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Transient analysis method for HEMi sabot structural design

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Abstract

The High Energy Missile (HEMi) design objective is to defeat 1000 mm of roll hardened armour with a weapon that measures less than 1.2 m long in its stored configuration. An innovative penetrator concept utilizing segmented penetrators was developed. To validate the hydrocode predictions of the penetrator performance, an experimental program to launch prototype segmented penetrators in a two-stage light gas gun was prepared. Acceleration of the penetrator to hypervelocity speeds requires a sabot that can withstand the high g-forces generated by the expanding gas and the inertia of the penetrator. This document discusses the finite element analysis strategy that was developed to calculate sabot stresses and displacements under static and transient conditions.

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1. Introduction

In 2000, the Canadian Forces (CF) expressed a need for a missile system that was capable of perforating the frontal armour of a T-80U and/or a T-72S main battle tank when fired from a light armoured vehicle (LAV) [1]. The missile was required to have an effective range between 400 and 5000 m with a kill probability of 0.95 at 5000 m. A minimum of eight missiles had to be immediately available for firing at all times and the missile had to be sized so that at least thirty missiles could be stowed in the internal volume of a LAV III.

In response to the CF requirement, the Defence R&D Canada – Valcartier initiated the High Energy Missile Technology Demonstration (HEMi-TD) Project in 2001. The objective of the project was to implement, integrate and demonstrate within the Canadian defence research and development community and defence industrial base, a lightweight, compact high energy kinetic energy missile capable of defeating a main battle tank. The project was sub-divided into technology areas comprised of aerodynamics, guidance, control, propulsion, structures, lethality and modelling and simulation.

An innovative penetrator concept utilizing segmented penetrators was developed for high lethality in a compact package. To validate the hydrocode predictions of the penetrator performance, an experimental program to launch prototype segmented penetrators in a two-stage light gas gun was prepared. Acceleration of the penetrator to hypervelocity speeds requires a sabot that can withstand the high g-forces generated by the expanding gas and the inertia of the penetrator. This document discusses the finite element analysis strategy that was developed to calculate sabot stresses and displacements under static and transient conditions. The strategy was subsequently employed by a consultant to study a variety of sabot designs for the experimental program.

2. Model Geometry and Loading Conditions

2.1 Model Geometry and Materials

A representative shape for the sabot and penetrator slug was selected. There was no need to match the dimensions of the actual test article because the objective of this work is to devise a strategy that gives a convergent and stable solution.

The axisymmetric solid model of the sabot and penetrator slug is shown in Figure 1 with the y-axis as the axis of rotation. The ANSYS finite element pre-processor allows the geometry to be defined by keypoints, lines and areas [2]. The penetrator slug is comprised of areas 1 and 2 while the sabot is comprised of areas 3 to 5. Since the penetrator and sabot are press fit for the experimental work, the solid models for the penetrator and sabot share the common lines 1, 6 and 7 so that there are no gaps in the geometry. The coordinates of the keypoints are given in Table 1.

