

The blast resistant ability of Ultra-high-performance concrete

Presenter: Ruobing Yan
Supervisor: Hassan Aoude
Department: Civil engineering

Introduction

Background

Terrorist attacks can result in building collapse and great loss of life, thus blast resistant materials and structural systems are necessary to protect structures and save human lives. Considering cost efficiency and blast resistance, Ultra-high-performance concrete (UHPC) is an ideal material with its high strength, high deformation capacity and high toughness, making it an ideal construction material for blast design when compared to conventional concrete.

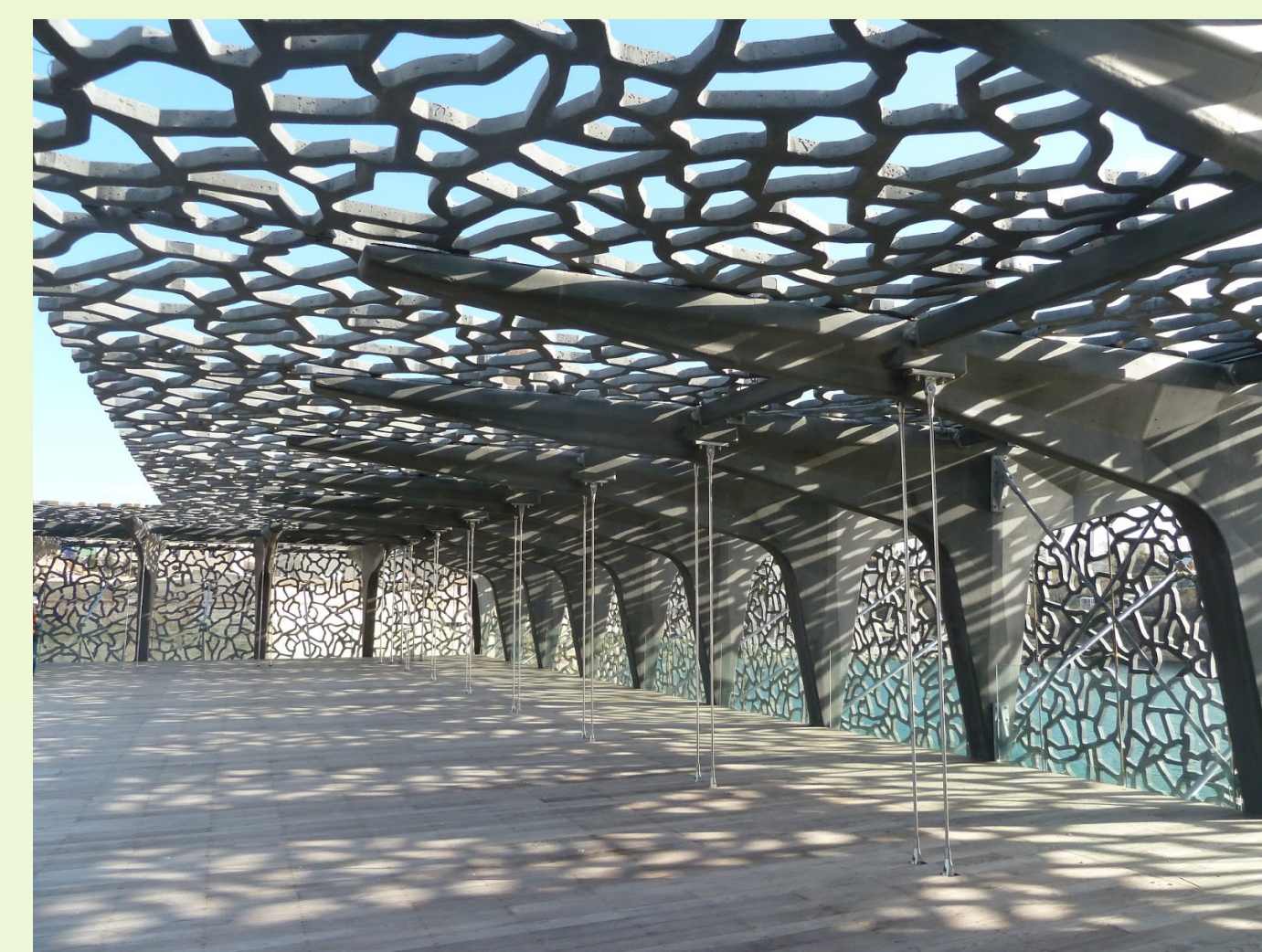


Figure 1: Museum of European and Mediterranean Civilizations, in Marseille, France [1]

UHPC has superior

•Strength

Compressive strengths 120 to 150 MPa and flexural strength 15 to 25 MPa, both are significantly higher than what can be achieved in conventional concrete.[2]

Ultra-high-performance concrete (UHPC)

•Ductility

UHPC also has much greater ductility than conventional concrete due to provision of steel fibers. The ductile behavior of this material is a first for concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking.[2]

•Durability

•Aesthetic design flexibility

which facilitates innovative designs.



