Lightweight Cable Supported Structures subject to Blast Fragmentation – An Overview

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This study is funded by **UK EPSRC** and **Arup** through an industrial **CASE project (No. CASE/CNA/07/107)**

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Context

- The use of high strength steel tension cables is a popular trend in the design and construction of stadia, bridges and other structural forms.




- But questions remain regarding their robustness and resilience when subjected to highly transient loading conditions in the form of:

→ Blast Pressure + High velocity fragment impact

- Recent research highlights cable vulnerability to failure when subjected to such loading conditions (Zoli, 2009).

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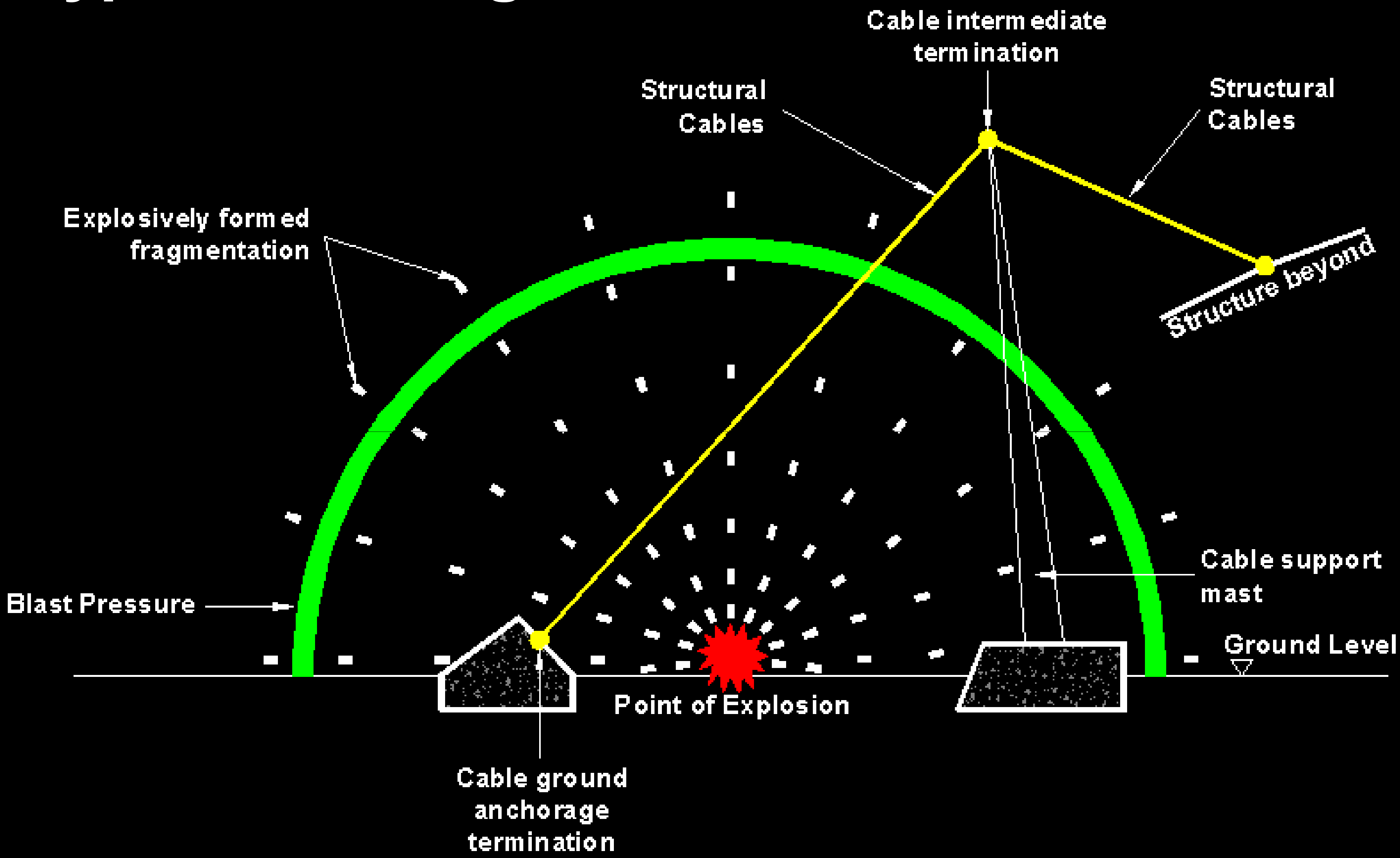
Current methods of protection!

Typical Loading Scenario



A CASE STUDY PROJECT

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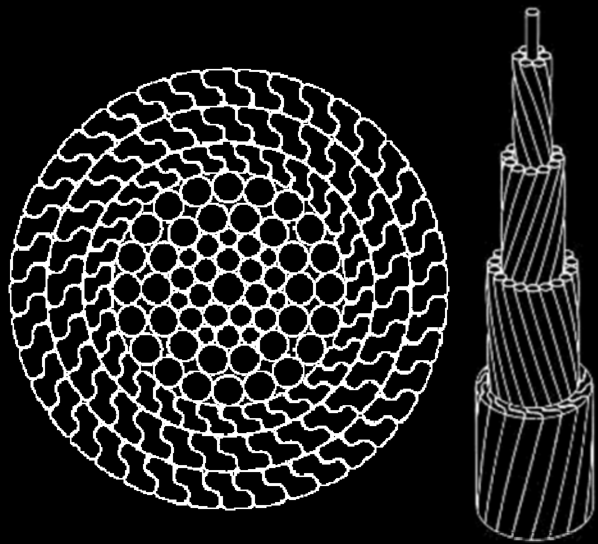
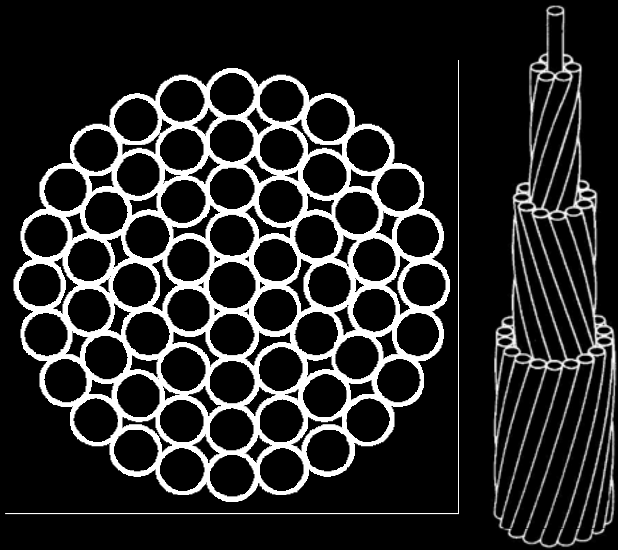
Vulnerable Components



