An Investigation of the Application of Bolt Pre-Stress and its Effect during Low Speed Impact Loading

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Summary:

This report is an initial investigation in to the effect of pre-stress of bolts during impact. The conclusions are not definitive but do indicate that for large strain analysis the effect of pre-stress in bolts is minimal. The effects are more noticeable for lateral impacts than in axial impacts. Further investigation is required to determine the effects of including friction and for other bolted configurations.
This report is not an AMEC document and is not subject to AMEC procedures.

Keywords:

Bolt, pre-stress, pre-load, impact, strain, energy, failure.

1 Introduction

In the impact analysis of large nuclear transport containers, historically the effects of bolt pre-load or pre-stress has been ignored. It has been argued that the effects are negligible when dealing with such high strains. This report is a brief investigation to compare a very simple model with various pre-stress states for two impact orientations at a number of accelerations. It does not claim to be definitive but is the start of what will hopefully be a more in-depth study for later consideration.
The results and findings of this report are preliminary and should not be used in part or whole for any safety case.

2 Generating the pre-load stresses

As with all types of analyses there are a number of ways in which loadings can be applied. In the case of bolt pre-load three methods are immediately apparent.

1. Extending the bolt by a known amount and using the life and death time of contacts accordingly.
2. Using a thermal material model to shrink the bolt by a known amount
3. Applying an initial stress field to the bolt based on the pre-load required.

All three methods rely upon some guess work as the stresses induced in the bolt due to the pre-load are dependent upon many factors and not just the bolt length and diameter.

For this report the third method has been used due to the simplicity of application. The model used is shown in Figure 1. The model is shown in section but a full 360 degree model was utilised. This is based on a M52 bolt typical of those used in a range of nuclear transport containers. The “lid” section is 0.1m thick and 0.3m square. For simplicity a bi-linear stress strain material option, *MAT_3, has been used for all materials but strain based failure is only applied to the shank.

Three stress states have been assessed, zero stress, 200MPa and 400MPa. The initial stress is applied only on the bolt shank using the *INITIAL_STRESS card.