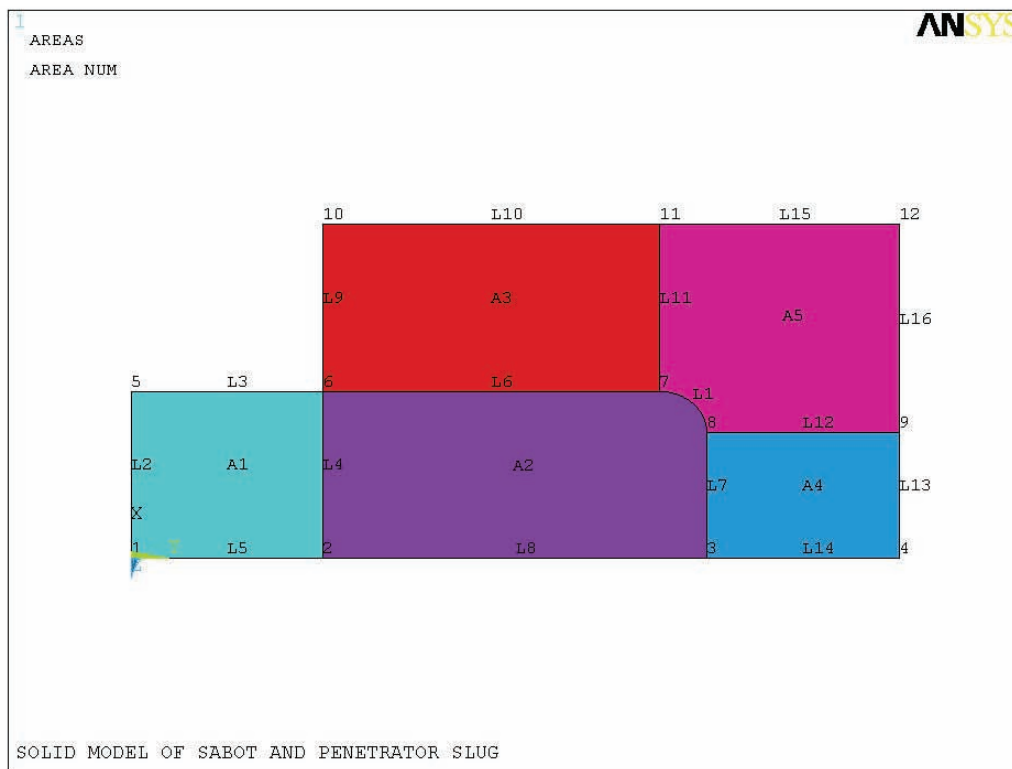


Figure 1. Axisymmetric solid model of sabot and penetrator

Table 1. Coordinates for solid model keypoints		
Keypoint	x-coord. (m)	y-coord. (m)
1	0	0
2	0	1
3	0	3
4	0	4
5	1	0
6	1	1
7	1	2.75
8	0.75	3
9	0.75	4
10	2	1
11	2	2.75
12	2	4
13	0.75	2.75

For the purpose of this study, the penetrator was assumed to be a homogeneous piece of tungsten. The sabot was assumed to be a homogeneous piece of polycarbonate. The material properties are given in Table 2.

Table 2. Material properties for penetrator and sabot		
Property	tungsten	polycarbonate
modulus (GPa)	200	2
Poisson ratio (-)	0.3	0.35
density (kg/m ³)	19650	1250

The solid model was meshed with 8-noded 2D structural solids set as axisymmetric elements [3] using the automated smartsize command, SMRTSIZE, found in ANSYS [4]. The size level parameter, SIZLVL, was set at 2 to generate a fairly fine mesh throughout the model. Large gradients in stress and strain were expected in the areas surrounding keypoints 3, 6, 7 and 8 because of the geometric discontinuities. Mesh refinement was carried out with the keypoint refine command, KREFINE, where the depth of mesh refinement, DEPTH, was set to 3 [5]. The final mesh is shown in Figure 2.

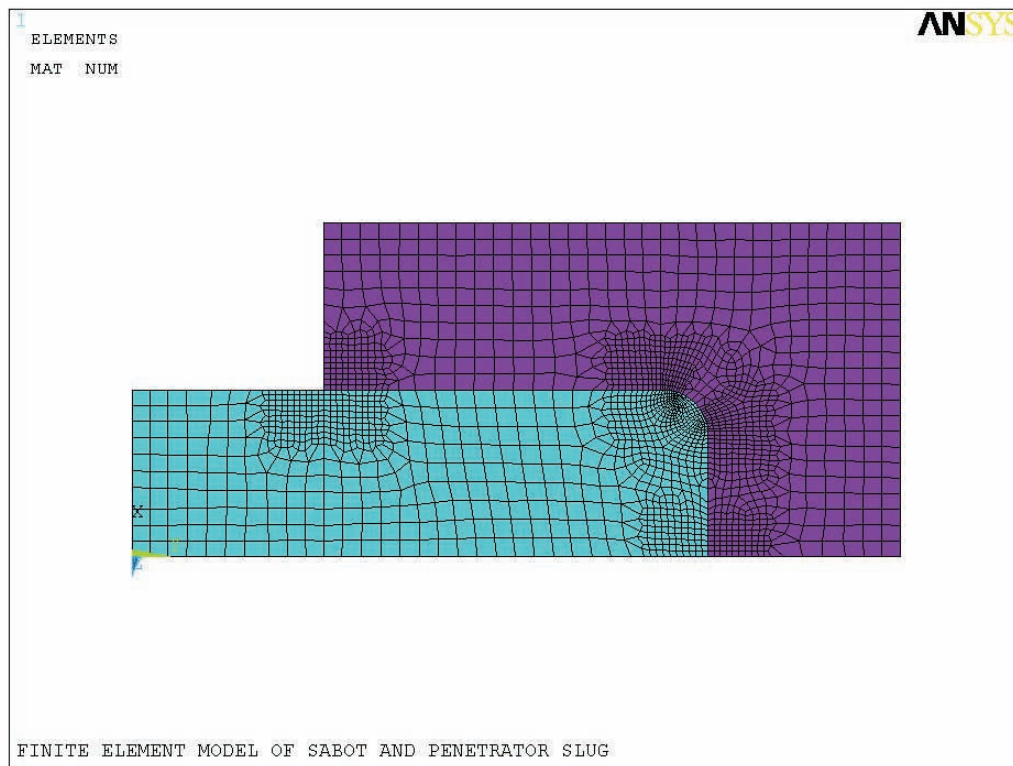


Figure 2. Axisymmetric finite element model of sabot and penetrator

2.2 Boundary Conditions

The axisymmetric model has one axis of symmetry and an outer surface that is constrained from moving in the radial direction. Both conditions are modeled by displacement constraints in the x-direction (see Figure 3). During the launching process, low pressures are present on the front faces of the penetrator and the sabot while high pressures exist on the back face of the sabot. The relative magnitudes and time profiles of the pressures are given in Figure 4 where $P_{\text{penetrator}}$ is the front face pressure and P_{sabot} is the back face pressure. The profiles were input as time-pressure pairs in the ANSYS input file with the loads being ramped from one time point to the next.