Locked Coil Strand



Spiral Strand

Solid Bar

End Terminations

Project Objectives

Primary Objectives

- Determine structural behaviour, perforation & penetration resistance of the cables and terminations when subject to high velocity fragment impact
- Determine optimum perforation and penetration velocity ranges
- Determine critical fragment characteristics

Secondary Objectives

- Determine global effects on surrounding structure in terms of cable damage and dynamic removal
- Determine critical scenario loading conditions
- Determine optimum mitigation methods
- Assess probability of significant damage

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Method - Predictive Numerical Simulation

- A complete description of **HIGH VELOCITY FRAGMENT IMPACT** would have to account for the following:

- **Geometry of the interacting bodies**
- **Elasticity and plasticity**
- **Shockwave propagation**
- **Hydro-dynamic material flow**
- **Finite strains**
- **Deformations**
- **Work hardening**
- **Thermal and frictional affects**
- **Inertia affects**
- **Initiation and propagation of failure**

Numerical solution of full equations of continuum physics coupled with an appropriate constitutive material model

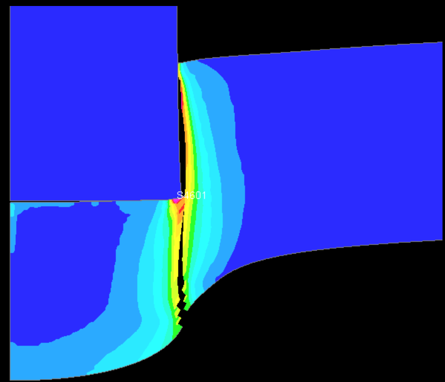
IMPORTANT - Constitutive relation

- A complete material description under **HIGH VELOCITY IMPACT**; stress-strain response highly dependant on strain, strain rate, temperature **AND** accumulation of damage and failure.

(Modified Johnson-Cook Model – *Borvik et al. 2001*)

$$\sigma_{eq} = [1 - D][A + Br^n][1 + \acute{r}^*]^C[1 - T^{*m}]$$

Validation with steel plates

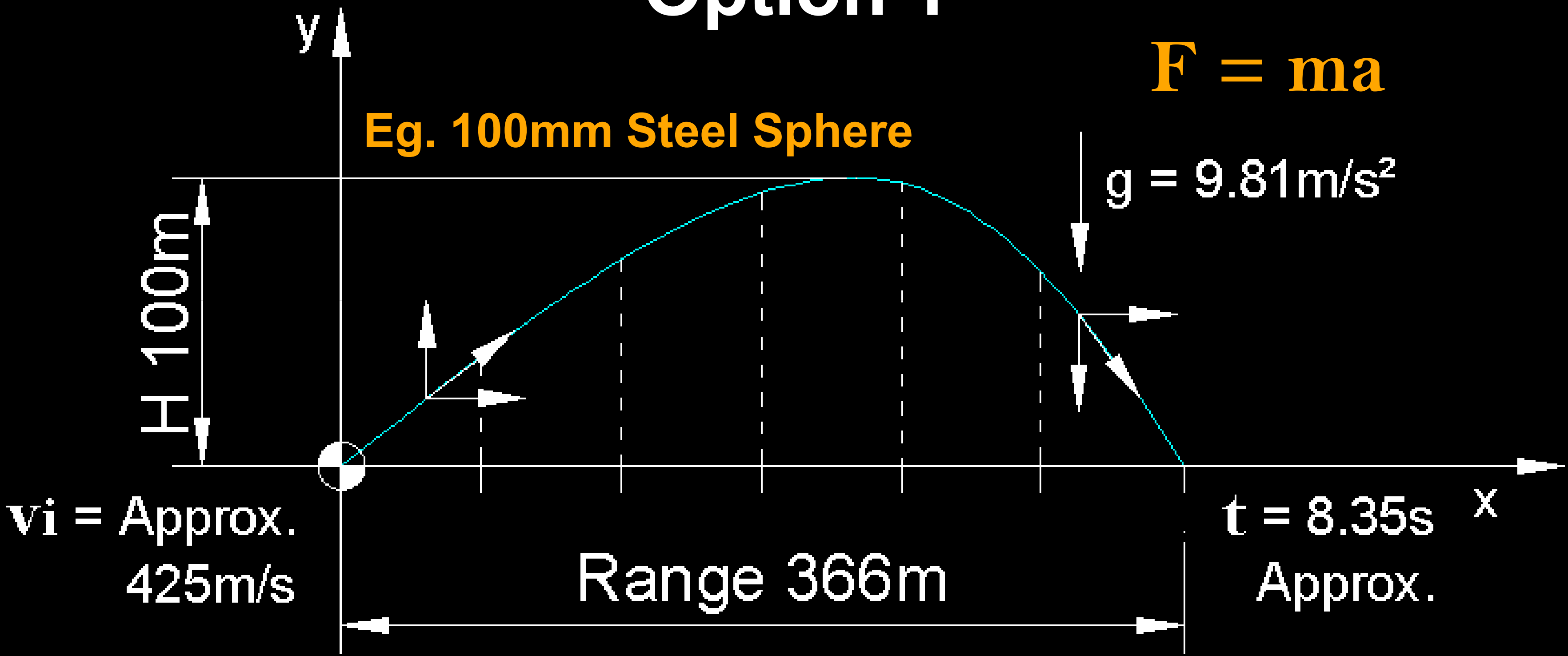


- The damage variable D - **0 (un-damaged)** and **1 (fully-broken).** Material fracture occurs at **D = Dc (<1).**

First Question;
How Fast do Fragments Travel?