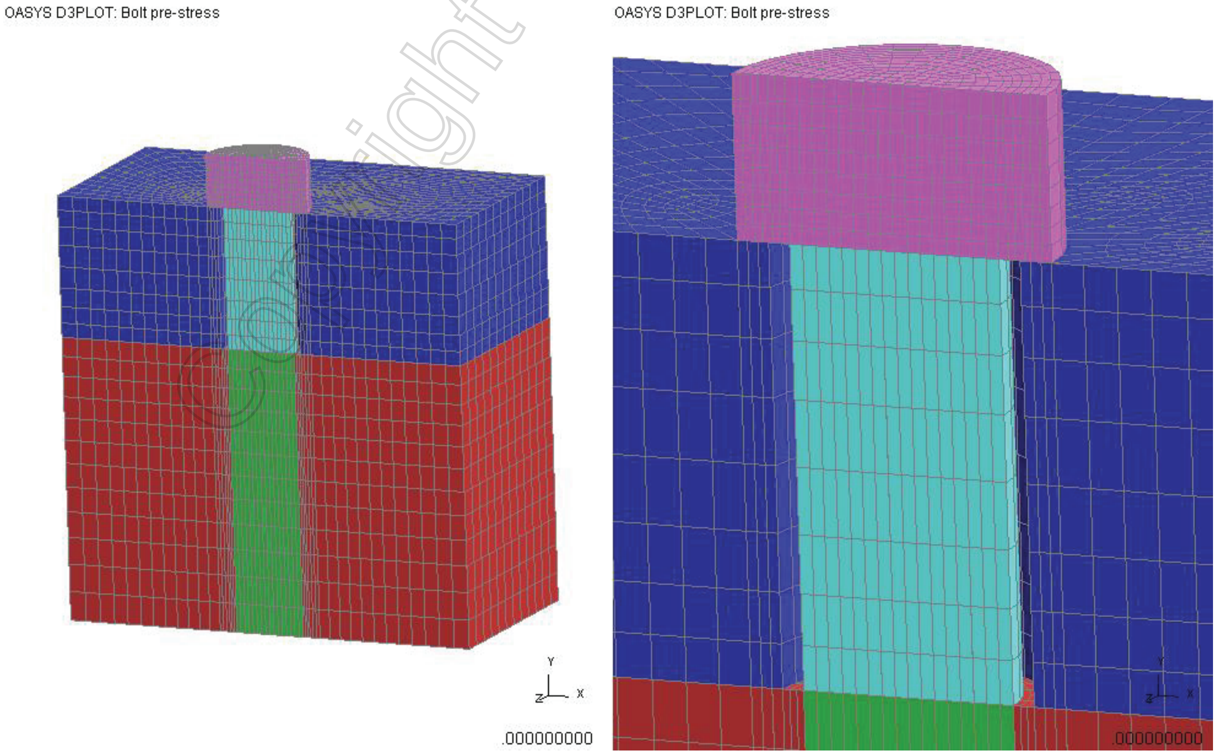

Figure 1: Finite element model

The analysis is then allowed to progress until minimal variation of the stress state is observed. This is achieved faster by using a high damping factor and by increasing the density of the materials to increase the timestep. Clearly for zero initial stress, all stresses in the model are zero. The final stress states of the initialisation for 200MPa and 400MPa are shown in Figure 2

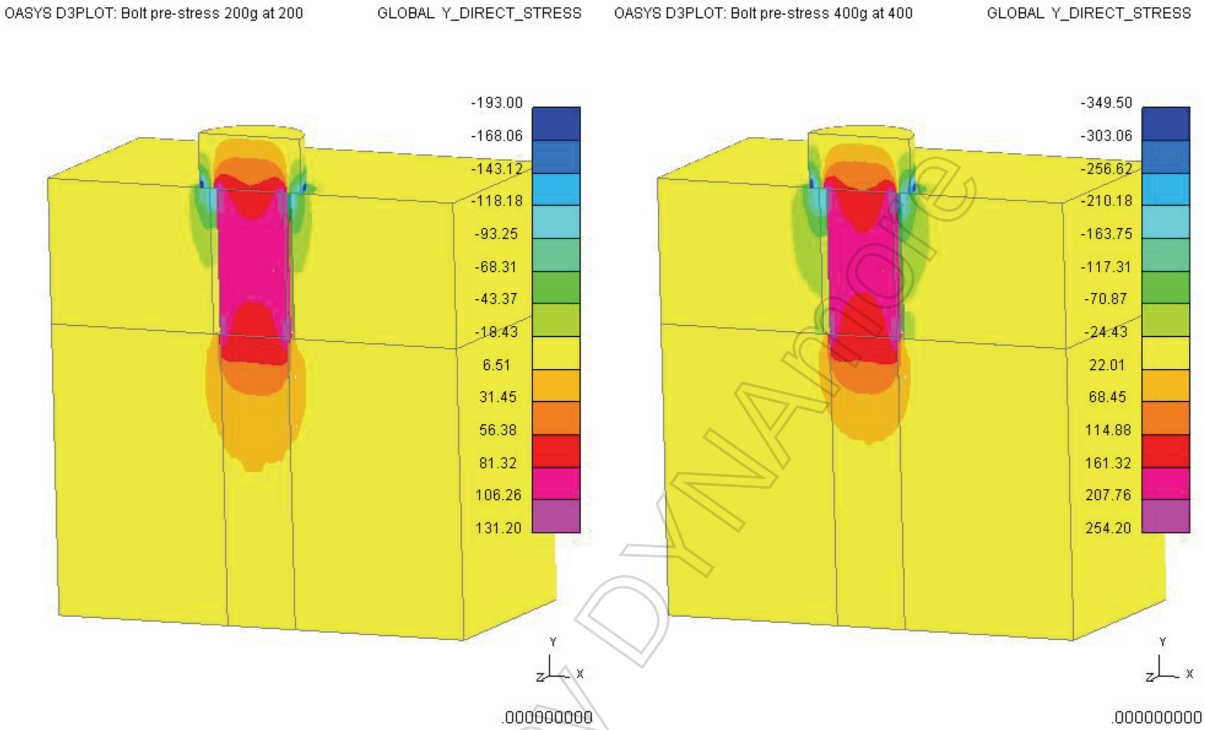

Figure 2: Initial stress states for 200MPa and 400MPa pre-stress

It can be seen that the initial 200MPa and 400MPa stresses are reduced to 130MPa and 254MPa respectively as the stress distributes through the rest of the model. It would be possible to iterate a number of times by taking this result, factoring the final stress state and using that in a subsequent analysis to approach the required pre-stress. This is very easy using the latest functionality within OASYS-D3PLOT using the “User Data” function and then writing out the new stresses as *INITIAL_STRESS. However, this has not been done in this case and the first pass stresses have been used for all the subsequent analyses.

