Stochastic reliability of unreinforced masonry walls subjected to blast

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Motivation

- Unreinforced bricks masonry (UBM) is widely used for wall construction
- They can present a significant hazard to occupants when subjected to blast loads
- There are considerable uncertainties associated with material properties, threat scenarios, as well as expected damage
- In this work, a stochastic simulation is conducted to evaluate the reliability of UBM wall subjected to blast load

Approach

- Nonlinear dynamic Finite Element Modeling (FEM) is used to simulate the brick and mortar wall
- Sensitivity to input parameters is tested so as to select the major factors
- The uncertainties of the major factors are included in the model simulation
- In order to reduce computational cost, sampling is performed using LHC technique
- The stochastic reliability analysis proved effective for studying the damage risks for UBM walls subjected to blast loadings
- Probability Density Function (PDF), Cumulative Distribution Function (CDF), and survival function are obtained

Literature Review 1

- Blasts acting in the out-of-plane direction pose the highest risk.
- Stewart and Lawrence [3] found that structural reliability is sensitive to wall width and workmanship.
- Hao and Tarasov [2] found that material model must reflect brick and mortar behavior at high strain rates.

Literature Review 2

- Heffler et al. [4] showed that unit bond strengths are statistically independent
- Eamon [5] found that the main variable that affects wall resistance are mortar joint strength and contact surface friction
- El-Domiaty et al. [8] proved that retrofitting un-reinforced masonry using FRP composites increases resistance to blast loads
- Wei and Stewart [10] predicted damage based on deflection response of the structure

Literature Review 3

- Doherty et al. [16] found that walls would not collapse until the mid-height deflection was equal to wall thickness.

- US Army Corps of Engineers recommends that deflection exceeding wall thickness be used as a failure criterion [17]

- Zapata and Weggel [18] reported that if the extreme deflection is greater than wall thickness, the infill walls will collapse

Method Overview

- In this work, the reliability of UBM walls is studied using Monte Carlo Simulation (MCS) in conjunction with Finite Element Modeling (FEM).
- The outer iterations are performed using MCS method, while the inner computations are performed using FEM method.
- Sensitivity analysis is used in conjunction with stochastic simulation to reduce the number of factors affecting reliability.
- Probability Density Functions (PDFs) of major factors are used in the simulation.

Reliability Estimation Method

The reliability prediction procedure consists of these steps:

1- Obtain PDFs of input variables (taken as random variables)

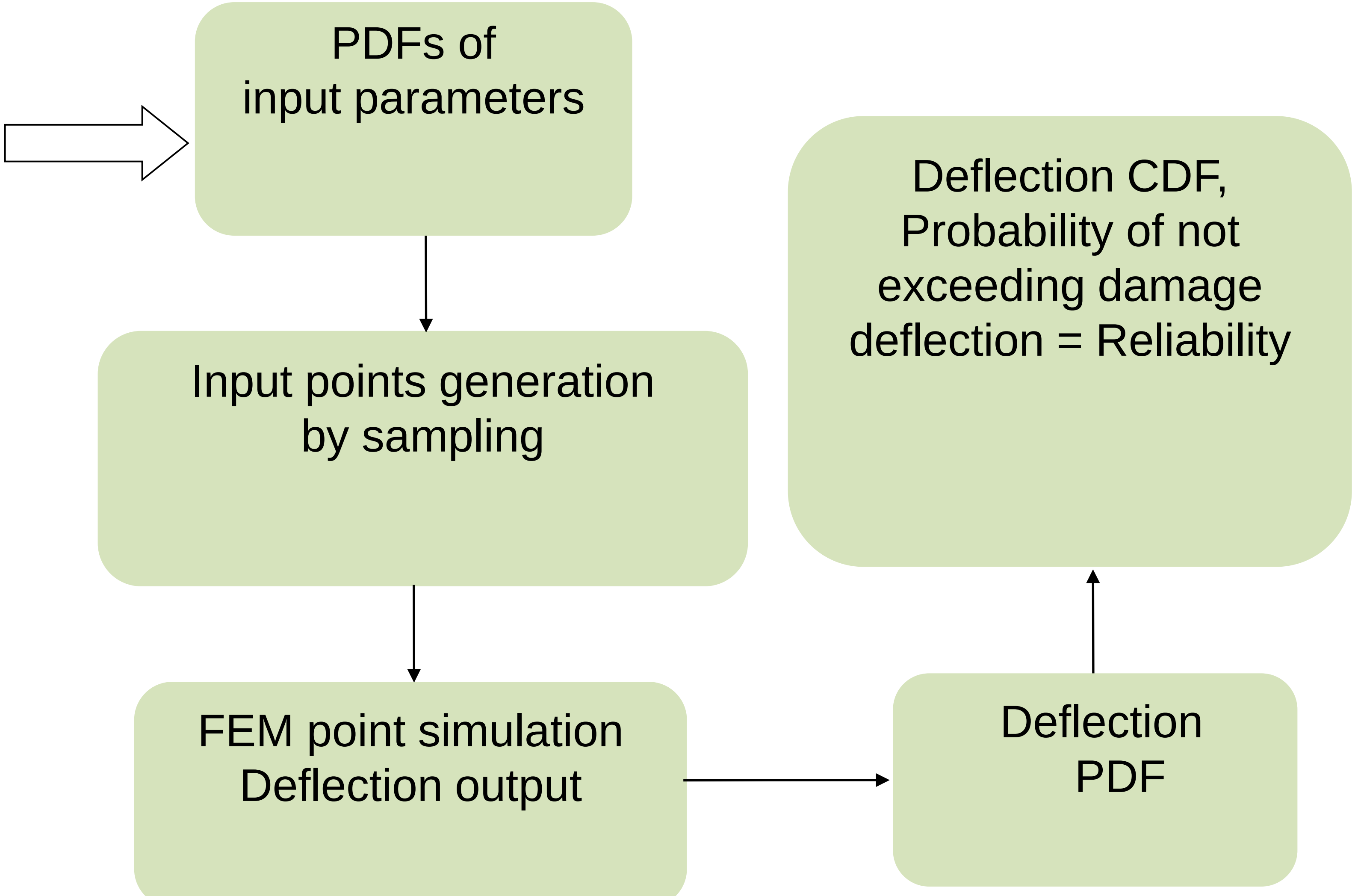
2- Random points of material strength and wall thickness are generated from their PDFs using MCS/LHC.