Figure 2: Example UHPC slab showing great architectural flexibility [1]

An Innovative Train Station Canopy is the first Use of Ultra-High-Performance Concrete [2]



Figure 3: The Shawnessy Light Rail Transit (LRT) Station

Composition: fine-grained sand, silica fume, small steel fibers, and special blends of high-strength Portland cement. No large aggregate is included. [2]

Objective

•Determine the performance of UHPC under blast with the use of shock tube by referring to the displacement vs time diagram

•Compare the deformations of UHPC specimen, UHPC specimen with high strength-steel and control(self compacting concrete (SCC) without fiber included) under same blast pressure

•Observe the fragmentation of UHPC specimen and SCC specimen under same pressure of blast

(Note: Choosing SCC as control for its high flowability and stability)

Description of research program

Material



Concrete slump OL steel fiber

No. 3 rebar

Setup

•Shock tube

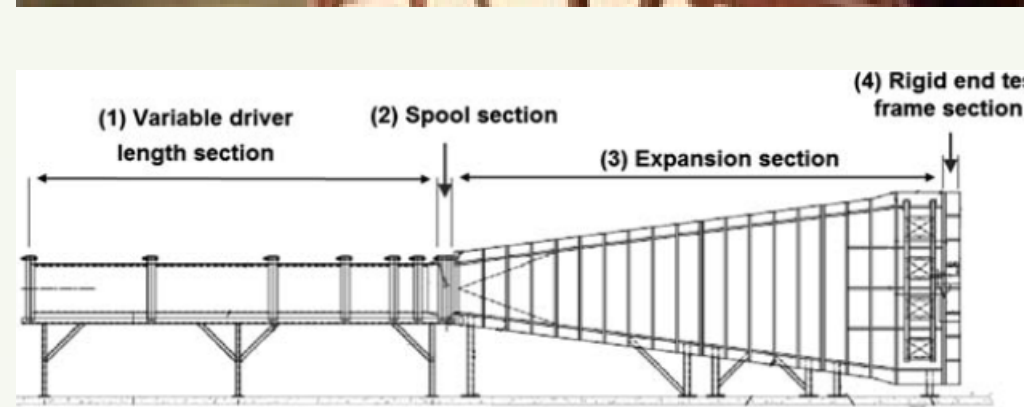
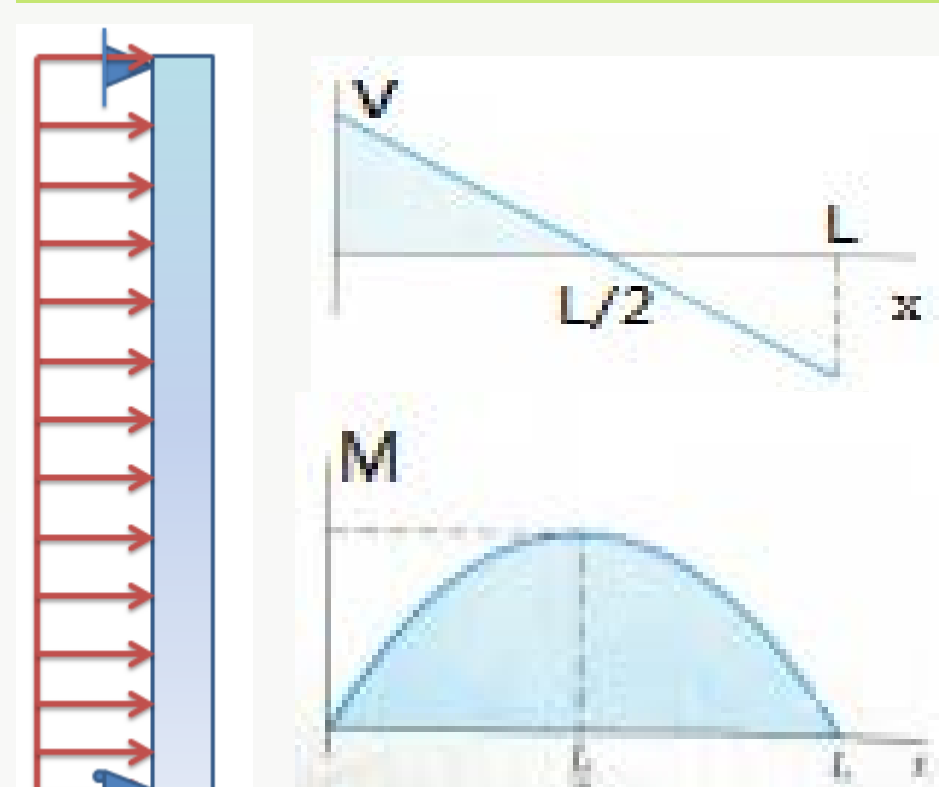


Figure 4: components of the shock tube[3]

The shock tube provides impulsive loads in uniform distribution to scaled concrete column specimens, inducing their displacements.

Theory



The uniform force distribution leads to the fact that the **mid-span** of the specimen has the largest bending moment, thus the most obvious deformation can be observed.

