



Report
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Impact Analysis of Protect-It Maxi

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1. Executive Summary

The Protect-it Maxi has been developed to offer a modular column protection device that is capable of being fitted to a variety of standard column sizes.

The Maxi's impact capability was initially developed to withstand the (European Code FEM 10.2.02) impact testing requirement. Due to market demands the need to protect against higher impact energies, such as forklift collisions has prompted this analysis of the Maxi impact capacity.

The individual Maxi exhibits principally linear elastic behaviour for impacts with an energy content below 400 [N.m] or [J]

This characteristic is not untoward as the device should be sacrificial as long as it ensures the column is protected.

Table 1: Maxi Performance for various Impact Energies

| Impact Energy [N.m]¹ | Forklift Speed² [km/hr] (mile/hr) | <u>Without Protect-it MAXI installed</u> | <u>With Protect-it MAXI installed</u> |
|--|---|--|---|
| < 400 ³ | < 2.0 (1.1) | Possible permanent damage the column (local impact region) | No damage to Protect-it MAXI or the column. |
| = 400 ³ | = 2.0 (1.1) | Permanent damage the column | No damage to the column. Minor damage to Protect-it MAXI but is still functional |
| 1200 ⁴ | 3.5 (2.0) | Permanent damage the column | No damage to the column. Minor damage to Protect-it MAXI but is still functional |
| 3750 ⁴ | 6.0 (3.3) | Permanent damage the column | No damage to the column. Some Maxi units may need replacing |

¹ Units of impact Energy can be expressed as Newton*meter [N.m] which is equivalent to a Joule [J] which is equivalent to 0.737 foot*pounds [ft.lb].

² Forklift weight is 2.7 [ton] or 6000 [lbs].

³ This corresponds to localised impact, such as fork point on forklift.

⁴ An impact with a forklift bumper would in a typical installation involve at least 3 Protect-It Maxis. Three Protect-It Maxi's were used in these impact conditions.

2. Introduction

The Protect-it Maxi is a new modular impact protection device. It is manufactured from HDPE (impact Grade) and its design allows it to absorb the applied impact loads in a spring like manor, thus reducing the peak load associated with an impact from damaging the column. The modular nature allows the device to be fitted to a large range of structural column sizes, from as little as 4 inches to 20 inches.

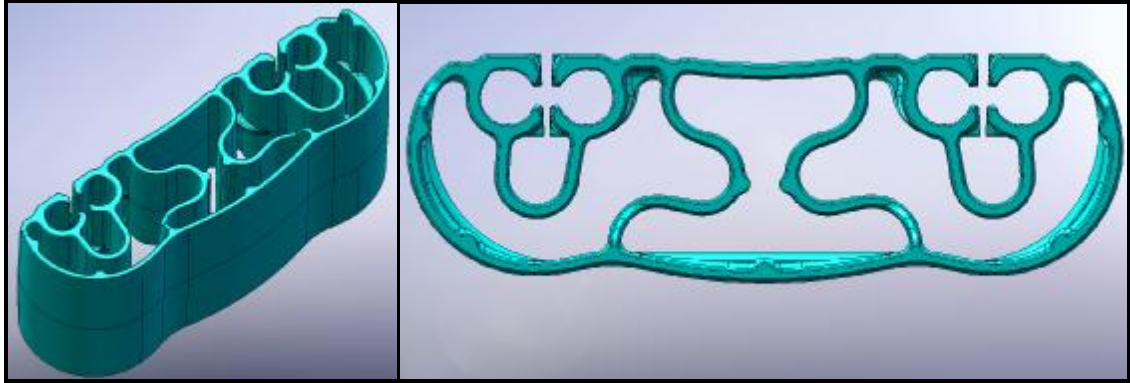


Figure 1: Protect-it Maxi

The protect-It Maxi's are assembled in a stack arrangement using a set of pins to inter-connect the individual pieces, see Figure 2 below.

This report covers the structural loading of the Protect-It Maxi and in particular its impact energy absorption capacity. The structural analysis models consider the behaviour of the Protect-It Maxi in both the linear elastic and non-linear plastic deformation modes.

A finite element technique has been used to assess the structural response of the structures. Attention has been applied to the non-linear plastic deformation of the device as the Maxi is a sacrificial element which can be replaced following a high energy impact.

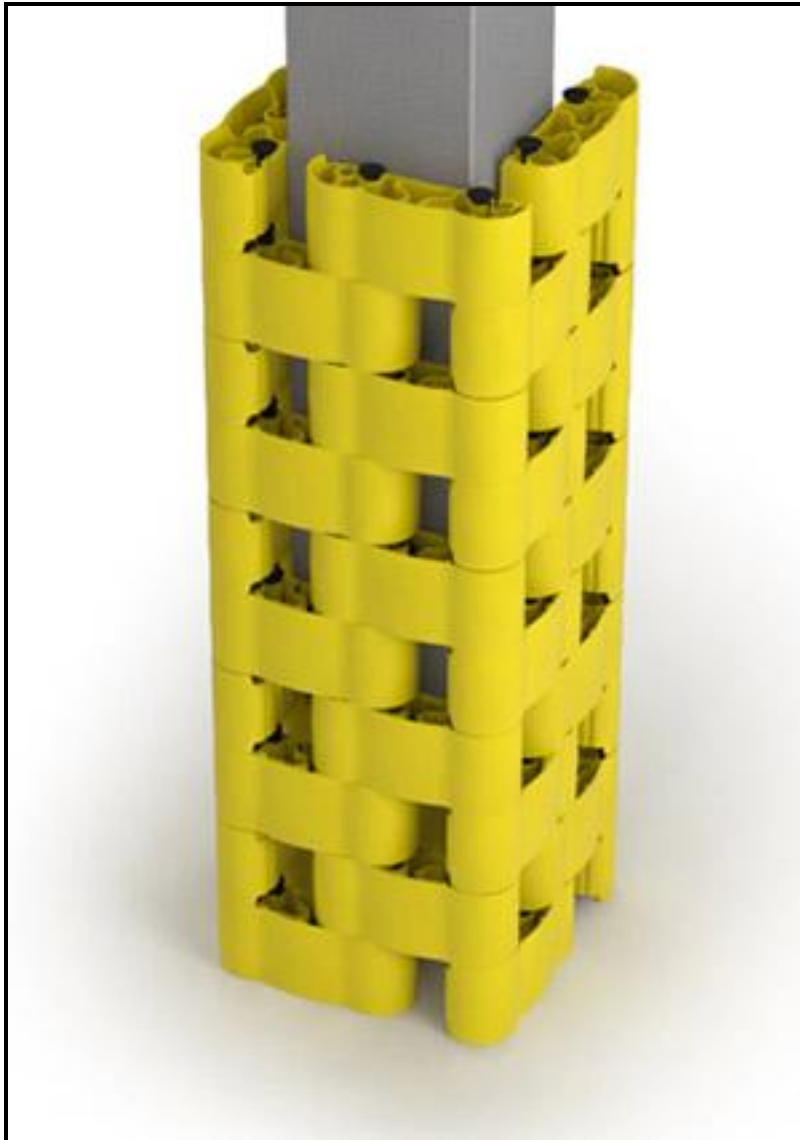


Figure 2: protect-It Maxi assembled on Column

3. Model Description

The protect-it Maxi was meshed using solid elements in all analysis, ensuring a minimum of at least 3 elements through any wall thickness.

Cosmos Linear Dynamic and Non-linear modules were used to determine the structural response of the Maxi.

Two type of impact loading profiles were used in assessing the response;

- An impact associated with the fork blade striking the Maxi was emulated using a rigid rectangular bar.
- The higher energy impact associated with a forklift vehicle impacting a column protected with Maxi's, used a large rigid flat surface, approximately the width of the Maxi itself (200mm).

The following impact cases were considered;

1. Impact against front of Maxi by forklift blade

2. Impact against front of Maxi by forklift bumper
3. Impact against Maxi's assembled on corner of post
4. High energy Impact by forklift bumper, associated with column

In all these cases, except the corner impact case, the Maxi was modelled as being mounted against a rigid object, i.e. as if assembled against a wall; see Figure 3 below which indicates of restraints applied to the model.

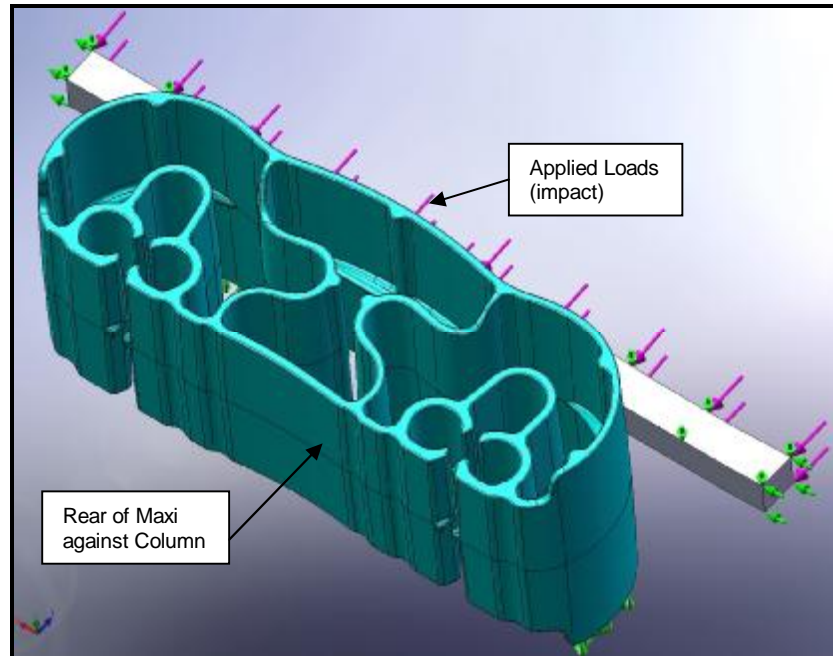


Figure 3: Impact against Maxi by Forklift Fork

NOTE: Importantly it should be noted that in all impacts associated with a forklift bumper (high energy impacts) the solution has 3 Maxi units involved in absorbing the energy (3 springs in parallel). The reason for this configuration is that for a typical installation against a column there would be 5 Maxi's stacked above one another (1m high) protection, but only three (3) would be within the forklift bumper impact zone.

With the corner impact analysis, the Maxi's were assembled in a typical stack, but around a rigid corner. The impact load was applied at 45°, thus simulating a pure side impact. The locking pin was modelled too, to ascertain the deflection characteristics.

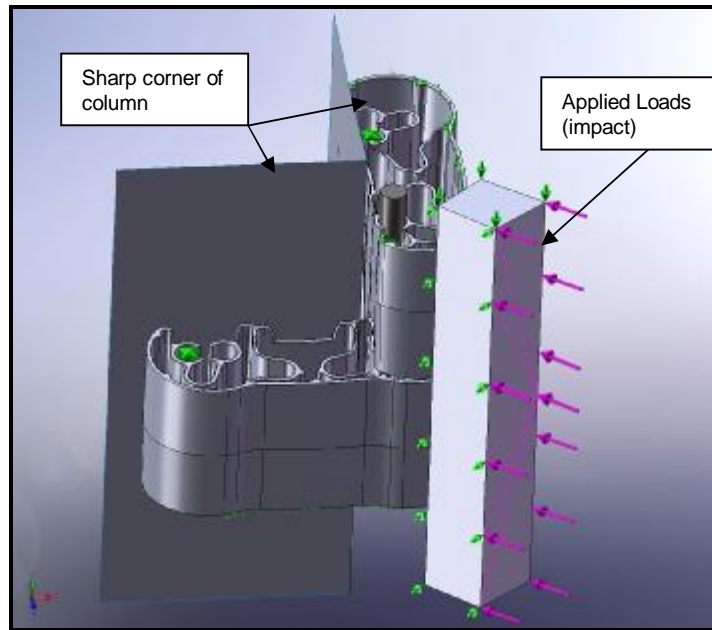


Figure 4: Blunt Side Impact against Maxi's assembled on Column

4. Impact Conditions

The modelling of impacts is considerably more complex than the simple static loading cases, as much of the impact load is a function of the energy dissipation in the model itself.

Importantly the response of the structure during high energy impacts is a function of both the elastic properties and once the material yield stress has been exceeded, the plastic strain energy characteristics.

The typical impact loads associated with a 2700 [kg] (6000 lb) forklift travelling at various speeds is indicated in Table 2 below. A simple test rig is employed to simulate impact tests and consists of a 40 [kg] steel mass dropped vertically onto the Protect-It. The equivalent drop height has been indicated for this test rig too, see column 3.

The equivalent static force is the static force that is required to produce the same deflection in the Maxi (3 units high), due to the dynamically (rapidly) applied load.

Table 2: Impact Energy and Loads

| Speed [km/hr] | Energy [J] / [N.m] | Drop Height [m] (for 40 kg mass) | Equivalent Static Force [N] (per Maxi) |
|------------------|-----------------------|--|--|
| 1 | 104 | 0.3 | 1121 |
| 2 | 417 | 1.1 | 2244 |
| 3 | 937 | 2.4 | 3365 |
| 4 | 1667 | 4.3 | 4487 |
| 5 | 2604 | 6.6 | 5609 |
| 6 | 3750 | 9.6 | 6731 |

Note: Table 2 above refers to a forklift of 2700 [kg] impacting against 3 Maxi's. Three Maxi's corresponds to the number that would be involved in an impact against a standard column with 1000 [mm] of protection.