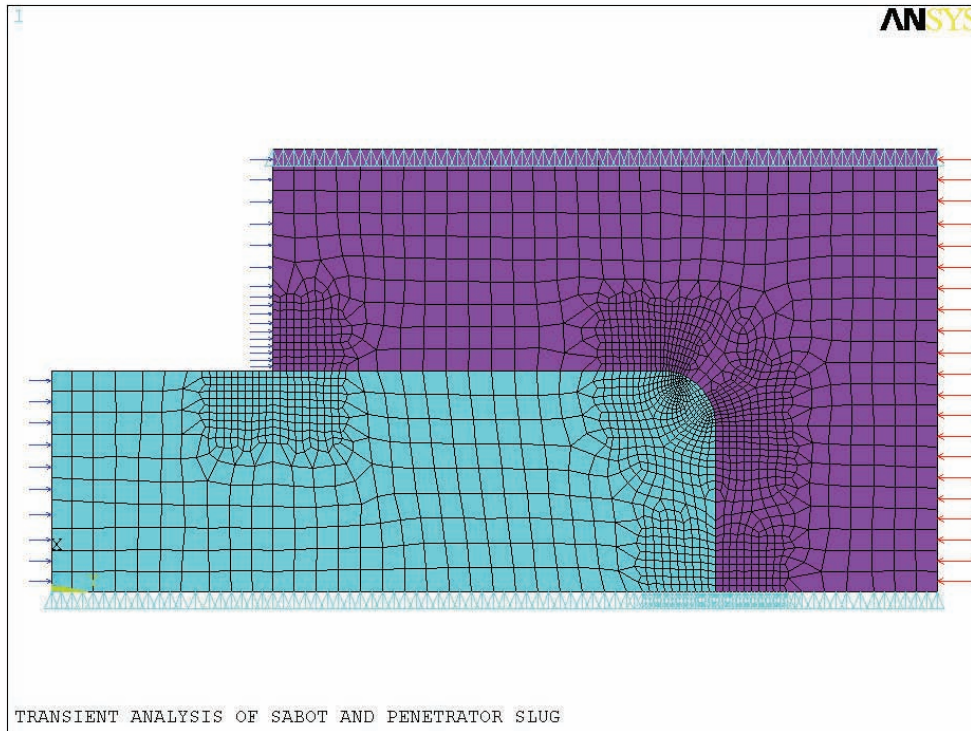


Figure 3. Boundary conditions on sabot and penetrator

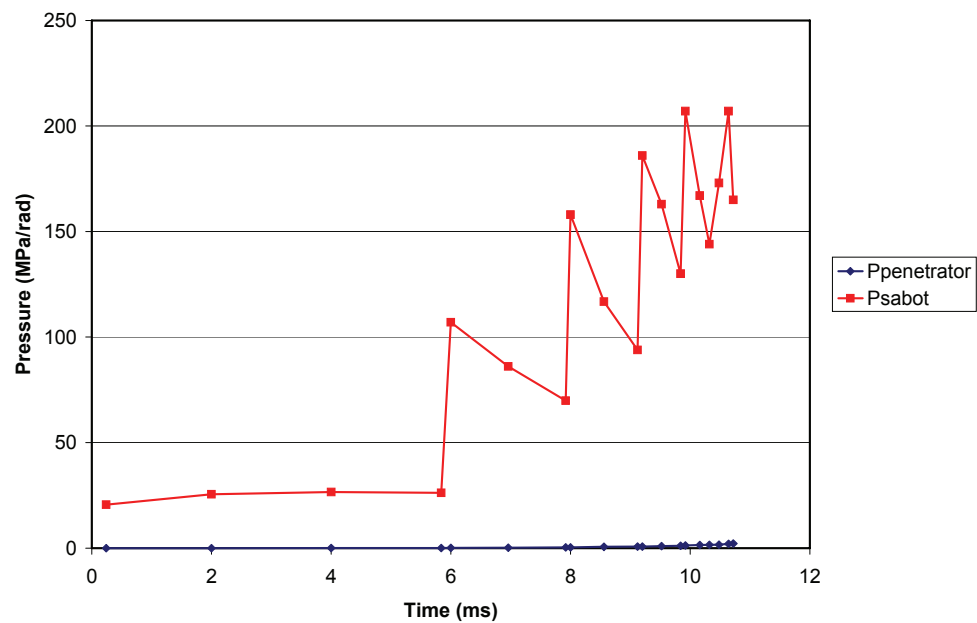


Figure 4. Pressure profiles on sabot and penetrator

3. Static Analysis

A static analysis of the penetrator plug and sabot was carried out for reference purposes. The boundary conditions were changed to zero displacement on the penetrator face and an applied surface pressure of 207 MPa/rad on the sabot face (see Figure 5).