Option 1

$$F = ma$$



$$F_x = -(v_x/v)bv^2 \qquad F_y = -(v_y/v)bv^2$$

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First Question;
How Fast do Fragments Travel?

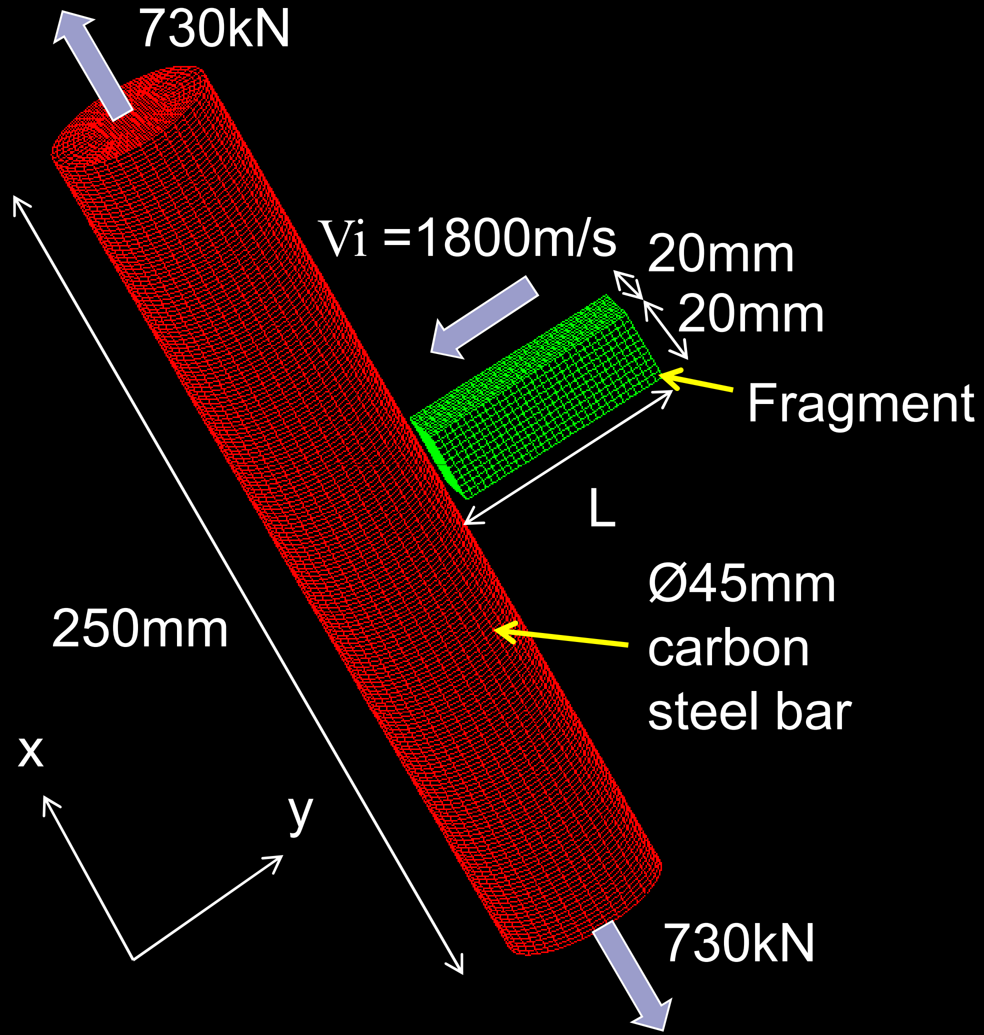
Option 2

- Use TM 5-1300 – Assume fragments are PRIMARY

$$Vs = Vo\ e^{-[12 kv Rf]}$$

$kv = (A/Wf)\,\rho_a\,C_D$ which is the velocity decay coefficient and Rf is the range or distance from explosion under consideration.

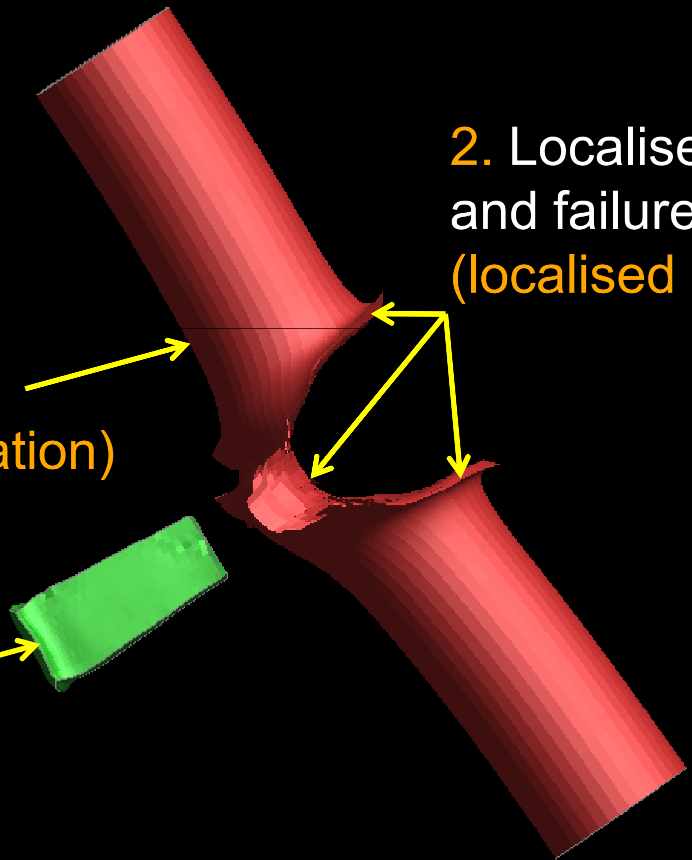
A study on the effects of Fragment Mass



- Fragment - Elastic-Plastic bilinear relation.
- Bar – MJC relation.
- Mesh – 8 noded solid elements, single integration points
- 4 simulations with; L = 20, 40, 60, 80mm