3- For each iteration; a transient dynamic structural FEM analysis is conducted for brick and mortar model.

4- PDF for Deflection response is obtained from these iterations

5- The reliability of UBM wall is the probability that Deflection does not exceed the damage threshold

Reliability Estimation Method

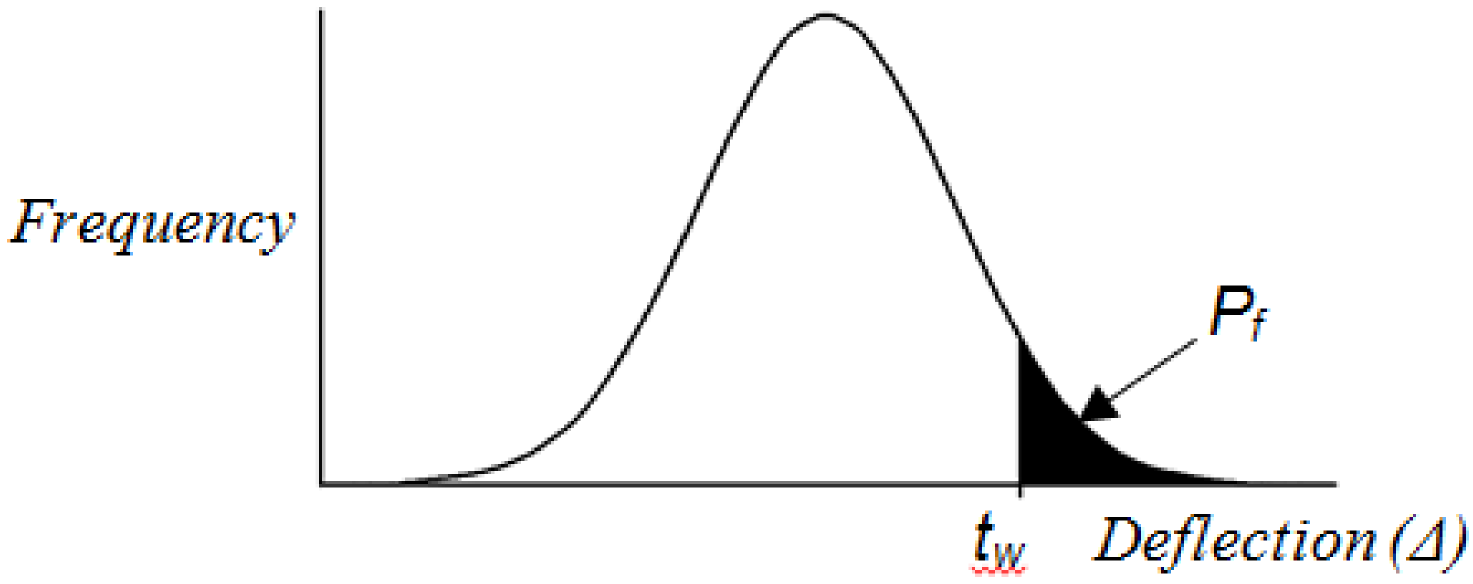


Calculating Reliability

- The damage criterion is wall collapse caused when wall deflection exceeds wall thickness [10].
- The structural reliability (R_s) is the probability that deflection does not exceed wall thickness
- In mathematical form, the reliability is expressed as:

$$R_s = 1 - P_f = 1 - P(\Delta > t_w)$$

Calculating Reliability



Reliability Simulation

- Sensitivity analysis yielded major factors affecting reliability such as wall thickness, blast pressure, bond and material strengths
- Blast pressure varies with weight and stand-off distance
- 27 random points are generated for FEM iterations
- PDF of deflection is built
- Damage state is related to peak deflection

BRICK AND MORTAR PARAMETERS

[10]

Part	Property	Mean	Coeff. of Variation	Distribution
Brick (B30)	$\alpha_t = \alpha_c$	1.0	---	Uniform
	V	0.15	---	Uniform
	σ_{st0} (MPa)	$\sigma_{sc0} * k_{st}$	---	Uniform
	σ_{sc0} (MPa)	30.0	0.1	Normal
	σ_{sttt0} (MPa)	$\sigma_{st0} * k_{sttt}$	0.1	Normal
	ε_{st0}	$0.048 * \varepsilon_{sc0}$	---	Uniform
	ε_{sc0}	$0.00212 + 7.5E\text{-}5 * \sigma_{sc0}$	---	Uniform
	k_{st}	0.0625	0.2	Normal
	k_{sttt}	0.025	---	Uniform