5. Analysis Results

5.1. Standard Impact Loads - 400[N.m]

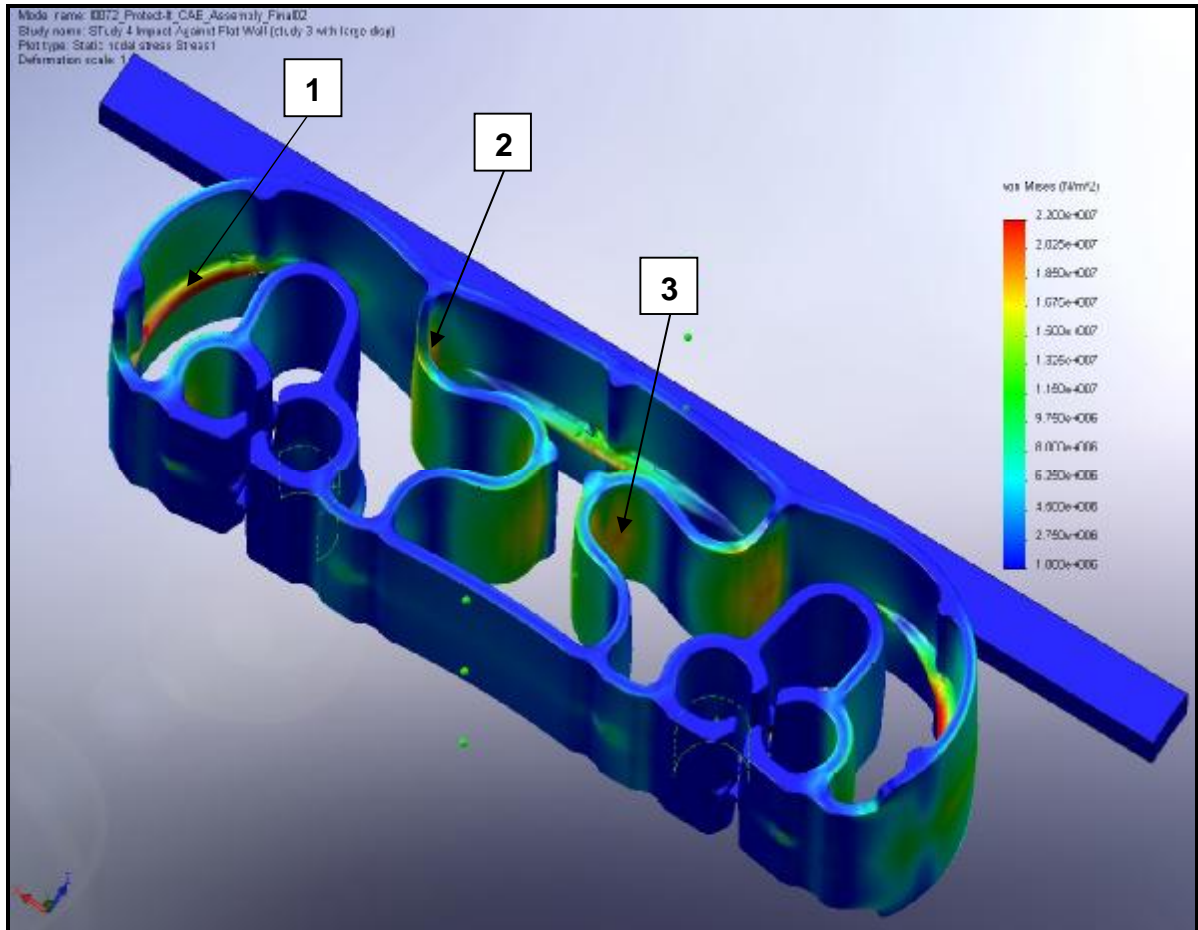


Figure 5: Stress in maxi during 400 [N.m] front Impact

With reference to Figure 5 above and Figure 6 below;

- Stresses in the Side rib features, see textbox-1, approach the material yield (22-24 [MPa]), but this is a compressive stress associated with the surface fibres, associated with largest strain. Average stress through part is approximately 13 [MPa].
- Stresses in the front part of the main spring elements, see textbox-2, are approximately 16 [MPa] but this is near the surface and average stress through wall is only 11.5 [MPa]. The stress varies from compressive to tensile through the wall, with the inner edge (arrow side) being in compression.
- Similarly the central spring element, see textbox-3 has stresses approaching 15 [MPa]. The inner edge (arrow side) is compressive stress, and varies to tensile on the other surface.

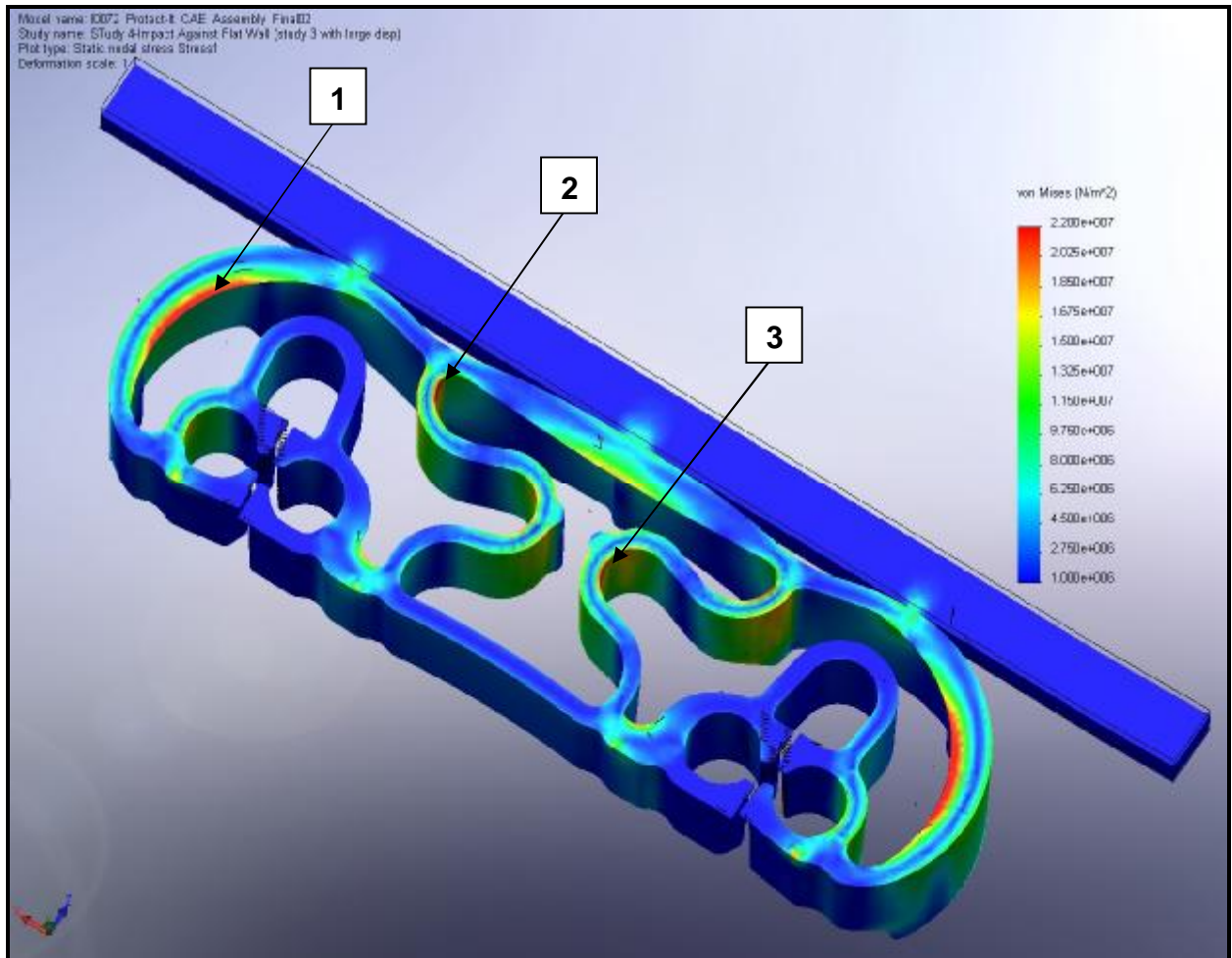


Figure 6: Stress in Maxi, sectioned through centre of part

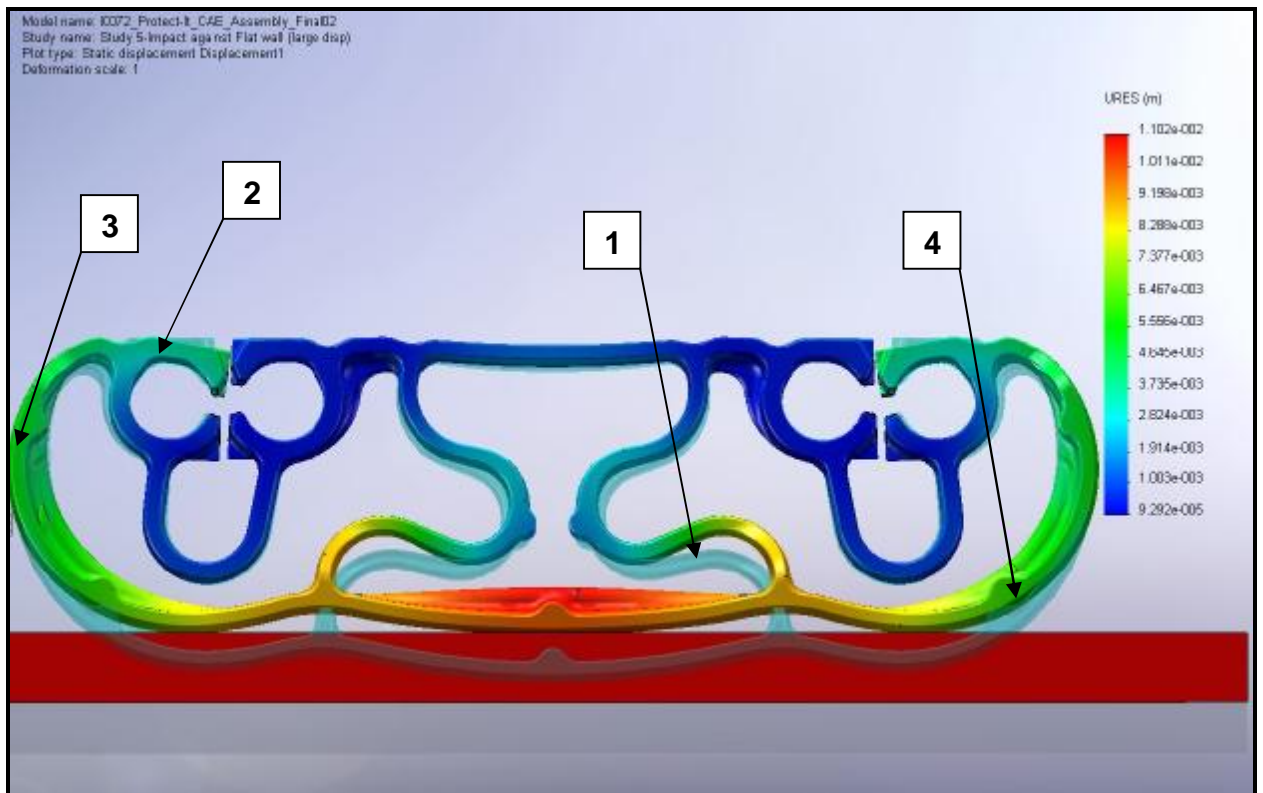


Figure 7: Displacement in Maxi during 400 [N.m] impact. (Undeformed Shape superimposed)

With reference to Figure 7 above;

- Maxi main spring elements exhibit suitable deflection characteristics, see textbox-1.
- Note that the unrestrained vertical pin clasps, see textbox-2, deflect inwards due to the loads transferred through the side wall, textbox-3.
- The side walls experience considerable deflection, see textbox-4, hence the strain and resultant stresses observed in the images above.