Kinetic Energy Transfer

- Penetration and/or perforation governed by - $K = \frac{1}{2} mV^2$



Results and Discussion

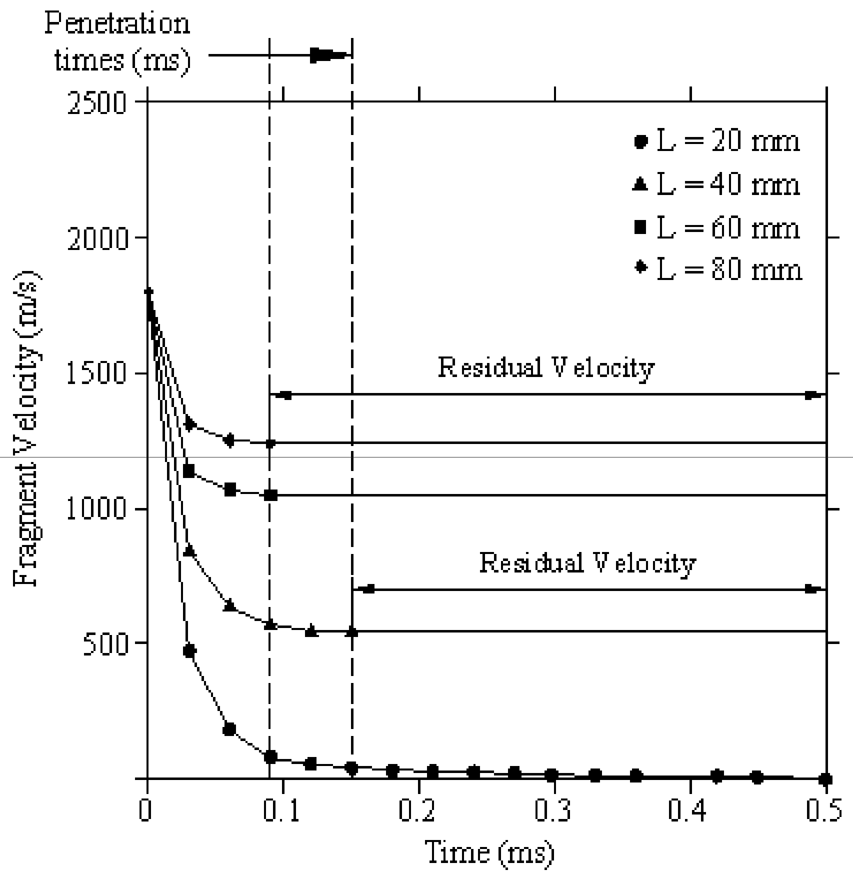


Figure 1 - Velocity time curves for each fragment up to 0.5ms

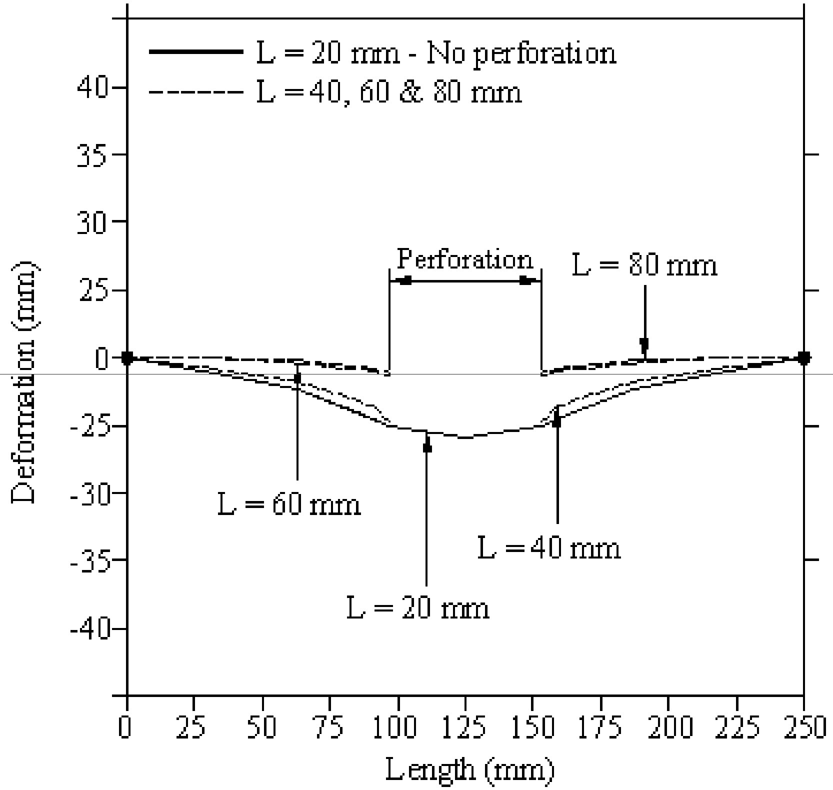
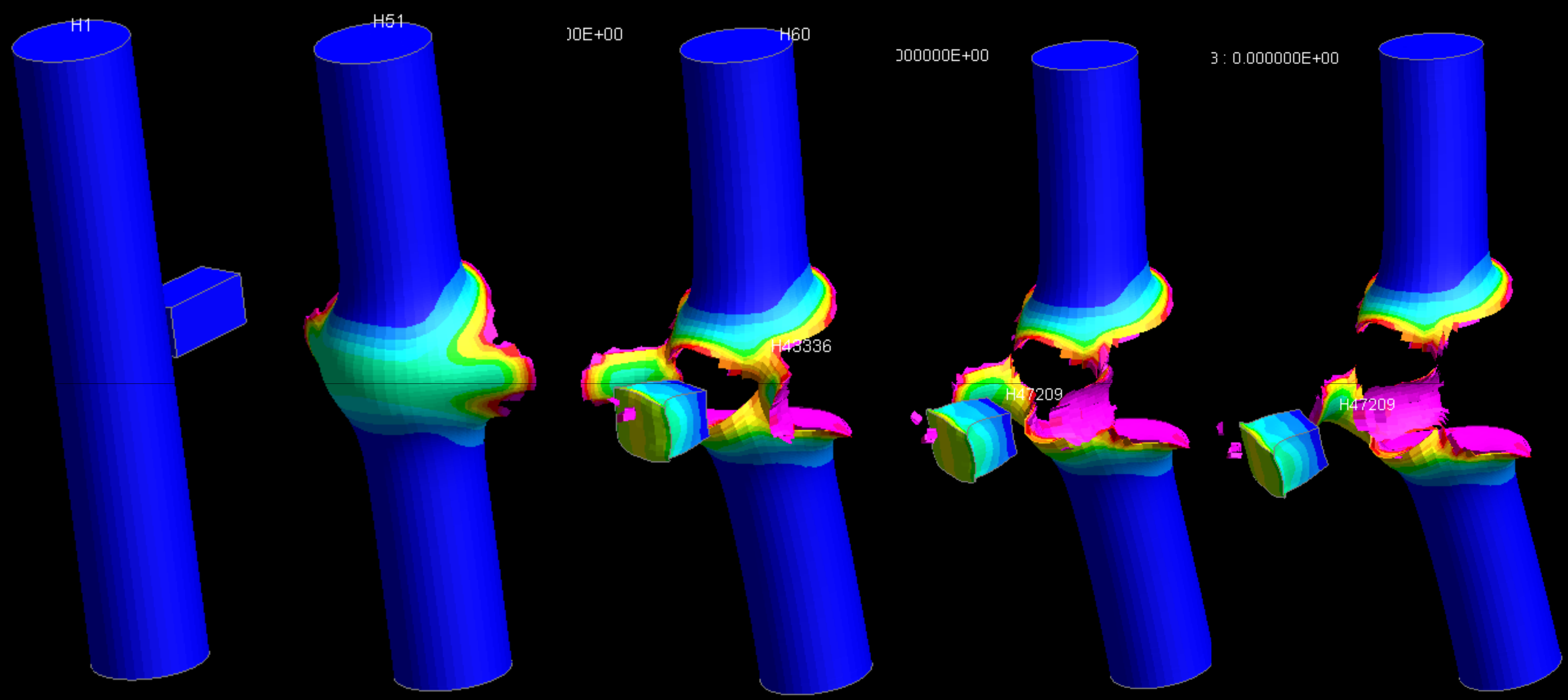


