Nano Particle Reinforced Composites for Critical Infrastructure Protection—With Multihazard Extension

Southeast Region Research Initiative (SERRI)

Semi-Annual Project Review

September 17, 2008, Jackson, MS

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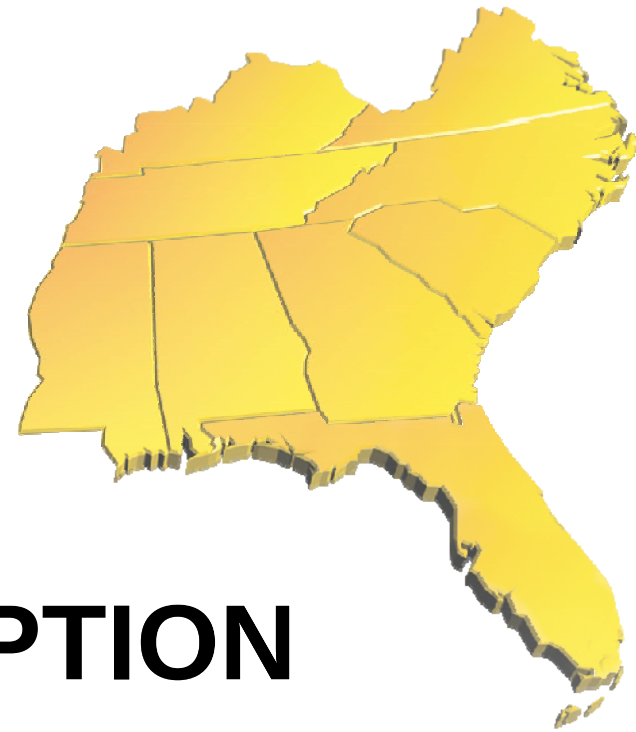


PROJECT DESCRIPTION

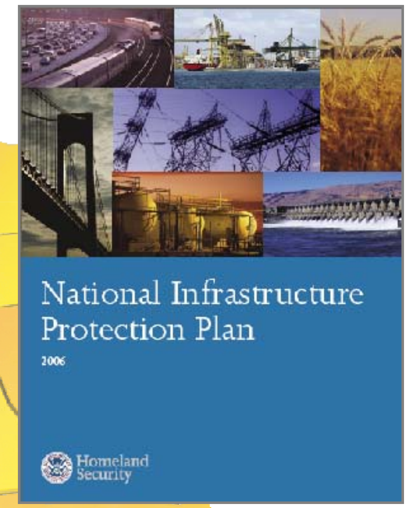
Purpose of Project

- To investigate the use of nano materials, advanced structures, and building technologies for the protection of the nation's critical infrastructures against terrorist threats.
- Extension: To extend the present scope to multihazard protection, particularly, fire hazard protection.

Project Outcome

- A benchmark analysis of infrastructure facilities subject to blast and other extreme loadings, which includes disaster simulation, mapping protection barrier, evaluation of evacuation procedure, and proposing structure improvement through retrofitting and the use of high-performance materials, including nano-structured materials.

Relevance to DHS S&T Objectives

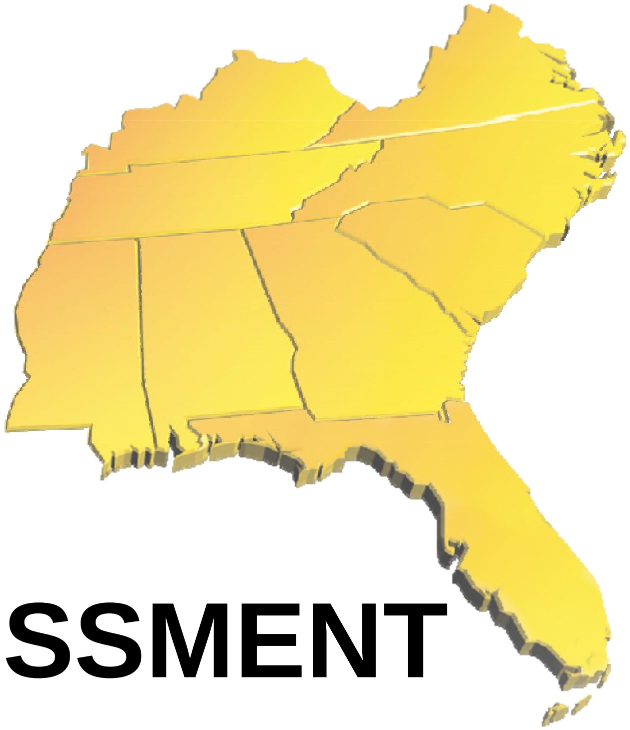


Build a safer, more secure, and more resilient America by enhancing protection of the Nation's critical infrastructure and key resources to prevent, deter, neutralize, or mitigate the effects of deliberate efforts by terrorists to destroy, incapacitate, or exploit them; and to strengthen national preparedness, timely response, and rapid recovery in the event of an attack, natural disaster, or other emergency. (The National Infrastructure Protection Plan, DHS, 2006)

Statement

(Secretary Chertoff, DHS)

The ability to protect the critical infrastructure and key resources (CI/KR) of the United States is vital to our national security, public health and safety, economic vitality, and way of life. U.S. policy focuses on the importance of enhancing CI/KR protection to ensure that essential governmental missions, public services, and economic functions are maintained in the event of a terrorist attack, natural disaster, or other type of incident, and that elements of CI/KR are not exploited for use as weapons of mass destruction against our people or institutions.

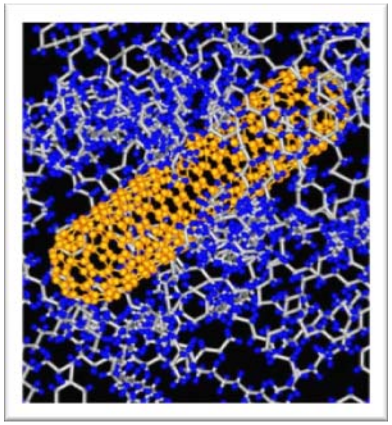


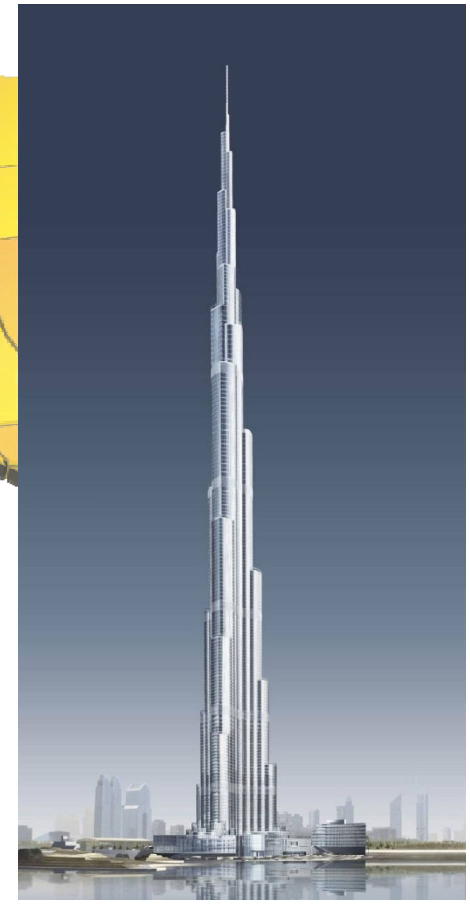
LANDSCAPE ASSESSMENT

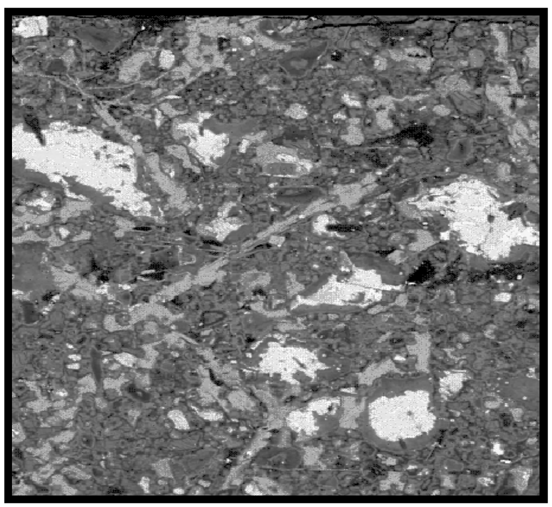
Uniqueness of Project

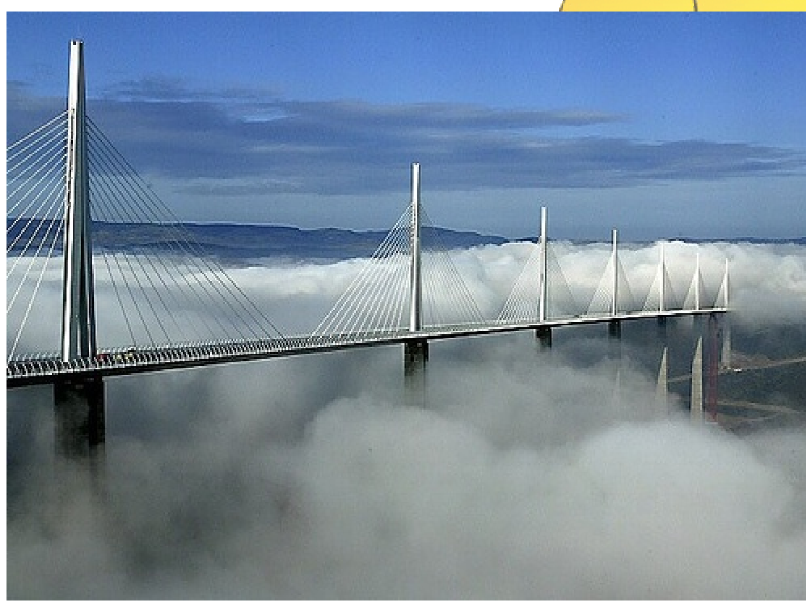
- The current research is unique in its application of the latest technology in nano material to protection of the nation’s critical infrastructure.

From Nanostructure to Infrastructure









Scientific Background

- During the last two decades, tremendous progress has been made in nanoscience.
- New classes of nano materials, such as carbon nanotubes, nanowire, quantum dot, are being assembled, atom by atom, with different applications in mind—electronics, biomedicine, energy, environment …
- However, these materials are still rare and quite expensive.

- For the protection of the nation’s critical infrastructure, we need nano materials, that are *low cost* and in *huge quantity*.
- Not all nano materials are man-made and expensive. There are many naturally occurring materials that are at or near nano size, such as nanoclay, volcanic and fly ash, and other minerals.
- These materials are low cost and abundant in quantity for infrastructure protection.

Ultimate Scientific Goal

- Design material physical principles: If we know how nano particles alter and improve upon material properties based on physical and mechanical laws, then we may be able to “design” infrastructure materials for the desirable performance, such as tensile strength, ductility, brittleness, energy dissipation, etc., required for different protection types (blast, impact, fire resistance, …).

What is Engineering Design?

- Structural design: Given a material, we seek the most effective and effcient design to deliver the maximum performance. (We put the material where it is needed.)
- Material design: When we reached the limit of structural design, we seek materials with better performance (at a cost).
- Design material: When existing materials cannot deliver the performance, we seek to design (new) materials.

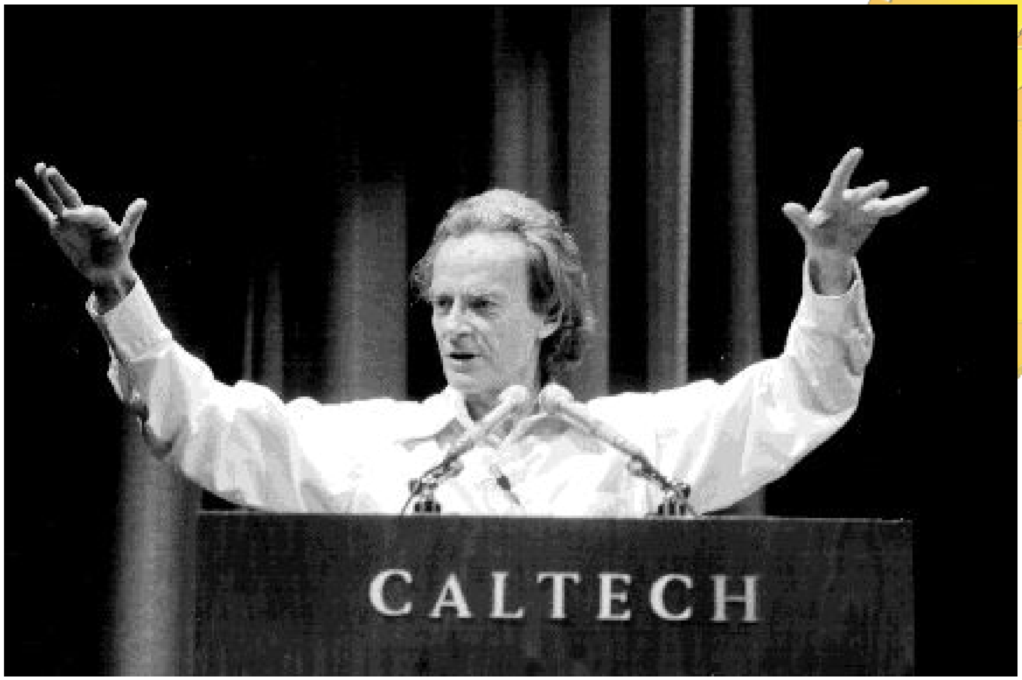
Mechanics Based Design

- Performance needed: Blast, impact, penetration, earthquake, fire, aging, corrosion, energy absorbing…
- Material properties: Tensile strength, hardness, ductility, brittleness, damping, viscoelastic, memory, rate dependent …
- Which material property delivers what performance?
- Answer these questions based on physical-mechanical laws

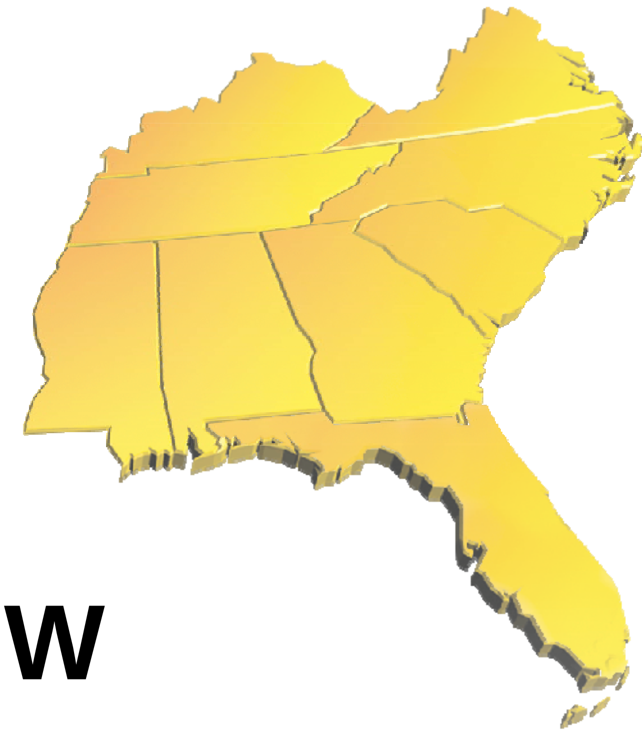
Are We There Yet?

- Almost.
- Recent advances are promising.
- Knowledge gaps need to be filled.
- Research needed.

"*There's plenty of room at the bottom*" (Richard Feynman)



SERRI
Southeast Region Research Initiative



TECHNICAL REVIEW

Four Thrust Areas

- **Material Research**
- **Structural Component Research**
- **Structural System Research**
- **Decision Support System Research**

Unique Research Strategy

Not Sequential

Material Research

↓

Structural Component Research

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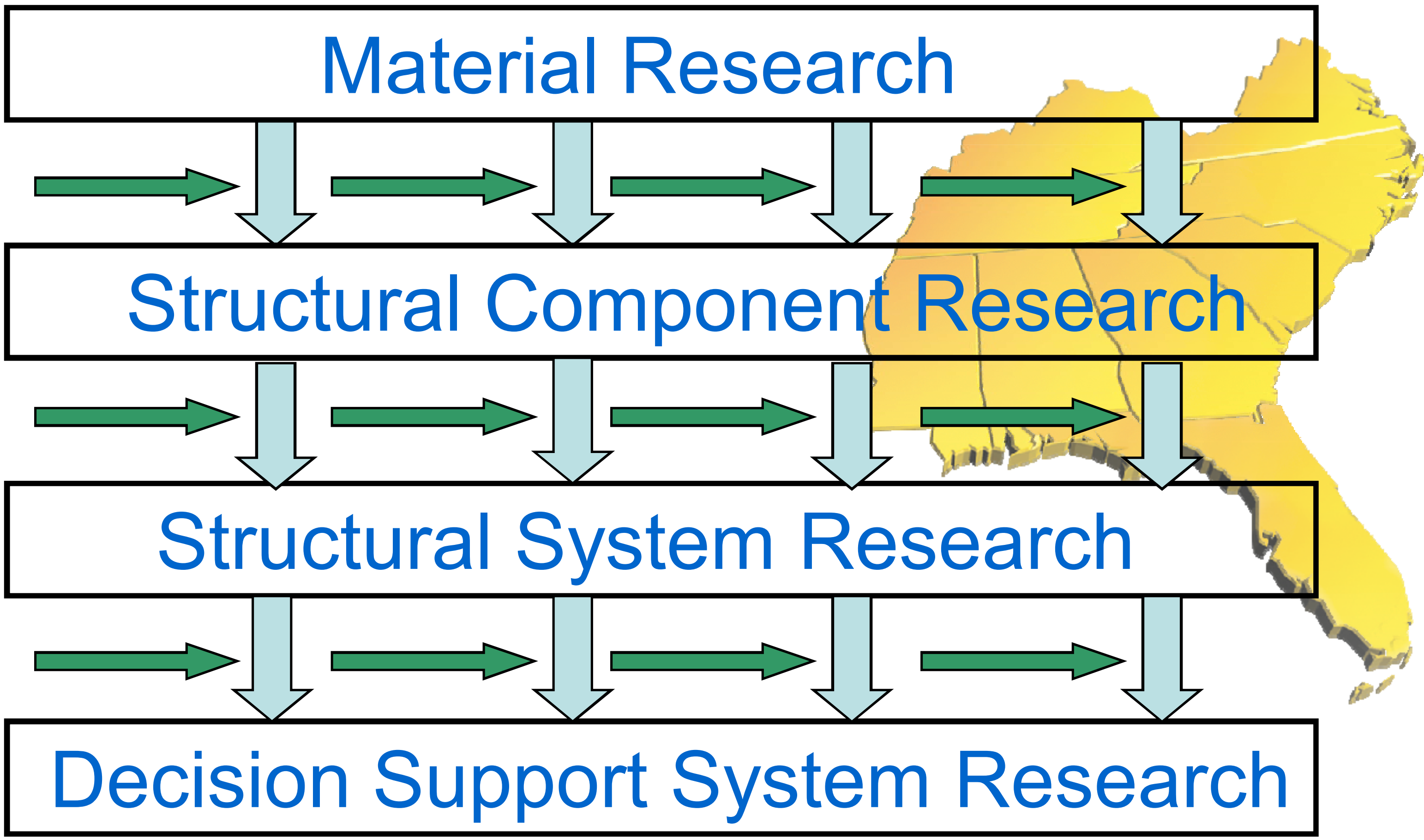
Structural System Research

↓

Decision Support System Research

Composite Structures and Nano Engineering Group, University of Mississippi

But Parallel with Continuous Feedback

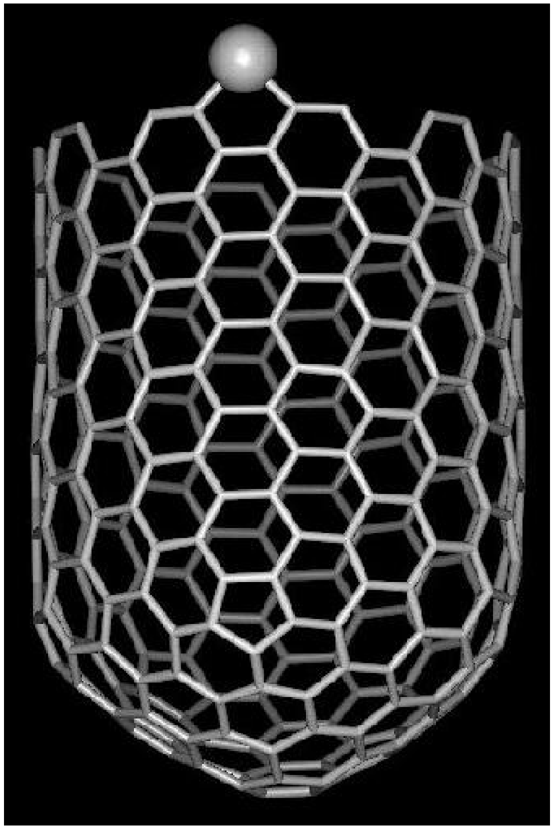


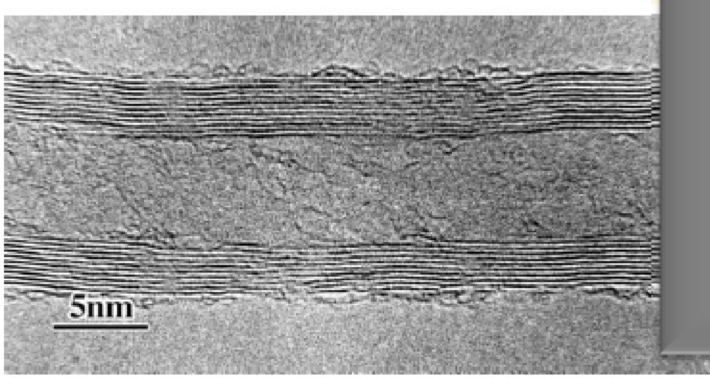
MATERIALS RESEARCH

Molecular Dynamics Simulation

- **Molecular dynamics** (**MD**) is a form of computer simulation in which atoms and molecules are allowed to interact for a period of time under known laws of physics, giving a view of the motion of the atoms.

