My Research or the Project of the MSs in Computer Aided Engineering which was done in ١٩٩٠ Coventry Polytechnic or at the moment Coventry University for the Rover Group Car Company in England, United Kingdom.

MSc Project/Research

Optimization of cost and weight efficiency of Rover “World” Front Seat Design in support of R٦X Programme.

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Supervisors, Mr. Steve Jerrams, Dr. Ray Jones

Summary

The desire for a weight reduction and deflection analysis and stress analysis of a new front seat for the Rover R٦X resulted in the necessity for Finite Element analysis.

A computer model was generated on CADDS-٤X system and the meshed geometry passed to a Harris computer running ANSYS and then transferred to SUN Workstation for further analysis.

Loading conditions to simulate the seat under rear impact by an unrestrained object during frontal collision were devised and applied to the model.

Cases of a ٣٤kg object hitting the seat at ٤m/s^{٢}, ٥١kg object at ٤m/s^{٢} and ٦٨kg object at ٤m/s^{٢} and ٨٤kg object at ٤m/s^{٢} were examined. Model conditions of (a) Original thicknesses (٠.٧mm, ١.٢mm), (b) Development thicknesses (٠.٦mm, ١.١mm), and (c) Production thicknesses (٠.٥mm, ١.٠mm) were investigated under these loading conditions.

The Finite Element Analysis was carried out on R٦X front seat squab frame using Linear Static analysis, and Non-linear Static analysis due to material properties and large displacements. These results showed and proved the prediction that it is possible to make cost saving by reducing material thicknesses and increased in size of some holes and the flange in the model in comparison with the original design.

١.٠ Introduction

Rover, as the case with other car world manufacturers are seeking to improve their product designs by reducing weight without impairing function. The front seat design, of which this project is concerned is an example. In addition to the usual service conditions the seat must also safely cope with crash situations. During sudden braking or a frontal impact of the vehicle unrestrained objects in the rear of the car are thrown forward and may hit the front seat. Under these conditions it is desirable that the seat does not fracture and become another projectile within the car. Nor is it desirable that the seat remains so rigid that it does not yield since the object hitting it could well be a rear seat passenger. To simulate these crashes resulting ٤m/s^{٢} deceleration were examined with objects such as ٣٤kg. Also the case of ٤m/s^{٢} deceleration with objects of ٥١kg, ٦٨kg and ٨٤kg were examined. Although the failure mode will be the same in these cases the degree of failure or amount of deflection can be judged. Since it is also of interest to reduce the seat weight different metal thicknesses will be examined.

The seat design is a fairly complex ٣-D problem that lend itself to an analysis by Finite Element Methods.

In order to produce the data for analysis, a fully three dimensional model of the seat was created on a CADDS-٤X system. From this a meshed model was produced and this information transferred to SUN-workstation using an ANSYS system for analysis. In line with standard techniques only a half model was required and changes to material thickness being performed within the ANSYS program.

As with all Finite Element Work, in addition to the generation of a sensible mesh, the careful selection of loads and constraints is important. It was decided that initially the loading would be applied in the form of a pressure load at the top of the seat and the constraints would be applied rigidly at the lumbar adjustment position. Once these initial conditions had been tested the development of the model could depend on whether the results suggested changes to the model, constraints or type of analysis were required since a non-linear static analysis and linear elastic analysis were necessary.

Since there is only a limited amount of time available for the project an exhaustive investigation was not possible. Under these circumstances only a preliminary investigation would be possible but indicating areas of future work.

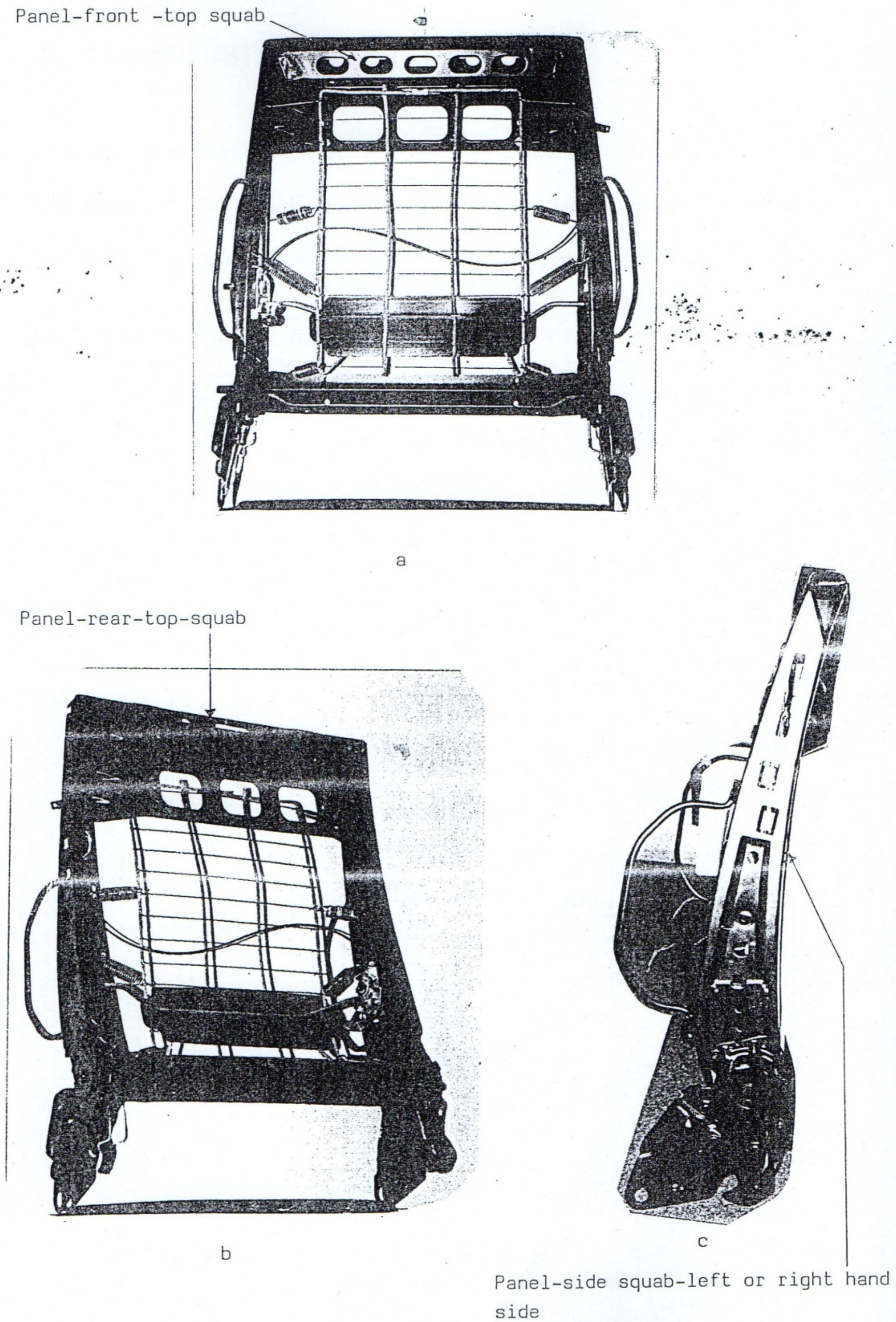
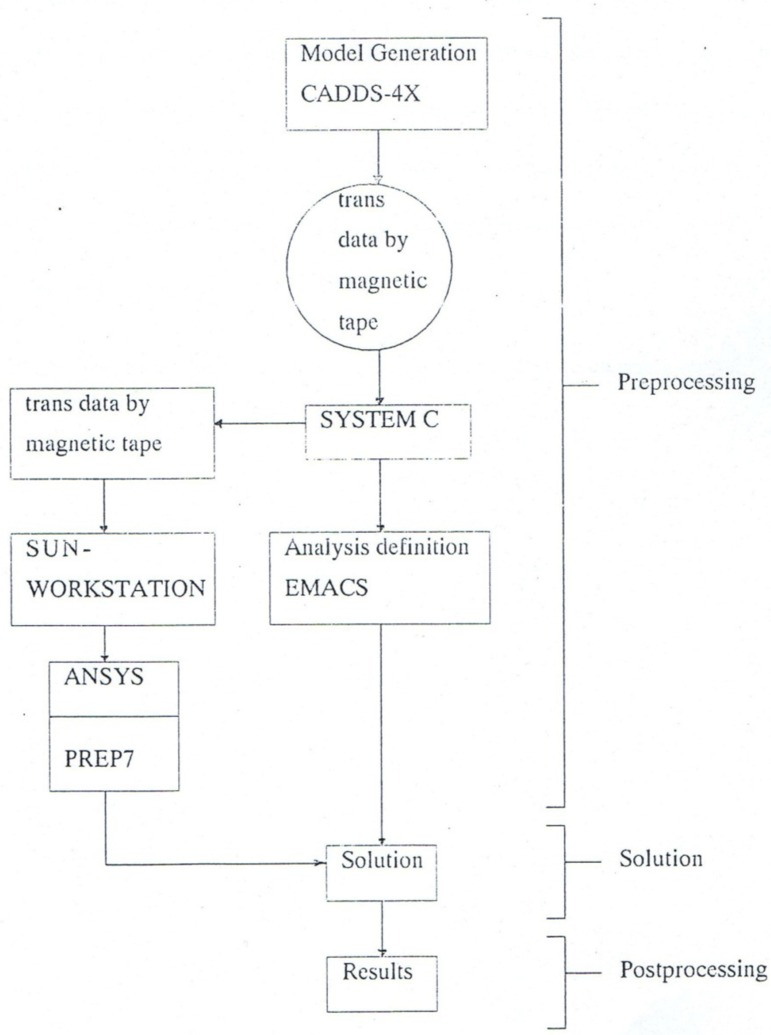


Figure 1 a, b and c shows three different views of the actual seat

2.0 ANSYS FINITE ELEMENT PACKAGE

To achieve the main activities of the project it was decided to use the facilities available for modelling, CADDS-4X chosen as a pre- processor and the new version of the ANSYS Package installed on a SUN-workstation for analysis and post processing.

Figure (2) shows how data transformed from CADDS-4X system to ANSYS.



2.1 BUILDING 2-D SIMPLIFIED MODEL

The simple 2-D model of half and full seat was generated using quadrilateral shell STIF63 element. This element has six degrees of freedom at each node. This type of element has an option for variable thickness.

Key-points were defined at certain part of the model. Lines and areas were then defined and elements generated along these. The mesh size of the elements were medium. The material of the seat was mild steel to BS1449 - Part 1:1983 and the values of thickness, poisson's ratio and modulus of elasticity were defined. The half model was for linear static analysis and the full model was intended for dynamic linear analysis (see Appendix A). Pressure load was applied to the forward direction as a rear impact by an unrestrained object during a sudden braking.

These models were an attempt to allow for the creation of a more complex model.

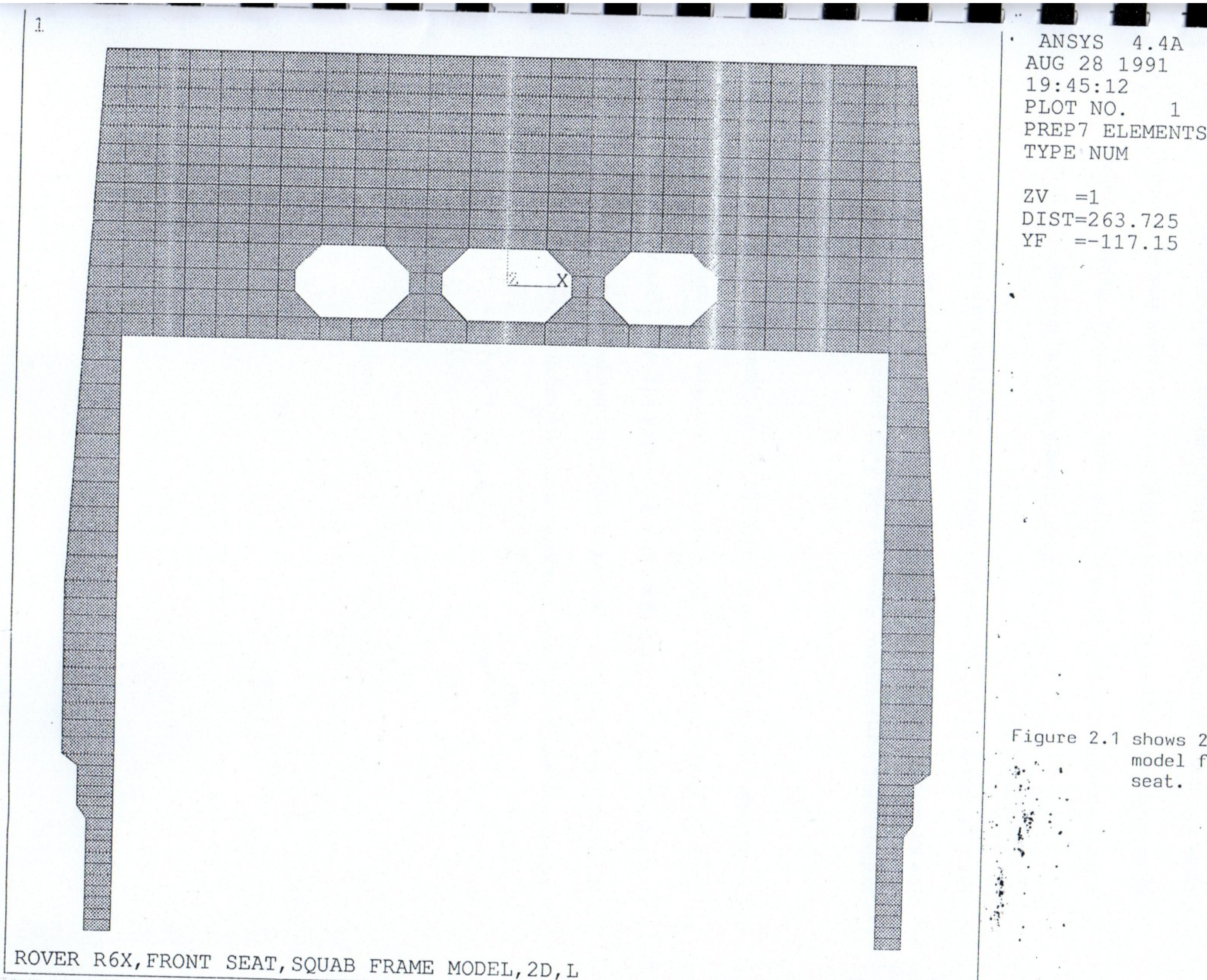


Figure 2.1 shows 2-D simplified model for a complete seat.

3.0 BUILDING 3-D MODELS

Due to the very complex geometry of the seat a large amount of project time would require to be spent modelling the seat to get as accurate as the dimensions shown on the original drawings. There was insufficient time to go for modelling complete seat, since only Linear and Non-linear analysis were required.

The 3-D model of one half of the seat was generated using CADDS- 4X as a pre-processor i.e. a wireframe model was described in terms of points and lines, grid points and elements then were generated along these by using computervision finite element manual.

Element type used was quadrilateral shell STIF63 element. This element has six degree of freedom at each node, translation in the nodal x, y and z directions and rotations about the nodal x, y, and z axes. The quadrilateral shell has an option for variable thicknesses. The data of this model was then successfully transferred to ANSYS pre-processor where material properties, constraints and loads were added. Figure (3) shows the elements plot of the model.