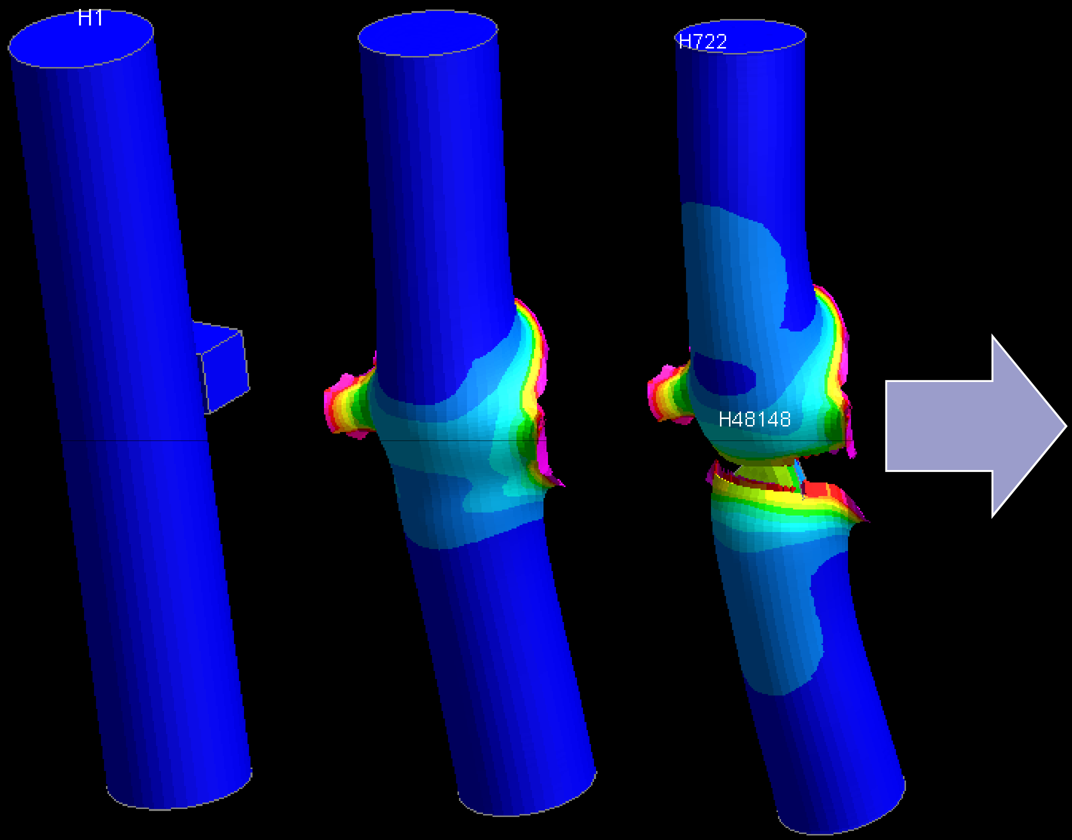
Figure 2 - Longitudinal bar deformation at 0.5ms

What's most interesting.....



- Perforation plots for L = 40mm fragment

and...



In global terms the end result is the same

- Perforation plots for L = 20mm fragment

Conclusions

- Fragment mass has significant effects on the perforation and penetration process in terms of energy absorption.