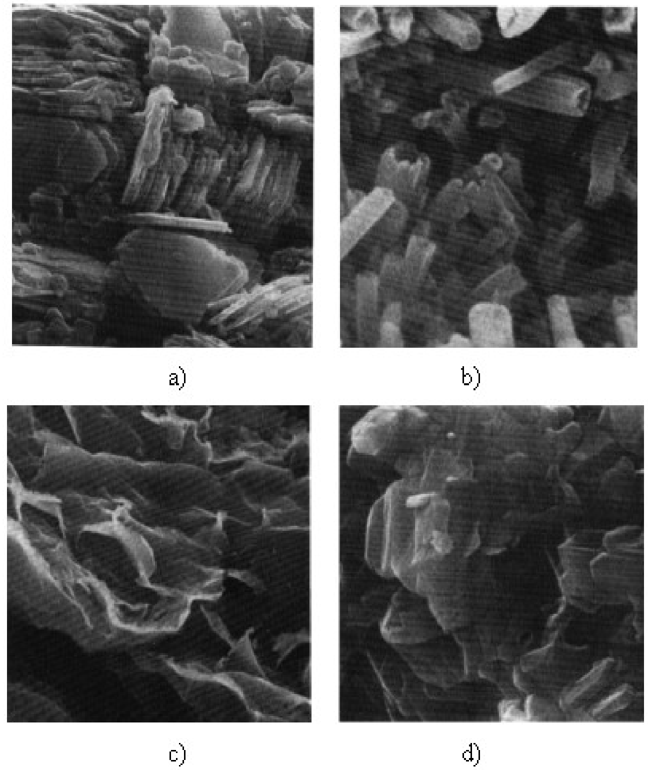
Carbon nanotube characteristics



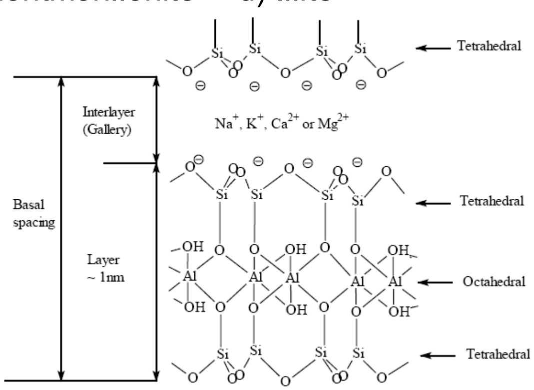


- Single-wall carbon nanotubes and multi-wall carbon nanotubes
- Diameter: ~ 1 *nm*
- Length: ~ 100 µ*m* (and larger)
- Superior Mechanical Properties
  - Elastic Modulus: ~ 1 TPa
  - Density 1/6th of steel
  - Conductive ability is 100,000 times that of copper
  - Yield Strain: More than 4%
  - Buckling Strain: ~ 5% (aspect ratio of 1/6)

Clay Minerals characteristics

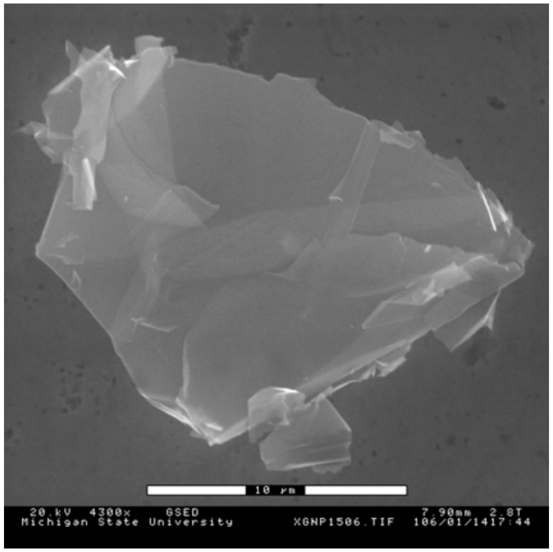


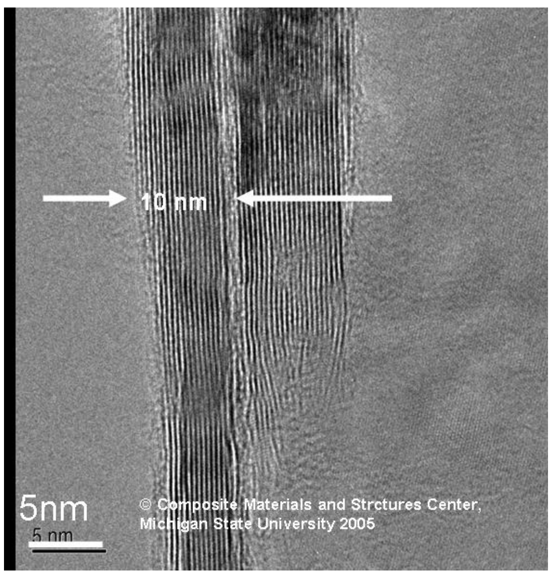
Clay minerals (from Mitchell, 1993 after Tovey, 1971) a) Kaolinite; b) Halloysite ; c)Montmorillonite d) Illite



- Clay Minerals are hydrous aluminum phyllosilicates
- Have variable amount of iron magnesium alkali metals and other cations
- Typical MMT have net charges distributed within the octahedral layer or tetrahedral layer
- Bulk modulus ~ 20-50 GPa
- Young's Modulus 6.2 GPa

Graphite & Graphene characteristics

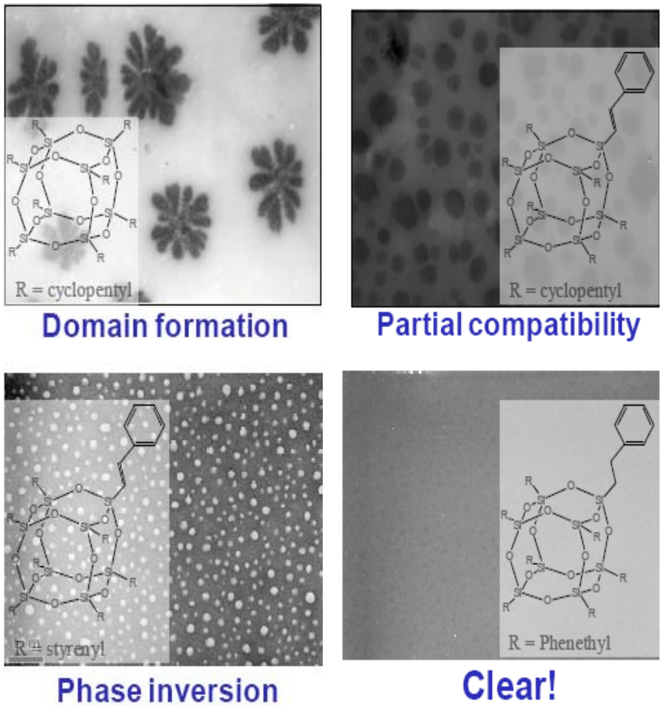




TEM (edge view) and SEM (lateral view) images of xGnP

- Single carbon Layer and multi carbon Layers
- Thickness: ~ 5-10 *nm*
- Length: ~ .86-15 μ*m* (and larger)
- Superior Mechanical Properties
  - Elastic Modulus: ~ 1 TPa
  - Intrinsic Strength ~ 130 GPa (Experiments conducted for a monolayer graphene by Lee at .el. 2008, reported that graphene is strongest material ever measured)

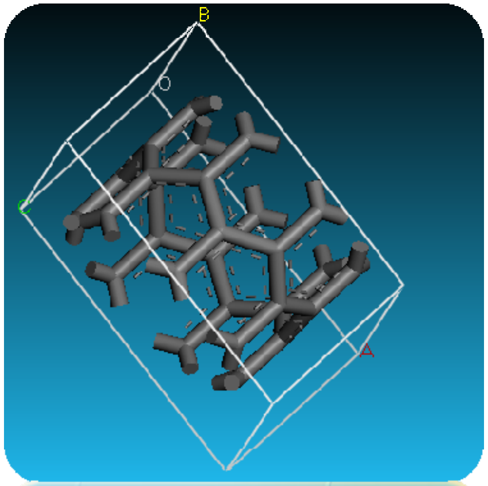
POSS Organic- Inorganic characteristics



POSS dissolving in a polymer.
http://www.hybridplastics.com/pdf/user.pdf

- A new class if organic –inorganic nanocomposites containing POSS monomers which have been copolymerized with organic monomers
- POSS hybrid chemical composition
- POSS molecules span 1~3 nm size range.
- Improve impact resistance
- Reduce friction and improve flow
- POSS can dissolve in polymers

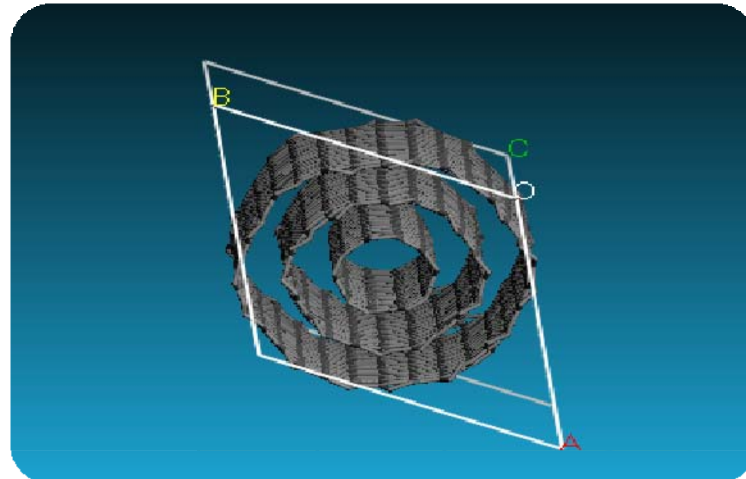
Nano Reinforcements



SWCNT

$$C_{ij} = \begin{bmatrix} 880.1 & 7.8 & 8.6 & 0 & 0 & 0 \\ 8.4 & 31.2 & 17 & 0 & 0 & 0 \\ 9.1 & 16.1 & 35.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & .8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5.7 \end{bmatrix} GPa$$

SWCNT stiffness matrix
Unit cell size: 20 Super cells
Number of Layers: 1
Chirality: (5_5)
Thermodynamic Ensemble: NVT

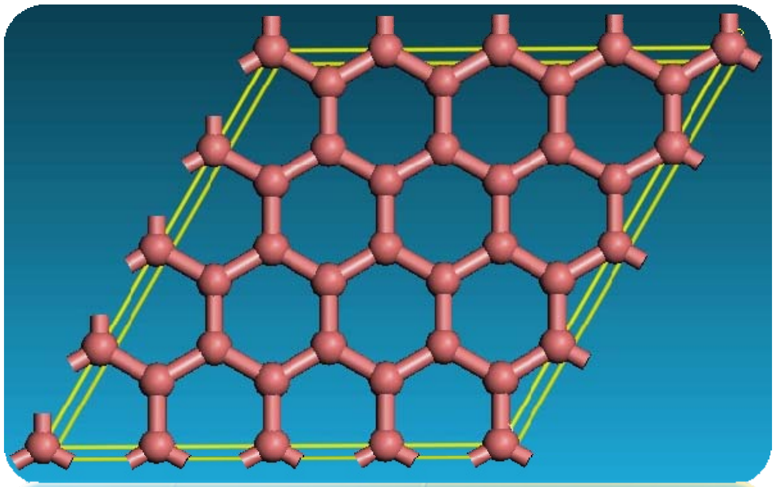


MWCNT

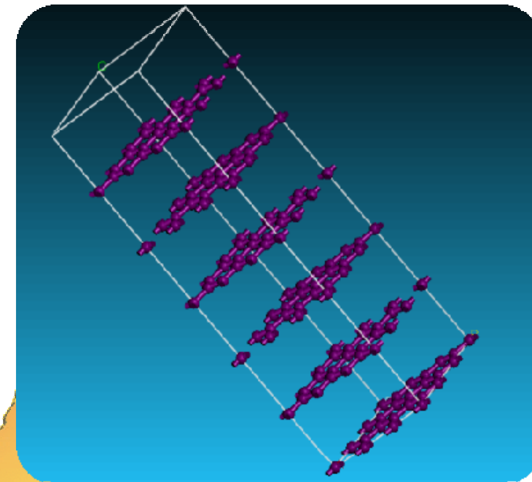
$$C_{ij} = \begin{bmatrix} 698 & 25 & 25 & 0 & 0 & 0 \\ 25 & 66.2 & 49 & 0 & 0 & 0 \\ 25 & 49 & 66.4 & 0 & 0 & 0 \\ 0 & 0 & 0 & .8 & 0 & 0 \\ 0 & 0 & 0 & 0 & .6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 8.6 \end{bmatrix} GPa$$

MWCNT stiffness matrix
Unit cell size: 20 Super cells
Number of Layers: 3
Chirality: (5n_5n)
Thermodynamic Ensemble: NVT

Nano Reinforcements



Graphene



Graphite

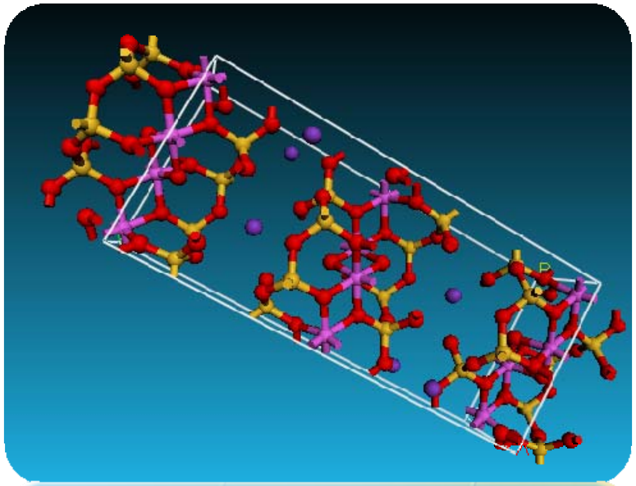
$$C_{ij} = \begin{bmatrix} 967 & 286.1 & 384 & 0 & 0 & 0 \\ 286.1 & 967 & 384 & 0 & 0 & 0 \\ 384 & 384 & 1609 & 0 & 0 & 0 \\ 0 & 0 & 0 & 340.5 & 47.3 & 0 \\ 0 & 0 & 0 & 47.3 & 92 & 0 \\ 47.3 & 0 & 0 & 0 & 0 & 92 \end{bmatrix} GPa$$

Graphene stiffness matrix
Unit cell size: 10*10 (2D)
Single Layer
Thermodynamic Ensemble: NVT

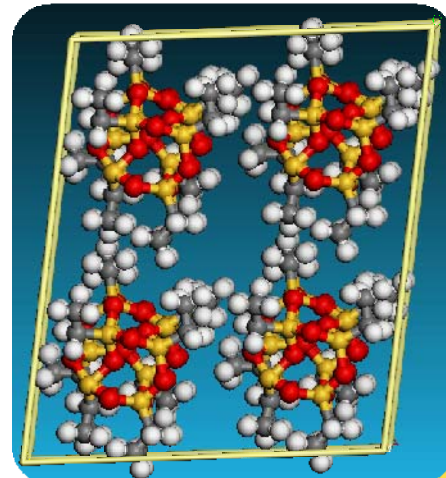
$$C_{ij} = \begin{bmatrix} 30.6 & 6 & 6 & 0 & 0 & 0 \\ 6 & 462.7 & 33 & 0 & 0 & 0 \\ 6 & 33 & 462.7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 214.8 \end{bmatrix} GPa$$

Graphite stiffness matrix
Unit cell size: 10*10 (2D)
Number of Layers: 6
Thermodynamic Ensemble: NVT

Nano- Reinforcements



CLAY (MMT)



POSS

$$C_{ij} = \begin{bmatrix} 308.6 & 69.3 & 52.9 & 0 & 0 & 0 \\ 69.2 & 466 & 123 & 0 & 0 & 0 \\ 52.9 & 123 & 140.6 & 0 & 0 & 0 \\ 0 & 0 & 0 & 108.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 46.2 \end{bmatrix} GPa$$

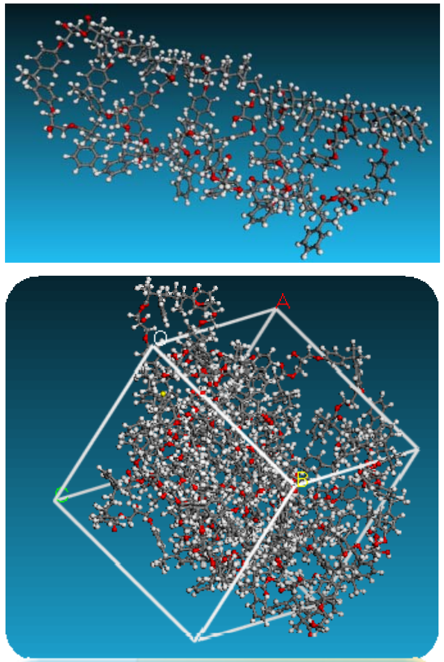
Graphene stiffness matrix
Unit cell size: 2*2*2 Super cells
Number of atoms: 1080
Thermodynamic Ensemble: NVT

POSS stiffness matrix
Unit cell size: 2*2 *2 Super cells
Number of atoms: 680
Thermodynamic Ensemble: NVT

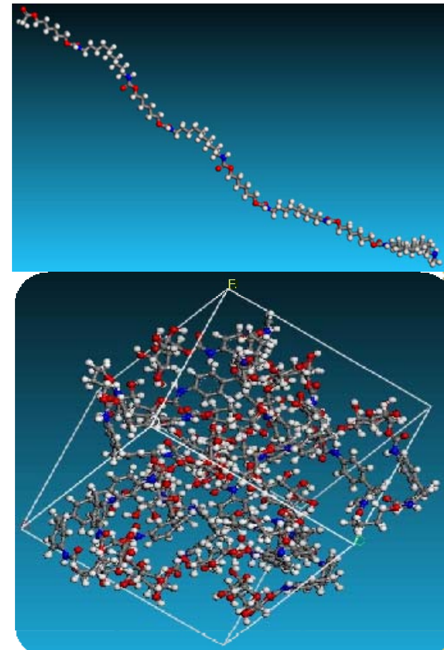
Nano- Reinforcements

Eng. Constants	SWCNT	MWCNT	Graphene	Graphite	MMT
E_{11} (GPa)	878	690	1373	461.4	84.1
E_{22} (GPa)	23.2	27.5	831	31.7	354
v_{12} (GPa)	0.16	0.33	0.30	0.012	0.23
G_{23} (GPa)	7.6	8.6	340.5	216	198.4
K_{23} (GPa)	24.6	57.6	624.1	248.6	267.6

Polymer- Matrices

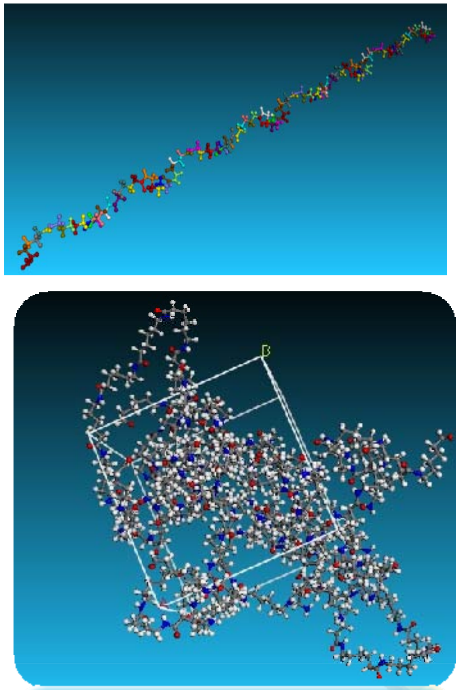


Vinyl Ester

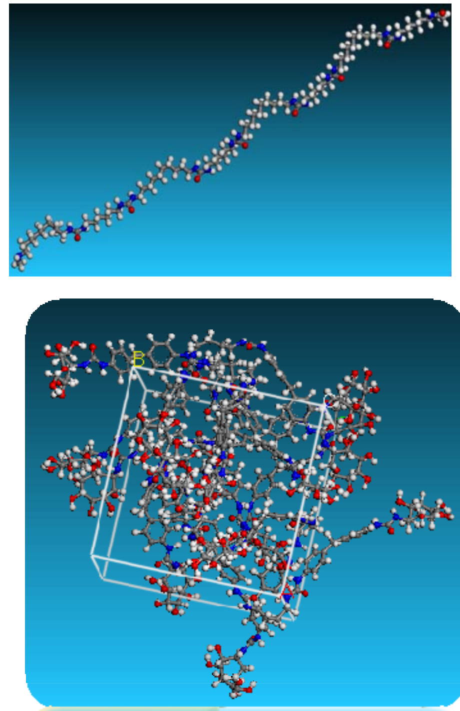


Polyurethane

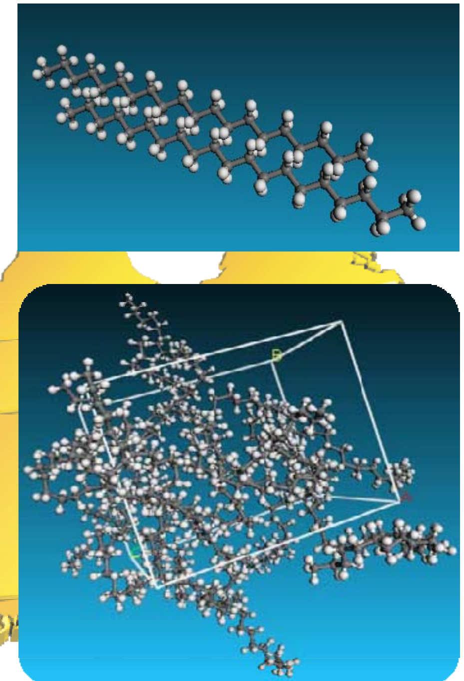
Polymer- Matrices



Nylon6,6



Polyurea



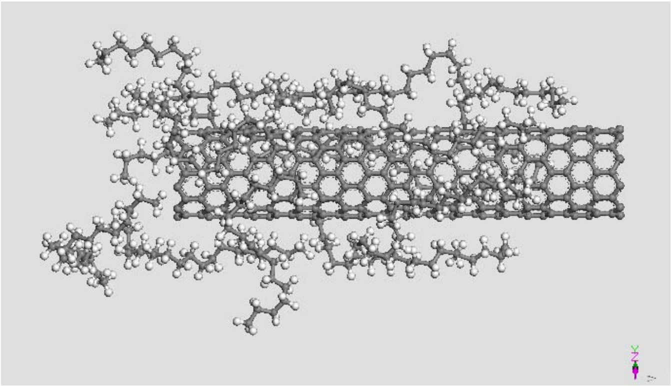
Polyethylene

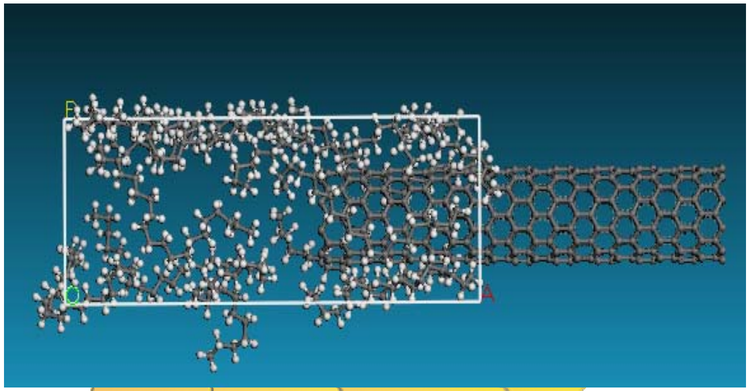
Polymer- Matrices

Eng. Constants	Nylon6,6	Vinylester	Polyethylene	Polyurea	Polyurethane
E_{11} (GPa)	**3.4**	**3.7**	**1.2**	**5.5**	**5.5**
v_{12} (GPa)	**.37**	**.31**	**.37**	**.29**	**0.32**
G_{23} (GPa)	**3.6**	**1.41**	**.45**	**4.4**	**2.1**
K_{23} (GPa)	**1.6**	**3.37**	**1.73**	**2.1**	**3.6**

Interface Nano- Composite

Polyethylene – SWCNT Interface





Polyethylene SWCNT:

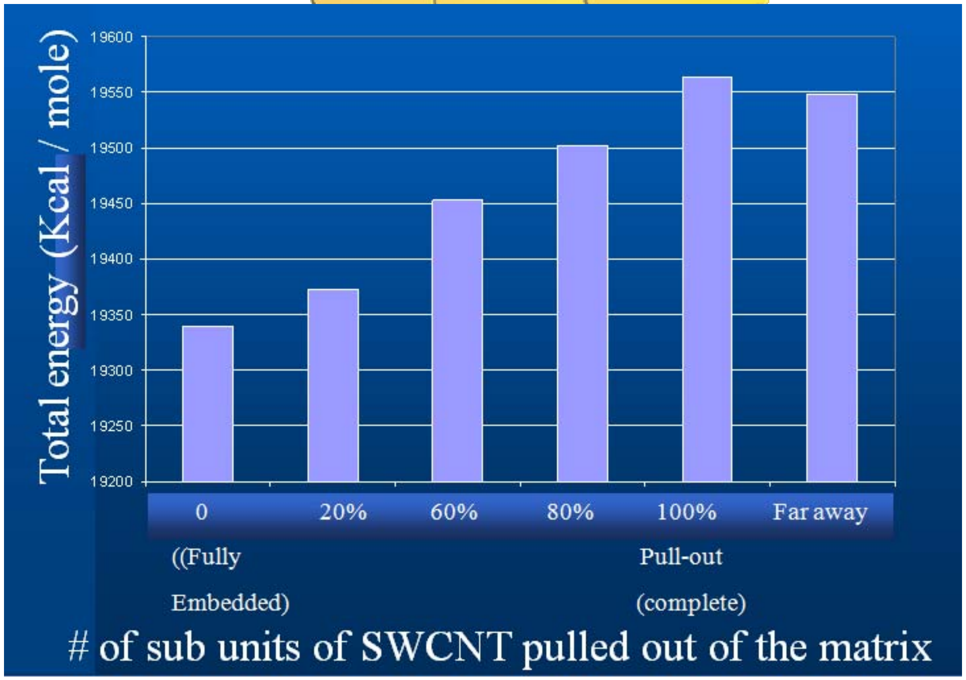
Minimization: Conj. Gradient

Density: 1.3 gm/cm^3

Number of atoms: 1206

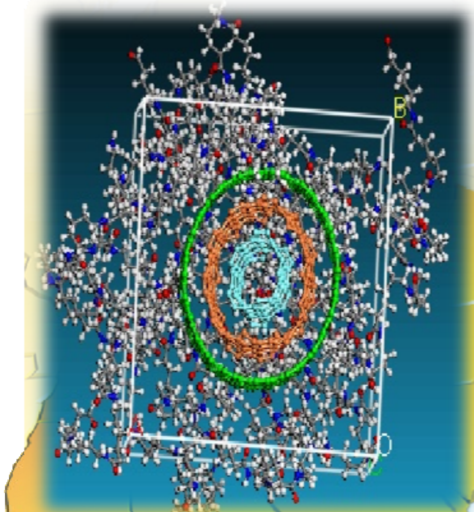
Unit cell Volume: 7.875*7.875*42.2 A

Length: 42.2A



Nano-Composites

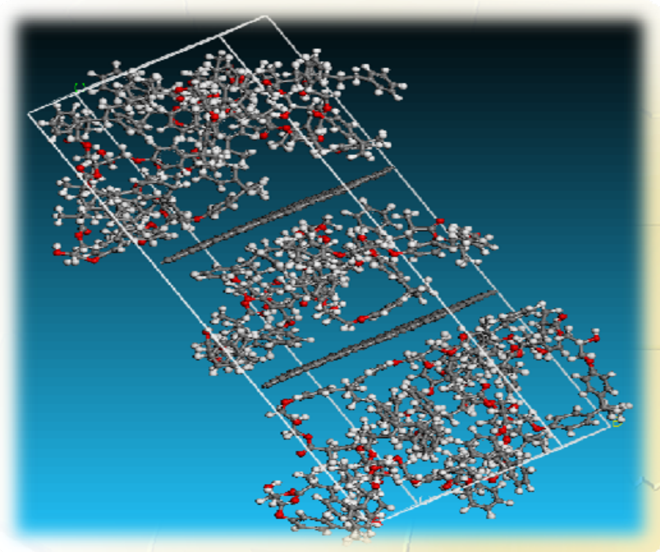
Nylon6,6 - DWNT



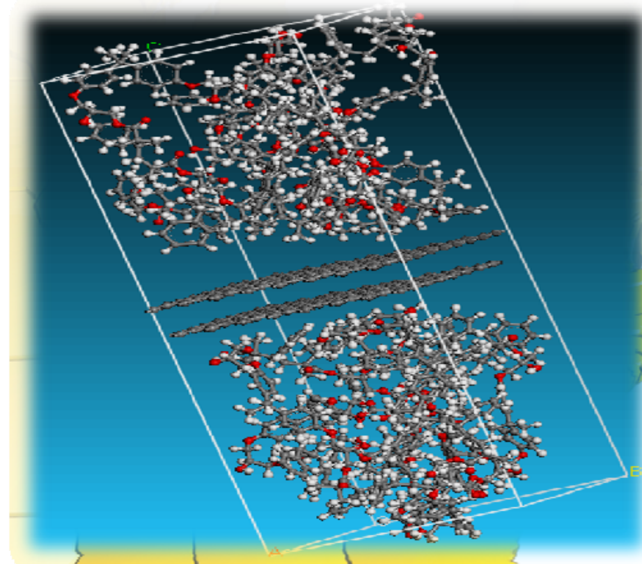
Nylon6,6 - MWNT

Composite Eng. Constants	5%	10%	20%
E_{11} (GPa)	5.5	13.6	73.5
E_{22} (GPa)	5	9.6	40.6
v_{12} (GPa)	0.32	0.31	-
G_{23} (GPa)	1.8	6.3	8.6
K_{23} (GPa)	5.3	10.5	18

Nano- Composites



Vinyl Ester - xGnP

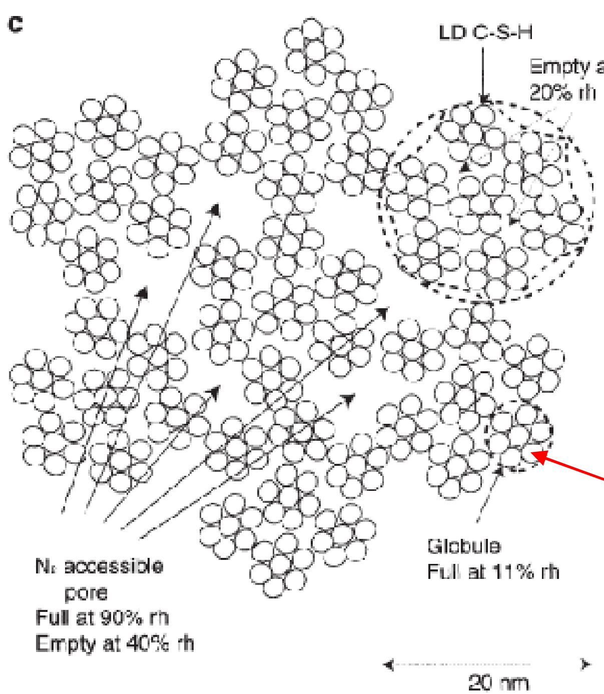


Vinyl Ester - xGnP

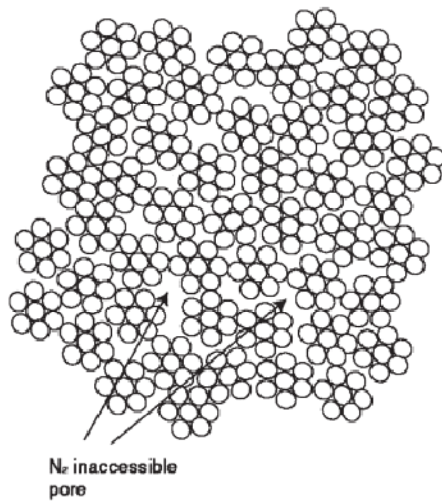
Composite Eng. Constants	10%	20%
E_{11} (GPa)	17.4	13.7
E_{22} (GPa)	113.9	140.6
v_{12} (GPa)	0.05	0.03
G_{23} (GPa)	41.8	49.4
K_{23} (GPa)	94.1	124.4

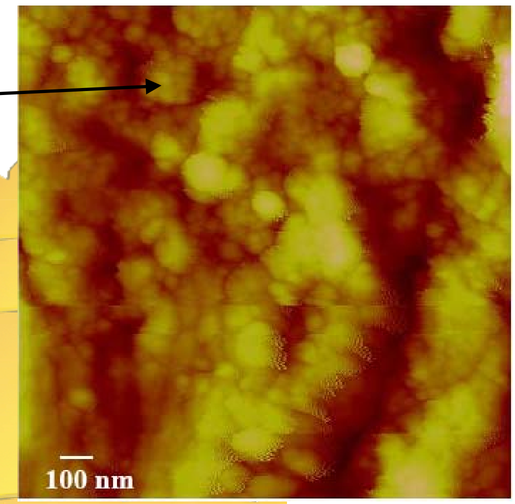
Composite Eng. Constants	10%	20%
E_{11} (GPa)	11.4	58.3
E_{22} (GPa)	81.8	160.7
v_{12} (GPa)	-	-
G_{23} (GPa)	27.9	56.4
K_{23} (GPa)	77	139.7

Concrete: C-S-H GEL MODEL

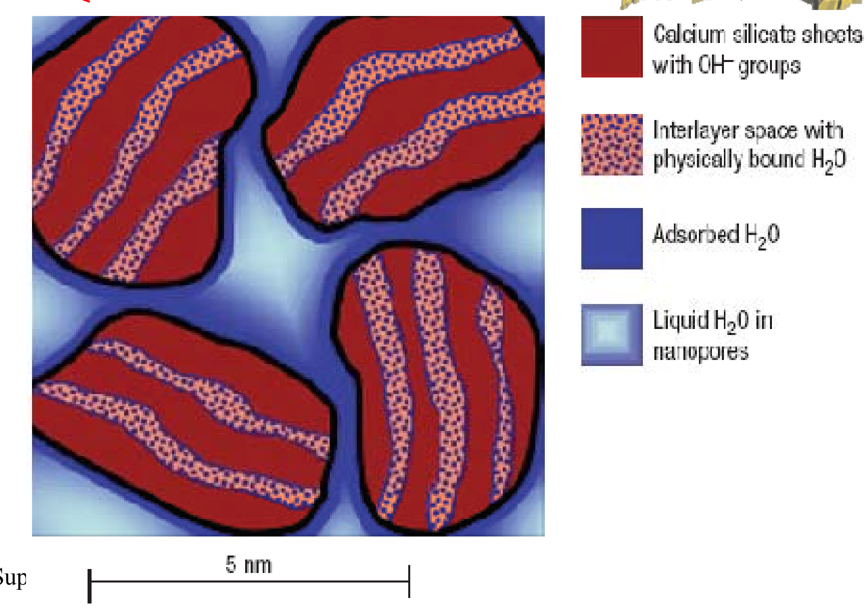


(Jennings, 2004)





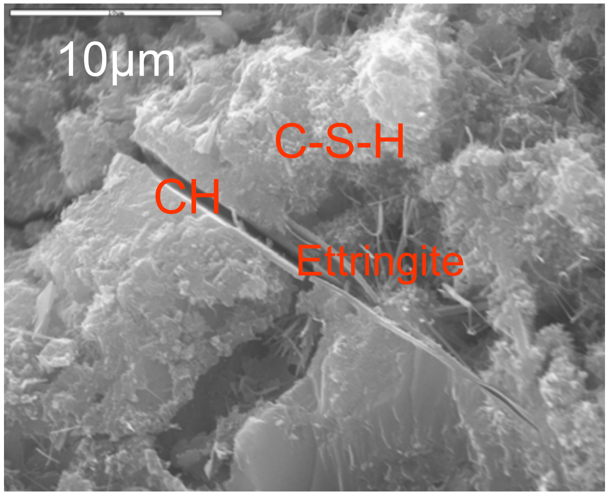
(Mondal P., Shah S.P., Marks L.,2006)

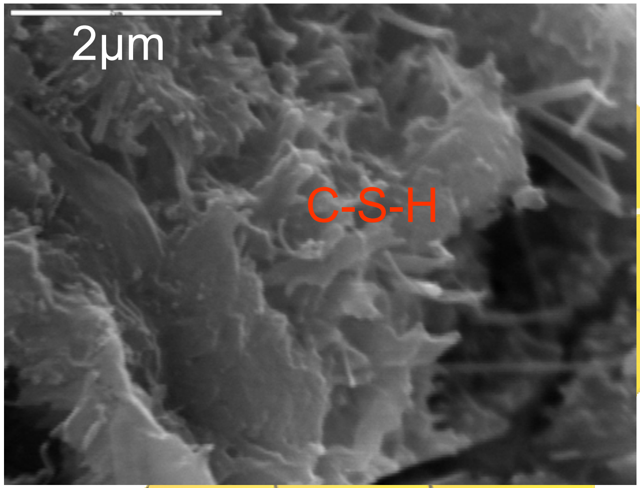


(Allen, et al 2007)

Multiscale of Concrete

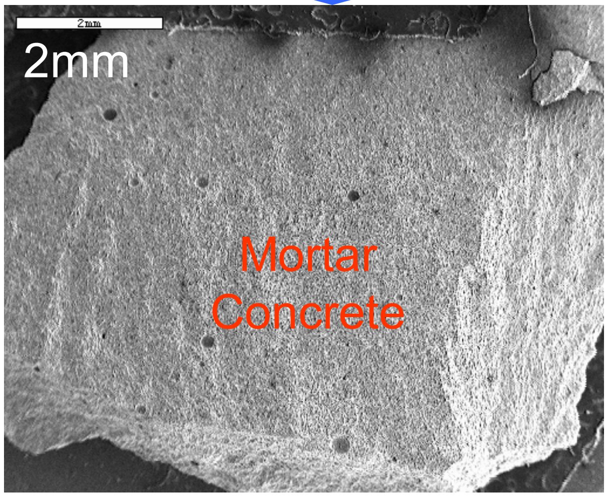
Micro

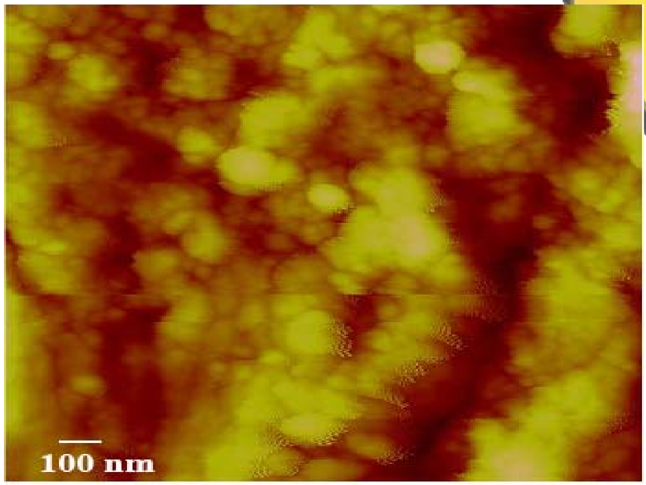




Sub-
micro

Macro



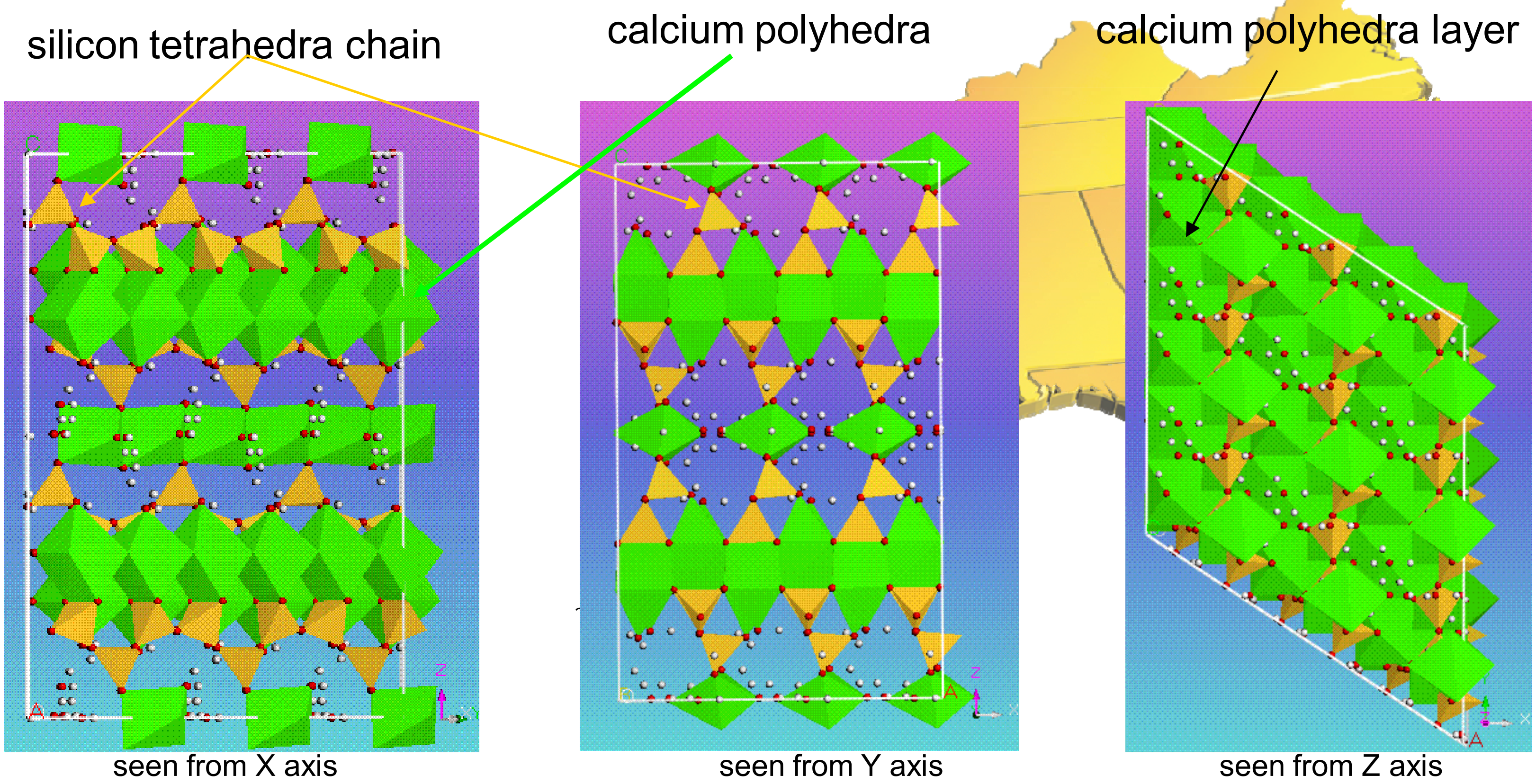


Nanoscale
C-S-H

AFM image
(Mondal, 2005)

Multiscale Modeling of HCP-Nano C-S-H: Tobermorite 14Å

C-S-H is structuraly related to tobermorite 14Å and Jennite



Crystal structure of tobermorite 14Å

•A typical Layered Structure

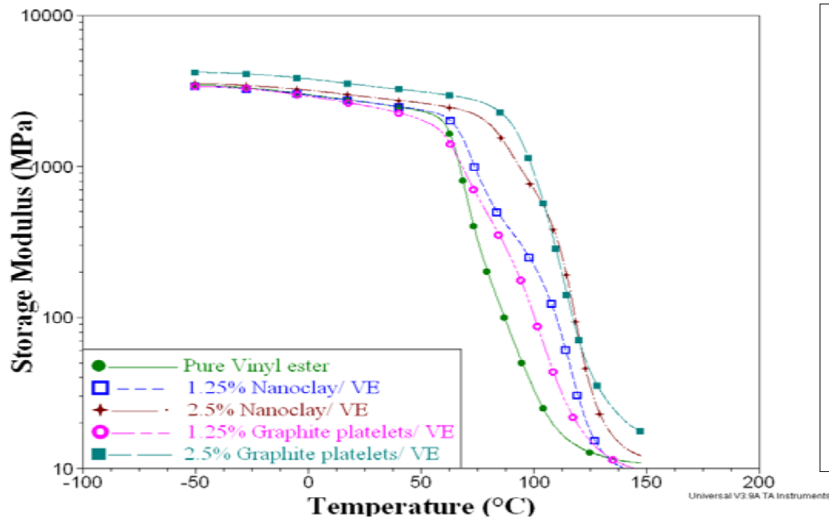
•Real C-S-H has a disordered nearly amorphous structure

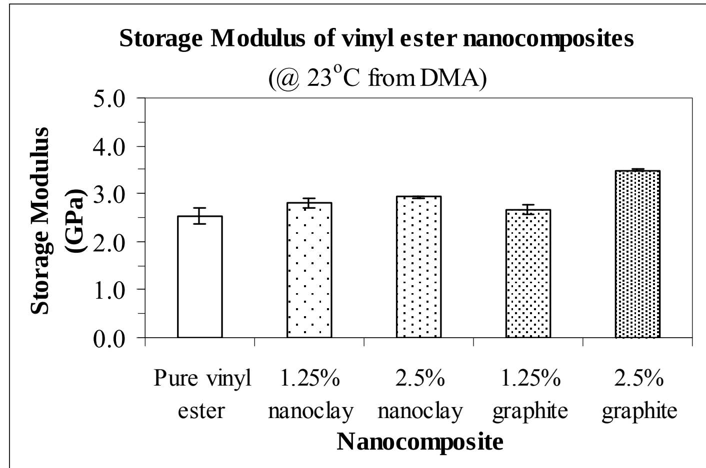
Dynamic Mechanical Analyzer (DMA)

- **Dynamic mechanical analysis (DMA)** is a technique used to study and characterize materials. It is most useful for observing the viscoelastic nature of polymers.