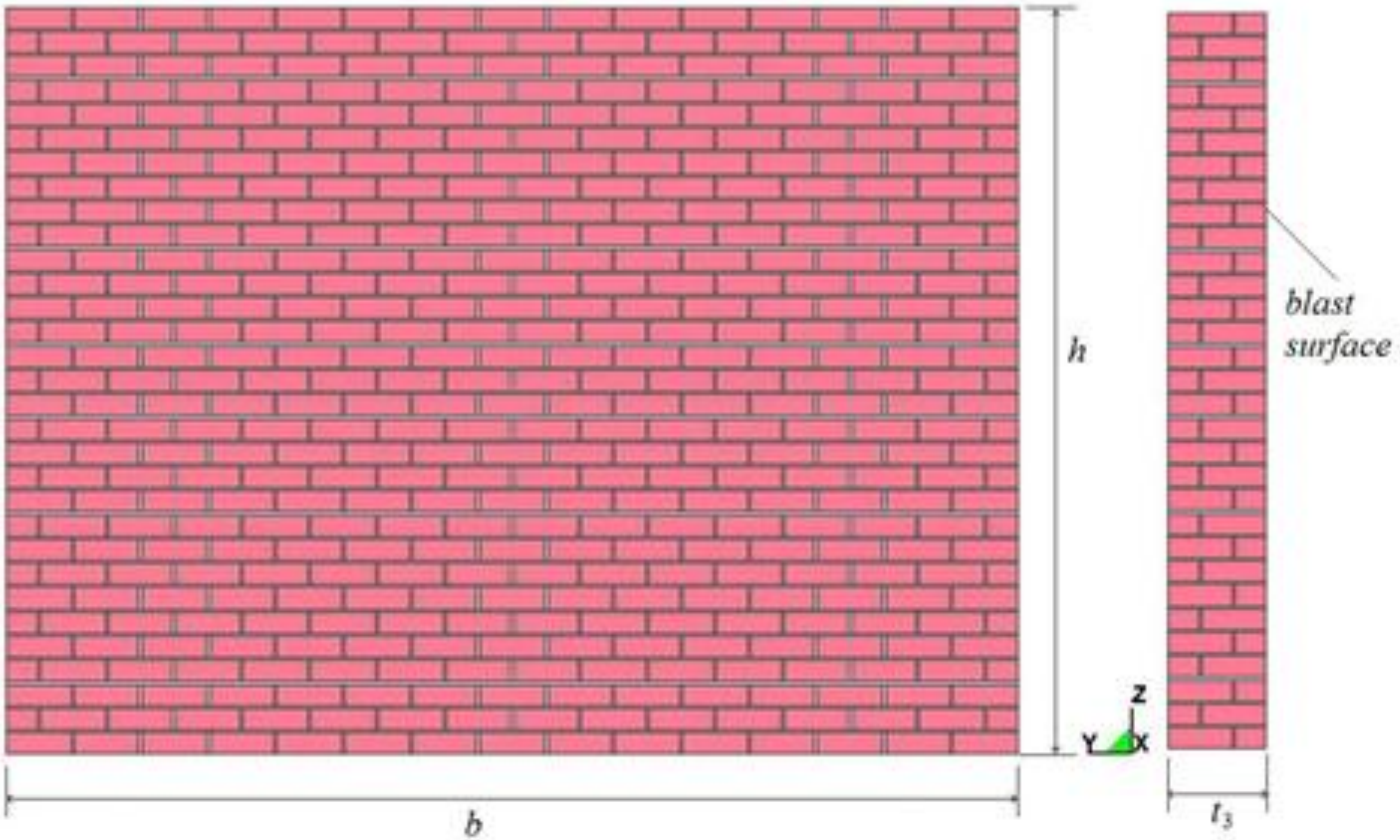
Stochastic FEM Simulation

- Nonlinear FEM with MCS is impractical. Therefore, LHC sampling is used
- Transient FEM simulation is used to determine wall response to dynamic pressure impact.
- Structural analysis aims to calculate maximum deflection, to predict damage due to each loading scenario [11].

CHARACTERISTICS OF INPUT PARAMETERS [10]

Property	Mean	Coeff. of Variation	Distribution
Bond Strength (MPa) [4]	0.51	0.8	Weibull
Charge Mass (W)	100 kg		Uniform
Stand-off Distance (R)	20 m		Uniform
Scaled R (Z) ($m/kg^{1/3}$)	4.3		Uniform
Wall Thickness (t)	355 mm	0.03	Normal
Blast Pressure (P)	4.3 MPa	0.002	Normal

UBM wall model



BRICK AND MORTAR MODEL [10]

- The 4 sides of the model are fixed [10]
- Under high compression, damage of a quasi-brittle material might occur owing to compressive crushing and tensile splitting.
- Behavior in uniaxial tension and compression is assumed to be linear elastic until the threshold strain is reached.
- The size of the clay bricks was 230 × 115 × 75 mm
- The wall size is $b \times h$ = 3.0 × 3.0 m.
- 3-D solid elements are used
- 3 different meshes are used for convergence.
- 19,000 elements used in wall model

Blast Pressure

Peak pressures were considered.

It depends on the radius of the blast sphere, The scaled R (Z) (m/kg$^{1/3}$) is defined as:

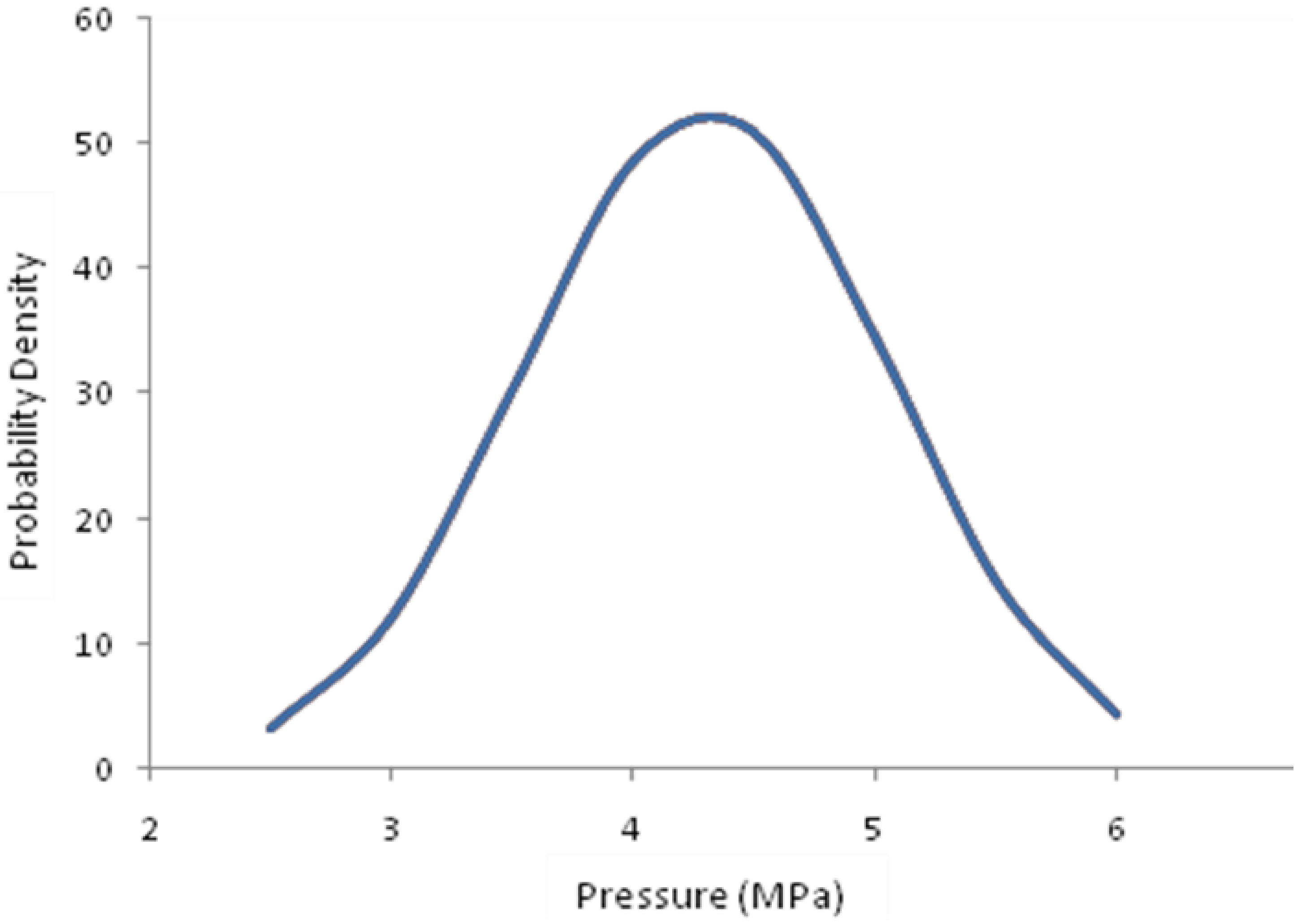
$$Z = \frac{R}{W^{\frac{1}{3}}}$$

R is distance from center of blast (meters)

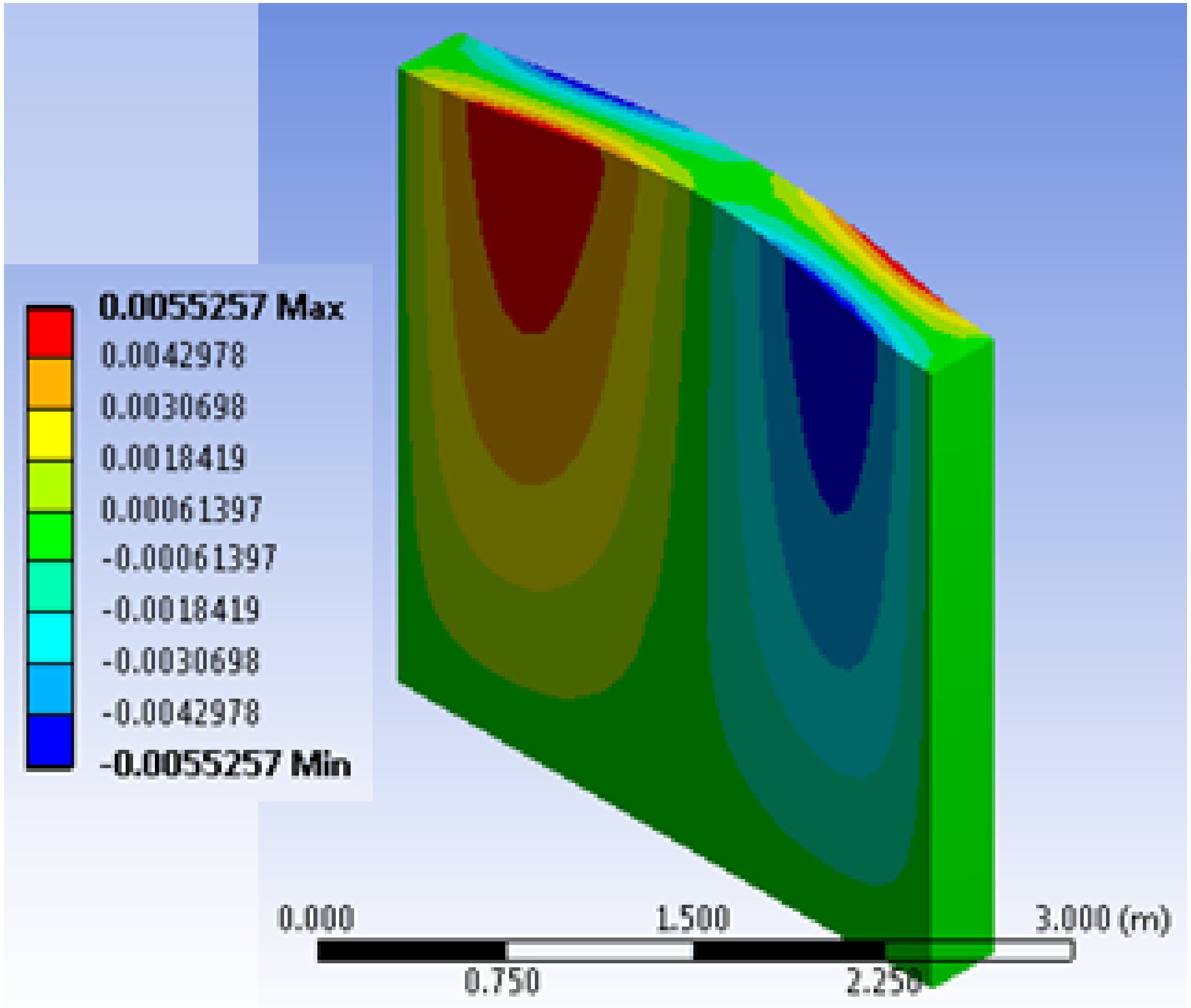
W is equivalent weight of TNT [22].