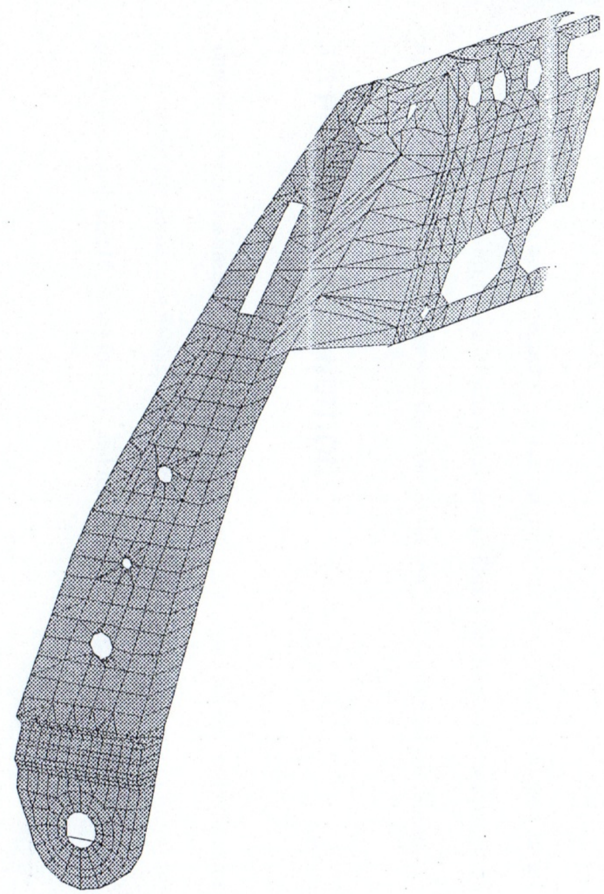


Figure 3. shows the elements plot of the model.

3.1 ORIGINAL CONDITION

This model is the main model which was generated using CADDS-4X and ANSYS package. This model was built up using the original thicknesses of the seat as it was designed. The thicknesses were (1.2 mm) for panel side squab and (0.7mm) for front and rear panel top squab. (see Appendix B). Fig.3.1 shows plot of two different thicknesses.

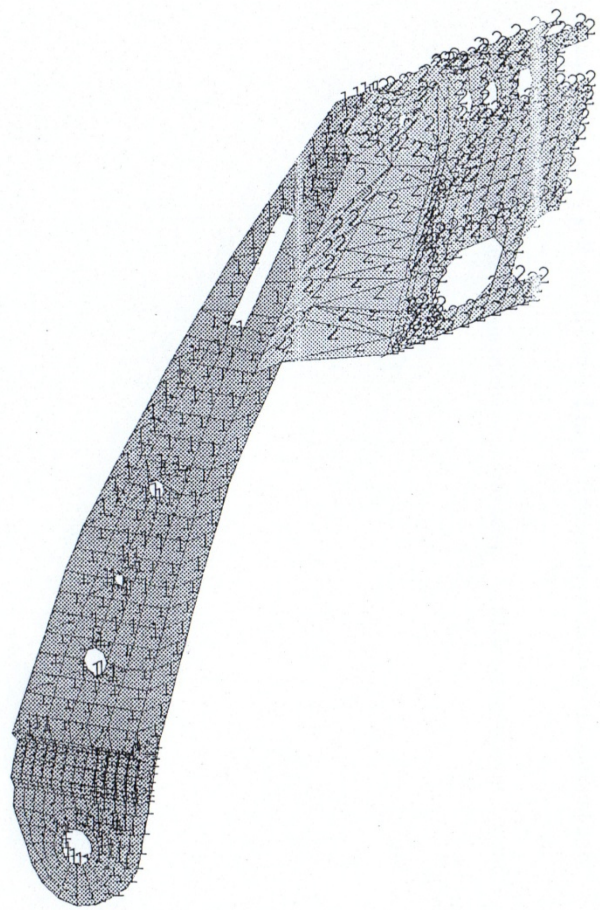
The material of the seat was mild steel to BS1449 - Part 1:1983 as stated on the drawing HFA10109 (squab frame). The mesh size of the elements were medium and fine mesh used on the area of most interest where the lumbar support bracketry restraint.

3.2 DEVELOPMENT CONDITION

This model has the same geometry of the original one but it was developed to the thicknesses of (1.1mm) for panel side squab and (0.6mm) for front and rear panel top squabs. The material of the seat was the same as the material of original condition.

3.3 PRODUCTION CONDITION

This model was presumed as a production of the seat model, again it has exactly the same geometry of the above conditions. The thicknesses of this condition were (1.0mm) for panel side squab and (0.5mm) for front and rear panel top squabs.



ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7),L

A[illegible]S[illegible]A
AUG 21 1991
15:12:37
PLOT NO. 1
POST1 ELEMENTS
TYPE NUM

XV =2
YV =1
ZV =3
DIST=301.548
XF =81.74
YF =207.95
ZF =-108.648

Figure 3.1 shows plot of two different thicknesses of the model.

4.0 RESTRAINTS AND LOADS

After transferring the data successfully from the CADDS-4X to the ANSYS pre-processor where material properties, constraints and loads were added. The seat was constrained along the centre line in the z-direction, and at lumbar support bracketry in all directions where the permanent fixing of full seat at both sides would occur. Loads were applied in a form of elements pressure as a rear impact (see Appendix D).

The type of loading applied was 51kg object at 4 m/s^2 for Linear static analysis on all three conditions.

The cases of 34 kg object hitting the seat at 4 m/s^2 and 51 kg object at 4 m/s^2, 68 kg at 4 m/s^2 and 84 kg at 4 m/s^2 for Non- Linear static analysis on original condition only.

For 3/4 of load and half load on three conditions see tables of linear analysis in Appendix (G).

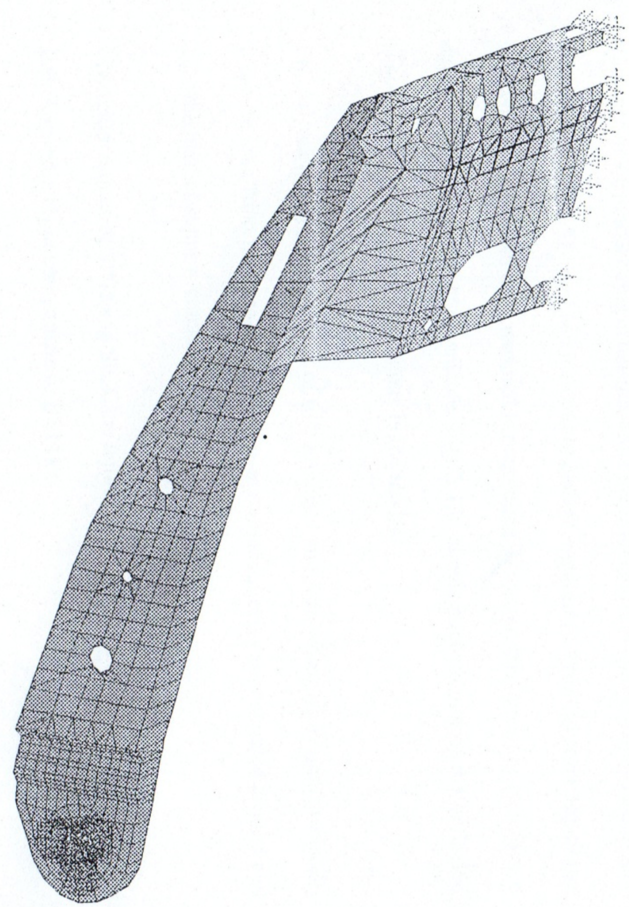


Figure 4 shows the constraints along the centre line and at lumbar support bracketry and pressure load applied on two rows of elements.

5.0 LINEAR STATIC ANALYSIS RESULTS

The results of the three models (original, development and production conditions) were obtained. These values represent deflections, principal stresses and Von Mises equivalent stress in maximum and minimum values. For SIG2 and SIG3 see the tables in Appendix (G).

5.1 ORIGINAL CONDITION

Fig. 5.1.a. shows analysis results with the deflected shape in dark colour and the undeflected shape in the broken line. The plot shows clearly two views of the model the back face of the model being in tension while the front face is in compression. This model was subjected to a 51 kg object resulted in displacement of (4.776mm) at the top of the seat which would seem to be reasonable magnitude, however, this cannot be exact since experimental data were not available. Fig. 5.1.b. shows contour plot of the deflected shape, lowest and highest deflections in the model.

Fig. 5.1.c, Fig. 5.1.d, show plots of first principal and Von Mises equivalent stress. As it can be seen from these contour plots the maximum stresses concentrated around and near the lumber support bracketry.

Maximum values of SIG1 and SIGE are within the permissible stress level of mild steel (see Appendix H) in comparison to BS1449.

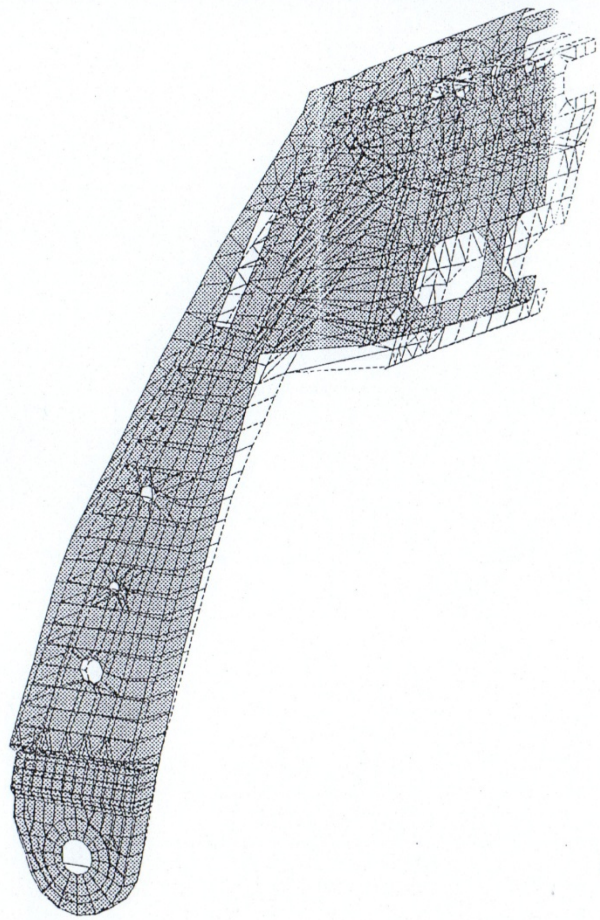


Figure 5.1.a. shows deflection results of original condition.

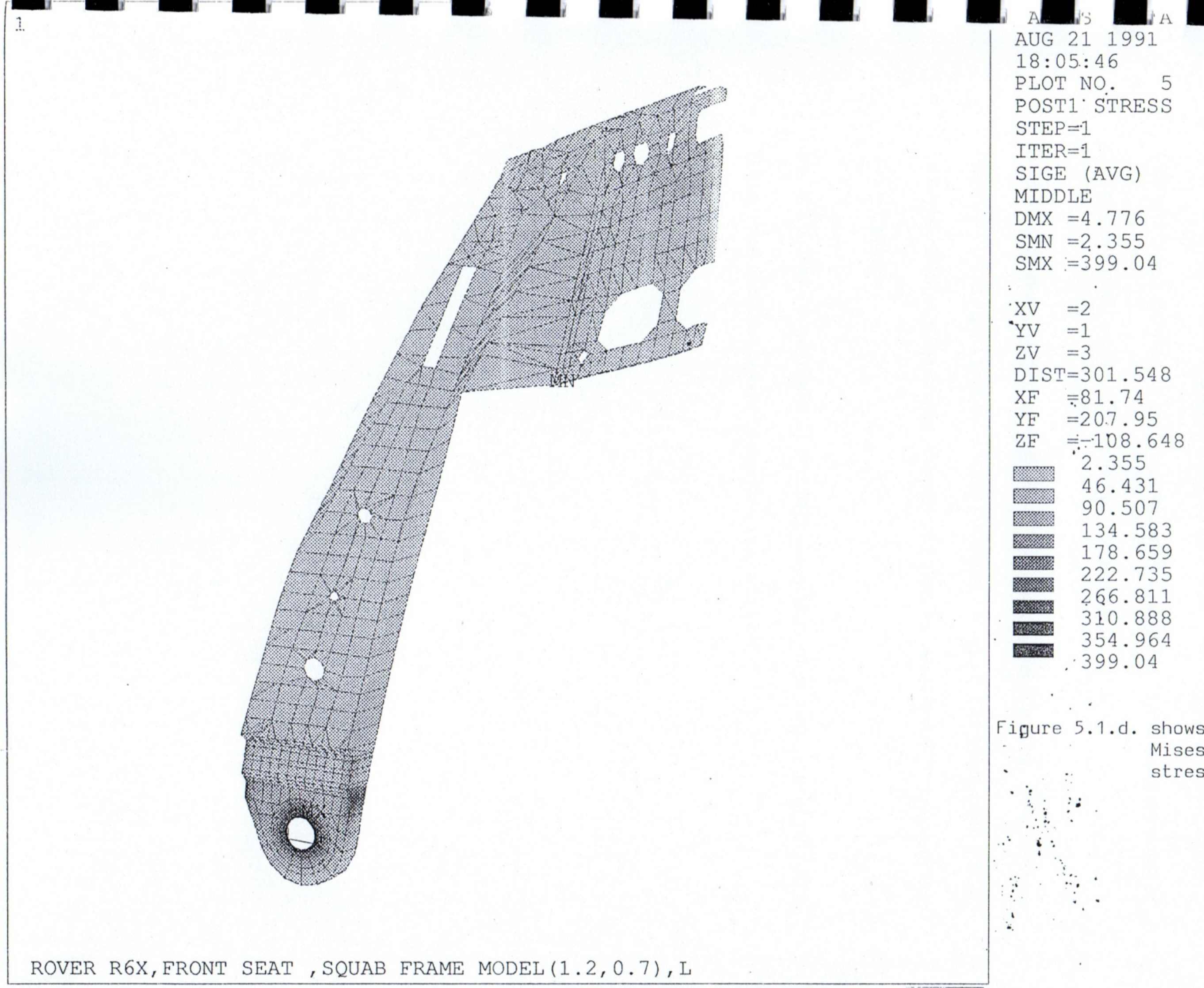


Figure 5.1.d. shows plot of Von Mises equivalent stress SIGE.

5.2 DEVELOPMENT CONDITION

Fig. 5.2.a. shows contour plot of first principal stress with value of (346.402 N/mm^2). This plot is also showing the deflection value which is (5.831mm). The same amount of loading of original condition is applied to this condition.

Since this model is smaller in thicknesses than the original condition, the deflection results is (1mm) higher than the original condition. Obviously this would cause a little bit higher level of stresses than the original condition, but it is still very near to the BS1449 values.

Fig. 5.2.b. shows contour plot of Von Mises equivalent stress with value of (436.727 N/mm^2) and this value is valid in comparison to BS1449.

