University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Master's degree in structural engineering and materials science/Specialization in offshore structures	Spring semester, 2014 Open
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Thesis title: Dropped object protection analyses	
Credits (ECTS): 30	
Key words: -Dropped object protection -Nonlinear finite element analysis -Membrane effect -USFOS	Pages: 87 + enclosure: 8 Stavanger, 13.06.2014

Summary

Impact from dropped object is a typical accident action (NOKSOK N-004, 2013). Hence, the DOP structure is to be analyzed in an accidental limit state (ALS) design practice, which means that a non-linear finite element analysis can be applied. The DOP structure will be based on a typical DOP structure.

Several FEM analyses are performed for the DOP structure. Different shapes size and weights and various impact positions are used for simulate the dropped object. By changing how the load from a dropped object is applied to the structure the result can be change. When the impact loads is applied to only one point of impact in the FE model. The plastic strain is much larger compared to the impact load is distributed between several points of impact.

In the analyses there will impact load in the middle of the plate, in the middle of the structure and the beam at the edge and in the end of the beam. Impact load in one node is compared to impact load in several nodes in the middle of the plate and in the beams. A DOP structure with additional beam is also model for reducing the strain and deflection. The DOP structure with additional beams is analyzed with impact in one node in the middle of the beams at the edge and the beam in the middle of the DOP structure. The DOP structure is also compared to a DOP structure without plates with respect to strain and deflection. There is also one analysis where the DOP structure is designed with aluminium for comparing with steel. Aluminium is about 1/3 of the weight of the steel.

The analyses are done by the nonlinear finite element program named USFOS, which also have dynamic capabilities. The DOP structure is first modelled in the structural analysis and design program Sesam GeniE. There are designed one original model, one model with modification for reducing the strain and deflection and one model without plates. The impact loads is designed as node mass with velocity for simulated the dropped object.

In analysis with a mass of 7000kg falling 3 meters acting in one node the maximum strain is 18.2%. 18.2% is achieved when the impact is in the middle of the beam at the edge of the DOP structure. The maximum strain is reduced to 12.5% when the mass is distributed evenly in three nodes. A DOP structure with added beams with the impact load in one node in the idle of the beam at the edge has maximum strain of 9.9%. With the extra beams in the DOP structure the beam span will be reduced, therefore lower strain and deflection.

The maximum expected strain in the middle of the plate is 17.9% with a mass of 7000kg falling 3 meters. If the mass is distributed over several nodes the maximum strain is reduced to 8.7% in the middle of the plate. For reducing the maximum strain in the plate the thickness can be increased.

A mass of 2000kg falling on the DOP structure will create 6.1% and 4.4cm deflection in the middle of the middle beam. If the plates on top of the DOP structure are removed the strain is increased to 8.1% and deflection to 9.1cm. The plates on top of the DOP structure obtain much of the energy with a membrane effect which results in reducing the strain and deflection. The DOP structure in aluminum with the same loading has maximum strain of 12.3% and deflection of 7.6cm.

Preface

This master thesis concludes master degree in Mechanical and structural Engineering with specialization in Offshore Structures at the University of Stavanger. The subject was proposed by the structural and marine department of Aker Solutions.

I would like to thank my supervisor Svanhild Alsvik for helping me with computer programs, valuable discussions and being an important motivator. I will also thank Aker Solutions for giving me this master thesis, the help that I needed and an office place. Thank to my supervisor Sudath Chaminda Siriwardane from the University in Stavanger (UiS) for guidance. At last I would thank my fellow student Bjarte Malmin for good discussions.

Stavanger, June 2014

Ingve Nilsen

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Nomenclature

Abbreviations

ALS	Accidental Limit State
DO	Dropped Object
DOP	Dropped Object Protection
FE	Finite Element
FEM	Finite Element Method
UiS	University of Stavanger
ULS	Ultimate Limit State

Symbols

δ	Deflection
ε_y	Yield strain
ε_u	Ultimate strain
Φ	Shape function
Γ_y	Yield function
Π	Total potential
θ	Angel of rotation
σ	Stress
σ_y	Yield stress
ρ_p	mass density of plate
A	Areal
E	Elasticity modulus
E_{kin}	Kinetic energy
f_y	Yield strength
f_u	Ultimate strength
g	Acceleration from gravity
H	Potential of external loads
I	Moment of inertia
K	Stiffness matrix
k	Stiffness
m	Mass
M	Moment
M_y	Yield moment
M_P	Plastic moment
N	Axial force
N_P	Plastic axial force
P	Point load
P_c	Collapse load
s	Distance
t	time
v	Velocity
U	Internal strain energy
W_e	External work
W_i	Internal work

1 Introduction

1.1Background

In modification work on existing platform there are often new and sensitive equipment installed. In lifting zone there is a risk for falling object and a DOP structure can be used for protecting the sensitive equipment in this area. The equipment can be pipelines, valves or important equipment which can be critical damaged by the dropped object. A dropped object protection (DOP) structure can be installed to protect the sensitive equipment and prevent damage.

Dropped object is considered an accidental action and therefore it should be designed for accidental limit state (ALS) (NORSOK N004, 2013). The DOP structure can be designed for using plastic material properties. In order to document the behaviour and the performance of the DOP structure, a FE-model of the structure is made in SESAM Genie and converted to USFOS for non-linear analysis.

The dropped object can have different shapes and sizes, which will affect the damages on the DOP structure. The position of the impact load is also import with respect to the damage on the DOP structure. Therefore analyses with impact in the most critical positions should be performed. There will be analyses for impact load in one node compered to impact in several nodes.

Impact load on a plate will create membrane effect. The membrane effect creates a strengthening effect for the plate during plastic collapse. There will be an analysis of a DOP structure with plates compared with DOP structure without plates, for checking this effect.

Aluminium is a lighter material than steel. Therefore will there be an analysis with aluminium compered to steel. The structural property for aluminium is not the same as steel, hence will give some other result than the steel.

1.2 Scope of work

The goal of this master thesis is to preform analysis on a DOP structure. The analyses will be checked in USFOS for different types of dropped object with respect to the weight and size and various impact positions. An objective is to study the membrane effect from the plate. There will also be proposed a solution for lower the strain and deflection of the structure.

2 Impact load

2.1 Accidental actions

Accidental actions are caused by technical failure or by an unusually operation. Accidental actions are for example:

- Dropped object
- Ship collision
- Fire and explosion
- Helicopter crash

There are usually done risk analyses for determination of accidental actions. For accidental actions an ALS check should be performed with an annual exceeding probability of 10^{-4} (NORSOK N-003 and NORSOK N-004).

2.2 Dropped objects

Dropped objects can for instance be:

- Dropped cargo from lifting gear
- Falling lifting gear
- Swinging objects

The energy from the dropped object depends on the lifting height and the weight of the dropped object. The kinetic energy is carried out by the formula:

$$E_{kin} = \frac{1}{2}mv^2 \qquad (2.1)$$

Where the velocity is given by:

$$v = \sqrt{2gs} \qquad (2.2)$$

The weight of the object can be based on the lifting capacity and lifting height. The shape and weight distribution of the object can also have an important influence for the calculations. For the calculation there should be assumptions for max lifting height and the impact at the most vulnerable place (NORSOK N-003). Equipment on another level could fall down can also be considered.

In the most cases most of the kinetic energy is transformed to strain energy for the impacted location and possibly for the dropped object. Often the dropped object is assumed as infinitely rigid, an all the deformation is in the impacted area. The strain energy can give large structural damage. The dropped object damage are usually local damage and rarely critical for the global integrity of the installation. The structural effects from dropped object can be calculated by a non-linear dynamic finite element analyses or by energy consideration in combination with simple elastic-plastic methods (NORSOK N-004).

2.3 ALS (Accidental limit state)

ALS should be checked for impact event with probabilities of 10^{-4}. The material and load factors are normally set to 1.0 for ALS check.
There should be a check in two steps for ALS

- Structure should be checked for resistance for accidental load
- The capacity of the structure after the accidental load.

(NORSOK N-001 and NORSOK N-004)
Global integrity should be maintained during and after the accidental load. The accidental load should not cause a structural collapse. (NORSOK N-004)

3 Elasto-plastic material

3.1 Nonlinear analyse

A nonlinear analyse or Elasto-plastic analyse is performed where the material reach the plastic zone. The material reaches at first the elastic zone, where the calculations are linear. After the elastic zone there are elastic-plastic where the calculation are non-linear. The last zone is the plastic zone (Figure 3.1). For reaching the plastic zone the material has to be a ductile material, if the material is brittle the material will have a sudden brittle failure.

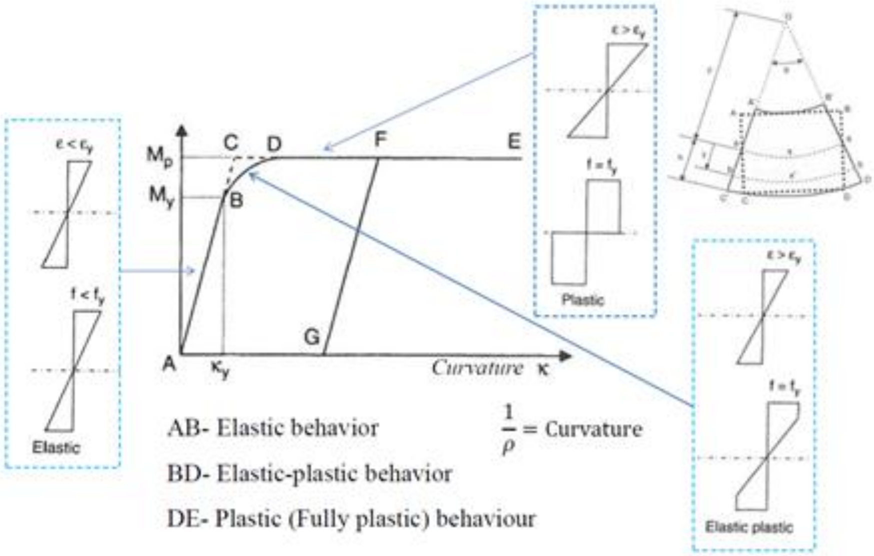

Figure 3.1 Elasto plastic (Siriwardane, 2013)

When the material reaches the plastic zone the deformation is permanent. For accidental load a permanent deformation can be allowable because of the low probability of the accident. The capacity is higher when the plastic zone is achieved.