3 Lateral impacts

A lateral impact is simuated by applying an initial velocity to all components and decelerating the base at a predefined rate. Accelerations of 200g, 400g, 800g, 1000g and 1200g have been applied all from an initial velocity of 15m/s. These accelerations are applied to the three initial stress states of zero, 200MPa and 400MPa giving 15 analyses in total. In all cases friction has been omitted.

The effective plastic strains at the end of each of the analyses are shown in Figure 3 to Figure 7. At 200g and 400g the zero and 200MPa pre-stress results are very similar and the 400MPa strains are low. Once the higher 400MPa pre-stress has been overcome, at 800g, the effective plastic strains in all three cases are similar.

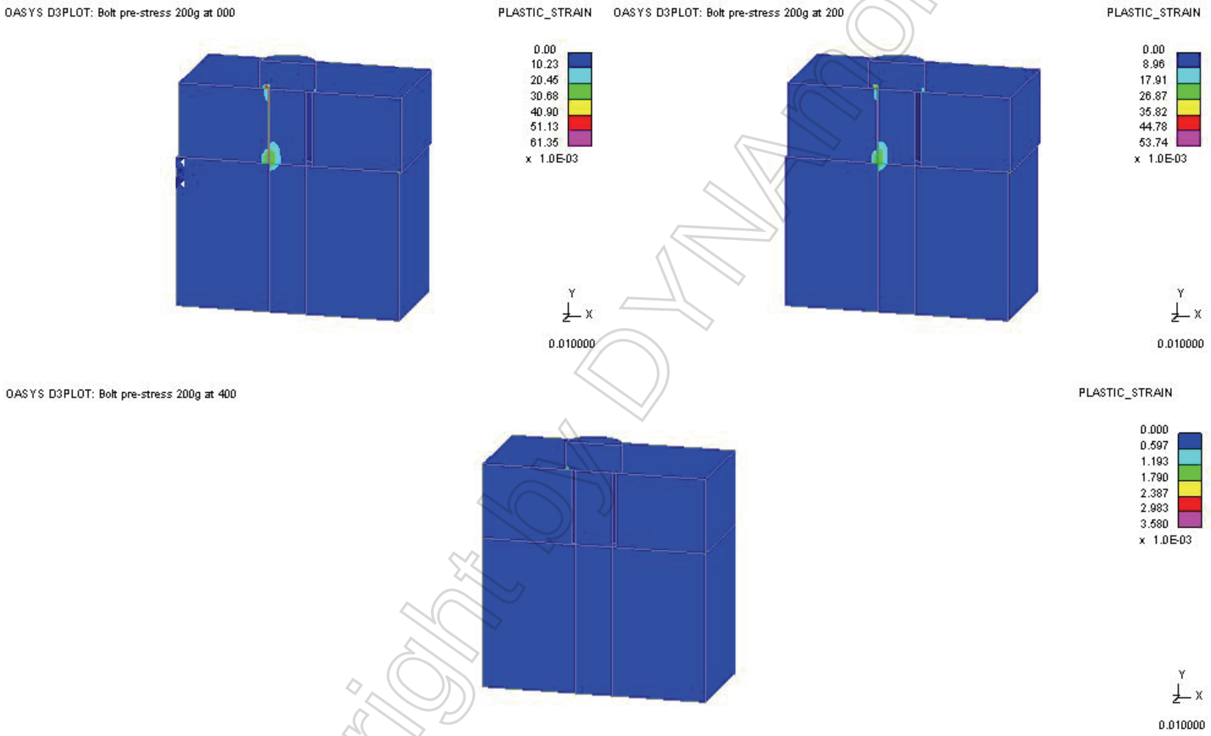

Figure 3: 200g lateral effective plastic strain

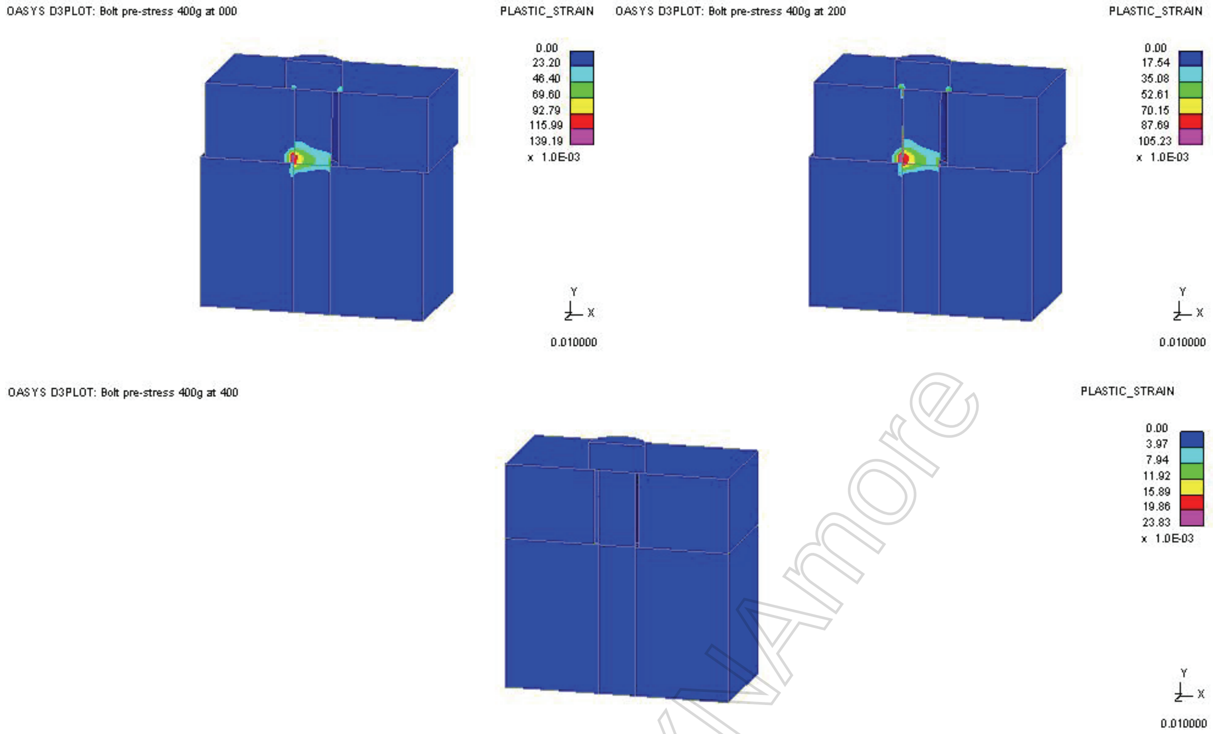

Figure 4: 400g lateral effective plastic strain

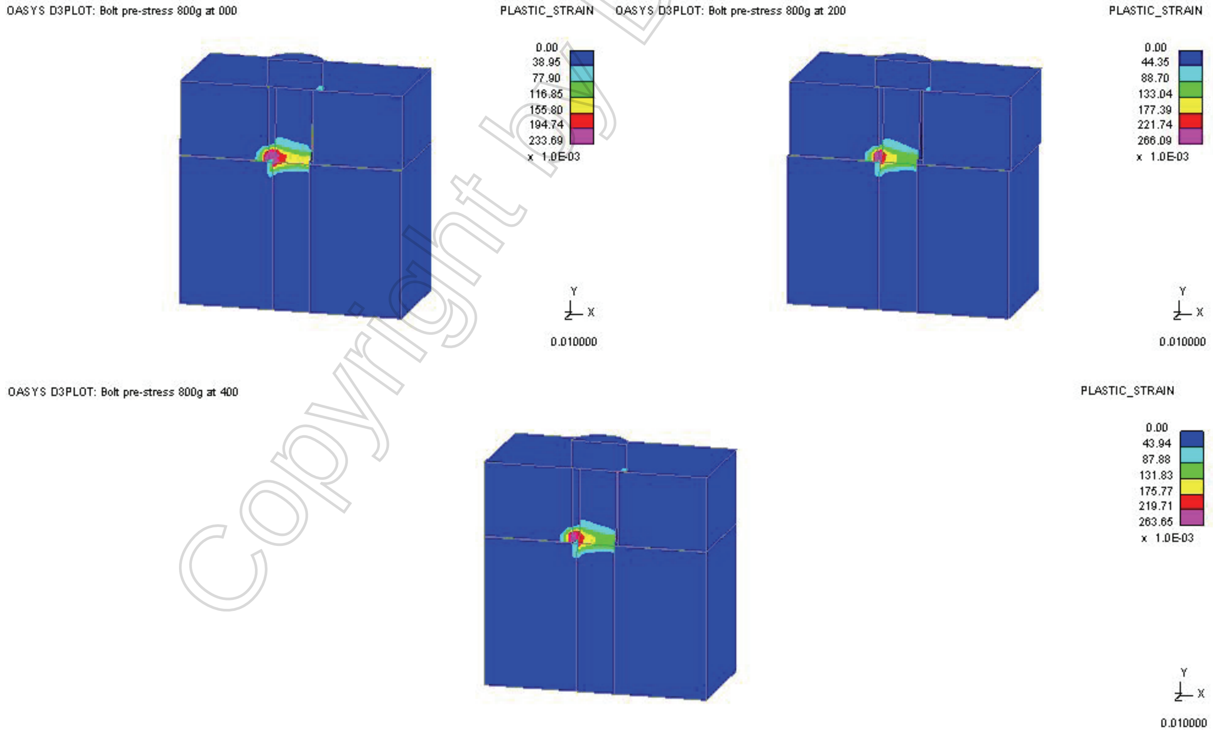

Figure 5: 800g lateral effective plastic strain

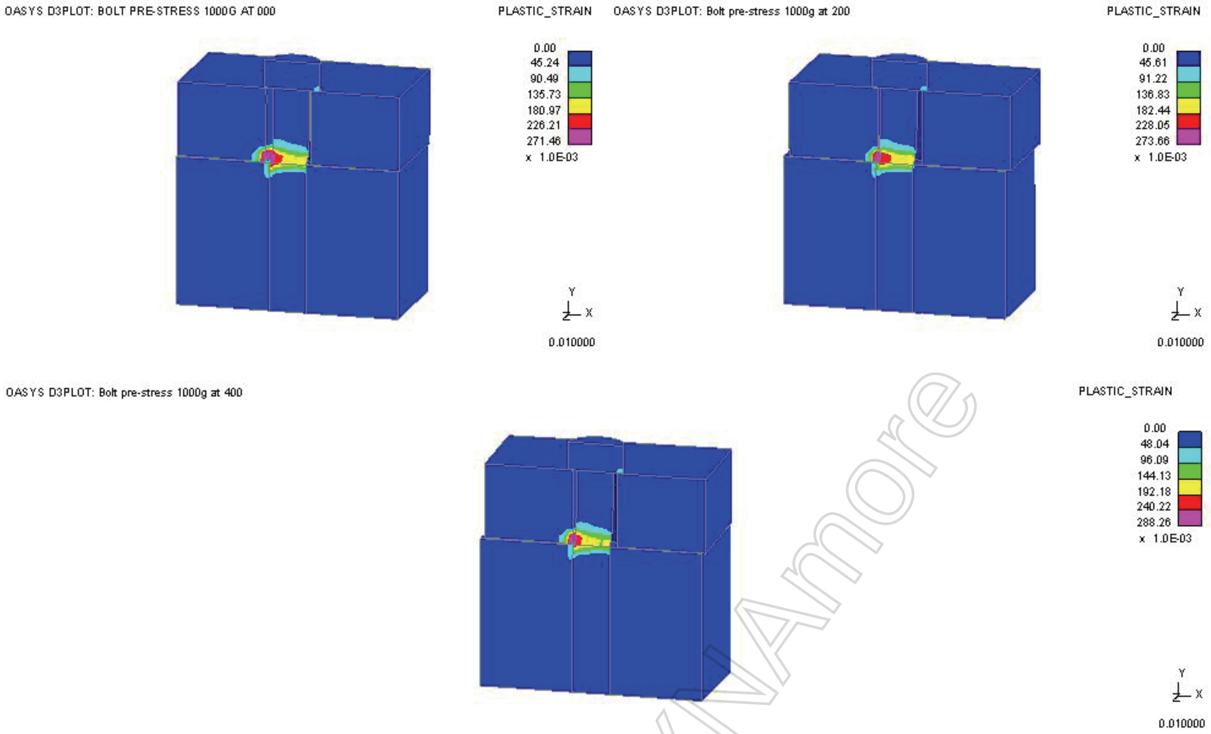

Figure 6: 1000g lateral effective plastic strain

