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Schlumberger Shaped Charge Manufacturing Facility AFT Xtegra's™ Blast Curtain Analysis

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Scope of Analysis

This project looks at the design and evaluation of an AFT Xtegra™ Blast Curtain and Support Frame for the Schlumberger Shaped Charge Manufacturing Facility. This includes a fifteen-foot high, thirty-three-foot-long extension to the existing explosive storage room. The active components in this storage room are up to 100lbs of Explosives (HMX, RDX, HNS) stored in an approved indoor explosives magazine.

The Facility uses a reinforced concrete storage area with an exterior blow out wall to protect workers inside the building from a detonation blast wave. The current scope of analysis will include an FEA of the extension of the current wall utilizing Auxetic curtains supported by a steel framework.

It is in the Scope of the Analysis to define the pressures resulting from a detonation of explosive energy at the areas of interest which include; the inside surfaces of the current facility; the surrounding surface walls; the blowout front wall and the pressures experienced along the entirety of the Auxetic curtain wall.

Specialized Advanced Fabric Technologies proprietary Software and Ansys Fluent and Ansys Mechanical software will be used for Simulations and Analysis.

Analysis Performed

There were three types of analysis performed:

1- A total energy assessment based on the expected worst-case pressure energy that would be found in the manufacturing facility.

2- Peak Pressure loading of the Xtegra™ blanketing and general blanket thickness calculations, consistent with the loading in total energy assessment (1).

3- Structural loading resulting on the Xtegra™ blanketing and the installed steel frame extensions based on Finite Element Analysis (FEA) to include: curtain, frame, and anchor points.

Facility Layout

The Shape Charge Manufacturing Facility was designed that in the case of an accidental detonation the energy of the explosion will be directed away from the building, thus protecting the Operators working in other parts of the facility building. The generated by the explosion is directed out of a building through an exterior .

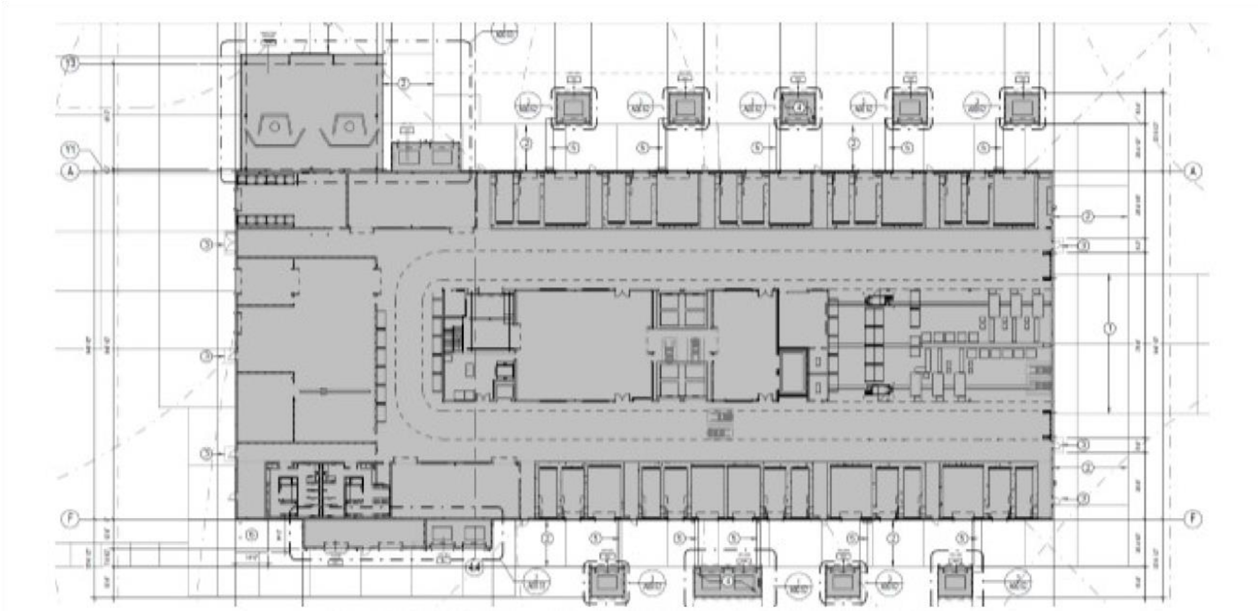

Figure 1: SCMF Site Plan from A00.51 Enlarged Site Plan

Explosives Storage Room Layout

The current explosives storage area is 15’ (H) x 23’ (L) x 7.6’ (W).

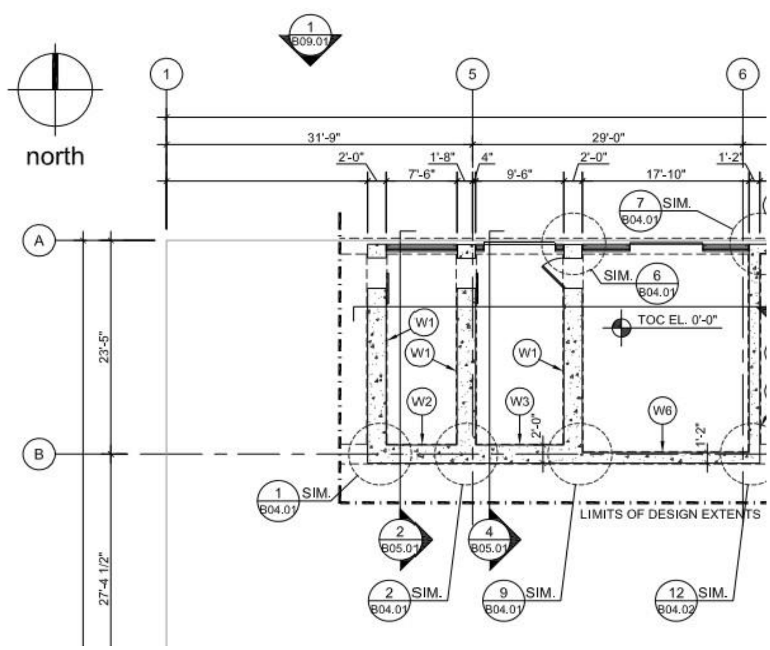

Figure 2: Close-up of Shape Charge Bays

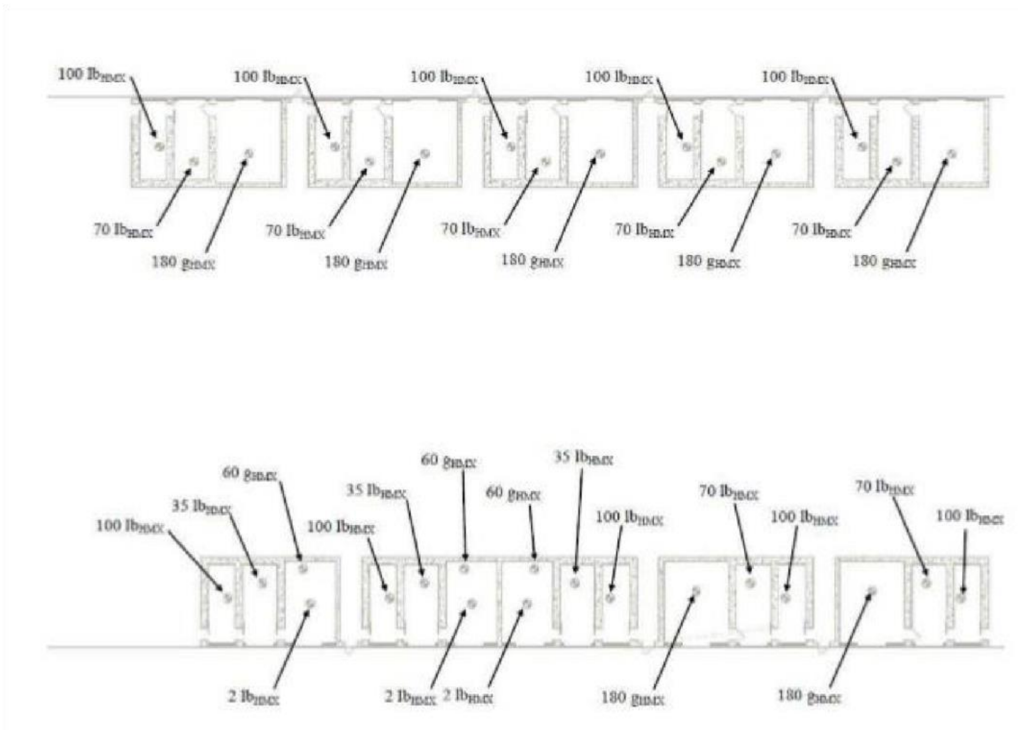

Figure 3: Location and size of Active Explosive Charges

Proposed Location of Curtain

In an attempt to permit maintenance in the areas behind the Bays during processing, an AFT Blast Curtain is proposed as an extension to the Blowout Wall. The AFT Xtegra™ Blast Curtain will be held up by a steel frame that will hold the Xtegra™ Curtain in place and withstand the pressure wave. This curtain will be 15 feet tall and 33 feet long; starting at the Blowout Wall and moving out perpendicular to the outside of the Bay area.

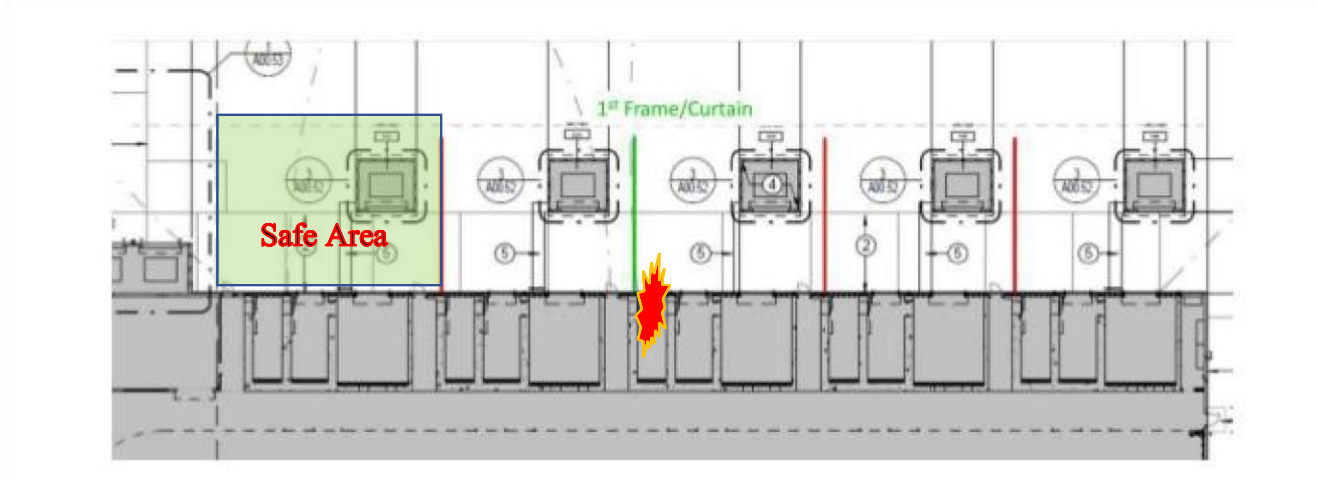

Figure 4: Location of AFT Xtegra™ Blast Curtain in Green

Xtegra™ Blast Curtain's Mounting Structure.

The AFT Xtegra™ Blast Curtain is mounted to a 6" x 6" welded square tubular steel frame. The curtain's mounting ropes will be attached to the steel frame at 6" intervals on all four sides of the vertical frame. There will also be a mounting rope running through the middle of the 15-foot height of the curtain that will be attached at each vertical 6" x 6" steel pillars. The 6" x 6" steel frame will be attached to bolts in a concrete pad.

Cases Analyzed

Three explosives were analyzed to determine which would produce the worst-case pressure loads on the Xtegra™ Blast curtain. A hundred pounds of HMX, RDX and HNS were examined in the Kingery-Bulmash Blast Parameter Equations (Reference 1). These equations estimate blast overpressures as Incident Pressure and Reflected Pressure. Each of the three explosives overpressures were calculated. RDX was found to have the largest Incident pressure at 711.86 KPa @ 5 feet; 47361.44 KPa @ 0.3 feet and Reflected Pressures at 3539.75 KPa @ 5 feet and 593647.06 KPa @ 0.3 feet. RDX also had the highest shock front velocity in both cases. RDX will then be used to do this analysis.

TNT Equivalency of RDX Analysis

The Kingery-Bulmash Blast Parameter Equations Calculator shows RDX is 114 percent TNT for equivalent pressure wave. To validate these numbers, the paper "TNT Equivalency of RDX" (Ref 2) was compared to the Kingery-Bulmash Blast Parameter Equations results.

From the paper, the raw data from the test detonations of RDX were collected and analyzed.

	100lbs	45.36 kg RDX					
Test #	10-80-C7-0	10-80-C7-1	10-80-C8-0	10-80-C2-1	10-80-C3-0	10-80-C3-1	
m	kPa	kPa	kPa	kPa	kPa	kPa	Ave kPa
4.24	2069	2534	1903	2327	2482	1810	2187.50
5.66	1451	1668	1197	1451	1306	1269	1390.33
7.64	559	420	642	294	633	294	473.67
12.73		139	124	97	133	92	120.67

Table 1: TNT EQUIVALENCY OF 100 lbs RDX

For each of the three detonations there were two pressure transducers 90 degrees apart. These pressure transducers were mounted near the ground at 4.34m, 5.66m, 7.64m, and 12.73m. It was unclear if the pressure transducers were mounted in a way to intercept the pressure wave at 90 degrees or some lesser angle. The average of each range was taken across the three tests and each transducer.