For a simplified perfectly plastic (Figure 3.2) assumption the plastic can be consider linear. This is a conservative solution which not considers the effect from the strain hardening (Siriwardane, 2013)

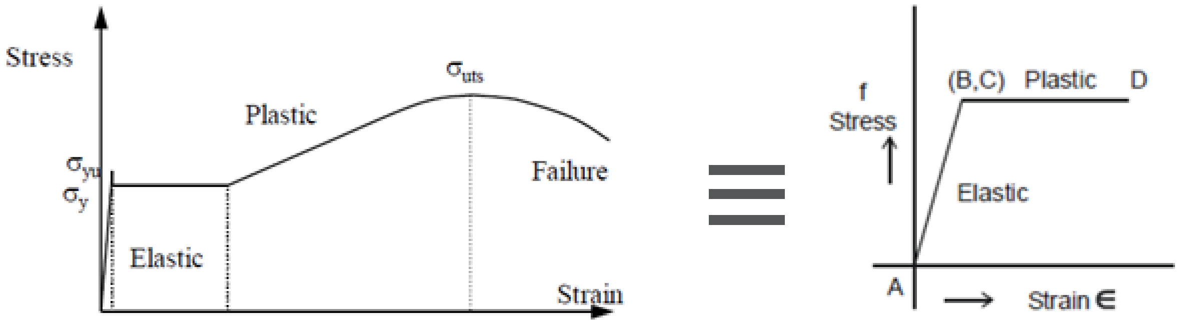

Figure 3.2 Simplified (Siriwardane, 2013)

3.2 Hardening

The size of the yield surface will change if the strain hardening material is loaded with a plastic loading. This is hardening and rule guiding this change in the yield is called hardening rule. (Siriwardane, 2013)

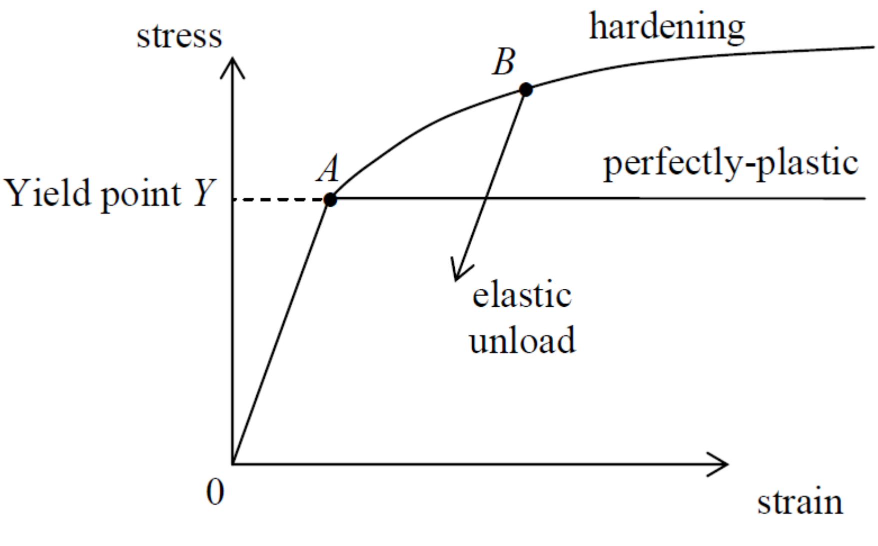

Figure 3.3 stress-strain curve (Engineering Auckland, 2012)

The stress-strain curve can varied depending on the case and material. In Figure 3.3 there are two cases, they divides into different cases after point A. The first case is perfectly-plastic and in this case the hardening is ignored. The plastic deformation is maintained as long as the stress is maintained at the yield point, when the stress is reduced there is elastic unloading. (Engineering Auckland, 2012)

In the hardening case the stress has to be increased for the plastic deformation. For example at the point b if there is no increased or reduced stress there will be no plastic deformation or elastic unloading (Engineering; Auckland).

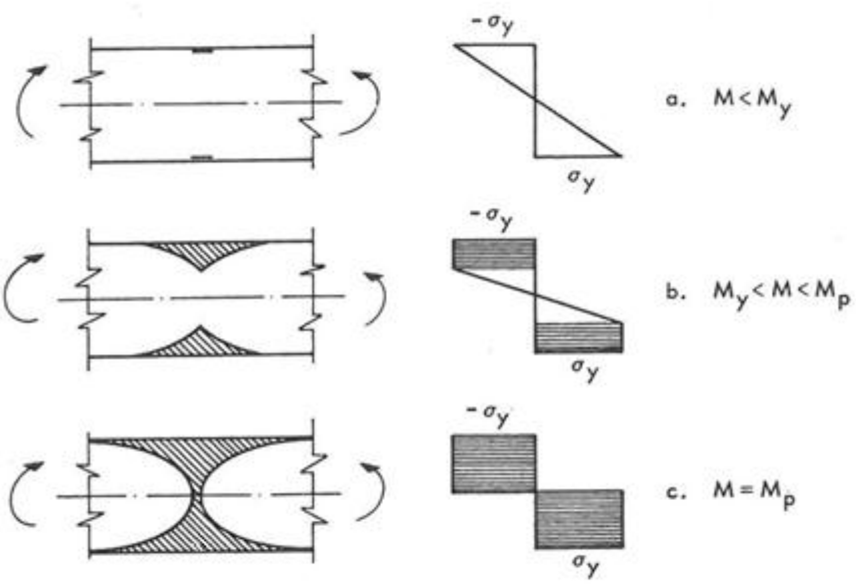

Figure 3.4 Formation of elastic zone to plastic zone (Siriwardane, 2013)

Figure 3.4 shows an elastic example and it is show stress pattern in bending. B shows a plastic-elastic example and C is a plastic example in bending.

3.3 Ductile material

The material must be ductile enough for plastic deformation without collapse, for example steel with steel grade of S450 or lower is usually ductile (Siriwardane, 2013). Ductile requirement for steel according to NS-EN 1993-1:2005+NA: 2008 is:

- $f_u/f_y \geq 1.10$
- Elongation at failure not less than 15%
- $\varepsilon_u \geq 15\varepsilon_y$, where ε_y is the yield strain ($\varepsilon_y = f_y/E$)
  (NS-EN 1993-1: 2005+NA: 2008, 2005)

Table 3.1 Critical strain (NORSOK N-004, 2013)

Steel grade	ε_{cr}
S 235	20 %
S 355	15 %
S 460	10 %

The critical strain for the steel grades according to NORSOK N-004 is as shown in Table 3.1.

3.4 Plastic hinge

Plastic hinges are created where the beams are bending because of the force. When the beam bends in the mid span and at both ends, there is created a kinematic mechanism. With more forces the beams start to deform more and more, and the beam deform in a V-shape. The plastic hinges create rotations concentrated to the plastic hinges. If the force is increased even more the beam is deformed into a chain-link. (USFOS getting started, 2001) Figure 3.5 show how the plastic hinge is created.

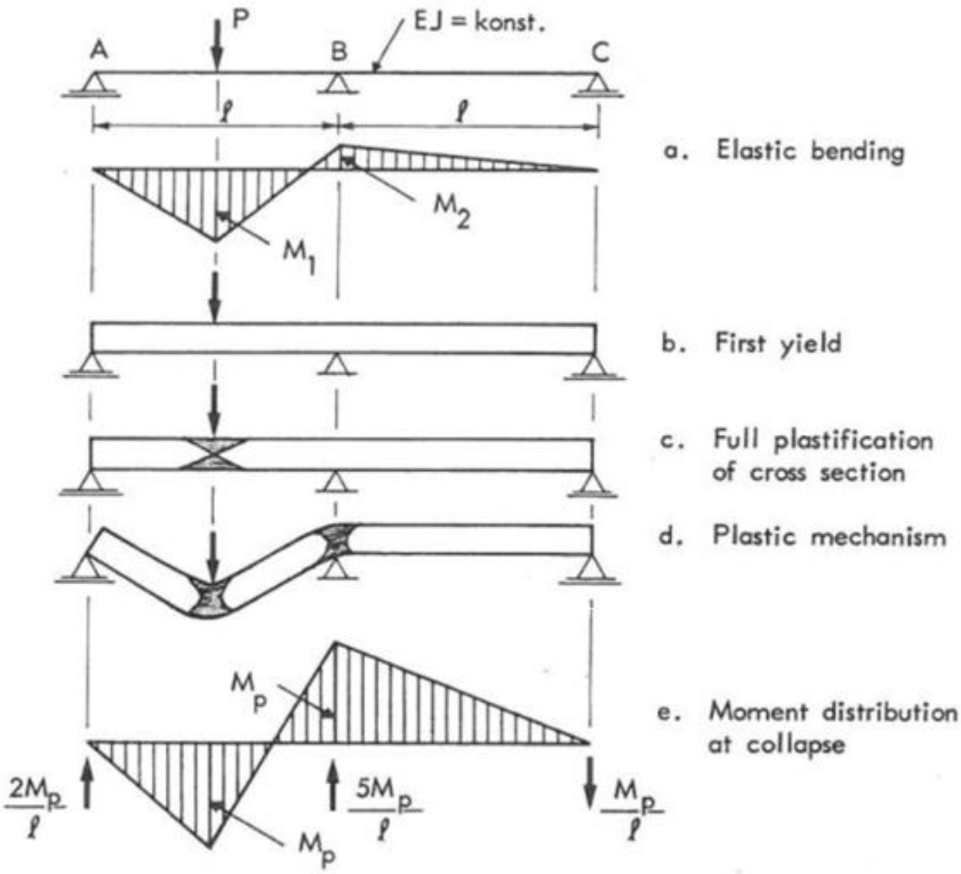

Figure 3.5 (Siriwardane, 2013)

3.5 Membrane effect

Plates which are connected to neighbouring structural elements create a strengthening effect from membrane action during plastic collapse. (Søreide, 1985)

In NORSOK N-004 the energy obtained in stiffened plate subjected to drill collar impact is:

$$E_{sp} = \frac{R^2}{2K}(1 + 0.48\frac{m_i}{m})^2 \tag{3.1}$$

Where the stiffness of the plate within the hinge circle is:

$$k = \frac{1}{2}\pi f_y t(\frac{1+5\frac{d}{r}-6c^2+6.25(\frac{d}{2r})^2}{(1+c)^2}) \quad (3.2)$$

$$c = -e^{-2.5(1-\frac{d}{2r})} \quad (3.3)$$

$$R = \pi \mathrm{d}t\tau \quad \text{where contact force for } \tau \leq \tau_{cr} \quad (3.4)$$

$$\tau_{cr} = f_u(0.42 + 0.41\frac{t}{d}) \quad (3.5)$$

For the mass of the plate inside the hinge circle:

$$m_i = p_p \pi r^2 t \quad (3.6)$$

m = mass of the dropped object
ρ_p = mass density of the plate
d = smallest diameter at threaded end of drill collar
r = smallest distance from the impact point to the plate boundary
(NORSOK N-004,2013)

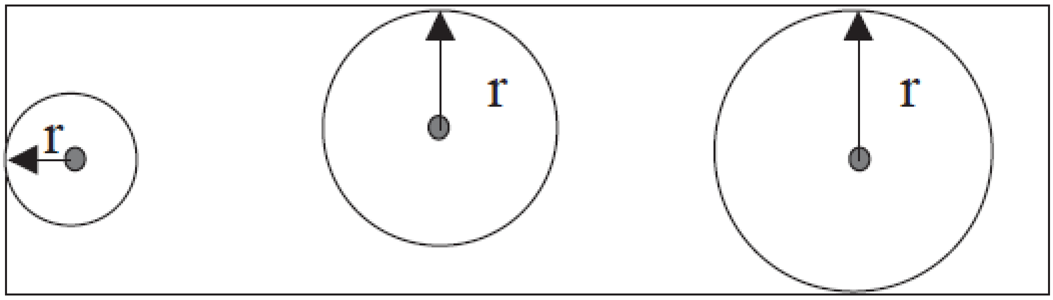

Figure 3.6 smallest distance from impact point to the plate boundary (NORSOK N-004, 2013)

3.6 Aluminium

Aluminium is a lighter material than steel and can be used as a replacement for steel in some cases. Aluminium strength and ductility is reduced in the welds and in heat affected zones in the hardened aluminium materials. Therefore must plastic hinges be avoided in or close to the welds (NORSOK N-001, 2012).