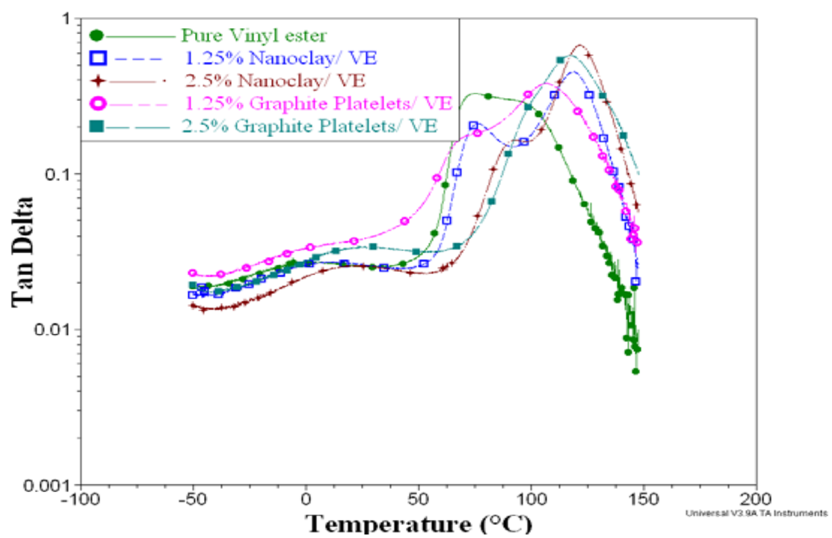
TA Instruments Q800 DMA

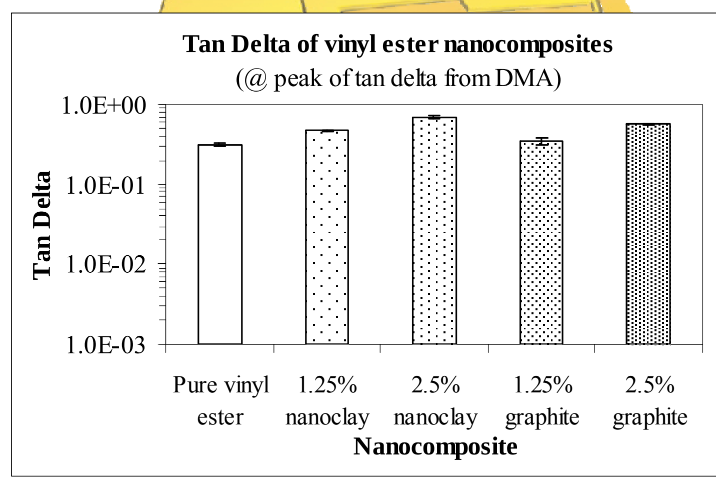
DMA - Results





Storage modulus of vinyl ester with different nano reinforcements





Damping of vinyl ester with different nano reinforcements

Impact Response of Nanocomposites

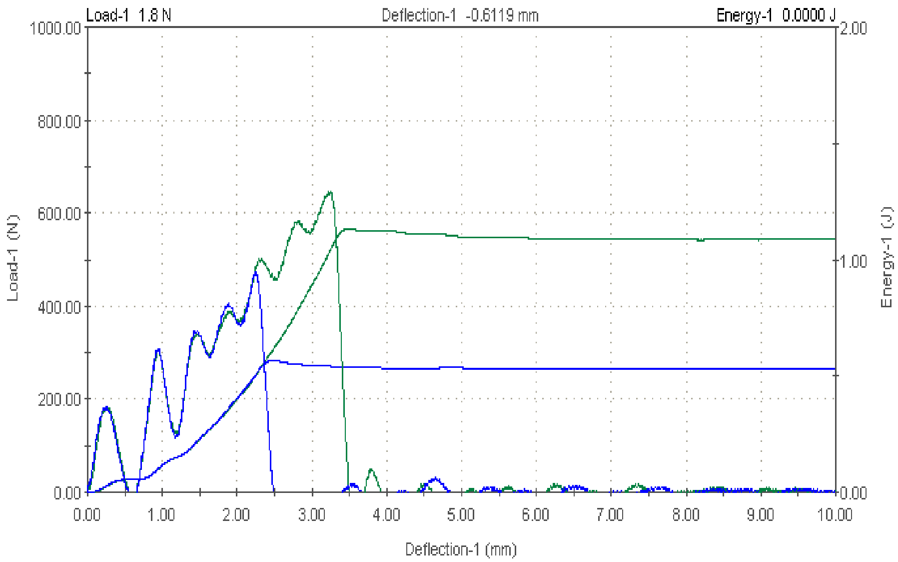
- Optimize energy absorption of nanocomposites at various strain rates

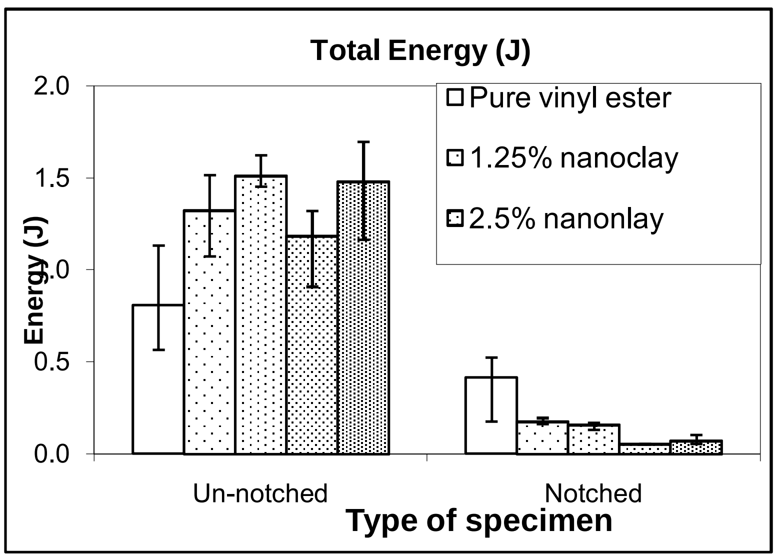
SERRI Southeast Region Research Initiative

LOW-VELOCITY IMPACT TESTS

- ASTM D-6110-06 with sample size of 127 mm x 9.9 mm x 12.7 mm (5” x 0.39” x 0.5”)
- 5 notched and un-notched specimens from each configuration
- Drop height of 177.8 mm (7”)
- Drop velocity of 1.86 m/s (6.1 ft/s)
- Impact energy of 5.78 J (4.26 ft-lbf)
- Approximate strain rate of 15 /sec

LOW-VELOCITY IMPACT TESTS





Energy absorption

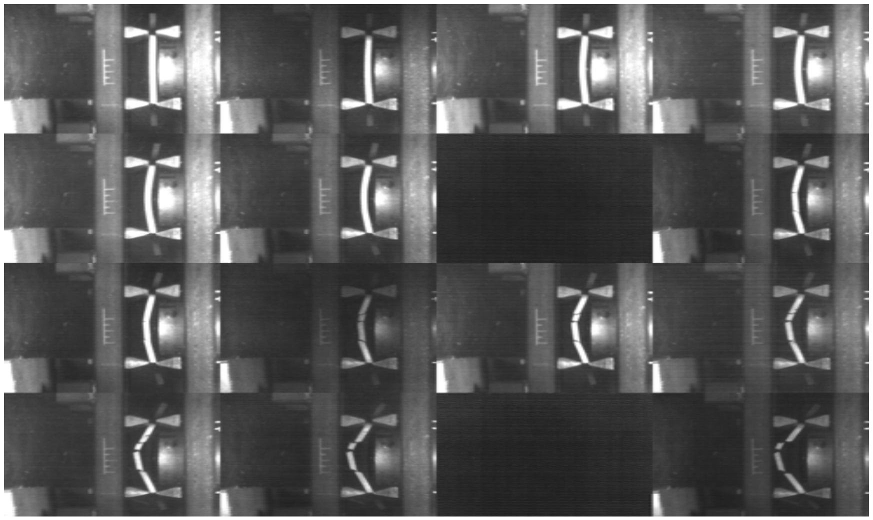
- Almost doubled with 2.5 wt percent reinforcement, for both graphite nanoplatelet as well as the nanoclay un-notched specimens
- Reduced by 50% for notched specimens with 2.5 wt percent reinforced nanoclay, and 75% for graphite nanoplatelets

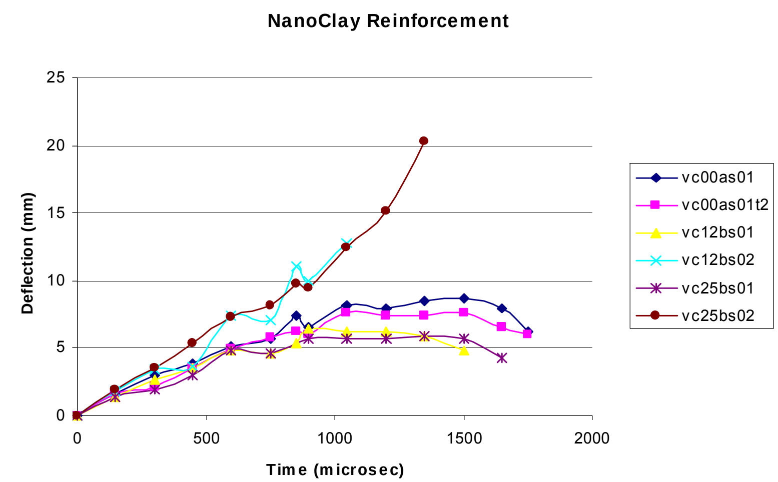
Shock Tube Experiment

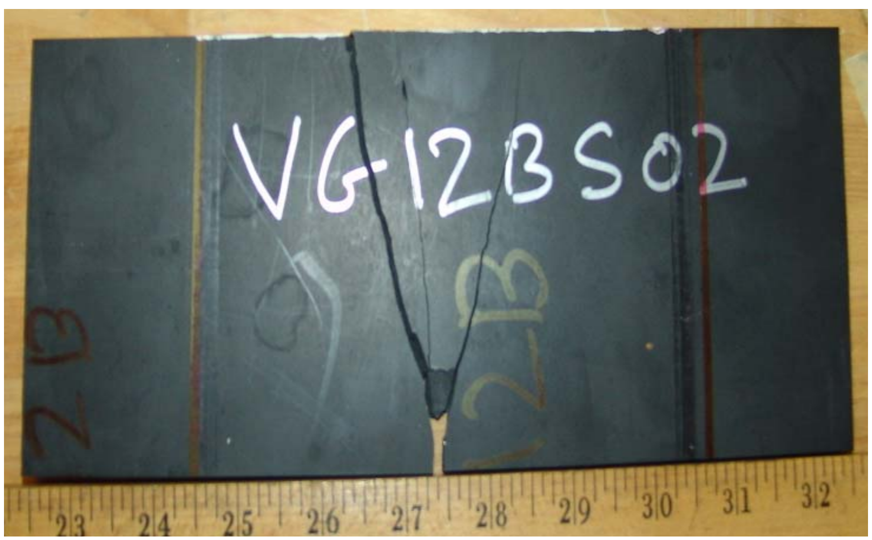
- Characterize shock response.

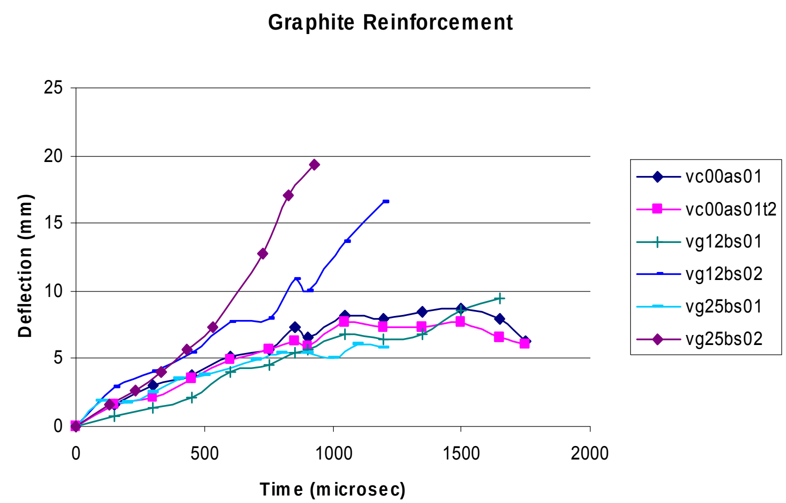
Shock Tube—University Rhode Island

Real Time Deformation and Analysis

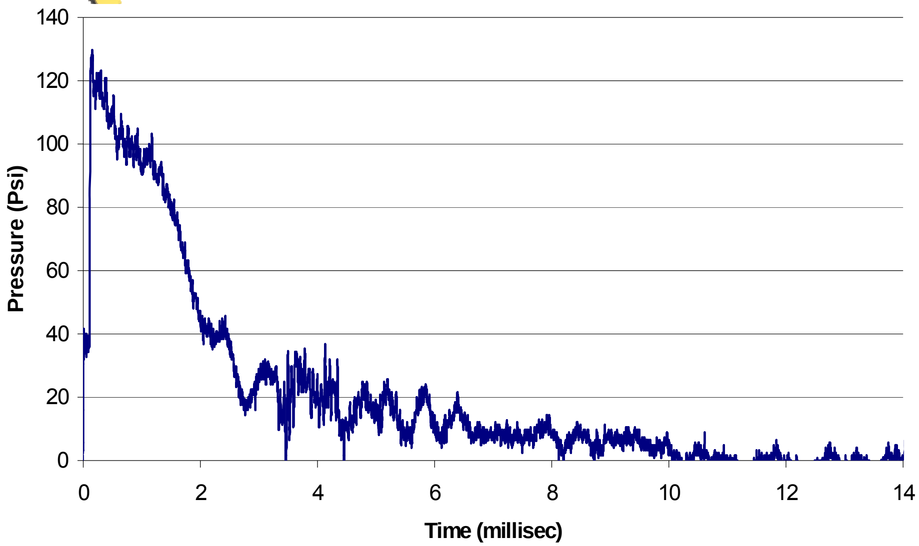


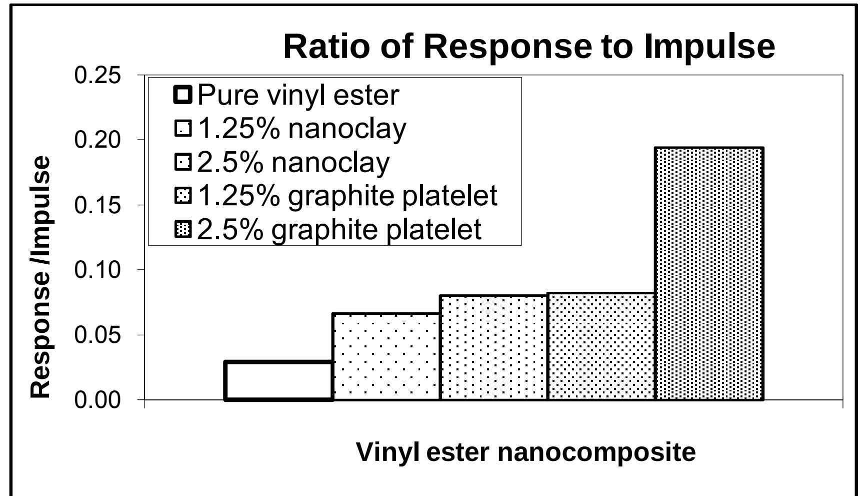


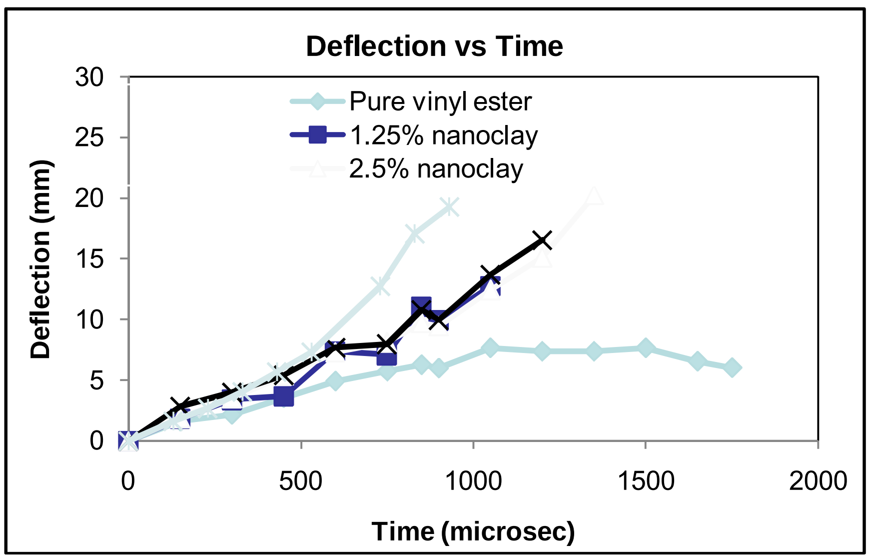




SHOCK TUBE TESTS





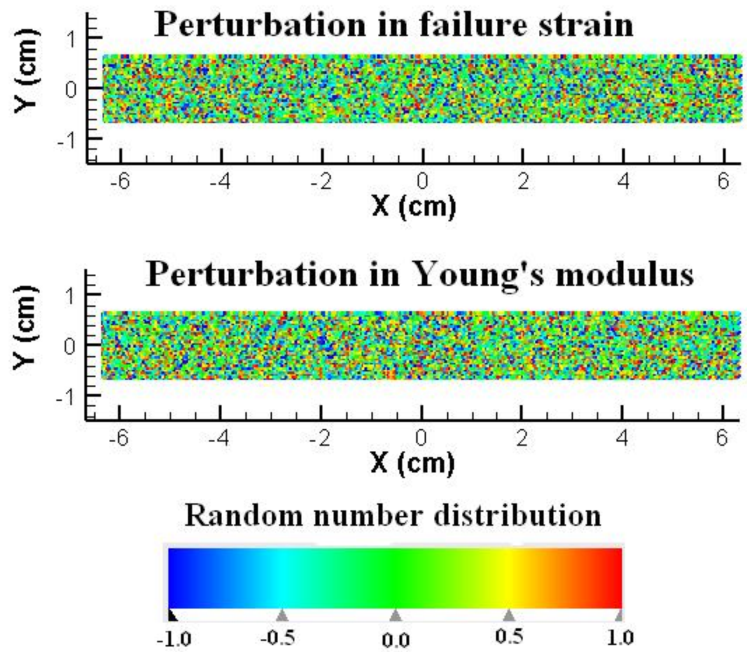


- Deflection vs time graph obtained from real time images captured at intervals of 100-150 microseconds.
- Samples tested at 70 psi peak pressure did not fail, while the samples tested at 120 psi peak pressure shattered into pieces.
- Nanoparticle reinforcement shows improved response for the 120 psi peak pressure loading.

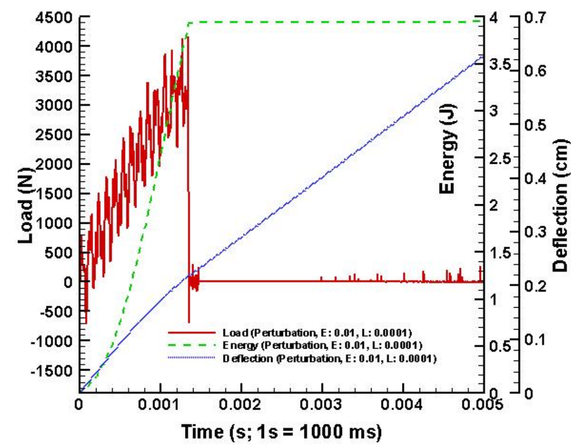
Particle Modeling

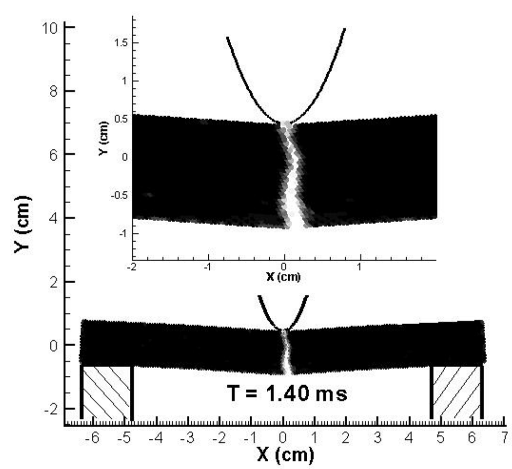
Computer modeling at a scale larger than molecular level.

(iv) Microscale inhomogeneity study



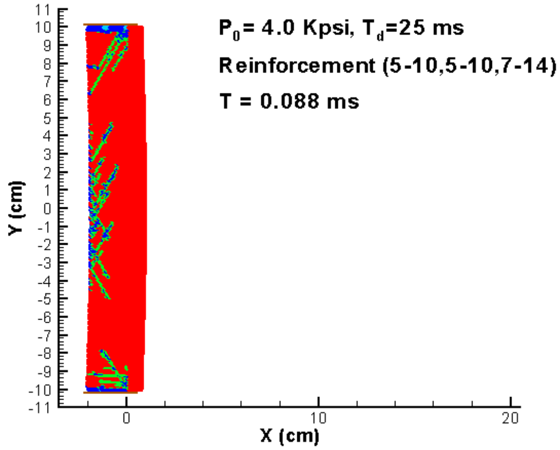
Matrix generation

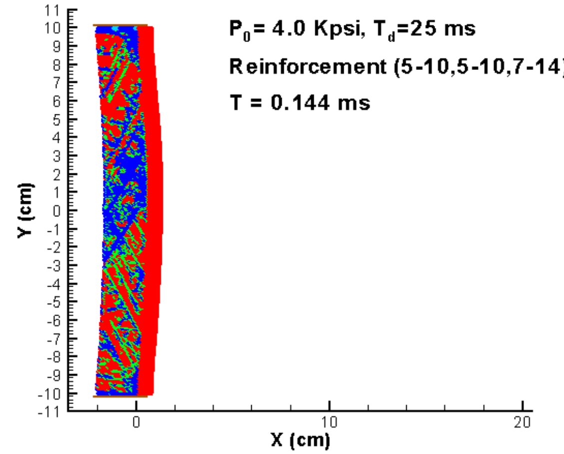


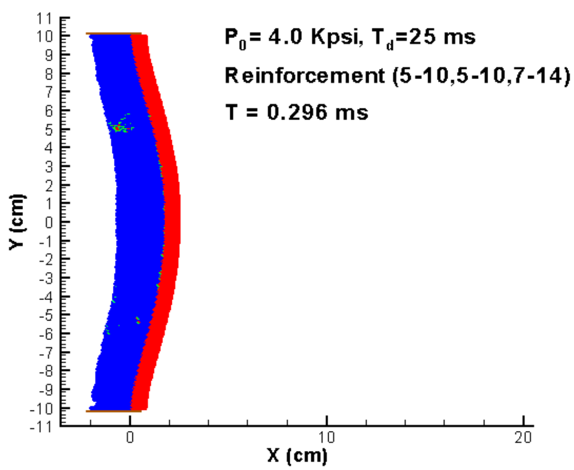


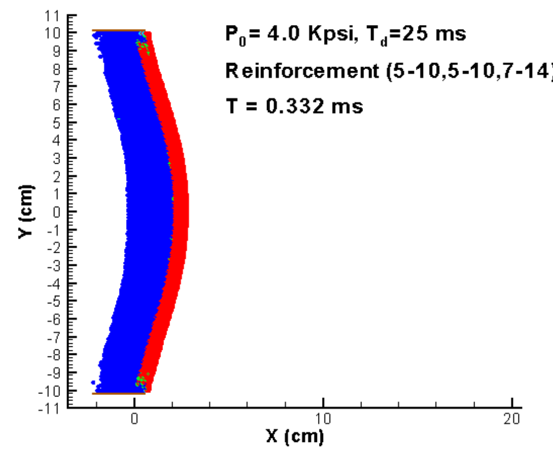
Young Modulus perturbation: [-0.01, 0.01]
Failure strain perturbation: [-0.0001, -0.0001]

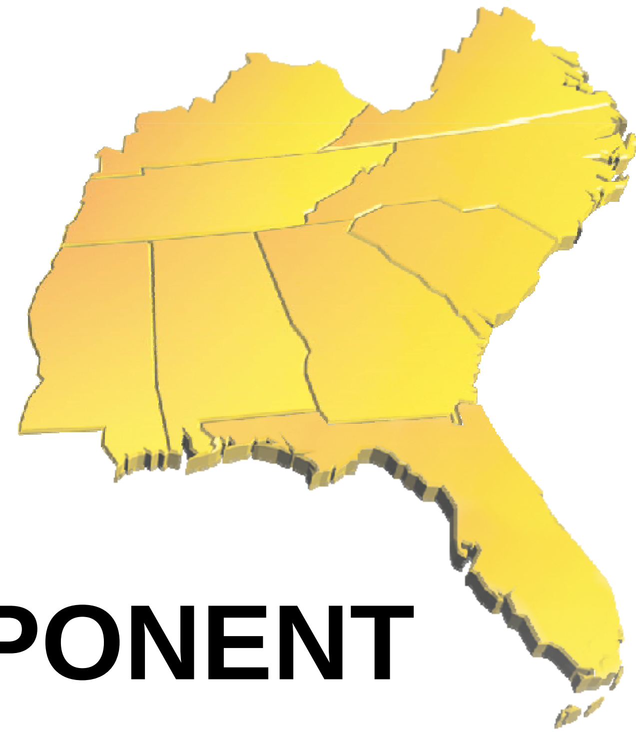
Simulated Blast result (Time Sequence)











STRUCTURE COMPONENT RESEARCH

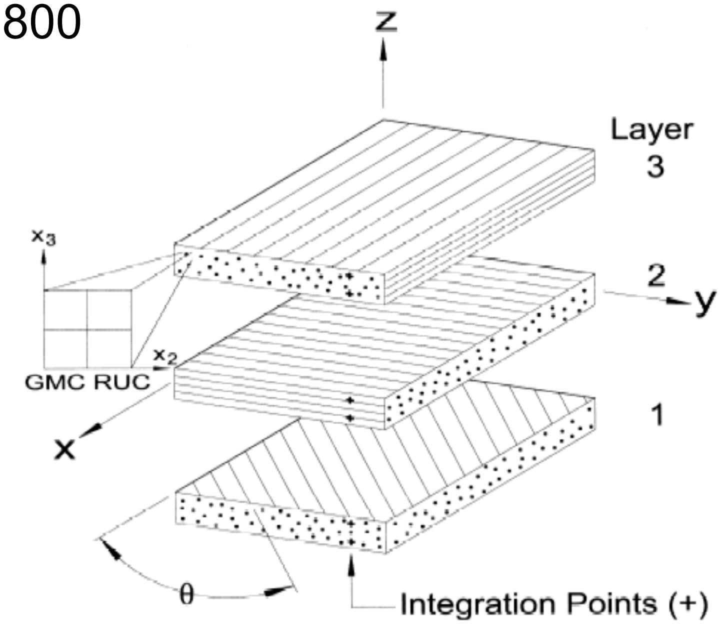
Composite Sandwich Panels

- A **Sandwich structured composite** is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density.