These pressures were then compared to the pressures derived using the Kingery-Bulmash Blast Parameter Equations for each of the same distances.

		K-B Blast Calc	
m		Incident kPa	Reflected kPa
4.24		1026	5695
5.66		535	2434
7.64		268	980
12.73		88	236

Table 2: Kingery-Bulmash Blast Parameters

Comparing the pressure numbers from the tests and the equations shows several things. First, the test numbers fall between the Incident Pressures and the Reflected Pressures. Second, it would be assumed that the pressure transducers in the tests would measure Reflected Pressure. If that assumption is correct, then the pressure transducers were not perpendicular to the shockwave as it passed over. To examine this, the Equation and Test Ratios can be compared.

m	Incident kPa %	Reflected kPa %	kg TNT Equiv
4.24	0.469028571	2.603428571	51.71 - 1.14%
5.66	0.384799808	1.750659314	51.71 - 1.14%
7.64	0.565798733	2.068965517	51.71 - 1.14%
12.73	0.729281768	1.955801105	51.71 - 1.14%

Table 3: Comparison of Kingery- Bulmash to Test Data

From a direct comparison of the pressures we see that the Incident Pressure ratios change with range. This would indicate that the test pressures are not Incident Pressures. Looking at the Reflected Pressures we see that all ranges of the Kingery- Bulmash numbers are about 2 times that of test data. This indicates that the test data was Reflected Pressure data and that the transducers were not perpendicular to the shockwave. As a result, we can safely calculate that the transducer intercept angle was approximately 60 degrees to the shockwave. With this, it appears that the Kingery- Bulmash numbers are within the range of the collected test data. With this result, we can then use the TNT Equivalent numbers for RDX. In this case; 114% or 51.7 kg of TNT to get the same pressure wave of 43.36kgs of RDX. (Appendix A: Contains the Kingery-Bulmash Blast Parameter Equations Calculator Outputs.

For this study, a value of 114% TNT equivalency will be used as the scaling value to do the pressure calculations need to evaluate the blast curtain and support structure

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Peak Shockwave Pressures

The Peak Shockwave Pressures can be found by scaling ratios based on the Energy and Distance. Figure 4 gives this relationship between the peak pressure in (MPa) and the scaled value of Distance over Energy (MJ) to the 1/3 power. If we use the 114% of TNT scaling for RDX, we get a shockwave energy of 208.49 MJ. This value was then used with the scaled relationship below and Ansys Fluent to generate a pressure distribution on the Xtegra™ Blast Curtain

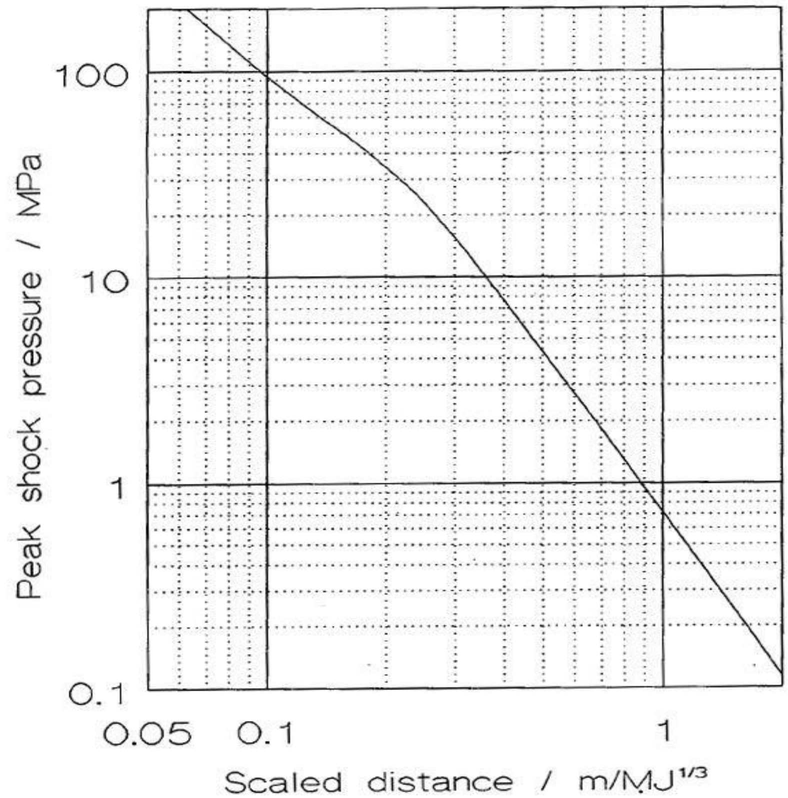

Figure 5: Peak Shock Wave Pressure vs. Scaled Distance

For 100 pounds of RDX, this results in a pressure plot over the Xtegra™ Blast Curtain as seen in Figure 6. It was assumed that the 100lbs of RDX was 3 feet off the ground and in the center of the Bay. It is also assumed that there is no ceiling outside the chamber allowing the hemispheric shockwave to grow without restriction. With this configuration, it can be seen that the max reflected shock pressure just outside the Blowout Wall is 350 psi. At the far end of the curtain, 33 feet away, the pressure drops to 11.5 psi. It should be noted that these are the pressures that will be seen by the Blast Curtain and are called Reflection Pressures. In this case, because the blast wave is not directly perpendicular to the Blast Curtain, the pressures are a little lower than that expected from the same blast directly hitting the curtain.

Simulations and previous explosive tests show that the Safe Area behind the Xtegra™ Blast Curtain, where the blast pressure is reduced from 350 psi at the top of the curtain to less than 2 psi will be some distance from this curtain. This is due to the shockwave rolling over the curtain and expanding into the space behind the curtain. The CFD simulations were not run for the large number of time steps that would be needed to determine the pressures beyond the Xtegra™ Blast Curtain, and thus, do not allow us to determine the Safe Area boundary beyond the curtain.

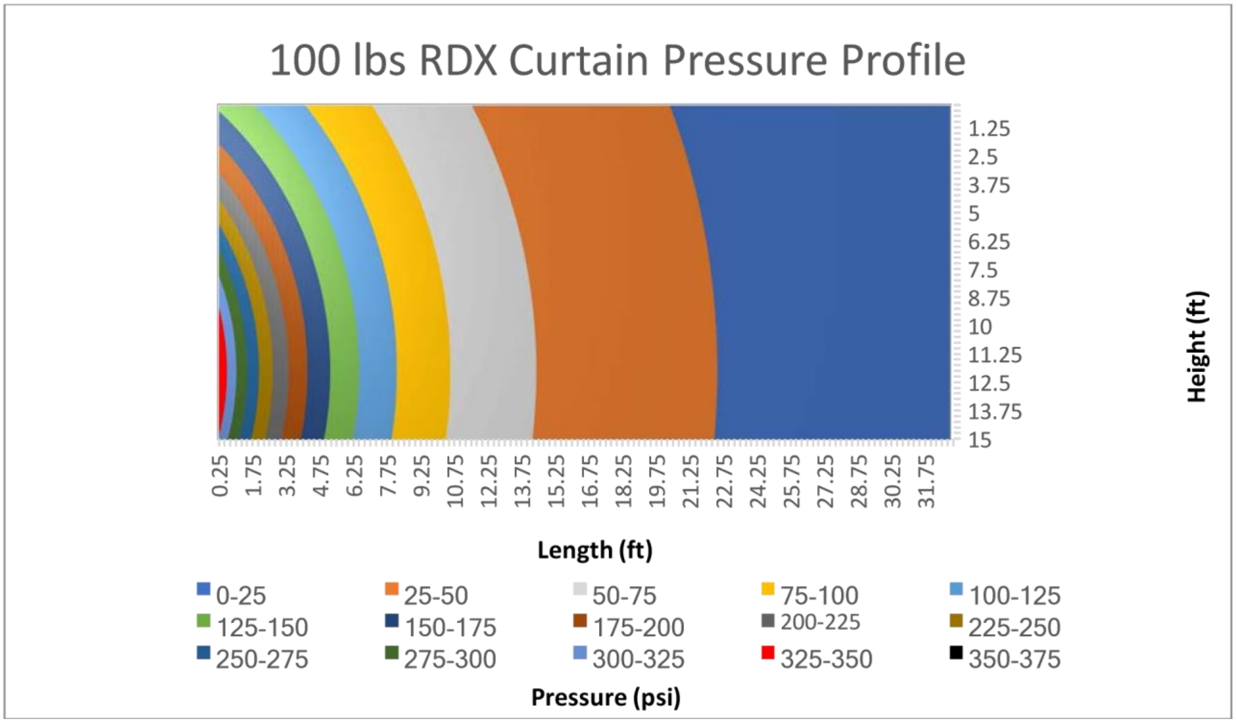

Figure 6: 100 lbs RDX Blast Curtain Pressure Plot

Shockwave Loading of AFT Xtegra Blast Curtain

From the Shockwave Pressure Data, it can be determined that three to four layers of AFT Xtegra™ Blast Curtain fabric would be needed handle the worst case scenario, located directly at the exit of the Blowout Wall. Here the pressure of 2500 KPa is at the upper edge of the 3-layer Xtegra™ Blast Curtain (*Figure 7*).

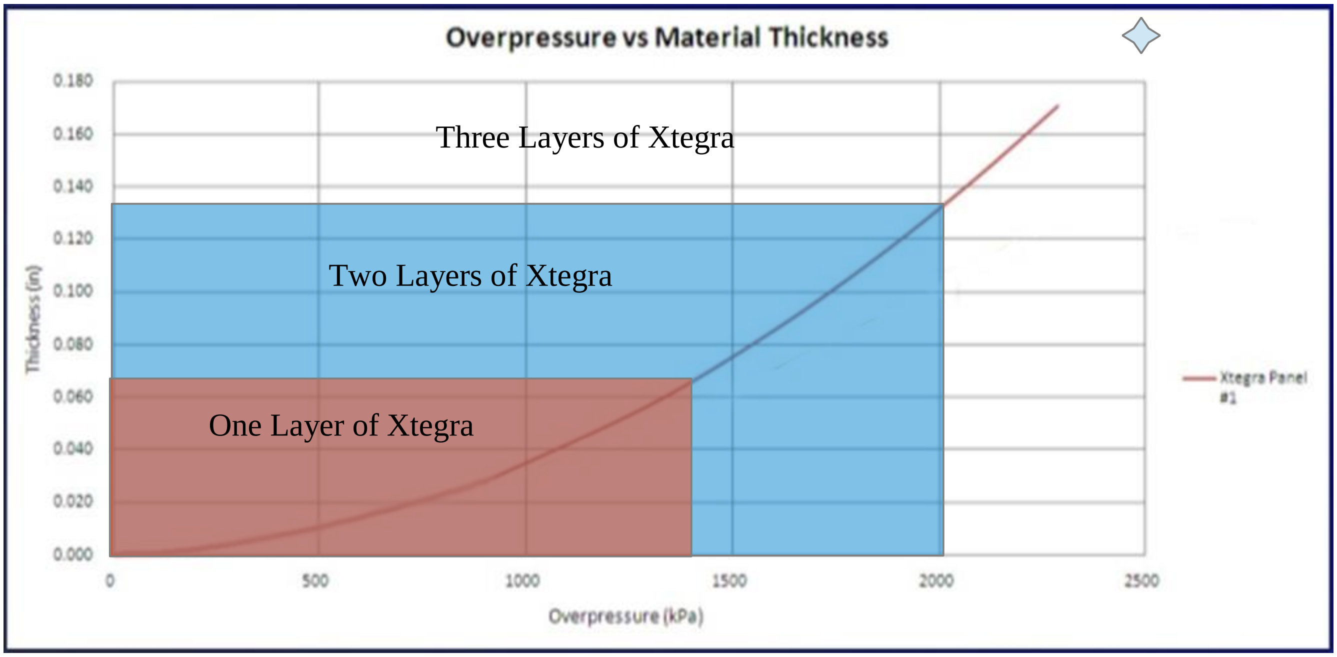

Figure 5 Xtegra's™ Thickness vs Overpressure

Shockwave Pressures FEA Structural Analysis

With the pressure profile developed, a structural design for the support frame was designed. The first attempt at this design was with a 6" x 6" square tubular steel frame with vertical supports every 5 feet, except for the first internal vertical support that was at 3 feet from the outer vertical support. This first 3-foot space was because of the 350 psi pressure that were to occur in this area. A simple FEA evaluation of this structure showed large deformations in the location of the higher psi loading. As a result, the 6" x 6" steel supports were added to each of the verticals. Figure 8 shows the final structure design used in the FEA analysis. Each of the verticals and the supports are bolted to a concrete pad and are simulated as fixed supports.

This Model is then meshed and the pressure profile is applied. The results of the FEA analysis are presented.