The prime alloy for aluminium is 5083 for plates and for profiles 6005 or 6082 other alloy should only be used for secondary applications according to NORSOK M-121. The numbers of alloys, tempers and filler materials should be limited to a minimum for reducing the cost and avoid using the wrong material. (NORSOK M 121, 1997)

4 USFOS Theory

4.1 UFSFOS

The calculations with the dropped object protection analyses are done with USFOS. USFOS is a nonlinear finite element program. The software program is developed by SINTEF marintek and Norwegian University of Science and Technology. USFOS is based on an updated Lagrange formulation. It can handle large displacements, but it is limited to moderate strains.

4.2 Green Strain

The formulas in USFOS are based on Green strains, defined as

$$\varepsilon_x = u_{,x} + \frac{1}{2}u_{,x}^2 + \frac{1}{2}v_{,x}^2 + \frac{1}{2}w_{,x}^2 \tag{4.1}$$

Where $u_{,x}$ $v_{,x}$ and $w_{,x}$ are the displacement in the x, y and z directions .

This method can give very accurate result of elements behaviour for example column buckling and membrane effects.
The total potential for elastic element is:

$$\Pi = U + H \tag{4.2}$$

Where U is the internal strain energy

$$U = \frac{1}{2}\int_0^l EA(\, u_{,x} + \frac{1}{2}v_{,x}^2 + \frac{1}{2}w_{,x}^2)^2 dx + \frac{1}{2}\int_0^l (EI_z\, v_{,xx}^2 + EI_y w_{,xx}^2)dx \tag{4.3}$$

The first integral in the equation is the axial straining and the last integral is bending. Torsion is not included in this equation, but added in the element stiffness matrix. (USFOS Getting Started, 2001)

The potential of external loads is:

$$H = -(F_i u_i + \int_0^l q_x\, udx + \int_0^l q_y\, vdx + \int_0^l q_z\, wdx) \qquad (4.3)$$

For total and incremental equilibrium equations are created by the strain energy and potential of the work.

$$\delta U = \int_0^l EAu_{,x}\, \delta u_{,x} dx + \int_0^l EI_z \left(v_{,xx}\delta v_{,xx} - \frac{N}{EI_z} v_{,x}\delta v_{,x} \right) dx + \int_0^l EI_y \left(w_{,xx}\delta w_{,xx} \frac{N}{EI_y} w_{,x}\delta w_{,x} \right) dx - \int_0^l (N + EAu_{,x})\delta u_{,x} dx \tag{4.4}$$

From the first integral in the equation represent the linear contribution from axial strain. The next two integrals are bending deformation, which includes the influence of axial forces (membrane effects). The last integral represents the nonlinear axial strain contribution from lateral deflections, it also balance the axial loads. The equation is used for calculating the internal equilibrium forces compared with external forces with equilibrium correction.

4.3 Finite element formulation

USFOS uses finite element method, which means the structure is divided into elements. USFOS defines beams with two-node beam.

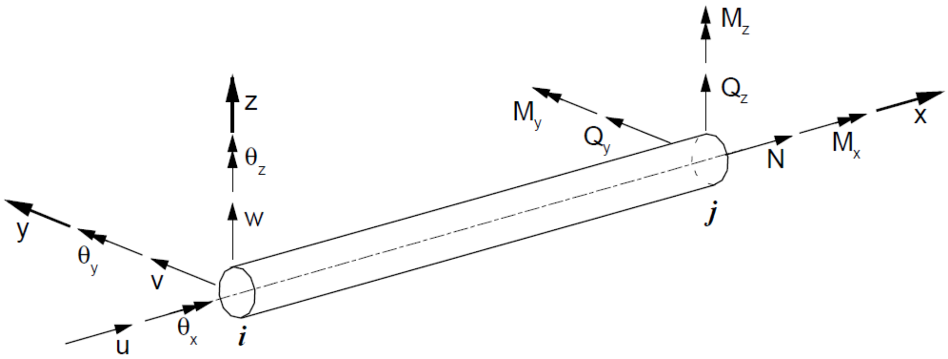

Figure 4.1 Two-node beam-element with six global degrees of freedom for each node (USFOS modelling, 1999).

USFOS equation is based on the solution of the 4th differential equation for a beam subjected to end forces. For small axial forces relative to Euler buckling shape functions becomes inaccurate, and a 3rd degree polynomical shape function is used. For larger strain an element shape function of trigonometric and exponential term is used (USFOS Modelling, 1999).

The incremental stiffness is defined with shape functions for the element displacement, and they can be express as follows:

$$u(x) = \phi^T q_u \qquad (4.5)$$
$$v(x) = \phi^T q_v \qquad (4.5)$$
$$w(x) = \phi^T q_w \qquad (4.6)$$

These formulations are used for an expression for the variation of increment in strain energy δΔU. Δ is the increment between two close configurations.

$$
\begin{aligned}
\delta\Delta \mathrm{U} = \ & \delta u^T \int_0^l EA\phi_{u,x}\, \phi_{u,x}^T dx\Delta \mathrm{u} + \delta v^T \int_0^l EI_z \left(\phi_{v,xx}\phi_{v,xx}^T \frac{N}{EI_z} \phi_{v,x}\phi_{v,x}^T \right) dx\Delta \mathrm{v} \\
& + \delta w^T \int_0^l EI_y \left(\phi_{w,xx}\phi_{w,xx}^T \frac{N}{EI_y} \phi_{w,x}\phi_{w,x}^T \right) dx\Delta \mathrm{v} + \delta v^T \int_0^l EA\phi_{v,x}\, v_{,x}\phi_{u,x}^T dx\Delta \mathrm{u} \\
& + \delta u^T \int_0^l EA\phi_{u,x}\, v_{,x}\phi_{v,x}^T dx\Delta \mathrm{v} + \delta w^T \int_0^l EA\phi_{w,x}\, w_{,x}\phi_{u,x}^T dx\Delta \mathrm{u} \\
& + \delta u^T \int_0^l EA\phi_{u,x}\, w_{,x}\phi_{w,x}^T dx\Delta \mathrm{w} + \delta v^T \int_0^l EA\phi_{v,x}\, v^2{}_{,x}\phi_{v,x}^T dx\Delta \mathrm{v} \\
& + \delta w^T \int_0^l EA\phi_{w,x}\, w^2{}_{,x}\phi_{w,x}^T dx\Delta \mathrm{w} + \delta w^T \int_0^l EA\phi_{w,x}\, w_{,x}v_{,x}\phi_{v,x}^T dx\Delta \mathrm{v} \\
& + \delta v^T \int_0^l EA\phi_{v,x}\, v_{,x}w_{,x}\phi_{w,x}^T dx\Delta \mathrm{w}
\end{aligned}
\tag{4.7}
$$

With equation 4.7 the elastic stiffness matrix can be established:

$$
K_T = \begin{matrix} k_{uu} & k_{uv} & k_{uw} \\ k_{vu} & k_{vv} & k_{vw} \\ k_{wu} & k_{wv} & k_{ww} \end{matrix} \tag{4.8}
$$

Where the sub-matrices are (USFOS Getting Started, 2001):

$$k_{uu} = \int_0^l EA\phi_{u,x}\, \phi_{u,x}^T dx \tag{4.9}$$

$$k_{vv}^I = \int_0^l EI_z \left(\phi_{v,xx}\phi_{v,xx}^T \frac{N}{EI_z} \phi_{v,x}\phi_{v,x}^T \right) dx \tag{4.10}$$

$$k_{ww}^I = \int_0^l EI_y \left(\phi_{w,xx}\phi_{w,xx}^T \frac{N}{EI_y} \phi_{w,x}\phi_{w,x}^T \right) dx \tag{4.11}$$

$$k_{wu} = \int_0^l EA\phi_{u,x}\, v_{,x}\phi_{v,x}^T dx \tag{4.12}$$

$$k_{vu} = \int_0^l EA\phi_{v,x}\, v_{,x}\phi_{u,x}^T dx \tag{4.13}$$

$$k_{wu} = k_{uw}^T \tag{4.14}$$

$$k_{vu} = k_{uv}^T \tag{4.15}$$

$$k_{vv}^{II} = \int_0^l EA\phi_{v,x}\, v_{,x}^2\phi_{v,x}^T \tag{4.16}$$

$$k_{ww}^{II} = \int_0^l EA\phi_{w,x}\, w_{,x}^2\phi_{w,x}^T \tag{4.17}$$

$$k_{wv} = \int_0^l EA\phi_{w,x}\, w_{,x}v_{,x}\phi_{v,x}^T dx \tag{4.18}$$

$$k_{wv} = k_{vw}^T \tag{4.19}$$

4.4 Plasticity

The plastic hinges are created at the element start, end or in the middle of the element. When there are created a plastic hinges in the middle, the element is divided into two sub elements. The hinges behaviour is following the principle of plastic flow theory. The plastic flow theory main assumptions are (USFOS Getting Started, 2001):

- There is a yield condition which is di defined by an initial yield surface.
- There is a flow rule which is relating the increment of stress with plastic strain
- There is a hardening rule which is relating the extension of yield surface to the plastic deformation.

USFOS define the yield condition by a yield function or yield surface Γ based on the plastic interaction between the elements.

$$\Gamma = f\left(\frac{N}{N_P}, \frac{Q_y}{Q_{yP}}, \frac{Q_z}{Q_{zP}}, \frac{M_x}{M_{xP}}, \frac{M_y}{M_{yP}}, \frac{M_z}{M_{zP}}\right) - 1 = 0 \tag{4.20}$$

The plastic interaction function is defined when the $\Gamma = 0$ there is full plasticisation, if $\Gamma > 0$ the result is in principle not a true solution. When the value of $\Gamma = -1$ there is no stress in the cross section.

Flow rule is given by:

$$\Delta v^P = \begin{bmatrix} g_1 & 0 \\ 0 & g_2 \end{bmatrix} \begin{bmatrix} \Delta\lambda_1 \\ \Delta\lambda_1 \end{bmatrix} = G\Delta\lambda \tag{4.21}$$

Where the surface normal of the yield surface

$$g_i^T = \frac{\delta\Gamma}{\delta S_i} = \left[\frac{\delta\Gamma}{\delta N}, \frac{\delta\Gamma}{\delta Q_y}, \frac{\delta\Gamma}{\delta Q_z}, \frac{\delta\Gamma}{\delta M_x}, \frac{\delta\Gamma}{\delta M_y}, \frac{\delta\Gamma}{\delta M_z}\right]_i \tag{4.22}$$

Index i refer here to the beam end 1 and end 2, and S_i is the current state. $\Delta\lambda$ is the scalar factor for the magnitude of the plastic displacement. (USFOS Getting Started, 2001)

The hardening rule is described by loading from one plastic state to one other plastic state. When a plastic hinge is created the state of forces should move from one plastic hinge to one other plastic hinges so that $\Gamma=0$.

For an elastic perfectly plastic material:

$$\Delta\Gamma = \frac{\delta\Gamma}{\delta N}\Delta N + \frac{\delta\Gamma}{\delta Q_y}\Delta Q_y + \frac{\delta\Gamma}{\delta Q_z}\Delta Q_z + \frac{\delta\Gamma}{\delta M_x}\Delta M_x + \frac{\delta\Gamma}{\delta M_y}\Delta M_y + \frac{\delta\Gamma}{\delta M_z}\Delta Q_z = g^T\Delta S_i = 0 \tag{4.23}$$

A plasticity model with partial plastification and strain hardening is based on the bounding surface concept. There are two interaction surfaces, one with yield surface and one with bounding surface. The bounding surface is defined by the state of full plastification of cross section. The yield surface is bound by the region of elastic cross section behaviour. When the force state is in contact with the yield surface it will correspond to initial yielding in the cross section. The yield surface and the bounding surface have the same shapes (USFOS Getting Started, 2001).