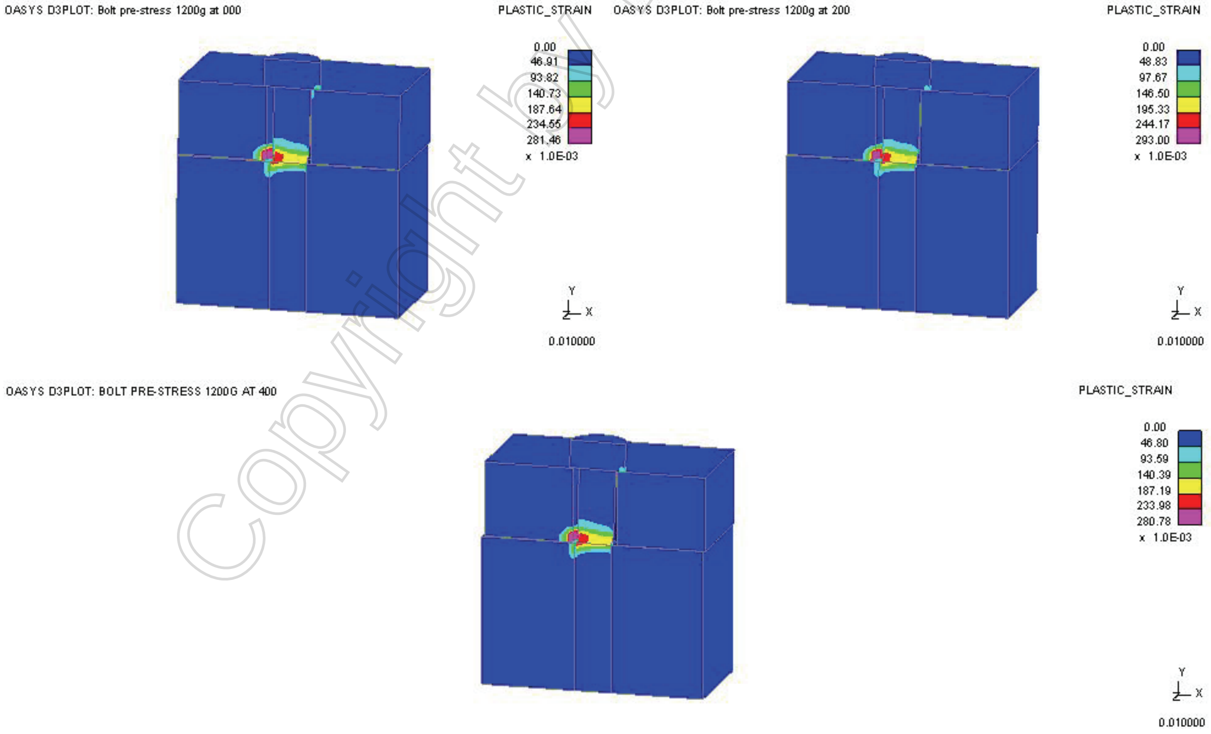

Figure 7: 1200g lateral effective plastic strain

As would be expected Figure 8 shows a similar trend in the internal energies of the bolt shanks with all three results being similar for accelerations of 800g and above. It is interesting to note that the initial internal energy, due to the pre-stress, shows as a negative internal energy.

