Simulation of a ballistic impact of a deformable bullet upon a multilayer fabric package

Rimantas Barauskas

System Analysis Department of Kaunas university of technology, Lithuania, rimantas.barauskas@ktu.lt

Aušra Abraitienė

Lithuanian Textiles Institute, Kaunas, Lithuania

Andrius Vilkauskas

Engineering Mechanics Department of Kaunas university of technology, Lithuania,

Problem formulation

- ballistic protection textiles: 10-15 layer multilayer textile package;
- each layer made of woven paraaramyde yarns;
- 9mm lead or full-metal jacket bullets;
- impact velocity ~300m/s;
- large deformations and failure of textiles accompanied by large deformations of the bullet

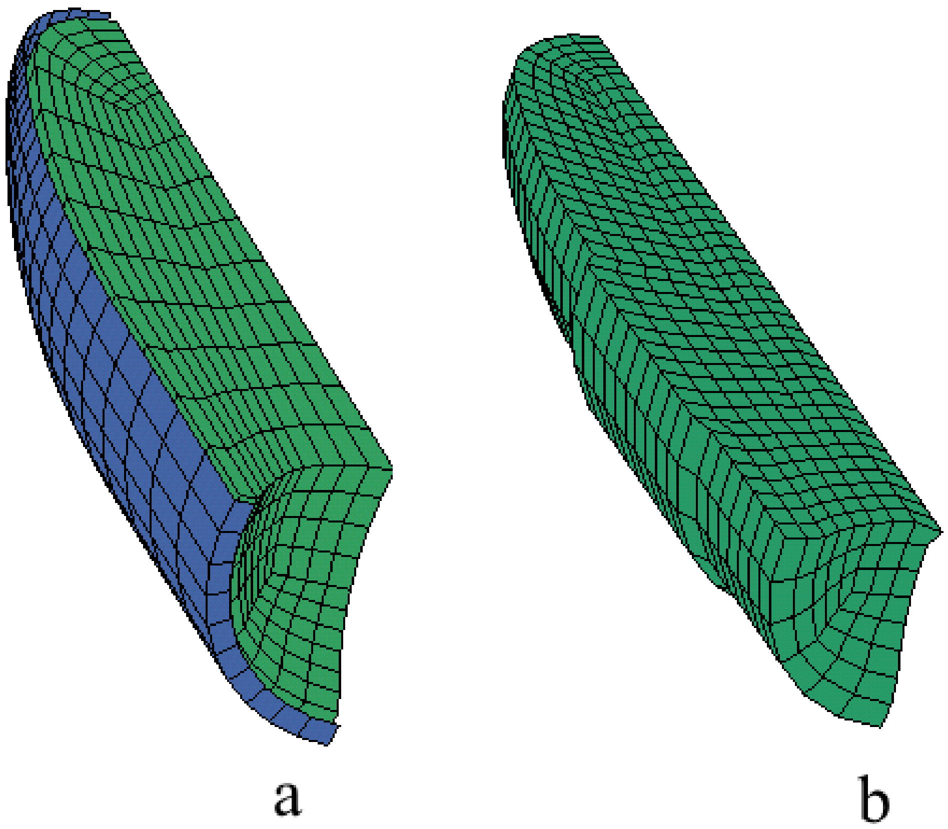
 

The protection level is defined by

- **Yarns**: the number and properties of filaments comprising a yarn;
- **Fabrics**: weave type, surface density, isotropy of the weave, tensile characteristics, trimming;
- **Fabrics package**: number of layers and their interconnection technique

Bullets

- Quarter symmetry models in Truegrid
- Contact interaction between the jacket and the stuff
- Brass jacket (shell): rho=8800kg/m^3; E=117GPa; nu=0.3; Yield_stress=80MPa
- Lead stuff (solid): rho=10880 kg/m^3; E=17GPa; nu= 0.41; Yield_stress= 8MPa



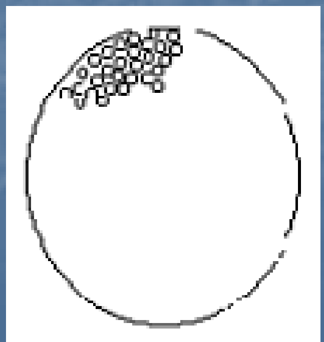
a - 9mm full metal jacket bullet;
b - Balle22 lead bullet

Paraaramyde Twaron Textiles

- TwaronCT:

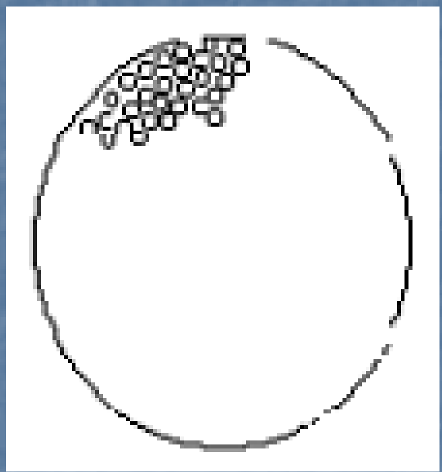
  Rho=1440 kg/m3; E=90GPa; nu=0.33;

  Yield stress = failure_limit = 0.6GPa
- Step of the weave 0.95mm
- Thickness 0.3mm
- Multi-filament yarns   (100-10000 filaments)



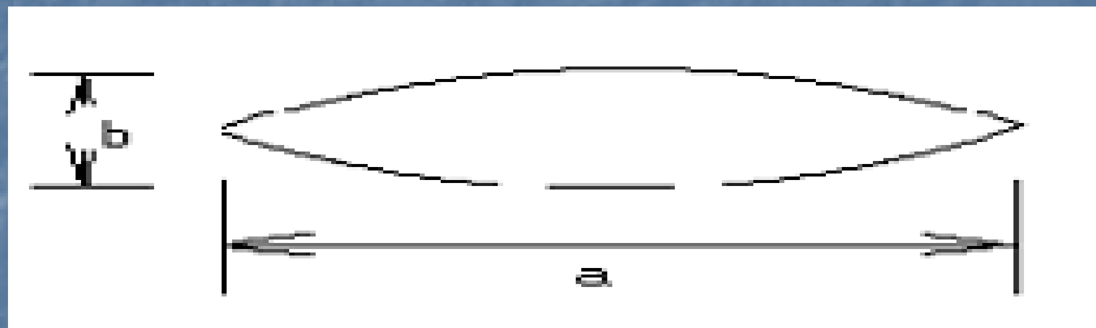
Multi-filament yarn deformed in a weave

Neutral



Circular cross-section

Woven in a fabrics



Cross-section shape as two circular arcs

a=0.95mm;
b=0.15mm

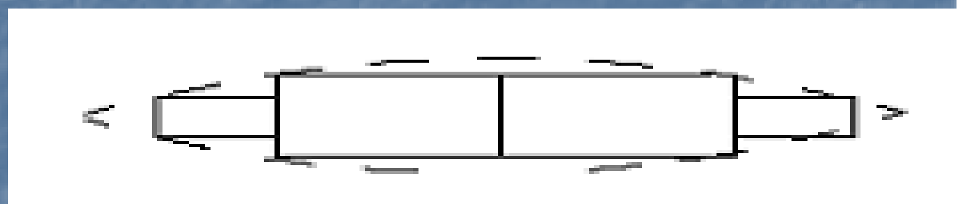
Model levels of a single fabrics layer

- "Micro-mechanical": a filament as primary component

Not used: too large, probably unrealistic today

- "Mezzo-mechanical": a yarn as primary component

Cross-section modeled by solid or shell elements

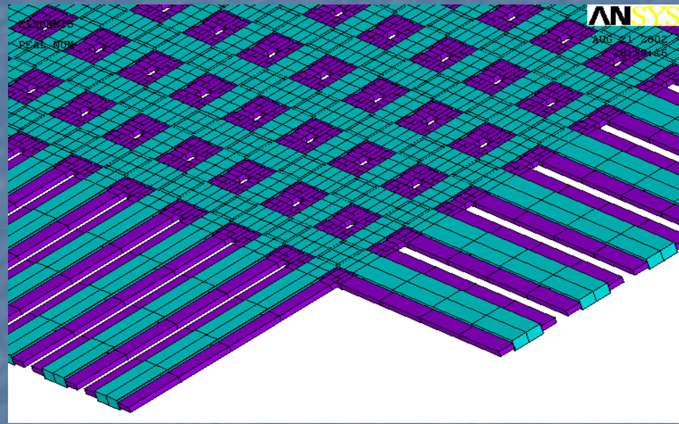


- "Macro-mechanical": fabrics as primary component

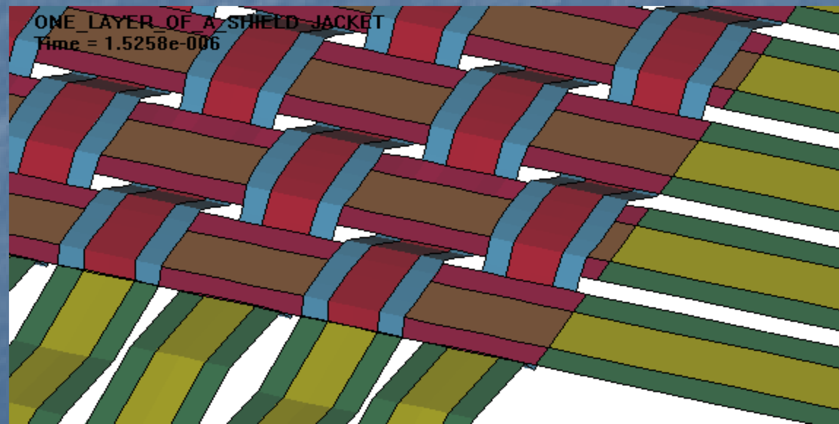
Cloth modeled as a thin membrane

One Layer of TwaronCT Textiles: geometry of the mezzo-mechanical model(1)