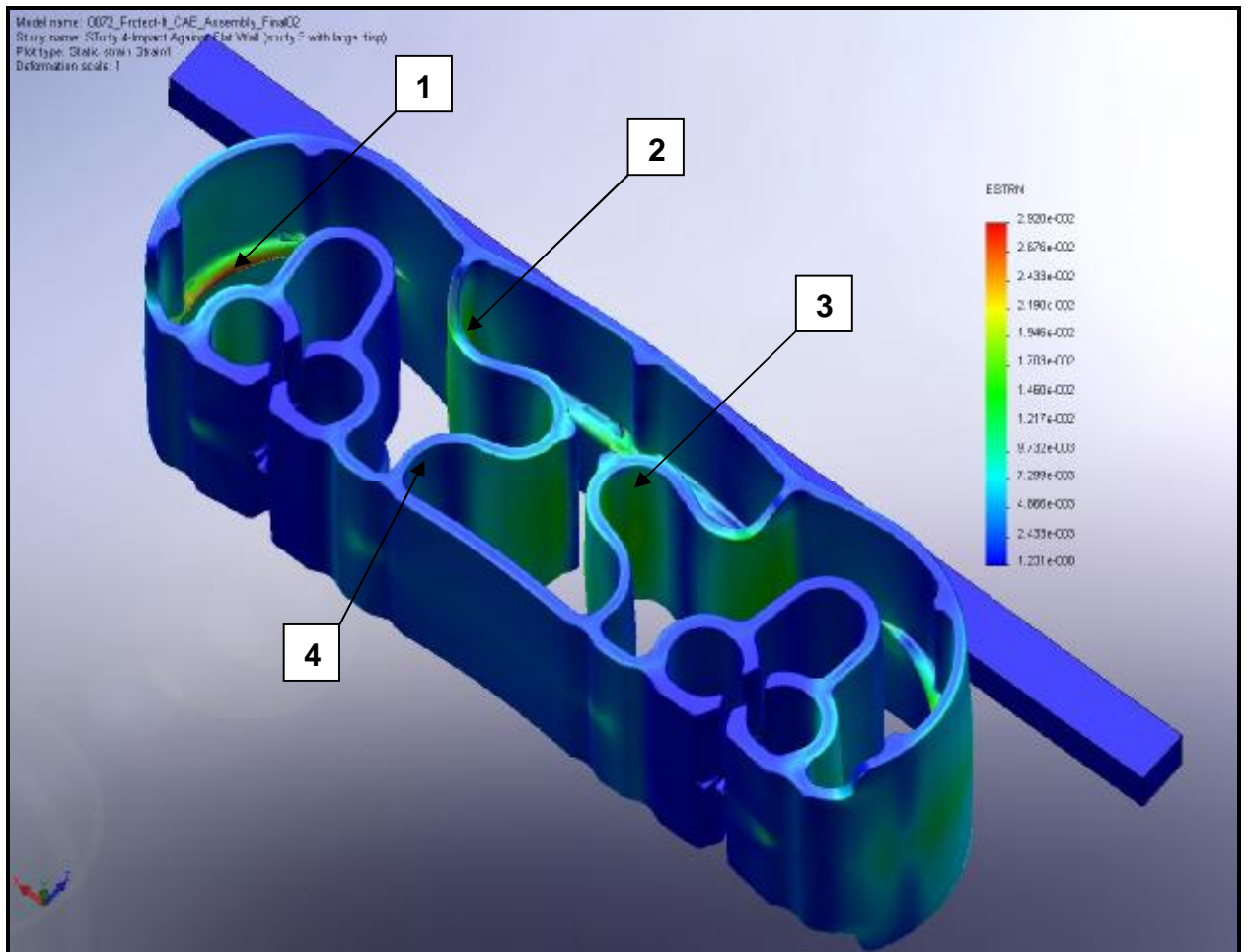


Figure 8: Strain magnitude in Maxi (400 N.m) impact

With reference to Figure 8above;

- Compressive strain in side wall rib, see textbox-1, indicative of a region of high deflection.
- Similarly the strain in the central spring elements, see textbox-2 and textbox-3, are large, indicative of the elastic deformation characteristics of the design.
- The root region of the Maxi central springs, see textbox-4, does not deflect much at this point and as such it may be possible to better utilise this region.

5.2.Side Impact Loads

The side impact model consists of two Protect-It Maxi's joined in a standard stack layout with the securing pin, see item indicated by textbox-3. The impact device indicated by textbox-2, is driven in at an angle of 45° to the two rigid walls, indicated by textbox-1, which represent a rigid column.

The two Maxi's are restrained from vertical motion by an external constraint, whilst the pin locations are allowed to displace sideways in the plane of the wall and rearwards as per the calculated deflection.

A 2000 [N] load is applied to the impactor, equivalent to a 400 [N.m] impact event.

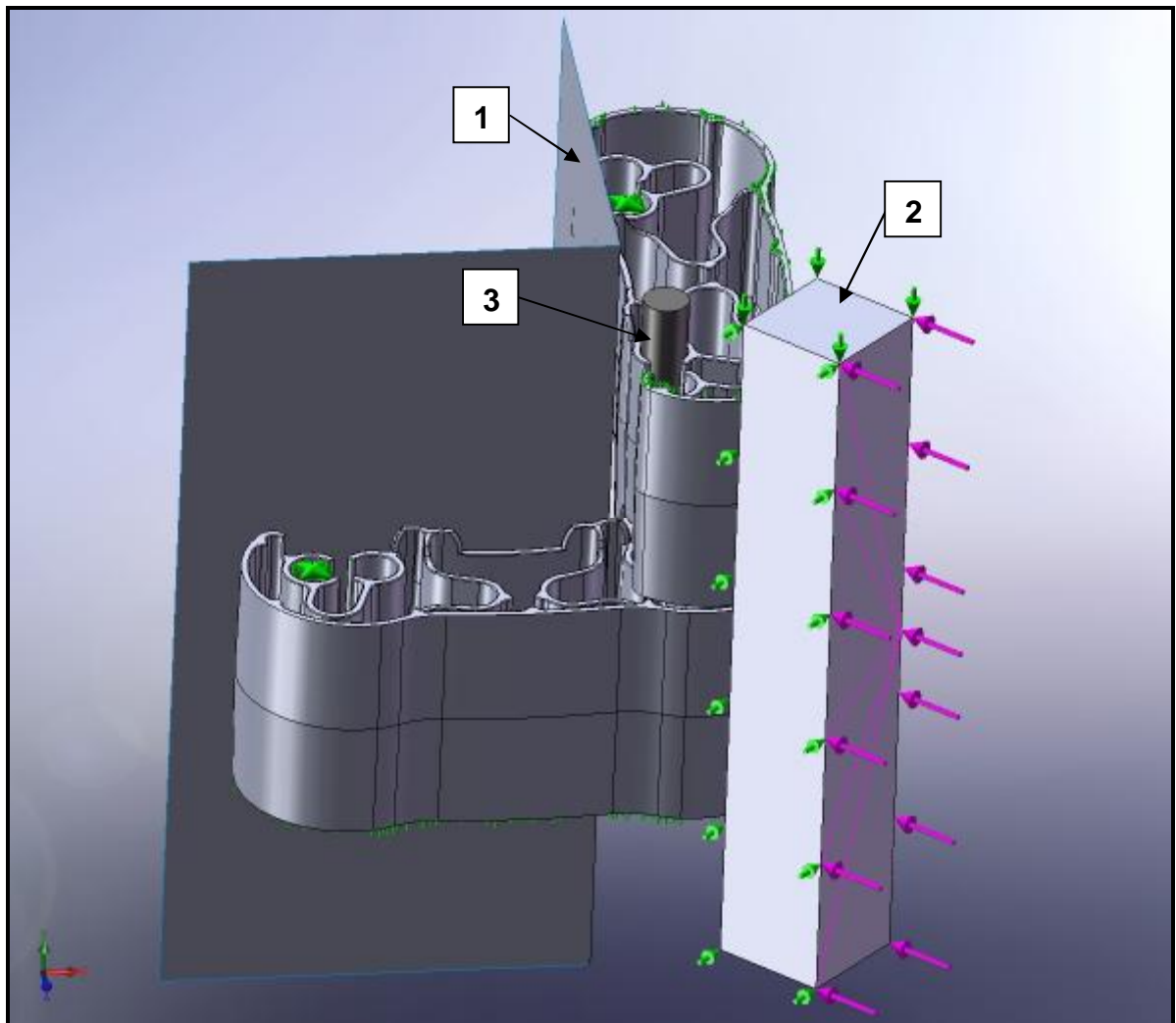


Figure 9: Side Impact Model

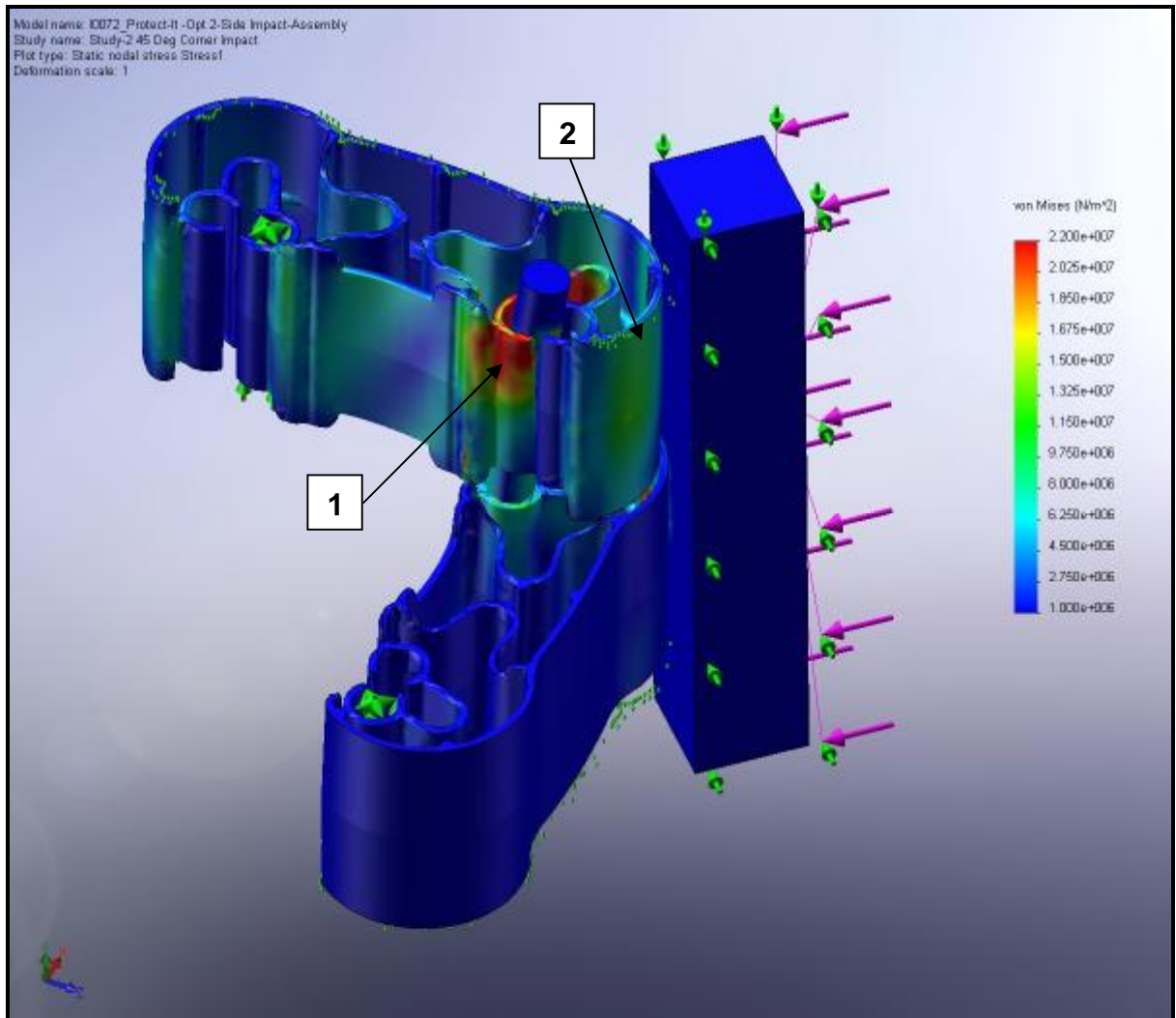


Figure 10: Von Mises Stresses in Structure (400 [N.m] impact at 45° to column walls)

With reference to Figure 10 above;

- Stresses around the pin location, see textbox-1, approaches the material yield stress. Since only a small section of the vertical pin was modelled, we can expect this stress magnitude to be lower in an actual impact as the pin will allow greater deflection, thus reducing the local strain.
- Stresses in the side wall of the Maxi, see textbox-2 are well below the material yield stress, 10 [MPa].
- In a standard installation there will always be a continuous stack of protect-It Maxi's up the vertical edge, and as such the layout ensures excellent protection on the edge of the column.

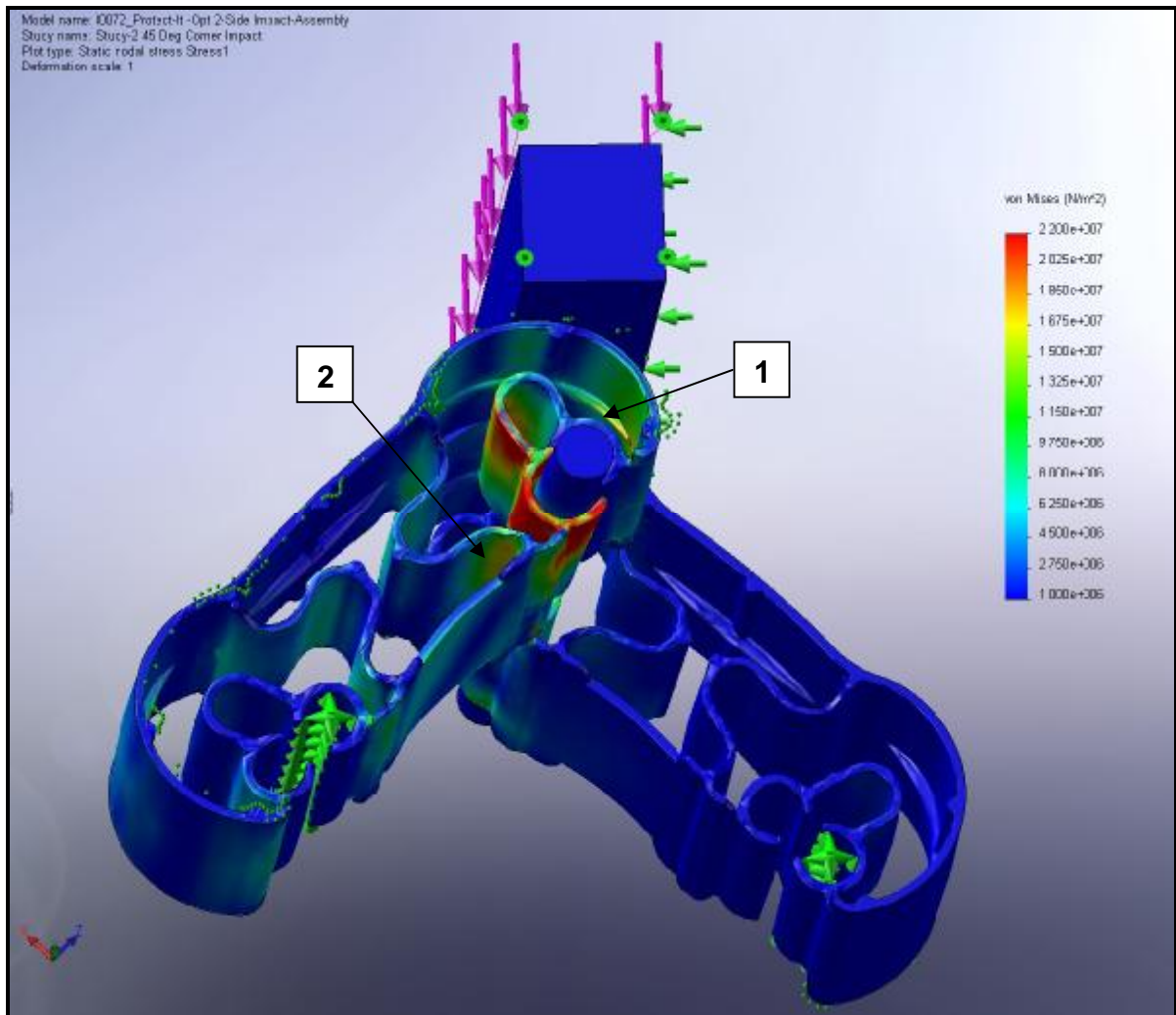


Figure 11: Von Mises Stresses (Inside View)