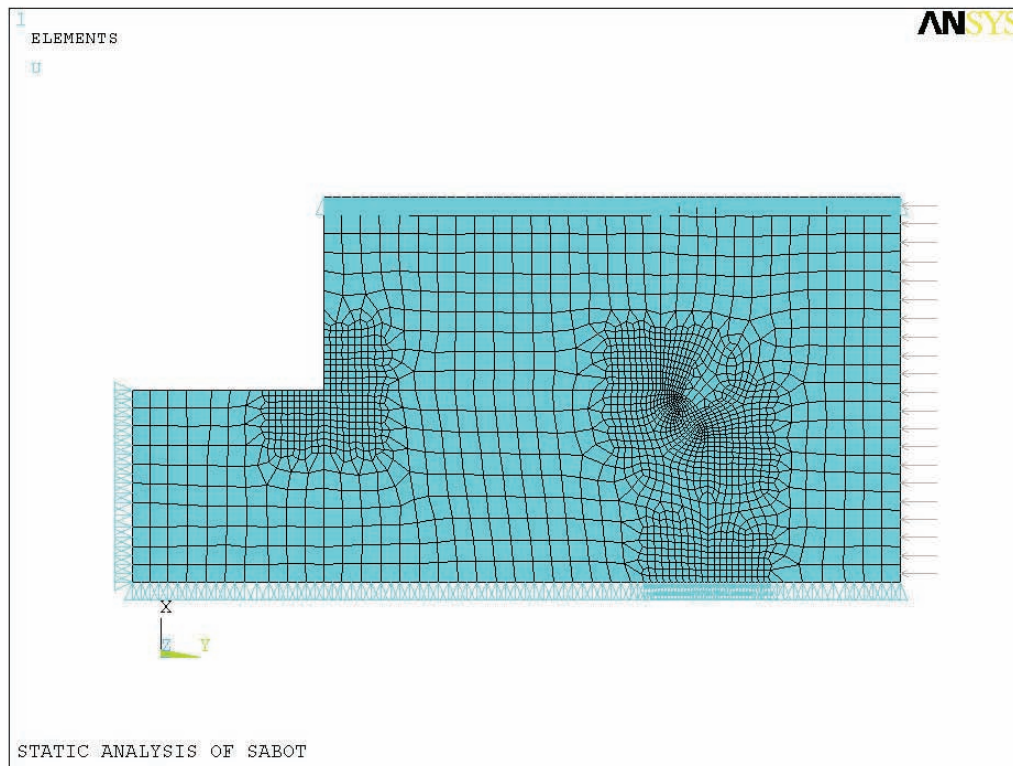


Figure 5. Boundary conditions for static analysis

The results for deformation, shear stress and von Mises stress in the sabot are given graphically in Figure 6 through Figure 8. Numerical values are given in Table 3.

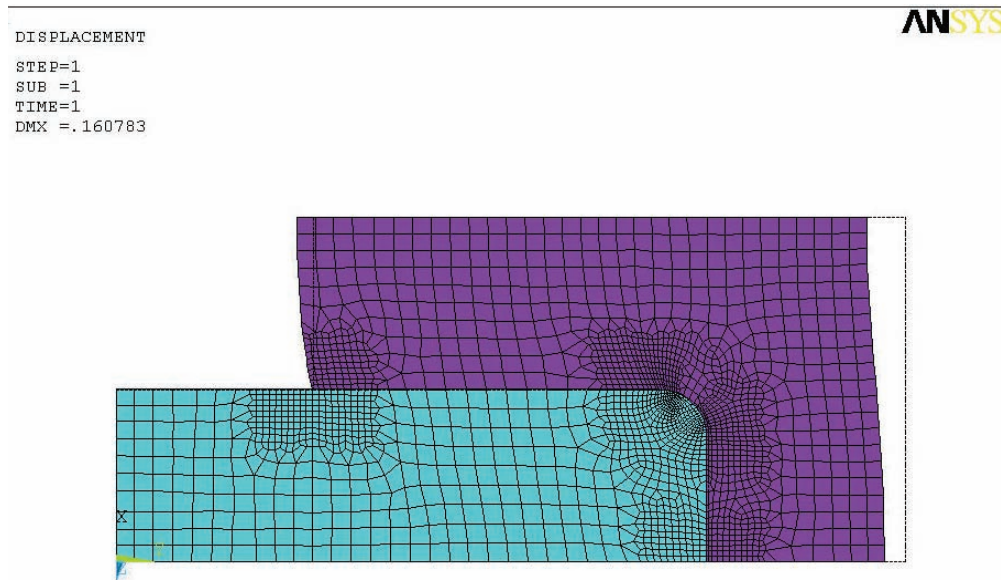


Figure 6. Deformation results for static analysis

Table 3. Static analysis results for the sabot						
	$D_{penetrator} (m)$	$\sigma_{xy} (MPa)$		$\sigma_{vm}(MPa)$		$D_{sabot} (m)$
	max^a	min	max	min	max	max^a
Static	0.011	-278	18.5	12.6	521	0.161
$D_{penetrator}$: penetrator displacement; σ_{xy} : shear stress; σ_{vm} : von Mises stress; D_{sabot} : sabot displacement a) The penetrator and sabot displacement values represent the maximum absolute movement of the penetrator and sabot at a point. It does not represent the maximum positive value as defined by ANSYS.						