5 Case model

5.1 Introduction

In this thesis there will be a DOP structure that will be analysed for different cases.

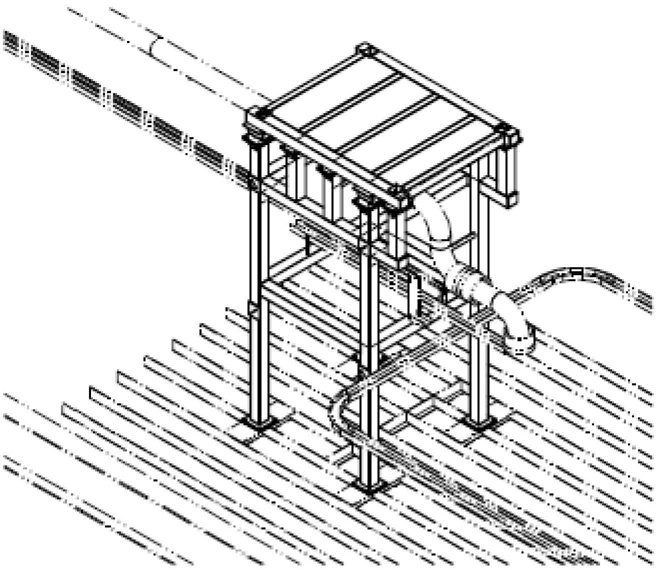

Figure 5.1 DOP Structure

The model of the DOP structure will be based on a typical DOP structure. In this case a DOP is made for protect a pipe from falling object. The module will be modelled in Sesam GeniE and transferred to USFOS for the non-linear dynamic analyse. USFOS uses two files one head file and one model file. The model file was converted from GeniE to a UFO file for USFOS.

A falling object to hit the considered is an accident and will therefore be checked for ALS.

The model will be analysed for different shapes and location of the impact.

5.2 Geometry

5.2.1 Beams and plates

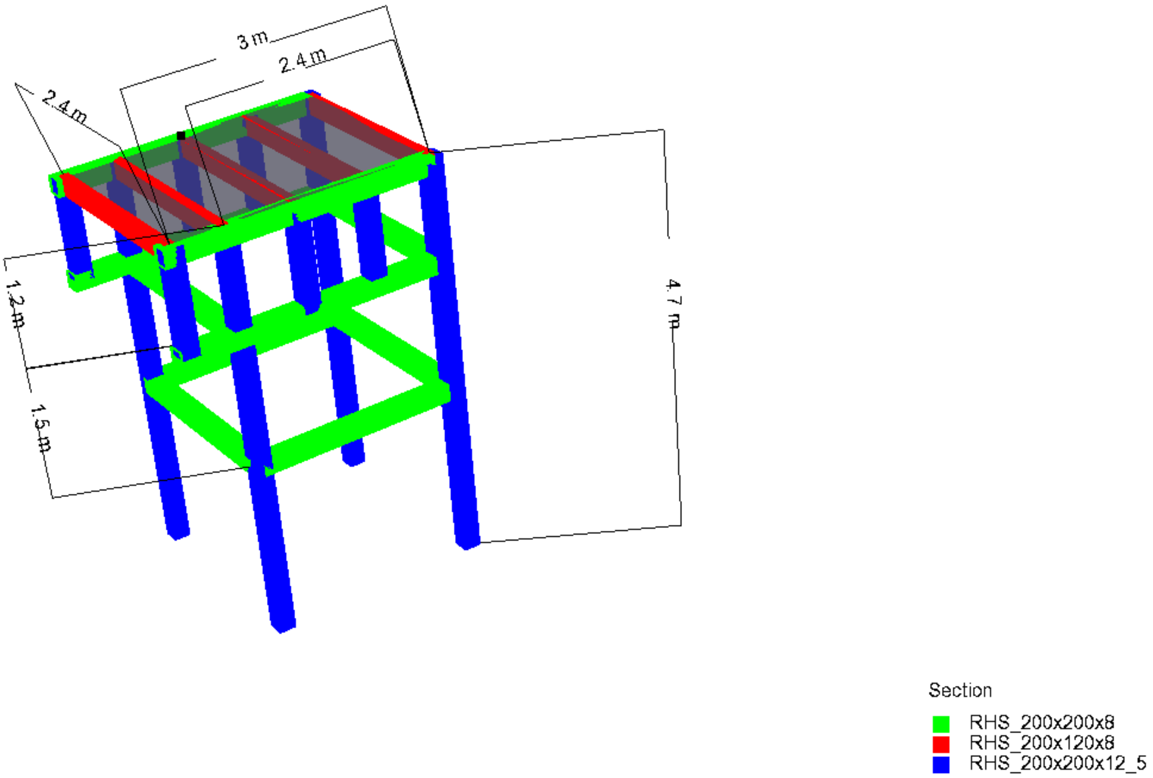

Figure 5.2 Beam types and lengths

The structure is 4.7m high, 3m long and 2.4m wide. The model consists of RHS 200x200x12.5, RHS 200x200x8 and RHS 200x120x8.0. On the top of the structure there are 8 mm thick plates. RHS 200x200x12.5 are used for the columns in the structure. RHS 200x120x8.0 are used for the horizontal beams under the plates. Rest of the horizontal beams are RHS 200x200x8. Cross-section have to be check to NS-ENV 1993 1-1 according to NORSOK N-004. These beams have been approved for Class 1 in according with NS EN 1993 1-1.

5.2.2 Material

The RHS grade of steel are S355 and the plates grade of steel are S420. The Elasticity modules is E= 210 000N/mm^2.

5.3 Loads

The behaviour and performance of the DOP structure will be documented for impact from falling object at the most critical positions.

Live load is given according to NOROK N-003(2007) where 1kN/m^2 is recommended for roofs, accessible for inspection and repair only, but the inspection should not be performed when there is object lifting in the area. The dead load for the structure is the self-weight of the structure.

For the environmental action it is specified in NORSOK N-003: "The expected environmental action occurring together with the 10-4 accidental can be neglected unless the accidental action is initiated by the environmental action". Therefore the wind load will be neglected.

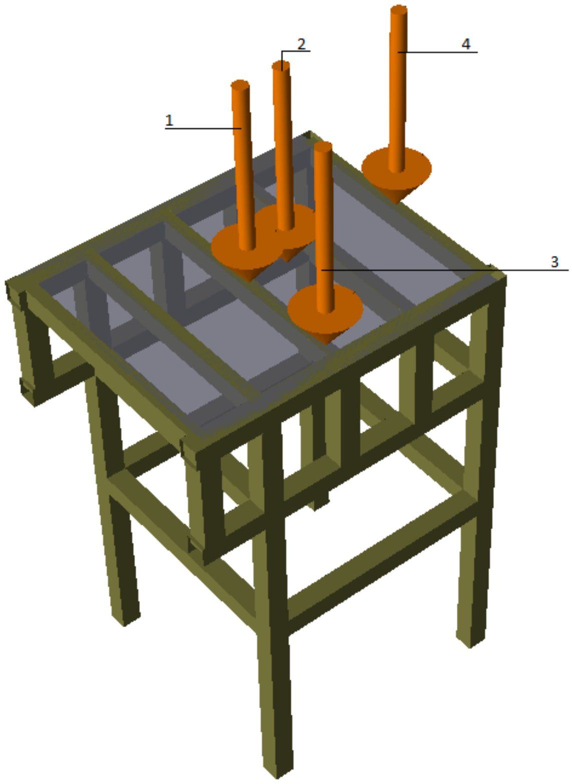

Figure 5.3 Load locations

The mass of the dropped object will be 7000kg, but is reduced to 2000kg for some of the analyses. The 7000kg is based for the maximum lifting capacity. The analyses with 2000kg are for the structure without plates, structure with plates for comparing and a structure with aluminium instead of steel. The mass will fall down from a height of 3 meters for both 7000kg and 2000kg. Figure 5.3 specifies where the load from the dropped object is applied, where node number is given for each of the four loads. These node numbers are in the impact locations of the dropped object. These numbers will be a reference for the location in the result of the analysis. The node numbers are not the same as in USFOS because there will be different nodes in some of the analysis, therefore are these new nodes given.

- Node 1 is in the centre of the middle RHS200x120x8.0

- Node 2 is in the centre of the plate between to RHS200x120x8.0
- Node 3 is in the end of the middle RHS200x120x8.0
- Node 4 is in the centre of the end RHS200x120x8.0

6 Analysis

6.1 Introduction

USFOS uses two files, the first file is the head file which is manual computed and the second file is a model file which is usually transferred from another analyses program. In this case the model file is converted from Sesam GeniE with Struman a tool in USFOS with the UFO command to a format which is readable for USFOS. The file can also be transferred directly from GeniE to USFOS but it is easier to read a UFO file.

The load will be given as mass in a node with a velocity in the node for simulate the dropped object. For simulate the dropped object it will be created as a dynamic load.

6.2 Dynamic

For creating a dynamic analyse the commands DYNAMIC and TIMEHIST are used. DYNAMIC is used for specify the loading through time. The command can specify how long the dynamic analyse is before it ends and how often the steps in the analysis are calculated and displayed. If there are many steps in the analysis it takes more disk place and longer time to analyse but it is more accurate (USFOS MANUAL, 1999).

```
'         T_end      dt        dT_res       dT_pri
Static     1.0      0.050       0.050        0.050
Dynamic    1.2      0.00001     0.001        0.001
Dynamic    2.0      0.01        0.01         0.01
'
```

Figure 6.1 Dynamic

Where the parameters are:

- T_end specify time increment to the end time
- Delta_T is time increment to the end time is reached
- dT_res is the time between the savings of the results
- dT_term is the time between it print to the terminal

The STATIC command is used for the self-weight and live-load, but is switch into dynamic after 1 second. STATIC command is used for adding the permanent load before the dynamic part start, for not creating extra vibration in the structure. In the analysis two DYNAMIC commandos is used. The first dynamic is from 1.0second to 1.2 seconds after the impact with many small step/increment for accurate calculations. The time last until 2 seconds which is longer time perspective but have larger step/increment.

6.3 Time history

TIMEHIST is used for specify the time history for the static loads. In this commando there are parameters to describe what kind of curve for the time history. There are also parameters that define what scaling factor and when the scaling factors are being used.

```
'
TIMEHIST   2 Points
'             Time    factr
               0        0
               1        1
               2        1
```

Figure 6.2 Time history

Here is the first number after TIMEHIST a reference for the time history number. The text after the number is reference for which type the time history is used, in this cases “Points” is used which is from point to point graph (Figure 6.3).