With reference to Figure 11 above;

- The stress in the edge rib feature approaches 16 [MPa], see textbox-1, and as such it represents a region of stress concentration. This is due to the larger strain resulting from the distance away from the wall neutral bending plane.
- The spring element once again is responsible for absorbing the impact energy and as such we notice the higher stresses in the root region, see textbox-2.

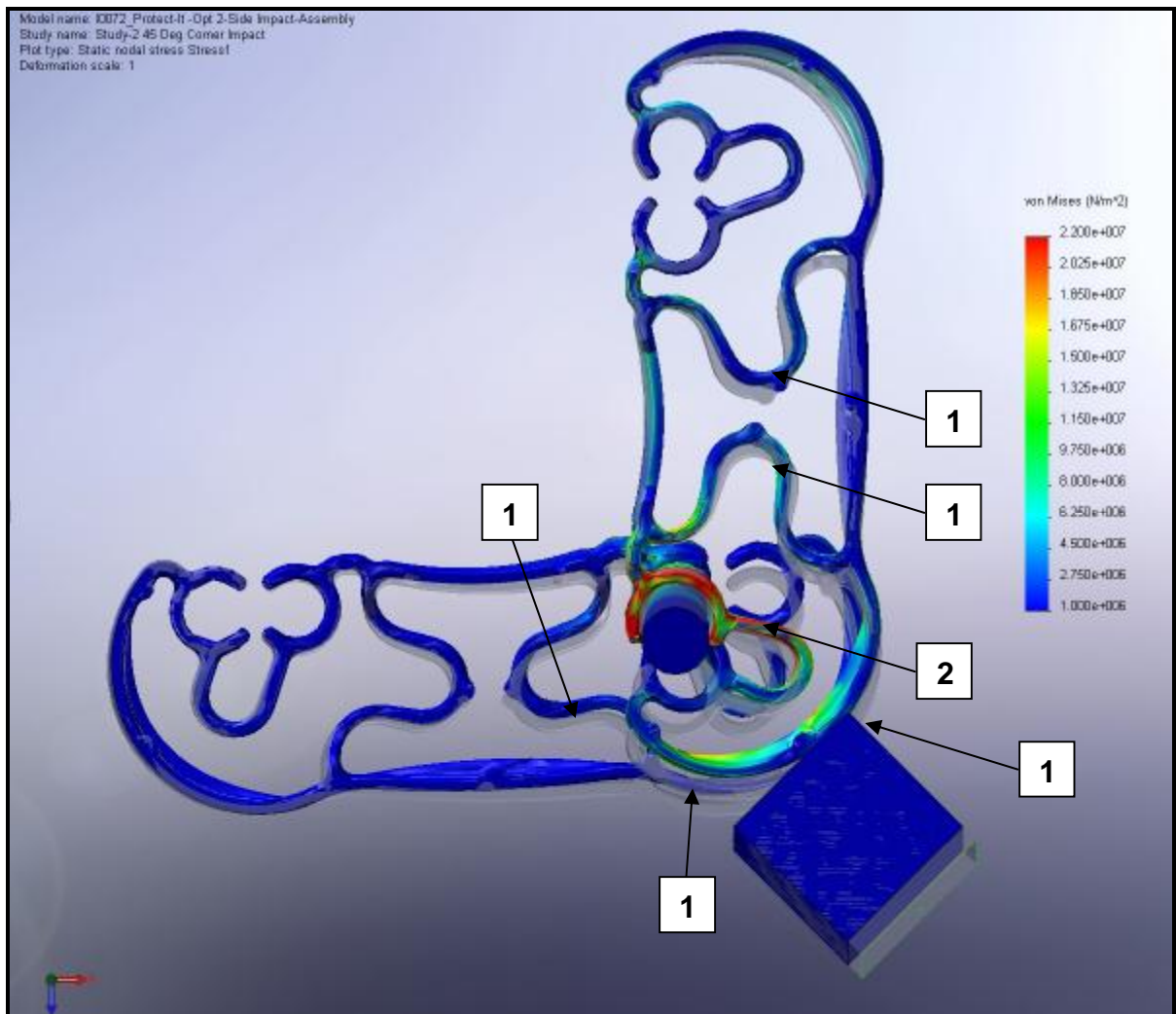


Figure 12: Stress in structure (Undeformed shape superimposed)

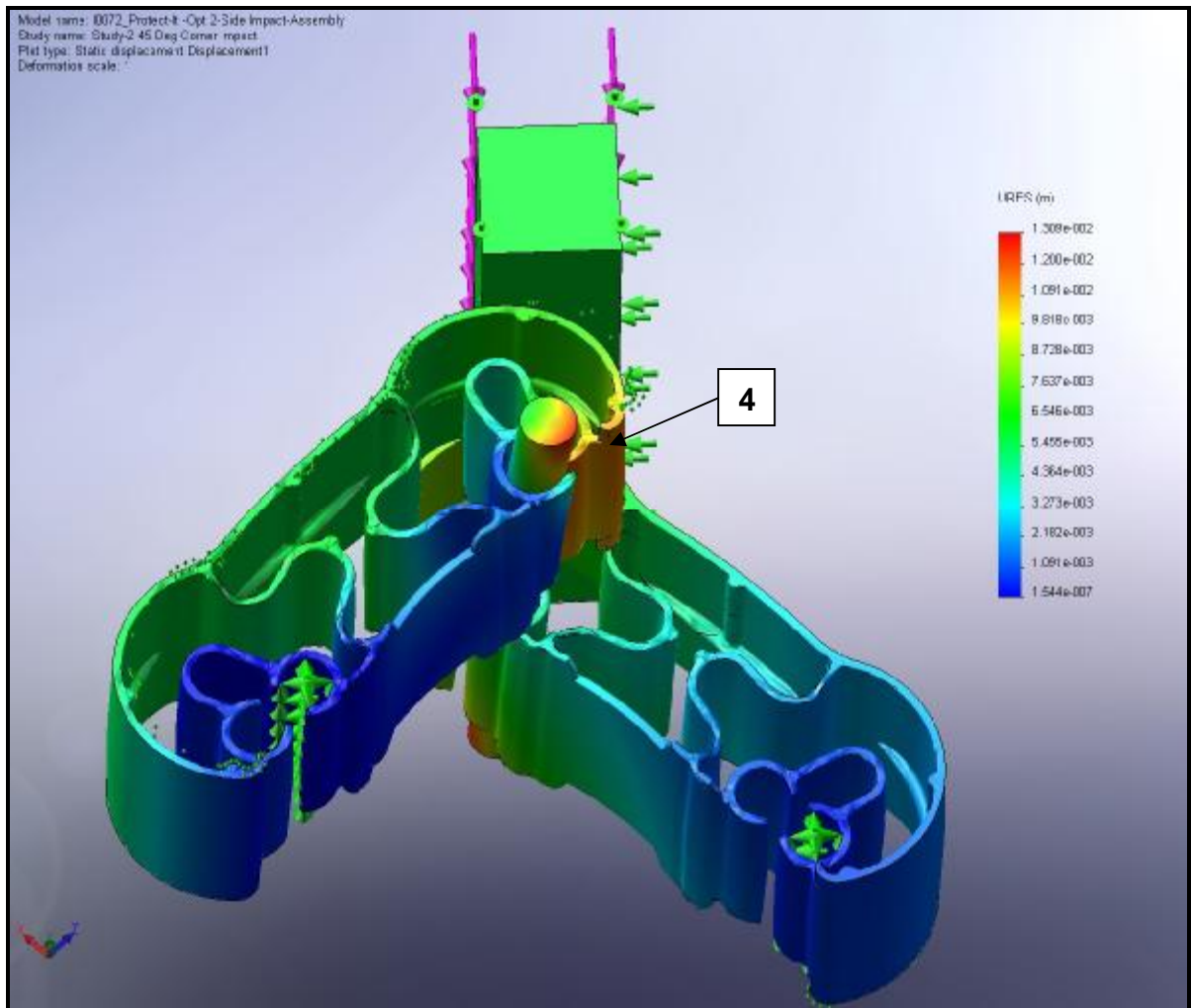


Figure 13: Deformation in Maxi during Side impact

With reference to Figure 12 and Figure 13 above;

- Deflection of the two Maxi's is skewed towards the side of the impact, and the image highlights the regions of the spring elements that are active in absorbing the impact load, see textbox-1.
- The vertical connector pins and clasp features within the Maxi experiences large deflection too, see textbox-2.

5.3.High energy Impacts (forklift impacts)

The high energy impact analysis of the Maxi requires a non-linear analysis as the HDPE material experiences large regions of yielding and hence further energy absorption in the component is within the strain energy of the material.

As such the Non-linear module of Cosmos Works was utilised to study the non-linear behaviour of the part under large deformation conditions.

In plastics such as HDPE the rate at which the force is applied affects the stress-strain behaviour of the material, and the Flexural modulus is of particular interest in the behaviour of the part. It is often noted that the stress at elongation is closer to the materials ultimate tensile stress/strength rather than the yield stress for rapid load application. For HDPE this ultimate tensile strength (UTS) is close to 45 [MPa].

The results detailed below are for a 1200 [N.m] impact, equivalent to a 4000 [N] static load and represents the 2700 [kg] forklift travelling at 3.6 [km/hr] or 1 [m/s].

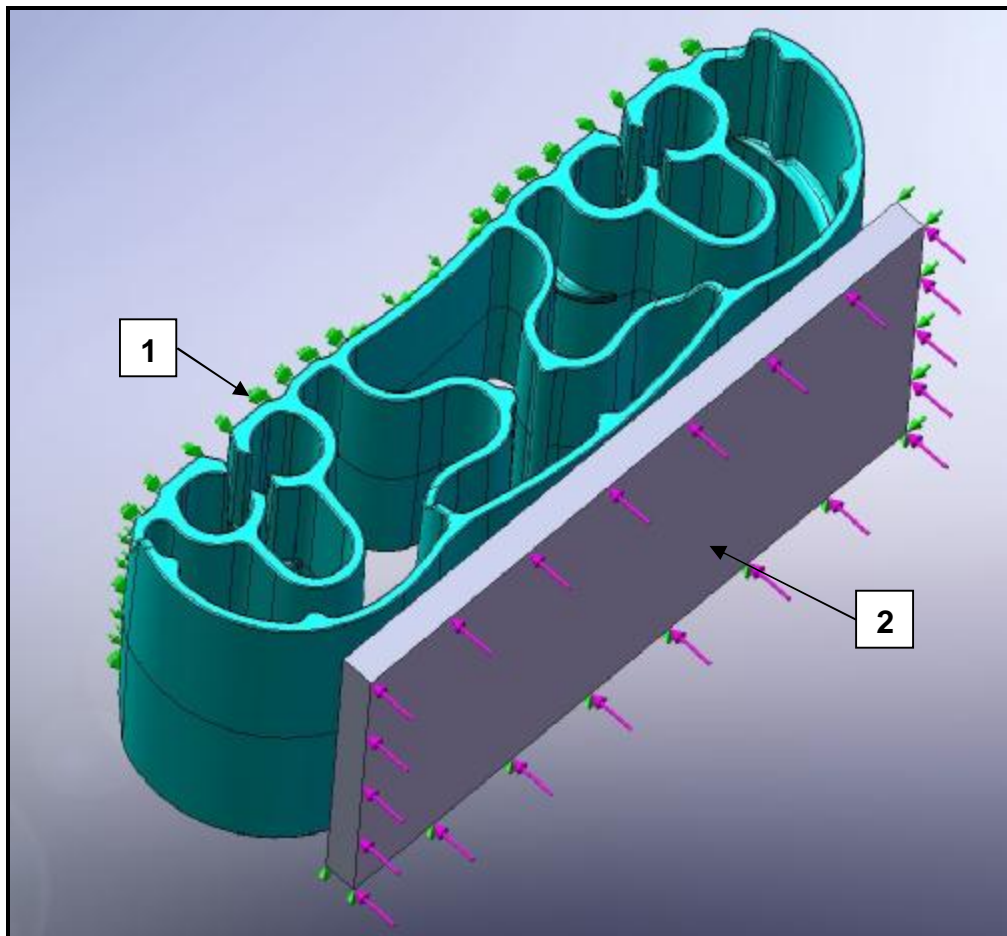


Figure 14: Model of Maxi for Non-Linear High Energy impacts

With reference to Figure 14 above;

- Maxi is restrained from moving rearwards against column, see textbox 1.
- Impactor, see textbox-2, is driven into the Maxi with equivalent static force, see Table 2 for details.

