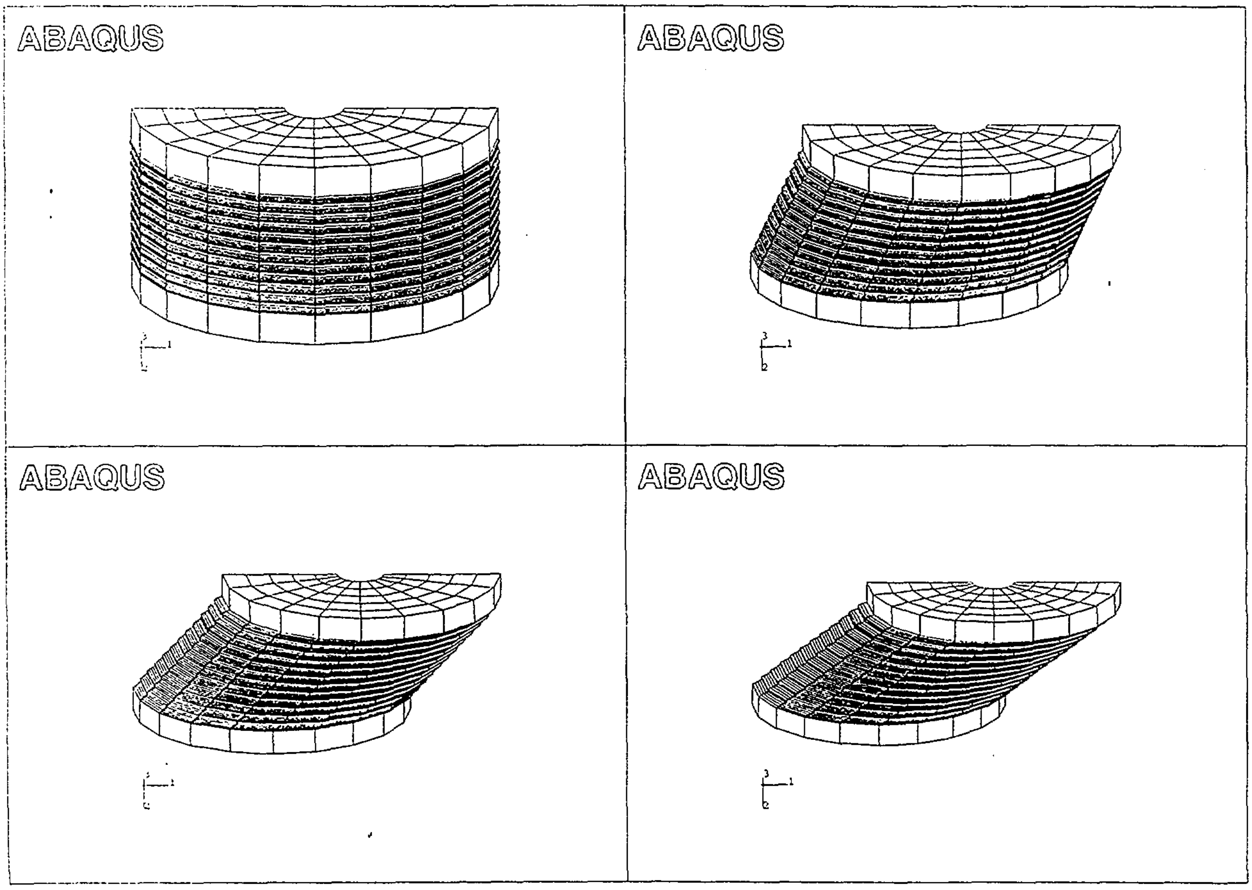


Fig.13 Analysis Model for ENEA HDRB

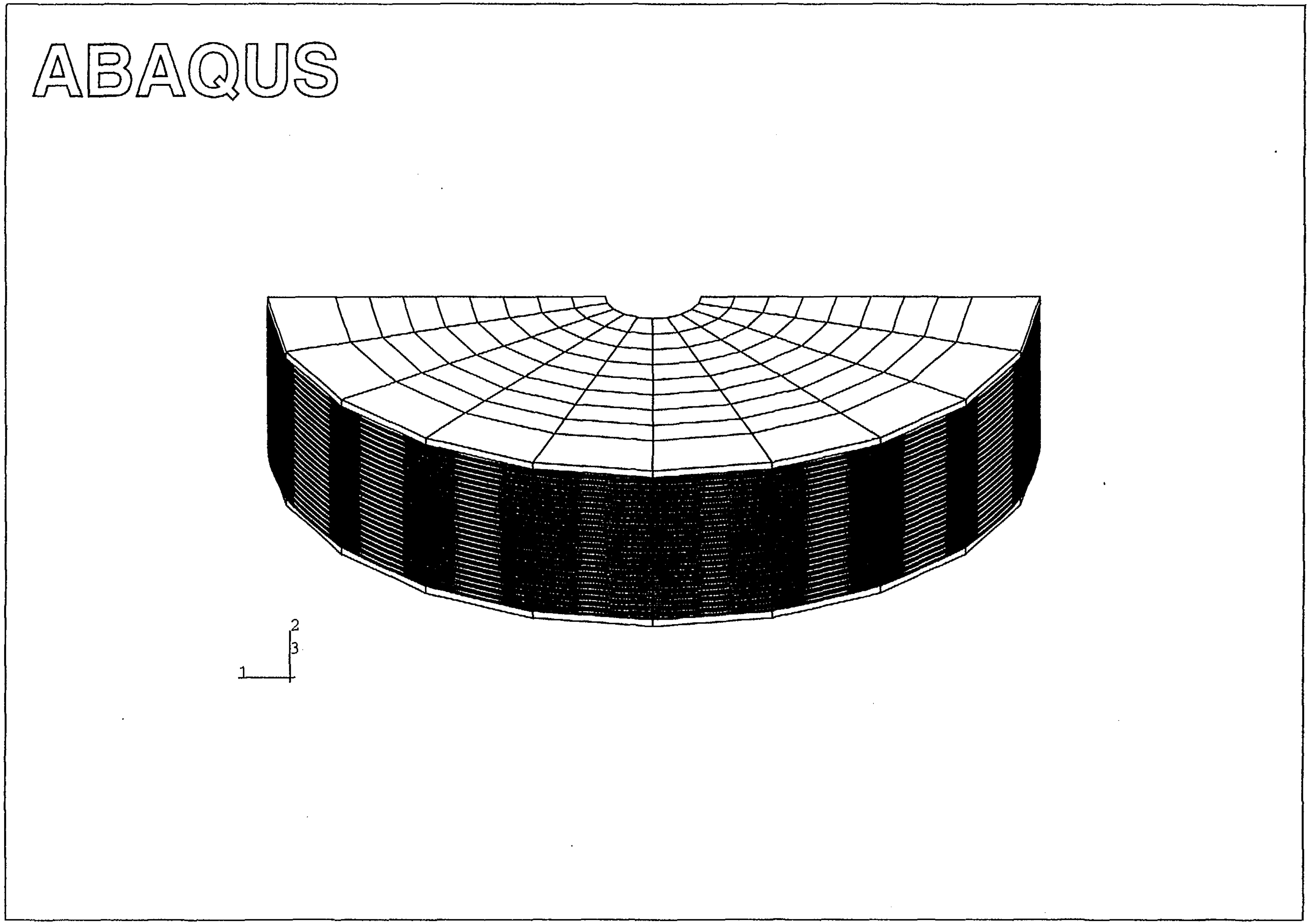


Fig.14 Analysis Model for CRIEPI NRB