Pressure is defined in terms of Z

PDF of blast pressure



Maximum deflection in FEM

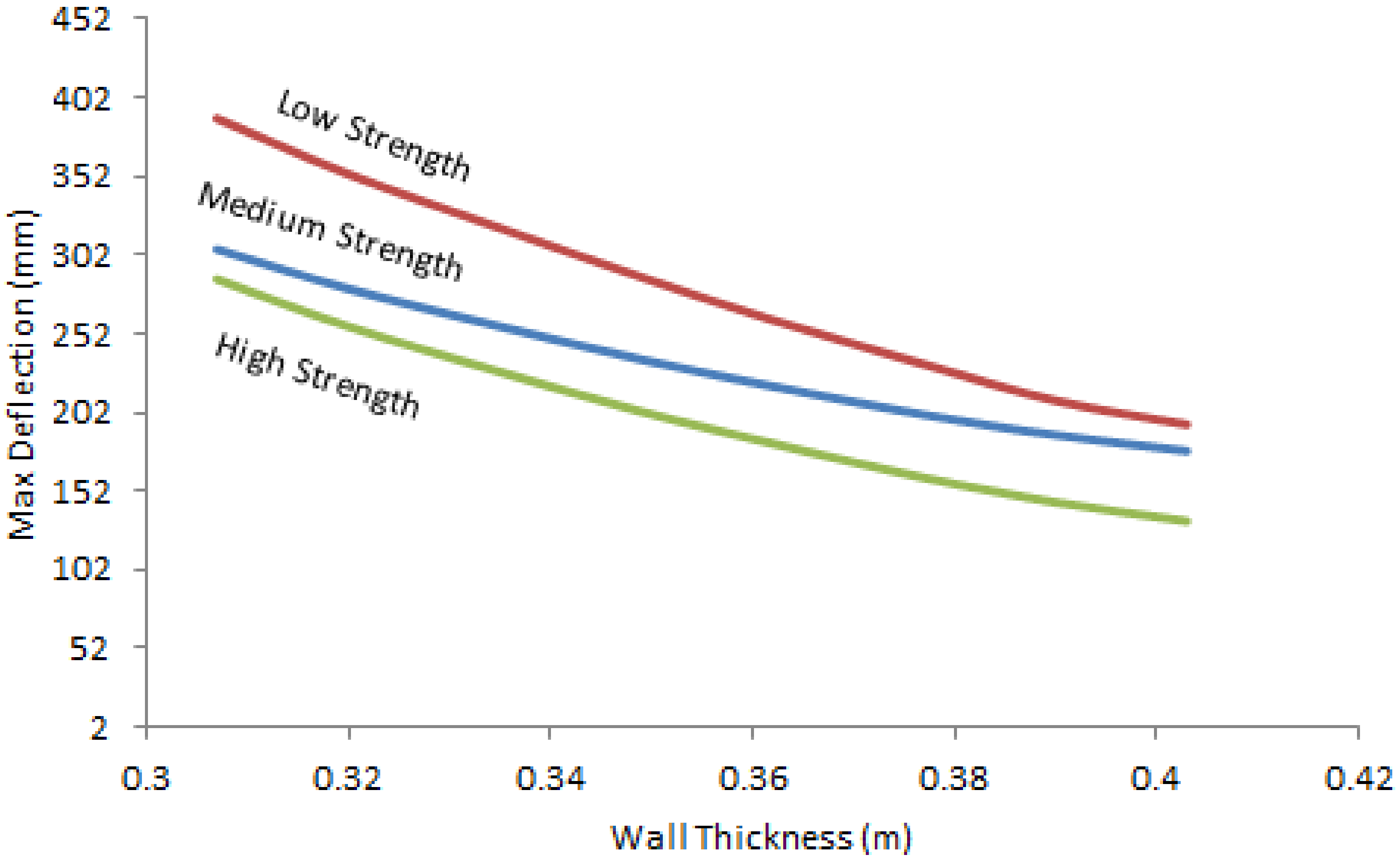


Simulation Results

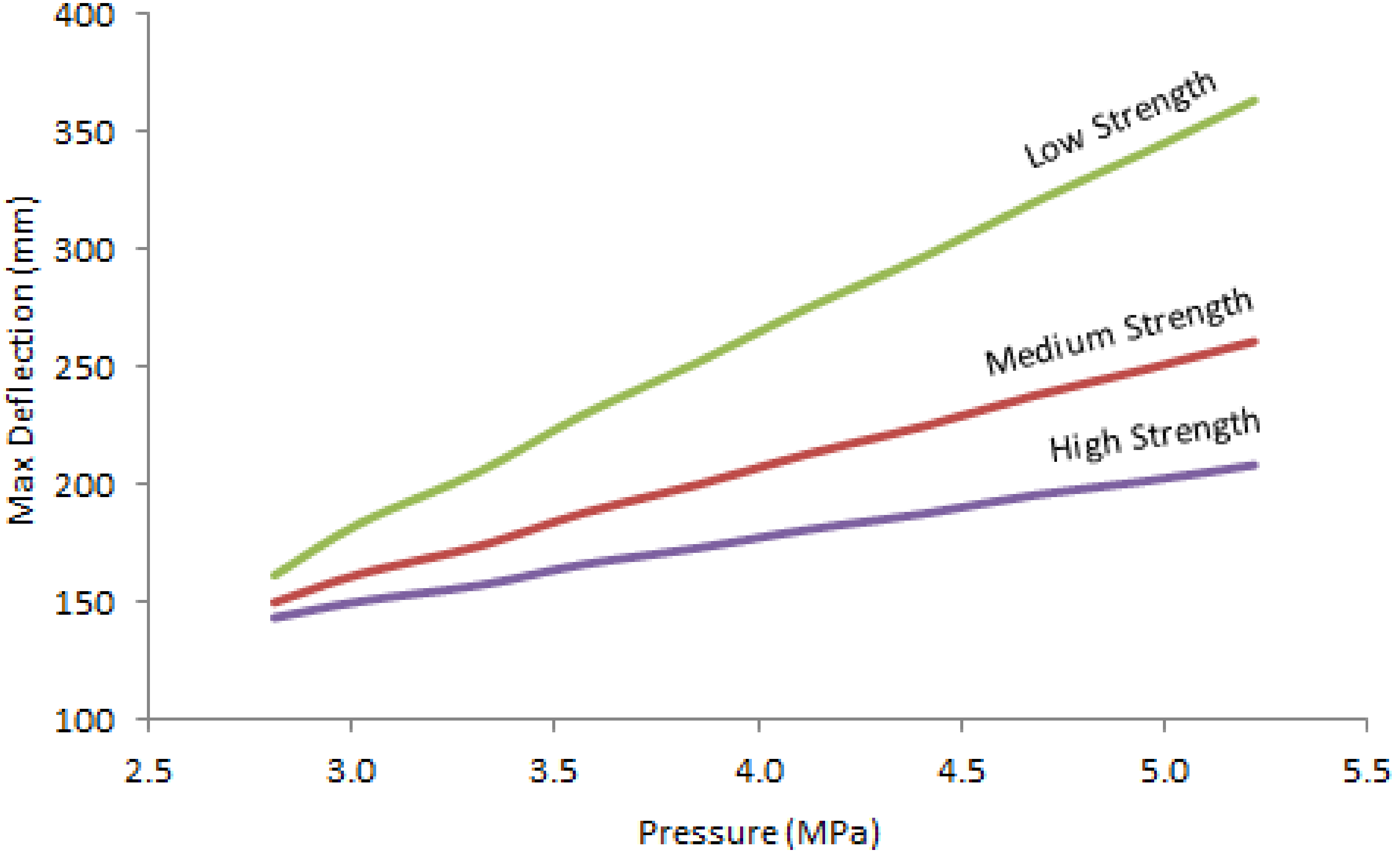
Inner Loop using Dynamic FEM

- The selected PDFs are used to generate input random variables for the FEM simulation.
- Maximum deflection is determined for each iteration, resulting in deflection PDF.
- Maximum deflection decreases with thickness
- Maximum deflection increases with pressure