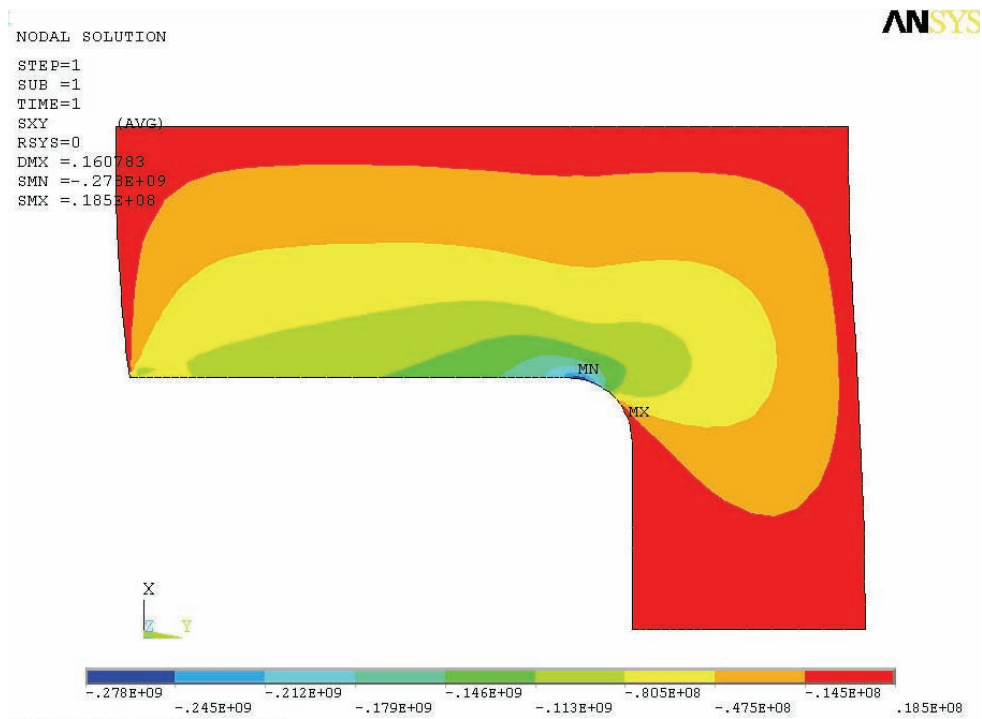


Figure 7. Shear stress results for static analysis

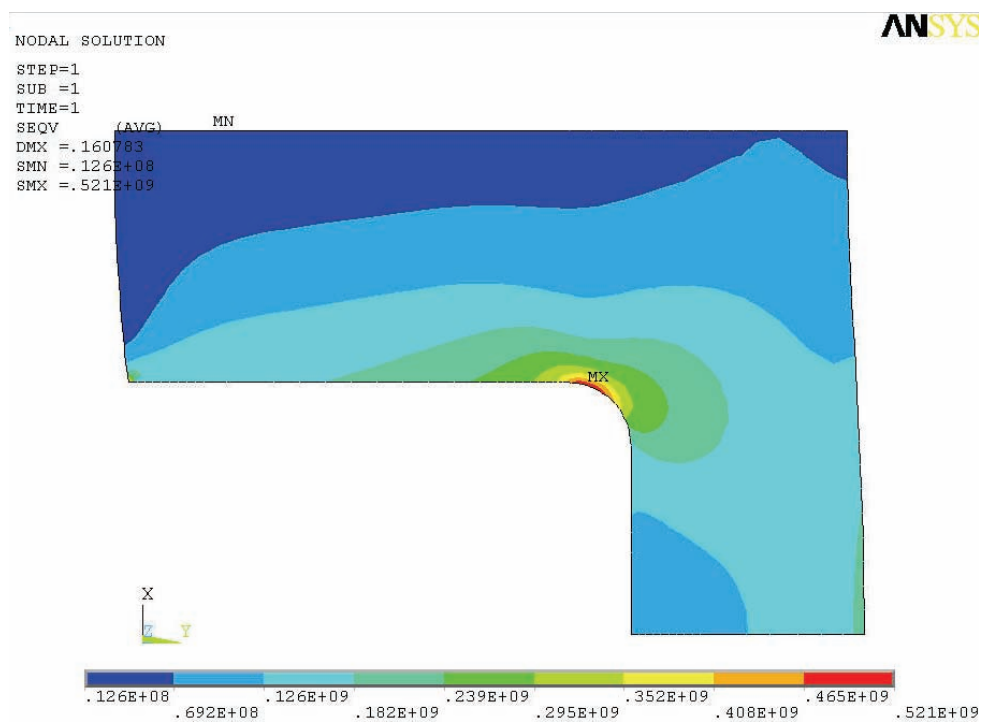


Figure 8. von Mises results for static analysis

4. Transient Analysis

The ANSYS finite element program offers a variety of methods to solve transient problems. The wavefront solver functions by minimizing the number of linear equations that are active in the assembled element matrix before solving by gaussian elimination [6]. The method requires that the problem be solved using in-core memory and so, may not be suitable for large problems with many degrees-of-freedom. As an alternative, conjugate gradient iterative solvers can be used. The Jacobi Conjugate Gradient solver is appropriate for well-conditioned problems. The Preconditioned Conjugate Gradient solver can be used for real symmetric and positive definite stiffness matrices that are ill-conditioned. The Incomplete Cholesky Conjugate Gradient solver is used for complex unsymmetric matrices. Since the iterative solvers can use out-of-core memory, large problems can be solved in machines with limited memory [7].