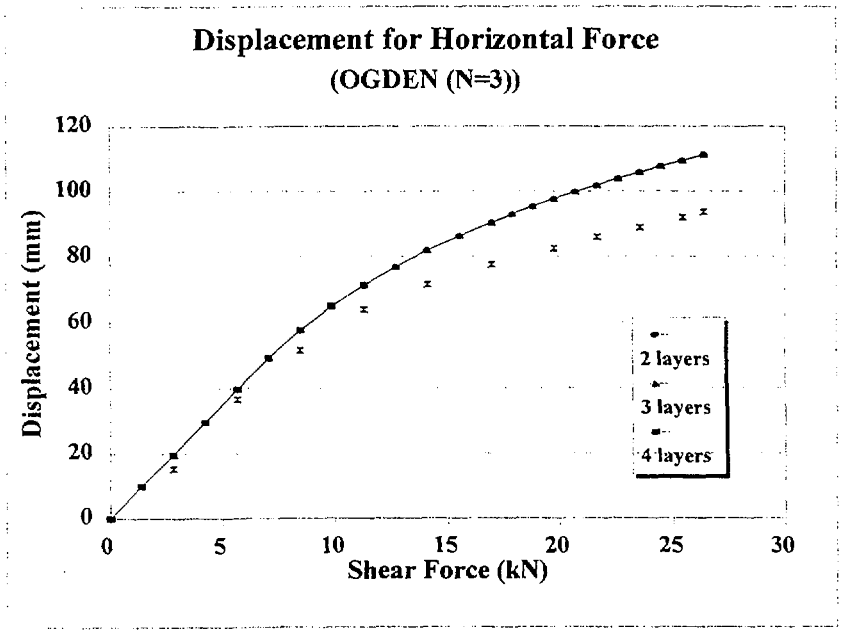


Fig.15 Analysis Results of Combined Compression and Shear with Variation of No. of Rubber Layers for ENEA HDRB(Soft Compound)