Maximum deflection vs. Thickness



Maximum deflection vs. pressure

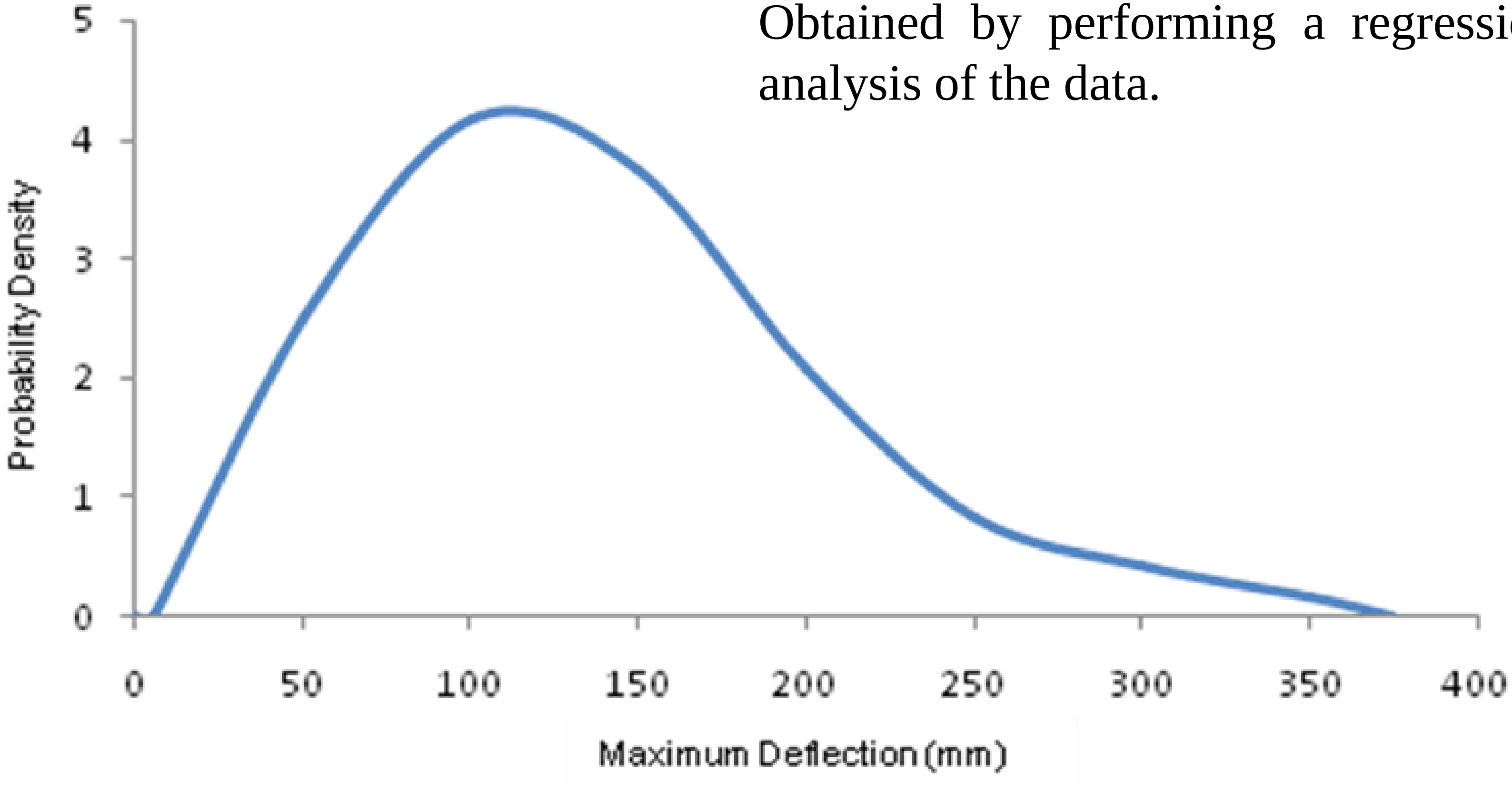


MCS of the Blast Load Model

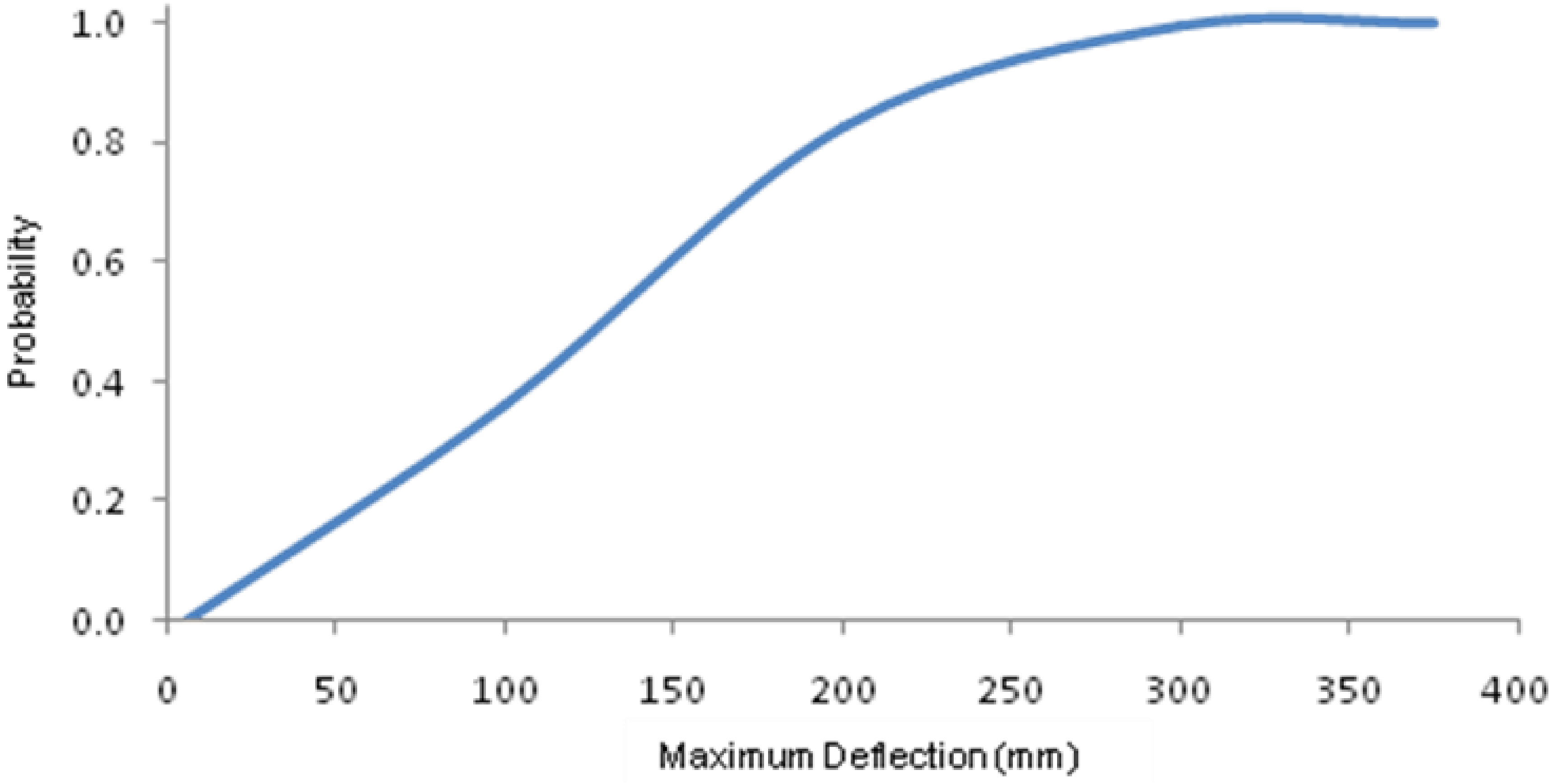
- MCS is conducted in conjunction with explicit FEM
- Weight of explosive (100 kg) and Stand-off distance (20 m)
- There is a small probability that maximum deflection exceeds wall thickness. Therefore, the occurrence of total wall collapse is a remote possibility [10]
- Deflection less than wall thickness may cause some degree of damage to the wall. These other –less than total- damage extents include intermediate (non-reusable) and minor (reusable) damages