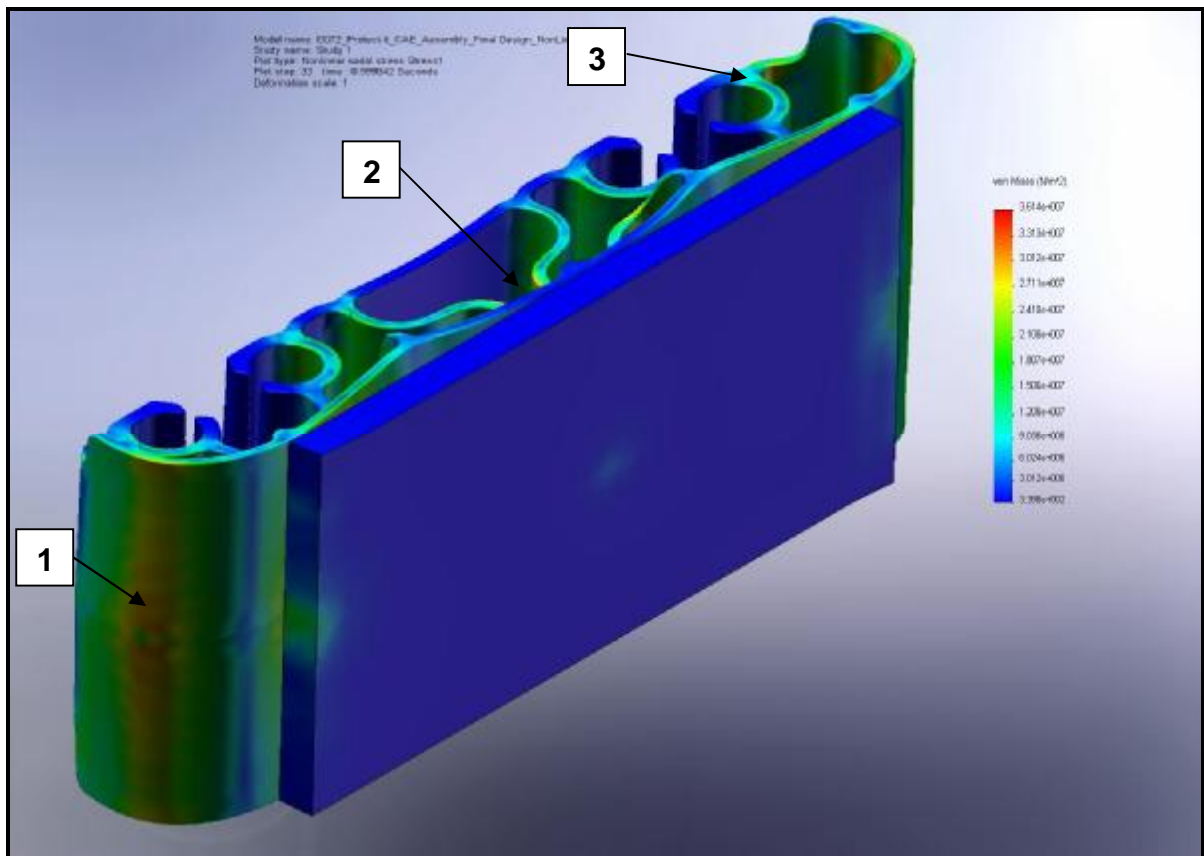


Figure 15: Stress in Maxi during 1200 [N.m] energy Impact

With Reference to Figure 15 above;

- Stresses within the Maxi exceed the material yield stress; see regions indicated by the three textboxes.
- The side wall of the Maxi, see textbox-1, is only fractionally above the material yield on the surface, but the yielding will result in permanent deformation once the load has been removed. This region of the Maxi experiences a large percentage of the impact loads (in all directions) and as such the inner rib feature is used to reduce the wall stresses.
- The central spring elements, indicated by textbox-2, absorb a considerable percentage of the total energy, and as such they will experience high stresses. The regions of smallest bend radii, concentrates the stresses. Similarly the outer wall of these regions experiences the largest strain and hence the stress in the material is strain related.

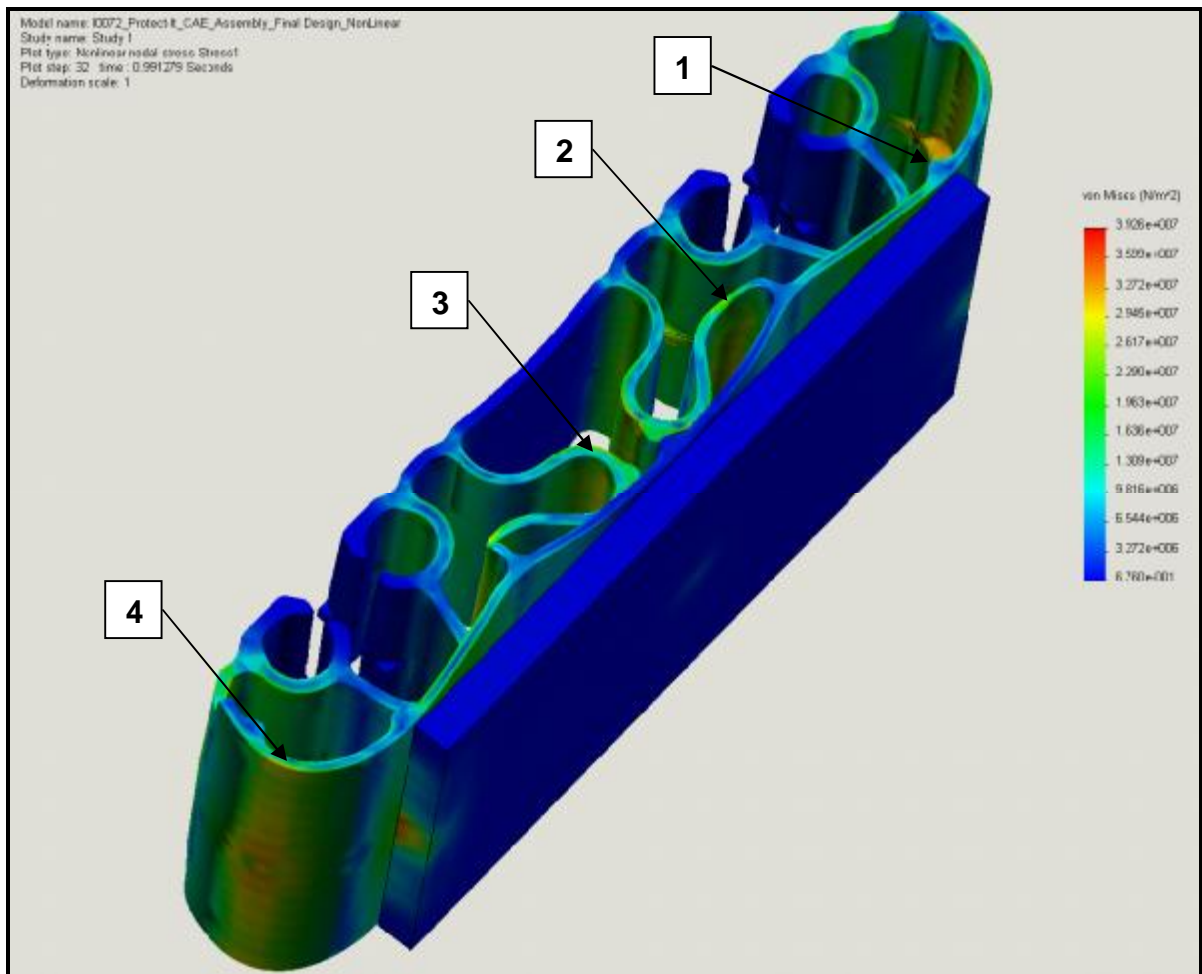


Figure 16: Stress in Maxi at Maximum Deflection Point

With reference to Figure 16 above;

- Stresses in the side rib, see textbox-1, are above yield stress at 34 [MPa].
- The stress in the main spring elements, see textbox-2 and textbox-3, are similarly above yield stress through the section and hence we will expect plastic deformation to occur.
- Stress in rear corner of side wall, see textbox-4, is above yield stress at 26 [MPa] and hence this region too will exhibit permanent deformation.

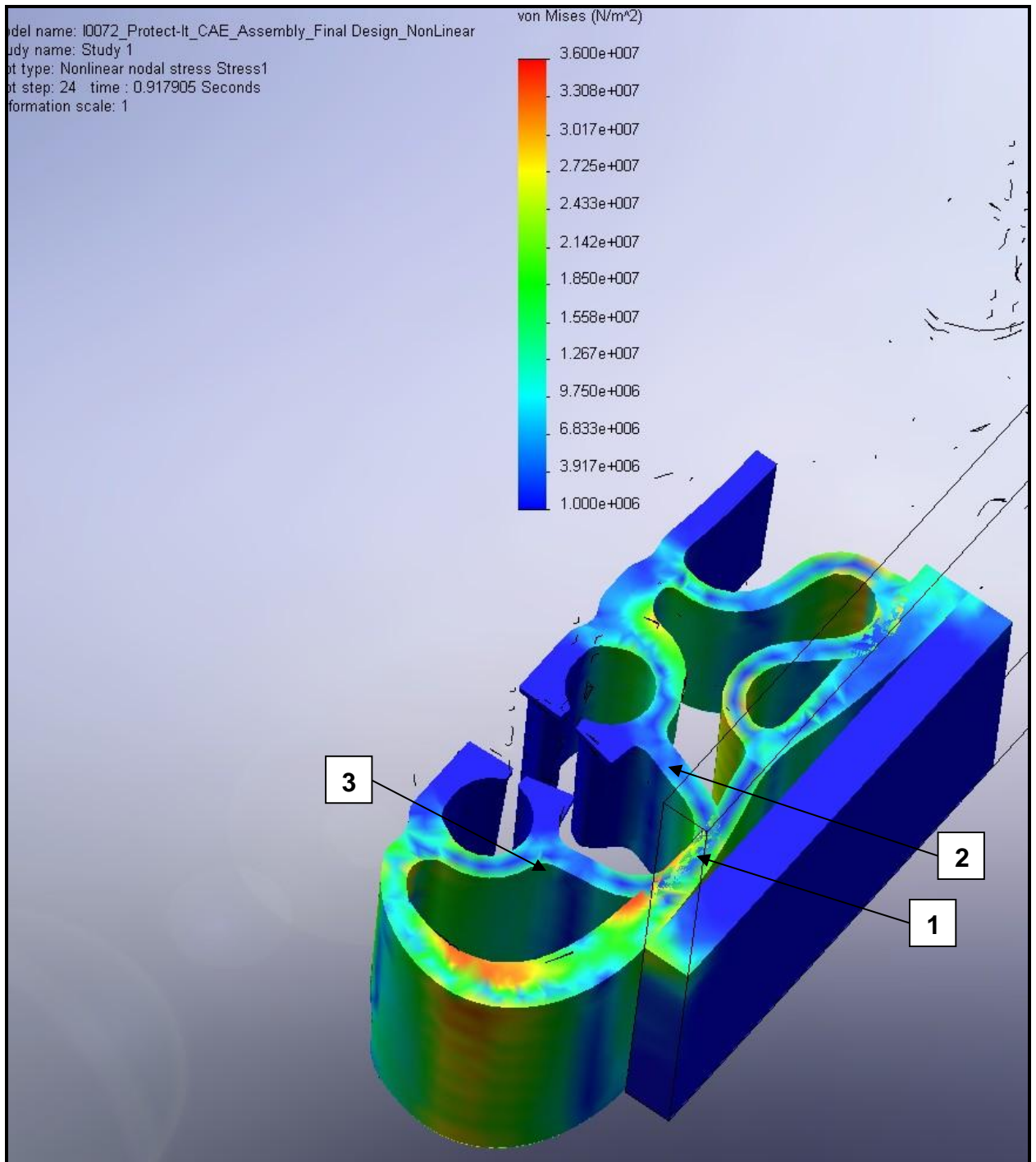


Figure 17: Stress in Maxi (section through mid-plane) due to 1200 N.m Impact

With reference to Figure 17 above;

- Stress in Maxi shows large regions above yield stress of 22 [MPa].
- Textbox-1 indicates region where solution does not account for wall impact and hence allows penetration. At this point the spring rate increases rapidly and the part indicated by textbox-2 would be responsible 'stopping' the deflection.
- The nose element, textbox-2, can be expected to exhibit local yielding in the corner regions indicated by textbox-3 as the deformation increases.