- Lower energy – overall global response

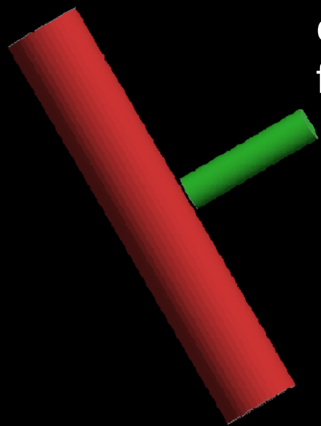
- Higher energy – localised response

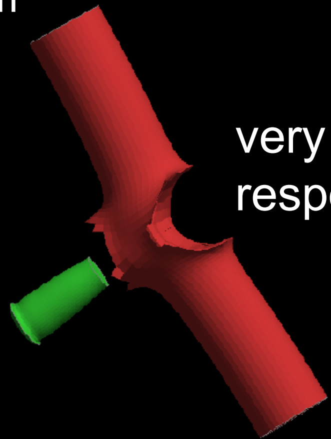
- In all cases rupture occurs as a result of the significant cross-sectional damage sustained on impact.

- Further parametric modelling is being carried out to study the effects of alternate fragment velocities, fragment shape, fragment hardness, angles of impact and glancing blows.

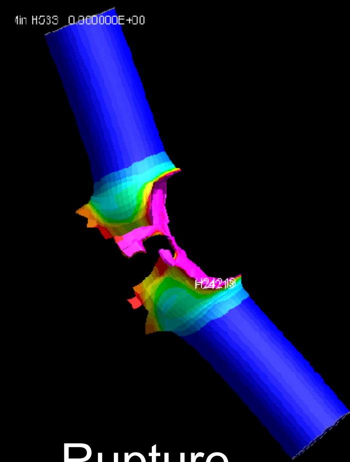
Effects of velocity range - 1800 & 900m/s

80mm x 20mm cylindrical fragment



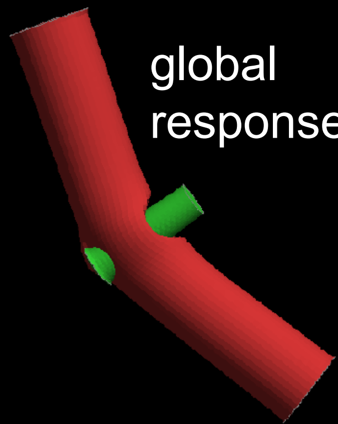


very localised response

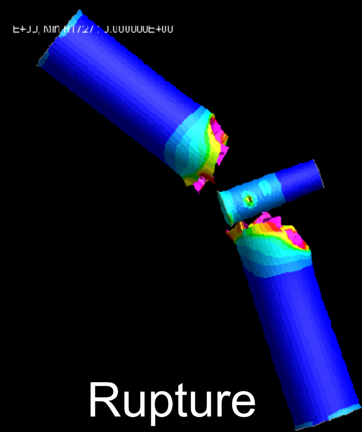


Rupture

'Fragment velocity directly influences structural behaviour. At the higher velocity range overall structural response is secondary to localised behaviour whilst the opposite prevails in the lower velocity range' (Judge, 2010!!).

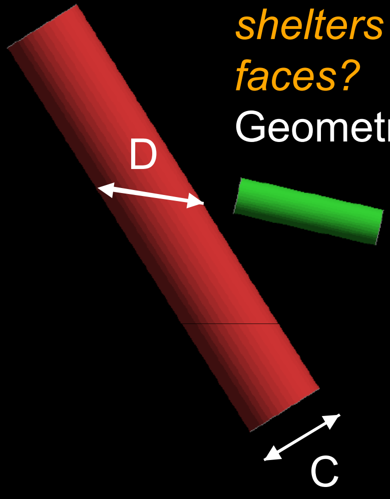


global response



Rupture

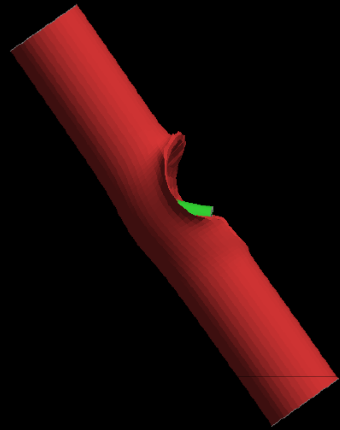
Effects of obliquity and glancing blows

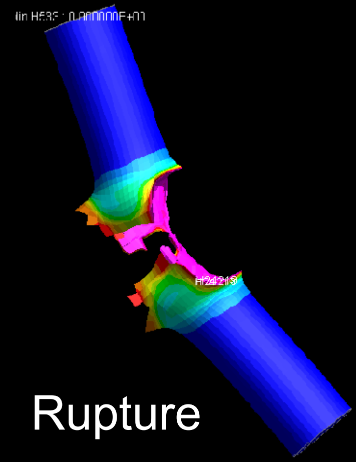


Ever wondered why bomb shelters have inclined faces?

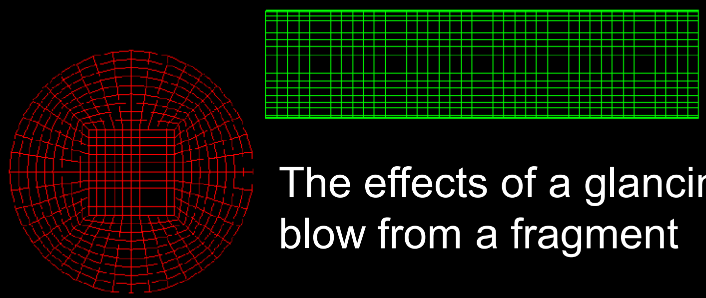
Geometric effect D > C.

Disruptive effect on fragment path due to inclination.