- Time is which time the scaling factor is used
- Factor is the scaling factor for the load

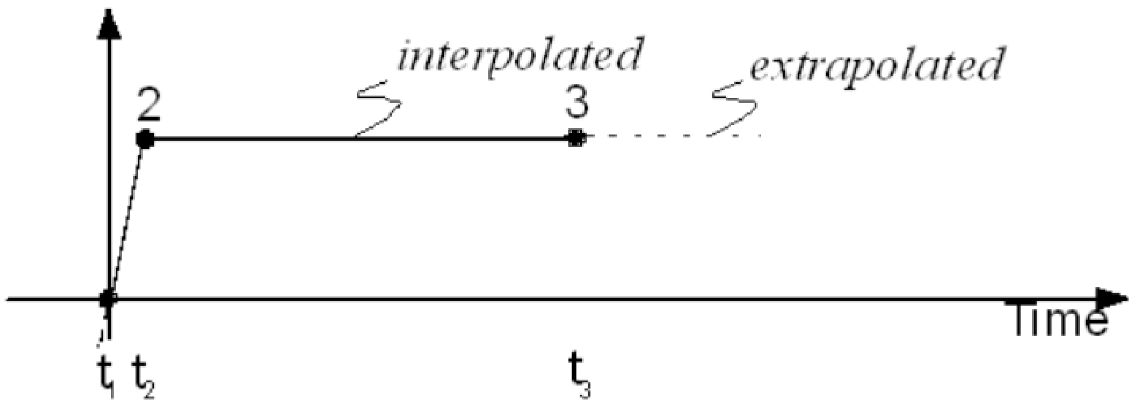

Figure 6.3 Time history (USFOS User’s Manual Commands, 1999)

6.4 Loads history

The commando LOADHIST is used to specify the load that is used for the analysis and to which time history.

```
Loadhist        3            2
Loadhist       10            2
```

Figure 6.4 Load history

The parameters are:

- Load_case define which load case is being used
- Time_hist define which time history is being used in combination with the load case

In the analysis there are two different load cases. The self-weight and the live load are used for the load histories.

6.5 Node mass

The commando NODEMASS is used for giving the dropped object a mass.

```
'            node_Id   Mass
'Nodemass     196       0  0  2000
'Nodemass     495       0  0  7000
 Nodemass     187       0  0  7000
'Nodemass     596       0  0  7000
'Nodemass     595       0  0  7000/3
```

Figure 6.4 Node mass

It is defined which node the mass is subjected to and which direction the mass will have.

6.6 Initial velocity

The initial velocity of the mass is given by the command Ini_Velo.

```
'           Type   Time     Vx   Vy    Vz     rVx  rVy  rVz   Id_1   Id_2
'Ini_velo    Node   1.001   0.0  0.0  -7.672  0.0  0.0  0.0   196
'Ini_velo    Node   1.001   0.0  0.0  -7.672  0.0  0.0  0.0   495
 Ini_velo    Node   1.001   0.0  0.0  -7.672  0.0  0.0  0.0   187
'Ini_velo    Node   1.001   0.0  0.0  -7.672  0.0  0.0  0.0   596
'Ini_velo    Node   1.001   0.0  0.0  -7.672  0.0  0.0  0.0   595
```

Figure 6.5 Initial velocity

The initial velocity is given a time when the velocity is going to be activated; in this case the velocity is activated after 1.001s. The velocity is also given with a direction; here it is -7.672 in z-direction. The last index is the node ID which must be the same as the node mass for creating the kinetic energy.

6.7 Damping

In USFOS Rayleigh damping or time dependent damping can be used. In this case Rayleigh damping is used for create the damping, but Rayleigh damping will often not be as important because of the effective damping will be predominated by hysteric material behaviour in plastic hinges(USFOS light,2001). There are two coefficients in Rayleigh damping; one mass proportional damping coefficient and one stiffness proportional damping coefficient. Since the node mass and initial velocity is used the mass of the dropped object will be attached to structures after the impact and creates larger vibrations than it would normally do.

7 Result

7.1 Introduction

There will be 13 different cases (Table 7.1); in analyses 1-10 there will be a mass of 7000kg for the dropped object, while in analysis 11-13 there will be a mass of 2000kg for the dropped object. Both masses will be dropped from 3 meters. The impact locations will be as shown in figure 5.3. The limits for the DOP will be strain and deflection. Critical strain is given in Table 3.1, which give 15% strain for S355 and 10% for S460, because the plate is S420 it will be limited to 10%. The maximum deflection is limited to not damage the equipment and therefore set a limit for maximum deflection of 25.0cm on the bottom of the beam.

Table 7.1 Analyses

Analyses	Description
Analysis 1 One node mass in node 1	Node mass of 7000kg will have an impact in the middle of the beam, which will create large bending moment in the beam
Analysis 2 One node mass in node 2	Node mass of 7000kg will have an impact in the middle of the plate, which will create large deflection and strain in the plate
Analysis 3 One node mass in node 3	Node mass of 7000 kg will have an impact at the start of the beam, which will create large shear forces in the beam
Analysis 4 One node mass in node 4	Node mass of 7000kg will have an impact in the middle of the beam at the edge of the structure,
Analysis 5 Three node masses in node 4 area	Total node mass of 7000kg evenly distributed on three nodes will have an impact in the middle of the beam at the edge.
Analysis 6 Nine node masses in node 1 area	Total node mass of 7000kg evenly distributed on nine nodes will have an impact in the middle of the beam
Analysis 7 Nine node masses in node 2 area	Total node mass of 7000kg evenly distributed on nine nodes will have an impact in the middle of the plate
Analysis 8 16 node masses in node 2 area	Total node mass of 7000kg evenly distributed on 16 nodes will have an impact in the middle of the plate
Analysis 9 One node mass in node 1 with extra beams	Node mass of 7000kg will have an impact in the middle of the beam The DOP structure will have extra beams
Analysis 10 One node mass in node 4 with extra beams	Node mass of 7000kg will have an impact in the middle of the beam at the edge. The DOP structure will have extra beams
Analysis 11One node mass in node 1 without plate	Node mass of 2000kg will have an impact in the middle of the beam The structures will not have plates.
Analysis 12 One node mass in node 1	Node mass of 2000kg will have an impact in the middle of the beam
Analysis 13 One node mass in node 1 (Aluminium)	Node mass of 2000kg will have an impact in the middle of the beam. The structure will be in aluminium instead of steel

7.2 Analysis 1 One node mass in node 1

7.2.1 General

Analyze 1 is analysis of the DOP structure with a mass of 7000kg dropped from 3 meters acting in the middle of the beam as shown in figure 7.1. The impact-load will give large deflection in the beam, but it will be reduced by the membrane effect from the plate.

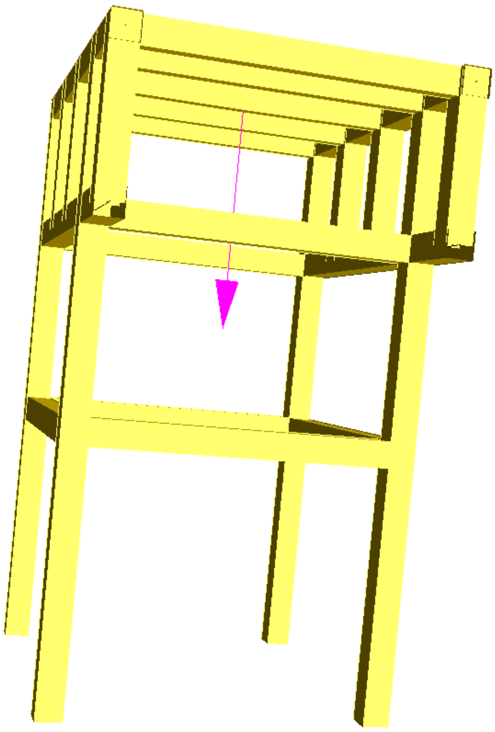

Figure 7.1 Load

7.2.2 Kinetic energy

With a mass of 7000kg falling 3 meters will create kinetic energy.
The velocity of the dropped object will be from equation 1.1:

$$v = \sqrt{2gs}$$

$$v = 7.672\ \frac{m}{s}$$

The kinetic energy from equation 1.2:

$$E_{kin} = \frac{1}{2}mv^2$$

$$E_{kin} = 206.01\ kNm$$

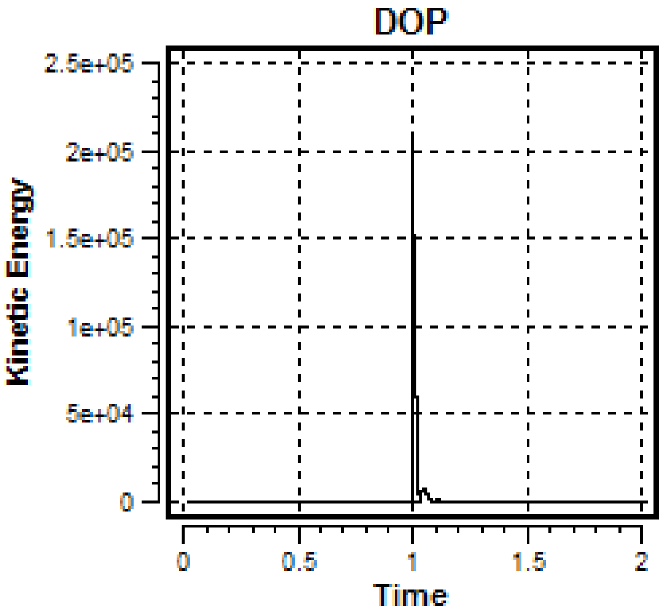

Figure 7.2 Kinetic Energy

Table 7.2 Kinetic energy

1.00099	1.07868e-011
1.001	1.08271e-011
1.00101	204849
1.00102	204137
1.00103	203652

From the text file (Table 7.2) for kinetic energy, the max value is 204.85kNm after the impact, which is slightly lower than the calculated kinetic energy which was 206.01kNm. In the analysis the step length is 0.00001s and the impact has a very low time of impact as seen in Figure 7.2 and Table 7.1. The impact happen after 1.001s, but it is the next step 1.00101s which has the max kinetic energy. The next step after 1.00102s has been lower by 0.712kNm and 0.485kNm in 1.00103, so the real energy is probably closer to calculated energy of 206.01kNm.

Figure 7.2 shows there is a small increasing in the kinetic energy right after the energy kinetic energy has reach 0 after the impact. This effect is some inaccurate, because this method have the dropped object attached with velocity when it bounce back, but this effect is reduced with damping.