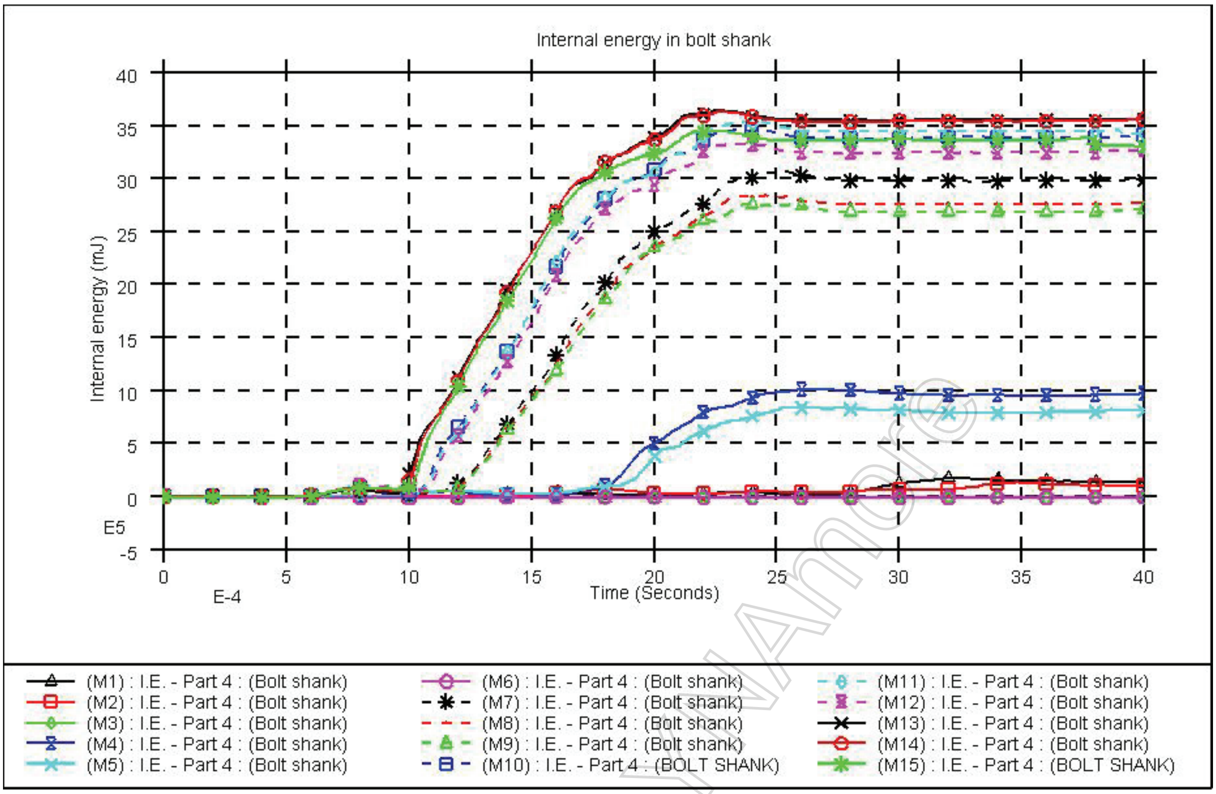

Figure 8: Internal energies in bolt shank for lateral impacts.

The relative x displacement between the „lid“ and „base“ components along with the strains and energies are given in Table 1.

Run	Pre-stress	Acceleration	Maximum effective plastic strain	Internal energy of bolt shank at failure	Maximum relative x displacement
1	Zero	200g	6.1%	140J	5.81mm
2	200MPa	200g	5.4%	100J	5.63mm
3	400MPa	200g	0.3%	-10J	0.32mm
4	Zero	400g	13.9%	967J	7.53mm
5	200MPa	400g	10.5%	80J	7.18mm
6	400MPa	400g	2.4%	-11J	0.79mm
7	Zero	800g	23.3%	3000J	10.7mm
8	200MPa	800g	26.6%	2800J	10.5mm
9	400MPa	800g	26.3%	2700J	10.4mm
10	Zero	1000g	27.1%	3400J	11.3mm
11	200MPa	1000g	27.3%	3400J	11.3mm
12	400MPa	1000g	28.8%	3300J	11.1mm
13	Zero	1200g	28.1%	3500J	11.6mm
14	200MPa	1200g	29.3%	3500J	11.6mm
15	400MPa	1200g	28.1%	3300J	11.4mm

Table 1: Results from lateral analyses

4 Axial impacts

An axial impact is simulated by applying an initial velocity to all components and decelerating the base at a predefined rate. Accelerations of 200g, 400g, 800g, 1000g and 1200g have been applied all from an initial velocity of 15m/s. These accelerations are applied to the three initial stress states of zero, 200MPa and 400MPa giving 15 analyses in total. In all cases friction has been omitted.

In all cases the effective plastic strain in the bolt shank exceeds 25%, selected as a failure strain, and the bolt fails. The failure time for each analysis has been taken from Figure 9 and is given in Table 2. The internal energy of the bolt shank at failure is the same for every case.