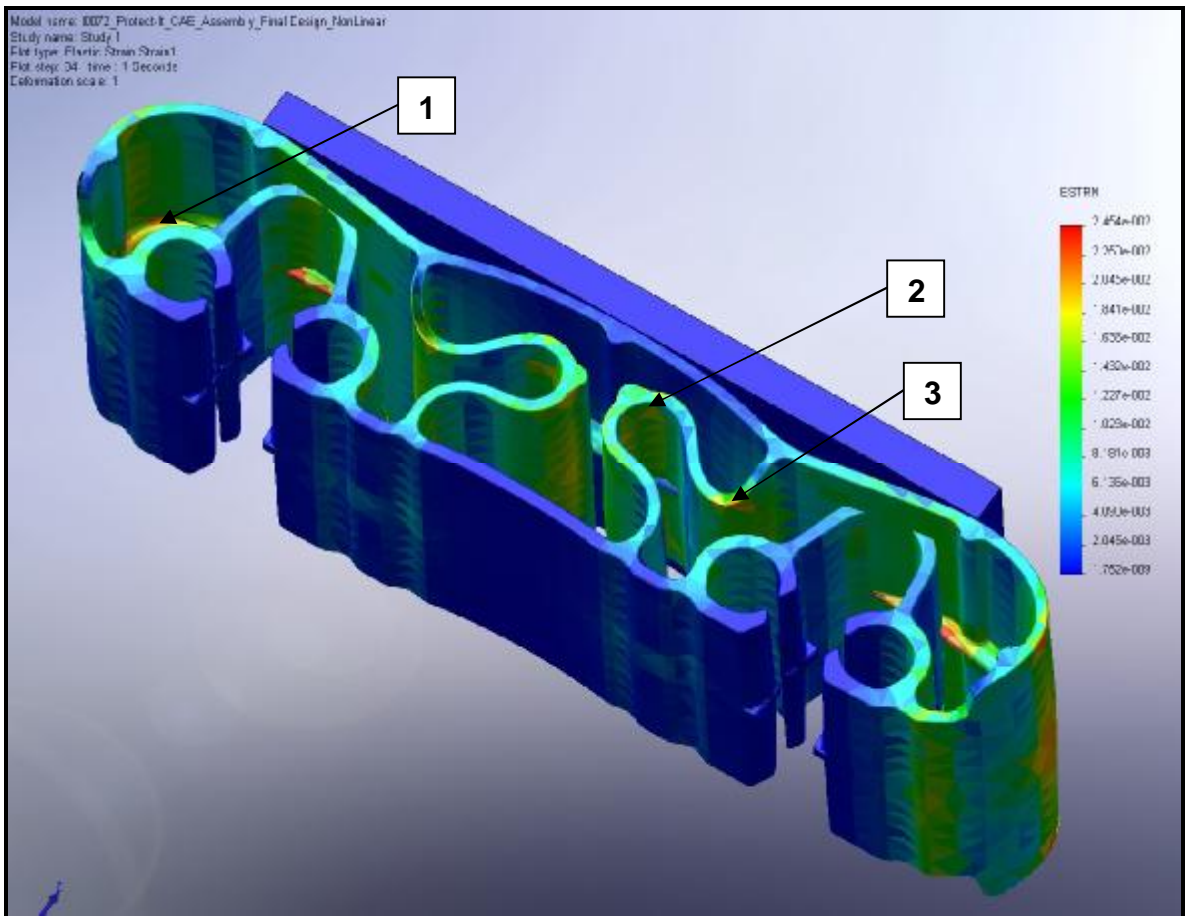


Figure 18: Elastic Strain within Maxi at maximum deflection point

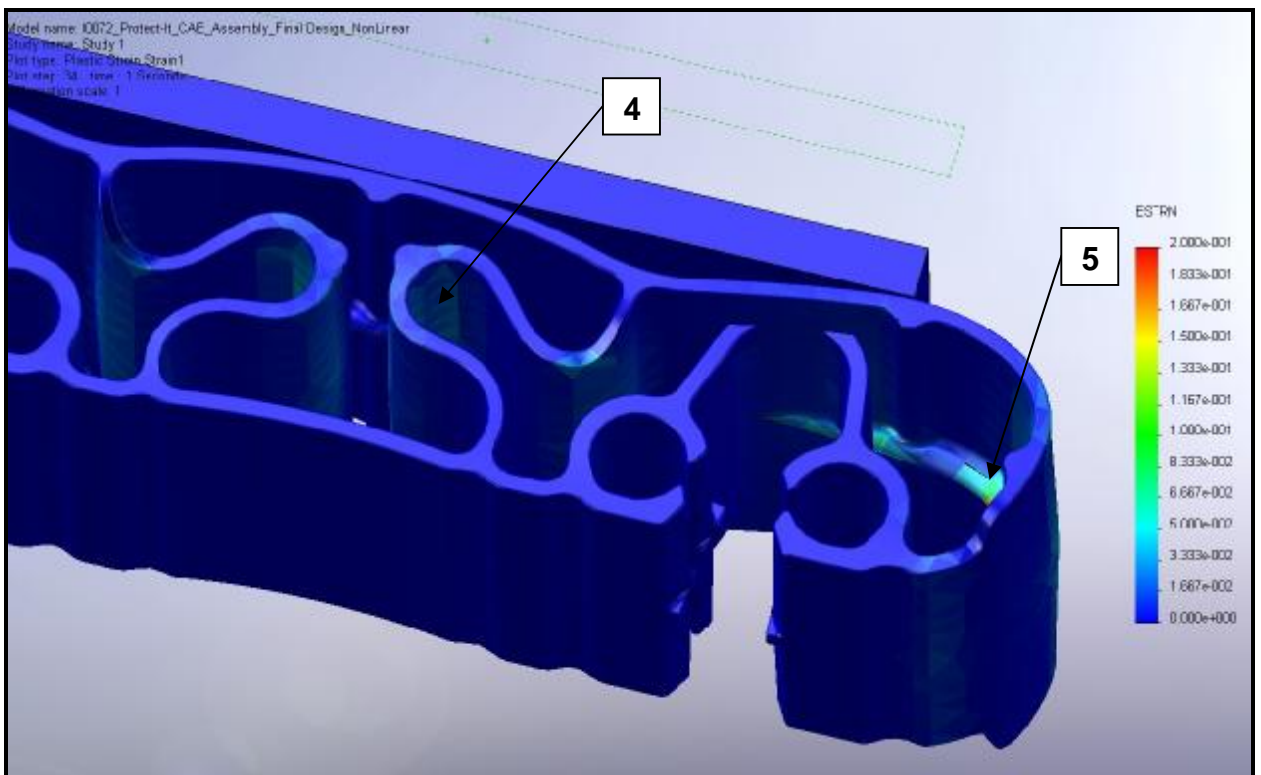


Figure 19: Plastic Strain within Maxi at Maximum deflection

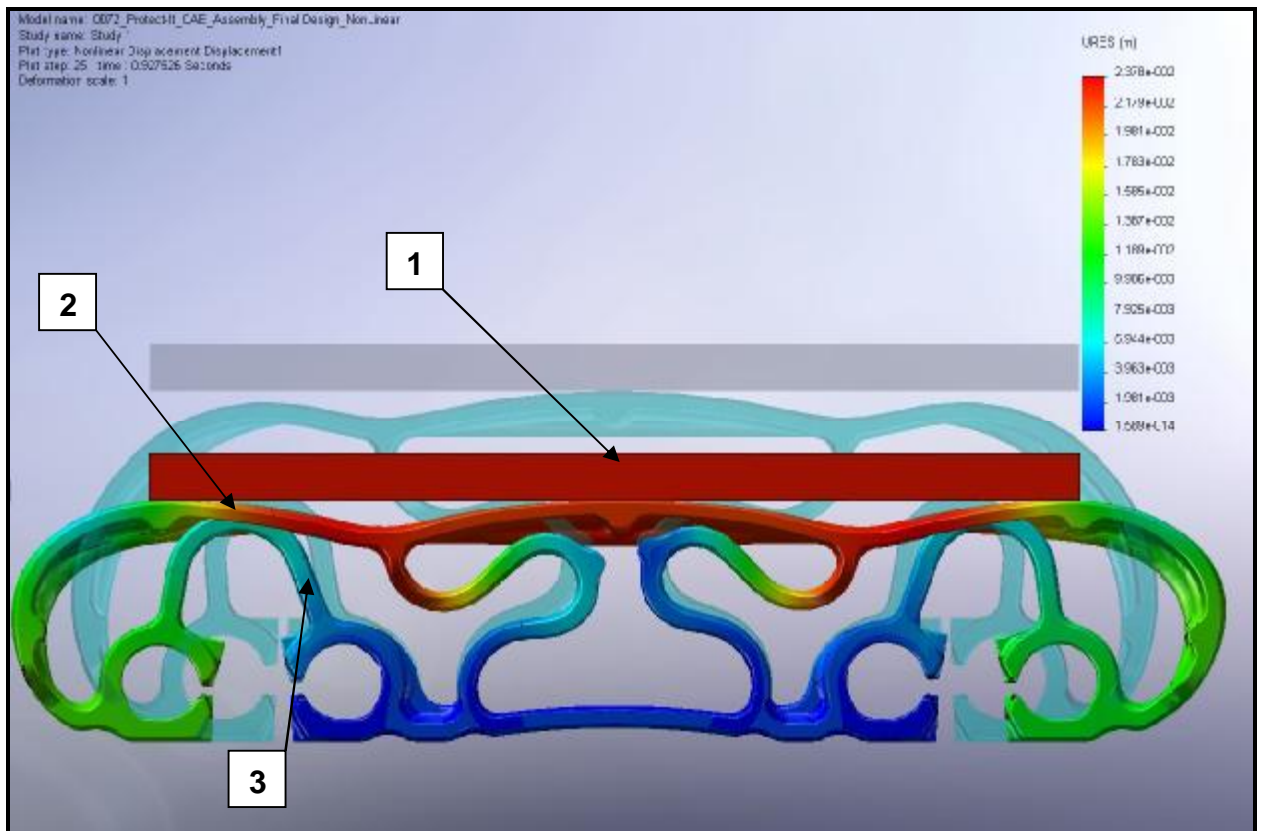


Figure 20: Displacement in Maxi during 1200 [N.m] energy Impact

With reference to Figure 20 above;

- In absorbing the impact load the deflection of Maxi is approximately 25 [mm], region indicated by textbox-1.
- Note penetration of nose feature, textbox-3, into the Maxi main wall, textbox-2, is the point at which the deflection stops. Note that this point is beyond the elastic limit of the product and plastic strain/permanent deformation will have occurred in the part for this condition.
- The spring rate of the Maxi, up to the model limitation condition mentioned above, is fairly uniform at 174500 [N/m].
- The impact energy, at which the front wall impacts the nose feature, is approximately 800 [N.m].