7.2.3 Γ-values (Interaction function values)

The interaction function values represent the stress level for each element. The range goes from -1.00 which is stress free to 0.00 which is when full plastic capacity is reached. The value must be under 0.00 for being a “true “solution. An exception is when it is a pushover analysis, when the interaction function value can be 0.05. (USFOS Getting started, 2001)

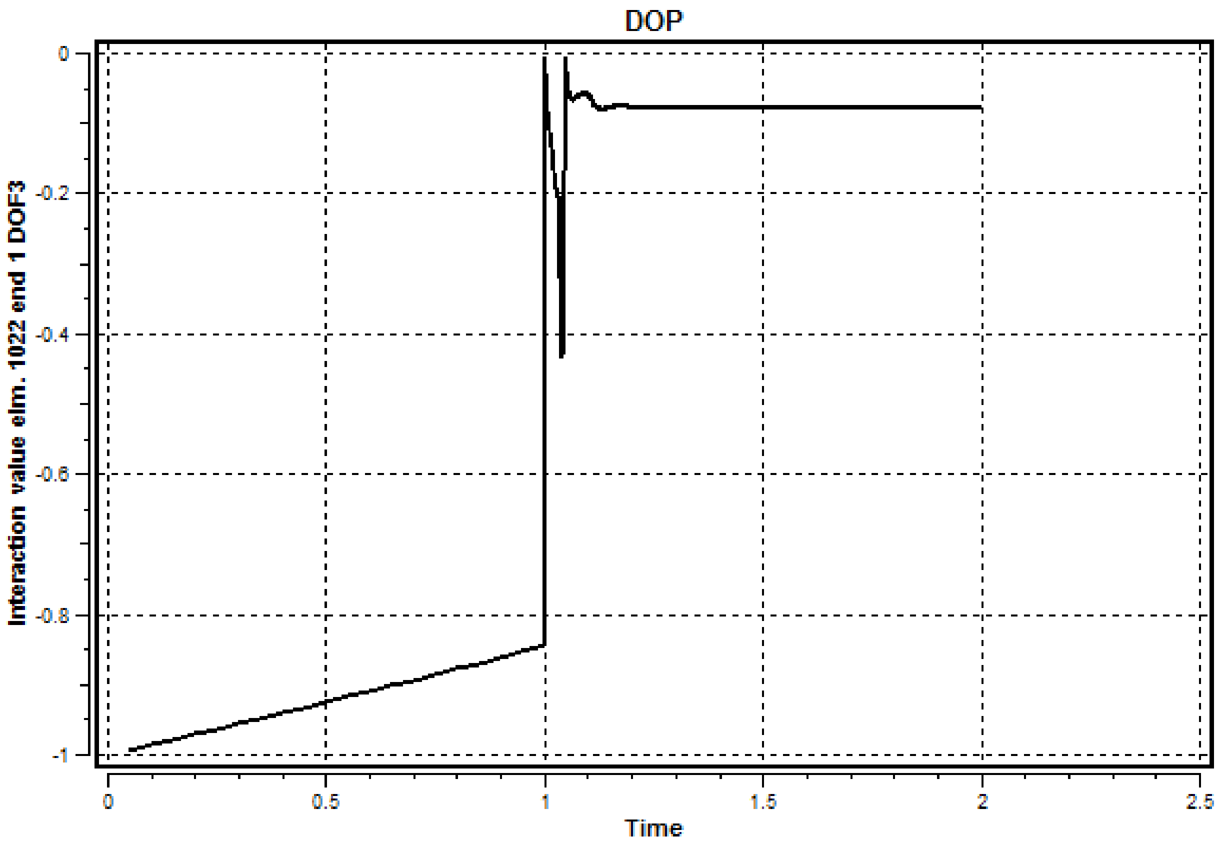

Figure 7.3 Interaction

The value from figure 7.3 shows that the interaction value do not exceed 0.0, this is then a valid solution.

7.2.4 Strain

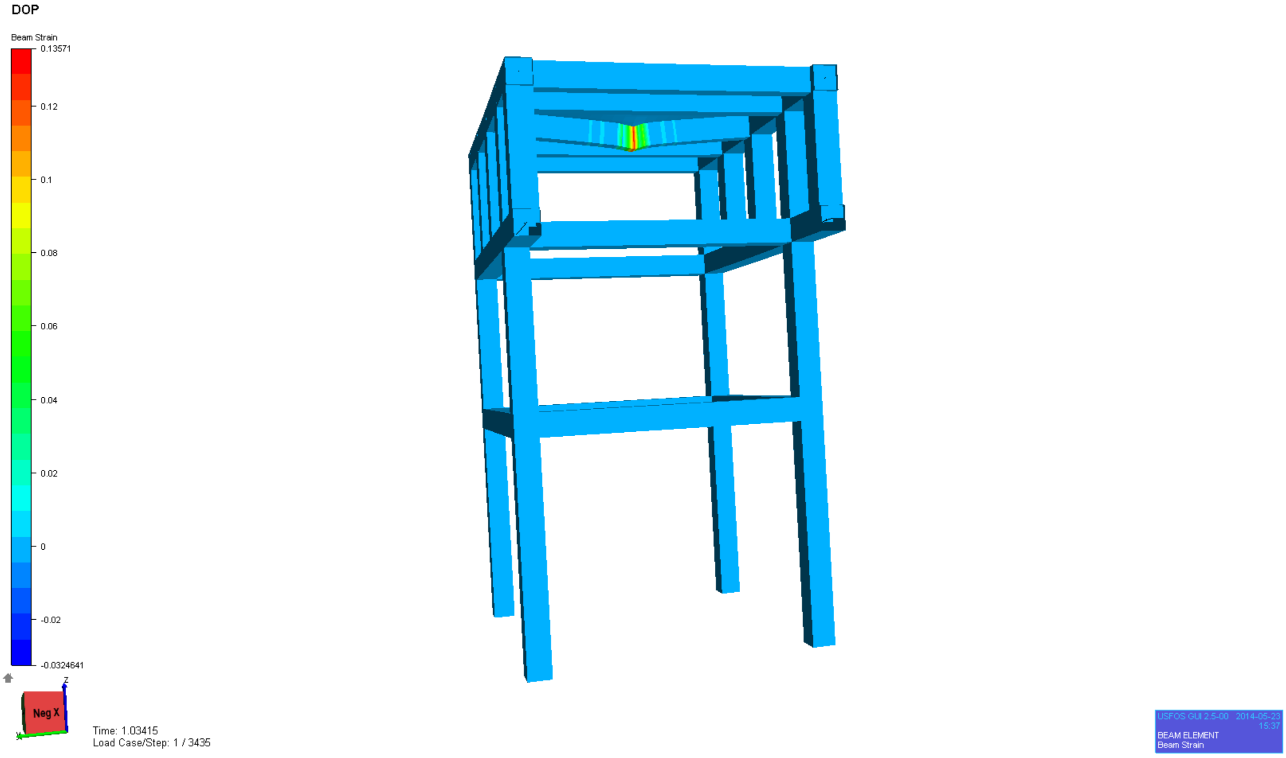

Figure 7.4 Strain in beam

According to NOROK N-004 the maximum strain for S355 is 15%. The maximum strain for the beam is 13.6 %, which is in the acceptable limit. Maximum strain is reached right after the impact in the impact area.

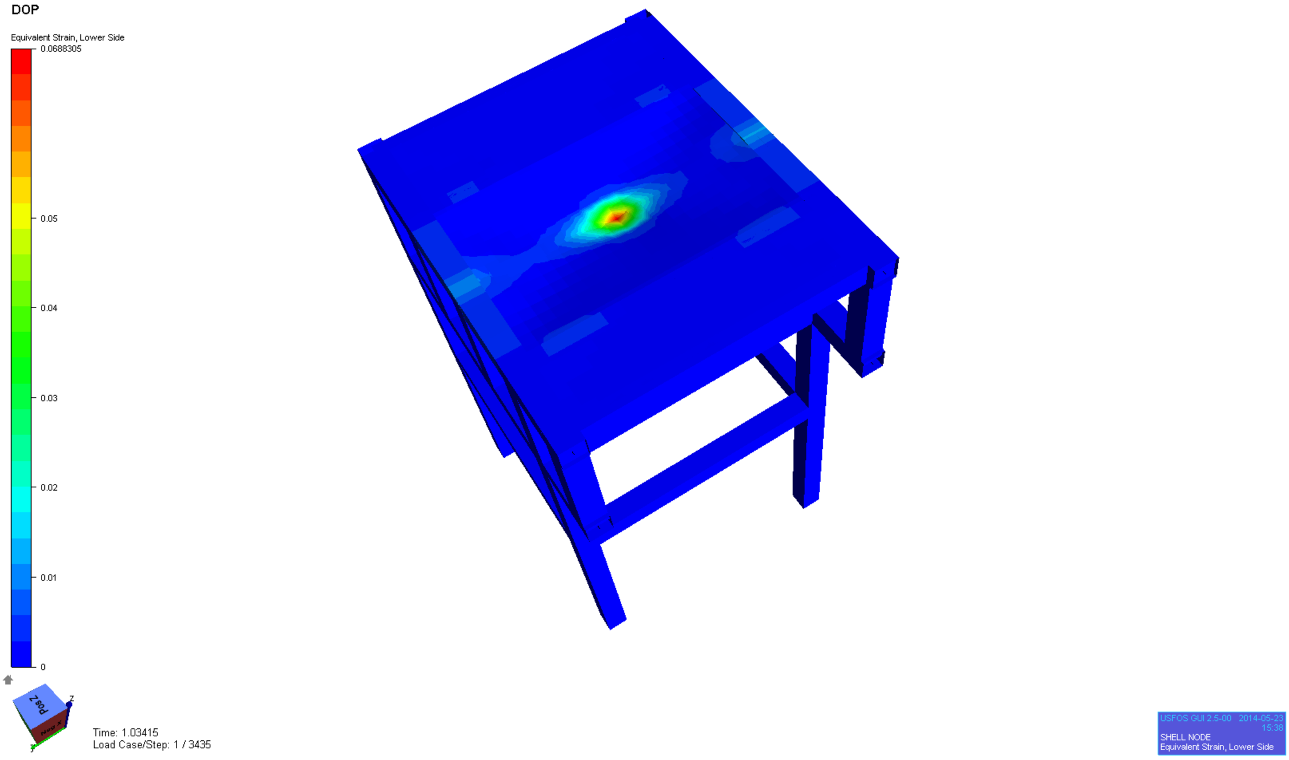

Figure 7.5 Strain

For steel with S460 the requirement is max 10% steel. For the plate with S420 the maximum strain that is achieved is 7.1% according to figure 7.5 which is in the approved range.

7.2.5 Displacement

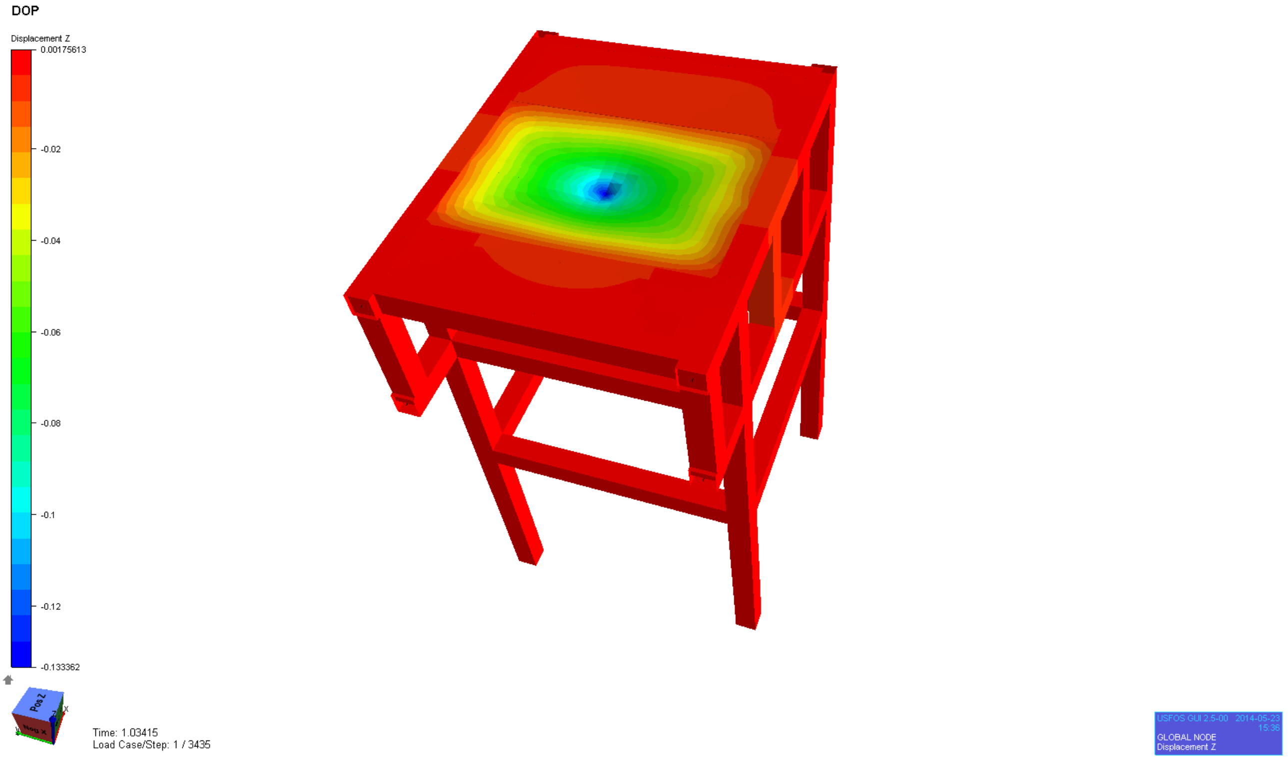

Figure 7.6 Displacement

Figure 7.7 Displacement

Figures 7.6 and 7.7 are showing the displacement for the plate and the beam. The maximum displacement is 13.3cm in z-direction in the middle of the beam.