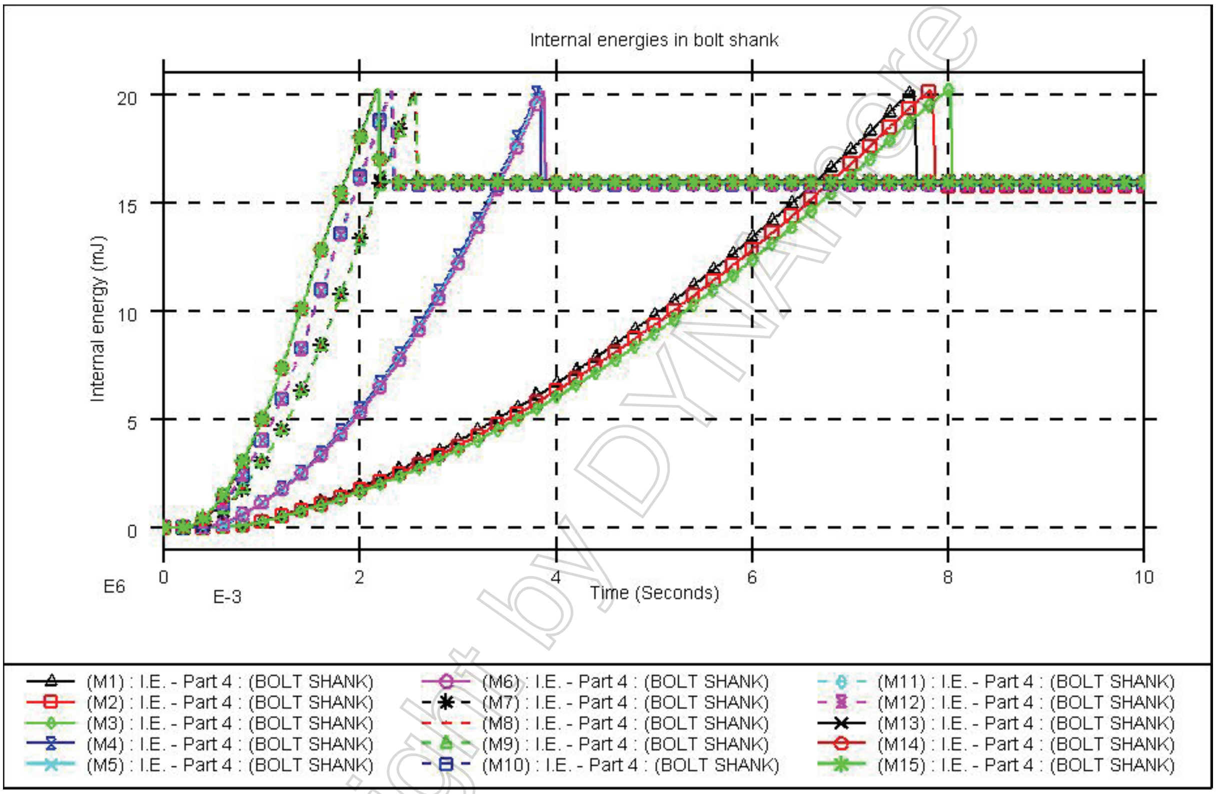

Figure 9: Internal energies in bolt shank for axial impacts

It can be seen from the table that the time of failure is related to the pre-stress applied but other than that there is very little to be concluded from these analyses. It is likely, but not possible to see from these analyses, that for an impact where the bolt remains elastic, the duration and size of any gap created would be less for a higher pre-stress.

Run	Pre-stress	Acceleration	Time of failure	Internal energy of bolt shank
1	Zero	200g	0.00764	20.2kJ
2	200MPa	200g	0.00782	20.2kJ
3	400MPa	200g	0.00800	20.2kJ
4	Zero	400g	0.00382	20.2kJ
5	200MPa	400g	0.00385	20.2kJ
6	400MPa	400g	0.00386	20.2kJ
7	Zero	800g	0.00255	20.2kJ
8	200MPa	800g	0.00256	20.2kJ
9	400MPa	800g	0.00257	20.2kJ
10	Zero	1000g	0.00231	20.2kJ
11	200MPa	1000g	0.00232	20.2kJ
12	400MPa	1000g	0.00233	20.2kJ
13	Zero	1200g	0.00218	20.2kJ
14	200MPa	1200g	0.00218	20.2kJ
15	400MPa	1200g	0.00218	20.2kJ

Table 2: Results from axial analyses.

5 Conclusions

This report is only a starting point for some more in depth investigation and doesn’t claim to be comprehensive. It is clear that for the cases considered the effects of applying pre-stress on the predicted strains and internal energies is minimal when large strains and deformations are expected.
In the case of elastic analyses it is likely that the effects would be noticeable but minimal.
The pre-stress shows more effect for lateral impacts, as would be expected, but it is also worth noting that the effects of friction have not been included in this investigation.