Laminates of Vinyl Ester reinforced with E-glass fibers:

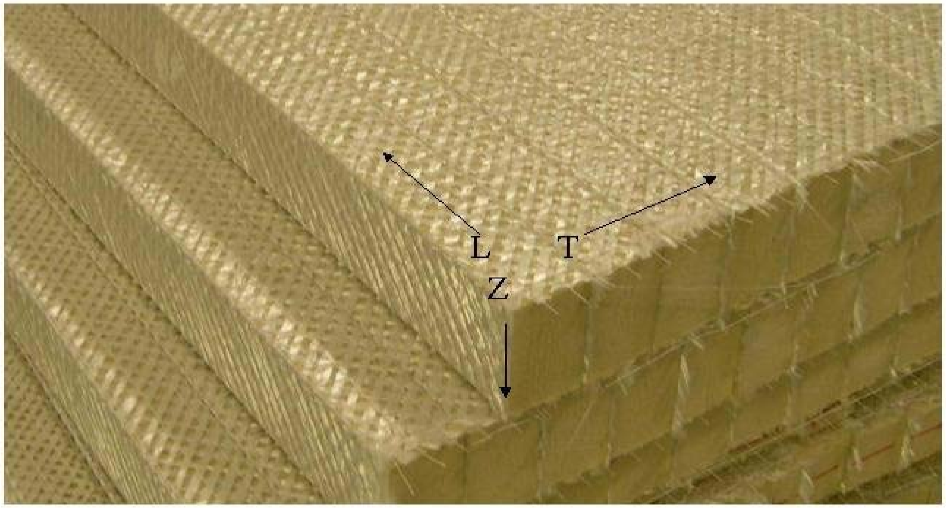
Vinyl Ester reinforced with EBX -2400, ELT-1800

Laminate Engineering Constants	EBX-2400	ELT-1800
E_{xx} (GPa)	53.1	42.6
N_{xy}	.237	.237
E_{yy} (GPa)	53.2	42.7
G_{xy} (GPa)	15.3	12.0

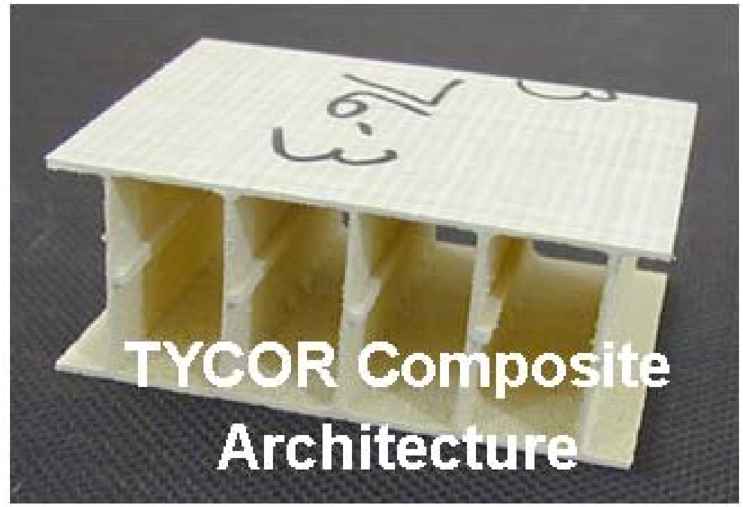


Vinyl Ester Composite, vf=55% reinforced E-glass

θ =90
θ =0
θ =45
θ =-45
θ =90
θ =0
θ =-45
θ =45
θ =90
θ =0



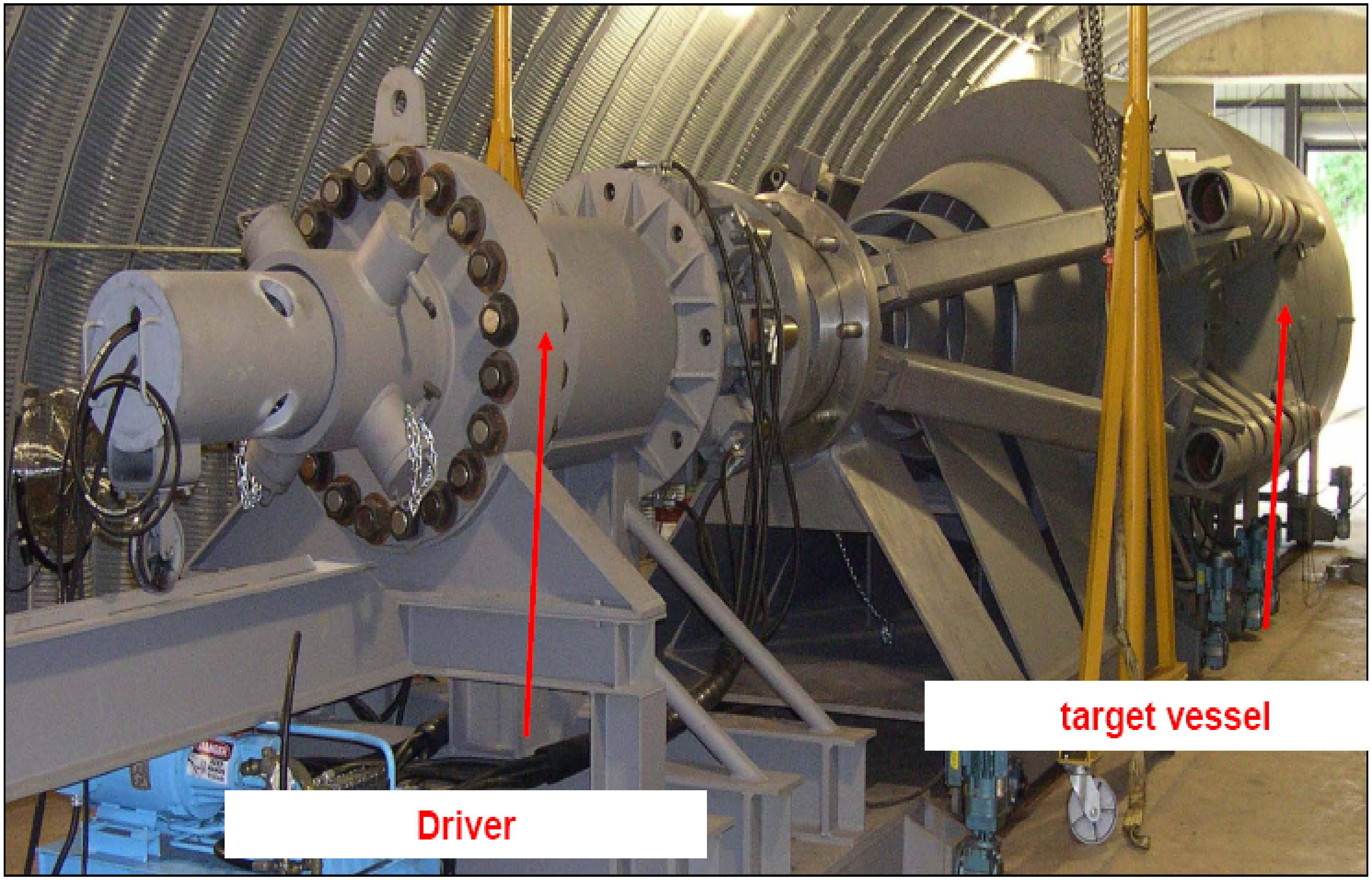
Observing the core, notice the construction. Core is made up of "sticks" bound together by a surface mesh. The length of the "sticks" is the longitudinal, or "L" direction. The through thickness is the "Z" direction. Across, or perpendicular to the "L" direction is the "T", or transverse direction.



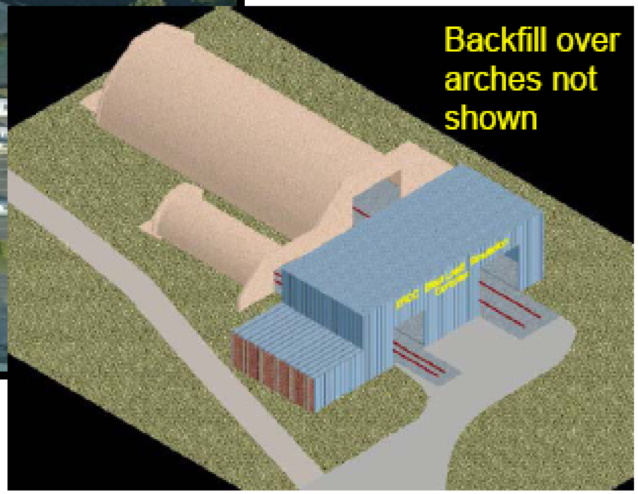
TYCOR® 3-D STITCHED FOAM

WEBCORE TECHNOLOGIES

Blast Load Simulator (BLS)



The pressure loading is generated by releasing compressed air from the driver, the small (4') cylinder. Shock waves are generated at the front of the expanding compressed air as it travels toward the large diameter (17') end of the tube and strikes the test specimen mounted in the target vessel. The pressure loading at the target is a function of the driver pressure (up to 1500 psi), the driver volume, the length of the transition tube, and the venting used along the length of the tube. Waveforms created by the release of the compressed gases replicate the positive and negative loading phase associated with high-explosive yields up to 20,000 lb.

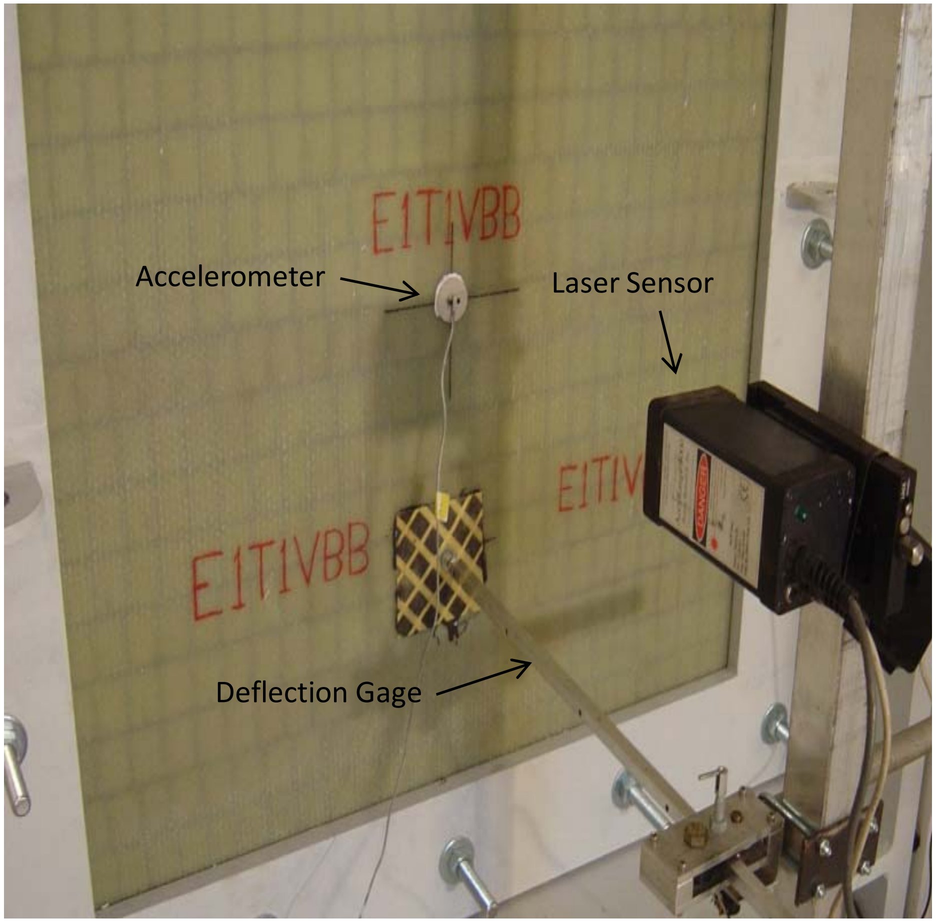


The Blast Load Simulator (BLS) program is a multiyear research effort which resulted in the design and construction of a state-of-the-art facility for blast effects research. At the heart of the facility is the BLS, a compressed gas driven shock tube, used to simulate blast loads associated with terrorist attacks on structural elements. The BLS is designed to simulate the blast pressure waveform for explosive yields up to 20,000 lb at peak reflected pressures up to 80 psi.

Composite Structures
and Nano Engineering
Group, University of

EXPERIMENTAL SET-UP

4' x 4' panel clamped inside target vessel

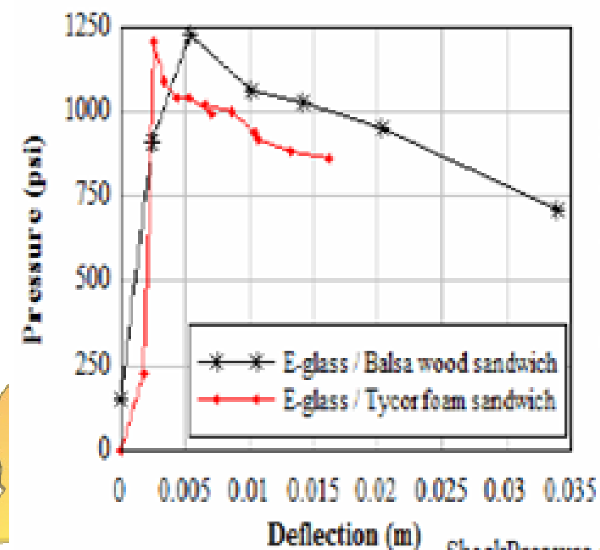


Instrumentation for data acquisition

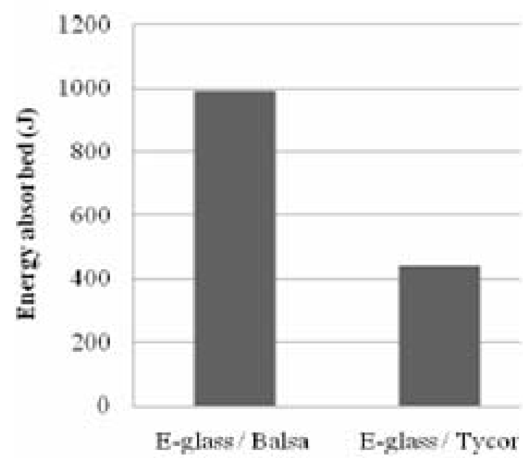
- One 64” x 34” E-glass/Balsa core panel was subjected to about 60 psi peak pressure with this alternate fixture.

- Panel slid through the supports and was completely damaged, with E-glass face skin on blast side shearing into two halves at the middle.
- Instrumentation, data acquisition and specimen clamping issues are being resolved for future full-scale blast experiments.

(a) Shock face, (b) back face, and (c) left side view of E-glass/Balsa sandwich composite; and (d) the splintered balsa core pieces after shock testing at 1200 psi (1340 m/s).



(a) Shock face, (b) back face, and (c) left side view of E-glass/Tycor sandwich composite; and (d) the splintered foam core pieces after shock testing at 1200 psi (1340 m/s).



Concrete Masonry Unit

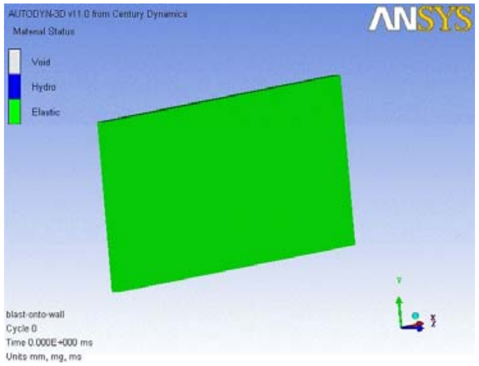
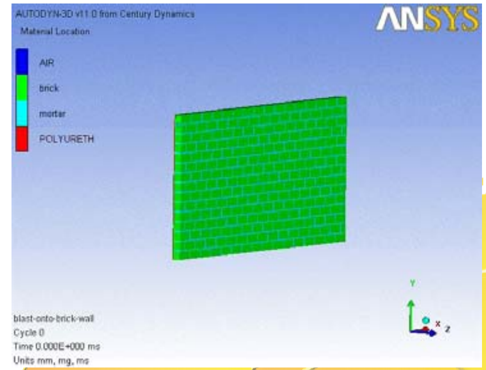
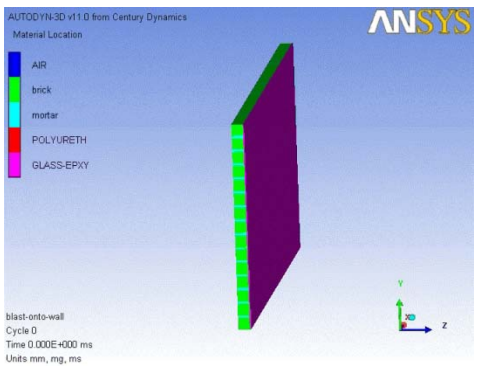
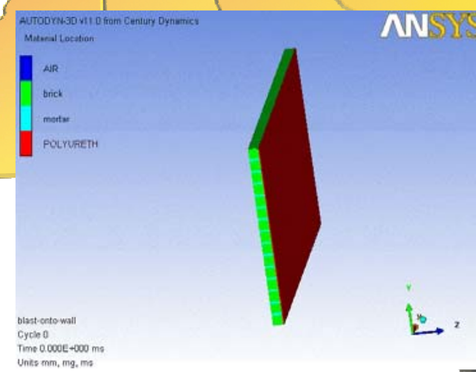
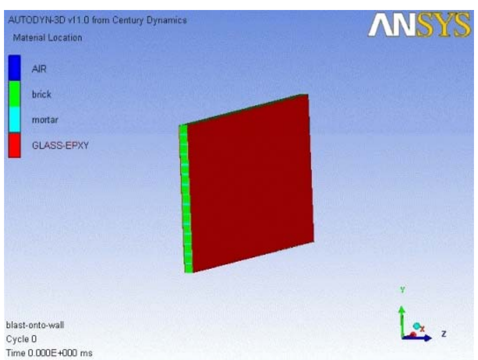
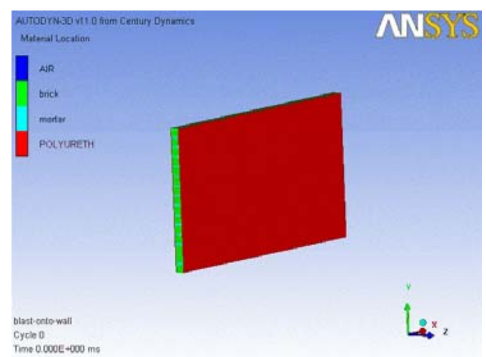
Protection by xGnP Reinforced Polyurea

ERDC Experiments

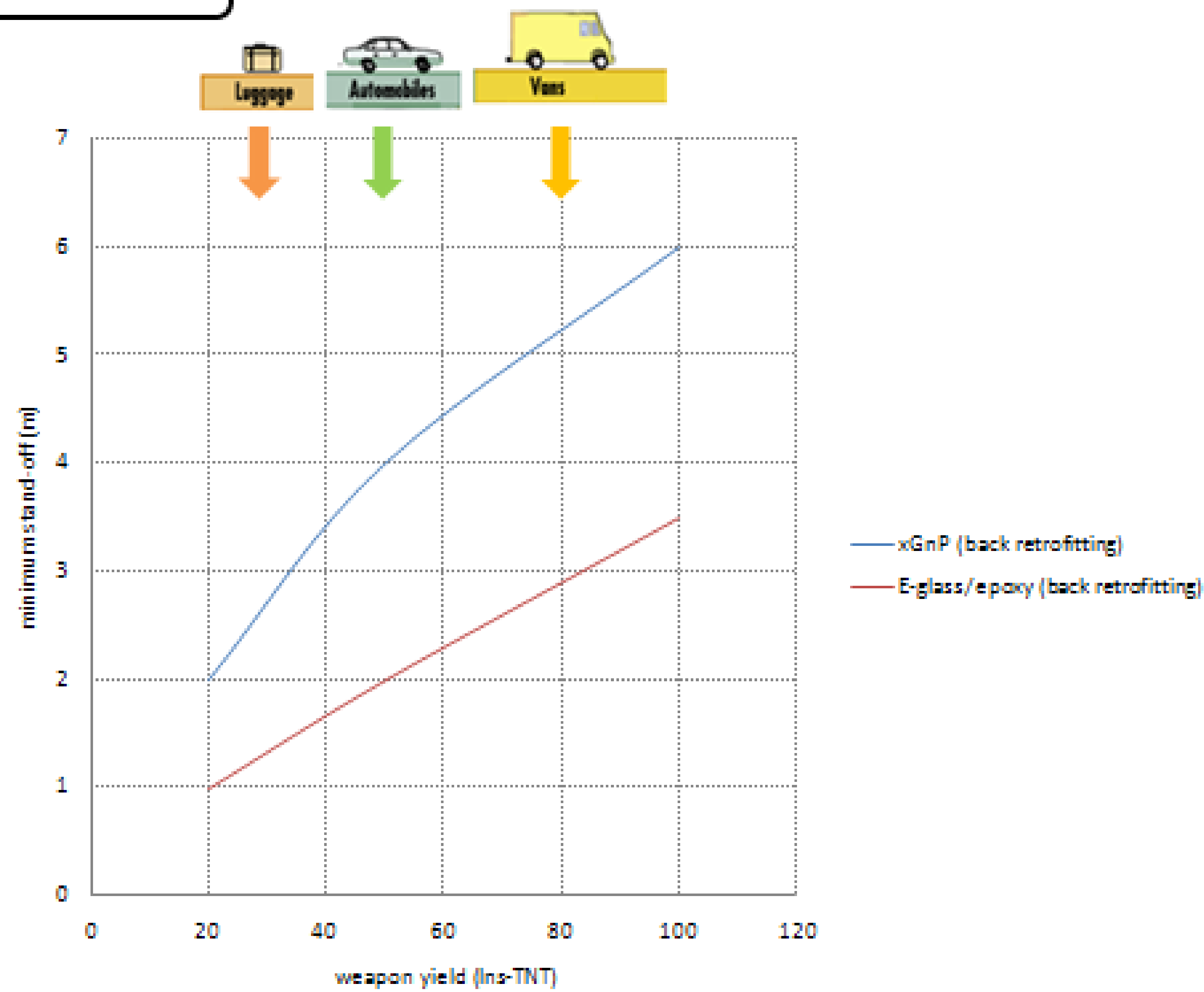
AUTODYN Simulation of Blast

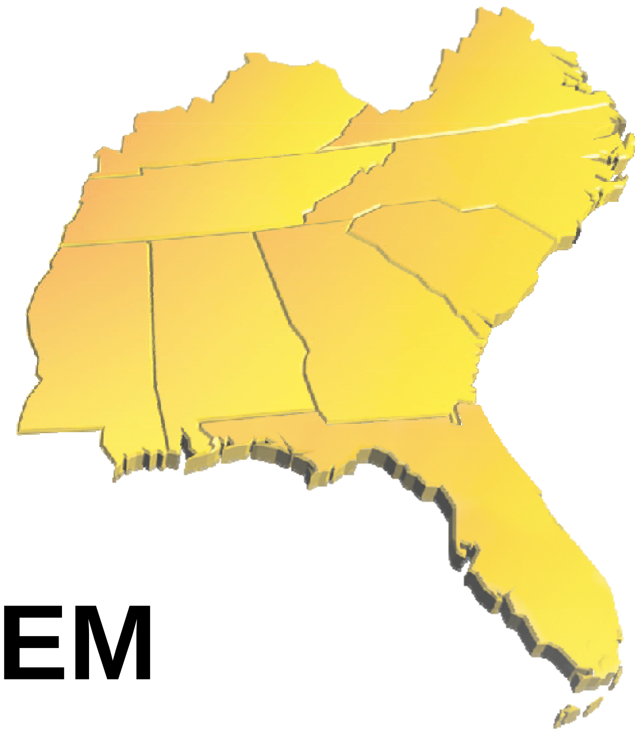
- **AUTODYN** is an explicit software package for non-linear dynamics. It incorporates finite element analysis, computational fluid dynamics, a meshfree SPH (Smooth Particle Hydrodynamics) capability and coupling between these techniques and material physics. It is now part of the ANSYS family of products.