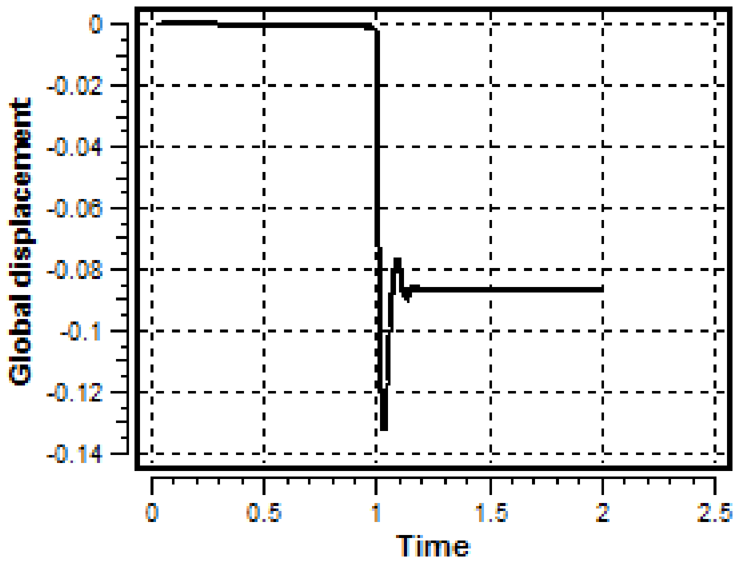

Figure 7.8 Global displacements as function of time in node 1

The static loads from the self-weight and live load occur from the start and have very little effect on the displacement (Figure 7.8). The impact happened right after 1 second and creates the maximum displacement. Since the mass is attached to the node the mass will get negative velocity after maximum displacement because of the mechanic vibrations, and this will create inaccurate result after the maximum value.

7.2.6 Plastic utilization

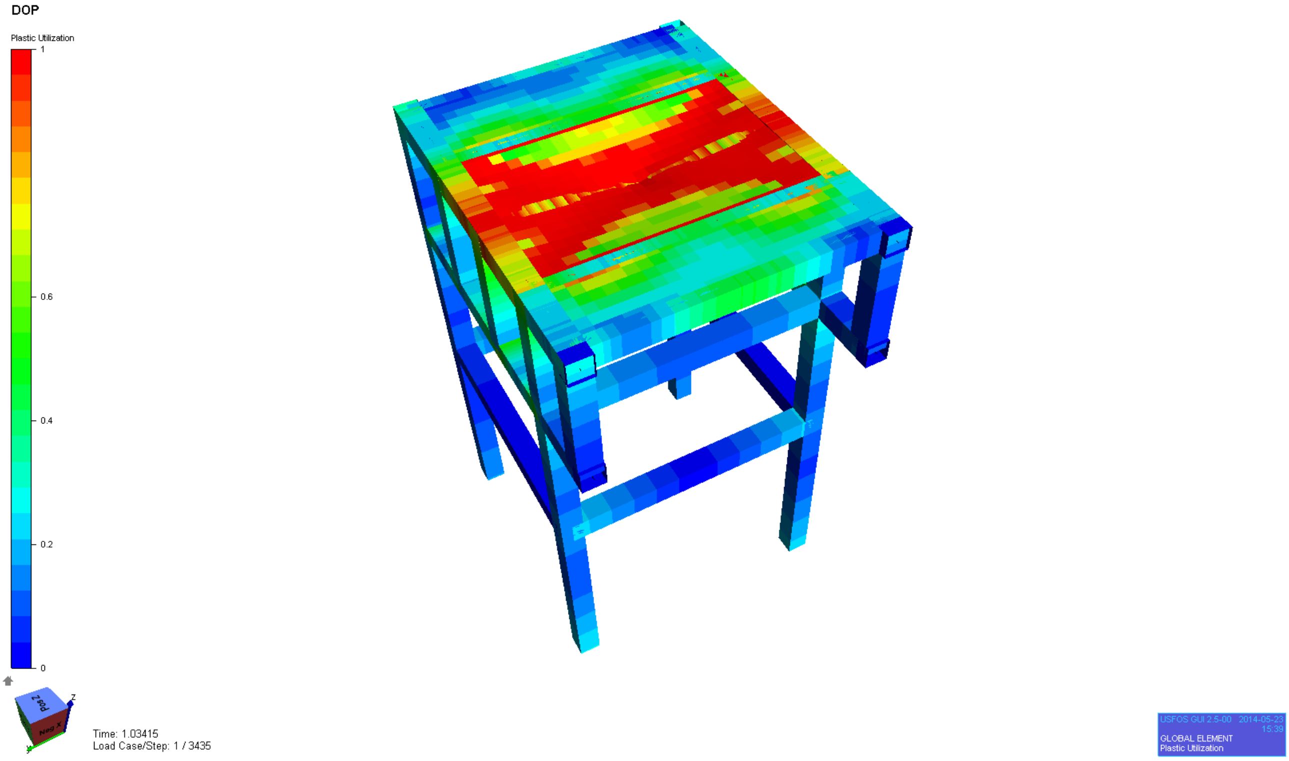

Figure 7.9 Plastic utilization

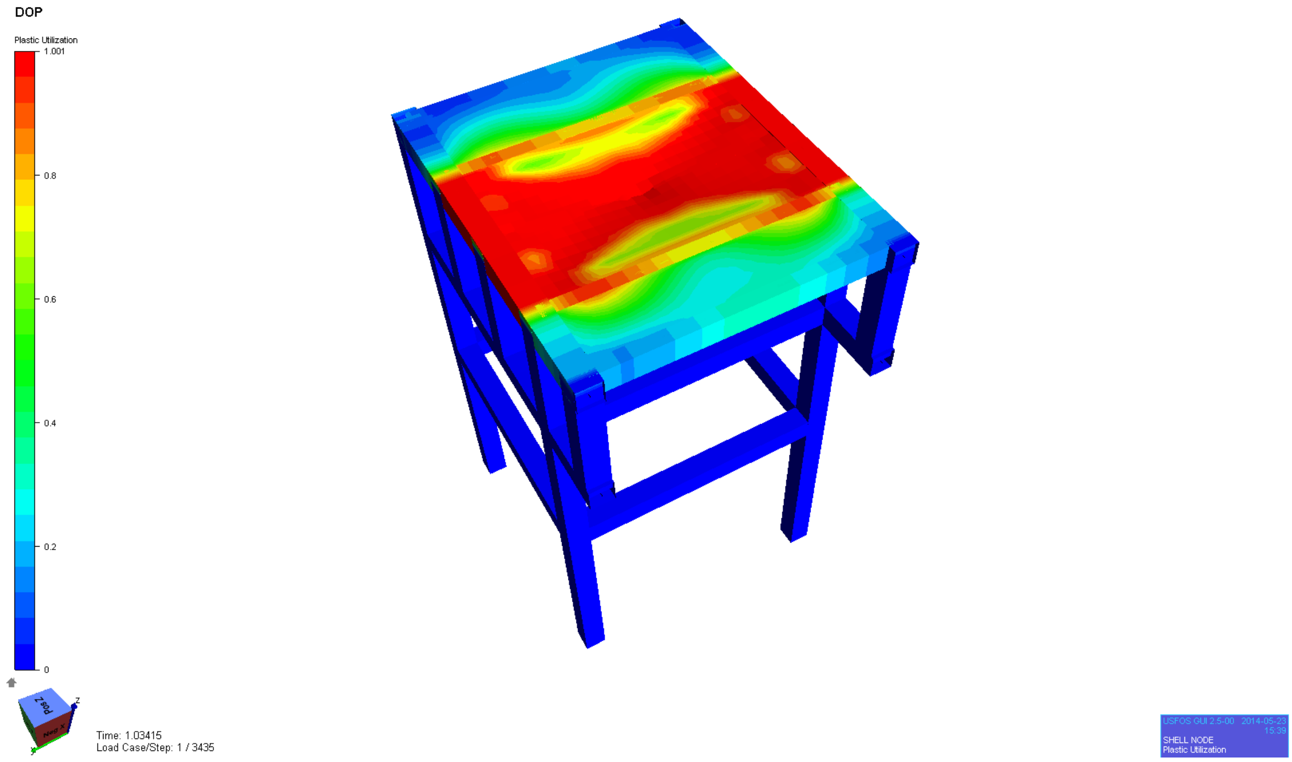

Figure 7.10 Plastic utilization in plate

Figures 7.09 and 7.10 shows plastic utilization for the whole structure and for the plate on the structure. In the plate there are created yield lines as a frame between the beam and with yield lines from the corners to the middle.

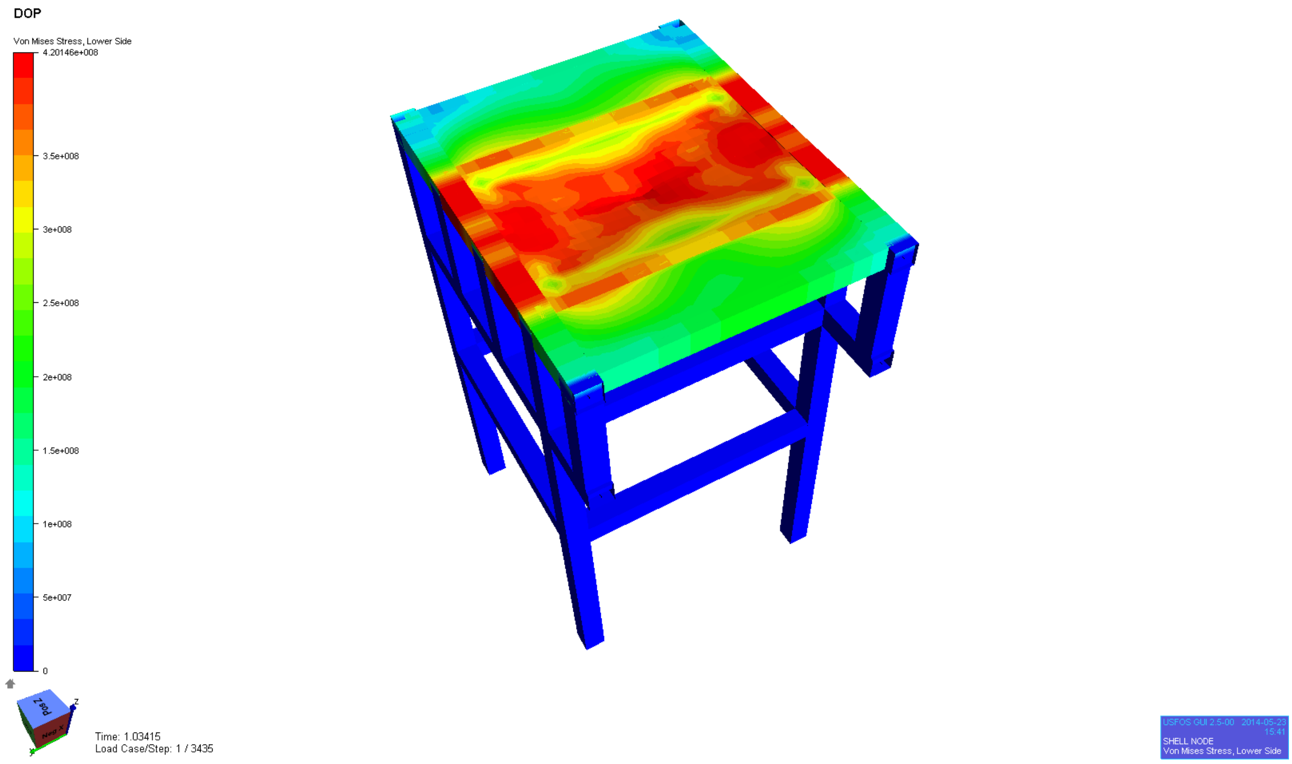

Figure 7.11 Von Mises Stress

The maximum Von Mises stress is 420.1 for the lower side of the plate. Figure 7.11 is similar to the plastic utilization of the plate as shown in figure 7.10.