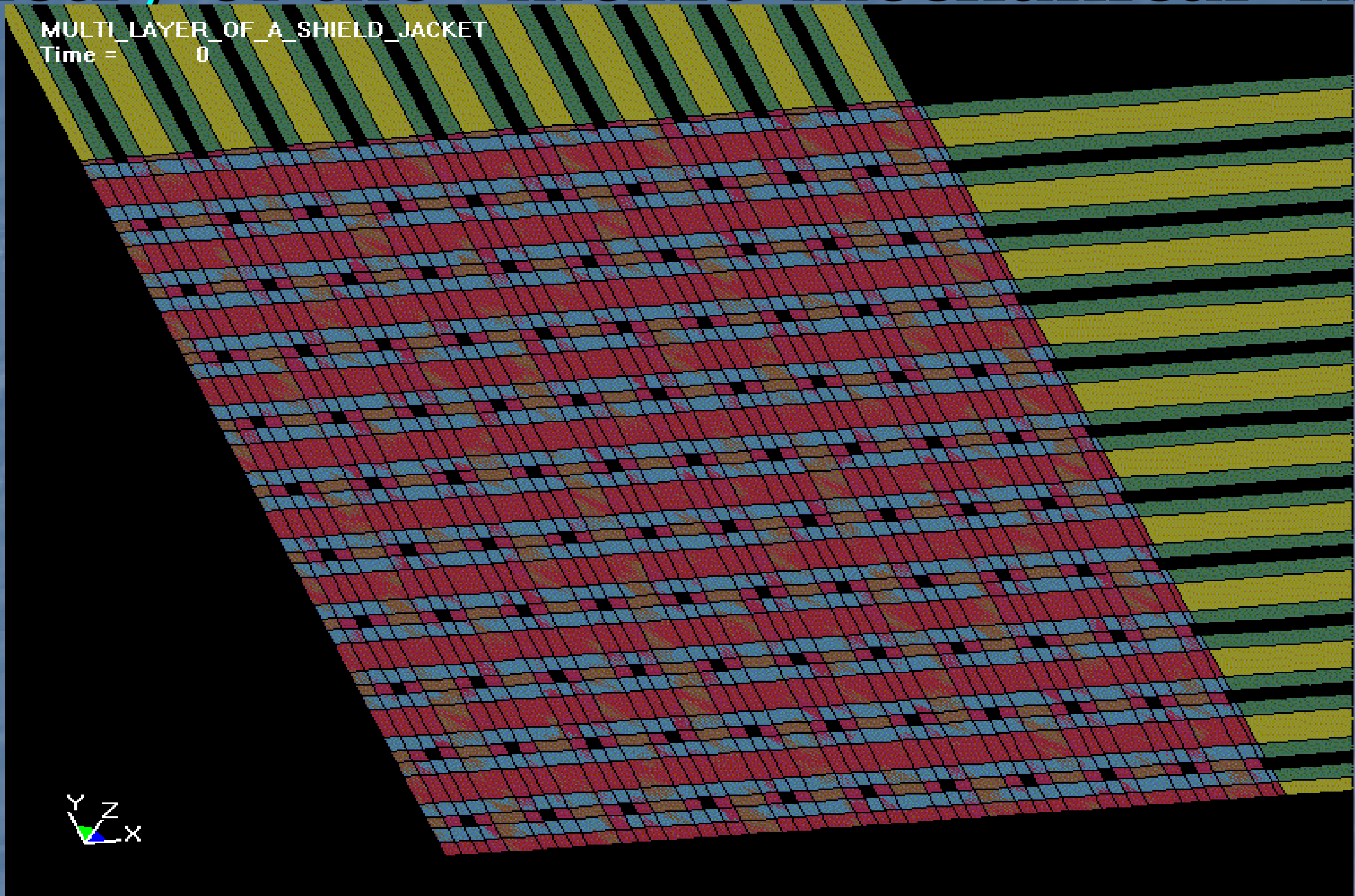
- Yarns modeled by one integration point shell elements (*SECTION SHELL,, ELFORM=11,,NIP=1)



- The weave gapes created by prescribing displacements of warp yarns followed by activation of contact search with the weft yarns



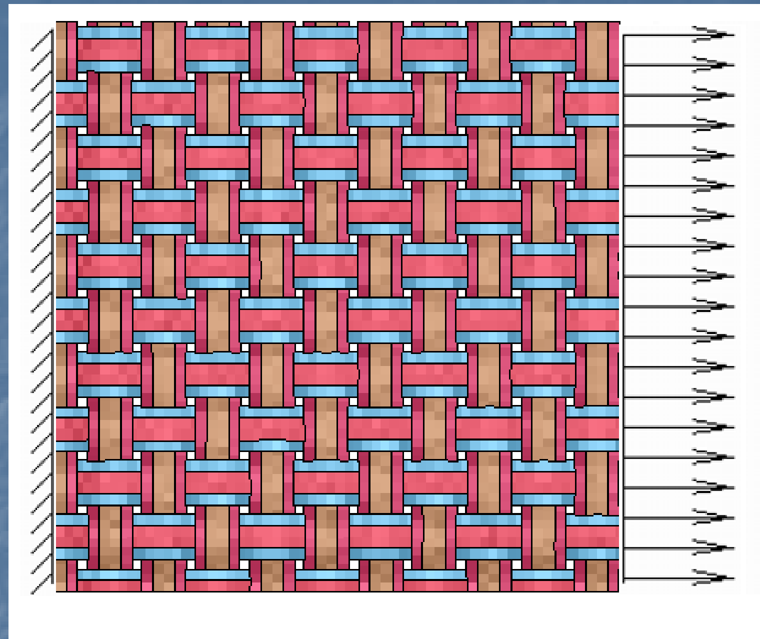
Single Layer of Fabrics : geometry of the "mezzo-mechanical"model(2)

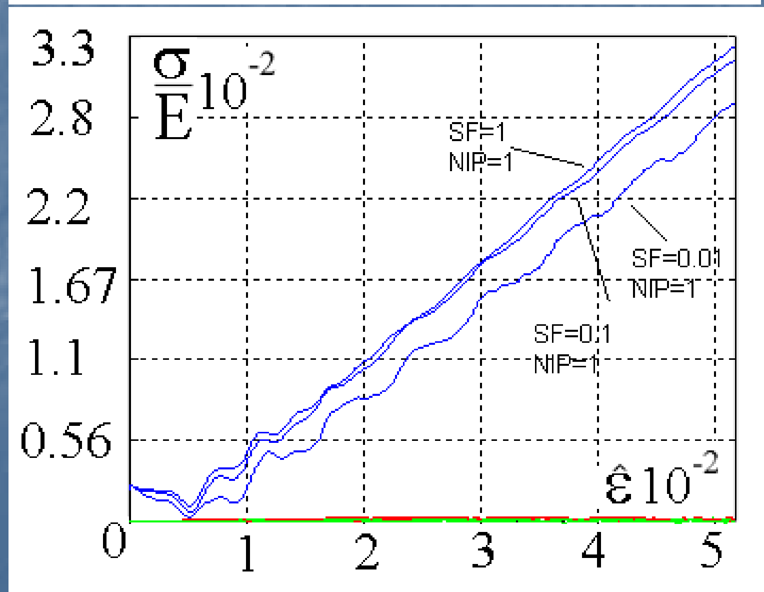


- The system left in a free condition to return elastically to equilibrium;
- Equilibrium stresses removed – imitation of the relaxation of stresses in multi-filament yarns