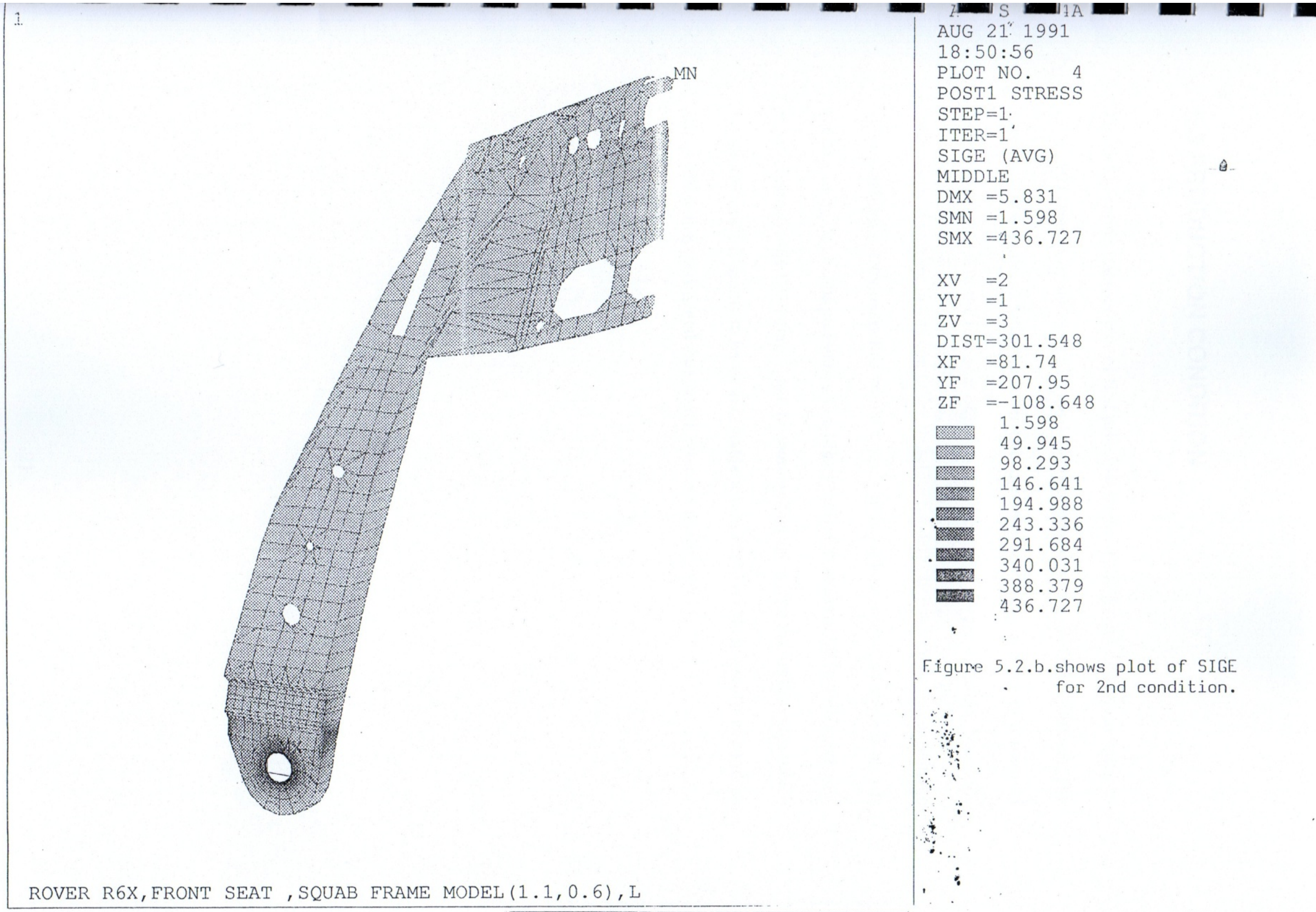


Figure 5.2.b.shows plot of SIGE for 2nd condition.

5.3 PRODUCTION CONDITION

Fig. 5.3.a. shows contour plot of first principal stress or SIG1 with maximum value of (396.779 N/mm^2), on the same plot the deflection value of this model is (7.399mm). The loading is the same as with the other two previous conditions a 51kg in a form of unrestrained object in the rear seat of the car is thrown to forward direction. Since the thicknesses is smaller in this condition, therefore the deflection would be larger than the other conditions. Obviously this would cause a little bit higher level of stresses as it is the case in fig. 5.3.b, this plot shows Von Mises equivalent stress or SIGE with maximum value obtained (481.961 N/mm^2) and to compare this value with that of BS value which is (480 N/mm^2) it seems to be of acceptable result. However these results need to be compared with experimental data which were not available.

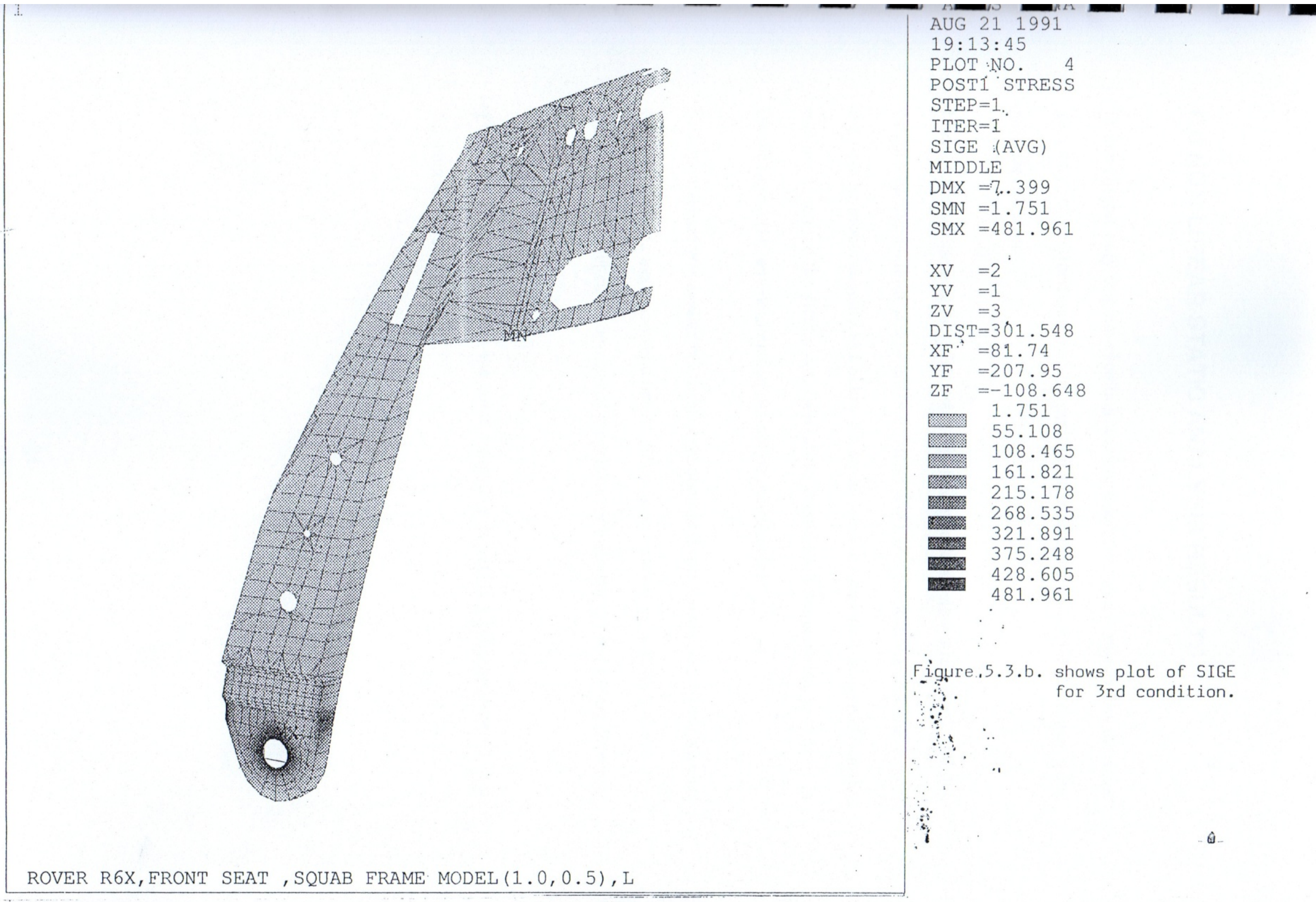


Figure.5.3.b. shows plot of SIGE for 3rd condition.

6.0 NON-LINEAR STATIC ANALYSIS RESULTS

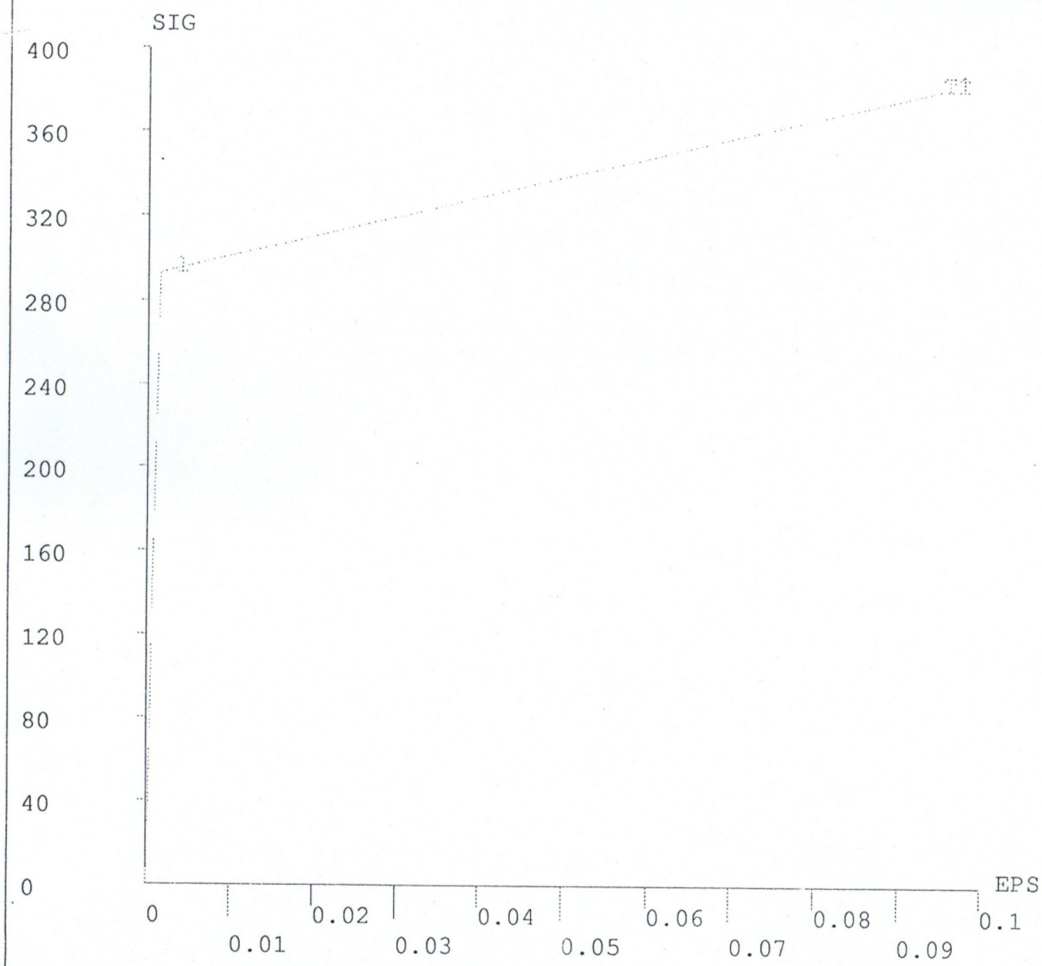
In this chapter only original condition was considered in which exactly has the same geometry, constrained and loading position as described earlier in the linear static analysis conditions.

Most of the engineering materials behave in linear pattern below stress level, and this called proportional limit. Below this limit, stress is in linear proportional to strain. Above the limit of proportionality and below the stress level the materials behave elastically and this is termed the yield point. Beyond the elastic limit the materials said to be in plastic region (i.e. any deformation can not be recoverable).

Incremental load was applied in a form of elements pressure. To check or to see whether this model or this analysis would behave in the same manner as described above, two plots of stress/strain curve of material properties for materials (1) and (2) are shown in Fig. 6.a, and Fig. 6.b.

The material which exhibits the same behaviour is called a bilinear material. See Appendices (C) and (D).

PLAS FOR MATERIAL 1



AUG 21 1991
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T2 =80

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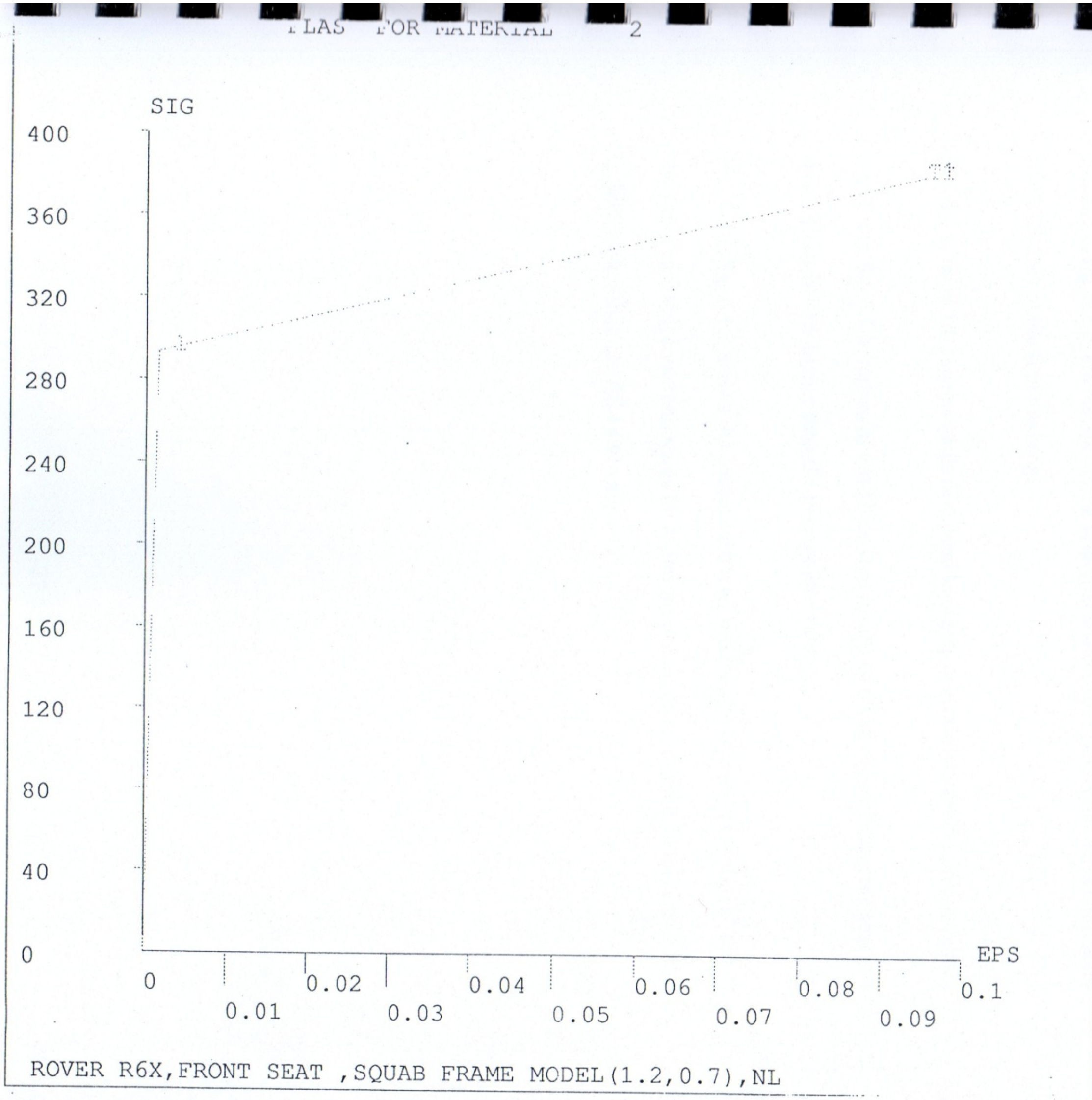
XF =0.5
YF =0.5
ZF =0.5
XRTO=1

ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7),NL

Figure 6.a. shows plot of stress/ strain curve of 1st material properties.