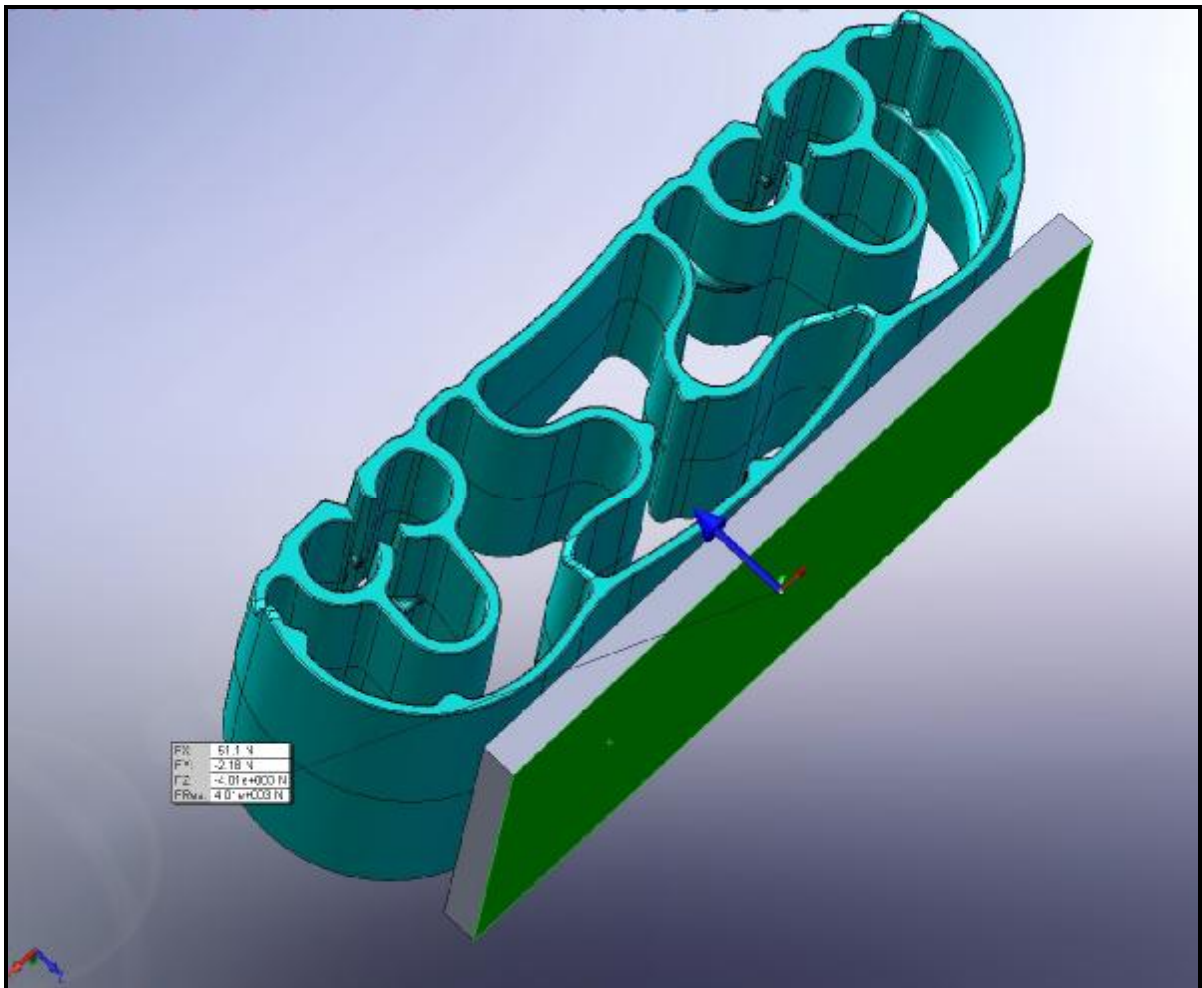


Figure 21: Load on impactor during deflection

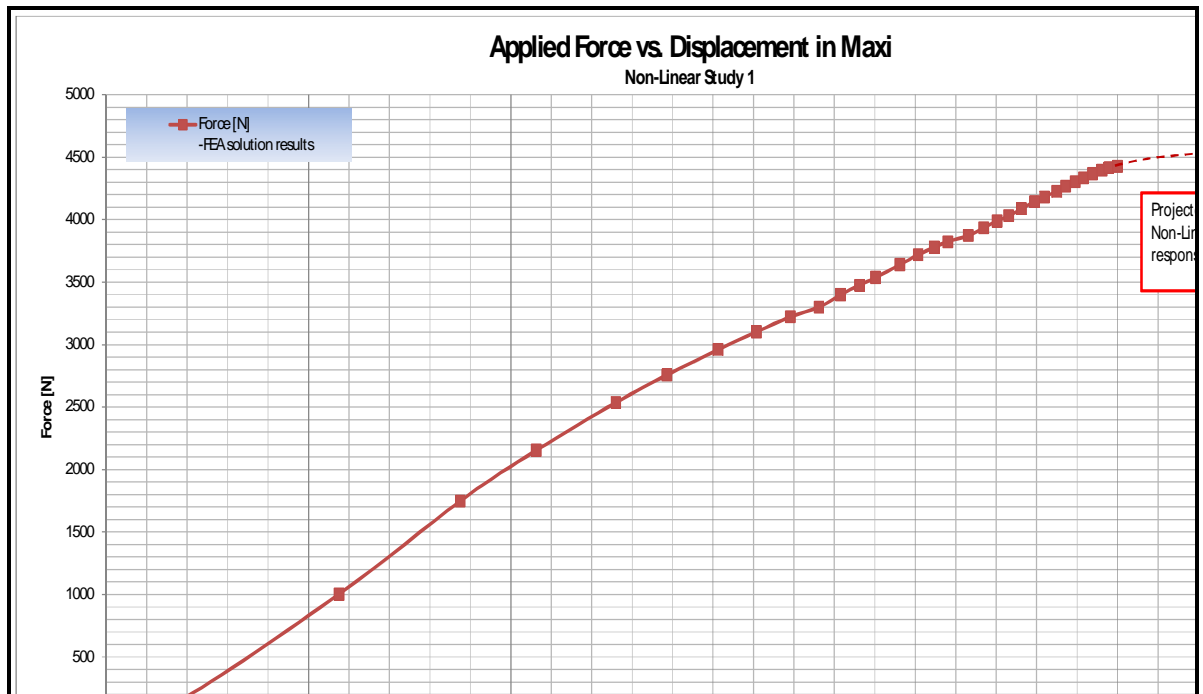


Figure 22: Non-linear Spring Characteristics of Maxi

5.4. Column Impacts

In order to make a quantitative assessment of the behaviour of Protect-it maxi during an impact, a standard 200UC column was used for comparison.

An unprotected column and a Maxi protected column were subjected to a 2700 [kg] forklift travelling at 6 [km/hr], using an impactor equivalent to the bumper region, 200 [mm] wide by 500 [mm] high.

5.4.1. Standard UC200 Building Column

For the impact assessment a building standard h-section column was used, UC200-59. This implies it is nominally a 200mm H-section with a weight per meter of 59 kg. The dimensions of the section are indicated in Figure 23 below.

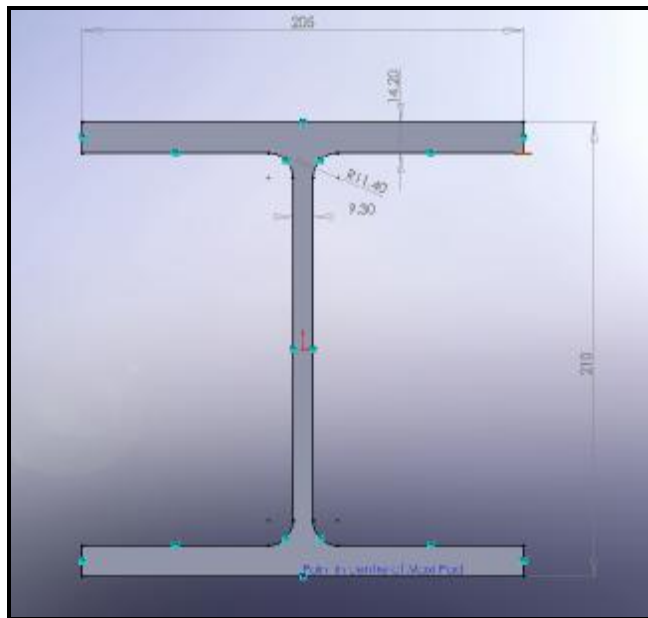


Figure 23: UC200-59 column dimensions

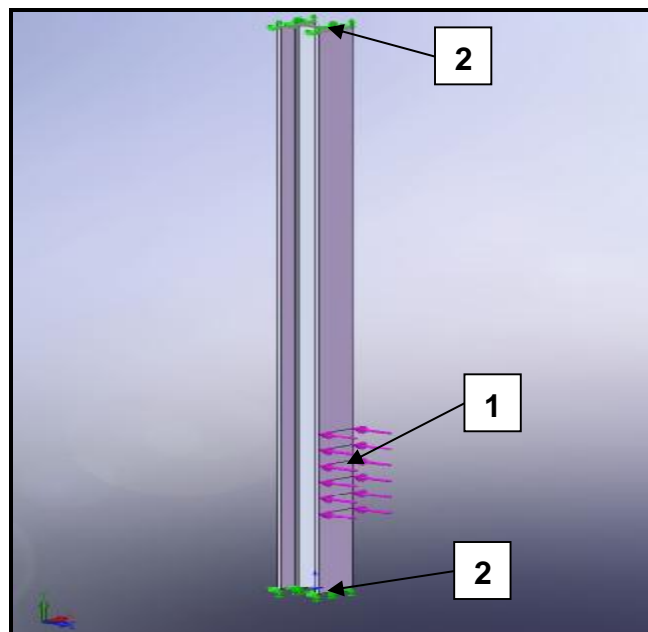


Figure 24: Impact Model on Column

With reference to Figure 24 above;

- The beam is modelled as being build-in on either end, see textbox-2, i.e. resisting both bending and shear and having zero slope at these points.
- The loaded area, see textbox-1, corresponds to a 200 [mm] wide by 500 [mm] high region. The full region is loaded for the simulated impact between forklift bumper and column. For the Maxi impact case three distinct regions corresponding o the rear face of 3 active Maxi's is simulated.

5.4.2.Unprotect Column Impact

The high stiffness of the column, $43.7e+10$ [N/m] implies that the impact duration is extremely small, typically 0.28 [msec]. Thus the impact amplification factor is large and the equivalent static load is approximately 840 [kN].

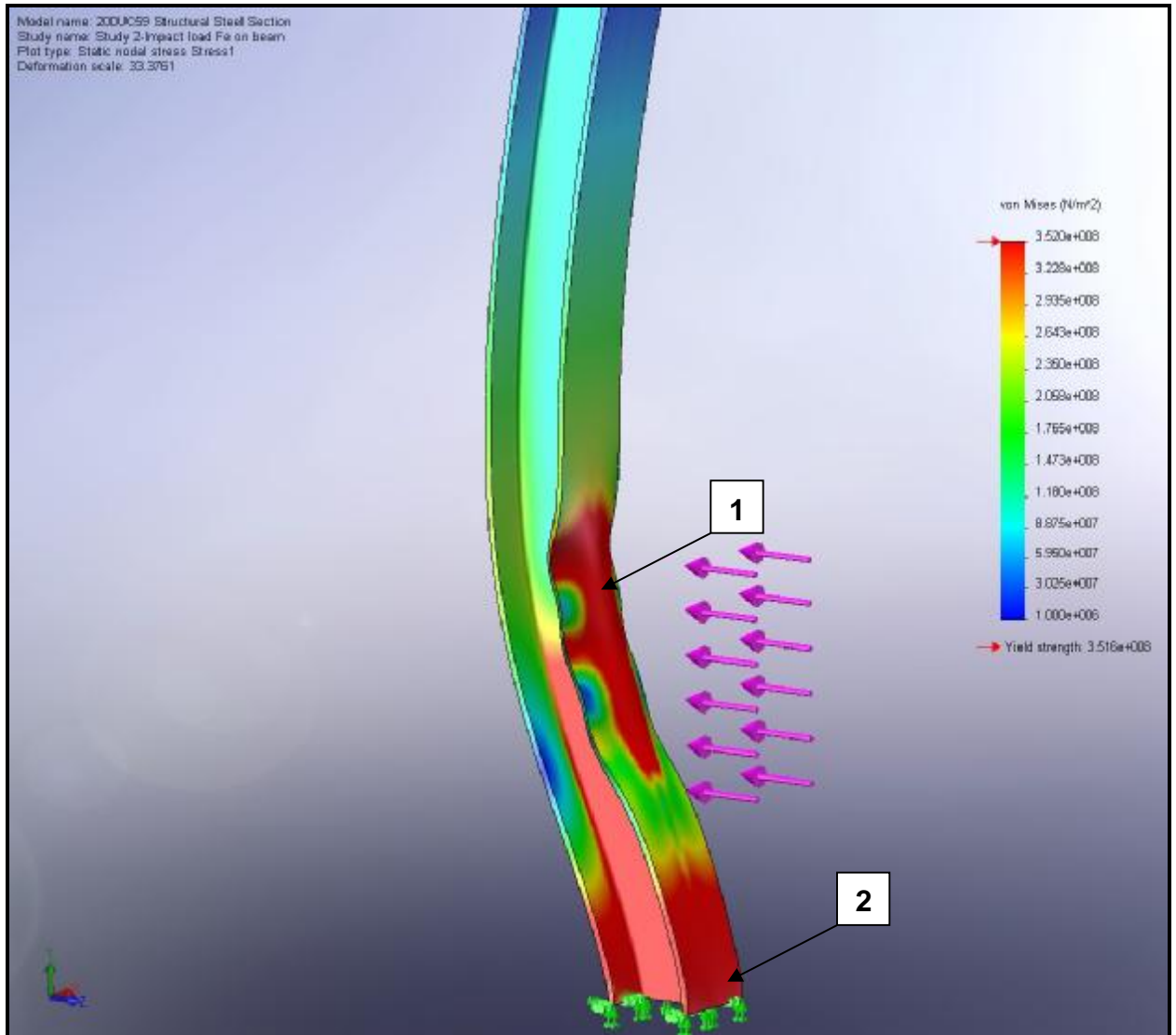


Figure 25: Stress in UC200 column subjected to 3750 [N.m] impact

With reference to Figure 25 above;

- The impact against column results in large scale yielding in the steel column, stresses exceed 350 [MPa].
- The impact region, indicated by textbox-1, exhibits plastic deformation associated with large stresses. Steel also exhibits the characteristic that for short duration impacts the stress at elongation (plastic transition) increases towards the material ultimate tensile strength. To this end the f deformation in the column would be less than the FEA

model indicates.

- Importantly the shear stress at the build-in ends of the beam, see textbox-2, exceeds the material yield stress and this implies permanent deformation of the column.