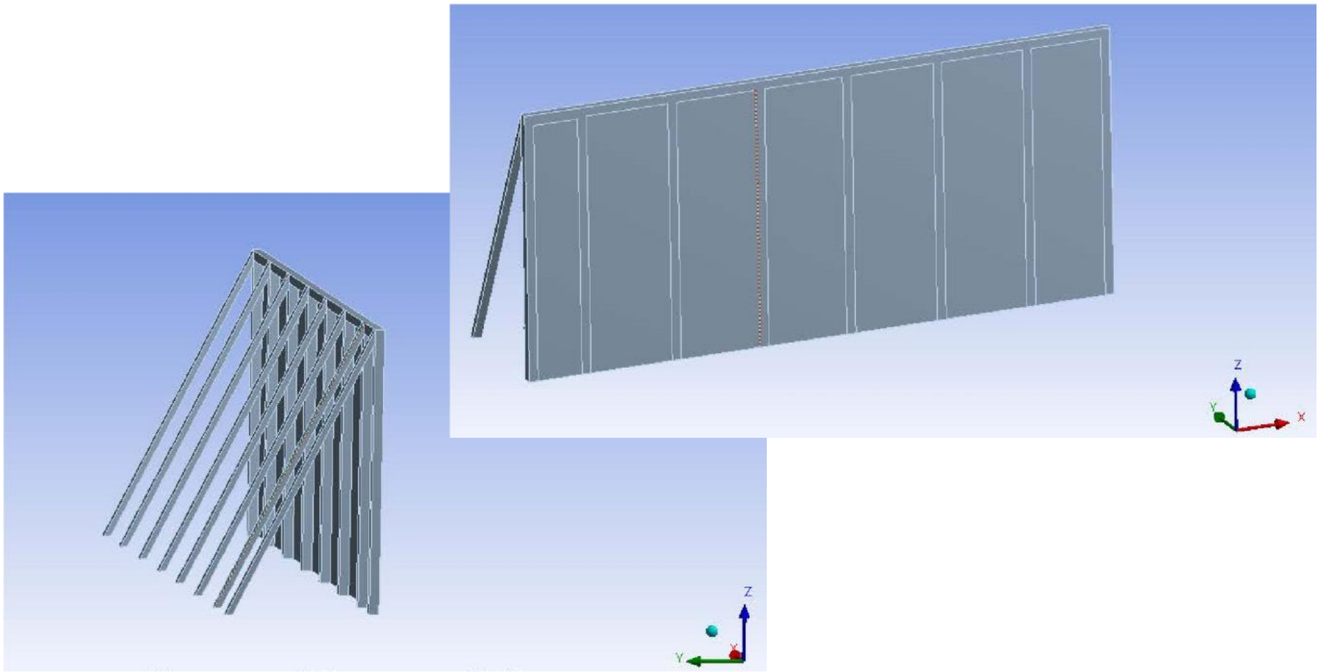

Figure8: 6” x 6” Square Tubular Steel Frame Work

The first item looked at is the displacement profile (Figure 9:). Here it can be seen that the 4-layer Xtegra Curtain is displaced 45 inches in the second space between uprights. This is a very large displacement for the Xtegra™ fabric. It is an indication that some of the layers of the 4-layer Xtegra™ Curtain have failed. To determine if this is the case, the Equivalent Stress is examined (Figure 10) to determine if these values exceed the values the Xtegra™ fabric can withstand. In this situation, it does look like there are material failures in any area that have green in Figure 10. Further analysis looking at these stress values indicate that both two and three Xtegra™ layers have also failed. These failures appear to occur along the sides of the uprights in the area of the attachment rope that runs through the middle of the curtain. Next, the support structure is examined (Figure 11). The displacements look reasonable, but does show that the structure will be permanently deformed. Again, we look at the Stress Intensity (Figure 12). In this case, we can see potential partial failure near the base of the second vertical upright.

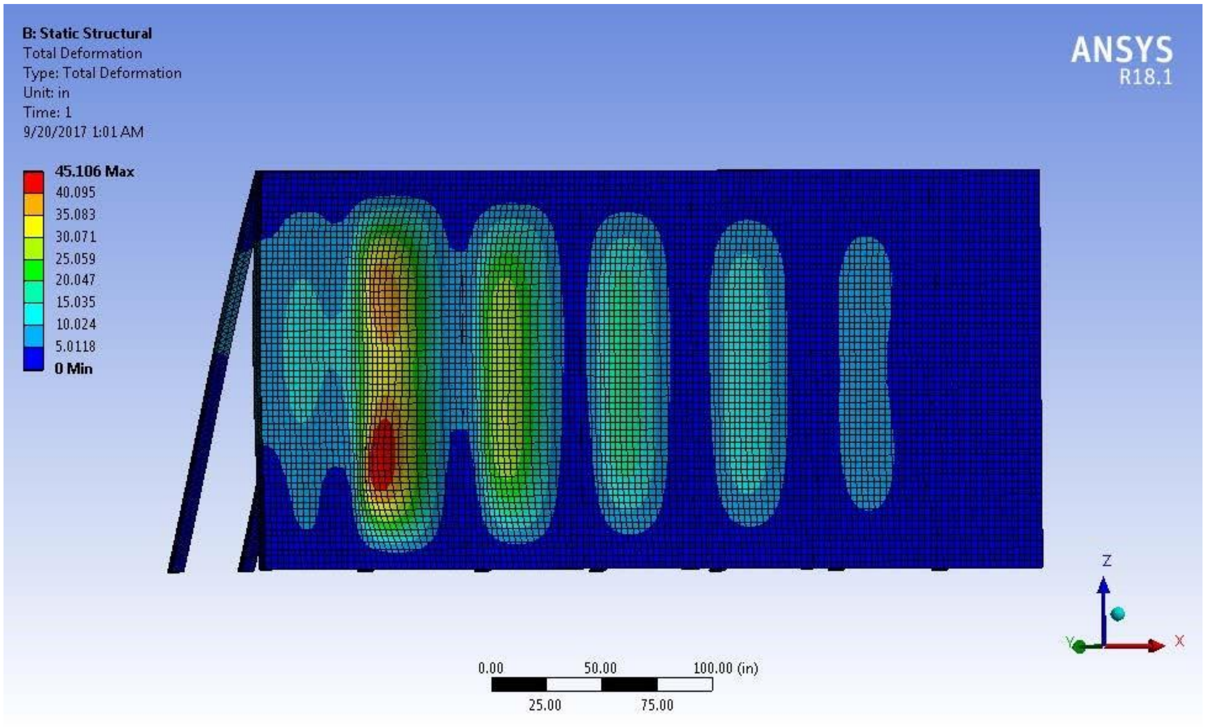

Figure 9: Front View of Displacement Plot

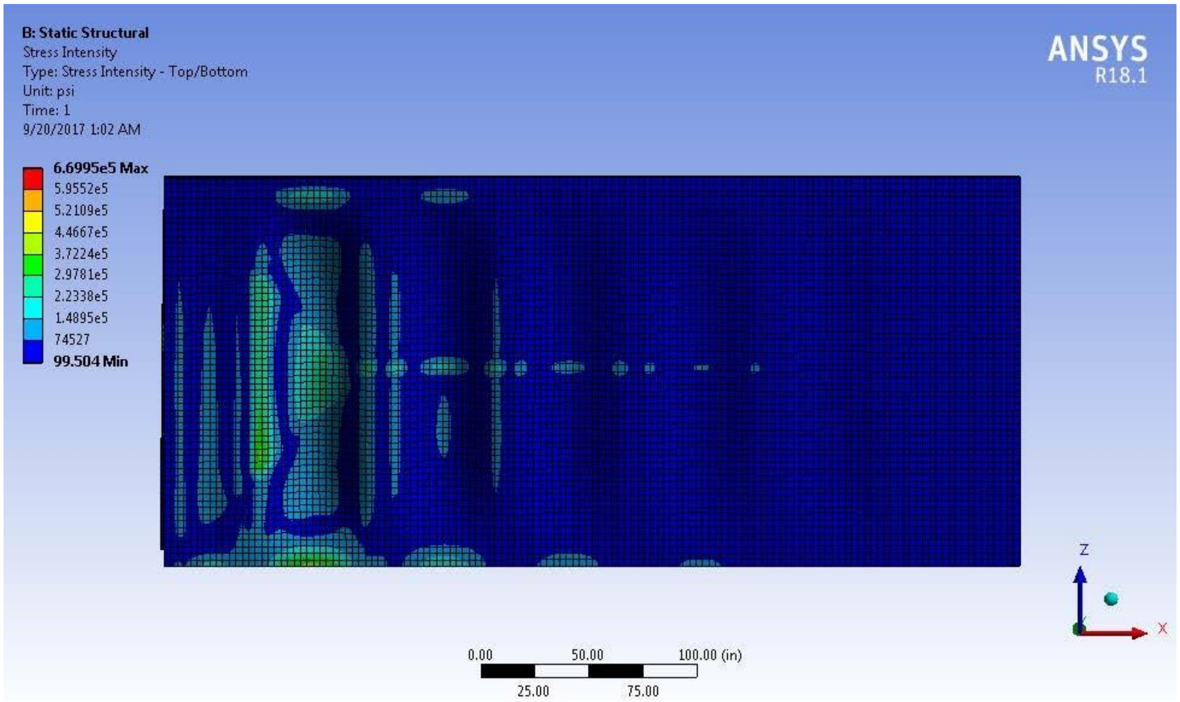

Figure 10: Stress Intensity

All other stress locations show areas of high stress, but no failures. It does appear that the failure area on this vertical would not cause complete failure of this upright or the full support structure.

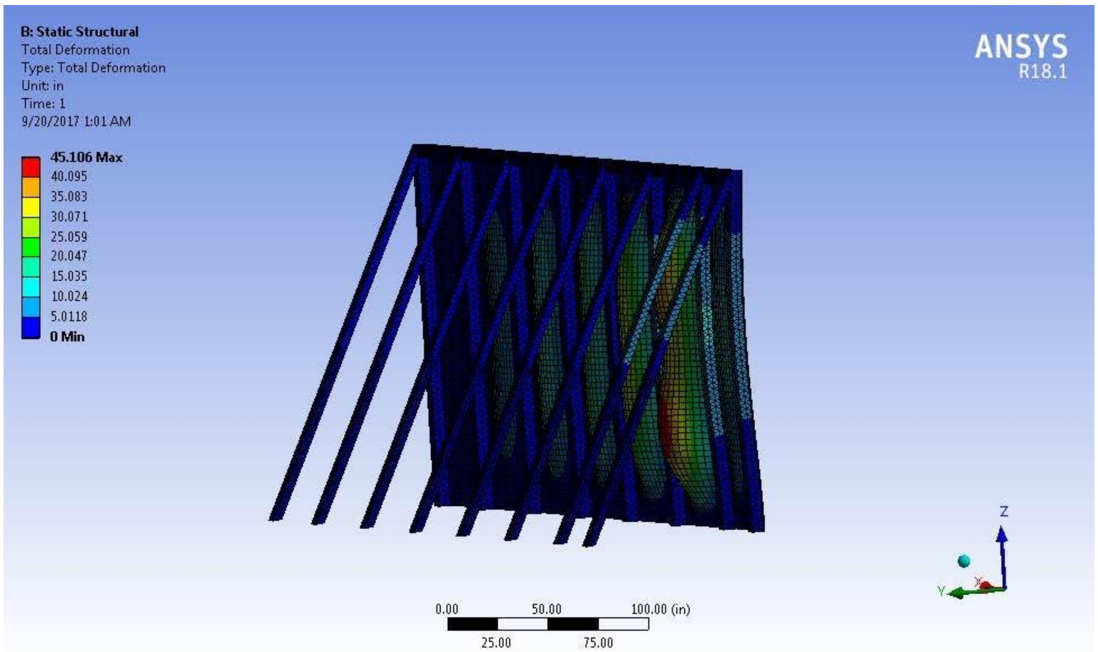

Figure 11: Displacement of Steel Support Structure

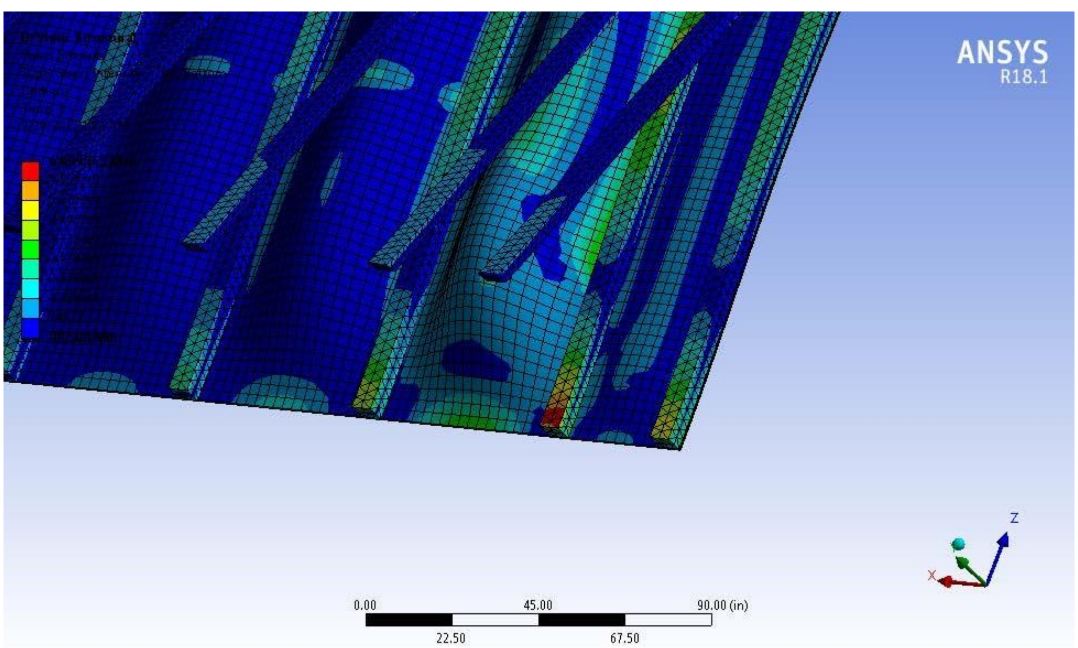

Figure12: Stress Intensity of Support Structure

100lbs RDX Safe Area Analysis

To determine the pressures in the Safe Area, the shockwave is propagated over the first Xtegra™ Blast Curtain and down the building to the Safe Area. It should be noted here, that to find the 2-psi level, pressures were taken at 6-foot point from ground level. This location allows for a 6-foot person to stand at any location within the Safe Area and these are representative of the pressures his head would see. We know that the pressures below this level will be lower. Thus, if 2 psi is achieved at this 6-foot level, below that height would also be considered safe.