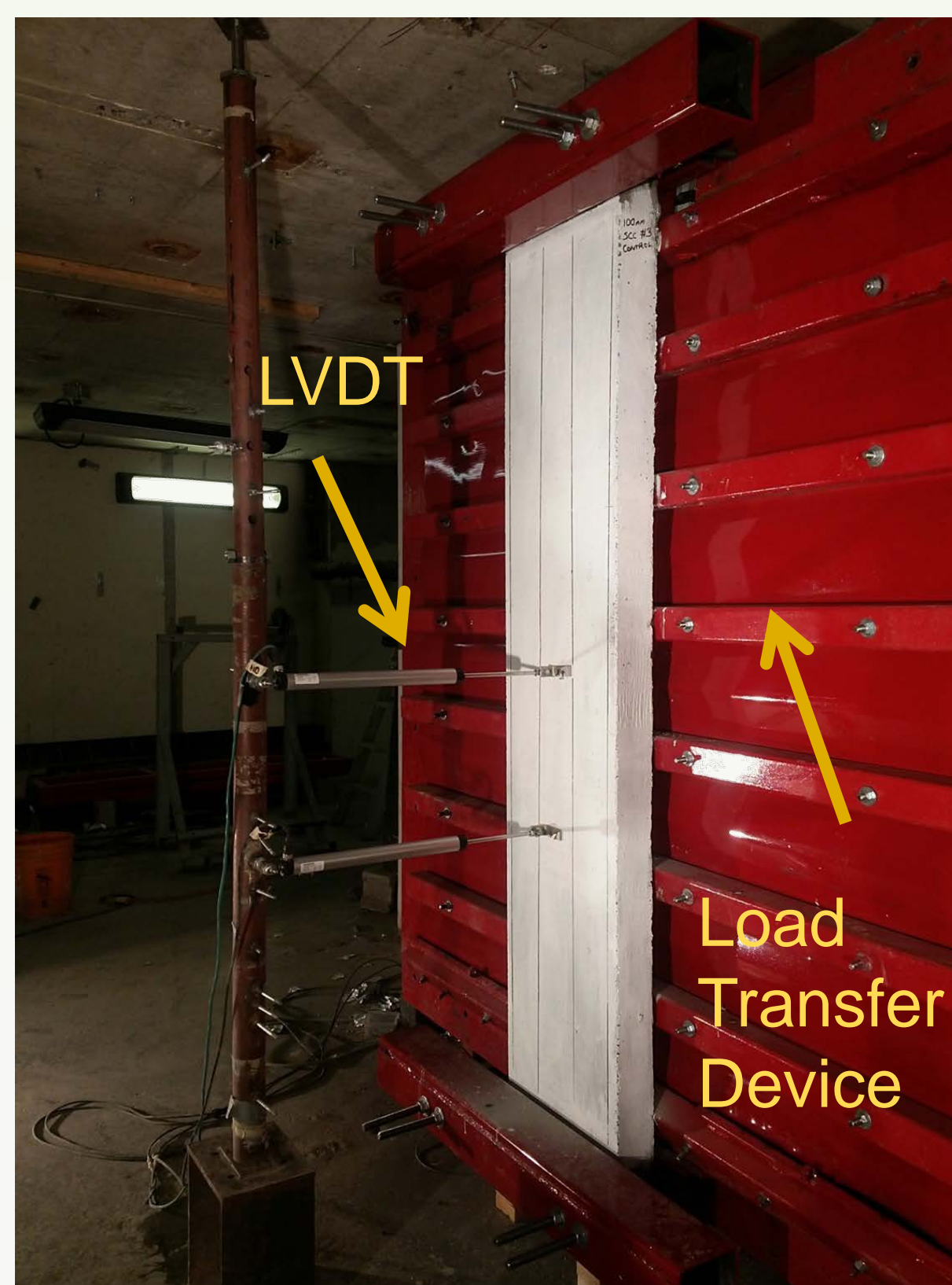
Specimen detail

Specimen detail	Concrete type	f'c (MPa)	Steel type
SCC-0% fiber	SCC	50	#3 rebar 400MPa
UHPC-2% OL fiber	UHPC	140	#3 rebar 400MPa
UHPC-2% (MMFX rebar)	UHPC	140	#3 rebar 689MPa (High strength)