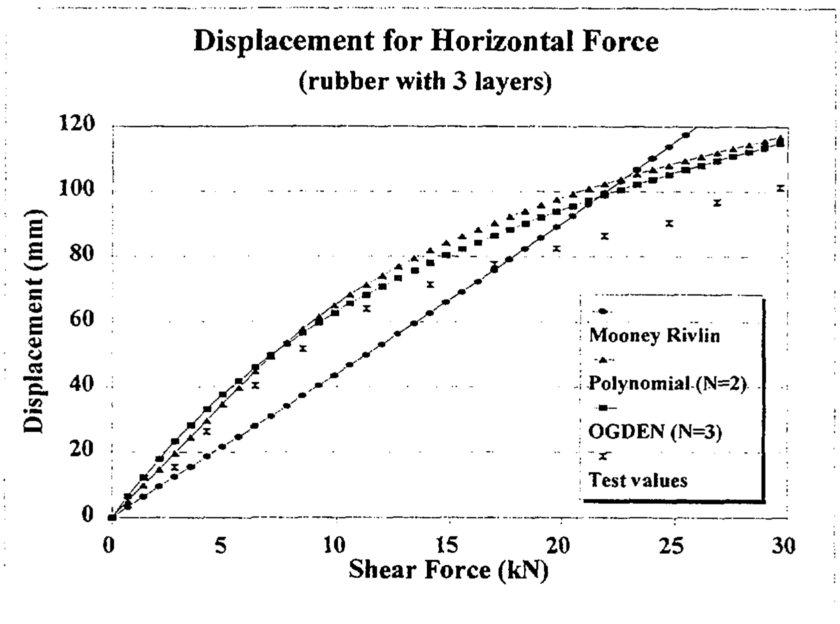


Fig.16 Analysis Results of Combined Compression and Shear with Different Rubber Models for ENEA HDRB(Soft Compound)

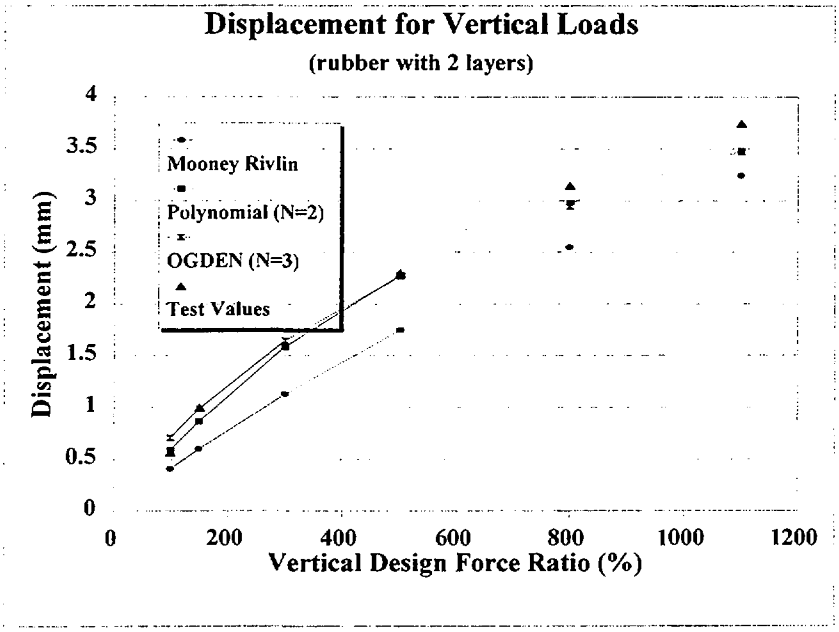


Fig.17 Analysis Results of Compression Test with Different Rubber Models for ENEA(Soft Compound) (No. of Rubber Layers=2)