The first attempt at this showed that pressures in the Safe Area, 40 feet away, were way above the 2-psi required for human safe operations. Because of this, a second Xtegra™ Curtain was placed at the 40foot location; running 33 feet away from the building. This second Xtegra™ Curtain provides a second pressure drop in an attempt to get the Safe Area pressures down to the safe 2 psi level. Figure 13 shows the Pressure Plot of this area. It can be seen that the pressures between the first curtain and the second curtain exceed 2 psi in all areas. With the addition of the second curtain, we have a small area that is below 2 psi. The rest of that area is considered "not safe". As a result, 100 lbs of RDX not only causes damage to the first curtain support, but does not result in the desired safe work area.

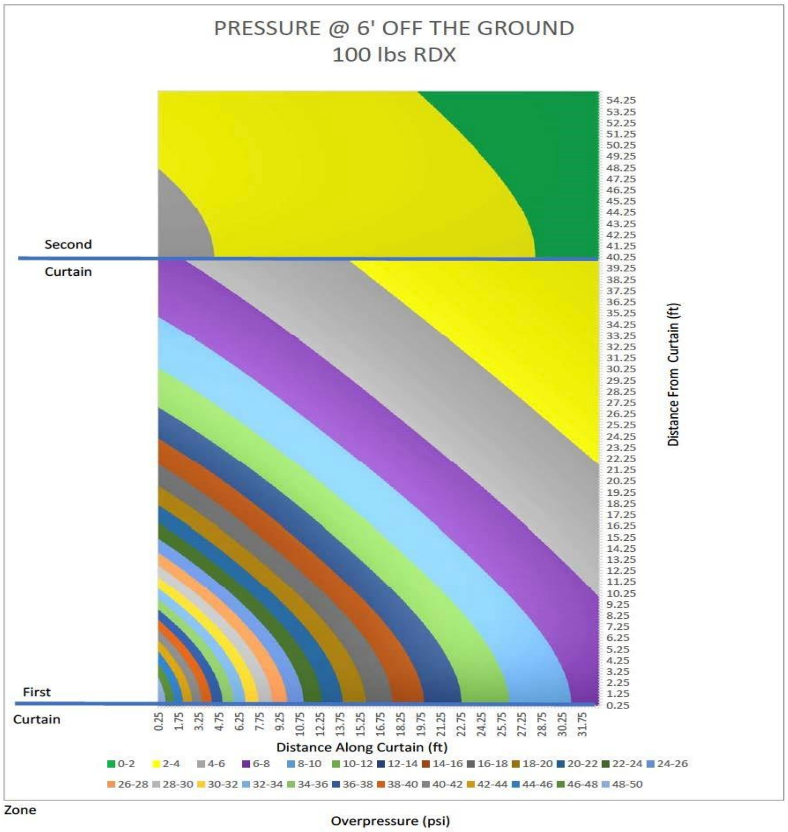

Figure 13: Pressure Plot from First Curtain to Safe Area 100 lbs RDX.

50 lbs RDX Analysis

Because of the Xtegra™ fabric's failure modes seen in the 100 lbs RDX case, a second analysis was conducted with a 50lbs RDX explosive. The same process was used to develop a pressure profile for the lower amount of explosive (Figure 13). In this second case, the maximum overpressure is reduced to 191 psi; this value indicated a two layers Xtegra™ Blast Curtain fabric is needed.

The Model was updated with the new pressure profile and using the new two-layer Xtegra™ Blast Curtain. The FEA analysis was rerun with the new settings generating a new set of Displacements and Stress Outputs. Looking at the displacement of the two-layer Xtegra™ curtain showed a more reasonable displacement of 25 inches (Figure 14). The reasonableness of this displacement was confirmed by looking at the Stress Intensity (Figure 15) showing that values are about five times lower and do not indicate large failures. Again, the same areas next to the verticals and the along the middle attachment rope are where the high stress area are shown.

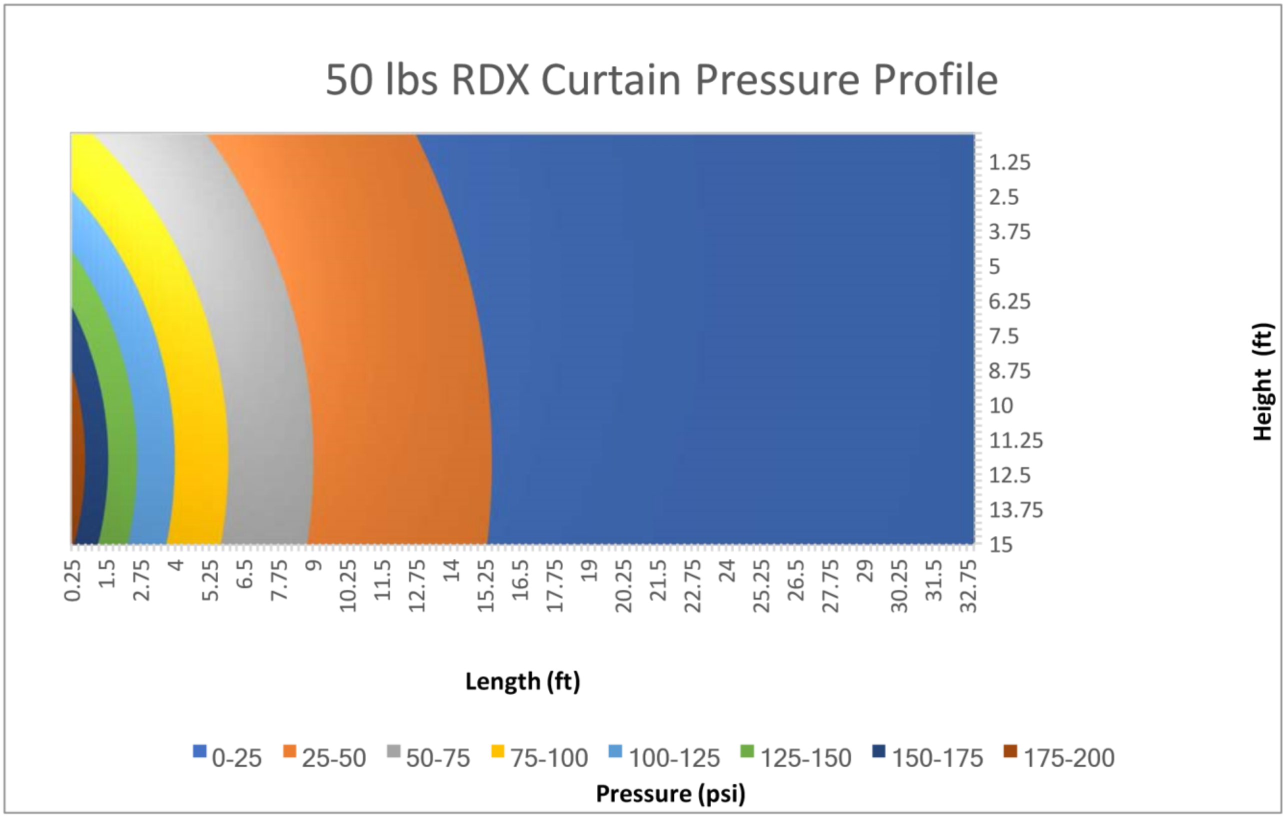

Figure 14: 50lbs RDX Pressure Profile

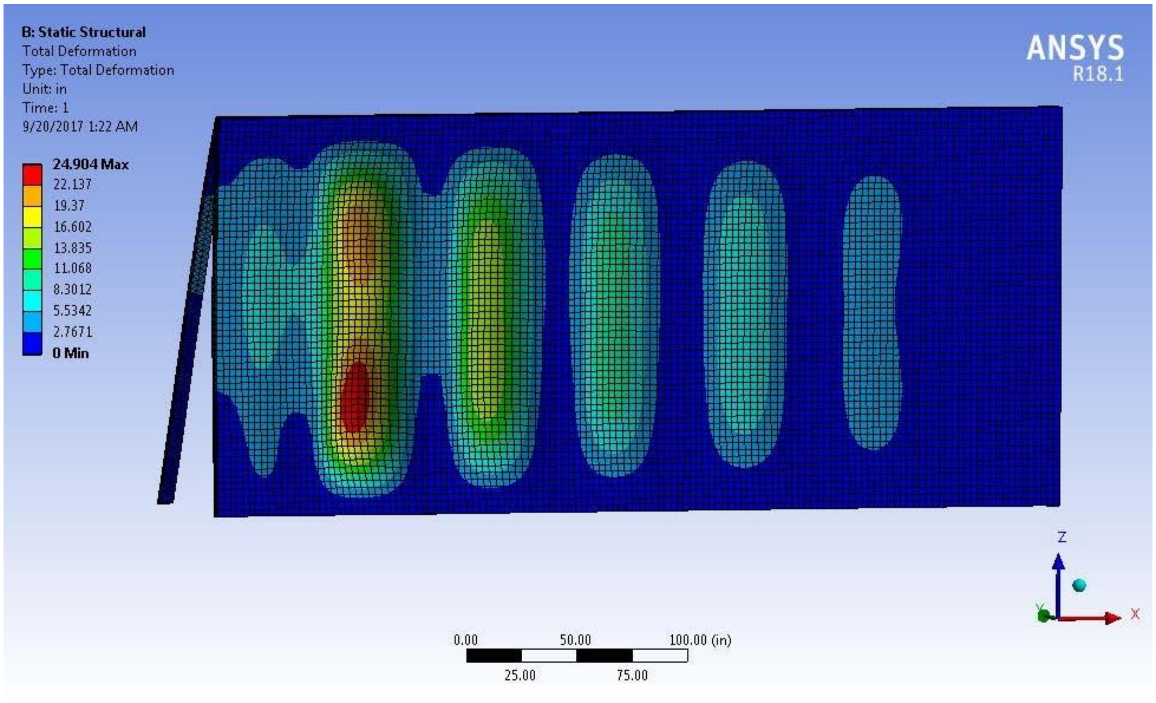

Figure15: 50lbs RDX Displacement Plot

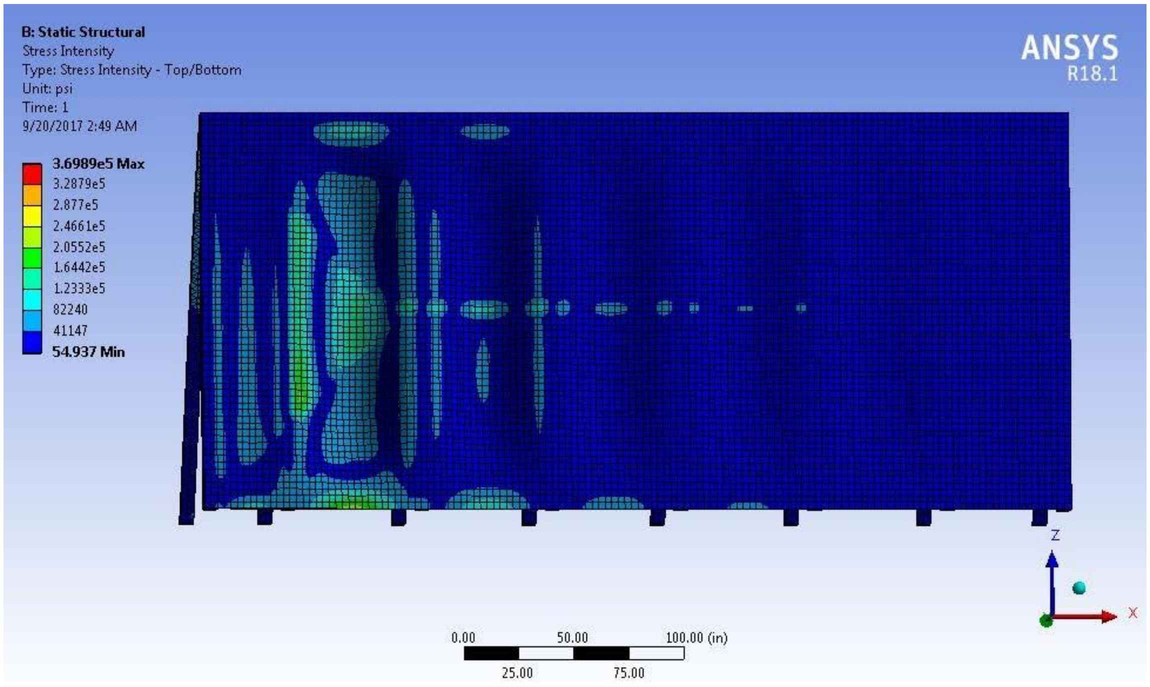

Figure 16: 50lbs RDX Stress Intensity Plot

To be complete, the Support Structure Displacement is examined (Figure 16). As with the Xtegra™ Blast Curtain, the support structure shows smaller displacements and there are no indications of any failure areas. It also shows that if there are permanent displacements, they will be fairly small.