SERRI Southeast Region Research Initiative

Rigid material (E-glass/epoxy)		Elastomeric material (Polyurethane)
	Back	
	Front	
	Both	

Standoff distance





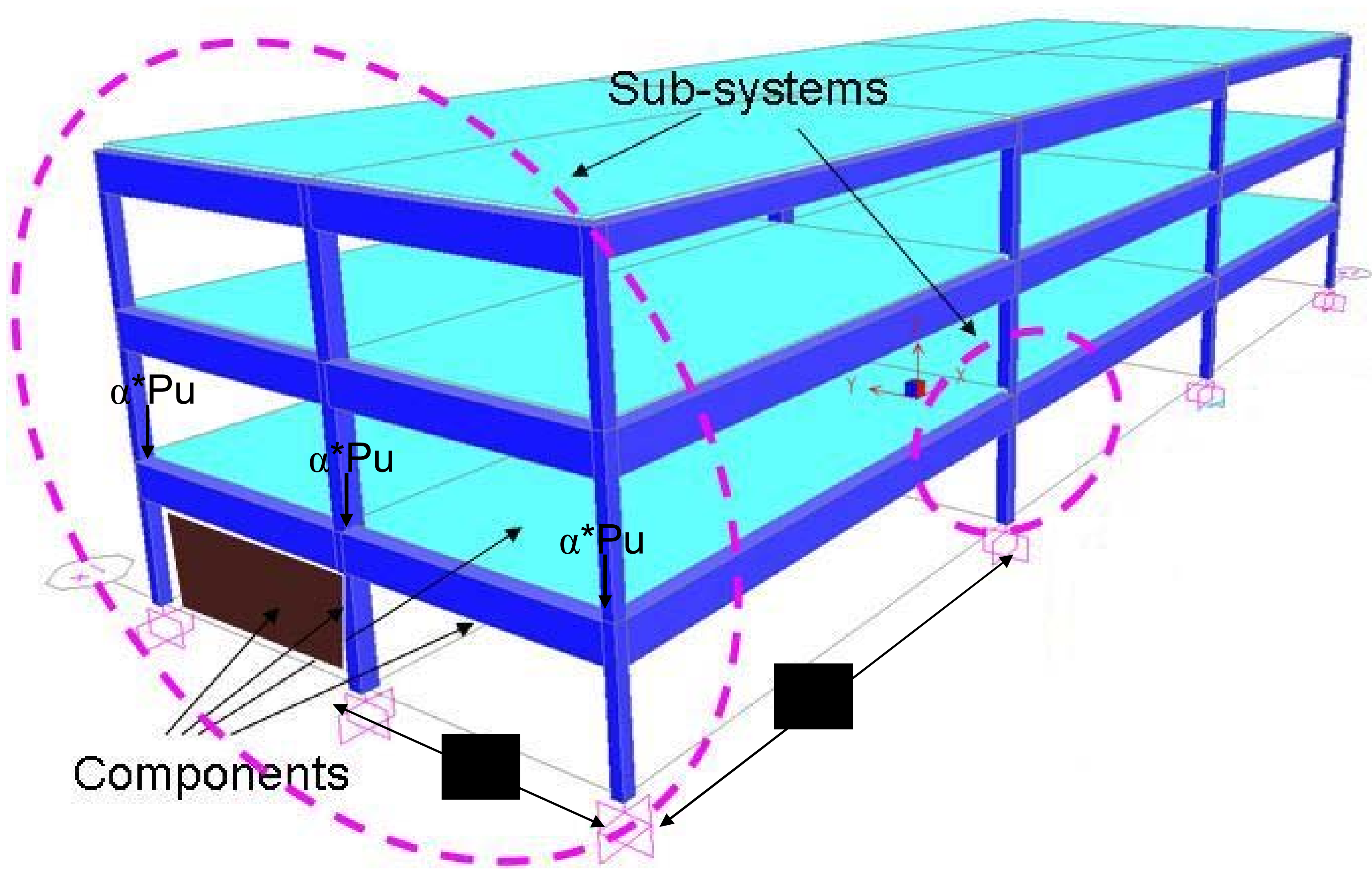
STRUCTURE SYSTEM RESEARCH

Static Model

- Live loads and spans are important parameters governing the preliminary design of a structure.
- At the member level, local vulnerabilities need to be identified in order to map the blast damage on the structure.
- The fiber model allows tracking of damage states in the concrete and rebar at points defined on the section .
- The collapse resistance of the damaged structure is analyzed by removal of severely damaged columns along the long axis of the building and studying the nonlinear static response of the structure.

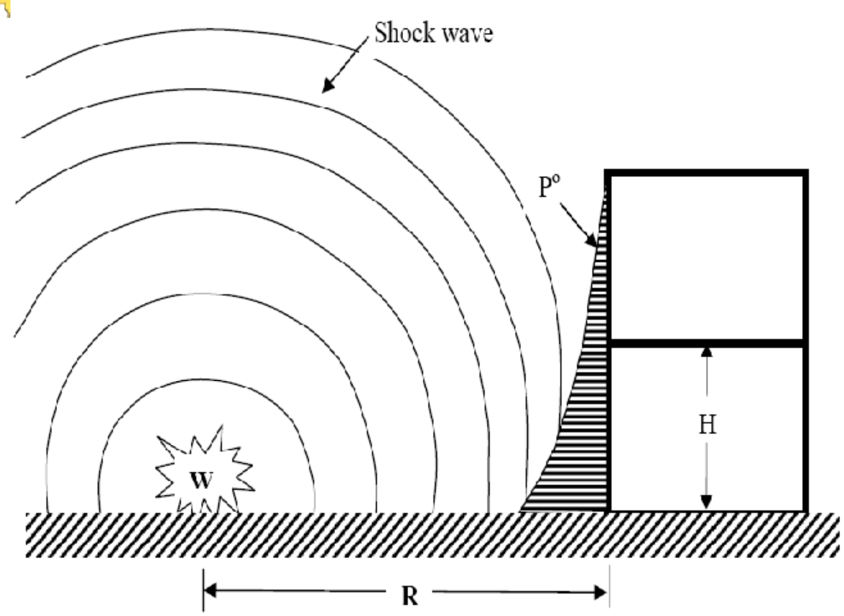
SERRI Southeast Region Research Initiative

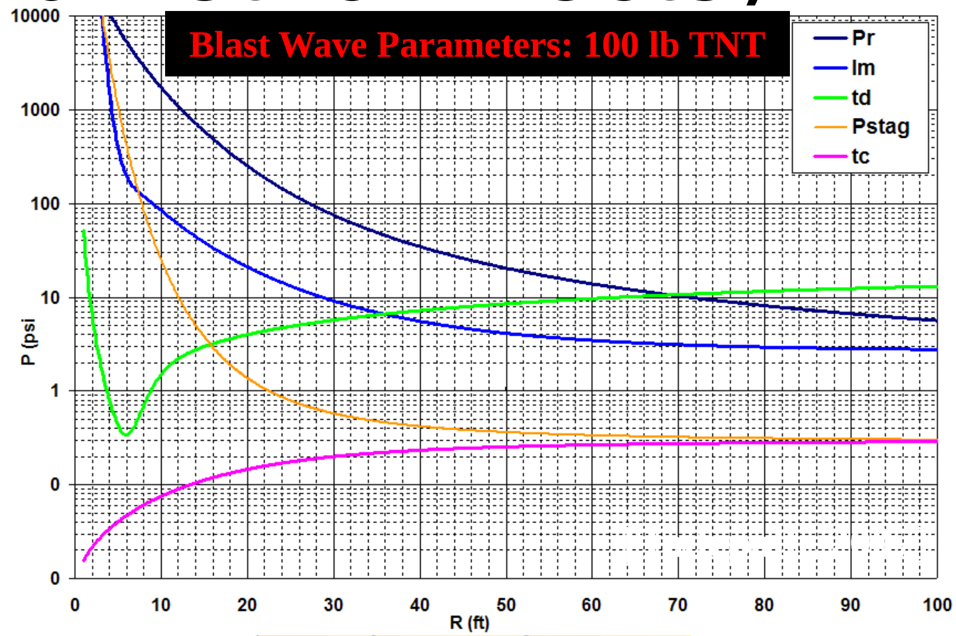
Typical Low Rise Structure



Typical Low Rise Structure

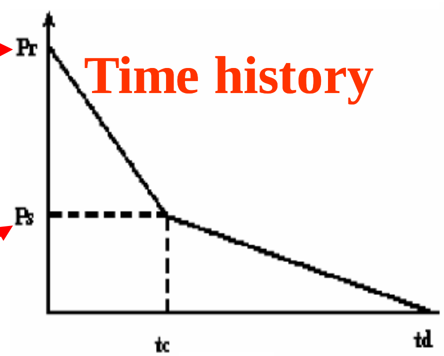
Air Blast (Volumetric Effects)





Peak Refl. pressure

Stagnation pressure



Over pressure ratio

$$\frac{P^{o}}{P^{atm}} = \frac{808\left[1+\left(\frac{Z}{4.5}\right)^{2}\right]}{\sqrt{1+\left(\frac{Z}{1.35}\right)^{2}}\sqrt{1+\left(\frac{Z}{0.32}\right)^{2}}\sqrt{1+\left(\frac{Z}{0.048}\right)^{2}}}$$

[K...ney, 1985]

Peak reflected pressure

Where:

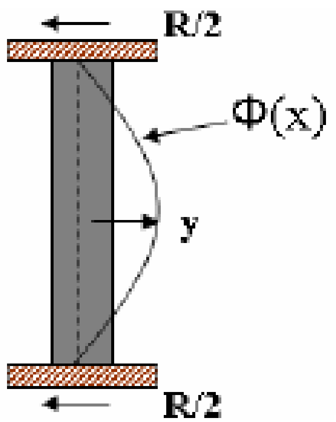
Scaled distance

$$Z = \frac{R}{W^{1/3}}$$

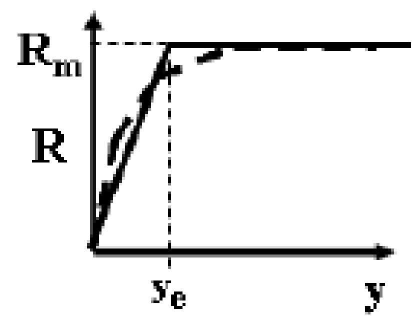
Z = Scaled Distance
R = Actual Distance (m) from source
W = Charge (Kg TNT)

Overview of Damage Mapping

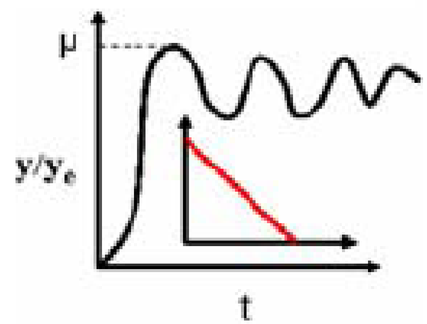
Component



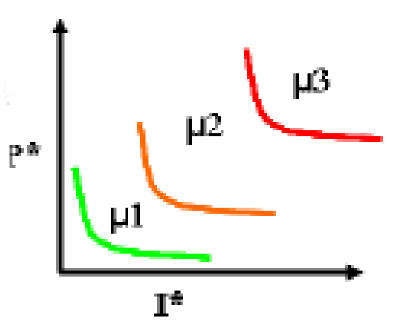
Resistance



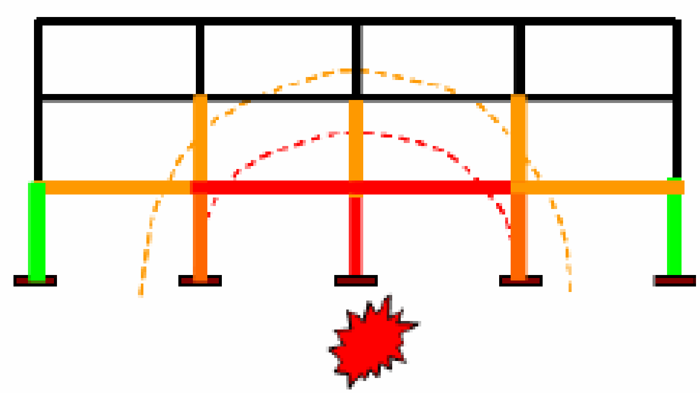
SDOF Model



Damage (P-I)



Mapping to System



Subsystem

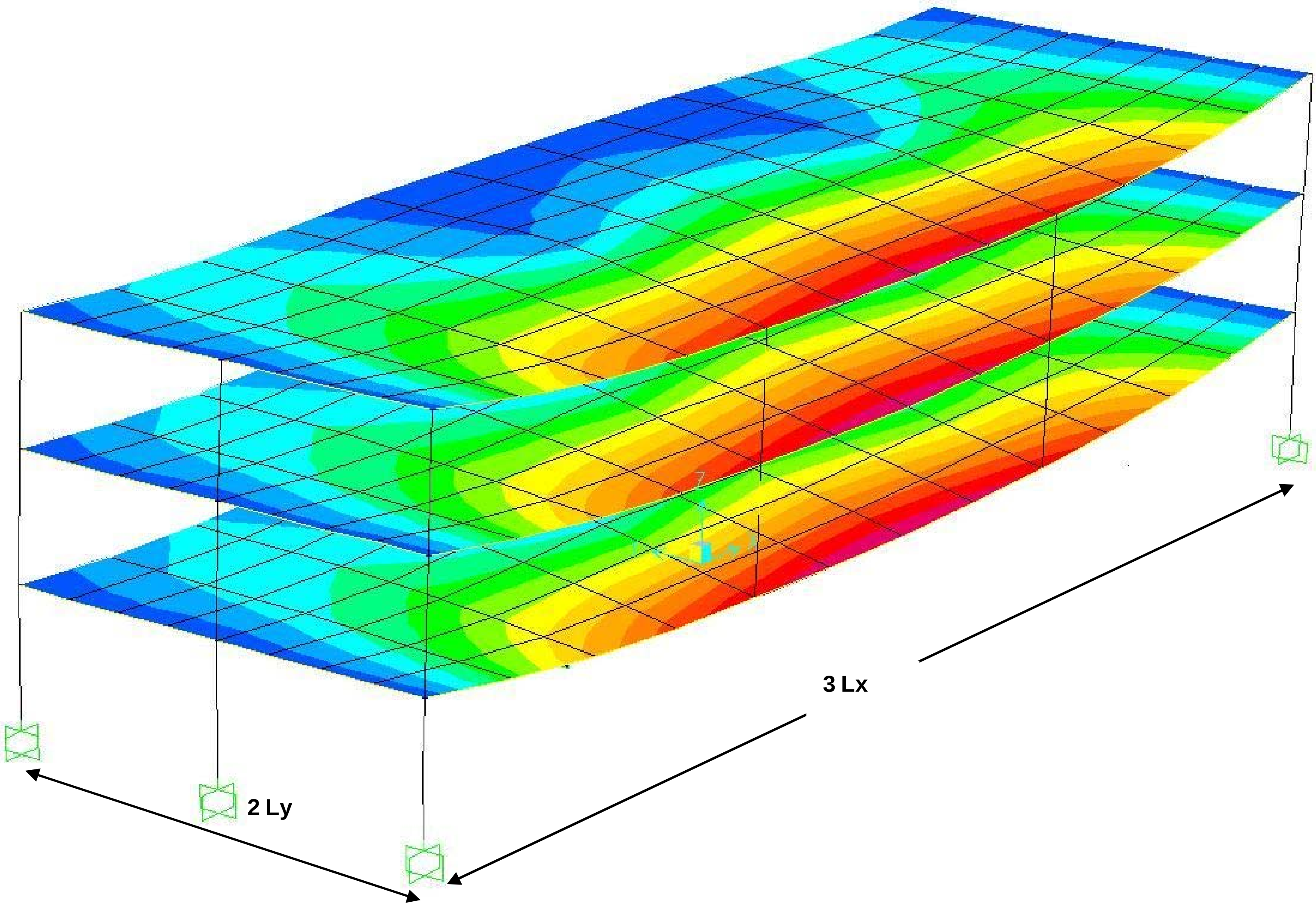
Subsystem

Subsystem

Stiffness contribution of slab

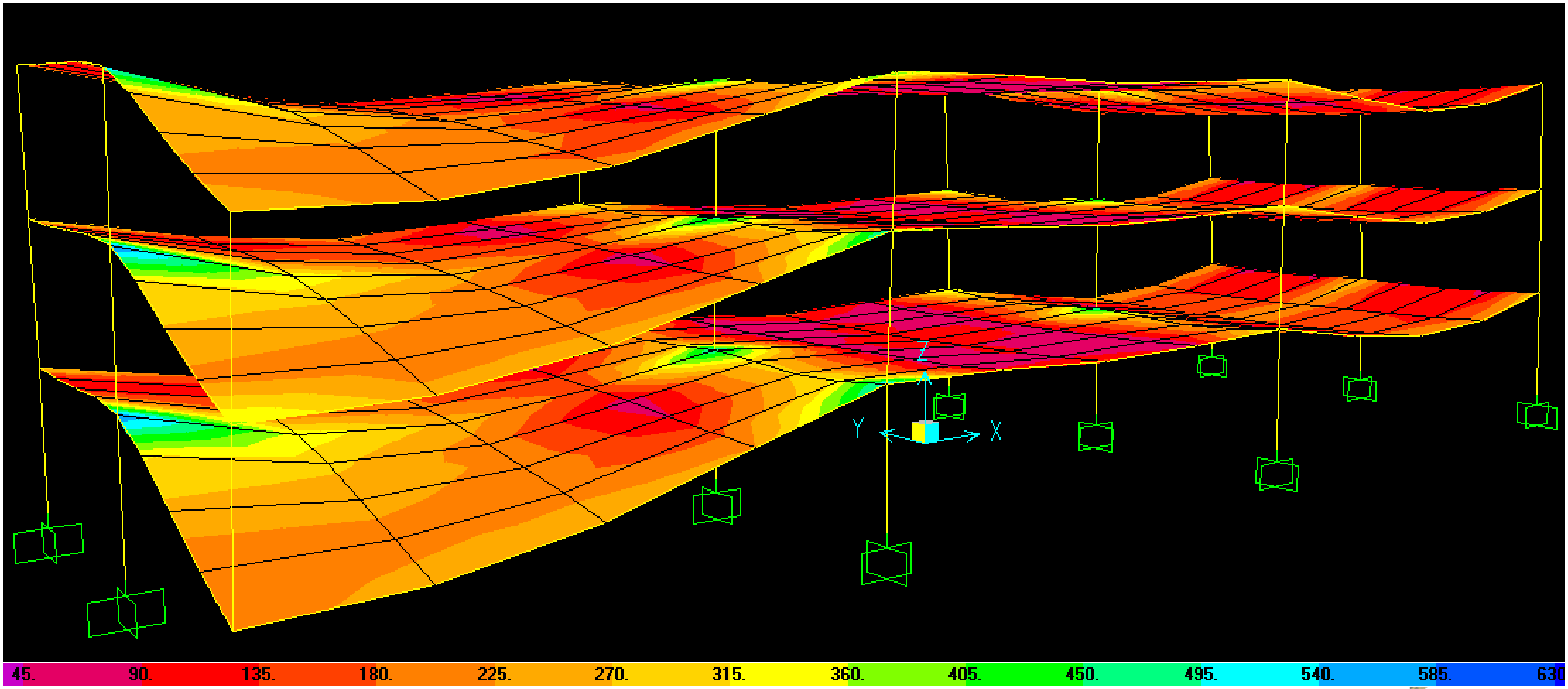
Subsystem

Collapse Analysis



Collapse of 3D Building: GSA Case 1

NL Static FE Analysis



Corner Column
Removed by Blast

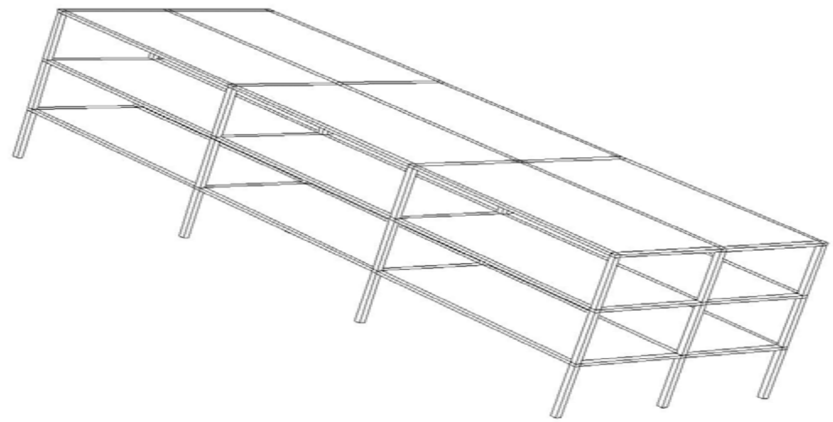
LS-DYNA

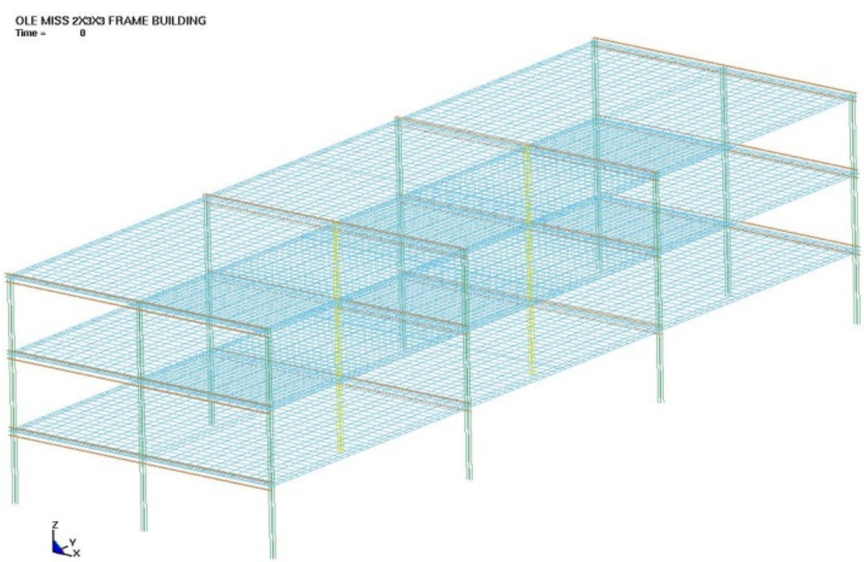
- **LS-DYNA** is an advanced general-purpose multiphysics simulation software package that is actively developed by the Livermore Software Technology Corporation (LSTC). Its origins and core-competency lie in highly nonlinear transient dynamic finite element analysis using explicit time integration. LS-DYNA is being used by Automobile, Aerospace, Military, Manufacturing, and Bioengineering companies.