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YF =0.5
ZF =0.5
XRTO=1

Figure 6.b. shows plot of stress/strain curve of 2nd material properties.

6.1 ORIGINAL CONDITION

This model represents the non-linear static analysis. The loading used in this model was stepped loading. Fig. 6.1.a. shows deflection results for load step one and first iteration. Fig. 6.1.b. shows contour plot of deflected shape showing the maximum and minimum results obtained in the first step.

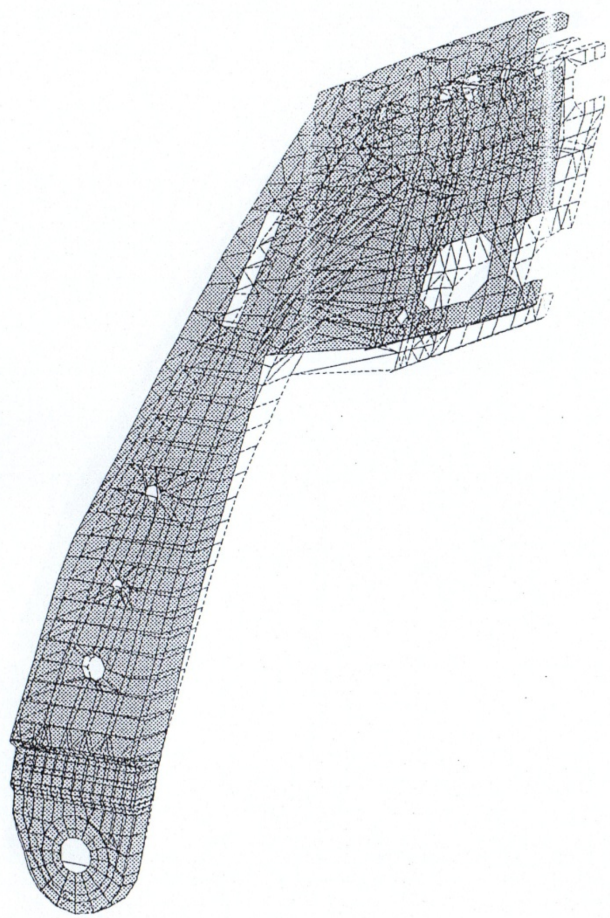
Fig. 6.1.c, fig. 6.1.d, are results of first principal stress (SIG1) and Von Mises equivalent stress (SIGE) of the first load step.

Fig. 6.1.e, fig. 6.1.f, shows results of second load step in maximum and minimum values.

Fig. 6.1.g, fig. 6.1.h, represent third load step results of 68 kg object hitting the seat at 4 m/s^2. SIGE is 10% higher than the permissible value.

Fig. 6.1.i, fig. 6.1.j, shows the fourth load step results of 84 kg object at 4 m/s^2 this is the worst case that could happen as far as this investigation concerned. In this case SIGE is 38% higher than the BS 1449 value.

1



ANSYS 4.4A
AUG 21.1991
13:20:04
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ITER=1
DMX =3.184

DSCA=9.471
XV =2
YV =1
ZV =3
DIST=301.548
XF =81.74
YF =207.95
ZF =-108.648

Figure 6.1.a. shows deflection results of Non-linear model.

ROVER R6X, FRONT SEAT , SQUAB FRAME MODEL(1.2,0.7),NL

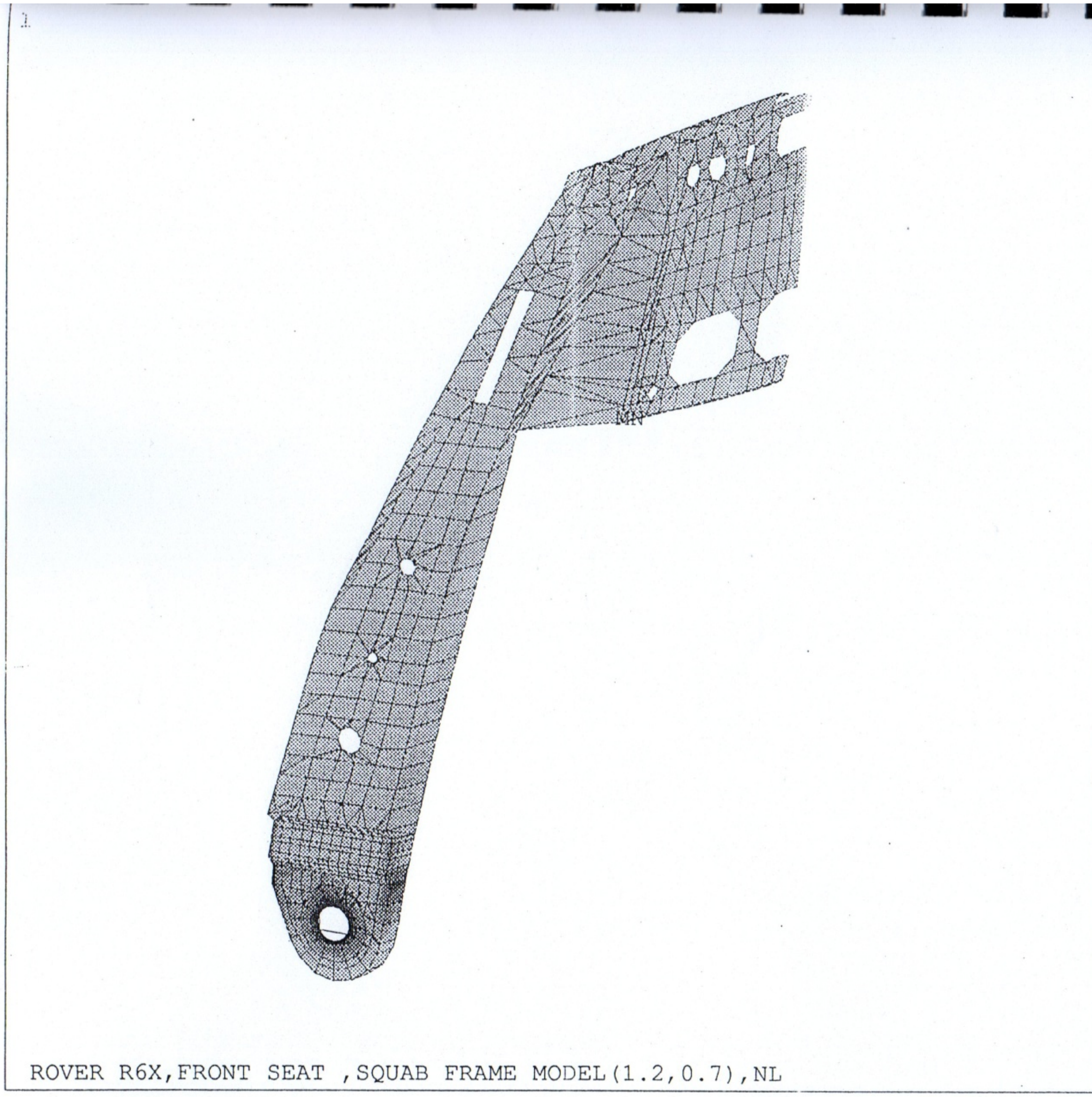


Figure 6.1.d. shows plot of SIGE for 1st load step.

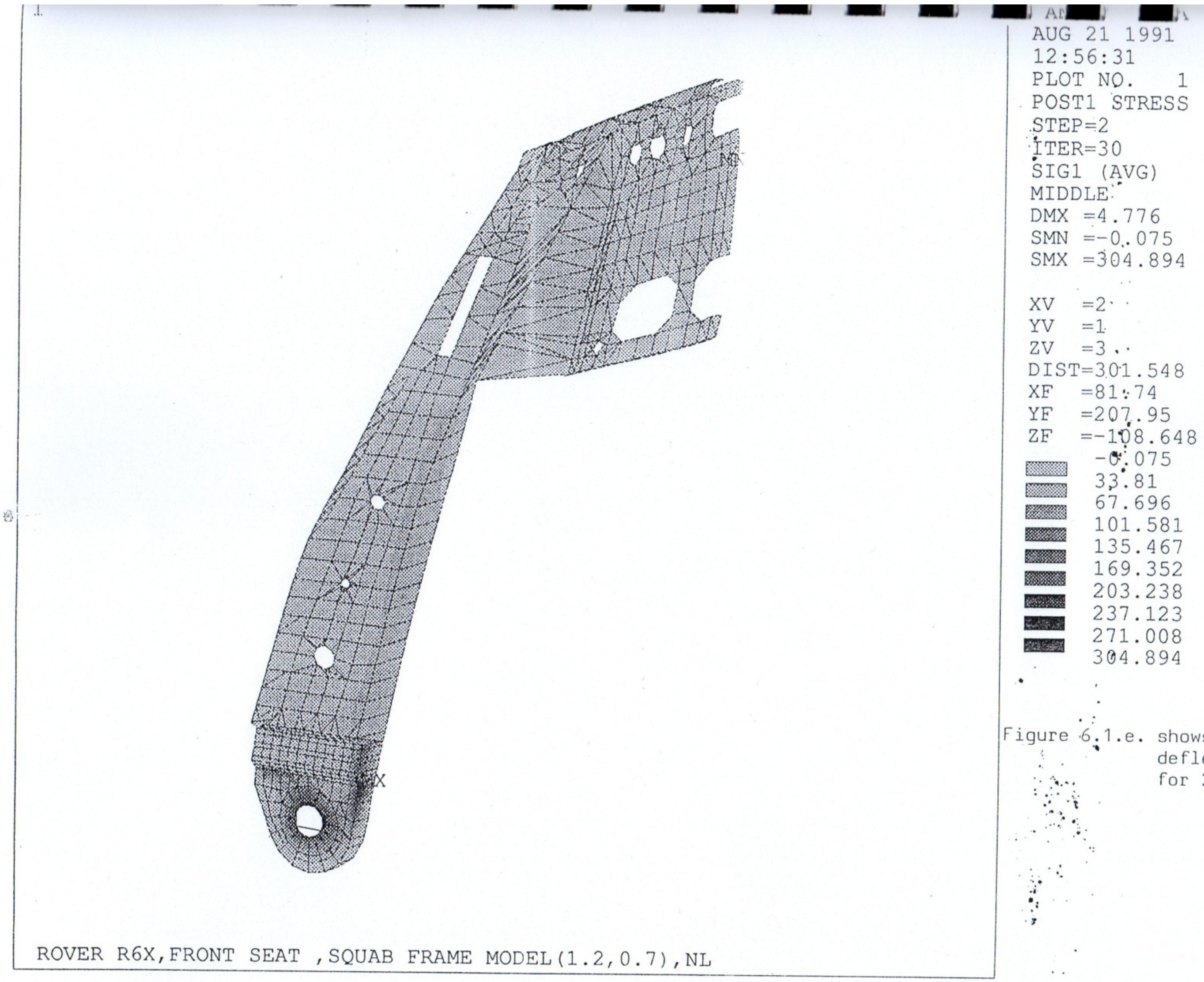


Figure 6.1.e. shows results of deflection and SIG1 for 2nd load step.

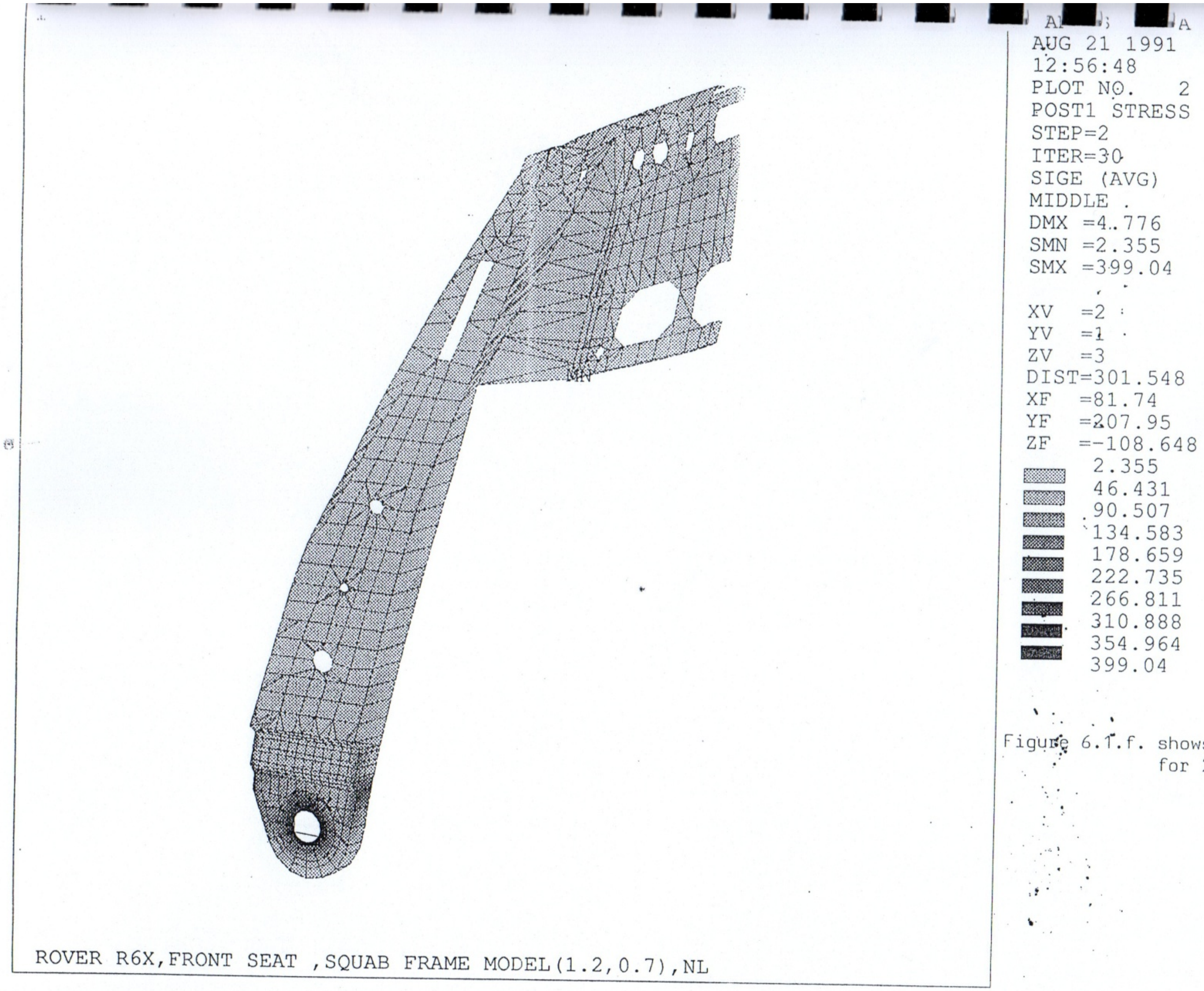


Figure 6.1.f. shows plot of SIGE for 2nd load step.