Simulation of the static tension test

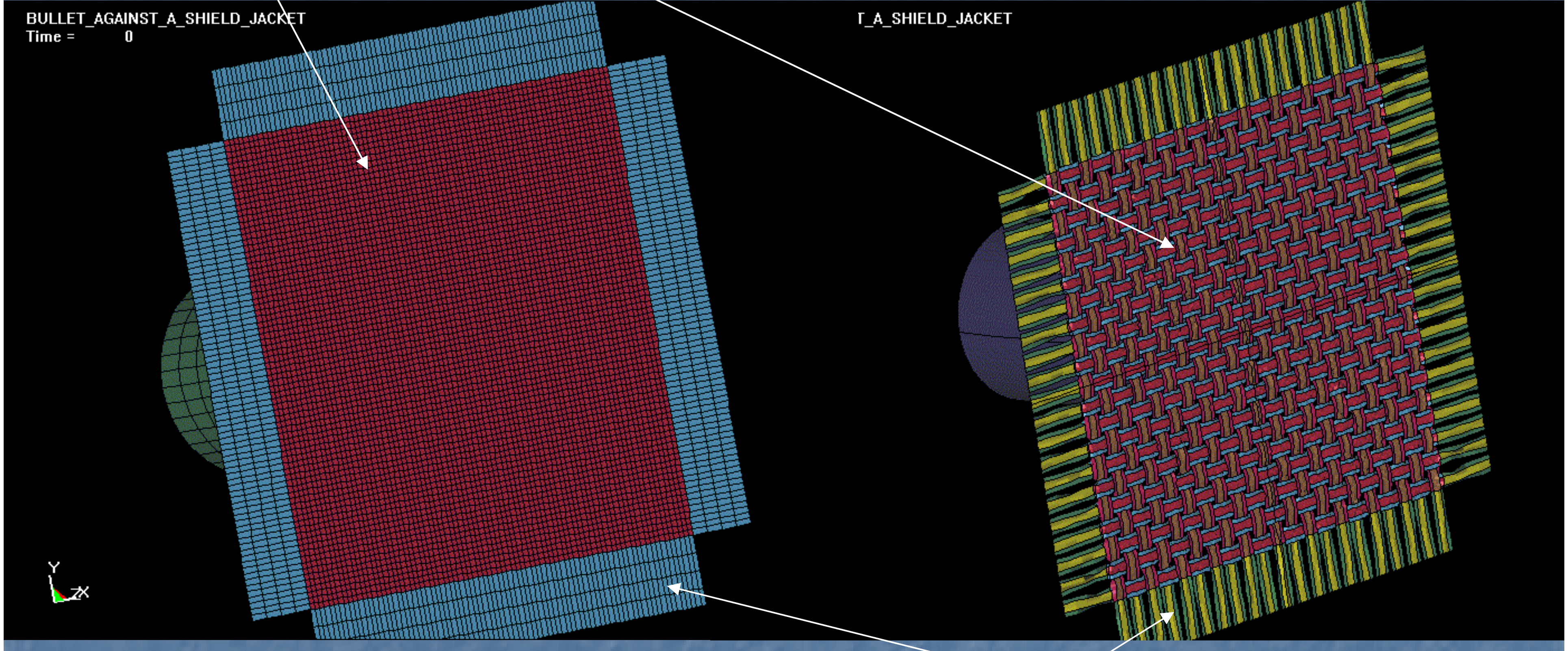
- Failure limit at ~3% elongation of yarns and ~5% elongation of the fabrics – results close to experimental
- proper value of the slave contact stiffness scale multiplier in the range 0.01 - 1 makes the curve closer to experimental





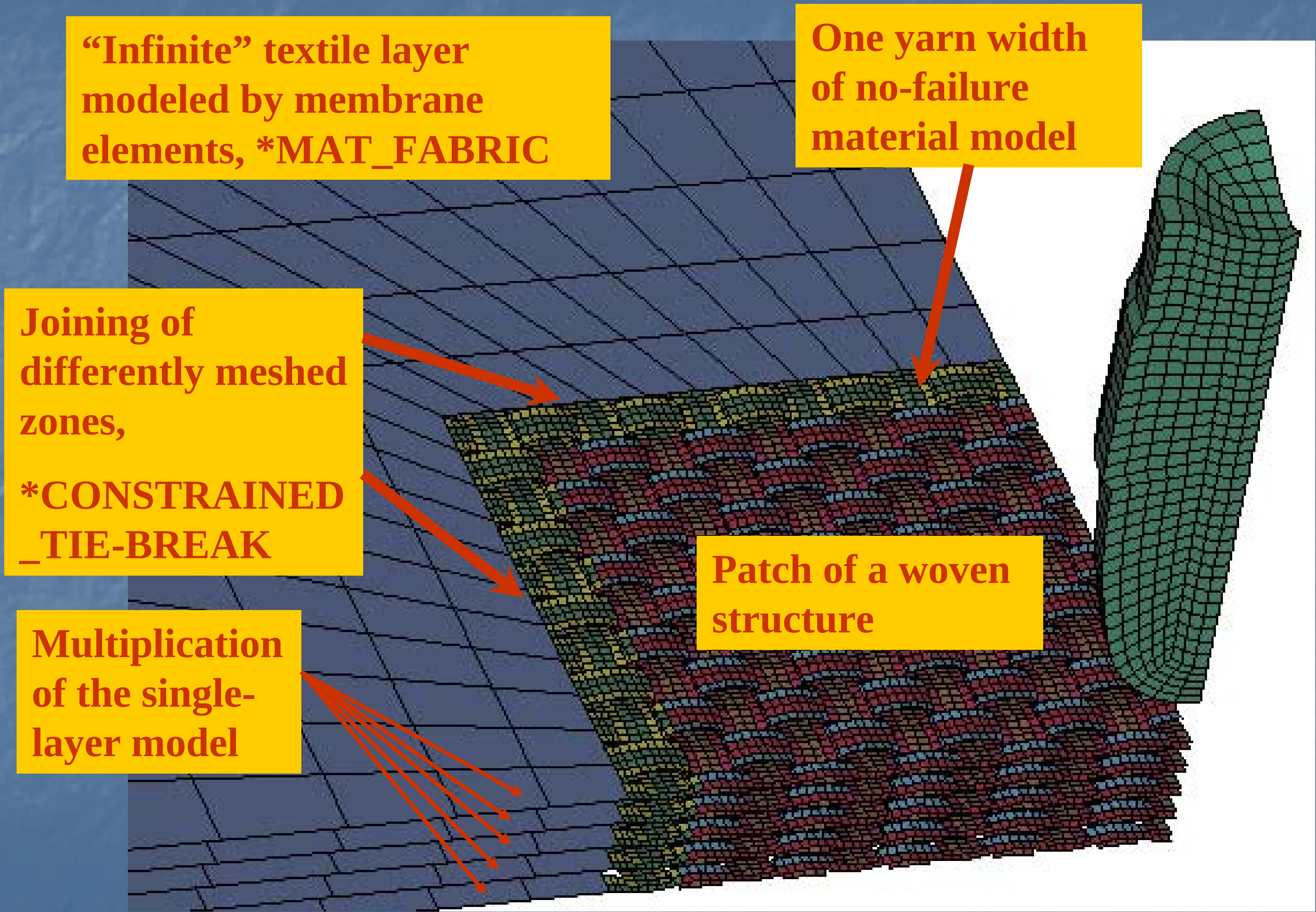
Single Layer of Fabrics Penetrated by a Bullet at 300m/s:

Macro- and Mezzo-mechanical models



"Infinite" textile layer modeled by elastic supports

Fabrics package model: combining "mezzo" and "macro-mechanical approaches



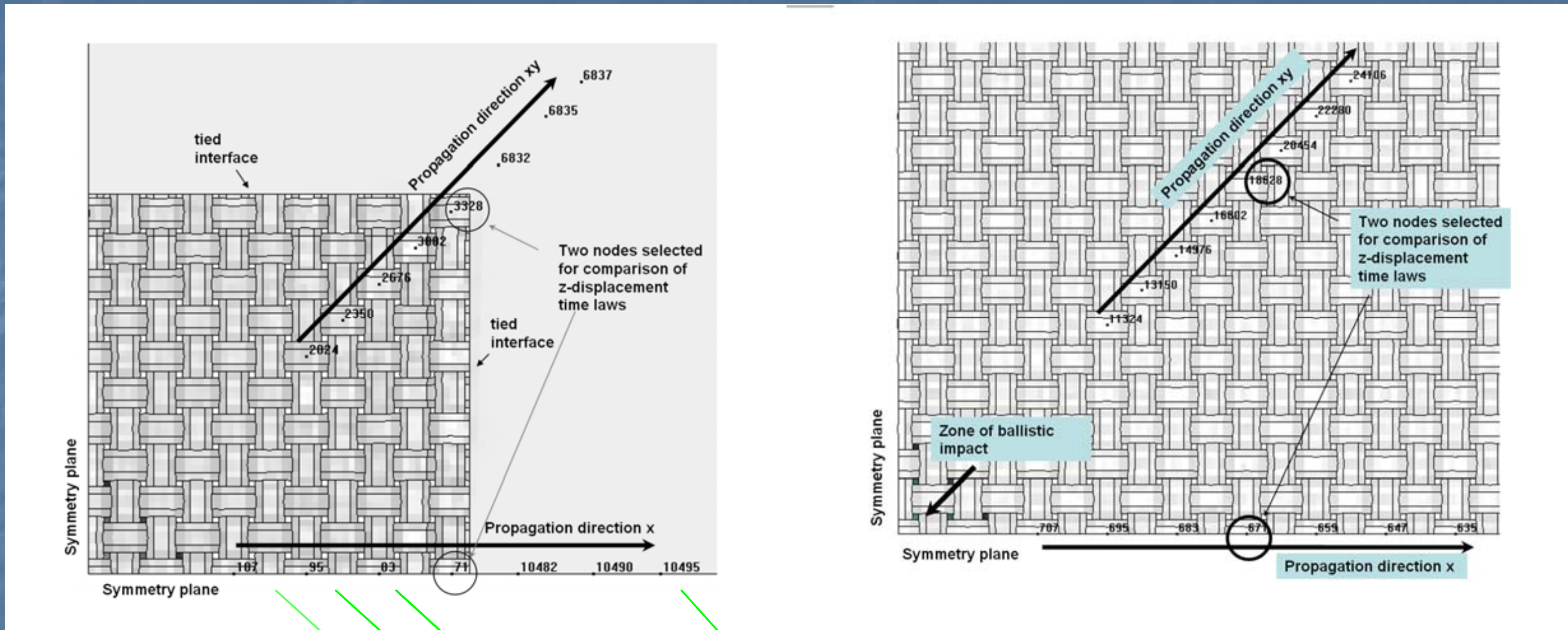
Sources of possible inadequacy of the model:

adjusting the material constants values
in the process of the model validation

- Very approximate model of a yarn;
- Lack of a full set of material constants (mostly dynamic ones);
- Limited size of a patch presented by a woven structure model