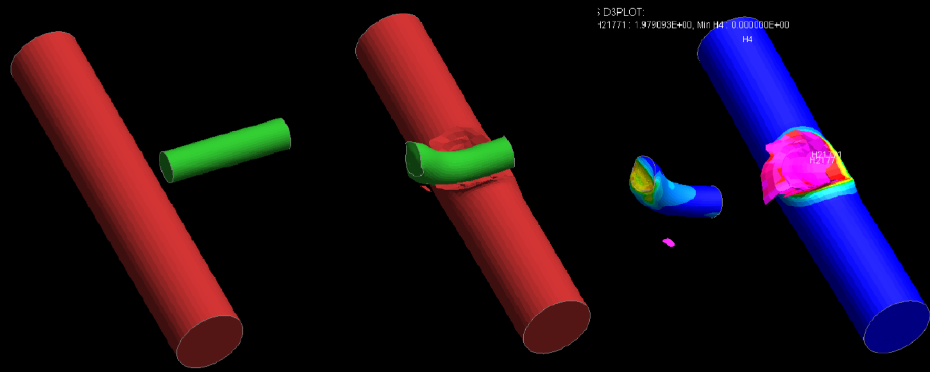




Rupture

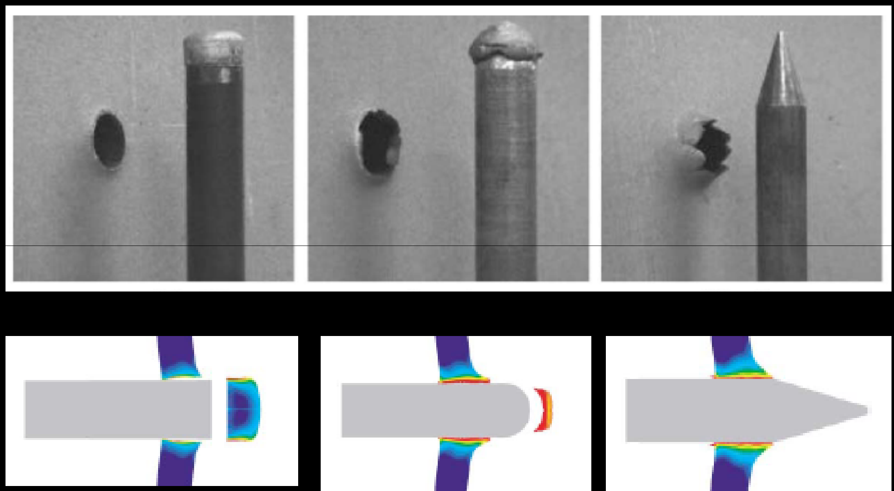


The effects of a glancing blow from a fragment



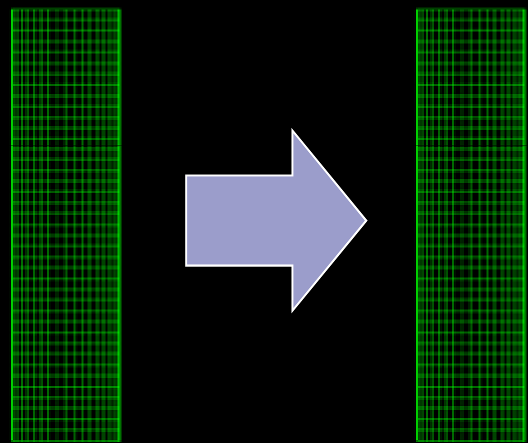
Other parametric studies

The effects of projectile nose shape



Borvik, T. Hopperstad, O.S. Berstad, T. Langseth, M. 2000. Perforation of 12mm thick steel plates by 20mm diameter projectiles. Int. J. Impact Engineering. 27, pp.37 -64

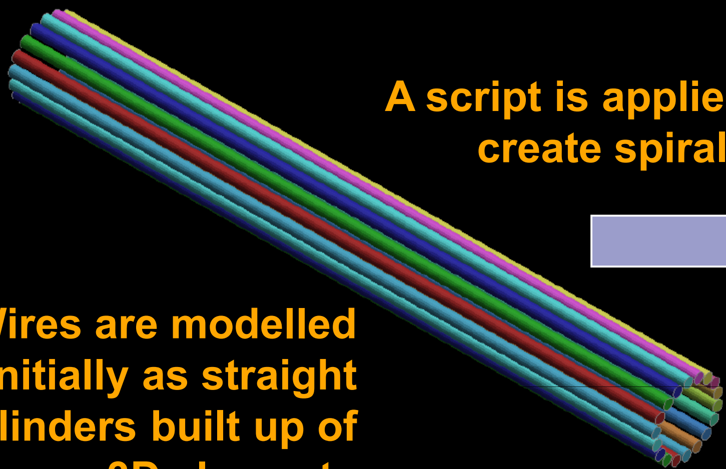
The effects of fragment hardness



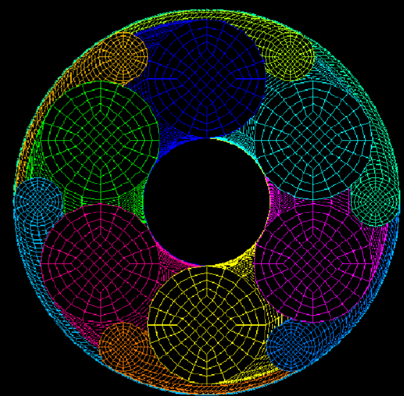
Current work

Spiral Strand Cable Model Building

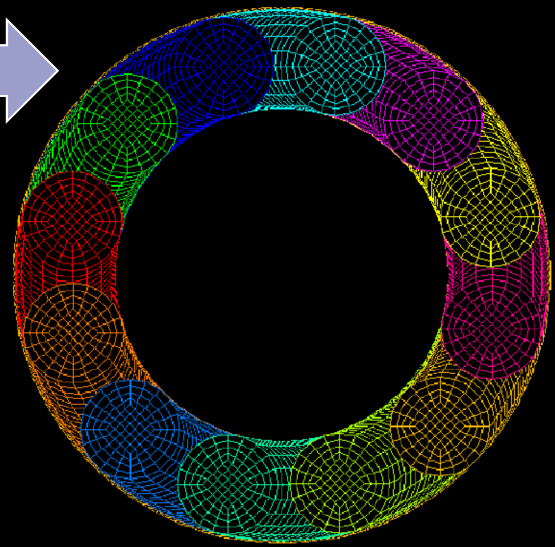
Wires are modelled initially as straight cylinders built up of 3D elements