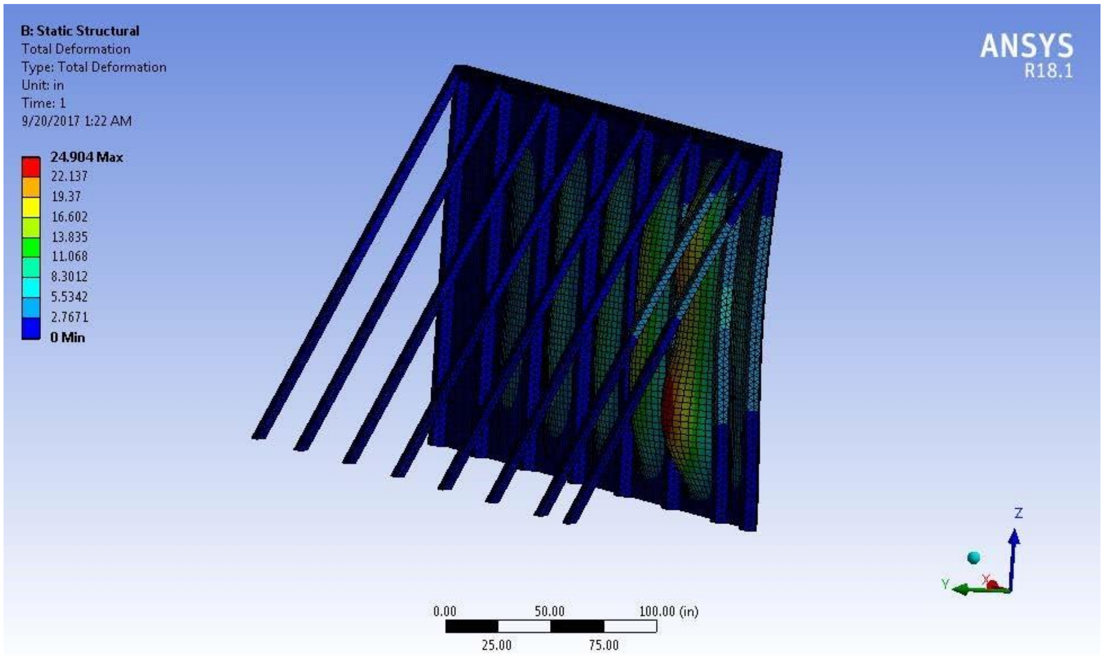

Figure 16: 50 lbs Support Structure Displacement Plot

50lbs RDX Safe Area Analysis

A second Xtegra™ Blast Curtain was again placed at the 40-foot location, running 33 feet away from the building. This second Xtegra™ Curtain provides a second pressure drop in an attempt to bring the Safe Area pressures down to the safe 2 psi level. Figure 18 shows the Pressure Plot of this area. It can be seen that the pressures between the first and the second Xtegra™ curtains exceed 2 psi in all area; except for a small corner, just before the second curtain. After the second Xtegra™ Curtain, we have a large area that is below 2 psi. The rest of the area is considered “not safe”, but is just over the 2 psi level. As a result, 50 lbs of RDX and the two Xtegra™ Blast Curtains result in large area of human safe working area.

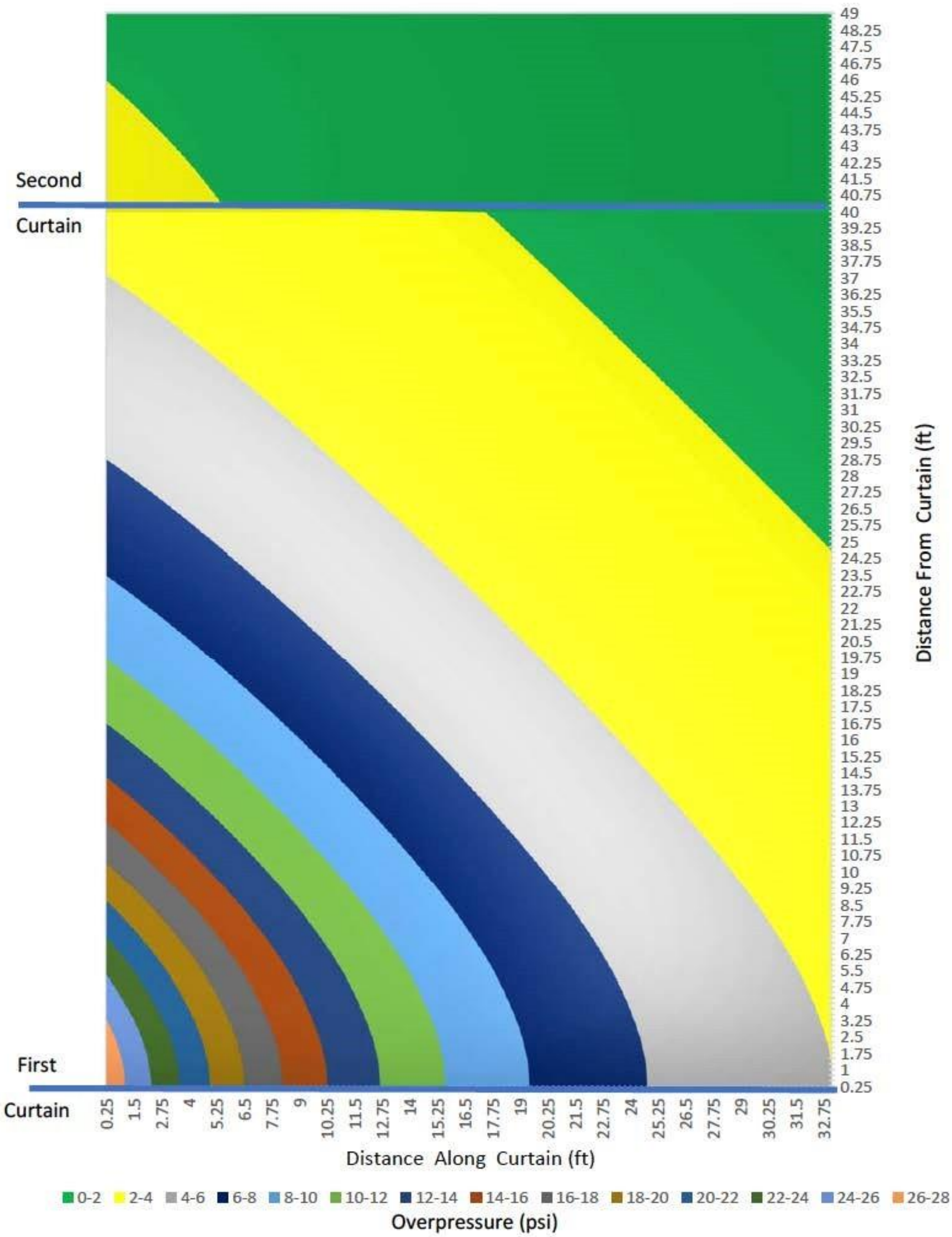

Figure 18: Pressure Plot from First Curtain to Safe Area 50 lbs RDX.

Scenario 2: Second Configuration Analysis

At the request of Schlumberger, a second configuration has been analyzed. In this case, the explosive area is on the left side and the Safe Area is just behind the first Xtegra™ Blast Curtain (Figure 18). The distance from the explosive area to the first Xtegra™ Blast Curtain is about 36 feet. The Xtegra™ Curtain is the same as above, with the same steel frame. For this analysis, the square building is not modeled. This scenario was, as simulated previously, with 100 lbs RDX and 50 lbs RDX.

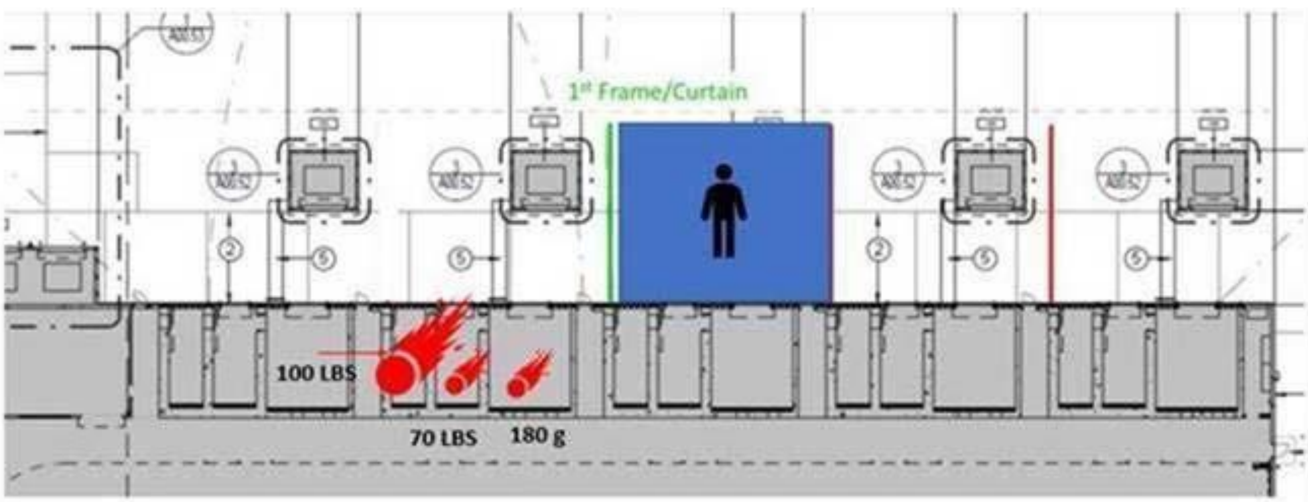

Figure 18: Analysis for Single Curtain Safe Area

Scenario 2: 100 lbs RDX Analysis

The Model was updated with the new arrangement and pressure profile for a Xtegra™ Blast Curtain 36.2 from the explosive chamber. The pressure profile for this Xtegra™ Blast Curtain is shown in Figure 19 and Figure 20. The FEA analysis was rerun on the new settings and generated a new set of Displacements and Stress outputs. For the safety margin; a 3-layer Xtegra Curtain is used. Looking at the Displacement of the Xtegra™ Curtain, a much more reasonable displacement of 11.6 inches is shown (Figure 21). The reasonableness of this displacement is confirmed by looking at the Stress Intensity (Figure 22) showing that values are well below failure loads. Again, the same areas next to the verticals and the along the middle attachment rope locations are where we see the higher stress areas. To be complete, the Support Structure Displacement is examined. The support structure shows very smaller displacements of less than 0.5 inches and there are no indications of any failure areas, nor any permanent deformations. As in the above analysis of the original scenario, the pressures in the Safe Area were examined.