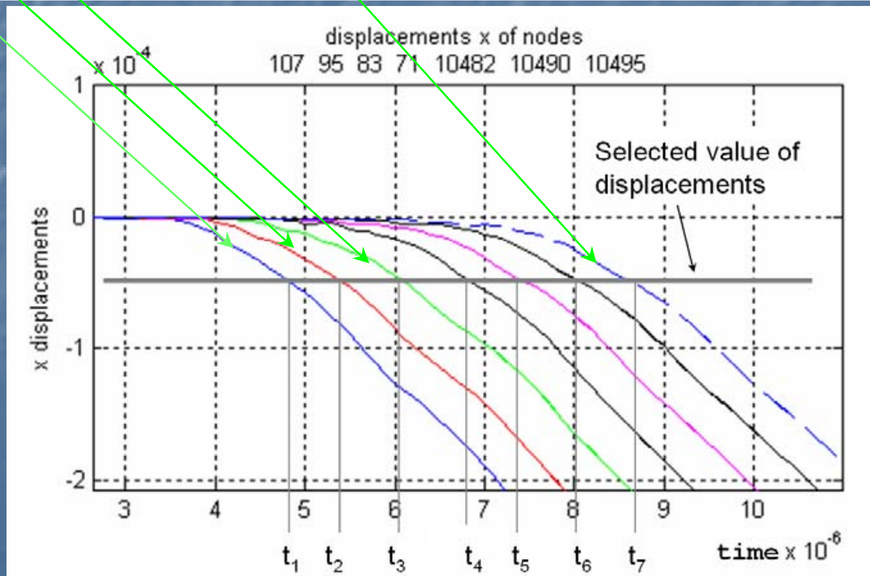
adjusting the *MAT_FABRIC constants
values in the process of the model verification

Verification of the single-layer model: adjustment of parameters of the membrane layer (1)



time laws of longitudinal displacements of nodes:

Required: No change in wave propagation velocity after crossing the tie-boundary

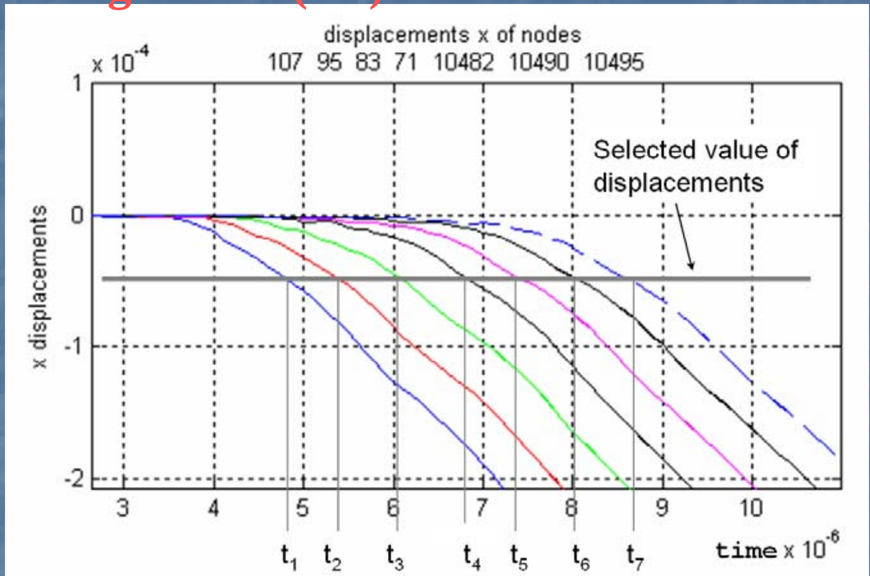


Propagation of the impact-excited longitudinal component of the wave across the tie boundary

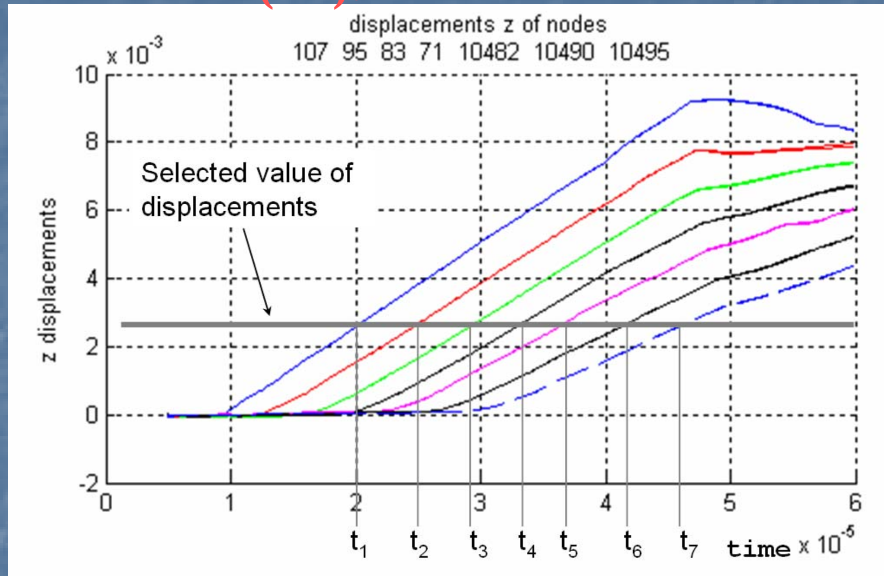
Verification of the single-layer model: adjustment of parameters of the membrane layer (2)

Displacements:

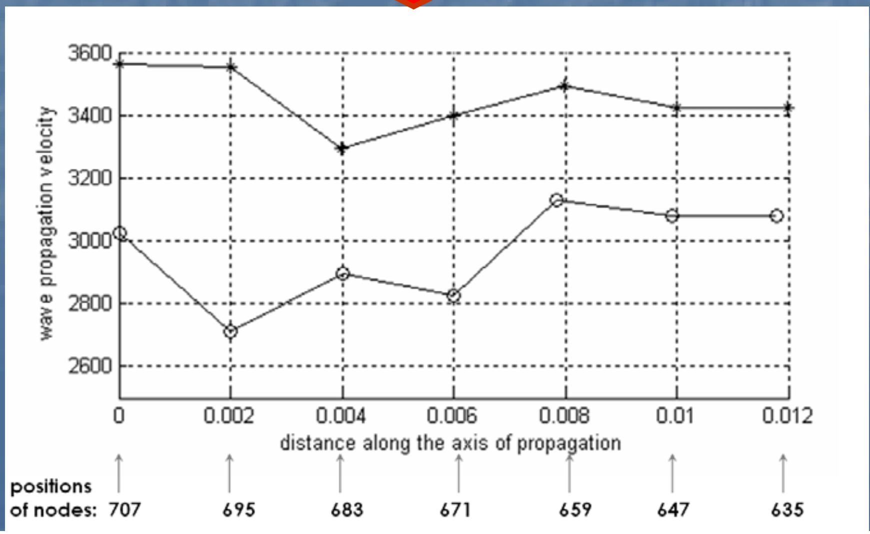
Longitudinal(Ox):

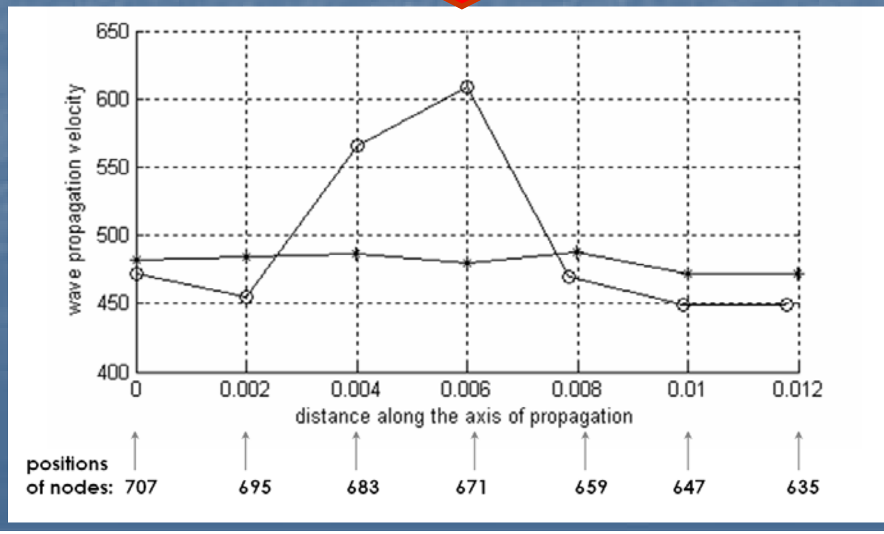


Transversal(Oz):