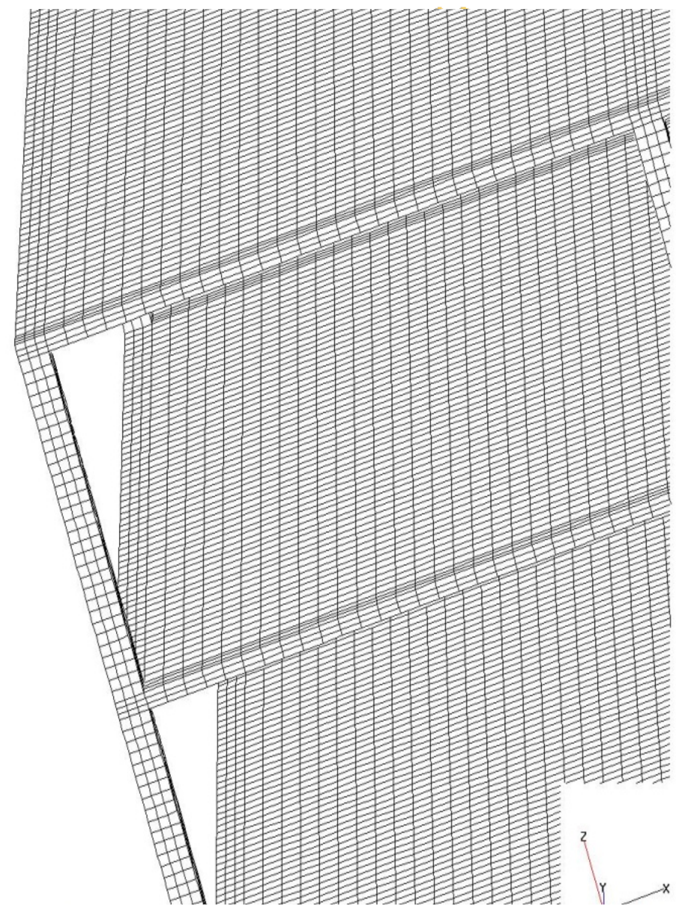
LS-DYNA Simulation

- We are able to build models into the tens of millions of elements/particles
- Able to numerically investigate multiple cases/scenarios relatively quickly
  - Examine variety of mitigation possibilities “easily”
  - Parameter studies performed numerically
- Experimental Database Impractical/Unaffordable
- Experiments Not Enough for Understanding All aspects of Behavior
- Optimally Use an Experimental and Analytical Approach to Research

Generic 3-Story Structure (LSDYNA Model)







RC Structure Design

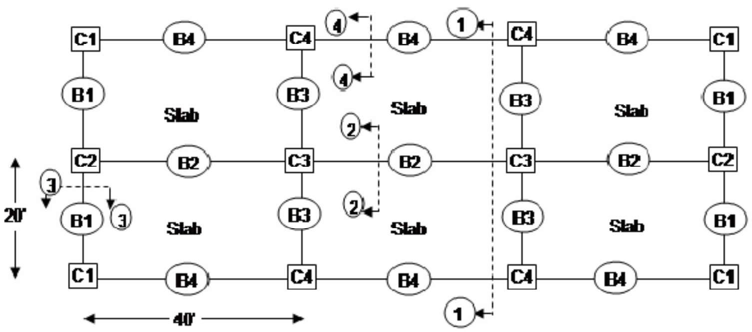


Fig. 1 Plan view

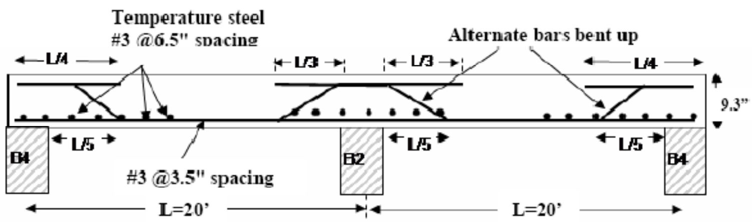


Fig. 2 Slab cross-section (1)-(1)

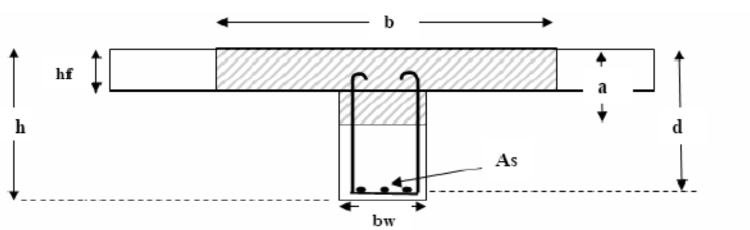


Fig. 3 T-Beams B2 (2)-(2) & B3

Table 1 Beam schedule – see Figs. 1-4

	Beam span ft	h (in)	d (in)	bw (in)	hf (in)	Nearest web ft	b (in)	bo (in)
B2 T-beams	40	25.9	23.4	13.0	9.3	20	120	74.3
B3	20	13.0	10.5	6.5	9.3	40	60	74.3
B1 L-Beams	20	13.0	10.5	6.5	9.3	40	***	20
B4	40	25.9	23.4	13.0	9.3	20	***	40

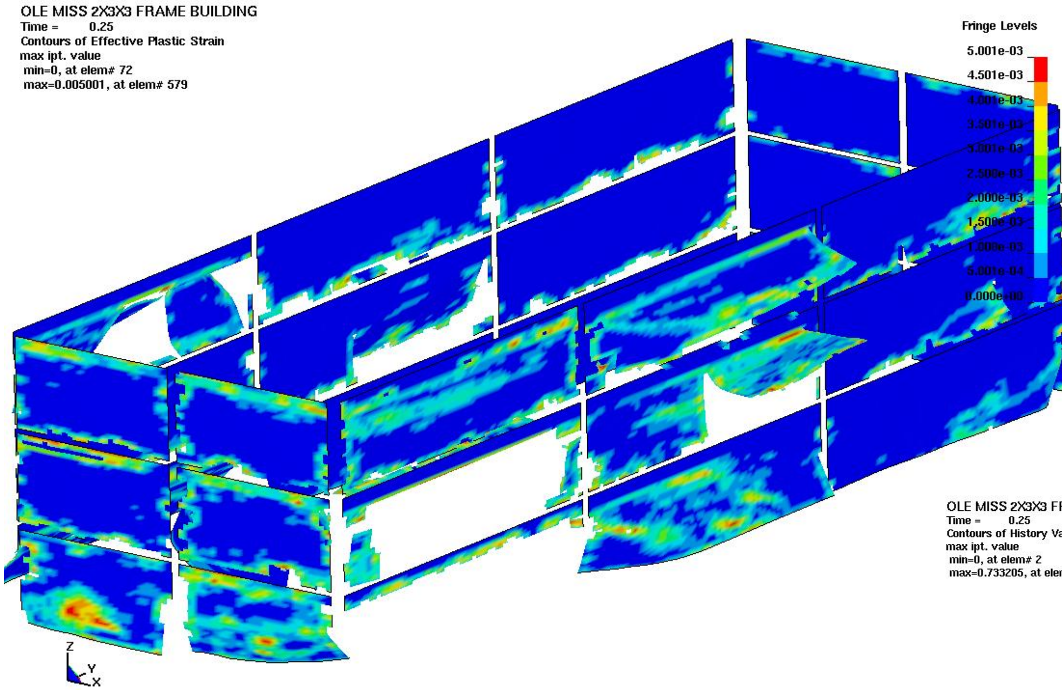
Table 2 Beam reinforcement schedule– see Figs. 3&4

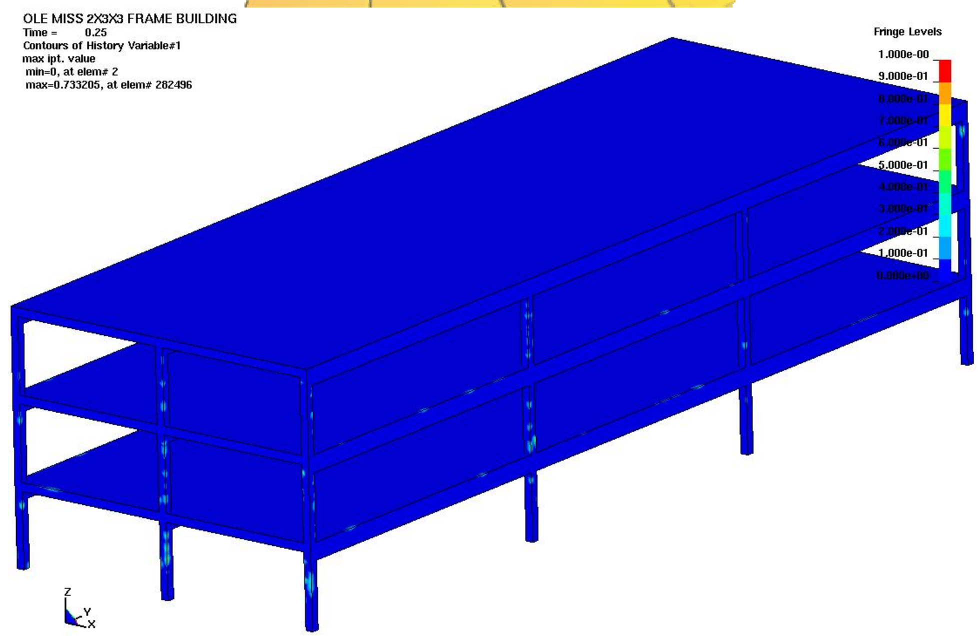
	Longitudinal (As)	Stirrups
B2 T-beams	4#5 bars	#3 @ 12"
B3	2# 5 bars top & bottom	#3 @ 12"
B1 L-Beams	2#5 bars top & bottom	#3 @ 12"
B4	4#5 bars	#3 @ 12"

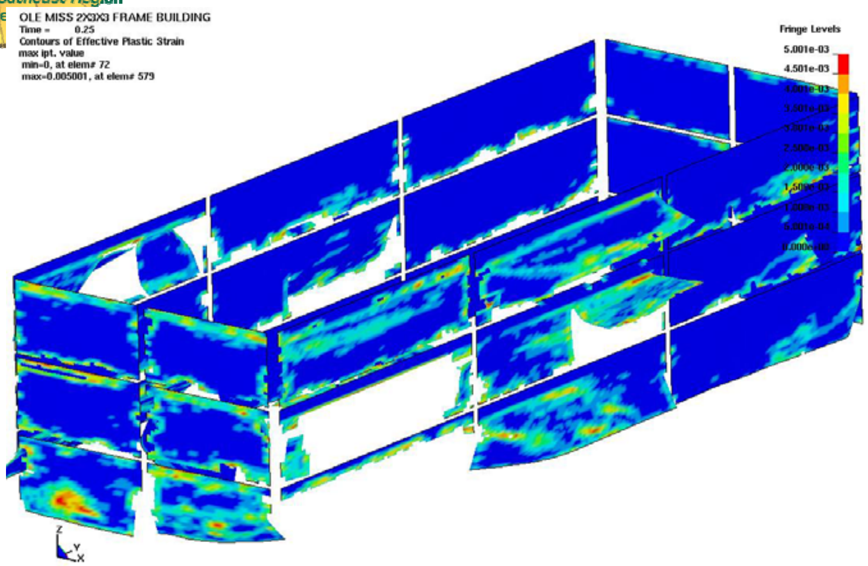
Table 3 Column schedule – see Fig.5

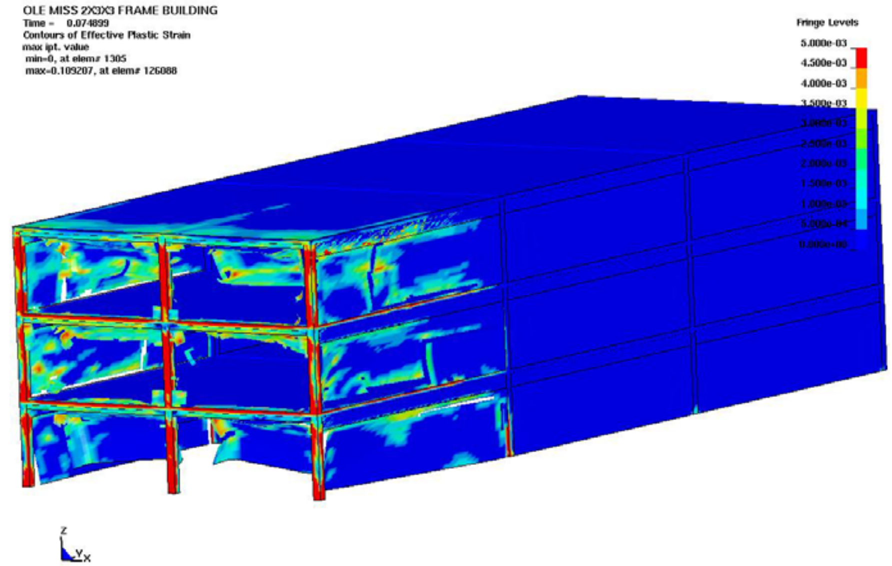
	Dimension B,D (in)	Long Reinf.	Shear Reinf. Ties
C1	12	4#8 bars	#3 bars @ 12"
C2	12	4#8 bars	#3 bars @ 12"
C3	16	4# 10 bars	#3 bars @ 12"
C4	12	4#8 bars	#3 bars @ 12"

Baseline: 50 lbs @ 10 feet






OLE MISS 2X3X3 FRAME BUILDING
Time = 0.25
Contours of Effective Plastic Strain
max ipt. value
min=0, at elem# 72
max=0.005001, at elem# 579
Fringe Levels
5.001e-03
4.501e-03


OLE MISS 2X3X3 FRAME BUILDING
Time = 0.074899
Contours of Effective Plastic Strain
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min=0, at elem# 1305
max=0.109207, at elem# 126088
Fringe Levels
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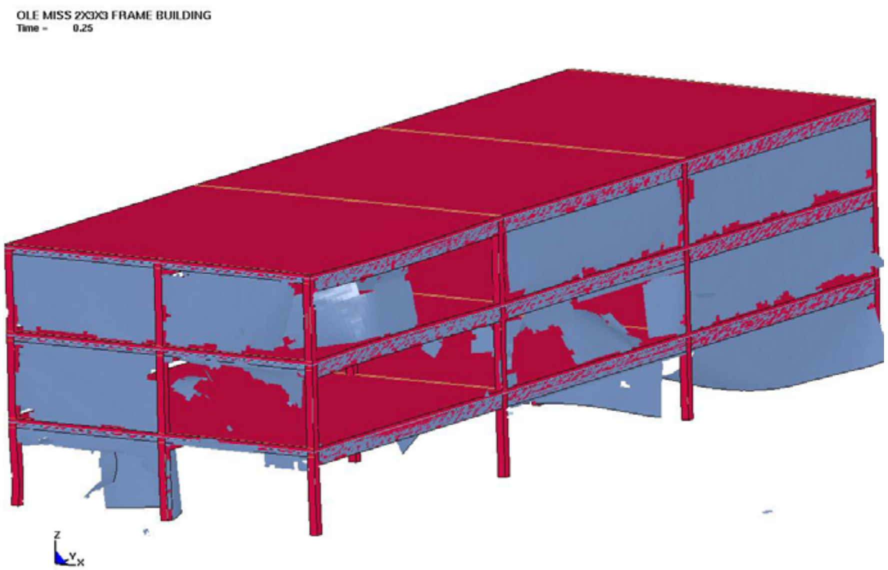
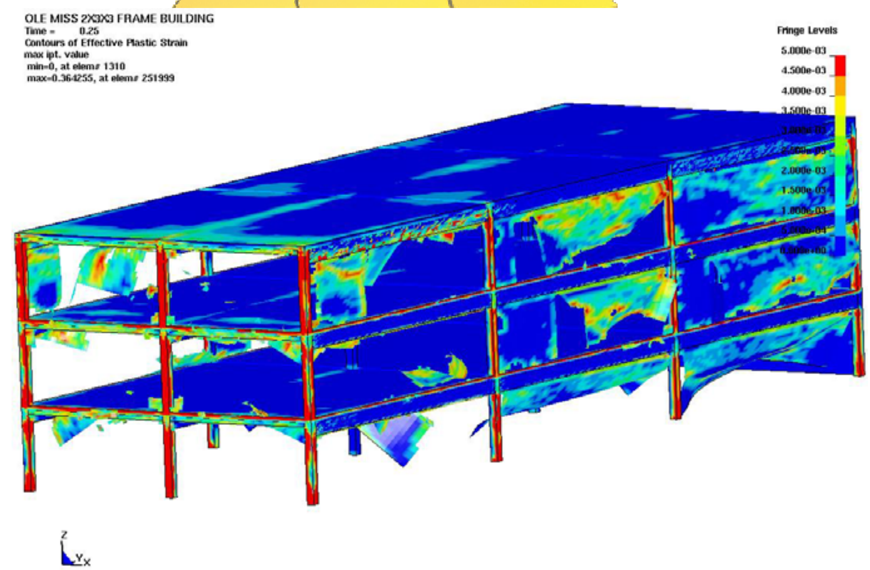
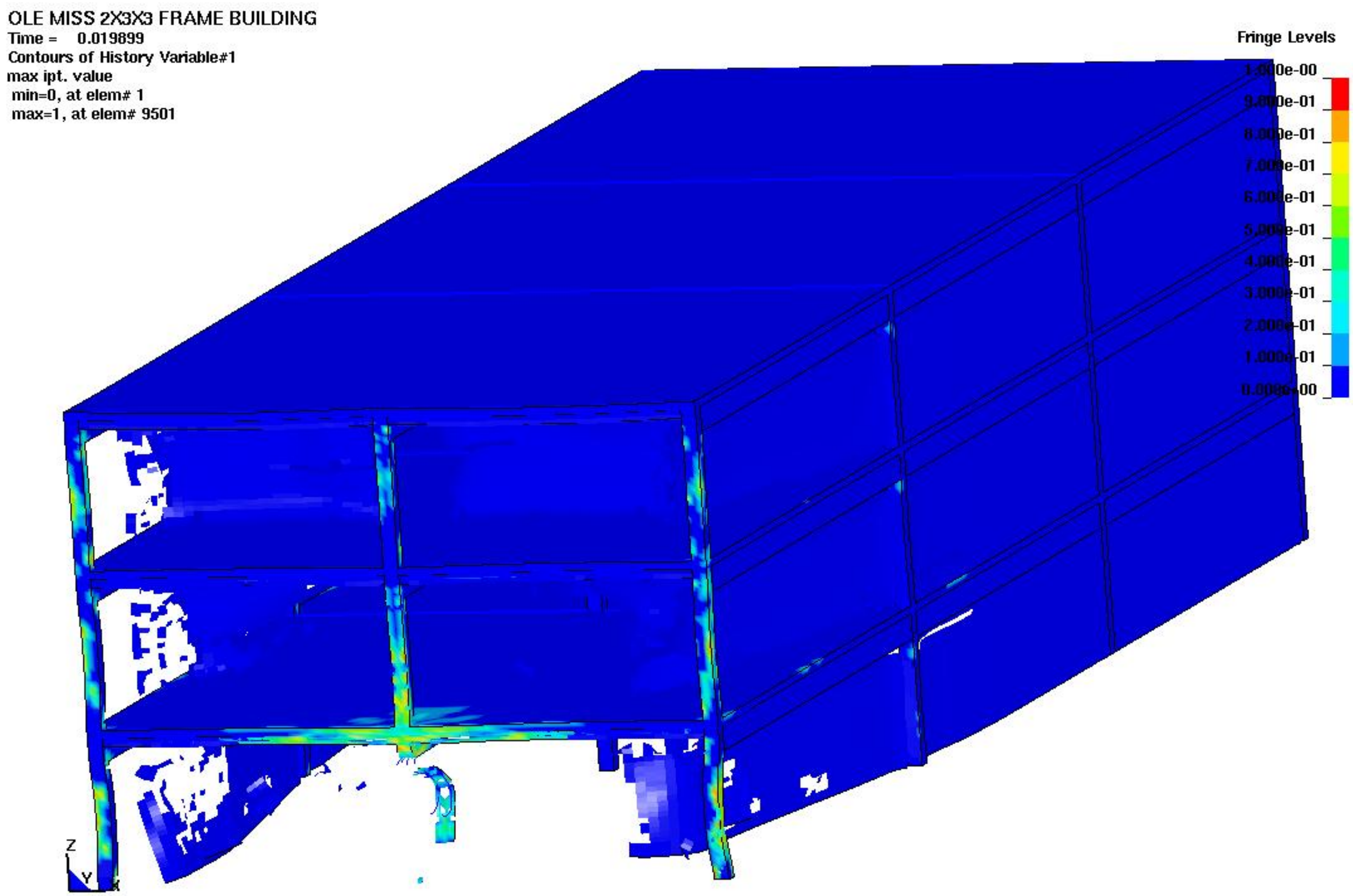
4.500e-03
4.000e-03


OLE MISS 2X3X3 FRAME BUILDING
Time = 0.25


OLE MISS 2X3X3 FRAME BUILDING
Time = 0.25
Contours of Effective Plastic Strain
max ipt. value
min=0, at elem# 1310
max=0.364255, at elem# 251999
Fringe Levels
5.000e-03
4.500e-03
4.000e-03

2500 lbs @ 5 feet off front center



DECISION SUPPORT SYSTEM RESEARCH

E-Sim

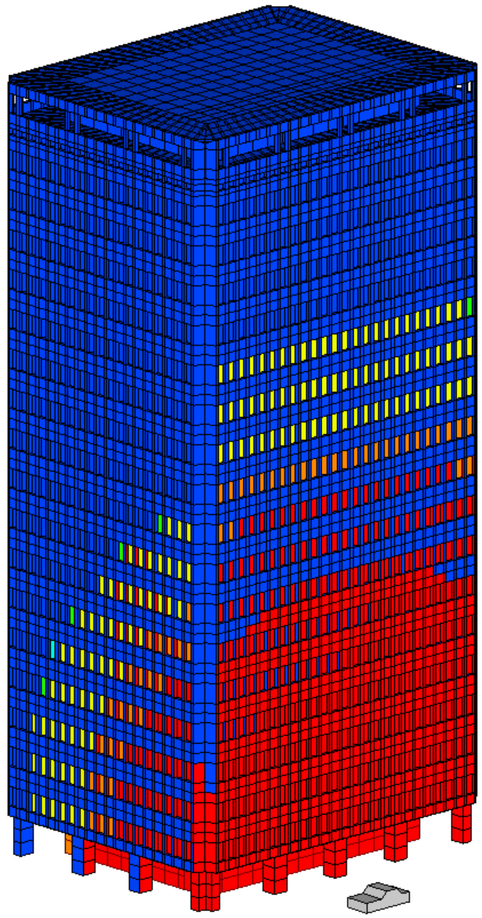
- To provide an animated, graphical means of evaluating and quantifying the impact on human egress/safety from nano-particle reinforced composites when a building is exposed to a blast load.