PDF of Maximum deflection

Obtained by performing a regression analysis of the data.



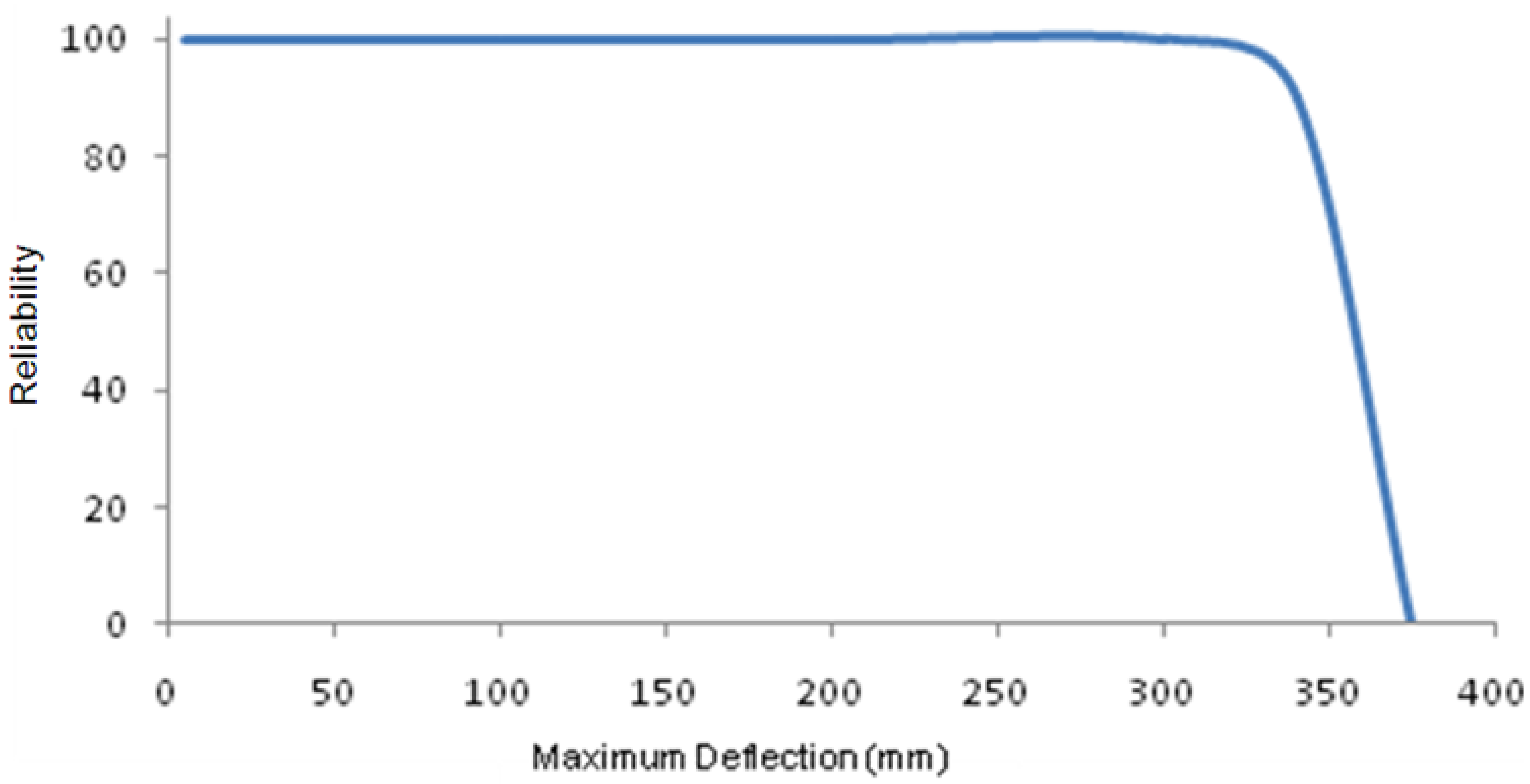
CDF of maximum deflection



Survival function

- By calculating reliability at various deflections, the survival function is obtained
- It is noted that reliability stays constant until it drops when the deflection comes closer to the wall thickness.
- If the definition of reliability is changed to less than total collapse, the shape of the curve will be different.

Survival function



Conclusions

- UBM wall has a high reliability in case of moderate blast
- Major factors affecting reliability are wall thickness, blast pressure, bond strength, and material strength.
- Uncertainties of charge weight and stand-off distance can be represented by uncertainties of dynamic pressure affecting the wall.
- Maximum deflection decreases with thickness.
- Effect of strength gets larger as wall thickness goes smaller
- Effect of strength gets larger as the pressure goes higher.
- Maximum deflection less than wall thickness may cause partial damage
- Reliability stays constant until it drops when deflection comes closer to wall thickness.
- If the definition of reliability is changed to partial damage, the curve will drop down earlier, depending on the new value of deflection.

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Thank You

Questions?