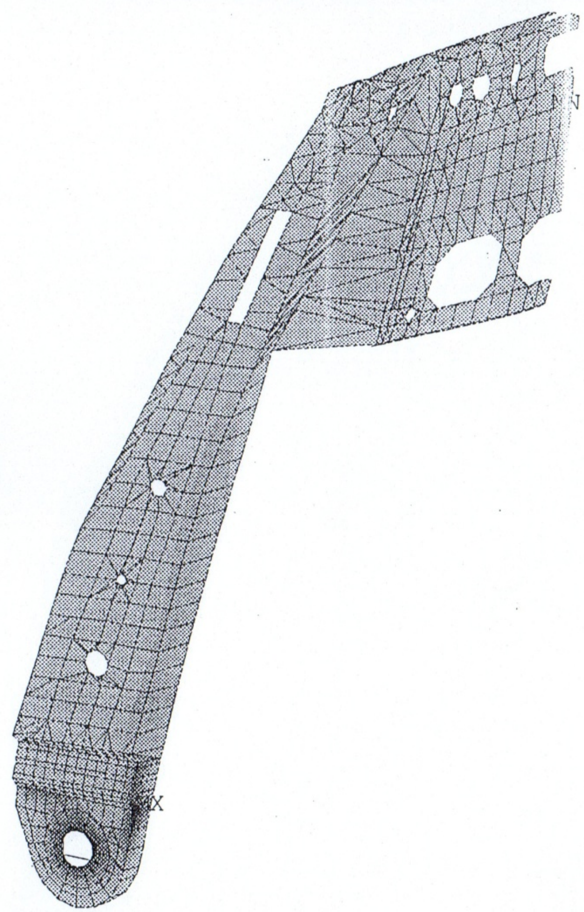


Figure 6.1.g. shows results of deflection and SIG1 for 3rd load step.

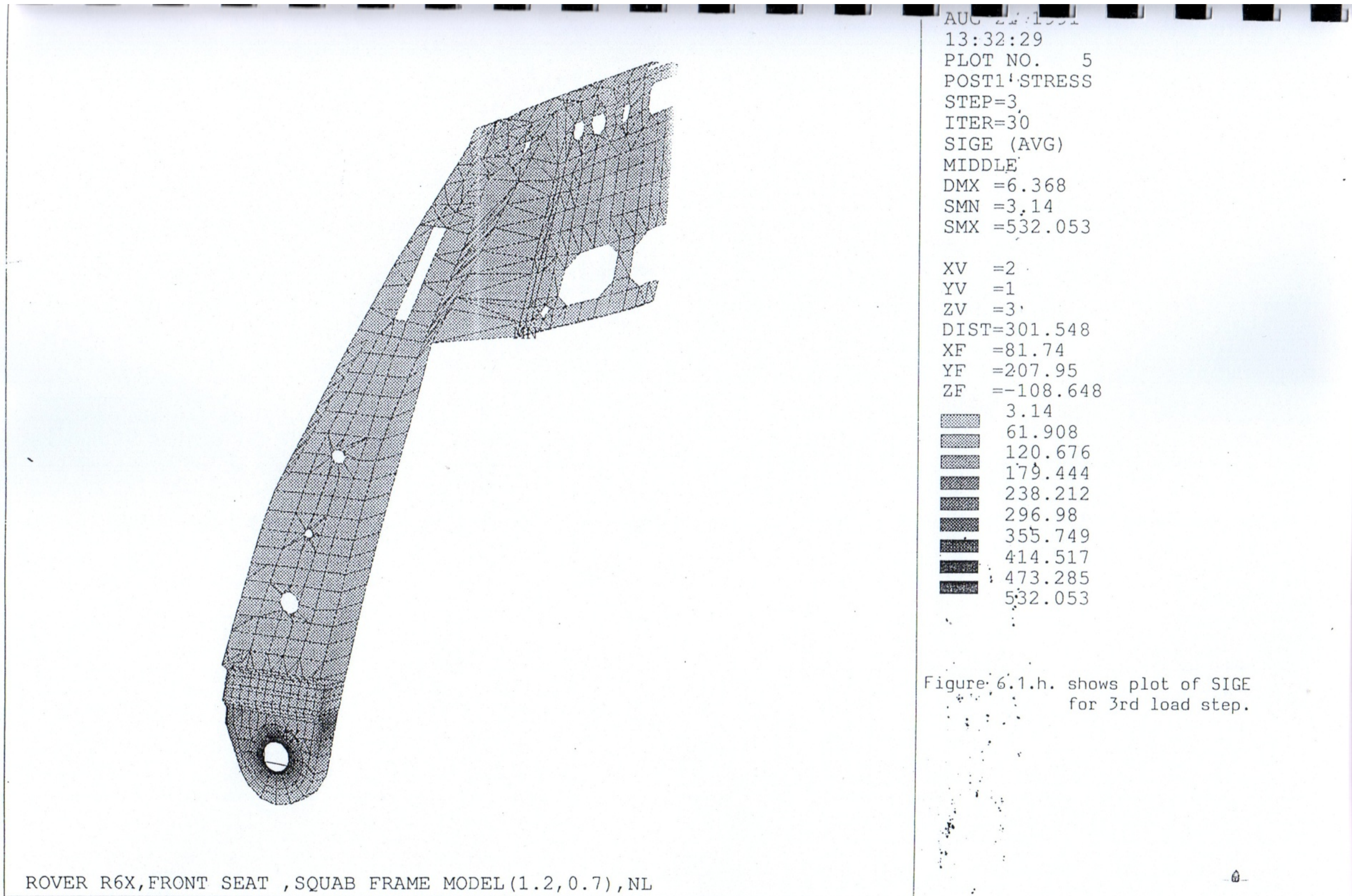


Figure 6.1.h. shows plot of SIGE for 3rd load step.

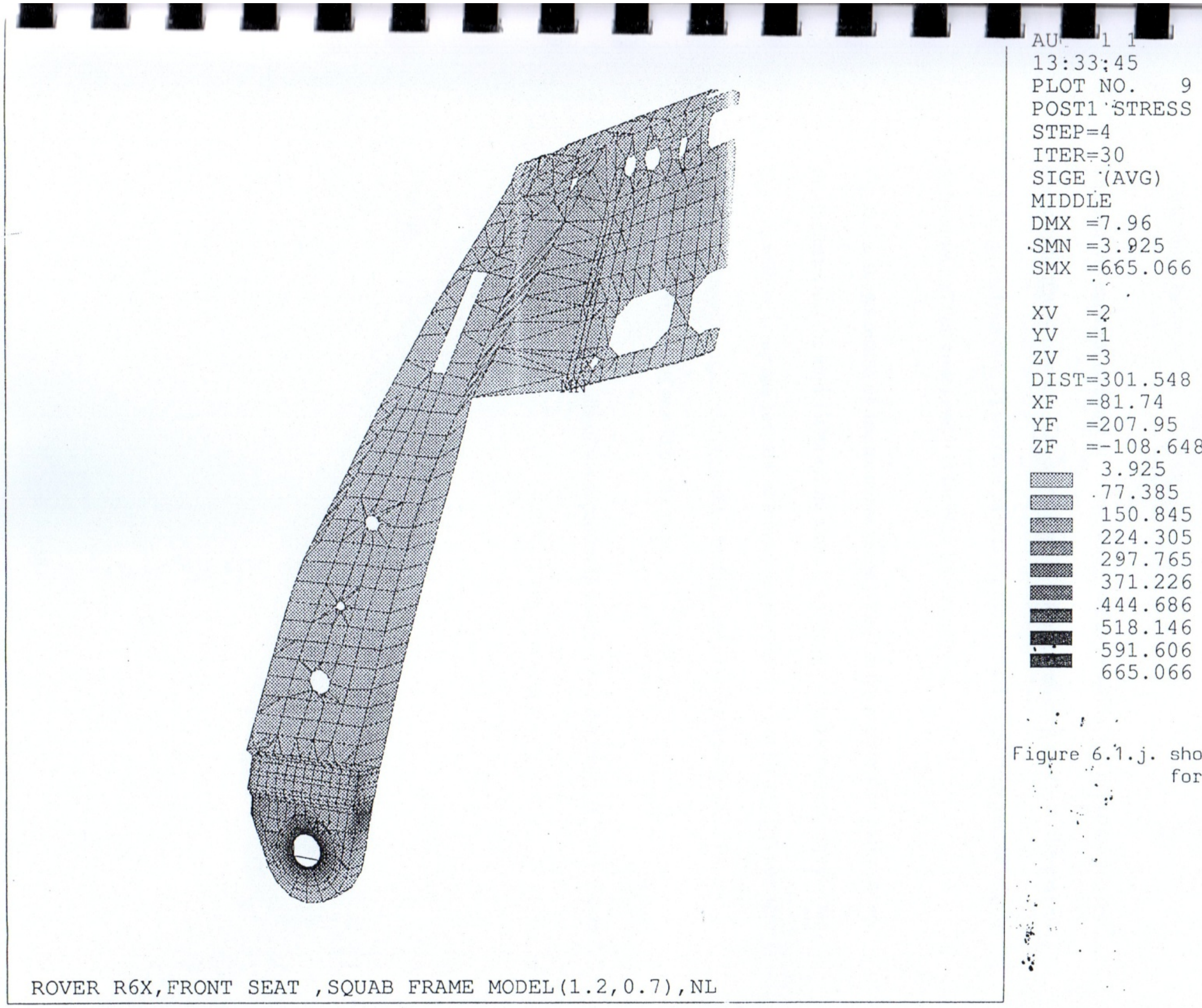


Figure 6.1.j. shows plot of SIGE for 4th load step.

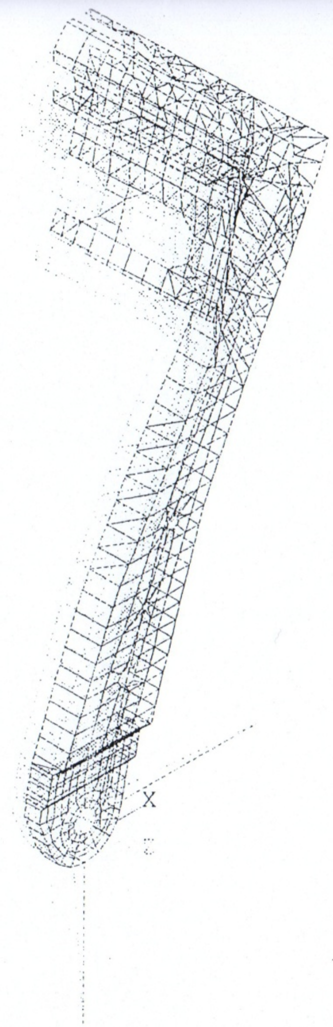
6.2 ATTACHING SPRING TO THE MODEL

This model was an attempt of attaching spring from a fixed point to the seat at lumbar adjustment position.

The seat was constrained along the centre line in the Z- direction, and not constrained at lumbar adjustment position. The same type of loading was used as it was the case of Non-linear analysis data. STIF39 was used in addition to STIF63, STIF39 has one degree of freedom and two nodes and it is for Non-linear analysis.

Fig. 6.2.a. shows results of displacement shape with deflection more than half a metre, this indicates that the model with spring alone is not good enough to further improve the analysis without using any restraint at lumbar support bracketry or simply it is not rigid enough to stand the impact during sudden braking and even if the stiffness of the spring was increased the results would be the same.

Fig. 6.2.b. shows the results of the second step loading. See Appendix (C) of the data input of this model.



A 8 91
18:50:25
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DSCA=0.061256
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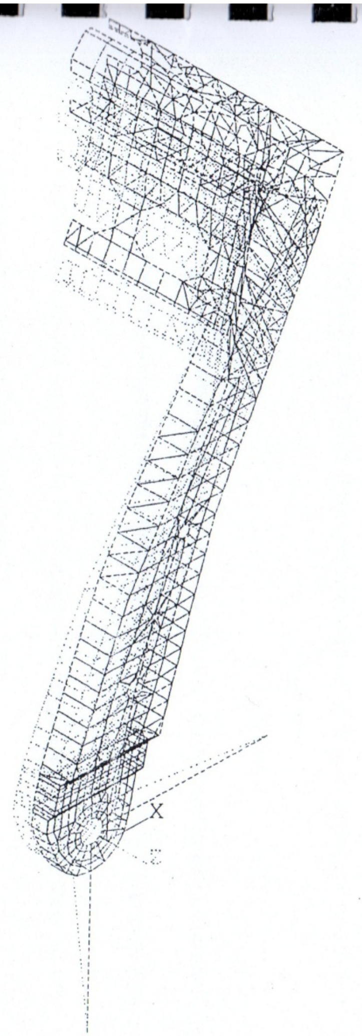
YV =1
ZV =1
DIST=377.351
XF =81.74
YF =144.2
ZF =-108.648

Figure 6.2.a. shows 1st load step deflection results of spring model.

ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7)



18:51:00
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ZV =1
DIST=377.351
XF =81.74
YF =144.2
ZF =-108.648

ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7)

Figure 6.2.b. shows 2nd load step deflection results of spring model.

7.0 DISCUSSION

To make optimisation of cost and to improve weight efficiency three assumptions of modelling the seat have been made using Finite Element analysis. These assumptions were Linear static analysis for (original, development and production condition), and Non-linear static analysis for the original condition due to large displacement.

The Linear static analysis results of the above conditions were affected according to their thicknesses, i.e. in the thinnest material case (Production condition) the deflection was highest, and naturally the thickest material case the deflections were the lowest.

The first principal stresses in second and third assumptions were higher than the first assumption. And also the situation is the same with Von Mises equivalent stress (failure criteria). Obviously the smaller thickness would result in higher deflection and stress values.

The models geometry were extremely well constructed and consists of quadrilateral shell elements. The thicknesses for these conditions were reasonable for achieving the tests.

The deflection results appeared to be of acceptable magnitude and there were no big differences between the three conditions.

Similarly stress analysis obtained were reasonable. For original condition the first principal stress SIG1 was (304.894 N/mm^2) and Von Mises equivalent stress SIGE was (399.04 N/mm^2), and the deflection was (4.776 mm). For development condition the SIG1 value was (346.401 N/mm^2), SIGE value was (436.727 N/mm^2) and the deflection was (5.831mm).

For the last assumption of Linear static analysis SIG1 was (396.779 N/mm^2), SIGE was (481.961 N/mm^2) and the deflection was (7.399mm).

The results of SIG1, and SIGE of Linear static analysis for the three conditions indicate that there is no big difference between these conditions and in comparison with BS 1449 or permissible value. The displacements of the three conditions again were reasonable and only (1mm) difference between each of them.

The Non-linear static analysis results of the original condition was also good, and in this assumption only four steps of loading were used. In the first step SIG1 was (203.263 N/mm^2, SIGE was (266.027 N/mm^2), and the deflection was (3.184mm). In the second step SIG1 was (304.894 N/mm^2, SIGE was (399.04 N/mm^2) and the deflection was (4.776mm). In the third load step results of 68kg object hitting the seat at 4 m/s^2 were (406.525 N/mm^2 and (532.052 N/mm^2) for SIG1 and SIGE respectively and the last value i.e. SIGE was 10% higher than the permissible value. The deflection was (6.368 mm).