Building Background

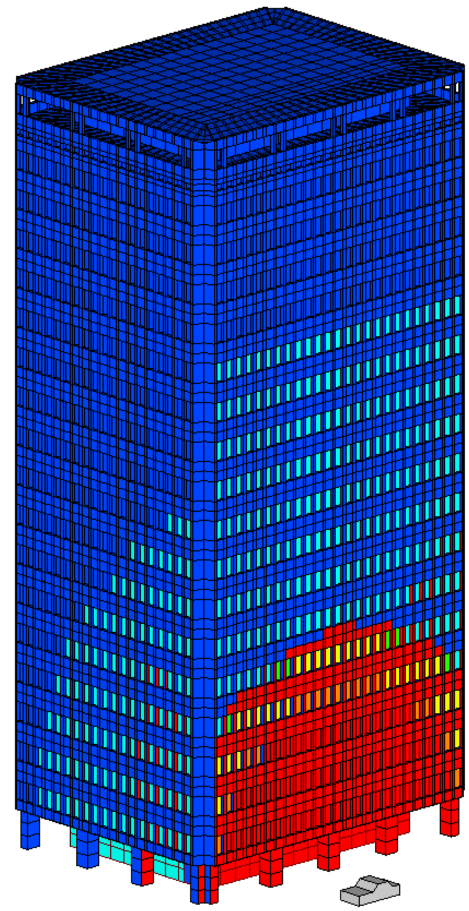
- Nineteen Floor Office Building with Unprotected Parking Below
- Contains High-profile State Government Officials
- Also Contains Offices for Other Important State-run Organizations

Blast Analysis

- Blast Model Generated to View Areas Sustaining Significant Damage During Unprotected & Protected Explosive Events
  - Typical 8"-Thick CMU Building Construction
  - Includes Glazing
  - Protected with 5mm Nylon 6,6-XGnP Nano-composites
- Blast Model Created Using ***AT-Assessor***
- Blast Loads Applied to E-Sim Model for Scenarios 2 & 3



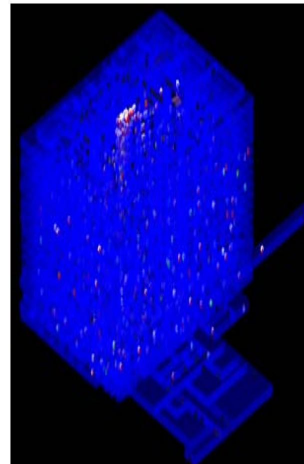
Unprotected Facility



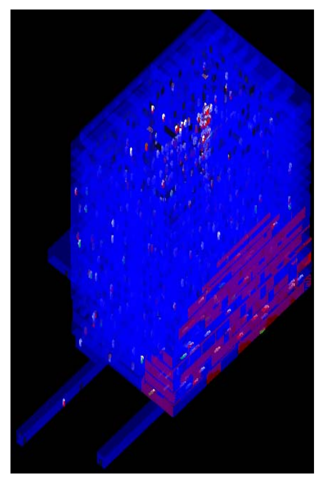
Protected Facility w/ Window Upgrades

Task 2: Scenario Simulations

- Scenario 1: Undamaged Building Under Normal Operation
- Scenario 2: Building Damaged by Blast without Nano-Particle Composites
- Scenario 3: Building Damaged by Blast with Nano-Particle Composites




Above: Normal Operation
Below: Blast Damage Unprotected



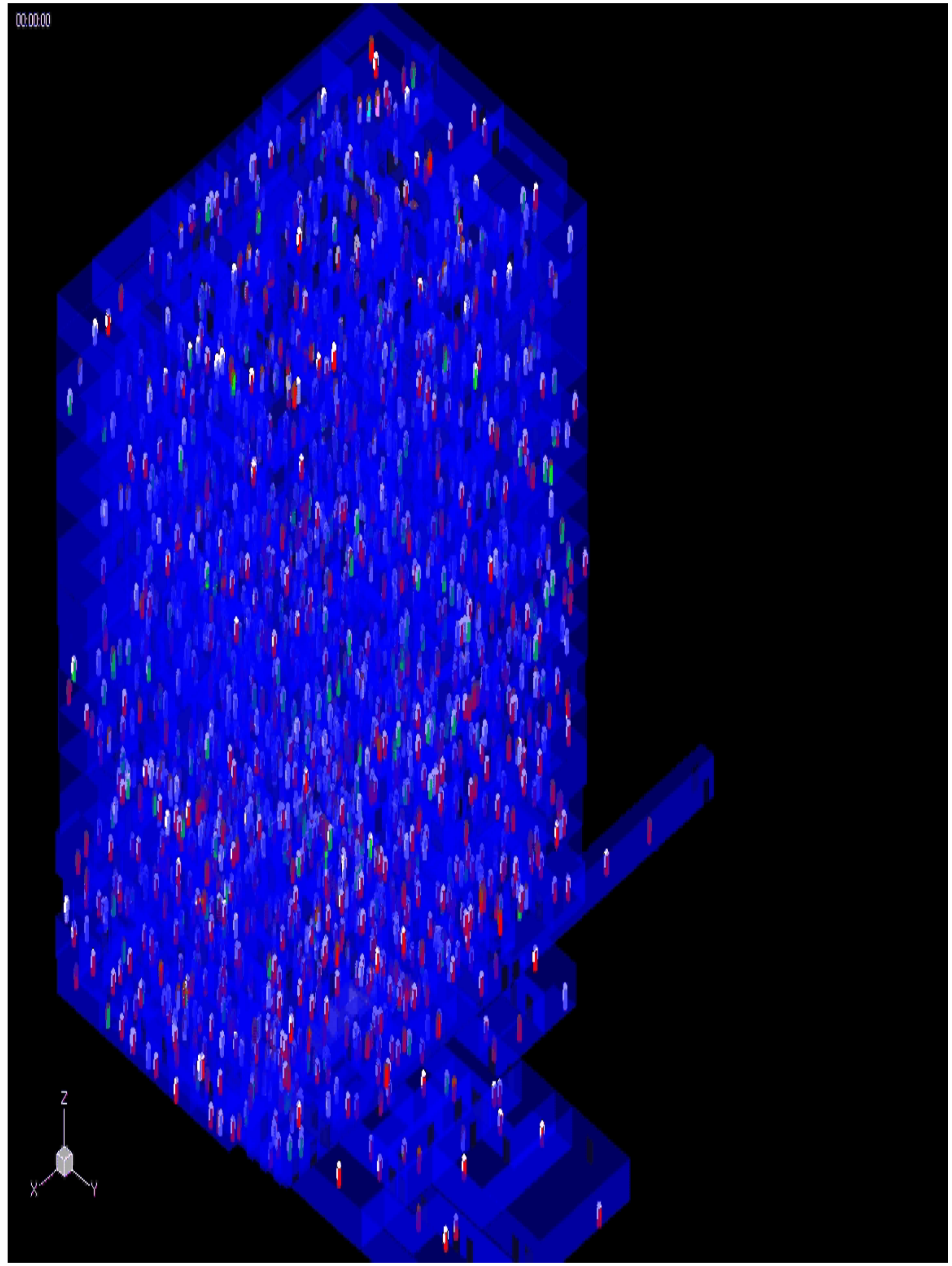

Multi-Scenario Simulations

Scenario 3: Nano-Reinforced Structure Subject to Damage

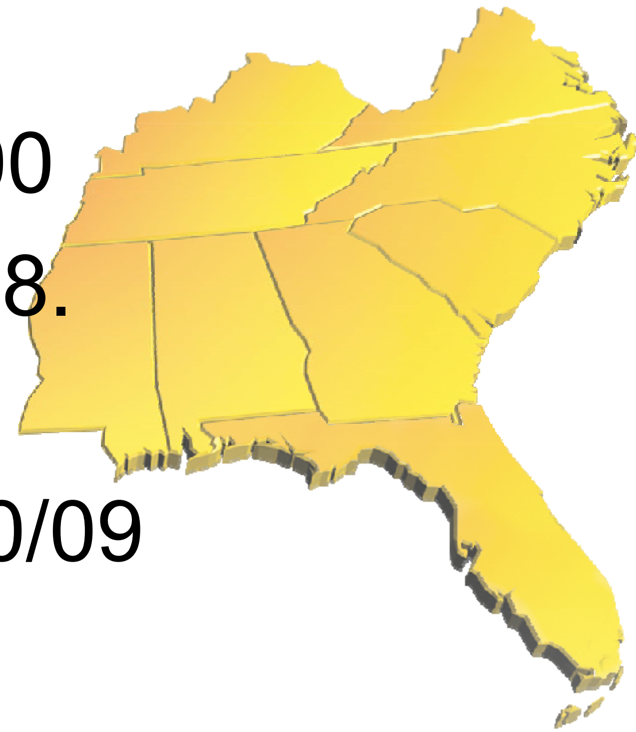
Simulation Statistics

Simulation Time	00:15:14
Running Time	00:16:44
Total Agents	1961
Total Escaped	1418
Total Died	289
Basement	0
Floor 1	30
Floor 2	20
Floor 3	136
Floor 4	19
Floor 5	7
Floor 6	10
Floor 7	1
Floor 8	146
Floor 9	2
Floor 10	3
Floor 11	1

Close



Budget Information

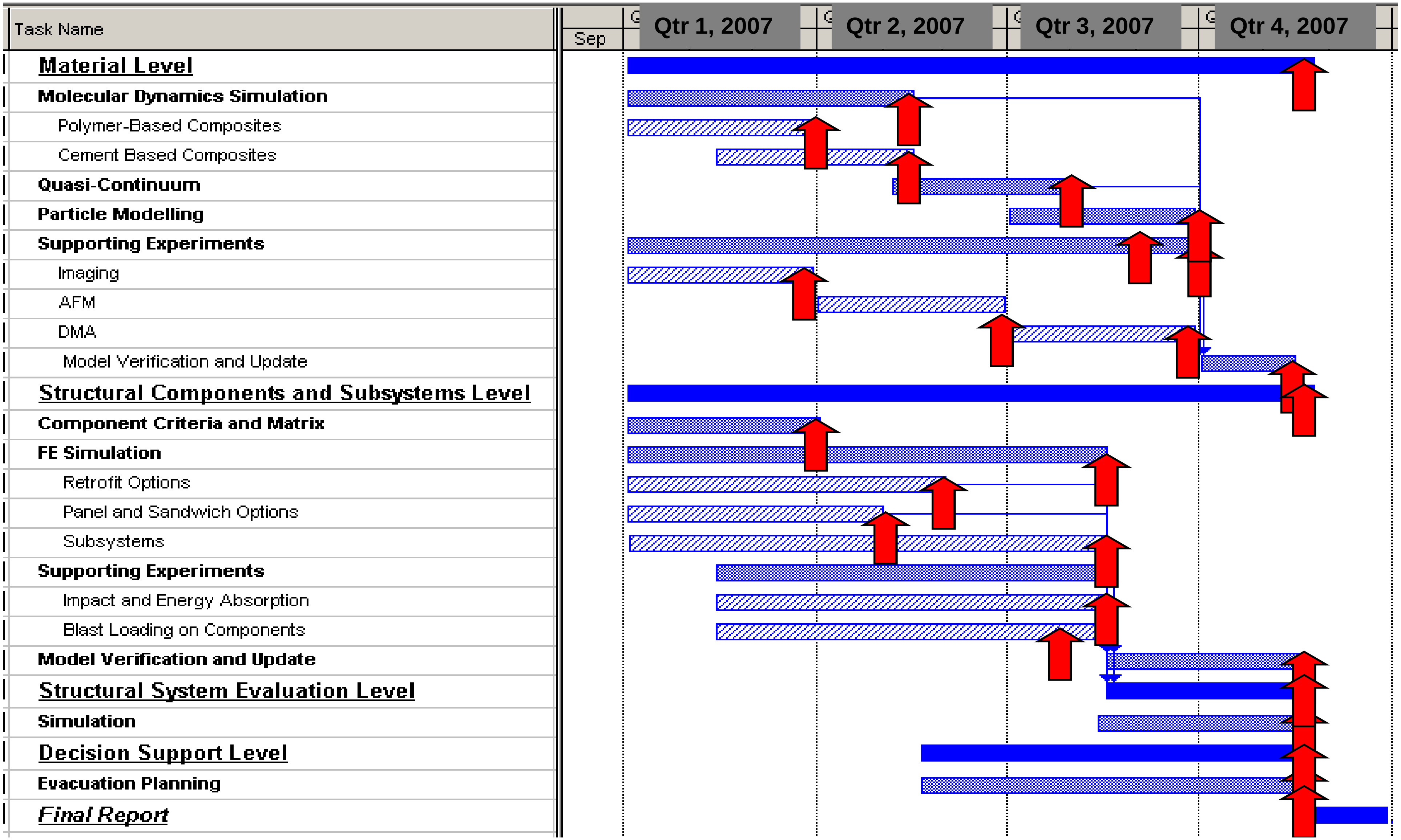


- Original amount: $769,800
- Project end date: 10/30/08.
- Extension: $394,667
- Extended end date: 10/30/09

Collaborative Opportunities

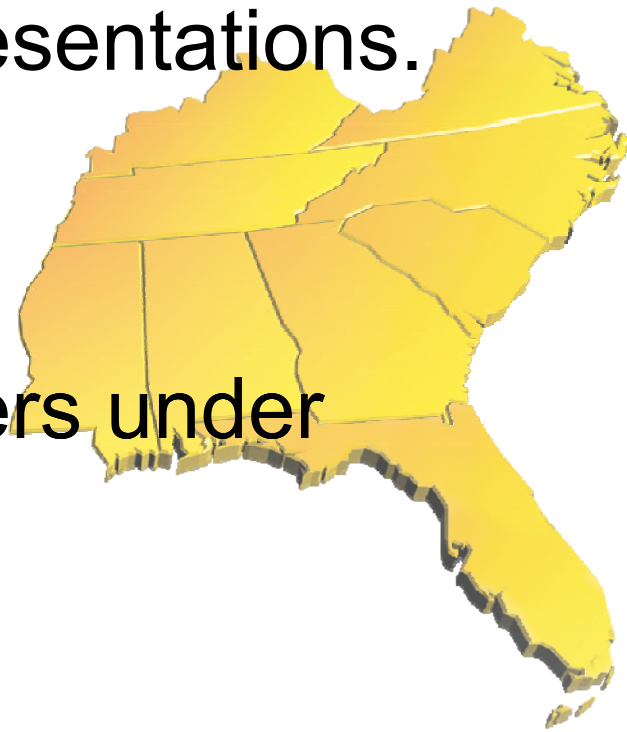
- Many connections with universities and private industries have been made. We are continuing to explore the opportunities.

Project Timeline



Technology Transfer

- 19 conference papers/presentations.
- 3 journal papers.
- 1 book chapter
- Half a dozen journal papers under preparation.



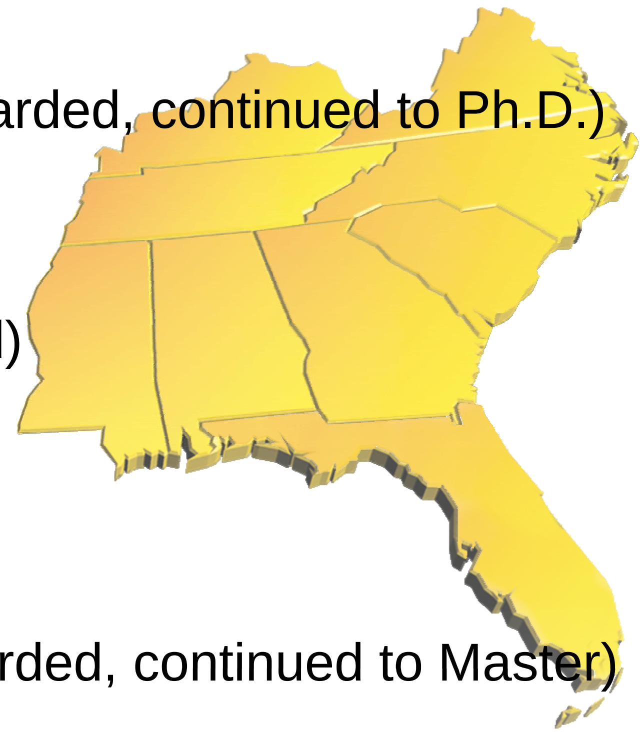
No.	Authors	Title	Type	Conference/Journal
1	Mullen, Tadepalli	Design Parameters Governing Post-Damage Stability of Low Rise Reinforced Concrete Frame Structures Subjected to External Blast Loading	Conference Abstract PowerPoint Presentation	ASCE/SEI Structures Congress 2008, Vancouver, Canada, April 24-26, 2008.
2	O'Daniel, Mullen, Tadepalli	Blast effects on two story frame building	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
3	Tadepalli, Mullen	Vulnerability of low rise buildings to external blast event: Damage mapping	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
4	Tadepalli, Mullen	Vulnerability of low rise buildings to external blast event: Collapse potential investigation	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
5	Rotenberry, Kelley, Brokaw	Demonstration of Effectiveness of Nano-Particle Reinforced Composites through Blast Modeling and Evacuation Simulation (*E-Sim*)	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
6	Irshidat, Al-Ostaz, Mullen, Cheng, Mantena	CMU Infill Wall Blast Simulation for Optimizing Performance of Nano-Particle Enhancement of Energy Absorption and Debris Mitigation	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
7	Wang, Al-Ostaz, Cheng, Mantena, Belal	Particle Modeling of Dynamic Fracture Simulations of a 2D Polymeric Material (nylon-6,6) Subject to the Impact of a Rigid Indenter	Conference Abstract PowerPoint Presentation	Inaugural International Conference of the Engineering Mechanics Institute, University of Minnesota, Minneapolis, May 18–21, 2008.
8	Wang , Al-Ostaz , Cheng, Mantena	A Hybrid Particle-Lattice Model for Dynamic Fracture Problems	Conference Abstract PowerPoint Presentation	Inaugural Conference of the American Academy of Mechanics, June 17-20, 2008, New Orleans, Louisiana
9	Wang , Al-Ostaz , Cheng, Mantena	Particle Modeling of Crack Propagation in Materials at Macroscopic Level	Conference Abstract PowerPoint Presentation	Inaugural Conference of the American Academy of Mechanics, June 17-20, 2008, New Orleans, Louisiana

10	Irshidat, Al-Ostaz, Mullen, Cheng, Mantena	Blast Resistance of CMU Infill Walls Retrofitted with Nano-Structured Materials	Conference Abstract PowerPoint Presentation	Inaugural Conference of the American Academy of Mechanics, June 17-20, 2008, New Orleans, Louisiana
11	Alkhateb, Al-Ostaz , Cheng, Mantena	Parametric Evaluation of Multi-wall Carbon Nanotube Reinforced Nylon 6,6 Nano Composites Using Molecular Dynamic Approach	Conference Abstract PowerPoint Presentation	Inaugural Conference of the American Academy of Mechanics, June 17-20, 2008, New Orleans, Louisiana
12	Wu, Al-Ostaz	MULTI SCALE MODELING OF CONCRETE AND ITS CONSTITUENTS	Conference Abstract PowerPoint Presentation	Inaugural Conference of the American Academy of Mechanics, June 17-20, 2008, New Orleans, Louisiana
13	Burchfield, Pangave, Russell, Mullen	Use of Nano-Particle Enhanced Composites to Reduce Blast Vulnerability of Low Rise RC Frame Buildings	Conference Abstract Conference Paper PowerPoint Presentation	American Society for Composites 23rd Annual Technical Conference, September 9-11, 2008, Memphis, TN .
14	Alkhateb, Wu, Al-Ostaz, Mantena, Cheng	Molecular Dynamic Simulation of Nano Composites and Their Constituents	Conference Abstract PowerPoint Presentation	American Society for Composites 23rd Annual Technical Conference, September 9-11, 2008, Memphis, TN .
15	Gupta, Mantena, Al-Ostaz	Effect of strain rates on energy absorption of exfoliated graphite platelet and cloisite nanoclay reinforced vinyl ester nanocomposites	Conference Abstract PowerPoint Presentation	American Society for Composites 23rd Annual Technical Conference, September 9-11, 2008, Memphis, TN .
16	Irshidat , Al-Ostaz , Mullen, Cheng, and Mantena	CMU Infill Wall Blast Simulation for Optimizing Performance of Nano-Particle Enhancement of Energy Absorption and Mitigation Debris	Conference Abstract PowerPoint Presentation	American Society for Composites 23rd Annual Technical Conference, September 9-11, 2008, Memphis, TN .

17	Wang , Al-Ostaz, Cheng, Mantena	Particle Modeling for Blasting Simulations	Conference Abstract Conference Paper PowerPoint Presentation	American Society for Composites 23rd Annual Technical Conference, September 9-11, 2008, Memphis, TN .
18	Gupta, Almagableh, Mantena, Al-Ostaz	Dynamic Mechanical analysis of graphite platelets and nanoclay Reinforced vinyl ester and MWCNT reinforced nylon 6,6 nanocomposites	Conference Abstract Conference Paper PowerPoint Presentation	Society for the Advancement of material and Process Engineering, Fall Technical Conference, Multifunctional Materials: Working Smarter Together, September 8-11, 2008, Memphis, TN
19	Wang , Al-Ostaz, Cheng	Particle Modeling of Dynamic Fracture Simulations of a 2D Polymeric Material (nylon-6,6) Subject to the Impact of a Rigid Indenter	Journal Paper	Computational Materials Science
20	Wang , Al-Ostaz, Cheng, Mantena	Hybrid Lattice Particle Modeling of Dynamic Fracture Simulations of 2D Elastic Spring networks: Theoretical Considerations	Journal Paper	Computational Materials Science
21	Wang , Al-Ostaz, Cheng, Radziszewski,	Particle modeling and its current success in the simulations of dynamics fragmentation of solids	Book Chapter	Strength of Materials: New Research Trends
22	Mantena, Cheng, Al-Ostaz	Blast and Impact Resistant Composite Structures for Navy Ships	Conference Abstract PowerPoint Presentation	ONR Solid Mechanics Review, September 17-18, 2008, University of Maryland, Adelphi, MD.
23	Wang , Al-Ostaz, Cheng, Mantena	A macroscopic-level hybrid lattice particle modeling of mode-I crack propagation in ductile and brittle materials	Journal Paper	Computational Materials Science

Educational Component

- Ph.D. students supported
  - Hunain Alkhateb (Master degree awarded, continued to Ph.D.)
  - Mohammead Irshidat
  - Tezeswi Tadepalli
  - Weidong Wu (Ph.D. degree awarded)
  - Ahmad Almagableh
- Master students supported
  - Nitin Pangavane
  - Charles Burchfield (B.S. degree awarded, continued to Master)
  - Swasti Gupta
- Undergraduate Research Assistant supported
  - Mark Russell



Commercialization Progress

- Several leads are being followed to submit SBIR proposals based on potentials demonstrated in this and other projects.

IP STATUS

- None so far.

Summary & Conclusions

- We are currently at 98% the planned goals.
- The blast load simulator task previously delayed has not caught up, and only analysis work remains to be done.
- Next phase: Nano materials for fire protection.