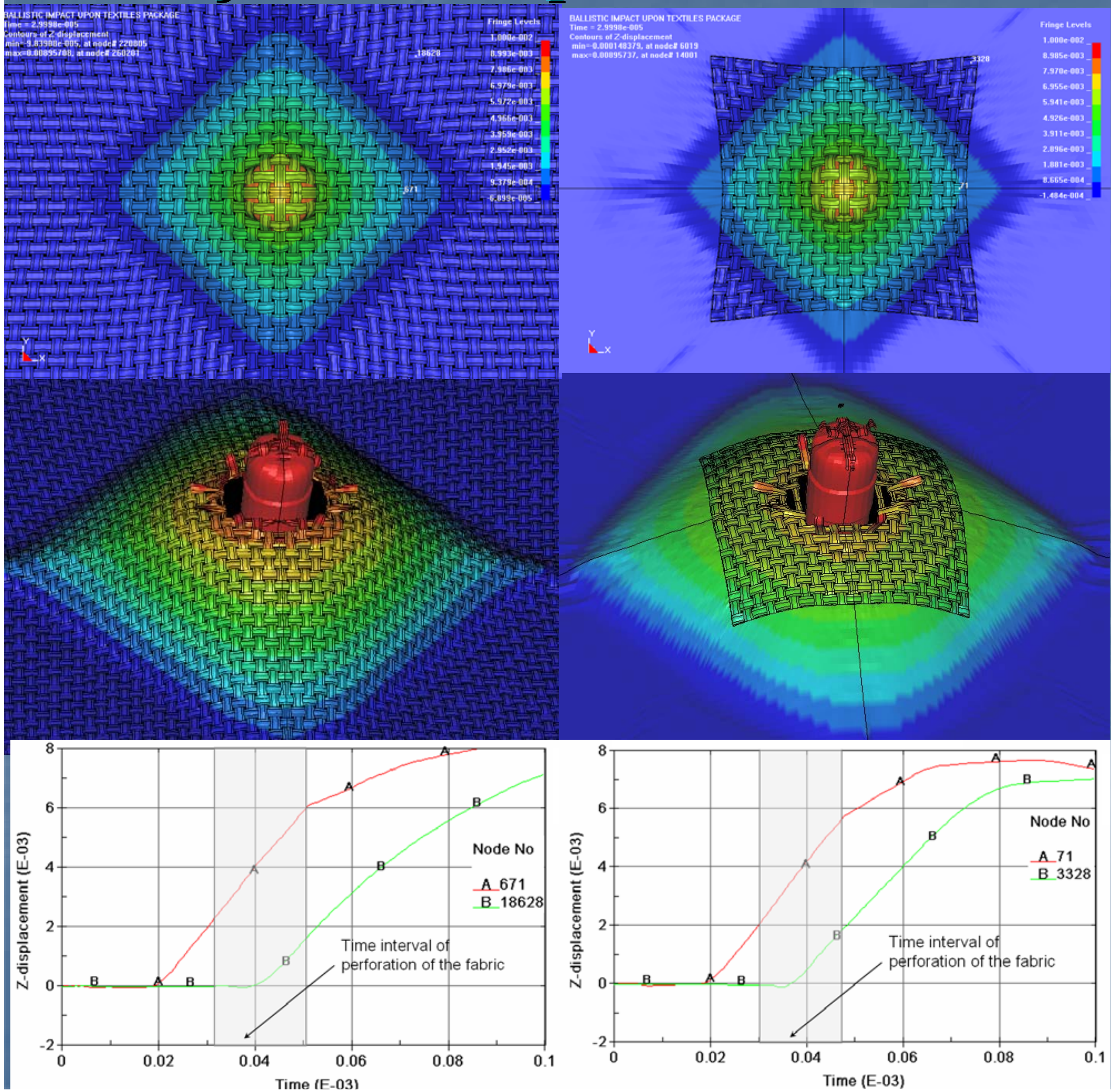


Propagation velocities:



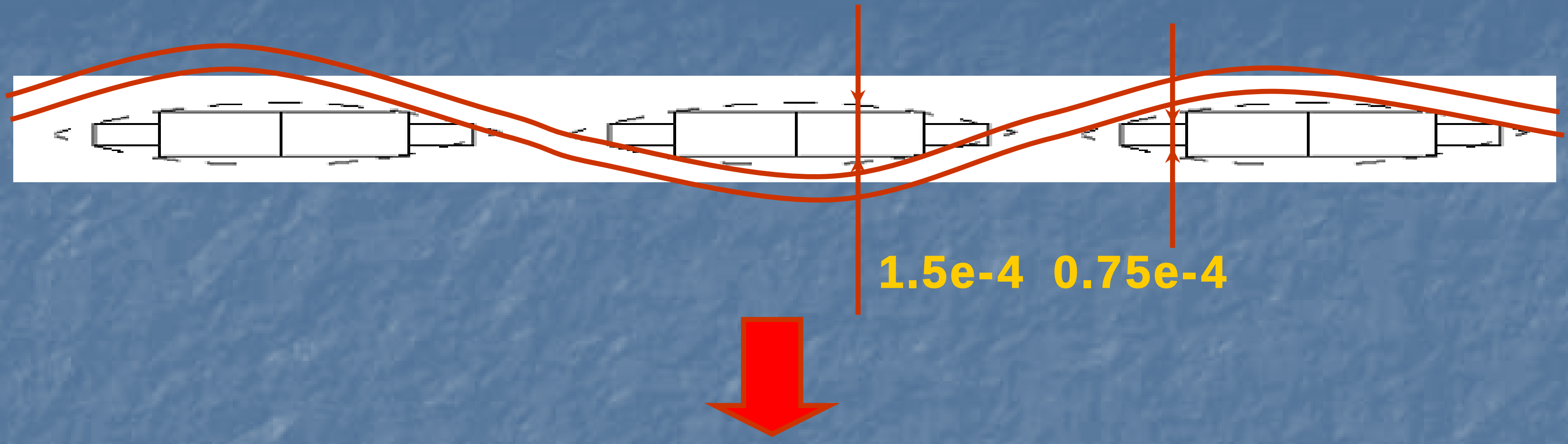


Verification of the single-layer model: adjustment of parameters of the membrane layer (3)



Propagation of the impact-excited transversal component of the wave across the tie boundary

Verification of the single-layer model: adjustment of parameters of the membrane layer (4)



$$\frac{\rho_m}{\rho} = \frac{2250}{1400}; \qquad \frac{E_m}{E} = \frac{2.75\times10^{10}}{9\times10^{10}}; \qquad G = 2\times10^{8}$$

Material models

- brass and lead are elastic-plastic materials (*MAT_PLASTIC_KINEMATIC)
- paraaramyde assumed to be perfectly elastic up to failure limit
- in high velocity impact interaction the yield stress is dependent upon the strain rate (Symonds-Couper model):

$$\sigma_Y = \sigma_{Y0} \left[1 + \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{p}} \right]$$

Bullet model validation:

Determining the lead material dynamic parameters

- numerical and physical experiments of shooting the lead bullet into 10mm thickness lead plate;
- The data obtained from the physical experiment:

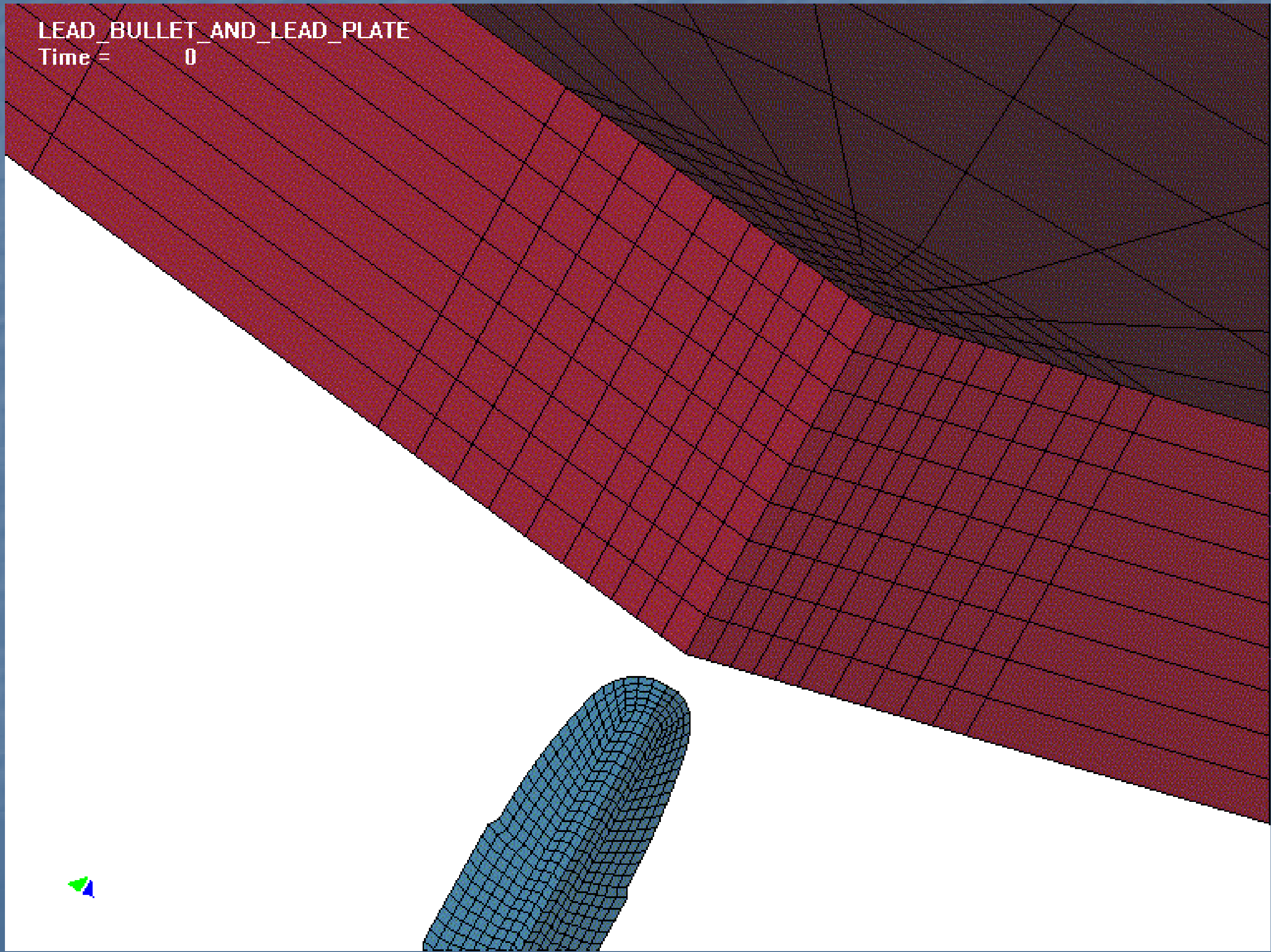
  -the measured linear momentum supplied to the plate;