Testing program

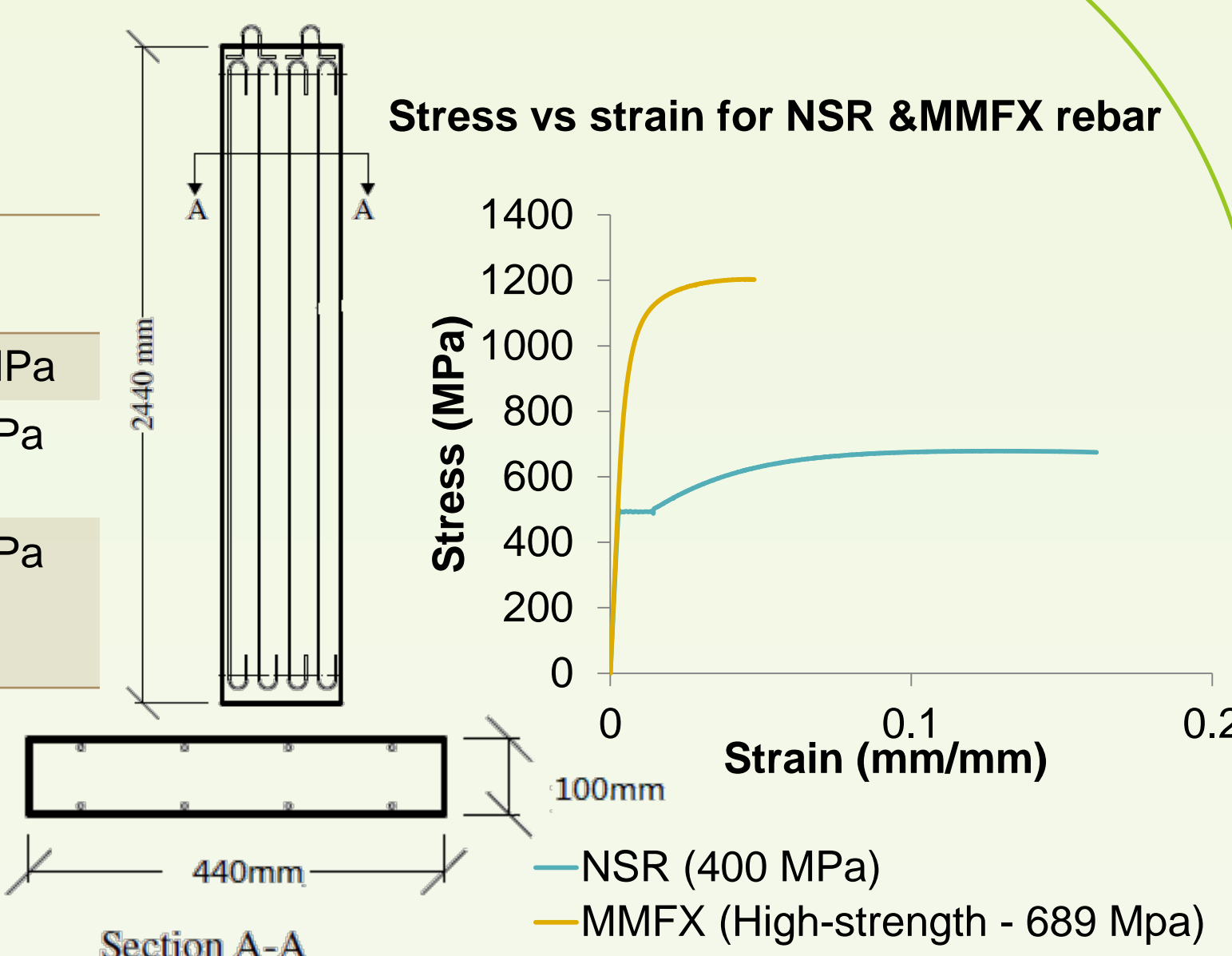


Build the rebar and precast the concrete

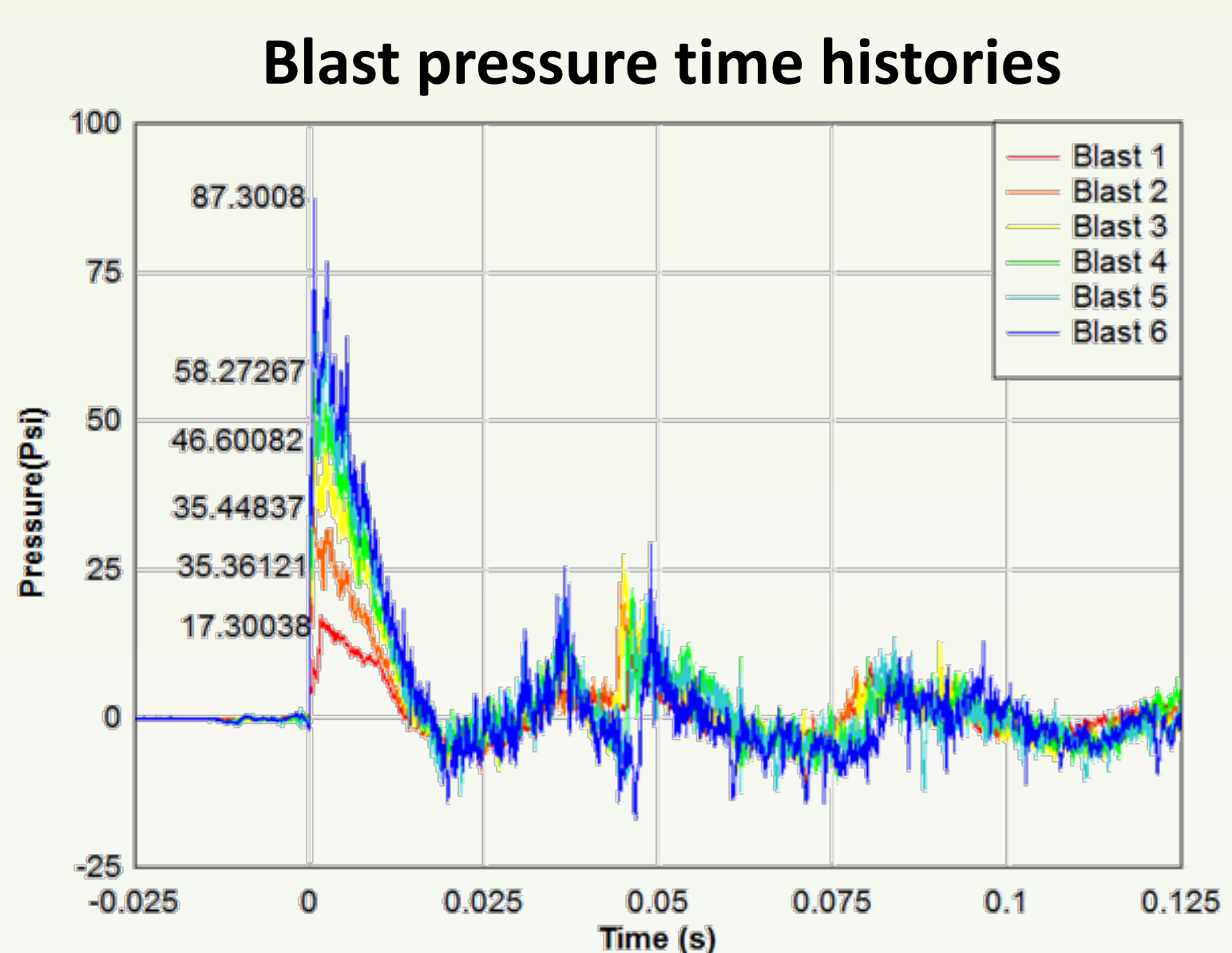


The specimen is placed in front of the load transfer device and LVDTs are used to measure the deformation at mid-span and one-third height when the test starts

Dimension of slab:
2440*440*100mm



Blast detail



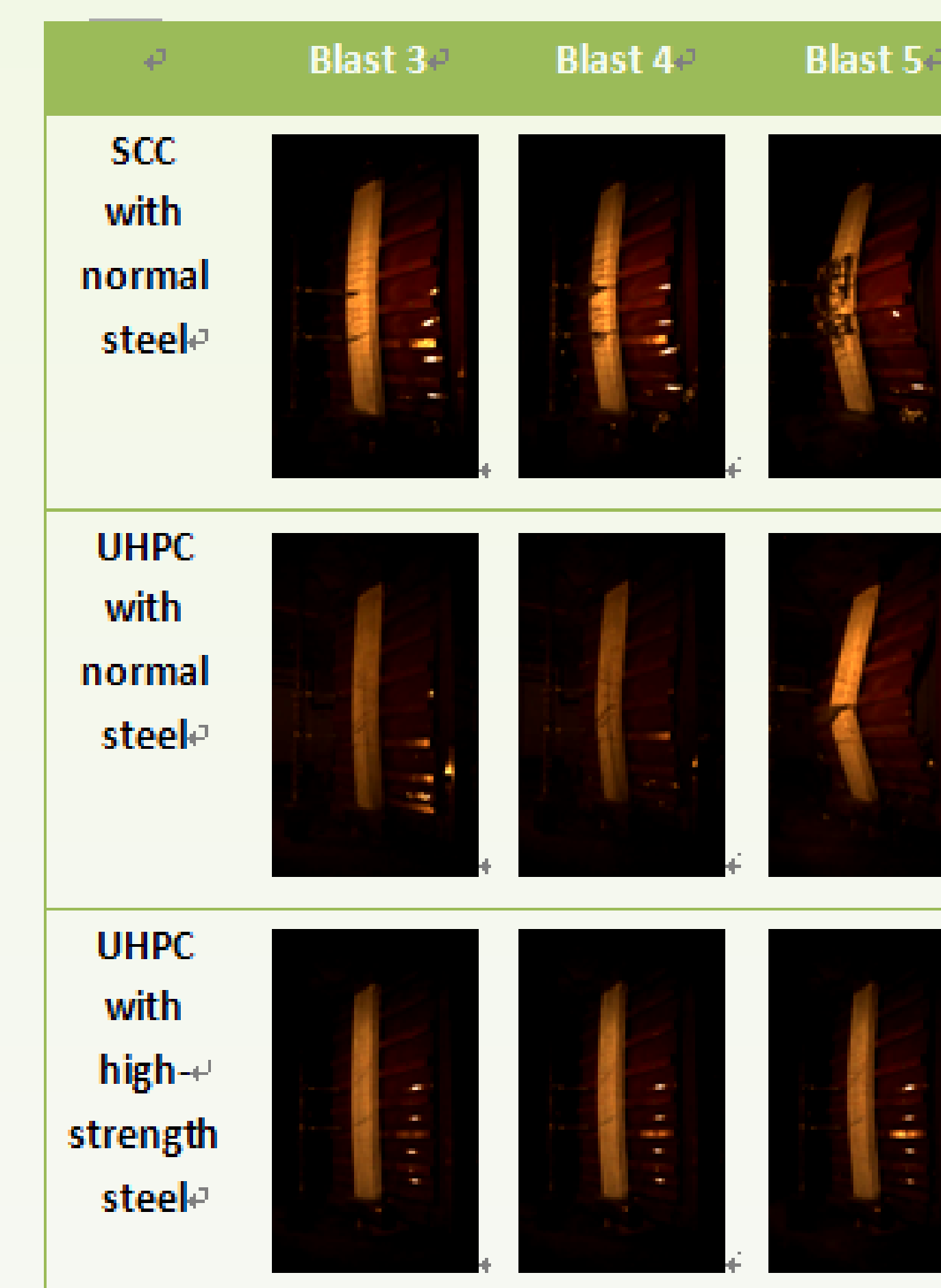
The specimens are tested under gradually increasing blast pressures. The initial blast loads (1 & 2) are executed in the specimen's elastic and yield range, which do not contribute to the results. Blast 3,4,5,6 are used to eventually fail the specimen and allow for examination of the effect of UHPC on **Mid-span** displacements, **damage tolerance** and overall **blast resistance**.