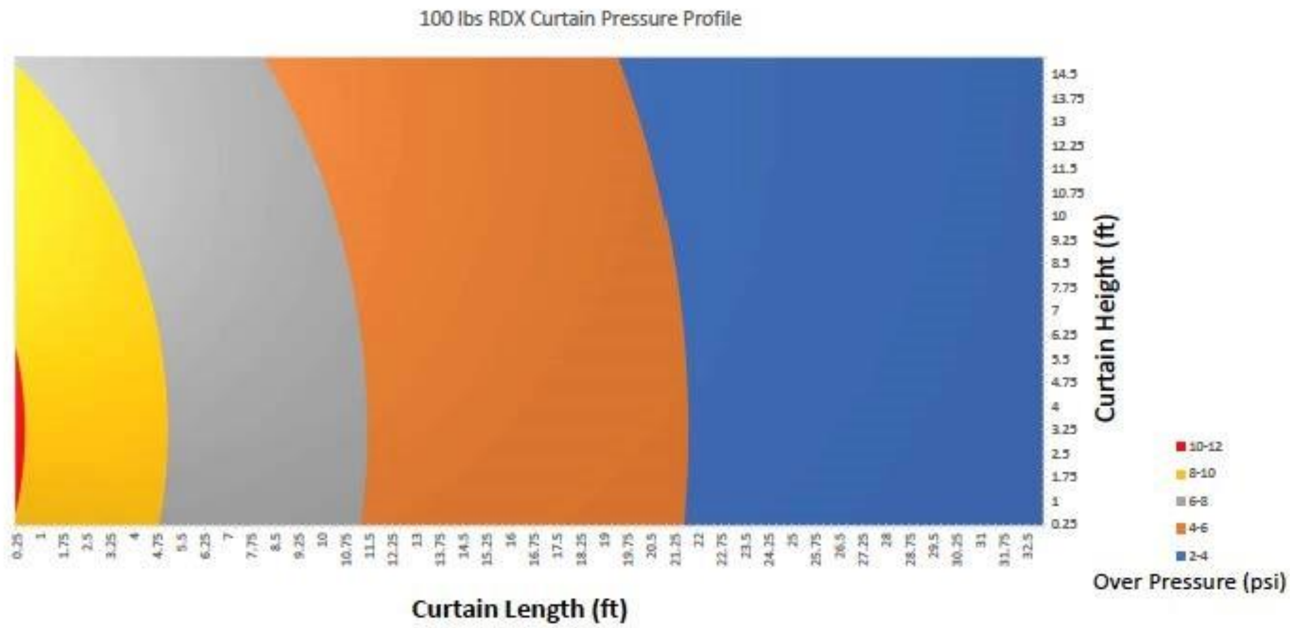

Figure 19: 100 lbs RDX Pressure Profile; Scenario 2 (viewed from the right side of the Curtain)

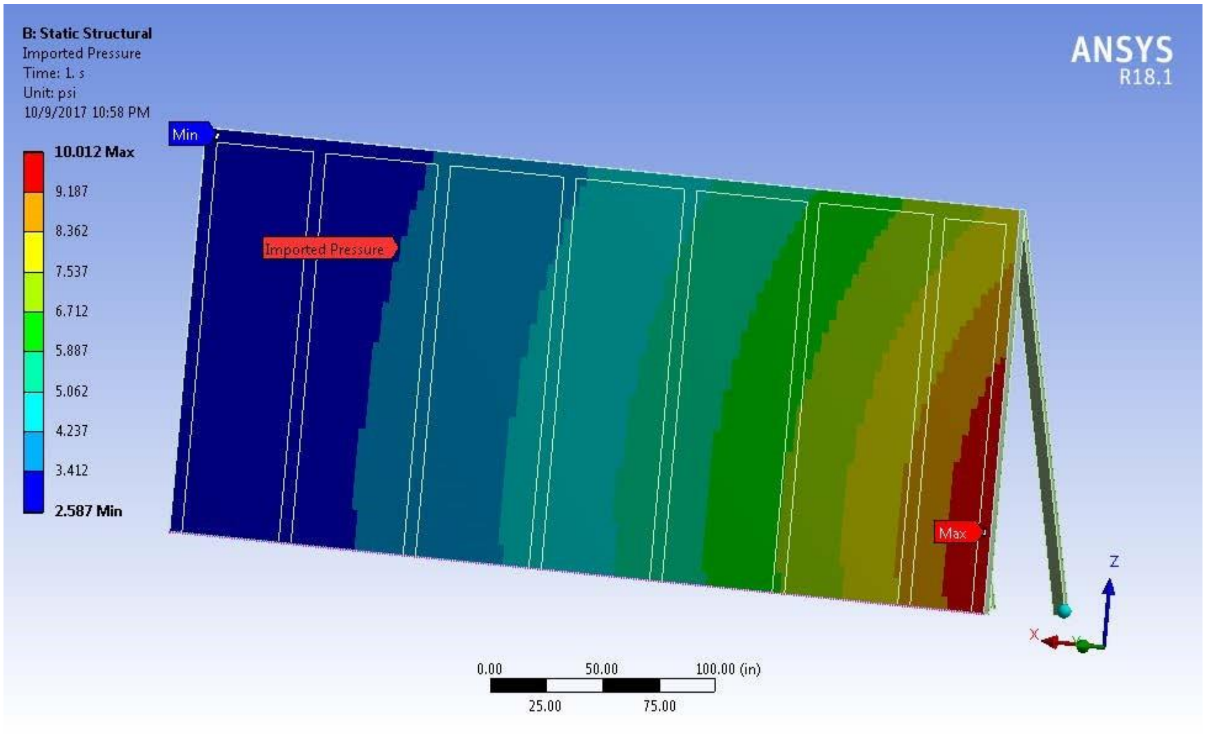

Figure20: 100 lbs RDX Shockwave Overpressure Pressure Plot; Scenario 2 (Applied to the Frame – Xtegra™ Curtain Structure viewed from the left side of the curtain)

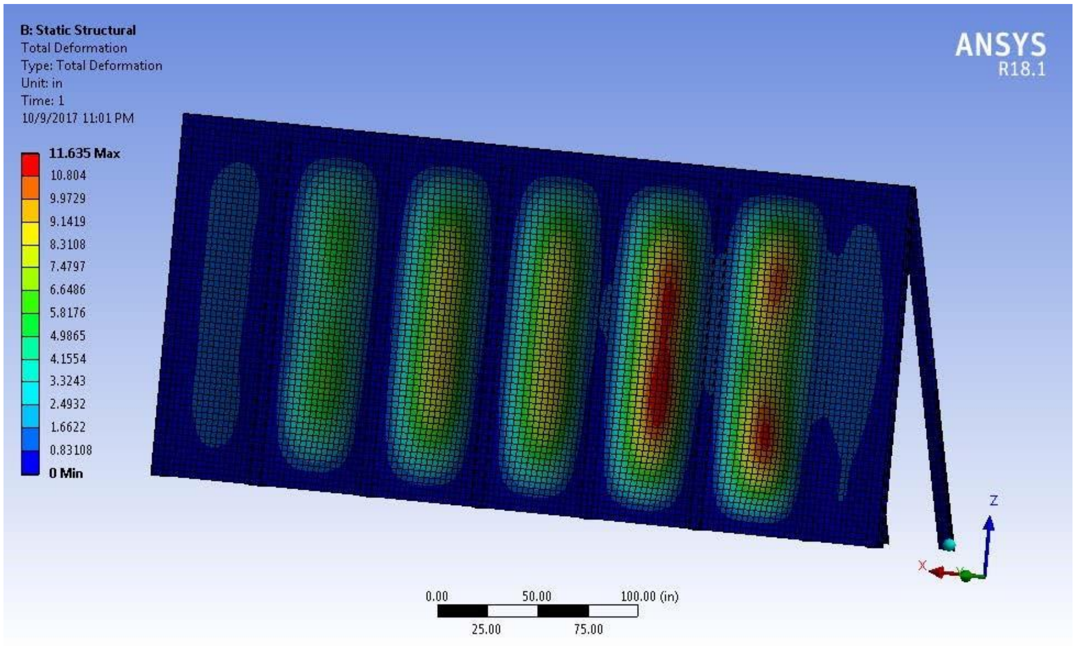

Figure21: 100 lbs RDX Displacement Plot; Scenario 2

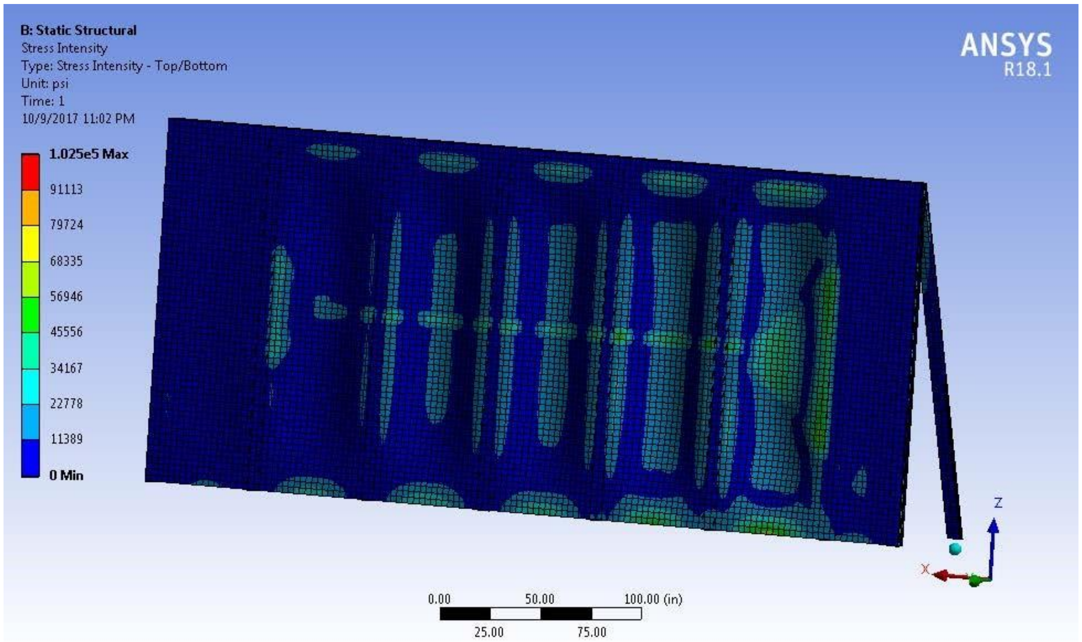

Figure 22: 100 lbs RDX Stress Intensity Plot; Scenario 2

Scenario 2: 100 lbs RDX Safe Area Analysis

Figure 23 shows the Pressure Plot of the Safe Area, just to the right of the 3-layer Xtegra™ Curtain. In this case, one third of the area is below 2-psi, but there still are two thirds of the area that is above the safe overpressure level. This area is considered “unsafe” for a human work area, but maxes out at only 4-psi level. As a result, 100 lbs of RDX does not present an overpressure level that would allow this to be a human work area.

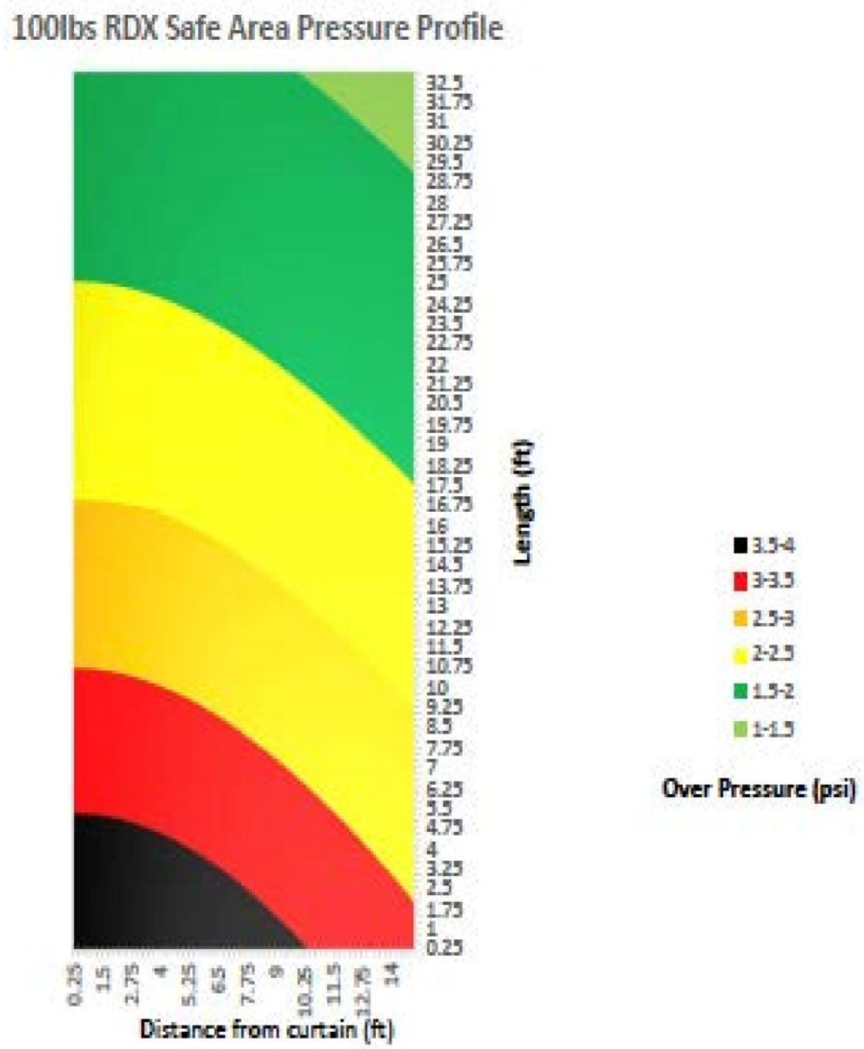

Figure 23: Safe Area Overpressure Plot for 100lbs of RDX; Scenario 2

Scenario 2: 50lbs RDX Analysis

The Model was updated with the new arrangement and pressure profile for a 50 lbs RDX explosion and is applied to the Xtegra™ Curtain; 36.2 feet from the explosive chamber. The pressure profile for this curtain is shown in Figure 24 and Figure 25. The FEA analysis was re-ran on the new parameters and pressures to generate a new set of Displacements and Stress outputs. To maintain a good safety margin, only 2 layers of Xtegra™ fabric were needed in this curtain. Looking at the Displacement of this curtain, it shows a displacement of 16.3 inches (Figure 26). With this Displacement, the Stress Intensity (Figure 27), confirms that the stress values are well below failure loads. As with all the other analyzed examples, the areas next to the verticals and the along the middle attachment rope locations are where we see the highest stress areas. Support Structure Displacement is examined and the. The support structure shows a much smaller displacement, less than 0.3 inches and there are no indications of any failure areas or any permanent damage.