4.1 Iterative Solver

The Preconditioned Conjugate Gradient solver was initially selected to reduce the demands on computer memory and to, hopefully, reduce analysis run-times. The transient option, TRNOPT, was set to FULL to specify that all degrees-of-freedom should be kept. The Newton-Raphson option, NROPT, was set to AUTO, to allow automatic selection of the tangent matrix update method.

The accuracy and stability of the solution is controlled by the size of the solver tolerance value, the size of the time step and the number of sub-steps within the time step. The size of the time step is specified by the pressure-time profile in Figure 4. A default value of $1\text{E-}8$ was used as the solver tolerance value. Therefore, only the appropriate sub-step parameter for the sabot problem needed to be found.

Table 4 shows the effect that the number of sub-steps has on the values for penetrator displacement, sabot shear stress, sabot von Mises stress and sabot displacement. An examination of the table values reveals that a higher number of sub-steps does not automatically result in a better or more valid solution. For example, for a sub-step of 7, the maximum sabot von Mises stress is 509 MPa. For a sub-step of 9, the sabot von Mises stress suddenly becomes 1160 MPa. Increasing the sub-step to 10, results in an even higher von Mises stress. The cause of this behaviour is attributed to round-off errors where numerical ‘noise’ starts to affect the accuracy of the solution [8]. When the number of sub-steps are too small, for example at 1, error also enters into the solution because the dynamics of the problem are not properly captured. It can be seen that at sub-step equal to 1, the maximum sabot von Mises stress is 470 MPa while the von Mises stress at sub-step equal to 3 is 507 MPa. It can be concluded from these results that the appropriate sub-step for the sabot problem falls somewhere between 3 and 7.

In comparison to the static analysis results, the transient results are reasonable because the sabot displacement is higher due to its forward movement. In terms of shear stress, the lack of displacement constraints on the penetrator in the transient case allows a higher shear stress to be produced. The von Mises stress is reduced for the same reason.

The ANSYS input file used for the iterative analysis method is found in Annex A.

Table 4. Transient analysis results for the sabot using the PCG iterative solver						
	$D_{\text{penetrator}} (m)$	$\sigma_{xy} (MPa)$		$\sigma_{vm}(MPa)$		$D_{\text{sabot}} (m)$
Sub-steps	max^a	min	max	min	max	max^a
10	0.132	-287	271	1.1	2420	0.258
9	0.123	-323	378	0.70	1160	0.272
7	0.119	-247	25.7	0.86	509	0.265
5	0.119	-247	25.7	0.85	509	0.260
3	0.120	-236	25.3	1.70	507	0.261
1	0.121	-255	36.8	190	470	0.250
static	0.011	-278	18.5	12.6	521	0.161
$D_{\text{penetrator}}$: penetrator displacement; σ_{xy} : shear stress; σ_{vm} : von Mises stress; D_{sabot} : sabot displacement a) The penetrator and sabot displacement values represent the maximum absolute movement of the penetrator and sabot at a point. It does not represent the maximum positive value as defined by ANSYS.						

4.2 Wavefront Solver

The uncertainty of what sub-step to use in an analysis can be eliminated by selecting the wavefront solver at the expense of increased in-core memory requirements. To examine the effect of the sub-step parameter using this solution method, a series of analyses were run using the FRONT option in the equation solver command, EQSLV.

Table 5 shows that for sub-steps varying between 1 and 20, the values for penetrator displacement, sabot shear stress, sabot von Mises stress and sabot displacement are reasonably close to one another. Selecting a sub-step that is too small, ie. 1, can still produce a solution that does not properly capture the dynamics of the situation. However, overestimating the number of sub-steps does not cause numerical errors to accumulate in the solution. In comparison to the iterative solver solution where the number of sub-steps is 5, the wavefront solver with sub-step equal to 9 predicts a 10% higher shear stress and a 4% higher von Mises stress.

Table 5. Transient analysis results for the sabot using the wavefront solver						
	$D_{penetrator} (m)$	$\sigma_{xy} (MPa)$		$\sigma_{vm}(MPa)$		$D_{sabot} (m)$
Sub-steps	max^a	min	max	min	max	max^a
20	0.119	-264	30.2	0.22	526	0.259
9	0.119	-255	28.8	0	528	0.259
1	0.119	-252	35.7	182	465	0.249
static	0.011	-278	18.5	126	521	0.161
$D_{penetrator}$: penetrator displacement; σ_{xy} : shear stress; σ_{vm} : von Mises stress; D_{sabot} : sabot displacement a) The penetrator and sabot displacement values represent the maximum absolute movement of the penetrator and sabot at a point. It does not represent the maximum positive value as defined by ANSYS.						