  -the deformed shape of the bullet imbedded into the target

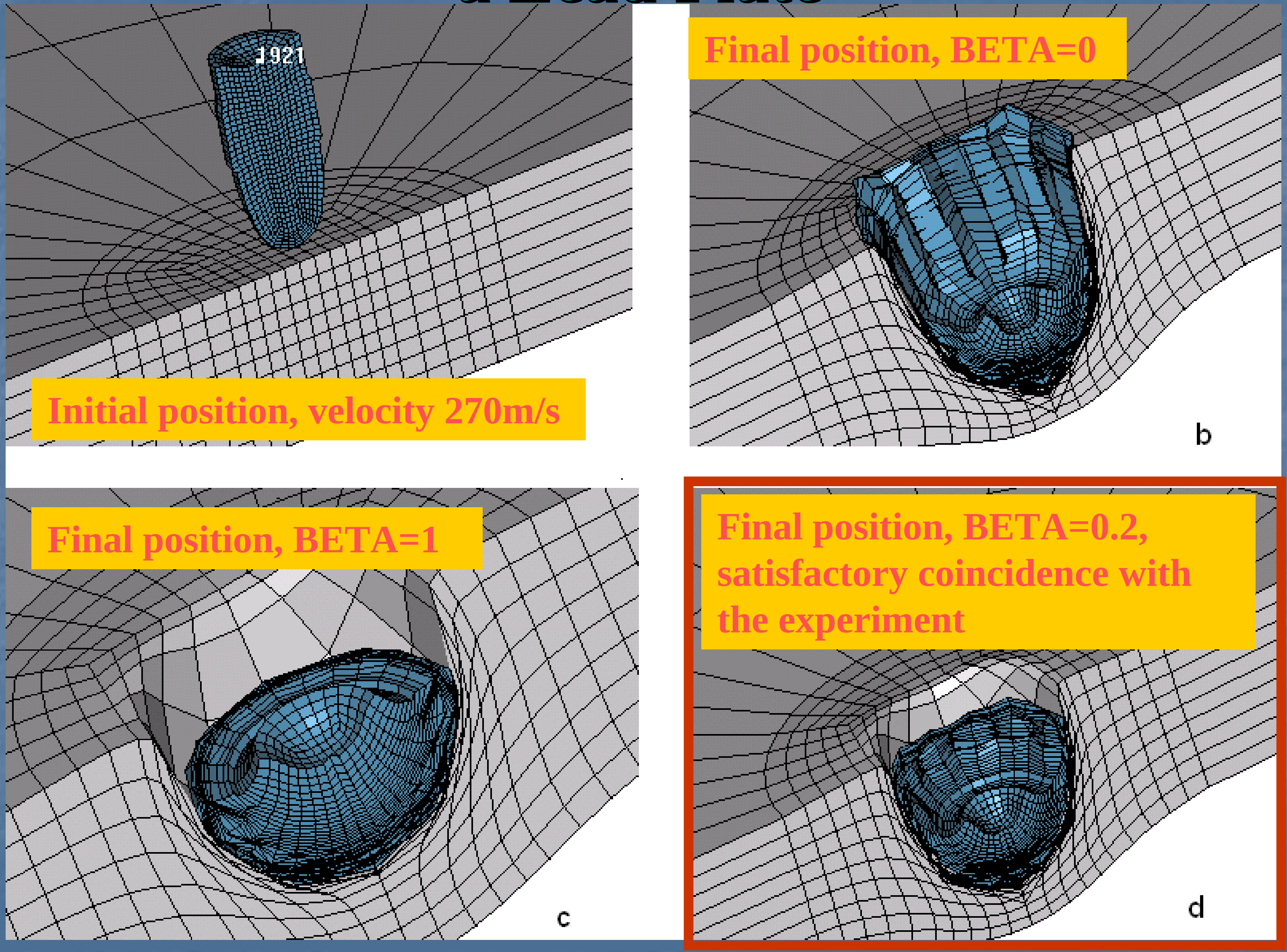
$MID	RO	E	PR	SIGY	ETAN	BETA
1	11270	1.7E+10	0.4	8.00E+06	1.5E+07	0.1-0.2

$SRC	SRP
600	3

Simulation of Impact of a Lead Bullet Against a Lead Plate

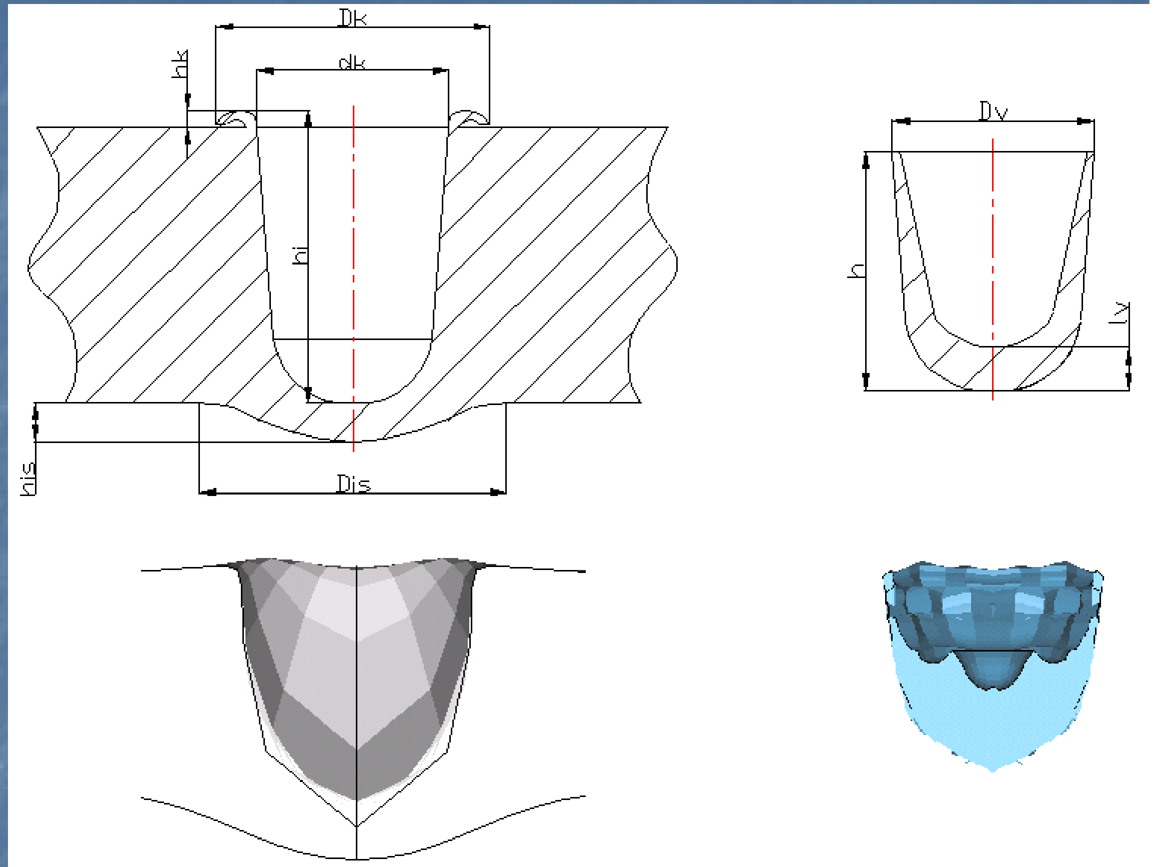


Simulation of Impact of a Lead Bullet Against a Lead Plate



Scheme of experimentally measured dimensions

- the pit punched in the plate (a)
- the remains of the bullet (b)



measured value	D_k	d_k	h_k	h_i	D_{is}	h_{is}		m_l	D_v	h	l_v
experimental	13,27	9,34	1,82	13,34	14,89	4,77		2,36	8,93	9,75	3,03
simulated		11,00		11,30	19,00	3,20		2,23	10,20	9,40	3,80

Single fabric layer model validation:

- numerical and physical experiments of shooting the lead bullet through a single fabric layer;
- The data obtained from the physical experiment:

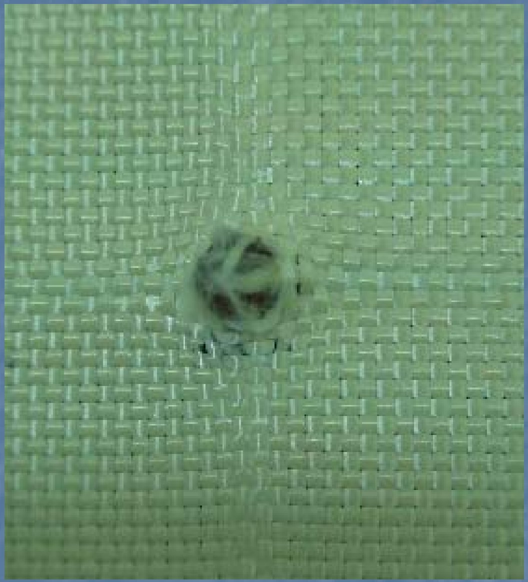
-the number and pattern of failed theads;