In the fourth load step results of 84 kg object at 4 m/s^2 this load step was the worst case that could happen to the seat as far as this investigation was concerned. In this load step SIG1 was (508.156 N/mm^2) and SIGE was (665.066 N/mm^2) which is 38% higher than the permissible stress. The deflection for this load step was (7.96 mm).

The results obtained from the above analysis indicates that there were no big differences between the three assumptions in the Linear static analysis and in Non-linear analysis the results showed that there is a small percentage higher than the BS 1449 values, since 68 kg and 84 kg become huge masses when they are thrown with a certain acceleration and from this argument therefore the cost can be optimised by choosing the concerned condition or masses in correlation with the experimental work.

8.0 CONCLUSIONS

The results of the three conditions in Linear static analysis were reasonable, first principal stress, Von Mises equivalent stress and deflection for original condition were (304.894 N/mm^2), (399.04 N/mm^2) and (4.776 mm) respectively and satisfy the BS1449-Part 1:83.

For development condition SIG1, SIGE were (346.402 N/mm^2), (436.727 N/mm^2) and deflection value was (5.831 mm).

Production condition values of SIG1, SIGE were (396.779 N/mm^2), (481.961 N/mm^2), and deflection value was (7.399mm).

The Non-Linear static analysis results were reasonably good with load step (1) values of SIG1, SIGE and the deflection were (203.263 N/mm^2), (266.027 N/mm^2) and (3.184 mm) respectively. Step (2) values were (304.894 N/mm^2) for SIG1 and (399.04 N/mm^2) for SIGE and (4.776 mm) for deflection. Step (3) values were (406.525 N/mm^2) and (532.053 N/mm^2) and (6.368 mm) for SIG1, SIGE and the deflection.

Results of last load step (4) were (508.156 N/mm^2) for SIG1 and (665.066 N/mm^2) and (7.96 mm) for SIGE and the deflection.

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E.J. HEARN
PERGAMON PRESS

ACKNOWLEDGEMENTS

The author would like to thank the following:

Dr. G. N. Blount	Associate Head of Department.
Dr. R. M. Jones	MSc Course Tutor
Mr. S. Jerrams	Project Supervisor
Mr. A.S. Manning	Lecturer
Mr. R. A. Hallam	Lecturer
Mr. F. Hayden	The Manager of Technical Support, Body Trim and Hardware.
Mr. J. Falloon	The Principal Engineer of Technical Support, Body Trim and Hardware.

APPENDIX C

```
/TITLE, ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7),L
KAN,0
C*** ELEMENT TYPE1 IS STIF63 1.2MM THICK
ET,1,63
R,1,1.2
C*** ELEMENT TYPE2 IS STIF63 0.7MM THICK
ET,2,63
R,2,0.7
EX,1,207E3
NUXY,1,0.3
EX,2,207E3
NUXY,2,0.3

/COM, START OF THE ELEMENT MODULE

E,        4,     3,     1,     2
E,        4,     6,     5,     3
E,        6,     8,     7,     5

N,    924,    172.4729,    297.1200,   -100.4637
N,    925,    167.8731,    288.3720,   -103.0532
N,    926,    165.6220,    286.8707,   -102.1608
/COM,  FINISH PREP7
/COM, THIS MODEL HAS AN ORIGINAL DESIGN THICKNESS OF:1.2MM FOR THE PANEL-
/COM, SIDE SQUAB AND OF 0.7MM FOR THE FRONT AND REAR PANEL-TOP-SQUABS,AND
/COM, PANEL-RAIL TRIM.
ALBC,1
KRF,1
D,918,UZ,0
D,915,UZ,,,916,1
D,912,UZ,0
D,909,UZ,,,910,1
D,736,UZ,0
D,905,UZ,0
D,901,UZ,,,902,1
D,898,UZ,0
D,608,UZ,,,609,1
D,606,UZ,,,607,1
D,665,UZ,,,666,1
D,663,UZ,,,664,1
D,244,ALL,,,255,1
D,258,ALL,,,261,1
CP,524,1,0.15,,527,1
CP,549,1,0.15
CP,751,1,0.15,,752,1
CP,568,1,0.15,,570,1
CP,737,1,0.15,,738,1
CP,572,1,0.15
CP,590,1,0.15,,594,1
CP,611,1,0.15,,615,1
CP,635,1,0.15,,636,1
CP,648,1,0.15
CP,650,1,0.15
CP,898,1,0.15
CP,899,2,0.15
CP,900,1,0.15
CP,901,2,0.15
ITER,1,1
```

Figure C.1. shows input data of 3-D model, linear static analysis.

```
/TITLE, ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7),NL
KNL,1
C*** ELEMENT TYPE1 IS STIF63 1.2MM THICK
ET,1,63
R,1,1.2
C*** ELEMENT TYPE2 IS STIF63 0.7MM THICK
ET,2,63
R,2,0.7
EX,1,207E3
NUXY,1,0.3
EX,2,207E3
NUXY,2,0.3
CONV,0.00001
TREF,70
TUNIF,70
NL,1,13,10
NL,1,25,293,293
NL,1,31,0.94E3,0.94E3
NL,1,19,60,80
NL,2,13,10
NL,2,25,293,293
NL,2,31,0.94E3,0.94E3
NL,2,19,60,80

/COM, START OF THE ELEMENT MODULE

E,          4,      3,      1,      2
E,          4,      6,      5,      3
N,    925,    167.8731,    288.3720,   -103.0532
N,    926,    165.6220,    286.8707,   -102.1608

/COM,  FINISH PREP7
/COM, THIS MODEL HAS AN ORIGINAL DESIGN THICKNESS OF:1.2MM FOR THE PANEL-
/COM, SIDE SQUAB AND OF 0.7MM FOR THE FRONT AND REAR PANEL-TOP-SQUABS,AND
/COM, PANEL-RAIL TRIM.
ALBC,1
KRF,1
KBC,0
D,918,UZ,0
D,915,UZ,,,916,1
D,912,UZ,0
D,909,UZ,,,910,1
D,736,UZ,0
D,905,UZ,0
D,901,UZ,,,902,1
D,898,UZ,0
D,608,UZ,,,609,1
D,606,UZ,,,607,1
D,665,UZ,,,666,1
D,663,UZ,,,664,1
D,244,ALL,,,255,1
D,258,ALL,,,261,1
```

Figure C.2. shows input data of 3-D model,
Non-linear static analysis.

```
/TITLE, ROVER R6X,FRONT SEAT ,SQUAB FRAME MODEL(1.2,0.7)
KNL,1
C*** ELEMENT TYPE1 IS STIF63 1.2MM THICK
ET,1,63
R,1,1.2
C*** ELEMENT TYPE2 IS STIF63 0.7MM THICK
ET,2,63
R,2,0.7
EX,1,207E3
NUXY,1,0.3
EX,2,207E3
NUXY,2,0.3
C*** ELEMENT TYPE3 AND TYPE3 ARE STIF39
ET,3,39,,,1
C*** ELEMENT TYPE4 AND TYPE4 ARE STIF39
ET,4,39,,,2
KAY,3,5
KAY,6,1
CONV,0.0001
TREF,70
TUNIF,70
NL,1,13,10
NL,1,25,293,293
NL,1,31,0.94E3,0.94E3
NL,1,19,60,80
NL,2,13,10
NL,2,25,293,293
NL,2,31,0.94E3,0.94E3
NL,2,19,60,80

/COM, START OF THE ELEMENT MODULE

E,          4,      3,      1,      2
E,          4,      6,      5,      3
N,    925,    167.8731,    288.3720,   -103.0532
N,    926,    165.6220,    286.8707,   -102.1608
N,    927,    160.0000,   -5.94377E-4 , -13.800
N,    928,     0       ,      -160.00  , -13.800
/COM,   FINISH PREP7
/COM, THIS MODEL HAS AN ORIGINAL DESIGN THICKNESS OF:1.2MM FOR THE PANEL-
/COM, SIDE SQUAB AND OF 0.7MM FOR THE FRONT AND REAR PANEL-TOP-SQUABS,AND
/COM, PANEL-RAIL TRIM.
ALBC,1
KRF,1
KBC,0
D,918,UZ,0
D,915,UZ,,,916,1
D,912,UZ,0
D,909,UZ,,,910,1
D,736,UZ,0
D,905,UZ,0
D,901,UZ,,,902,1
D,898,UZ,0
D,608,UZ,,,609,1
D,606,UZ,,,607,1
D,665,UZ,,,666,1
D,663,UZ,,,664,1
TYPE,3
REAL,3
E,927,255
E,928,251
R,3,0.0,0.0,0.1,2E5,0.2,2E6
R,4,0.0,0.0,0.1,2E5,0.2,2E6
D,927,ALL
D,928,ALL
```

Figure C.3. shows input data of 3-D model, Non-linear, spring model.

```
TER,1,1,1
EP,524,1,0.1,,527,1
P,549,1,0.1
P,751,1,0.1,,752,1
EP,568,1,0.1,,570,1
EP,737,1,0.1,,738,1
P,572,1,0.1
P,590,1,0.1,,594,1
EP,611,1,0.1,,615,1
EP,635,1,0.1,,636,1
P,648,1,0.1
P,650,1,0.1
EP,898,1,0.1
P,899,2,0.1
P,900,1,0.1
EP,901,2,0.1
WRITE
TER,-30,,30
P,524,1,0.15,,527,1
EP,549,1,0.15
EP,751,1,0.15,,752,1
P,568,1,0.15,,570,1
P,737,1,0.15,,738,1
EP,572,1,0.15
P,590,1,0.15,,594,1
P,611,1,0.15,,615,1
EP,635,1,0.15,,636,1
EP,648,1,0.15
P,650,1,0.15
P,898,1,0.15
EP,899,2,0.15
EP,900,1,0.15
P,901,2,0.15
WRITE
```

Figure C.4. shows the data of load step 1 and 2.

```
ITER,-30,,30
EP,524,1,0.2,,527,1
EP,549,1,0.2
EP,751,1,0.2,,752,1
EP,568,1,0.2,,570,1
EP,737,1,0.2,,738,1
EP,572,1,0.2
EP,590,1,0.2,,594,1
EP,611,1,0.2,,615,1
EP,635,1,0.2,,636,1
EP,648,1,0.2
EP,650,1,0.2
EP,898,1,0.2
EP,899,2,0.2
EP,900,1,0.2
EP,901,2,0.2
LWRITE
ITER,-30,,30
EP,524,1,0.25,,527,1
EP,549,1,0.25
EP,751,1,0.25,,752,1
EP,568,1,0.25,,570,1
EP,737,1,0.25,,738,1
EP,572,1,0.25
EP,590,1,0.25,,594,1
EP,611,1,0.25,,615,1
EP,635,1,0.25,,636,1
EP,648,1,0.25
EP,650,1,0.25
EP,898,1,0.25
EP,899,2,0.25
EP,900,1,0.25
EP,901,2,0.25
LWRITE
```

Figure C.5. shows the data of load step 3 and 4.

APPENDIX D (LOAD CALCULATIONS)

1.0 Calculations of the area of pressure load

Length = 149 mm

Width = 11.125 mm

Number of elements = 31

Area = $A_1 = L_1 * \omega_1 = 149*11.125 = 1657.625\ mm^2$

Total Area = $A_1 * 2 = 1657.625 * 2 = 3315.25\ mm^2$

Linear static analysis

It has been assumed for this analysis that 0.15 N of pressure load on each element.

Force = Pressure * Area

F = 0.15 * 3315.25 = 497 N

and $mass = \frac{Force}{acceleration} = \frac{497}{9.81} = 51\ kg$ mass of the object at rest

Car at speed of 25 mph

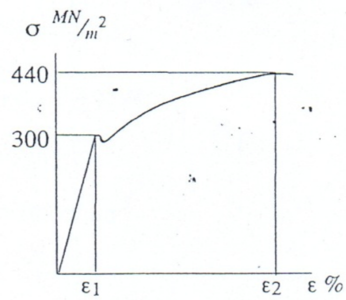
$\frac{25 * 1.61 * 10^3}{3600} = 11.18\ m/s$ when the car takes a sudden brake at time t = 3 Sec

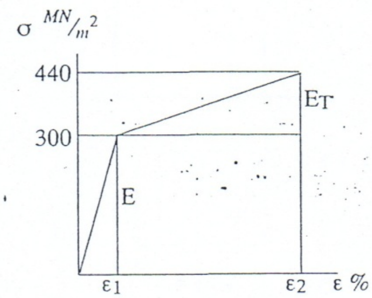
$a = \frac{v}{t} = \frac{11.18}{3} = 3.73\ m/s^2$

$F = m\ a$

and $m = \frac{F}{a} = \frac{497}{3.73} = 133.2\ kg$ the mass of the object during impact.

Non-linear static analysis





E = Modulus of elasticity = $207 * 10^3$ N/mm^2

E_T = The plastic slope

$$E = \frac{stress}{strain} = \frac{\sigma}{\varepsilon}$$

$$\varepsilon_1 = \frac{\sigma}{E} = \frac{300}{207 * 10^3} = 1.449*10^{-3} \; or \; 0.1449 \, \%$$

$\varepsilon_2 = 0.15$ (for mild steel)

$$\Delta\varepsilon = \varepsilon_2 - \varepsilon_1 = 0.15 - 1.449 * 10^{-3} = 0.148551 \approx 0.149$$

$$\Delta\sigma = \sigma_2 - \sigma_1 = 440 - 300 = 140 \, {}^{N}/_{mm^2}$$

$$E_T = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{140}{0.149} = 940 \, {}^{N}/_{mm^2}$$

$$\text{Plasticity ratio} = \frac{E_T}{E} = \frac{940}{207 * 10^3} = 4.54*10^{-3} \approx 0.00454$$

when this ratio is less than 0.05 (5%) use 0.05

∴ Load increments no larger than 0.05

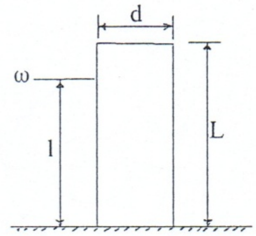
Hence the load increments would be as follows :-

Load Steps (N)	Mass at rest (kg)	Mass at impact (kg)
0.1	34	88.4
0.15	51	133.2
0.2	68	178.0
0.25	84	222.2

Verifications

Calculation of deflections

$$Y = \frac{\omega L^2}{2EI}\left(L - \frac{l}{3}\right)$$

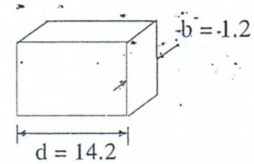


$\omega = 0.15 * 31 = 4.65\ N$

L = 448.4 mm

$E = 207 * 10^3\ N/mm^2$

l = 399 mm



$$I = \frac{bd^3}{12}$$

$$Y_o = \frac{4.65 * (448.4)^2}{2 * 207 * 10^3 * 286.3}\left(448.4 - \frac{399}{3}\right)$$

$$I = \frac{1.2\,(14.2)^3}{12} = 286.3\ mm^4$$

Y_o = 2.6 mm (deflection of original condition)

$$I = \frac{1.1\,(14.2)^3}{12} = 262.5\ mm^4$$

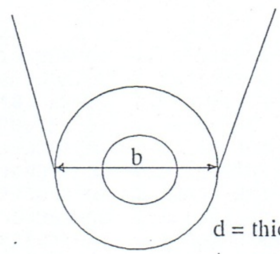
Y_d= 2.9 mm (deflection of development condition)

$$I = \frac{1.0\,(14.2)^3}{12} = 238.6\ mm^4$$

Y_p= 3.2 mm (deflection of production condition)

In the same way the deflections of non-linear analysis would be calculated.