5. Conclusions

To validate the hydrocode predictions of the penetrator performance in the High Energy Missile (HEMi) project, an experimental program to launch prototype segmented penetrators in a two-stage light gas gun was prepared. A sabot design method was required to determine how well different designs could withstand the acceleration of the penetrator to hypervelocity speeds with an expanding gas.

A transient analysis strategy was developed with the ANSYS finite element program to handle the design task. An iterative method like the Preconditioned Conjugate solver with a sub-step number between 3 and 7 can be used if the model contains a high number of degrees of freedom and if computer resources are limited. For smaller models, the wavefront method can be used without an extensive verification of the impact that the sub-step parameter has on the solution stability and accuracy.

6. References

1. Wells, P. J., ``Draft Statement of Operational Requirements for High Energy Missile Technology Demonstrator'', 27 March 2001, private communication.
2. ANSYS Modeling and Meshing Guide, Release 5.3, 1996.
3. ANSYS Elements Reference, Release 5.3, 1996, pp. 4-575 to 4-587.
4. ANSYS Commands Reference, Release 5.3, 1996, pp. 3-849 to 3-851.
5. ANSYS Commands Reference, Release 5.3, 1996, pp. 3-469.
6. "Wavefront Solver", ANSYS Theory Manual, Release 5.3, 1996, pp. 15-18 to 15-22.
7. "Conjugate Gradient Solvers", ANSYS Theory Manual, Release 5.3, 1996, pp. 15-63 to 15-65.
8. "Transient Dynamic Analysis", ANSYS Structural Analysis Guide, Release 5.3, 1996, pp. 5-48 to 5-51.

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Annex A

ANSYS Input File for Transient Analysis

```
!*  TRANSIENT ANALYSIS OF SABOT/PROJECTILE
/FILNAM,SABOT-TRAN
/TITLE,TRANSIENT ANALYSIS OF SABOT
/PREP7
ET,1,PLANE82
KEYOPT,1,3,1    ! AXISYMMETRIC
!*
MP,EX,1,200e9    ! TUNGSTEN
MP,NUXY,1,0.3
MP,DENS,1,19653
MP,EX,2,2e9      ! POLYCARBONATE
MP,NUXY,2,0.35
MP,DENS,2,1250
!*
K,1,0,0,,
K,2,0,1,,
K,3,0,3,,
K,4,0,4,,
K,5,1,0,,
K,6,1,1,,
K,7,1,2.75,,
K,8,0.75,3,,
K,9,0.75,4,,
K,10,2,1,,
K,11,2,2.75,,
K,12,2,4,,
K,12,2,4,,
K,13,.75,2.75,,
!*
LARC,7,8,13,0.25
!
A,1,5,6,2
A,2,6,7,8,3
A,6,10,11,7
A,3,8,9,4
A,7,11,12,9,8
SAVE
!
TYPE,1
MAT,1
REAL,
ESYS,0
SMRTSIZE,2
MSHAPE,0,2D
MSHKEY,0
AMESH,1,2      ! TUNGSTEN AREAS
!*
MAT,2
AMESH,3,5      ! POLYCARBONATE AREAS
```

```

!*
!* REFINE AT PENETRATOR CORNERS
FLST,5,4,3,ORDE,4
FITEM,5,3
FITEM,5,6
FITEM,5,7
FITEM,5,8
CM,_Y,KP
KSEL, , , ,P51X
CM,_Y1,KP
CMSEL,S,_Y
CMDELE,_Y
!*
!*
KREFINE,_Y1, , ,1,3,1,1
CMDELE,_Y1
!*
FINISH
/SOL
!*
!ANTYPE,0 ! 0=STATIC, 4=TRANSIENT
!
DL,5,1,SYMM
DL,8,2,SYMM
DL,14,4,SYMM
!
DK,1,UX,0,,1
DK,2,UX,0,,1
DK,3,UX,0,,1
DK,4,UX,0,,1
DK,10,UX,0,,1
DK,11,UX,0,,1
DK,12,UX,0,,1
!DK,1,UY,0,,1
!DK,5,UY,0,,1
!*
SBCTRAN
/PBC,U,,1
EPLO
FINISH
!
!* PRESSURE-TIME PROFILE DEFINITION
!
!* LINES DEFINING FRONT FACE
FRTFC1 = 2
FRTFC2 = 9
!* LINES DEFINING BACK FACE
BCKFC1 = 13
BCKFC2 = 16
!*
NSTEP = 5
!*
RADIANS = 1
/SOL
ANTYPE,4
TRNOPT,FULL
NROPT,AUTO