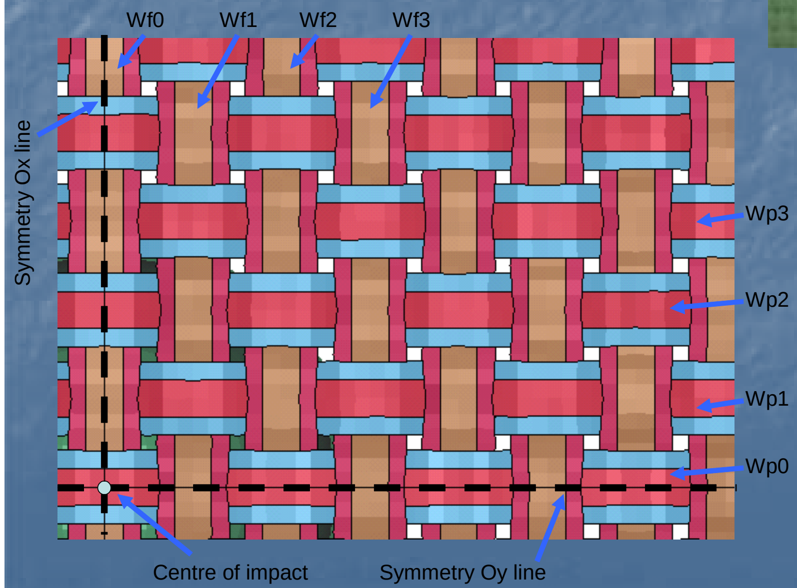
-maximum transverse deflection of the fabric;

-plastic deformation of the tip of the bullet;

$MID	RO	E	PR	SIGY	FStrain
1	**1400**	**9.00E+10**	**0.3**	**3.60E+09**	**0.04**

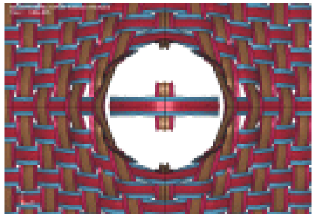
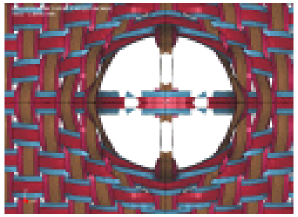
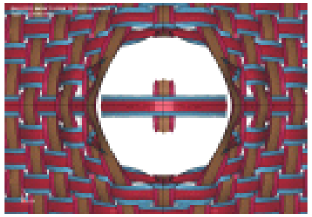
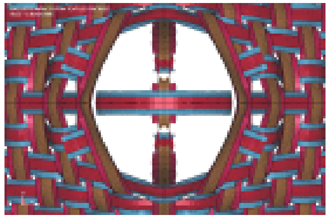
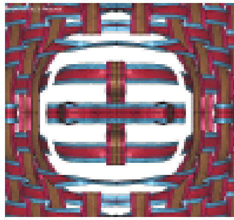
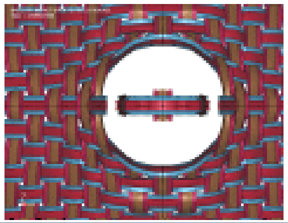
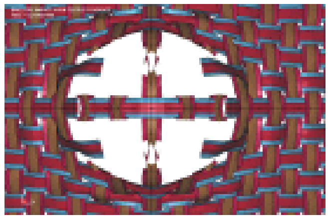
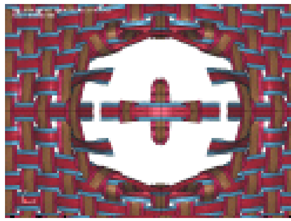
Single fabric layer model validation: experimental data

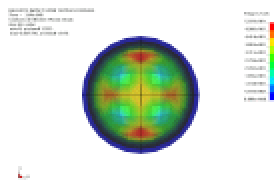
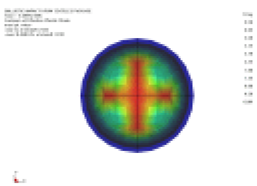
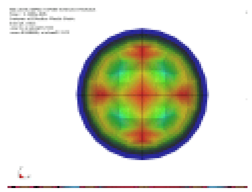
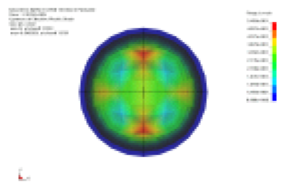
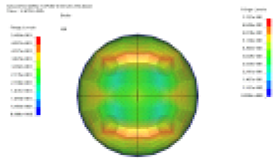
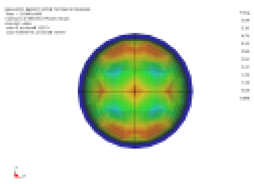
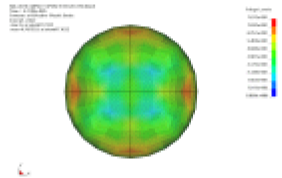
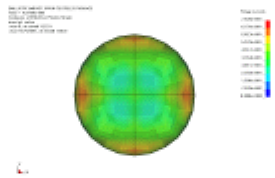




Notation of failing threads:

Wpi(warps) and **Wf**i(wefts)

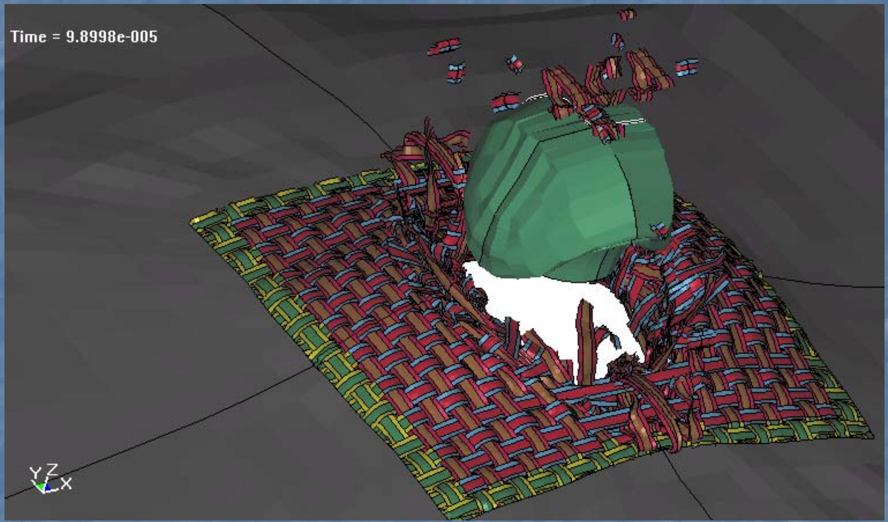
FSs	FSk=0	FSk=0.1	FSk=0.15	FSk=0.2
0.15			t=2.58e-5;3.06e-5s; z=0.0063,0.0075 epmax=0.55 **Wf0, 2Wp1 -> Wp0 (4)** 	
0.2	t=2.4e-5;2.7e-5s; z=0.0058,0.00665 epmax=0.45 **Wf0 -> Wp0 (2)** 	t=2.58e-5;3.36e-5s; z=0.0063,0.0082 epmax=0.5 **2Wp1 -> Wf0 -> Wp0 (4)** 	t=1.86e-5;3.06e-5s; z=0.0044,0.00715 epmax=0.55 **2Wp1 -> Wf0-> Wp0 (4)** 	t=3.18e-5;4.68e-5s; z=0.0077,0.01166 epmax=0.6 **2Wf1 -> Wf0 -> Wp0 -> 2Wp1 (6)** 
0.3	t=2.28e-5;3.6e-5s; z=0.0055,0.00873 epmax=0.5 **2Wf1 -> Wf0->Wp0 (4)** 	t=3.54e-5;5.22e-5s; z=0.0085,0.0124 epmax=0.65 **2Wf2 -> 2Wf1 -> 2Wp1-> ->Wf0 >Wp0 (8)** 		t=3.18e-5;4.98-5s; z=0.0077,0.0118 epmax=0.65 **2Wf2 ->2Wf1,2Wp1-> ->Wf0 >Wp0 (8)** 