Calculation of stresses



d = thickness

b = breadth

b = 68 mm

$$\sigma = \frac{MY}{I}$$

$$Y_o = \frac{1}{2}t = \frac{1}{2} * 1.2 = 0.6\ mm$$

$$Y_d = \frac{1}{2} * 1.1 = 0.55\ mm$$

$$Y_p = \frac{1}{2} * 1.0 = 0.5\ mm$$

Moment = Force * distance

$$M = 4.65 * 149 = 692.85\ N\,mm$$

$$\sigma_o = \frac{692.85 * 0.6}{9.792} = 42.45\ {}^{N}/_{mm^2}$$

$$\sigma_d = \frac{692.85 * 0.55}{7.542} = 51\ {}^{N}/_{mm^2}$$

$$\sigma_p = \frac{692.85 * 0.5}{5.67} = 61\ {}^{N}/_{mm^2}$$

$$I = \frac{bd^3}{12}$$

$$I = \frac{68(1.2)^3}{12} = 9.792\ mm^4$$

$$I = \frac{68(1.1)^3}{12} = 7.542\ mm^4$$

$$I = \frac{68(1.0)^3}{12} = 5.67\ mm^4$$

APPENDIX E.

TIME= 0. LOAD CASE= 1

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY
767	-2.6689364	1.5084818	0.91218720E-02	-0.32103880E-02	-0.95958868E-02
770	-2.5754233	1.4822371	0.11567196E-01	-0.46514627E-02	-0.11930036E-01
771	-2.6378747	1.5029220	0.14048104E-01	-0.11621479E-02	-0.12143834E-01
773	-2.5835662	1.4747690	-0.10770015E-01	0.60396702	-0.91396523
774	-2.4987540	1.4582022	0.11519328E-01	-0.37683230E-02	-0.12606213E-01
775	-2.5722124	1.4850247	0.17694837E-01	-0.37167556E-02	-0.10574147E-01
776	-2.5050643	1.4481273	-0.10722309E-01	-0.69309795E-01	0.83728965E-01
777	-3.5489066	1.7392126	-0.23856936E-01	0.91588486E-03	0.33693474E-02
779	-3.5283335	1.7319429	-0.26883121E-01	0.11902302E-02	0.35468595E-02
780	-3.5123035	1.7296868	-0.31532303E-01	0.18729279E-02	0.47804772E-02
781	-3.5171315	1.7322346	-0.35116745E-01	0.20869602E-02	0.59568176E-02
782	-3.5487803	1.7395917	-0.34598510E-01	0.18763102E-02	0.64581402E-02

***** POST1 NODAL DISPLACEMENT LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY
783	-3.5872134	1.7496002	-0.26700506E-01	0.92241400E-03	0.52188700E-02
784	-3.5685968	1.7463228	-0.24582668E-01	0.85629415E-03	0.41022121E-02
785	-3.5819348	1.7463753	-0.31373444E-01	0.10635666E-02	0.62170190E-02
786	-3.5594663	1.7431760	-0.45305718E-01	0.10991760E-02	0.66706234E-02
787	-3.4638997	1.7203871	-0.35853571E-01	0.90674198E-02	0.31324671E-02
788	-3.5226403	1.7276604	-0.34871040E-01	0.20308339E-02	0.44516281E-02
789	-3.1363756	1.6252020	-0.16781793E-01	0.51679521E-03	-0.44497002E-03
790	-3.2866778	1.6889114	-0.31817041E-01	0.19373953E-02	0.14926740E-02
791	-3.1308123	1.6109541	-0.15363500E-01	-0.30194649E-02	0.45932748E-03
793	-2.7639730	1.5403615	0.17175009E-01	0.28227010E-03	-0.71089666E-02
794	-2.9863058	1.5785094	-0.32848840E-02	-0.28673688E-02	-0.25222605E-02
795	-2.7009420	1.5272240	0.23263850E-01	0.34314788E-02	-0.41509875E-02

***** POST1 NODAL DISPLACEMENT LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY
796	-2.9463690	1.5546350	-0.21174028E-02	-0.29420796E-02	-0.27046116E-02
797	-2.5607631	1.4839299	0.21601501E-01	-0.13222194E-02	-0.92497662E-02
798	-2.6816519	1.5187176	0.20889129E-01	-0.72228342E-05	-0.85563933E-02
799	-2.5971838	1.5086086	0.34330343E-01	-0.30742559E-03	-0.63639493E-02
800	-2.4578830	1.4572650	0.27619342E-01	0.27922395E-03	-0.10605578E-01
801	-2.5254199	1.4736403	0.22377938E-01	-0.64579039E-02	-0.83181105E-02
802	-2.5332523	1.4777776	0.24328935E-01	-0.84274190E-02	-0.83098128E-02
803	-2.4369943	1.4484527	0.25132604E-01	-0.48124576E-02	-0.10918469E-01
804	-2.4290130	1.4438169	0.23032806E-01	-0.81083705E-02	-0.10668410E-01
807	-2.3411420	1.4069514	0.11321437E-01	-0.45088548E-02	-0.13038761E-01
808	-2.3395557	1.3910000	-0.11572389E-01	0.79967903E-03	-0.21559398E-01
812	-3.6752567	1.7815274	-0.16868208E-01	0.14445605E-02	0.50965715E-02

***** POST1 NODAL DISPLACEMENT LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

242	104.75354	0.	-69.035391	173.78893	152.10450
243	174.83178	0.	-155.43406	330.26583	288.48929
244	236.60408	0.	-212.54247	449.14654	394.89926
245	221.44474	0.	-211.74786	433.19260	380.65642

***** POST1 NODAL STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1
SHELL STRESSES ARE AT MIDDLE

NODE	SIG1	SIG2	SIG3	SI	SIGE
246	207.07356	0.	-226.43802	433.51158	381.02263
247	210.35160	0.	-234.04643	444.39803	390.76501
248	219.14983	0.	-218.48597	437.63580	384.70928
249	214.15198	0.	-192.72302	406.87501	357.92319
250	196.54375	0.	-175.90873	372.45247	327.56614
251	179.83800	0.	-174.98225	354.82026	311.84507
252	174.03994	0.	-187.56619	361.60613	317.91082
253	185.32838	0.	-206.22834	391.55672	344.47006
254	213.63550	0.	-215.90402	429.53952	377.71627
255	241.65633	0.	-203.15600	444.81234	391.42705
257	161.04126	0.	-128.66843	289.70969	254.27886
258	241.67981	0.	-186.99156	428.67137	377.73648
259	222.31026	0.	-194.96040	417.27066	366.83780

***** POST1 NODAL STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1
SHELL STRESSES ARE AT MIDDLE

NODE	SIG1	SIG2	SIG3	SI	SIGE
260	219.32272	0.	-215.74730	435.07002	382.34066
261	232.66563	0.	-221.36135	454.02698	399.03982
262	177.43649	0.	-157.19622	334.63271	291.94424
263	62.857970	-0.25527437E-09	-21.664953	84.522924	76.878968
264	93.410084	0.	-68.173629	161.58371	141.85683
265	44.770351	0.71724875E-10	-30.073693	74.844044	66.641565
266	23.079848	0.18553109E-09	-12.727545	35.807393	31.963225
267	18.315049	0.17423618E-09	-15.922087	34.237136	30.045525
268	12.802031	0.60767449E-10	-13.834861	26.636892	23.089785
269	8.2674588	0.47042083E-10	-21.580224	29.847682	26.720947
270	11.386179	0.	-17.480894	28.867073	25.206816
271	14.099899	0.	-10.844094	24.943993	21.698622
272	18.782196	0.	-11.444374	30.226570	26.435392

***** POST1 NODAL STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0. LOAD CASE= 1
SHELL STRESSES ARE AT MIDDLE

NODE	SIG1	SIG2	SIG3	SI	SIGE
273	18.507201	0.	-6.1186165	24.625818	22.239534
274	29.289722	0.	-5.1665973	34.456319	32.200016
275	22.336613	0.	-9.0289315	31.365544	27.968426
276	24.982018	0.	-2.9924010	27.974419	26.610350
277	20.428290	0.	-5.3155700	25.743860	23.543375
278	31.590575	-0.17578770E-09	-2.9030271	34.493602	33.160619
279	25.674850	-0.44497864E-08	-1.6043008	27.279151	26.531749
281	7.8769715	0.33399255E-10	-2.3213705	10.198342	9.3389519
283	12.272951	0.69431011E-10	-2.8627724	15.135724	13.973940
284	0.25573355	-1.2409914	-9.4181208	9.6738544	9.1205596
285	0.26629175	-0.64460871	-12.955027	13.221318	12.794351
288	0.25077695	-0.88568556E-01	-37.410481	37.661258	37.492897

NODE	SIG1	SIG2	SIG3	SI	SIGE
246	345.12261	0.	-377.39669	722.51930	635.03772
247	350.58599	0.	-390.07738	740.66338	651.27501
248	365.24972	0.	-364.14329	729.39301	641.18213
249	356.91997	0.	-321.20504	678.12501	596.53865
250	327.57291	0.	-293.18121	620.75412	545.94357
251	299.73001	0.	-291.63709	591.36709	519.74178
252	290.06657	0.	-312.61032	602.67689	529.85136
253	308.88063	0.	-343.71390	652.59453	574.11677
254	356.05917	0.	-359.84004	715.89921	629.52711
255	402.76055	0.	-338.59334	741.35390	652.37841
257	268.40210	0.	-214.44739	482.84949	423.79809
258	402.79969	0.	-311.65260	714.45229	629.56080
259	370.51710	0.	-324.93400	695.45110	611.39634

***** POST1 NODAL STRESS LISTING *****

LOAD STEP 4 ITERATION= 30 SECTION= 1
TIME= 0. LOAD CASE= 1
SHELL STRESSES ARE AT MIDDLE

NODE	SIG1	SIG2	SIG3	SI	SIGE
260	365.53787	0.	-359.57883	725.11670	637.23444
261	387.77605	0.	-368.93558	756.71163	665.06637
262	295.72748	0.	-261.99371	557.72119	486.57374
263	104.76328	-0.42547682E-09	-36.108256	140.87154	128.13161
264	155.68347	0.	-113.62272	269.30619	236.42805
265	74.617252	0.11952970E-09	-50.122821	124.74007	111.06927
266	38.466414	0.30921389E-09	-21.212574	59.678988	53.272041
267	30.525082	0.29039965E-09	-26.536811	57.061894	50.075875
268	21.336718	0.10128959E-09	-23.058101	44.394819	38.482975
269	13.779098	0.78400983E-10	-35.967039	49.746137	44.534912
270	18.976965	0.	-29.134823	48.111788	42.011359
271	23.499831	0.	-18.073490	41.573321	36.164370
272	31.303660	0.	-19.073957	50.377617	44.058987

APPENDIX G TABLES OF RESULTS

Model	Dmx displacement (mm)	SIG1 N/mm^2	SIG2 N/mm^2	SIG3 N/mm^2	SIGE N/mm^2
Original Condition D40r6x (1.2,0.7)	4.776	maximum	maximum	maximum	maximum
		304.894	52.627	0.768E-07	399.04
		minimum	minimum	minimum	minimum
		-0.075	-54.833	-331.003	2.355
Development condition D41r6x (1.1,0.6)	5.831	maximum	maximum	maximum	maximum
		346.402	59.636	0.661E-07	436.727
		minimum	minimum	minimum	minimum
		-0.075	-59.395	-374.437	1.598
Production condition D42r6x (1.0,0.5)	7.399	maximum	maximum	maximum	maximum
		396.779	68.043	0.582E-07	481.961
		minimum	minimum	minimum	minimum
		-0.075	-64.557	-426.845	1.751

Table (1) results of Linear Analysis (full load).

Model	Dmx displacement (mm)	SIG1 N/mm^2	SIG2 N/mm^2	SIG3 N/mm^2	SIGE N/mm^2
Original Condition D40r6x (1.2,0.7)	3.582	maximum	maximum	maximum	maximum
		228.7	39.5	0.576E-07	299.3
		minimum	minimum	minimum	minimum
		-0.06	-41.1	-248.3	1.766
Development Condition D41r6x (1.1,0.6)	4.373	maximum	maximum	maximum	maximum
		260.0	44.73	0.661E-07	327.5
		minimum	minimum	minimum	minimum
		-0.06	-44.55	-281.0	1.198
Production Condition D42r6x (1.0,0.5)	5.549	maximum	maximum	maximum	maximum
		297.6	51.0	0.582E-07	361.5
		minimum	minimum	minimum	minimum
		-0.06	-48.42	-320.0	1.31

Table (2) results of Linear Analysis (3/4 load).

Model	Dmx displacement (mm)	SIG1 N/mm^2	SIG2 N/mm^2	SIG3 N/mm^2	SIGE N/mm^2
Original Condition D40r6x (1.2,0.7)	2.388	maximum	maximum	maximum	maximum
		152.45	26.314	0.384E-07	199.52
		minimum	minimum	minimum	minimum
		-0.0375	-27.416	-165.5	1.177
Development Condition D41r6x (1.1,0.6)	2.915	maximum	maximum	maximum	maximum
		173.2	29.818	0.331E-07	218.4
		minimum	minimum	minimum	minimum
		-0.0375	-29.697	-187.2	0.799
Production Condition D42r6x (1.0,0.5)	3.699	maximum	maximum	maximum	maximum
		198.39	34.0	0.291E-07	241.0
		minimum	minimum	minimum	minimum
		-0.0375	-32.278	-213.42	-0.876

Table (3) results of Linear Analysis (1/2 load).

Model	Dmx displacement (mm)	SIG1 N/mm^2	SIG2 N/mm^2	SIG3 N/mm^2	SIGE N/mm^2
D27r6x (1.2,0.7) set,1,1	3.184	maximum	maximum	maximum	maximum
		203.263	35.085	0.512E-07	266.027
		minimum	minimum	minimum	minimum
		-0.05	-36.085	-220.669	1.57
set,2,30	4.776	maximum	maximum	maximum	maximum
		304.894	52.627	0.768E-07	399.04
		minimum	minimum	minimum	minimum
		-0.075	-54.833	-331.003	2.355
set,3,30	6.368	maximum	maximum	maximum	maximum
		406.525	70.17	0.102E-06	532.053
		minimum	minimum	minimum	minimum
		-0.1	-73.111	-441.337	3.14
set,4,30	7.96	maximum	maximum	maximum	maximum
		508.156	87.712	0.128E-06	665.066
		minimum	minimum	minimum	minimum
		-0.125	-91.389	-551.672	3.925

Table (4) results of Non-linear Analysis

3.5.2 **Weldability.** All the grades specified in tables 10 and 12 shall be weldable provided that the welding techniques employed make allowance for composition and thickness. See BS 693, BS 1140, BS 2630, BS 5135 and BS 6265.