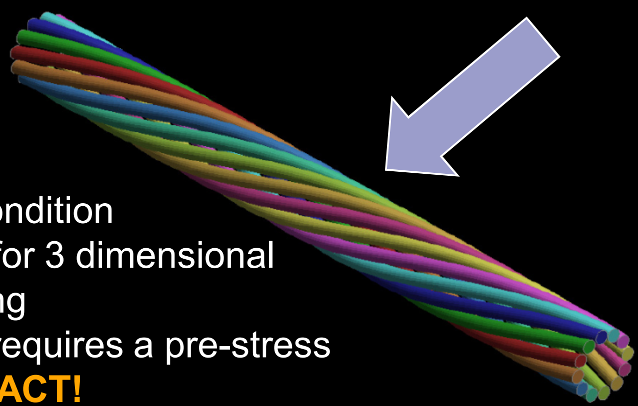


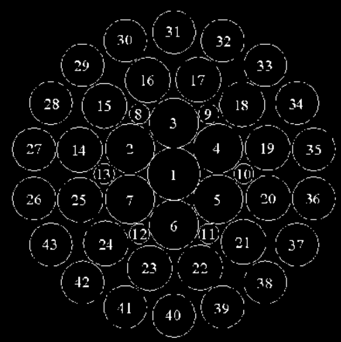
A script is applied to create spiralling



This is repeated for each layer







- Each wire requires a contact condition
- MJC relation used for material for 3 dimensional stress, strain and failure modelling
- Once constructed entire cable requires a pre-stress

ALL BEFORE FRAGMENT IMPACT!

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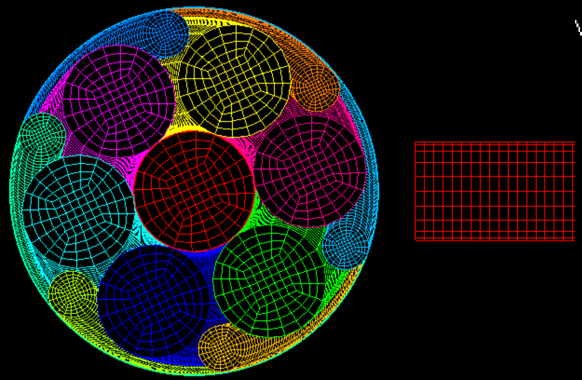
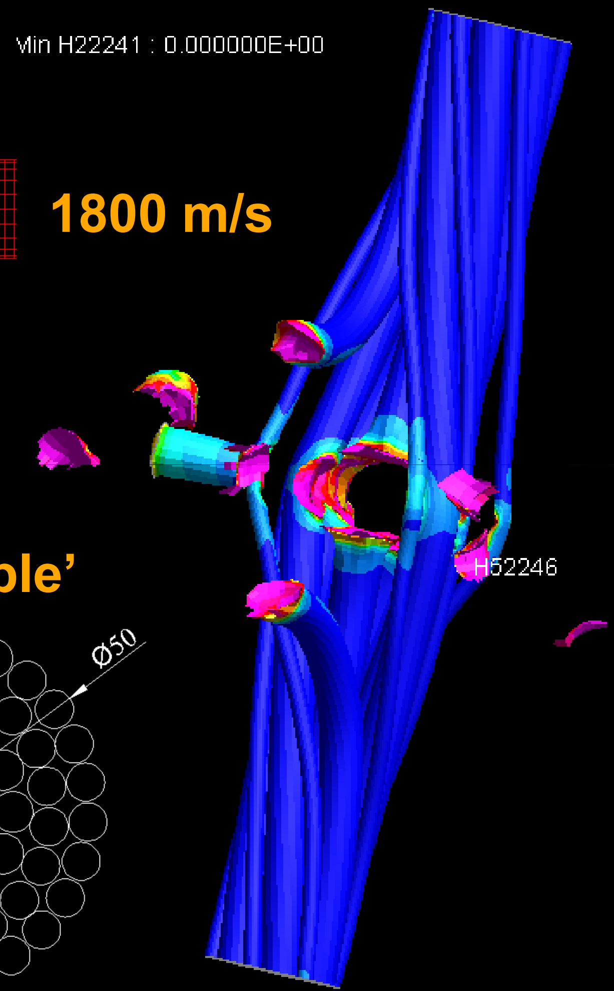
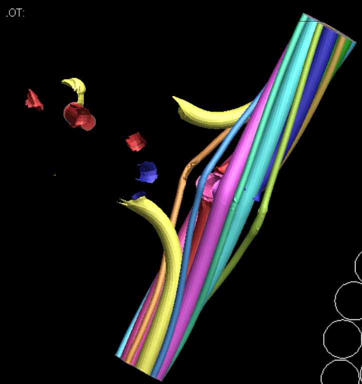
Current work

Spiral Strand Cable Impact Modelling

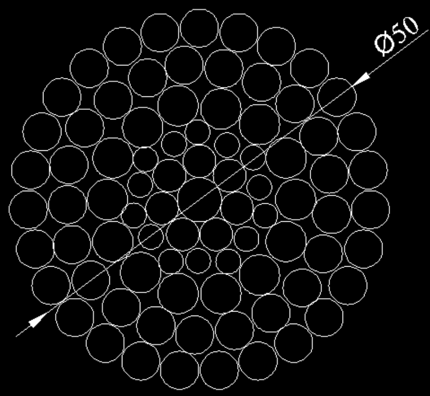


1800 m/s





'Zoli Cable'



Zoli Speeds:
5000ft/s
8000ft/s

Future work

- Calibration of the modified Johnson-Cook model for the wire strands
- Carry out spiral strand impact modelling and validate against work by Zoli
- Cable impact testing
- Begin termination modelling
- Begin termination to cable modelling
- Aim to submit journal paper mid – to late 2010

Thankyou.........any questions