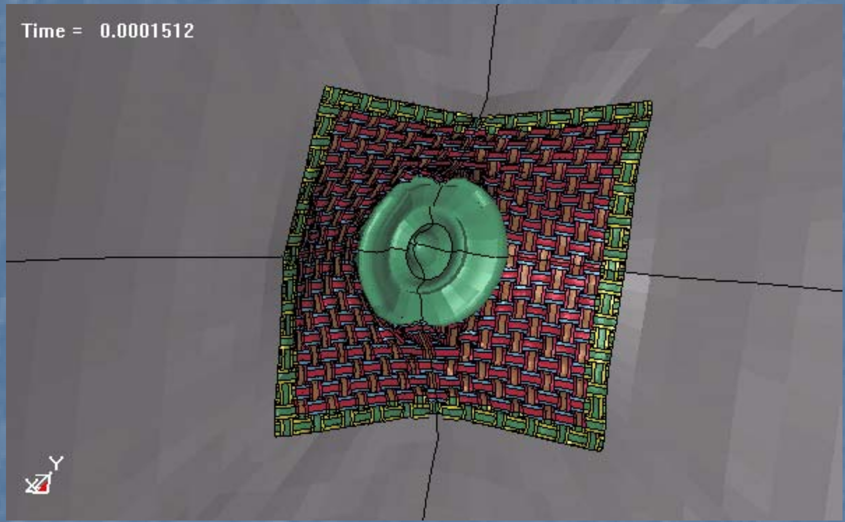
FSs	FSk=0		FSk=0.2	FSk=0.5
0.15			t=2.58e-5;3.06e-5s; z=0.0063;0.0075 	
0.2	t=2.4e-5;2.7e-5s; z=0.0058;0.00665 epmax=0.45 	t=2.58e-5;3.36e-5s; z=0.0063;0.0082 epmax=0.5 	t=1.86e-5;3.06e-5s; z=0.0044;0.00715 epmax=0.55 	t=3.18e-5;4.68e-5s; z=0.0077;0.01166 epmax=0.6 
0.3	t=2.28e-5;3.6e-5s; z=0.0055;0.00873 epmax=0.5 	t=3.54e-5;5.22e-5s; z=0.0085;0.0124 epmax=0.65 		t=3.18e-5;4.98-5s; z=0.0077;0.0118 epmax=0.65 

Future task: validation of the model of the full metal jacket bullet and identification paraaramyde fabric model parameters

- Experiments of shooting the full metal jacket bullet into lead or brass targets;
- Measurement of the shape of the pit and of the remains of the bullet
- Shooting experiments against paraaramyde fabric packages

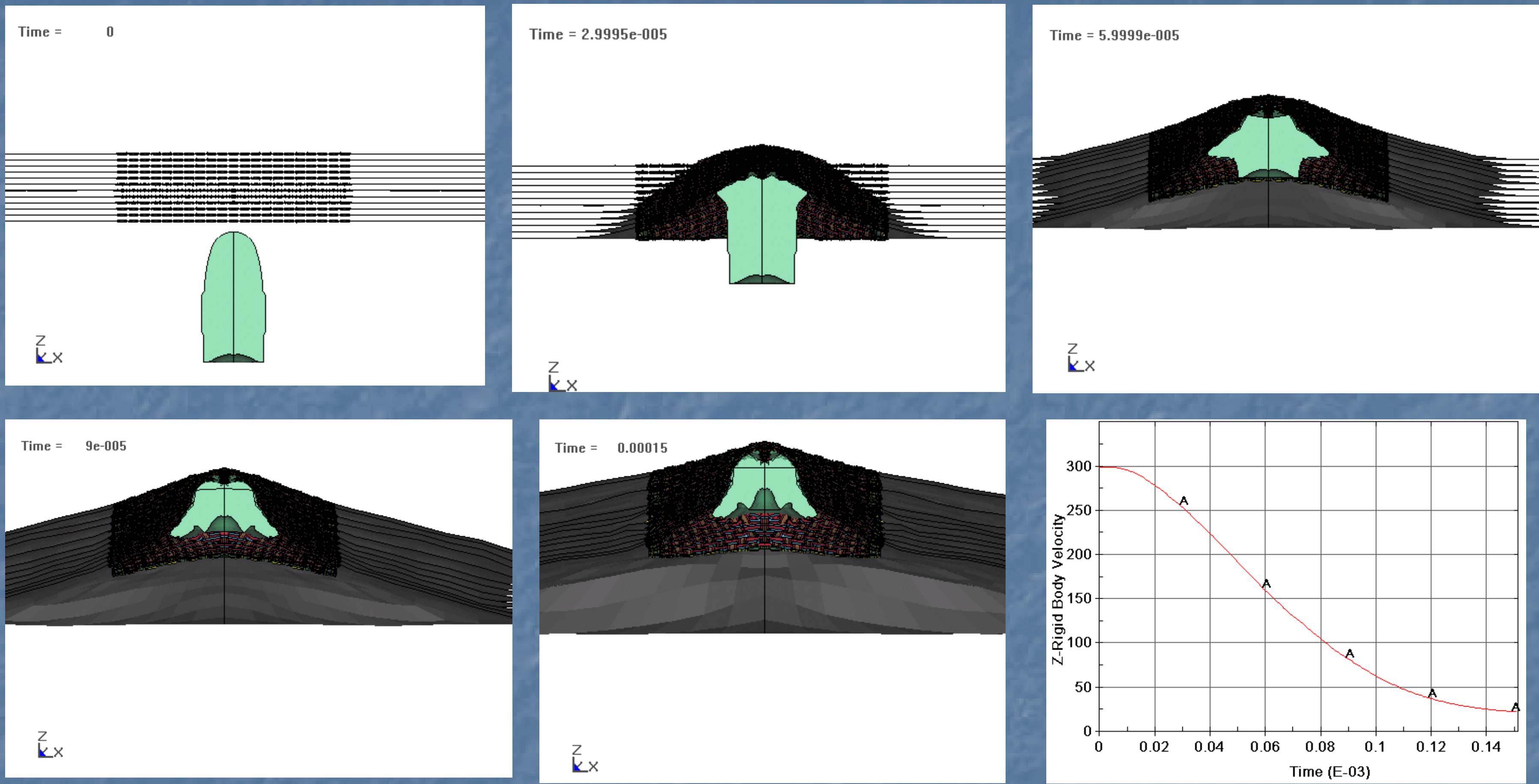
Simulation of 300m/s velocity lead bullet impact upon a multi-layer fabric package



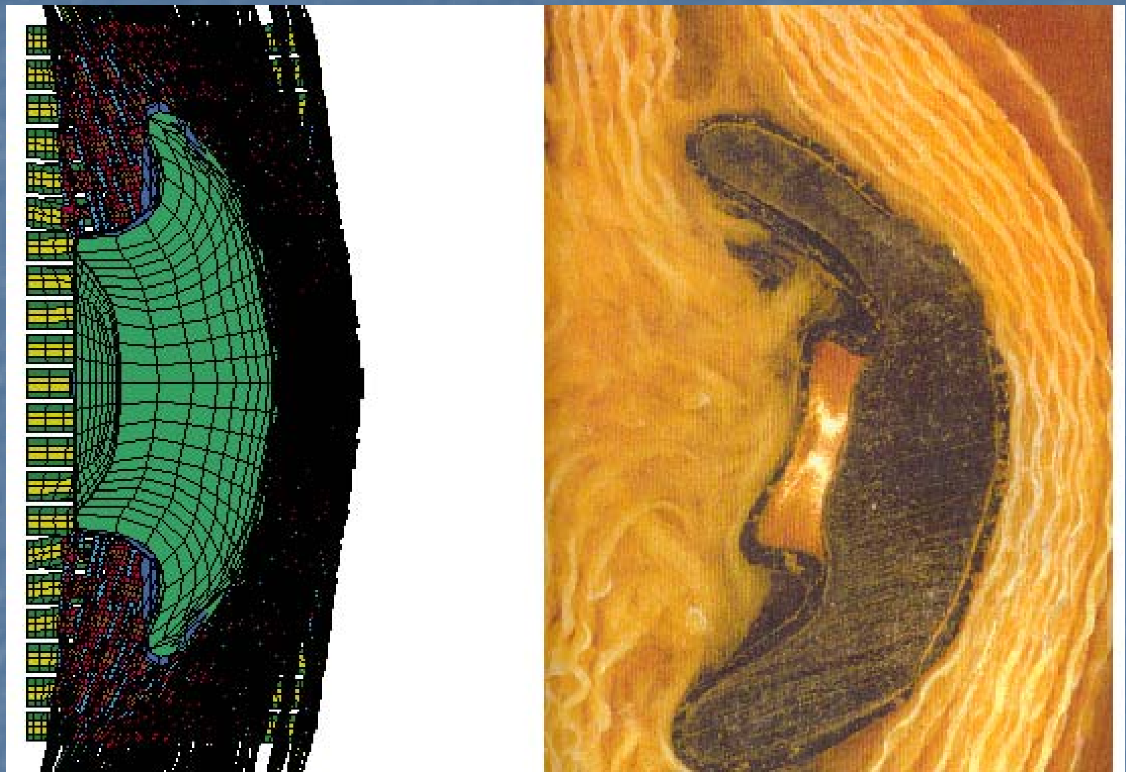


5 layers 12 layers

Simulation of 300m/s velocity lead bullet impact upon a 12-layer fabric package



The impact of the full metal jacket bullet multi-layer package : bullet stopped



a b

a - simulation result;

b - experimental result (photo taken from the circular of TwaronCT textile)

Conclusions (1)

- The finite element analysis of the interaction process of the paraaramyde multi-layer fabric package against 9mm bullets has been performed in LSDYNA;
- Real geometries of interacting parts and real material properties have been taken into account;
- The size of the model was reduced to reasonable dimensions by presenting the yarns of the textiles as narrow bands of a prescribed cross-section
- The size of the domain presented by the woven structure reduced by connecting it to a membrane model by using *CONSTRAINED_TIE-BREAK constraint

Conclusions (2)

- This work is devoted mainly to the validation of the model. The check-points between simulated and experimental results have been selected;

- for obtaining models close to reality it is not sufficient to use the material properties determined by static or quazi-static experiments only. The model can be improved considerably by scaling the yield stress limit against the strain rate value.

End of the presentation