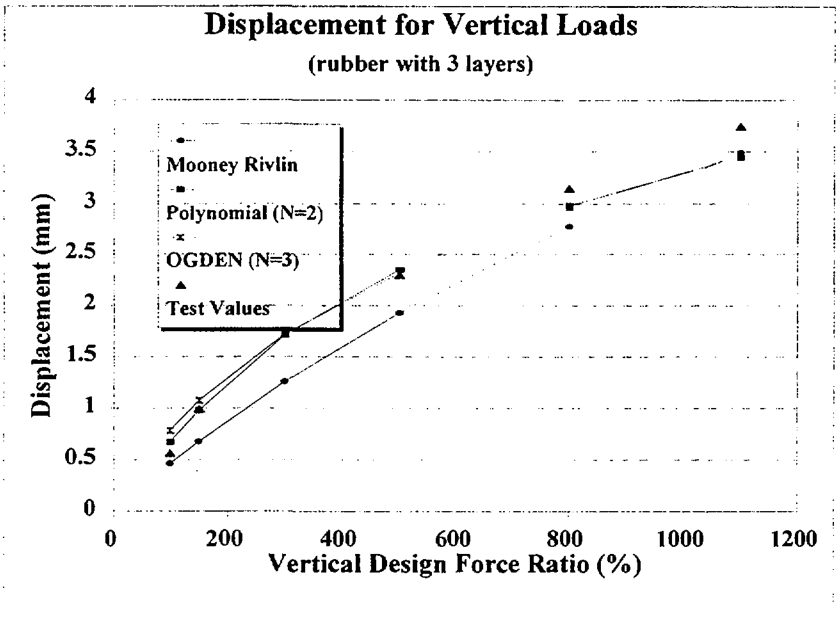


Fig.18 Analysis Results of Compression Test with Different Rubber Models for ENEA(Soft Compound) (No. of Rubber Layers=3)

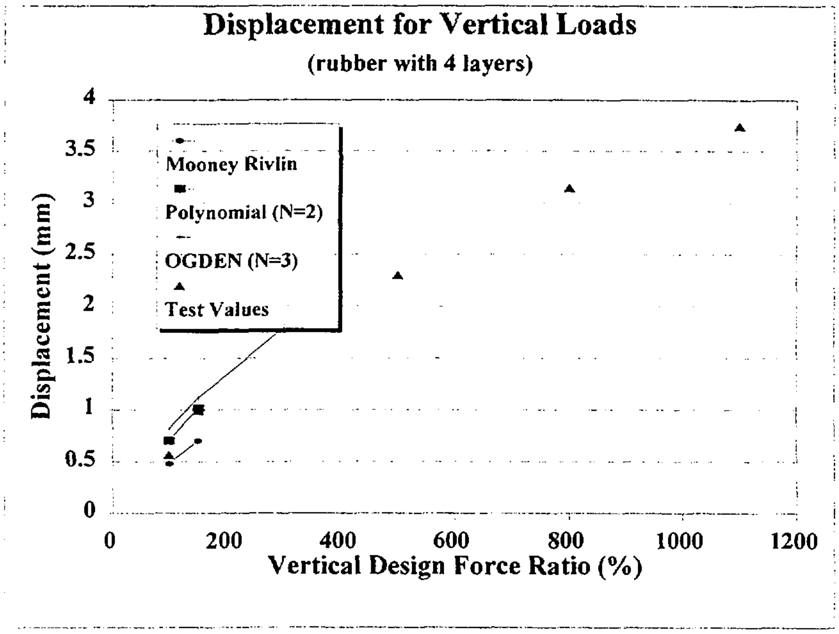


Fig.19 Analysis Results of Compression Test with Different Rubber Models for ENEA(Soft Compound) (No. of Rubber Layers=4)