```

```

EQSLV,ITER,1E-8 ! AUTO SELECTED, TOLER
!EQSLV,FRONT ! USE FRONTAL METHOD
!
! USE EXISTING DISPLACEMENT BC'S ON EDGES
!*
! NO NEED TO SPECIFY IC'S BECAUSE INITIALLY AT REST
TIMINT,ON
! PT 1
TIME,0.24E-3
SFL,BCKFC1,PRES,20.6e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,20.6E6/RADIANS,
SFL,FRTFC1,PRES,0.02e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.02E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 2
TIME,2E-3
SFL,BCKFC1,PRES,25.5e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,25.5E6/RADIANS,
SFL,FRTFC1,PRES,0.03e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.03E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 3
TIME,4E-3
SFL,BCKFC1,PRES,26.6e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,26.6E6/RADIANS,
SFL,FRTFC1,PRES,0.05e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.05E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 4
TIME,5.84E-3
SFL,BCKFC1,PRES,26.2e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,26.2E6/RADIANS,
SFL,FRTFC1,PRES,0.09e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.09E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 5
TIME,6E-3
SFL,BCKFC1,PRES,107e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,107e6/RADIANS,
SFL,FRTFC1,PRES,0.10e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.10E6/RADIANS,
KBC,0 ! *STEP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE

```

```

!*****
! PT 6
TIME,6.96E-3
SFL,BCKFC1,PRES,86.1e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,86.1E6/RADIANS,
SFL,FRTFC1,PRES,0.21e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.21E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 7
TIME,7.92E-3
SFL,BCKFC1,PRES,69.9e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,69.9E6/RADIANS,
SFL,FRTFC1,PRES,0.38e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.38E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 8
TIME,8E-3
SFL,BCKFC1,PRES,158e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,158E6/RADIANS,
SFL,FRTFC1,PRES,0.40e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.40E6/RADIANS,
KBC,0 ! *STEP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 9
TIME,8.56E-3
SFL,BCKFC1,PRES,116.8e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,116.8E6/RADIANS,
SFL,FRTFC1,PRES,0.64e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.64E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 10
TIME,9.12E-3
SFL,BCKFC1,PRES,93.9e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,93.9E6/RADIANS,
SFL,FRTFC1,PRES,0.76e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.76E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
!*****
! PT 11
TIME,9.2E-3
SFL,BCKFC1,PRES,186e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,186E6/RADIANS,
SFL,FRTFC1,PRES,0.76e6/RADIANS, ! FRONT FACE

```

```

SFL,FRTFC2,PRES,0.76E6/RADIANS,
KBC,0                      ! *STEP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 12
TIME,9.52E-3
SFL,BCKFC1,PRES,163e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,163E6/RADIANS,
SFL,FRTFC1,PRES,0.96e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,0.96E6/RADIANS,
KBC,0                      ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 13
TIME,9.84E-3
SFL,BCKFC1,PRES,130e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,130E6/RADIANS,
SFL,FRTFC1,PRES,1.15e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,1.15E6/RADIANS,
KBC,0                      ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 14
TIME,9.92E-3
SFL,BCKFC1,PRES,207e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,207E6/RADIANS,
SFL,FRTFC1,PRES,1.28e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,1.28E6/RADIANS,
KBC,0                      ! *STEP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 15
TIME,10.16E-3
SFL,BCKFC1,PRES,167e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,167E6/RADIANS,
SFL,FRTFC1,PRES,1.54e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,1.54E6/RADIANS,
KBC,0                      ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! *****
! PT 16
TIME,10.32E-3
SFL,BCKFC1,PRES,144e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,144E6/RADIANS,
SFL,FRTFC1,PRES,1.59e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,1.59E6/RADIANS,
KBC,0                      ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 17

```

```

TIME,10.48E-3
SFL,BCKFC1,PRES,173e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,173E6/RADIANS,
SFL,FRTFC1,PRES,1.66e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,1.66E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 18
TIME,10.64E-3
SFL,BCKFC1,PRES,207e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,207E6/RADIANS,
SFL,FRTFC1,PRES,2.0e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,2.0E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
! PT 19
TIME,10.72E-3
SFL,BCKFC1,PRES,165e6/RADIANS, ! BACK FACE
SFL,BCKFC2,PRES,165E6/RADIANS,
SFL,FRTFC1,PRES,2.2e6/RADIANS, ! FRONT FACE
SFL,FRTFC2,PRES,2.2E6/RADIANS,
KBC,0 ! RAMP
NSUBST,NSTEP
AUTOTS,ON
LSWRITE
!* SOLVE TRANSIENT
/PBC,ALL,0
/PSF,PRESS,NORM,2,,OFF
/PBC,U,,1
EPLO
LSSOLVE,1,19 ! SOLVE AT ALL TIME STEPS
FINISH
/POST1
ESEL,S,MAT,,2 ! SELECT SABOT ELEMENTS
/GRAPHICS,OFF
PLNSOL,S,EQV ! PLOT VON MISES STRESSES

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The High Energy Missile (HEMi) design objective is to defeat 1000 mm of roll hardened armour with a weapon that measures less than 1.2 m long in its stored configuration. An innovative penetrator concept utilizing segmented penetrators was developed. To validate the hydrocode predictions of the penetrator performance, an experimental program to launch prototype segmented penetrators in a two-stage light gas gun was prepared. Acceleration of the penetrator to hypervelocity speeds requires a sabot that can withstand the high g-forces generated by the expanding gas and the inertia of the penetrator. This document discusses the finite element analysis strategy that was developed to calculate sabot stresses and displacements under static and transient conditions.

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