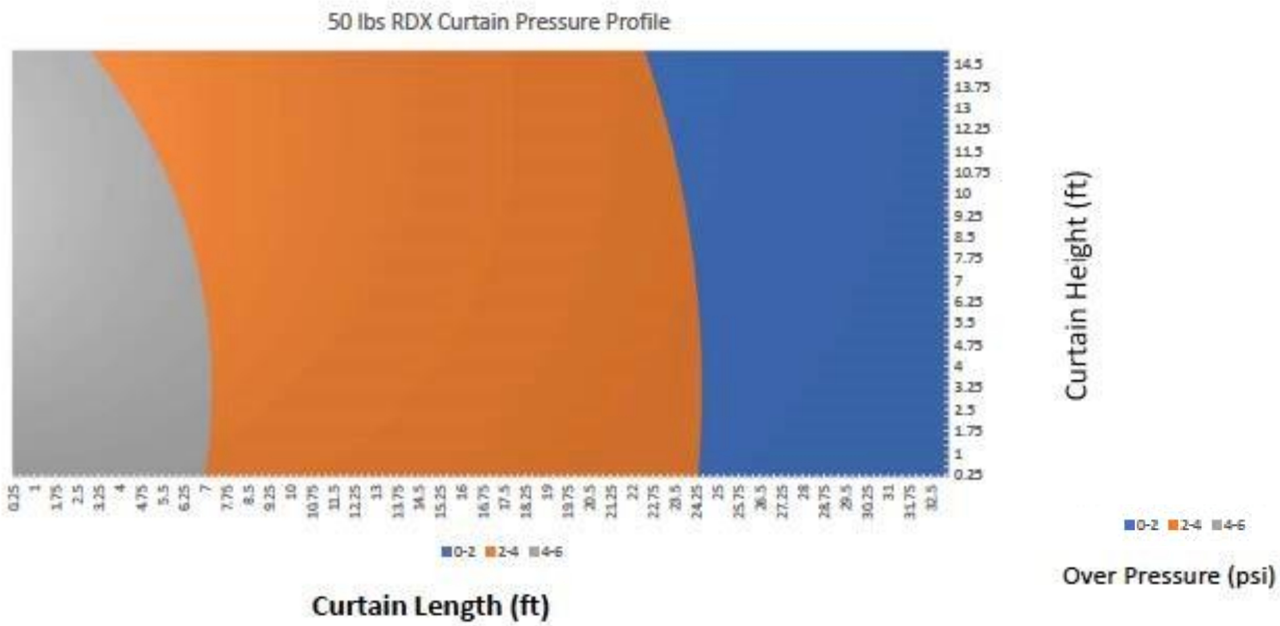

Figure24: 50 lbs RDX Shockwave Pressure Plot; Scenario 2 (viewed from the left side of the Curtain)

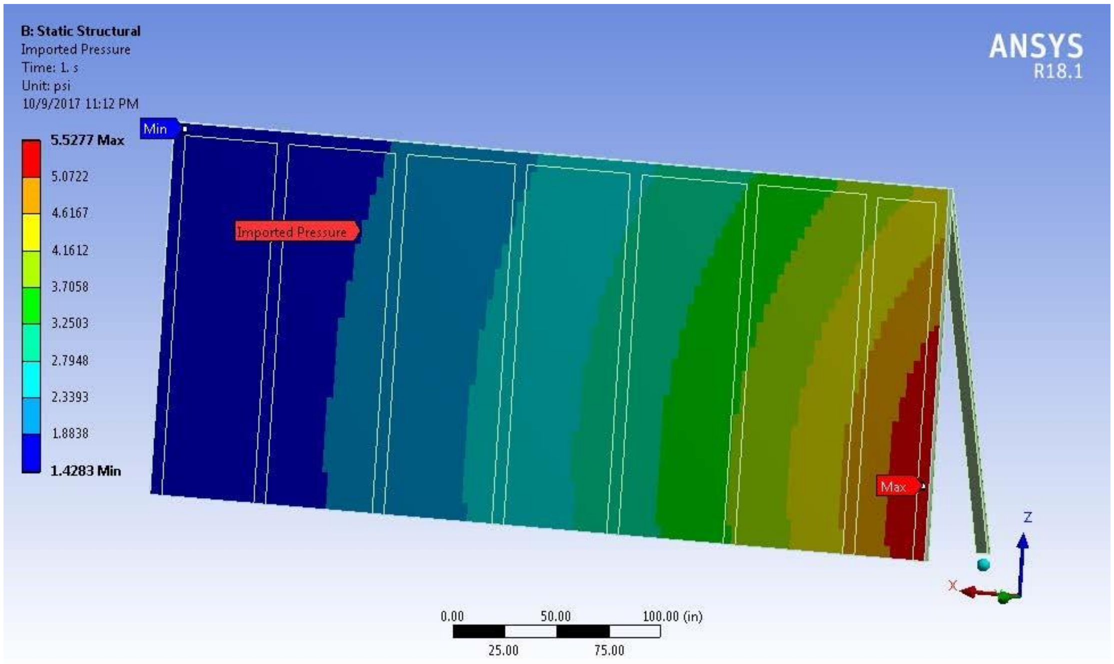

Figure25: 50 lbs 100 lbs RDX Shockwave Pressure Plot; Scenario 2 (applied to the Frame – Curtain Structure viewed from the right side of the Xtegra™ Curtain)

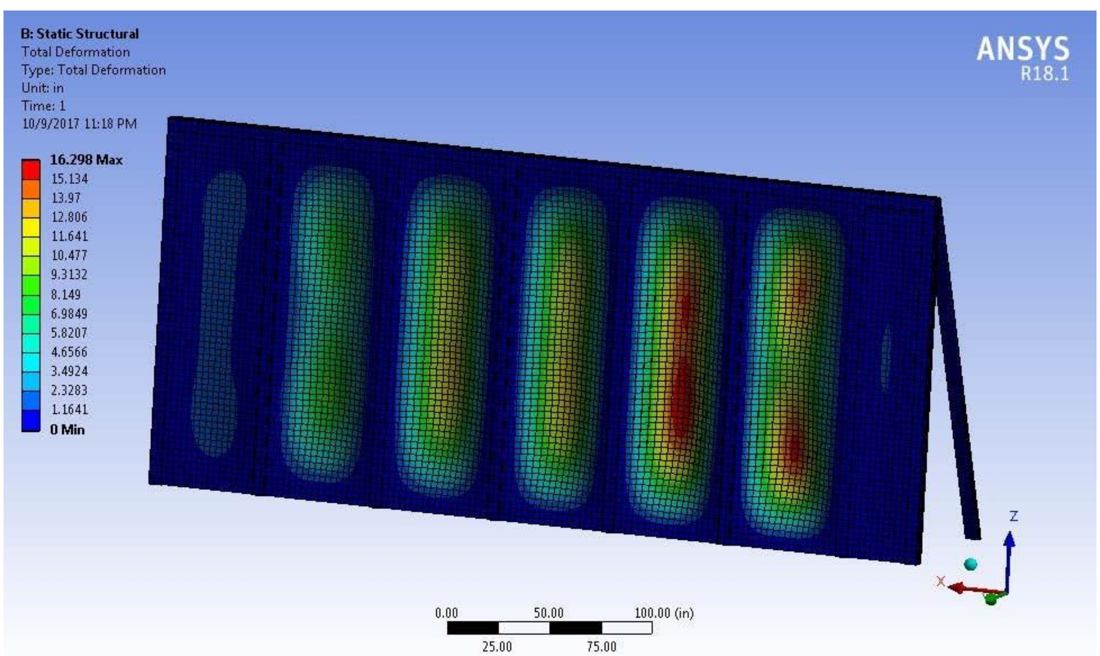

Figure 26: 50 lbs RDX Displacement Plot; Scenario 2

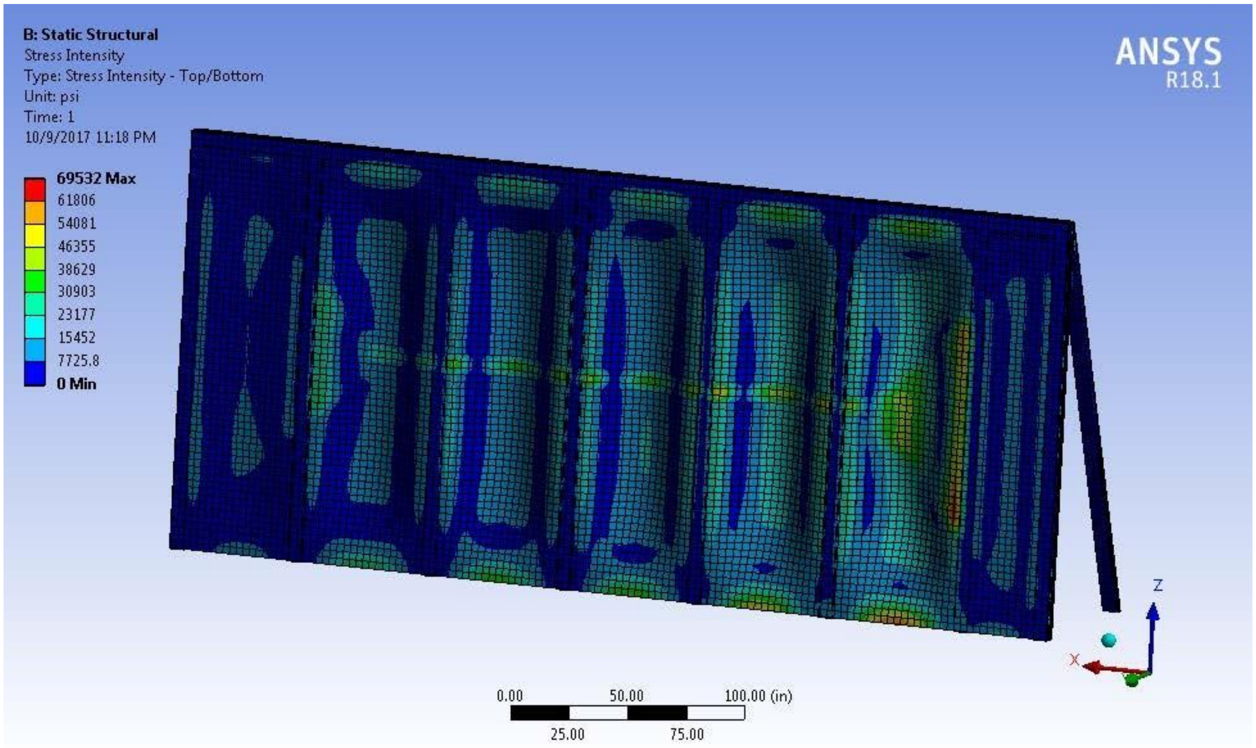

Figure 27: 50 lbs RDX Stress Intensity Plot; Scenario 2

Scenario 2: 50 lbs RDX Safe Area Analysis

Figure 27 shows the pressure plot of the safe area, just to the right of the 2-layer *Xtegra™* Curtain. In this scenario, about 90% of the area is below 2-psi, but still have a small area that is above the safe overpressure level. That small area is just over the "unsafe" for a human work area at 2.2-psi level. With the Pressure Model being used for this analysis being a conservative model, the 2.2 psi area could be considered with in the error range. If this is an acceptable assumption, it would be possible to rate this area as "human safe". In the worst case scenario, this small area is mostly in the area of the support structure for the frame and could be cordoned off as a Do Not Enter area. This would leave a large work area that could be considered "human safe".