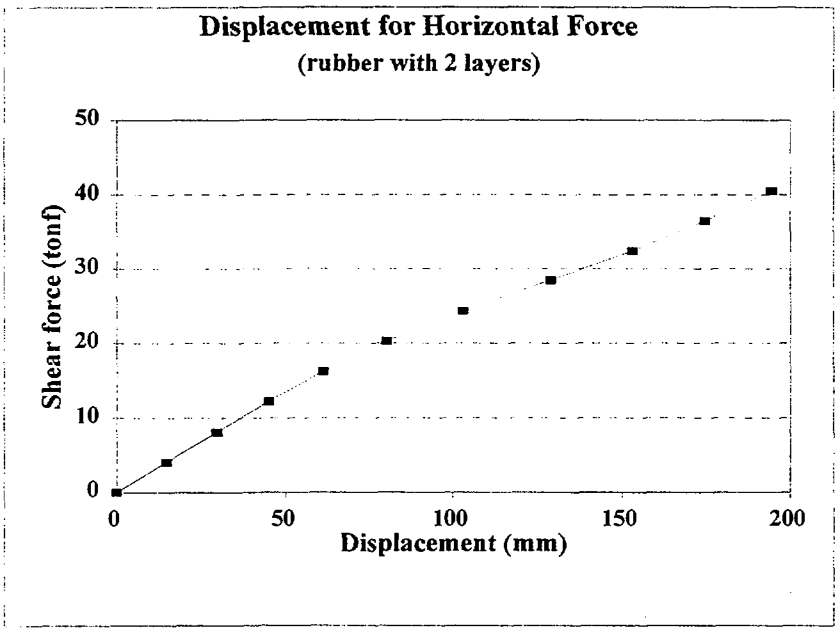


Fig.20 Analysis Results of Combined Compression and Shear for CRIEPI NRB (No. of Rubber Layers=2)

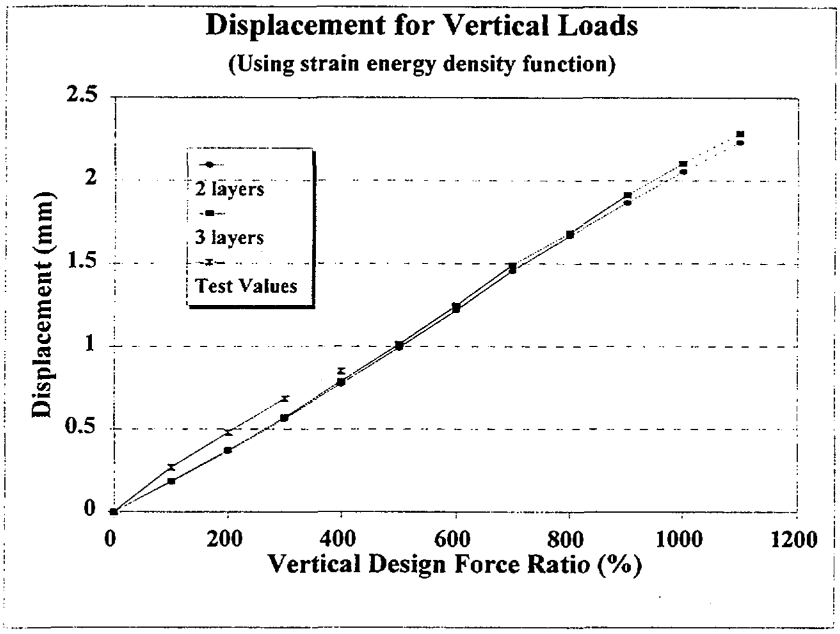


Fig.21 Analysis Results of Compression without offset for CRIEPI NRB

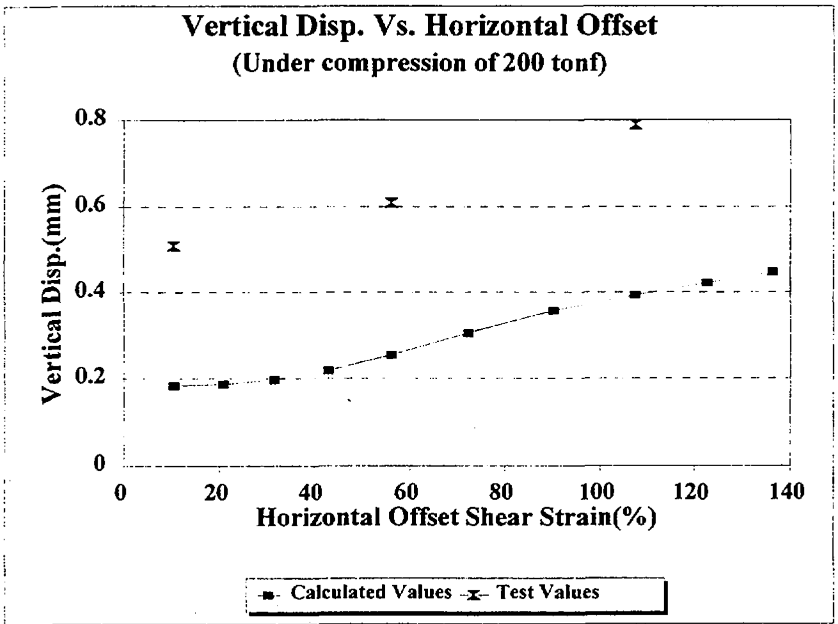


Fig.22 Analysis Results of Compression with offsets for CRIEPI NRB