Reference:

- <http://www.ductal.com/wps/portal/ductal/2-Structural>
- <http://www.cement.org/for-concrete-books-learning/concrete-technology/concrete-design-production/ultra-high-performance-concrete>
- Burrell, R., Aoude, H., & Saatcioglu, M. (2014). Response of SFRC Columns under Blast Loads. *Journal of Structural Engineering*.

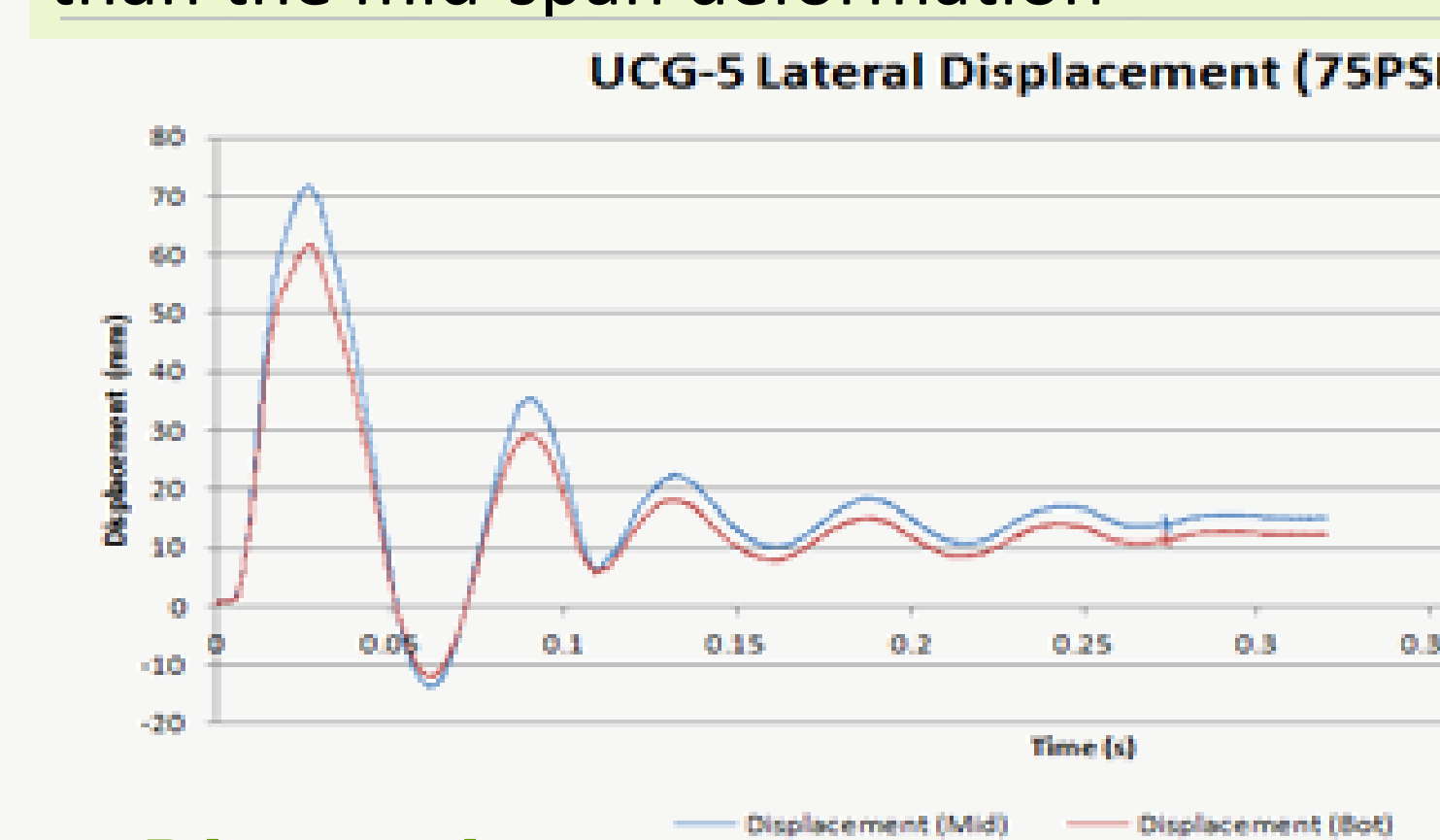
Research result

The performance of specimen made of SCC NSR without fiber, UHPC NSR-2% OL fiber content and UHPC MMFX-2% OL.



Conclusion 1:

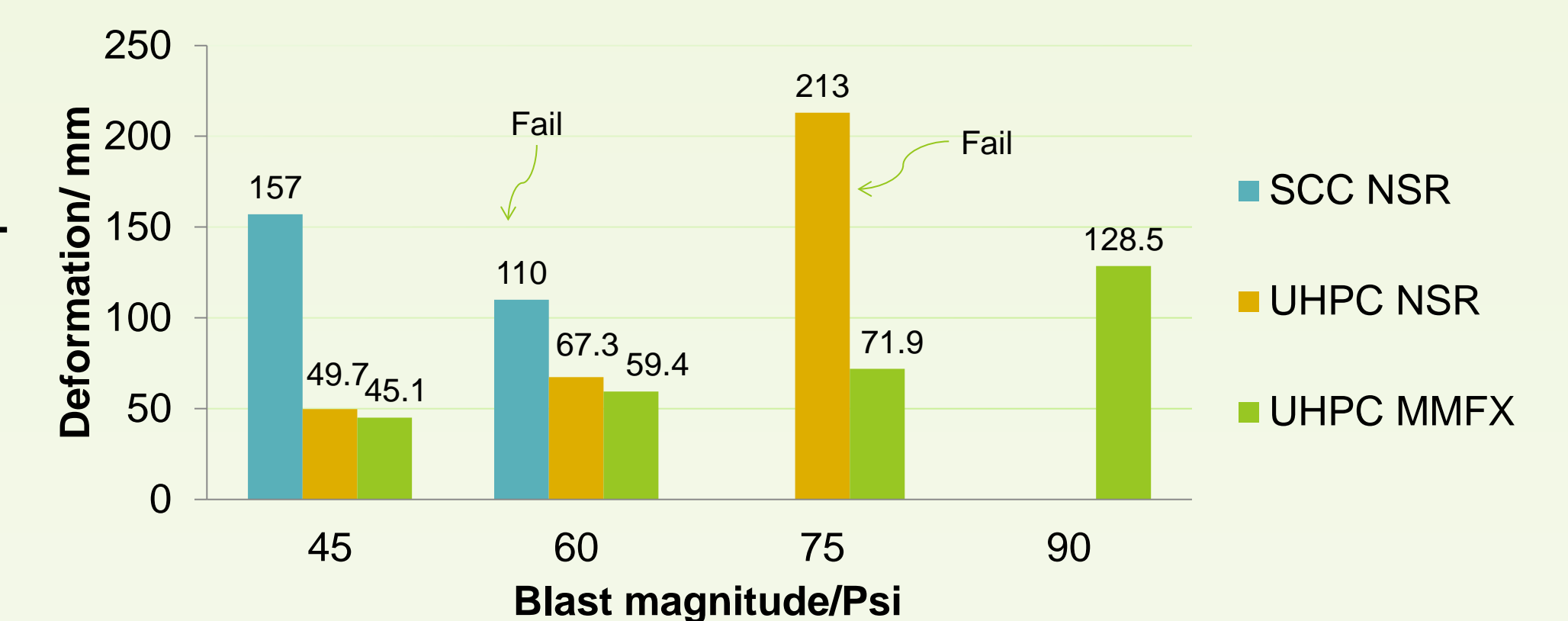
•The 1/3 span deformation is always less than the mid-span deformation



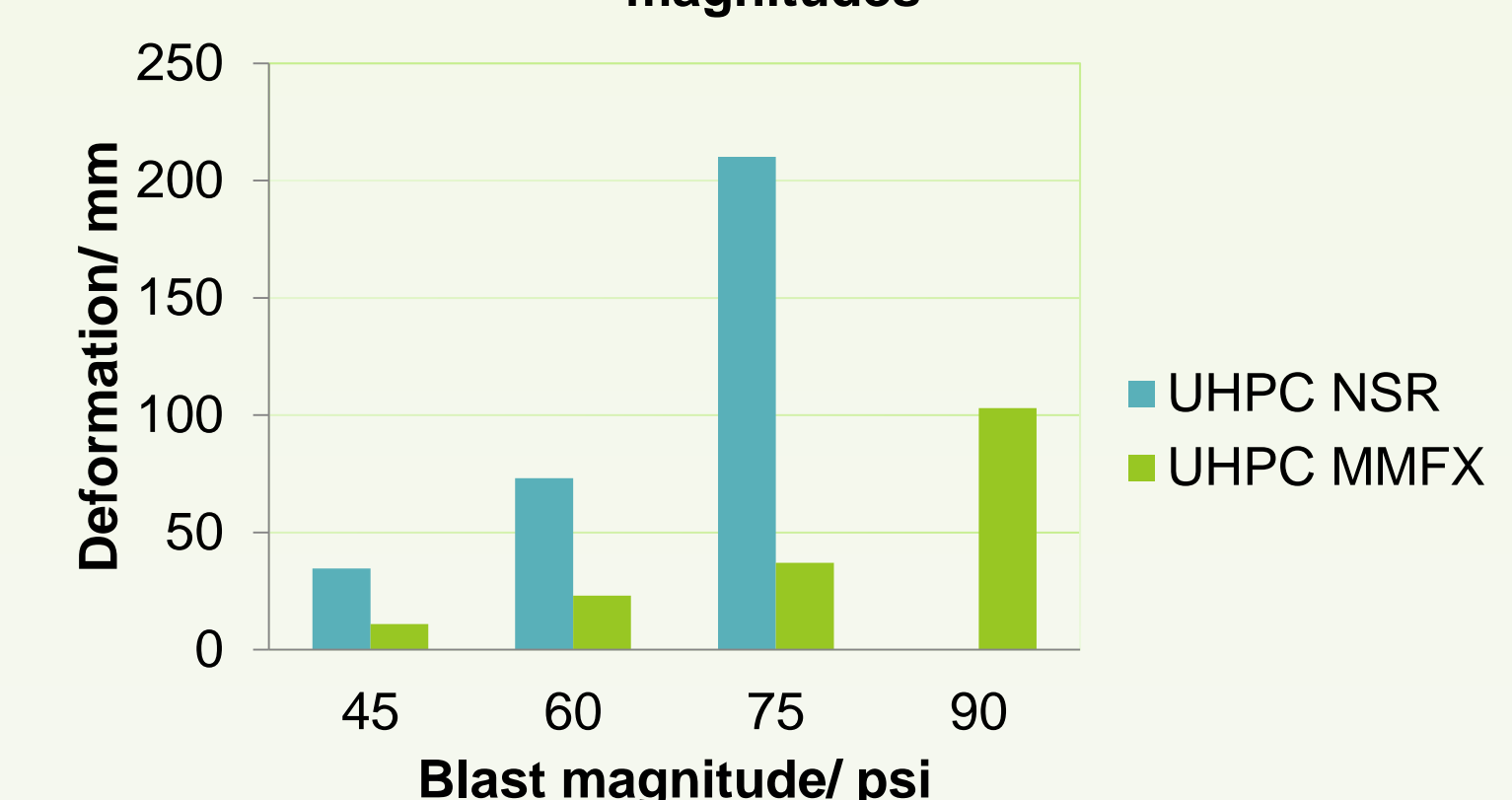
Discussion:

The column made of UHPC with steel fibers has a better blast resistance compared to the conventional concrete.

The maximum mid-span deformation of SCC NSR, UHPC NSR and UHPC MMFX under different blast magnitudes

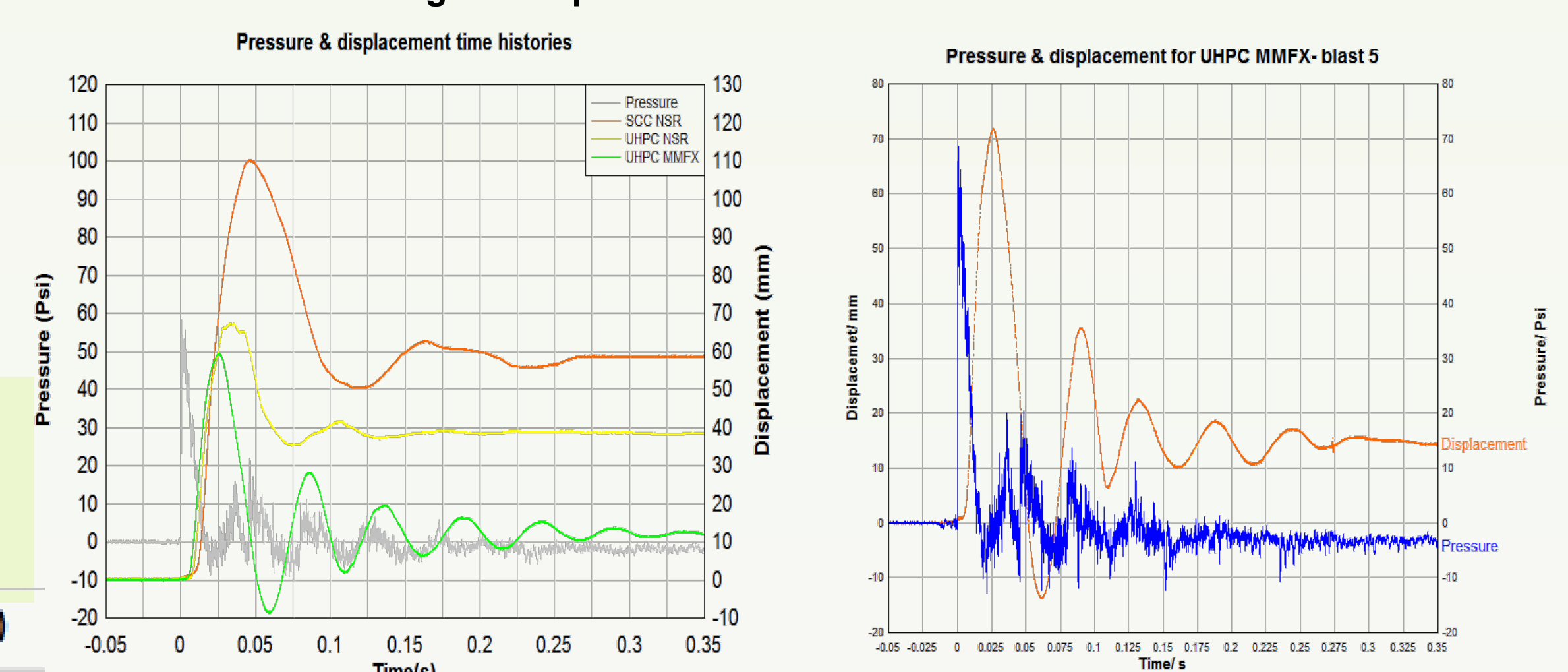


The residual mid-span deformation of UHPC MMFX and UHPC NSR under different blast magnitudes



Conclusion 2:

•SCC fails at 60psi, while UHPC NSR and UHPC MMFX survive at pressures of 75 psi and 90 psi, respectively



Conclusion 3:

•Mid-span deformation of specimen increases as the blast magnitude increases
•UHPC has improved blast resistance when compared to SCC (concrete) because of:

- ✓ Reduced deformations
- ✓ Increased damage tolerance (less fragments)
- ✓ Increased resistance (higher failure impulse)

Recommendation:

This research study demonstrates clear benefits associated with combined use of UHPC and MMFX steel in blast applications. Further research focusing on beams and columns is recommended, in addition to the development of analysis models for predicting the blast response of UHPC under blast.