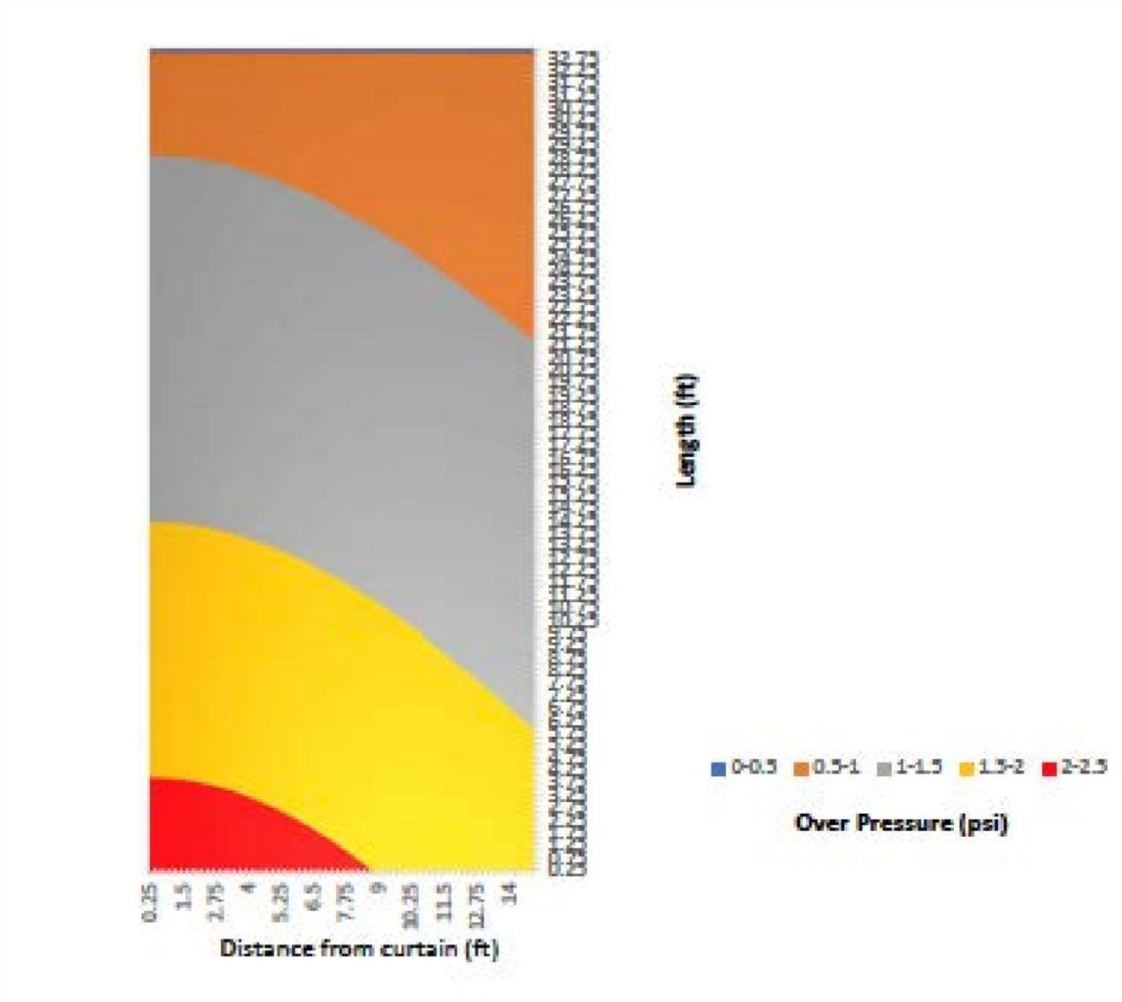

Figure 28: Safe Area Overpressure Plot; Scenario 2, for 50lbs of RDX

Again, a second Xtegra™ Blast Curtain was placed at the 40-foot location, running 33 feet away from the building. This second Xtegra™ curtain provides a second pressure drop in an attempt to get the Safe Area pressures down to the safe 2 psi level. Figure 18 shows the Pressure Plot of this area. It can be seen that the pressures between the first curtain and the second curtain exceed 2 psi in all areas; except for a small corner just before the second curtain. After the second curtain, we have a large area that is below 2 psi. The rest of the area is considered “not safe”, but is just over the 2 psi level. As a result, 50 lbs of RDX and the two Xtegra™ Curtains result in large area of “human safe” working area.

Conclusions

The 100 lbs of RDX presents a very large and damaging Overpressure Profile. This Analysis shows that the Support Structure will survive this large blast, but with some permanent damage. The 4-layer Xtegra™ Blast Curtain has a very large displacement and show that it is heavily damaged in the blast. The design of the Support Structure is just enough to survive this heavy overpressure and allow the Xtegra™ fabric to take the large hit. When the Xtegra™ Curtain fabric is restricted more by making the space between uprights smaller; it increased the load on the Support Structure and resulted in the complete failure of the second upright. This modification to the Support Structure was only a quick look, but provided the results that were expected when the Auxetic fabric is over restricted and not allowed to absorb the energy of the overpressure wave. The Safe Area, even with a second Xtegra™ Blast Curtain does not result in a "safe working area" with overpressures below 2 psi.

The 50 lbs of RDX case shows that the Shockwave Pressure Profile is much smaller and that the Displacements and Stresses on both the Support Structure and Xtegra™ Blast Curtains are well within the bounds of the materials. In this case, a large area of the Safe Area is below the 2- psi level and might be considered "human safe".

With the second analysis in the Scenario 2, switching the Safe Area and the Explosive Area results in much different results in both the 100 lbs and 50 lbs RDX analysis.

For the 100 lbs RDX detonation in Scenario 2, we see that the pressures on the Xtegra™ Blast Curtains are much lower. This is because the shockwave has expanded and in that expansion the overpressure is reduced.
In this 100 lbs analysis, the max overpressure is around 10 psi. This is still a very dangerous pressure level, but one that can easily be handled by the 3-layers Xtegra™ Curtain fabric and the steel frame support structure. In the Safe Area, about 1/3 of the area that is below the 2-psi safe level, at six feet above the ground. It still leaves two thirds of the area from 2-psi to 4-psi. These are not very high, but generally considered "not safe" for a human work area.

The 50 lbs RDX detonation in Scenario 2 shows a much better pressure situation. The overpressures that are seen by the 2-layer Xtegra™ Curtains max out at 5.5 psi. Again, easily handled by a 2-layer Xtegra™ Curtains and support frame. This Scenario also shows a Safe Area that is 90% below the 2psi human safe level. The small area that is above 2-psi maxes out at 2.2 psi. This is above the human safe value, but within the conservative error range of this analysis.

The bottom line is that in both scenarios, the 100lbs RDX explosive charge presents a case that exceeds AFT's ability to bring the pressures down to a safe level throughout the Human Workspace. The above Analysis is conservative and so the predicted pressures should be higher than we see in an actual event, but the margin in this conservative approach varies. This is especially true around corners and in areas were the shockwave can reflect off of walls and other objects. As such AFT cannot recommend a solution that we consider "human safe" for 100 lbs of RDX.

The 50 lbs of RDX cases, and especially the Scenario 2 case, do show that AFT's Xtegra™ Blast Curtain solutions can provide "human safe" work areas. The 50 lbs; Scenario 2, case only exceeds the 2 psi value in a small area and by a very small margin of 0.2 psi at the six-foot level. With the conservative approach to this Analysis AFT feels that this solution is within the "human safe" range. If the assumption that the 0.2 psi over is unacceptable, this small area could be cordoned off, allowing for 90% of the space as usable.

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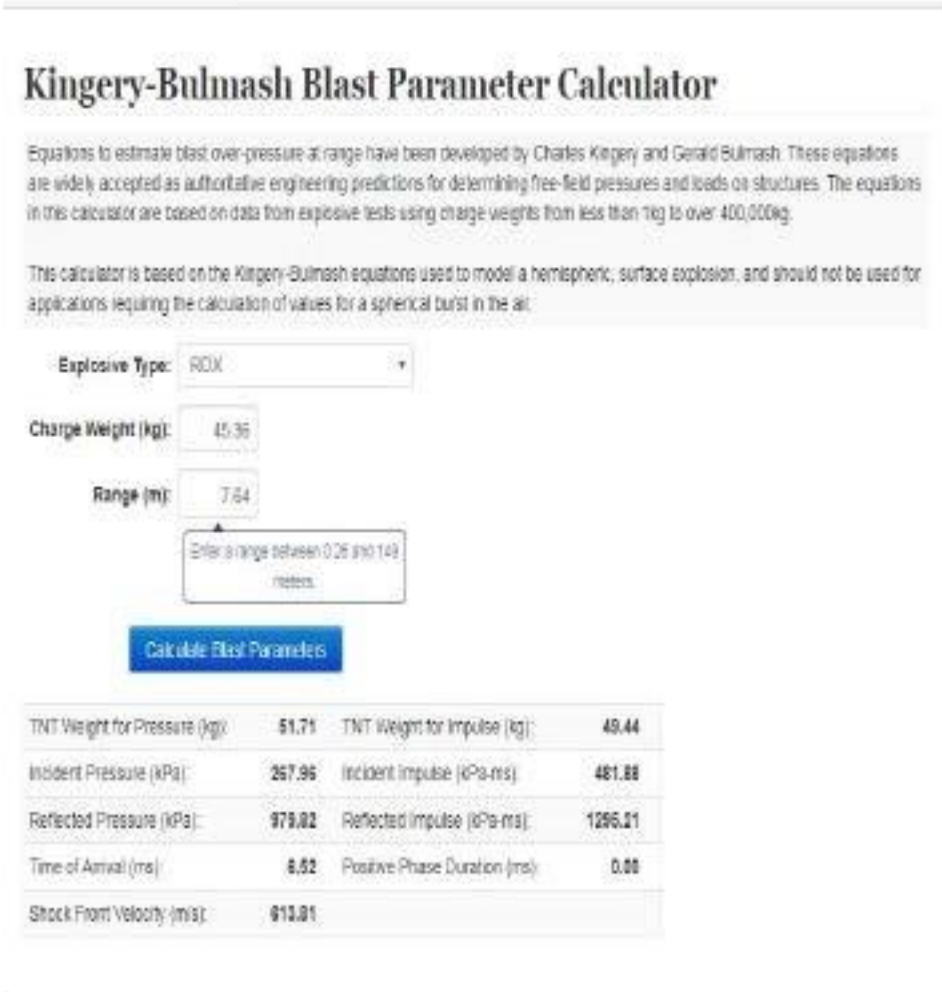
Appendix A:

Kingery-Bulmash Blast Parameter Equations Calculator



Kingery-Bulmash Blast Parameter Calculator

Equations to estimate blast over-pressure at range have been developed by Charles Kingery and Gerald Bulmash. These equations are widely accepted as authoritative engineering predictions for determining free-field pressures and loads on structures. The equations in this calculator are based on data from explosive tests using charge weights from less than 1kg to over 400,000kg.

This calculator is based on the Kingery-Bulmash equations used to model a hemispheric, surface explosion, and should not be used for applications requiring the calculation of values for a spherical burst in the air.

Explosive Type: RDX

Charge Weight (kg): 45.36

Range (m): 7.64

Enter a range between 0.26 and 149 meters.

Calculate Blast Parameters

TNT Weight for Pressure (kg):	51.71	TNT Weight for Impulse (kg):	49.44
Incident Pressure (kPa):	267.96	Incident Impulse (kPa-ms):	481.88
Reflected Pressure (kPa):	979.82	Reflected Impulse (kPa-ms):	1296.21
Time of Arrival (ms):	6.52	Positive Phase Duration (ms):	0.00
Shock Front Velocity (m/s):	613.01		

Kingery-Bulmash Blast Parameter Calculator

Equations to estimate blast over-pressure at range have been developed by Charles Kingery and Gerald Bulmash. These equations are widely accepted as authoritative engineering predictions for determining free-field pressures and loads on structures. The equations in this calculator are based on data from explosive tests using charge weights from less than 1kg to over 400,000kg.

This calculator is based on the Kingery-Bulmash equations used to model a hemispheric surface explosion, and should not be used for applications requiring the calculation of values for a spherical burst in the air.

Explosive Type: RDX

Charge Weight (kg): 45.36

Range (m): 12.73

Enter a range between 1.26 and 149 meters

Calculate Blast Parameters

TNT Weight for Pressure (kg):	**51.71**	TNT Weight for Impulse (kg):	**49.44**
Incident Pressure (kPa):	**88.43**	Incident Impulse (kPa-ms):	**303.71**
Reflected Pressure (kPa):	**206.38**	Reflected Impulse (kPa-ms):	**708.13**
Time of Arrival (ms):	**16.38**	Positive Phase Duration (ms):	**11.46**
Shock Front Velocity (m/s):	**480.55**		

Kingery-Bulmash Blast Parameter Calculator

Equations to estimate blast over-pressure at range have been developed by Charles Kingery and Gerald Bulmash. These equations are widely accepted as authoritative engineering predictions for determining free-field pressures and loads on structures. The equations in this calculator are based on data from explosive tests using charge weights from less than 1kg to over 400,000kg.

This calculator is based on the Kingery-Bulmash equations used to model a hemispheric, surface explosion, and should not be used for applications requiring the calculation of values for a spherical burst in the air.

Explosive Type: RDX

Charge Weight (kg): 45.36

Range (m): 5.66

Enter a range between 0.26 and 149 meters

Calculate Blast Parameters

TNT Weight for Pressure (kg):	**61.71**	TNT Weight for Impulse (kg):	**49.44**
Incident Pressure (kPa):	**634.87**	Incident Impulse (kPa-ms):	**642.25**
Reflected Pressure (kPa):	**2433.45**	Reflected Impulse (kPa-ms):	**1880.48**
Time of Arrival (ms):	**3.72**	Positive Phase Duration (ms):	**0.00**
Shock Front Velocity (m/s):	**796.83**		

Kingery-Bulmash Blast Parameter Calculator

Equations to estimate blast over-pressure at range have been developed by Charles Kingery and Gerald Bulmash. These equations are widely accepted as authoritative engineering predictions for determining free-field pressures and loads on structures. The equations in this calculator are based on data from explosive tests using charge weights from less than 1kg to over 400,000kg.

This calculator is based on the Kingery-Bulmash equations used to model a hemispheric, surface explosion, and should not be used for applications requiring the calculation of values for a spherical burst in the air.

Explosive Type: RDX

Charge Weight (kg): 45.36

Range (m): 4.24

Enter a range between 0.26 and 149 meters.

Calculate Blast Parameters

TNT Weight for Pressure (kg):	**51.71**	TNT Weight for Impulse (kg):	**49.44**
Incident Pressure (kPa):	**1026.59**	Incident Impulse (kPa-ms):	**815.47**
Reflected Pressure (kPa):	**5695.62**	Reflected Impulse (kPa-ms):	**2732.82**
Time of Arrival (ms):	**2.17**	Positive Phase Duration (ms):	**6.18**
Shock Front Velocity (m/s):	**1053.57**		