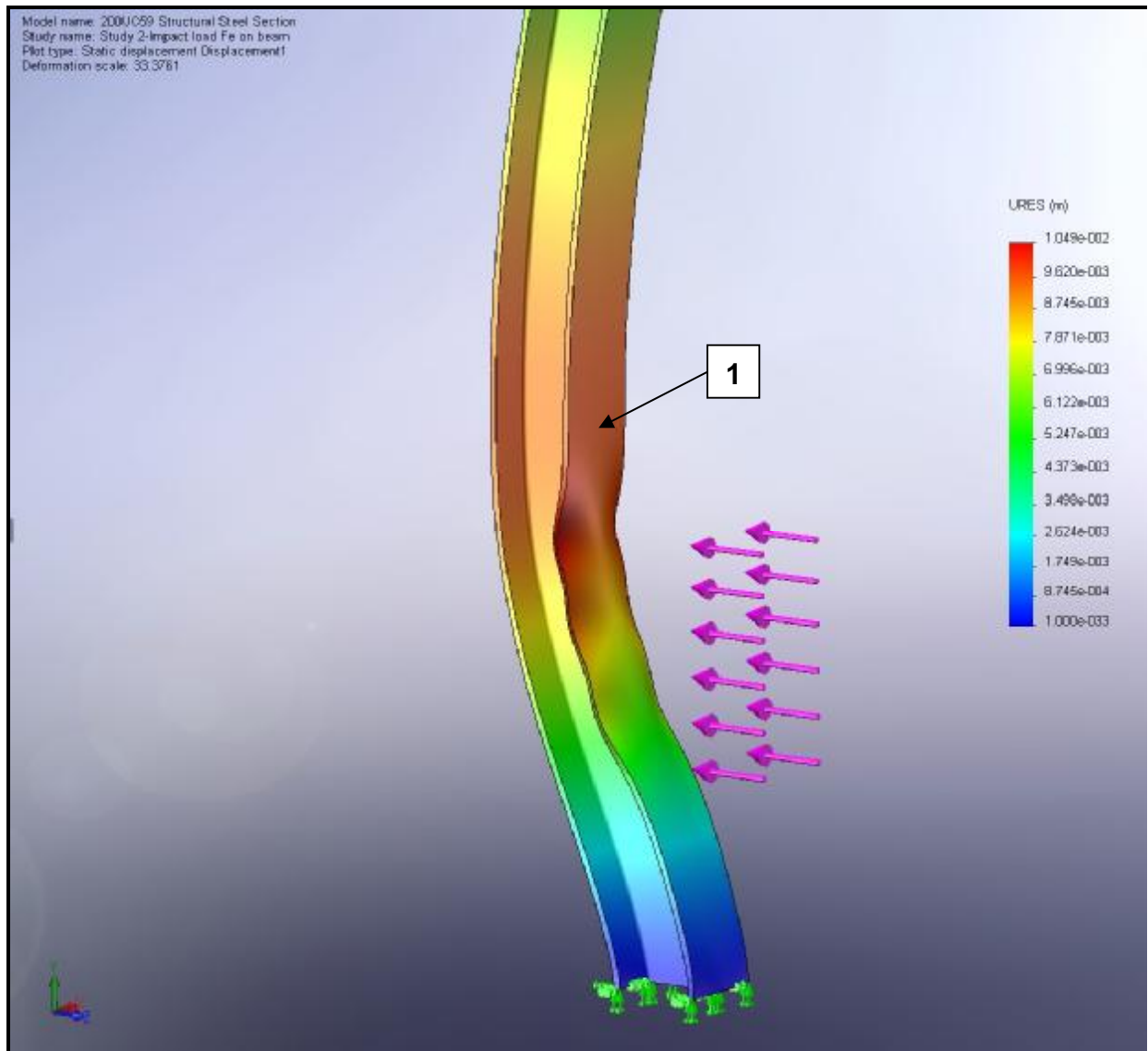


Figure 26: Deflection of UC200 Column

With reference to Figure 26 above;

- Maximum deformation in beam during impact approaches 10 [mm]. The degree of permanent deformation can only be determined through a non-linear study.

5.4.3. Maxi Protected Column Impact

The impact region corresponds to three Maxi units spaced apart over the same impact region. The maxi units act as parallel springs in absorbing the energy.

By resolving the stiffness of the combined structure, we note that the Maxi units dominate and typically they result in an impact duration of 0.23 [sec], i.e. 1000 times longer than the standard beam.

As the Maxi will be operating well within its plastic deformation region, the spring

characteristics were treated as being constant after 25 [mm] of deflection, see Figure 22 for details.

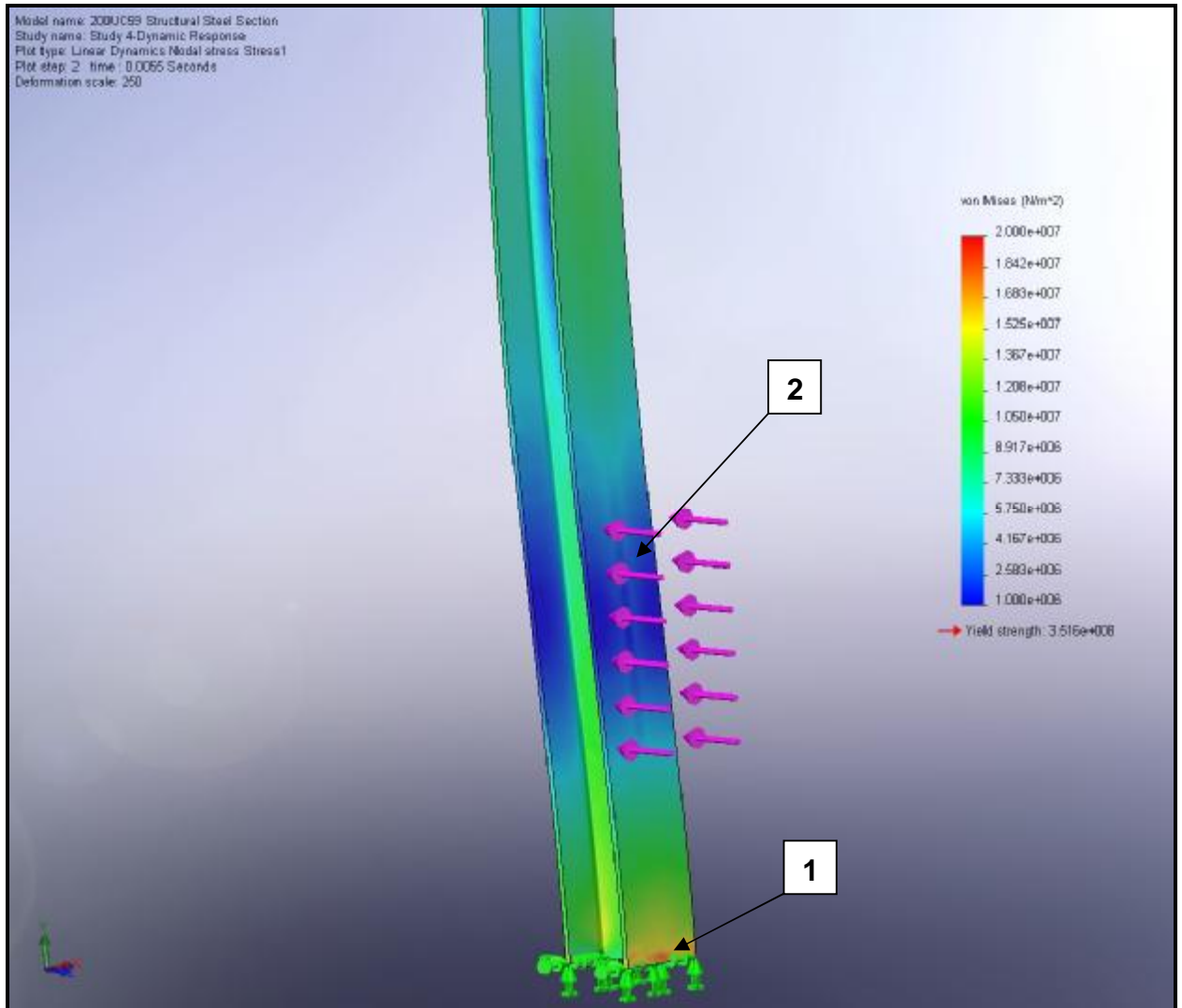


Figure 27: Stress in Maxi protected column subjected to 3750 [N.m] impact

With reference to Figure 27 above;

- Maximum stress within column is 204 [MPa], which is well below the material yield stress of 350 [MPa]. This maximum stress is located in the built-in part of the column, see textbox-1.
- Of particular interest is the impact region of the column behind the Maxi's. Here the stresses are well below yield and this demonstrates the value of using a Maxi unit to protect a column.

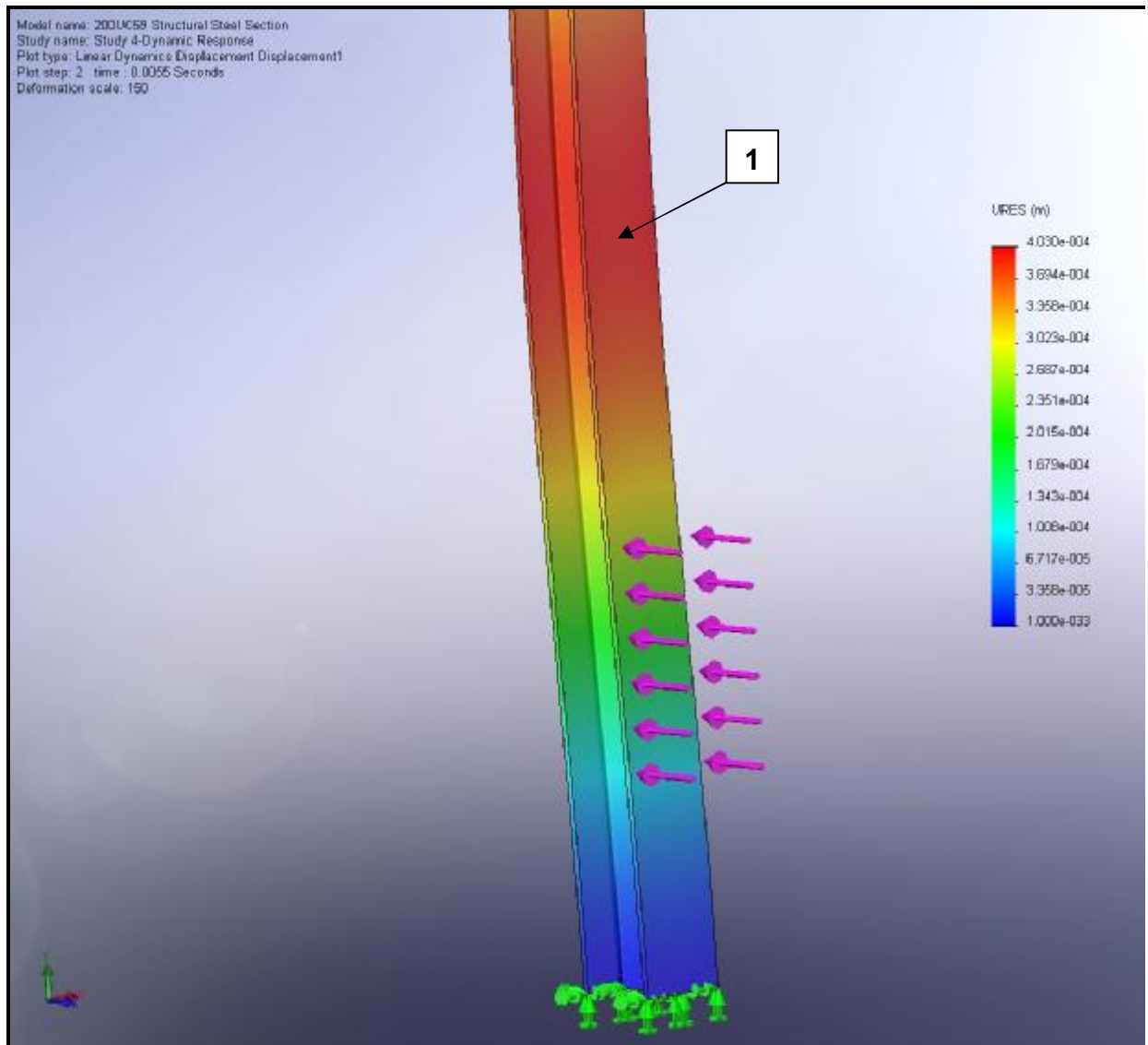


Figure 28: Displacement in Maxi protected Column subjected to 3750 [N.m] impact

With reference to Figure 28 above;

- Maximum deflection in the Maxi protected column is only about 0.4 [mm]. Due to the sudden increase in stiffness of the Maxi as it collapses beyond 30 [mm] deflection, the actual deflection of the beam will be slightly larger than this.



6. Conclusion and Recommendations

The overall design of the Maxi ensures it can meet the impact standard (European Code FEM 10.2.02).

The Maxi has an additional requirement, i.e. to absorb an impact from a 2700 [kg] forklift bumper travelling at 6 [km/hr]. This requirement places considerably greater loads on the Maxi and as such the design cannot meet the full impact without experiencing plastic deformation.

A brief outline of the Maxi's impact capacity is outlined below;

1. The standard impact test, (DIN European Code FEM 10.2.02), is a 400 [N.m] or [Joule] impact. The Maxi can absorb this impact within the elastic limit of the material, and hence suffer no permanent deformation. From Table 2 we can see this equates to a forklift travelling at 2 [km/hr].
2. As the total impact energy exceeds 1200 [N.m] (400 [N.m] per Maxi) local plastic/permanent deformation will have occurred in the walls of the Protect-It Maxi. This equates to a forklift travelling at just over 3.0 [km/hr].
3. As the total impact energy approaches 3750 [N.m], 2.7 [ton] forklift at 6 [km/hr] the Maxi will experience large scale plastic strain/deformation and may exhibit cracking in the most highly stressed regions. Importantly the maxi will absorb the energy of the impacts, albeit sacrificially, but in so doing it reduces the load transmitted through to the column to a magnitude that ensures stresses in the column are well below the steel yield stress. The energy absorbed by the Maxi in this impact case is thus extensively plastic strain energy.
4. A 3750 [N.m] impact against an unprotected UC200-59 built-in column will result in extensive column damage/yielding. With the installation of a Protect-It Maxi protection system the same impact energy would not result in any damage in the same column.
5. The energy absorption capability of the Maxi's is adequate to ensure protection against permanent damage in the smaller UC100-18 column⁵, for the same 3750 [N.m] (2.7 [ton] forklift at 6 [km/hr]) impact.

⁵ The analysis was carried out on a UC100 and UC200 column. For smaller columns it would be necessary to establish the column's structural response before making this claim. Obviously for larger columns the impact resistance improves and extrapolating the results would be conservative.