3.5.3 **Strain-age-embrittlement.** Where proof of freedom from strain-age-embrittlement is required (see 3.2(g)), the method of test shall be agreed between the manufacturer and the purchaser, as the test defined in 1.11 may not be appropriate to all the steels in this section.

Table 13. Mechanical properties: micro-alloyed steels

Grade	Rolled condition (see note 1)	Yield strength, R_e, min. (see note 2)	Tensile strength, R_m, min.	Elongation, A, min. Original gauge length, L_o			Bend mandrel diameter (180° bend) (see note 3)
				50 mm	80 mm (note 4)	200 mm	
		N/mm²	N/mm²	%	%	%	
40/30	HR, HS, CS	300	400	26	(24)	18	2*a*
43/35	HR, HS, CS	350	430	23	(21)	16	2*a*
46/40	HR, HS, CS	400	460	20	(18)	12	3*a*
50/45	HR, HS, CS	450	500	20	(18)	12	3*a*
60/55	–, HS, CS	550	600	17	(15)	10	3.5*a*
40F30	HR, HS, CS	300	400	28	(26)	20	0*a*
43F35	HR, HS, CS	350	430	25	(23)	18	0.5*a*
46F40	HR, HS, CS	400	460	22	(20)	14	1*a*
50F45	HR, HS, CS	450	500	22	(20)	14	1.5*a*
60F55	–, HS, CS	550	600	19	(17)	11	1.5*a*
68F62	–, HS –	620	680	18	(16)	10	2*a*
75F70	–, HS –	700	750	15	(13)	8	3*a*

a is the thickness of the bend test piece.

NOTE 1. The properties of HS materials are only applicable up to and including 8 mm. For material thicker than 8 mm, the properties are to be agreed between the manufacturer and purchaser.

NOTE 2. A specific range for the yield strength of any particular grade and thickness may be agreed between manufacturer and purchaser at the time of ordering.

NOTE 3. The bend test requirements quoted in this table are for specially prepared test pieces (see 1.10); conditions during fabrication may be more severe and not simulate those during laboratory testing (see note, 'Manipulation', to section three and table 14).

NOTE 4. The 80 mm gauge length is currently not used in the UK but, as a step towards conforming with European practice, tentative values have been included.

Reasonable freedom from stretcher strain can be achieved in skin passed material by effective roller levelling immediately prior to pressing at the customer's plant.

Complete freedom from stretcher strain and also freedom from deterioration in ductility, due to strain-age-hardening, is achieved by the supply of skin passed, stabilized, steels as established by the test in 1.12.

Table 5. Chemical composition

Grade (see notes 2 and 3)	Rolled condition (see note 2 to 2.5)	Quality	C max.	Mn max.	S max.	P max.
			%	%	%	%
1	HR, HS	Extra deep drawing aluminium-killed steel	0.08	0.45	0.030	0.025
	CR, CS	Extra deep drawing aluminium-killed stabilized steel	0.08	0.45	0.030	0.025
2	HR, HS, CR, CS	Extra deep drawing	0.08	0.45	0.035	0.030
3	HR, HS, CR, CS	Deep drawing	0.10	0.50	0.040	0.040
4	HR, HS,* CR, CS*	Drawing or forming	0.12	0.60	0.050	0.050
14	HR, HS,	Flanging	0.15	0.60	0.050	0.050
15	HR, HS,	Commercial	0.20	0.90	0.050	0.060

*See also section four.

NOTE 1. For improved atmospheric corrosion resistance, material can be supplied with a specified copper content by special agreement between the manufacturer and the purchaser.

NOTE 2. Steels that have received a decarburizing treatment are not supplied against these grades unless previously agreed between the manufacturer and purchaser.

NOTE 3. Steels in this section may not be suitable for case-hardening (see grade 10 in table 15).

Table 6. Mechanical properties of hot rolled material (note 1)

Rolled condition and grade	Yield strength, R_e, min.	Tensile strength, R_m, min.	Elongation, A, min. (note 2) Original gauge length, L_o 50 mm	80 mm (note 4)	200 mm (note 3)	Bend mandrel diameter (180° bend) $a < 3$ mm	3 mm > a < 10 mm	$a > 10$ mm
	N/mm²	N/mm²	%	%	%			
HR1, HS1 HR2, HS2	170	290	34	(32)	25	0a	0a	–
HR3, HS3	(170)	(290)	(28)	(26)	(21)	0a	0a	–
HR4, HS4 HR14, HS14	(170)	(280)	(25)	(23)	(18)	1a	2a	3a
HR15, HS15	(170)	(280)	–	–	–	2a	3a	4a

a is the thickness of the bend test piece.

NOTE 1. The mechanical properties shown correspond to material in the despatched condition only. The strength will increase with cold forming. Tensile properties given in brackets are for guidance only and are not mandatory unless specially agreed at the time of ordering. Tensile test results are not normally requested for grades 3, 4, 14 and 15.

NOTE 2. For material of less than 2.5 mm thickness the percentage elongation is reduced by 1 for each 0.25 mm reduction in thickness.

NOTE 3. Elongation values measured on 200 mm gauge length are applicable to material rolled on wide mills only.

NOTE 4. The 80 mm gauge length is currently not used in the UK but, as a step towards conforming with European practice, tentative values have been included.

Table 7. Mechanical properties of cold rolled material produced on wide mills (i.e. rolled in widths ⩾ 600 mm) (note 1)

Rolled condition and grade	Yield strength, R_e, min.	Tensile strength, R_m, min.	Elongation, A, min. (note 2) Original gauge length, L_o			Bend mandrel diameter (180° bend)	Modified Erichsen cupping test
			50 mm	80 mm (note 3)	200 mm		
	N/mm²	N/mm²	%	%	%		
CR1	140	280	38	(36)	29	0*a*	See figure 3 for minimum values
CR2	140	280	36	(34)	27	0*a*	
CR3	(140)	(280)	(34)	(32)	(25)	0*a*	
CR4	(140)	(280)	—	—	—	0*a*	

a is the thickness of the bend test piece.

NOTE 1. Tensile properties given in brackets are for guidance only and are not mandatory unless specially agreed at the time of ordering. Tensile test results are not normally requested for grades 3 and 4.

NOTE 2. For material less than 1.00 mm thick, the percentage elongation is reduced by 1 for each 25 mm reduction in thickness.

NOTE 3. The 80 mm gauge length is currently not used in UK but, as a step towards conforming with European practice, tentative values have been included.

Table 8. Mechanical properties of cold rolled material produced on narrow mills (i.e. rolled in widths < 600 mm and thicknesses ⩽ 3 mm) (see note 7)

Rolled condition and grade	Annealed (A) or skin passed (SP) condition	Hardness HV max. (notes 2, 5 and 6)	Yield strength, R_e, min. (note 2)	Tensile strength, R_m, min. (note 2)	Elongation, A, min. (notes 2 and 3) Original gauge length, L_o		Bend mandrel diameter (180° bend) (note 2)
					50 mm	80 mm (note 8)	
			N/mm²	N/mm²	%	%	
CS1	A	95	140	270	38	(36)	0*a*
	SP	105	140	270	36	(34)	0*a*
CS2	A	95	140	270	36	(34)	0*a*
	SP	100	140	270	36	(34)	0*a*
CS3	A	100	(140)	(280)	(34)	(32)	0*a*
	SP	110	(140)	(280)	(34)	(32)	0*a*
CS4	A	105	(140)	(280)	—	—	0*a*
	SP	115	(140)	(280)	—	—	0*a*

a is the thickness of the bend test piece.

NOTE 1. Tensile properties given in brackets are for guidance only and are not mandatory unless specially agreed at the time of ordering.

NOTE 2. Narrow strip is supplied to comply with either the hardness and bend tests or the tensile and bend tests but in no case with both the hardness and tensile tests.

NOTE 3. For material less than 1.0 mm thickness, the percentage elongation is reduced by 1 for each 0.25 mm reduction in thickness. Values should be agreed between the manufacturer and purchaser for thicknesses of less than 0.5 mm.

NOTE 4. The mechanical properties apply to material in the as-received condition only. The strength will increase with cold forming. Due note should be made of any possibility of age hardening (see note to 2.5).

NOTE 5. For condition SP, with plating finish (PF) or mirror finish (MF) or material which is supplied 'free from stretcher marks', the maximum hardness may be increased by 5 points HV or the tensile strength by 20 N/mm².

NOTE 6. The hardness values for grades CS2, CS3 and CS4 apply only to rimmed steels.

NOTE 7. For material with thickness exceeding 3 mm, the mechanical properties are to be agreed at the time of ordering.

NOTE 8. The 80 mm gauge length is currently not used in the UK but, as a step towards conforming to European practice, tentative values have been included.

Table 11. Mechanical properties: carbon-manganese steels

Grade	Rolled condition (see note 1)	Yield strength, R_e, min.	Tensile strength, R_m, min	Elongation, A, min. Original gauge length, L_o 50 mm	80 mm (note 4)	200 mm	Bend mandrel diameter (180° bend) (see notes 2 and 3)
		N/mm²	N/mm²	%	%	%	
34/20	HR, HS, CR, CS	200	340	29	(27)	21	2*a*
37/23	HR, HS, CR, CS	230	370	28	(26)	20	2*a*
43/25	HR, HS	250	430	25	(23)	16	3*a*
50/35	HR, HS	350	500	20	(18)	12	3*a*

a is the thickness of the bend test piece.

NOTE 1. The properties of HS materials are only applicable up to and including 8 mm. For material thicker than 8 mm, the properties are to be agreed between the manufacturer and purchaser.

NOTE 2. In the case of grades 34/20 and 37/23, for steel 3 mm thick and over, the bend test requirement is for a mandrel diameter of 3*a*. For special applications, these grades together with grades 43/25 and 50/35 may be ordered with a bend test requirement of a mandrel diameter of 2*a*.

NOTE 3. The bend test requirements quoted in this table are for specially prepared test pieces (see 1.10.2); conditions during fabrication may be more severe and not be simulated by those during laboratory testing (see note, 'Manipulation', to section three and table 14).

NOTE 4. The 80 mm gauge length is currently not used in UK but, as a step towards conforming with European practice, tentative values have been included.

The symbols, if required, denoting material condition (see table 1 and note 2 to 3.5.1) shall be given before the grade number of the steel, in the following order:

(a) the symbol R, B or K signifying the type of steel;

(b) the symbols HR, HS, CR or CS, signifying the method of rolling.

NOTE 1. Attention is drawn to the fact that it is not obligatory for the purchaser of a fabricated component to specify the manufacturing method for the flat rolled product.

In this section the grade number shall indicate, respectively, minimum tensile strength/minimum yield strength in N/mm² x 10^{-1} (see the example below). A letter F in place of the oblique line, e.g. 40F30, shall denote steels which offer superior formability for the same strength levels as the corresponding steels in the upper part of table 13.

Symbols denoting surface finish shall appear after the grade number of the steel.

Example. HR37/23P signifies a hot rolled wide material having a specified minimum tensile strength and yield strength of 370 N/mm² and 230 N/mm² respectively, supplied with a pickled finish.

NOTE 2. **Conditions and surface finish.** The following material conditions are available; more complete descriptions are given in table 1 and table 2:

- HR Hot rolled on wide mills. Also available pickled (P).
- HS Hot rolled on narrow mills. Also available pickled (P).
- CR Cold rolled on wide mills. Grades 34/20 and 37/23 are available as general purpose only (GP).
- CS Cold rolled on narrow mills. These steels are normally supplied with a bright finish (BR).

Table 12. Chemical composition: micro-alloyed steels

Grade (see note 1)	Rolled condition	C max.	Mn max.	S max.	P max.
		%	%	%	%
40/30	HR, HS, CS	0.15	1.20	0.040	0.040
43/35	HR, HS, CS	0.15	1.20	0.040	0.040
46/40	HR, HS, CS	0.15	1.20	0.040	0.040
50/45	HR, HS, CS	0.20	1.50	0.040	0.040
60/55	– HS, CS	0.20	1.50	0.040	0.040
40F30	HR, HS, CS	0.12	1.20	0.030	0.030
43F35	HR, HS, CS	0.12	1.20	0.030	0.030
46F40	HR, HS, CS	0.12	1.20	0.030	0.030
50F45	HR, HS, CS	0.12	1.20	0.030	0.030
60F55	– HS, CS	0.12	1.20	0.030	0.030
68F62	– HS –	0.12	1.50	0.030	0.030
75F70	– HS –	0.12	1.50	0.030	0.030

NOTE 1. These grades are fine-grained, fully killed steels containing additions of micro-alloying elements such as Nb and Ti. The manufacturer, at his option, may also add certain elements, e.g. Ca, Ce and Zr, in order to modify the shape of the sulphide inclusions to achieve the high degree of formability offered by these steels, particularly the F series (see note 2).

NOTE 2. The steels including F in their designation offer superior formability for the same strength levels as the corresponding steels in the upper part of the table.

NOTE 3. For improved atmospheric corrosion resistance, these grades may be supplied with a specified minimum copper content by agreement between manufacturer and purchaser.

3.5.2 **Weldability**. All the grades specified in tables 10 and 12 shall be weldable provided that the welding techniques employed make allowance for composition and thickness. See BS 693, BS 1140, BS 2630, BS 5135 and BS 6265.

3.5.3 **Strain-age-embrittlement**. Where proof of freedom from strain-age-embrittlement is required (see 3.2(g)), the method of test shall be agreed between the manufacturer and the purchaser, as the test defined in 1.11 may not be appropriate to all the steels in this section.

Table 13. Mechanical properties: micro-alloyed steels

Grade	Rolled condition (see note 1)	Yield strength, R_e, min. (see note 2)	Tensile strength, R_m, min.	Elongation, A, min. Original gauge length, L_o 50 mm	80 mm (note 4)	200 mm	Bend mandrel diameter (180° bend) (see note 3)
		N/mm²	N/mm²	%	%	%	
40/30	HR, HS, CS	300	400	26	(24)	18	2*a*
43/35	HR, HS, CS	350	430	23	(21)	16	2*a*
46/40	HR, HS, CS	400	460	20	(18)	12	3*a*
50/45	HR, HS, CS	450	500	20	(18)	12	3*a*
60/55	–, HS, CS	550	600	17	(15)	10	3.5*a*
40F30	HR, HS, CS	300	400	28	(26)	20	0*a*
43F35	HR, HS, CS	350	430	25	(23)	18	0.5*a*
46F40	HR, HS, CS	400	460	22	(20)	14	1*a*
50F45	HR, HS, CS	450	500	22	(20)	14	1.5*a*
60F55	–, HS, CS	550	600	19	(17)	11	1.5*a*
68F62	–, HS –	620	680	18	(16)	10	2*a*
75F70	–, HS –	700	750	15	(13)	8	3*a*

a is the thickness of the bend test piece.

NOTE 1. The properties of HS materials are only applicable up to and including 8 mm. For material thicker than 8 mm, the properties are to be agreed between the manufacturer and purchaser.

NOTE 2. A specific range for the yield strength of any particular grade and thickness may be agreed between manufacturer and purchaser at the time of ordering.

NOTE 3. The bend test requirements quoted in this table are for specially prepared test pieces (see 1.10); conditions during fabrication may be more severe and not simulate those during laboratory testing (see note, 'Manipulation', to section three and table 14).

NOTE 4. The 80 mm gauge length is currently not used in the UK but, as a step towards conforming with European practice, tentative values have been included.