7.2.7 Plastic work

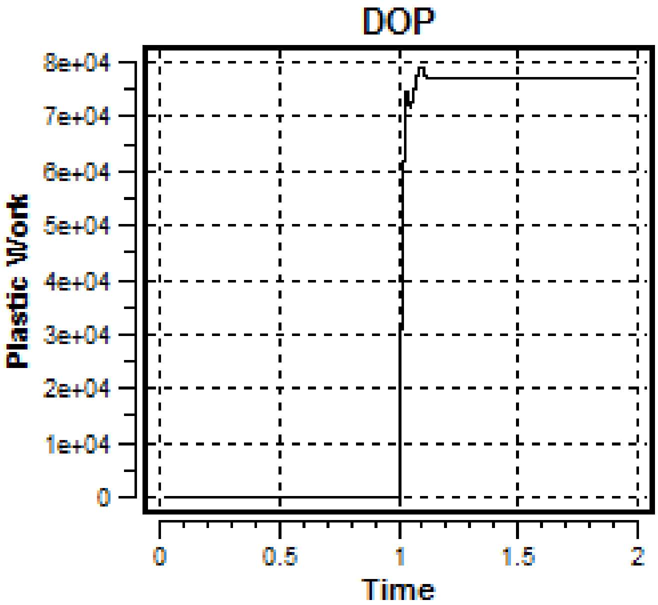

Figure 7.12 Plastic work

According to figure 7.12 the plastic work done is just below 80kN. All the plastic work is done by the dropped object.

7.3 Analysis 2 One node mass in node 2

7.3.1 General

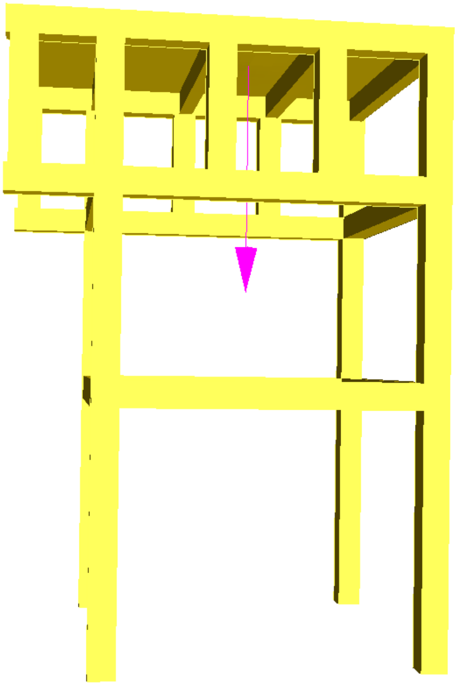

Figure 7.13 Load

In Analysis 2 there is a node mass in node 2 in the middle of the plate between two RHS 200x120x8.0 (Figure 7.13). The impact load in the plate will create large deflection and the membrane effect from the plate will absorb much of the energy.

7.3.2 Strain

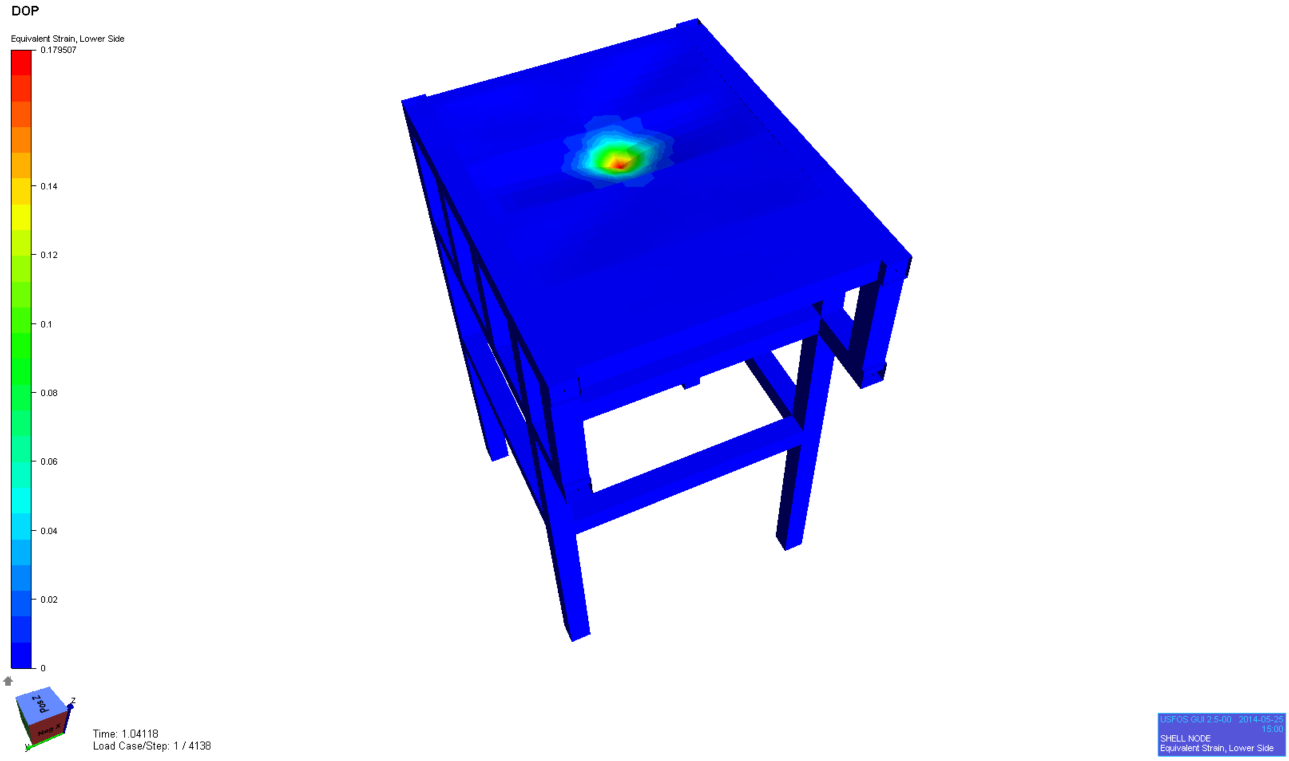

Figure 7.14 Strain

The strain in the plate is at maximum 17.9% (Figure 7.14) this is larger than the requirement from NOROK N-004. This load is in one node and therefore conservative. For reducing the strain the thickness on the plate can be increased, but that will result in a heavier and more expensive structure.

Figure 7.15 Strain

Strain in the beams is 1.5% according to Figure 7.15. The load is not directly on the beam which is distributed evenly on two beams. The plate also absorbs much of the energy.

7.3.3 Displacement

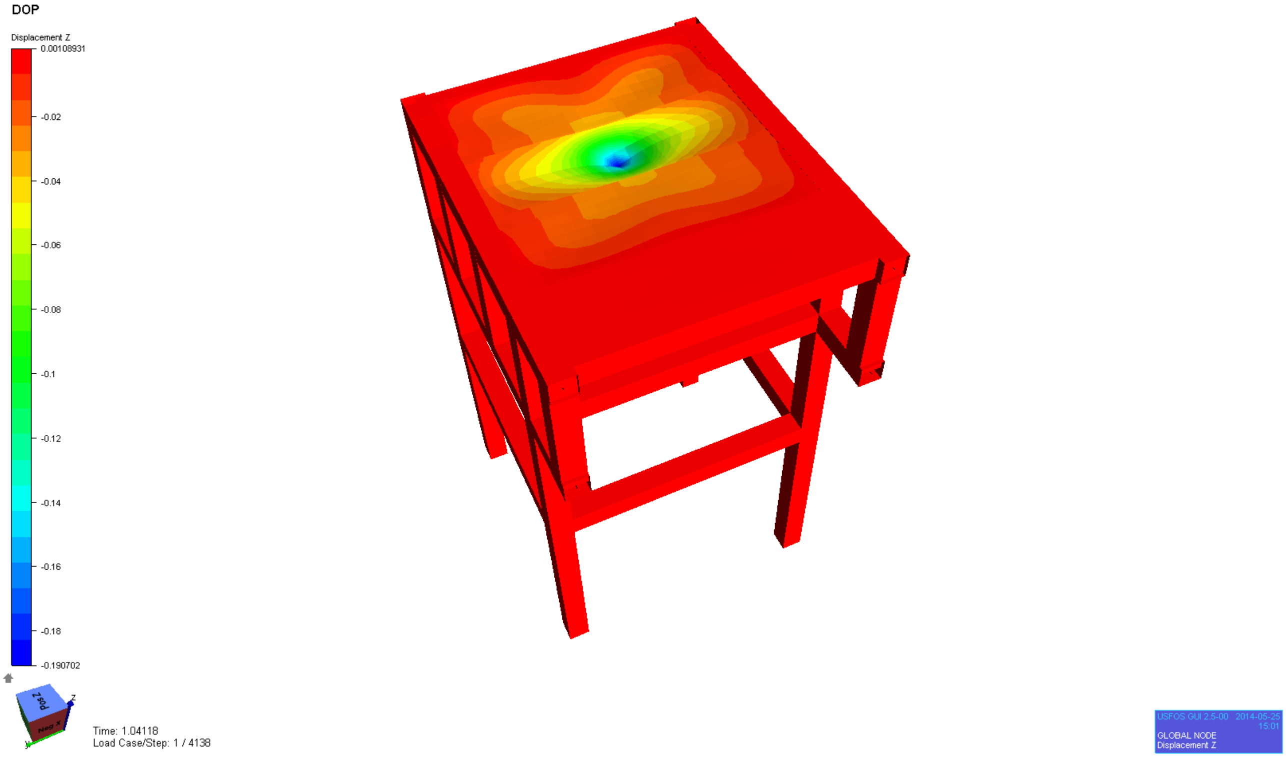

Figure 7.16 Deflection

The maximum displacement in z-direction in the plate is 19.1 cm (Figure 7.16), which is smaller than the maximum allowable displacement for the plate. Figure 7.17 is showing the maximum deflection in the middle beam which is 3.3 cm in z-direction.

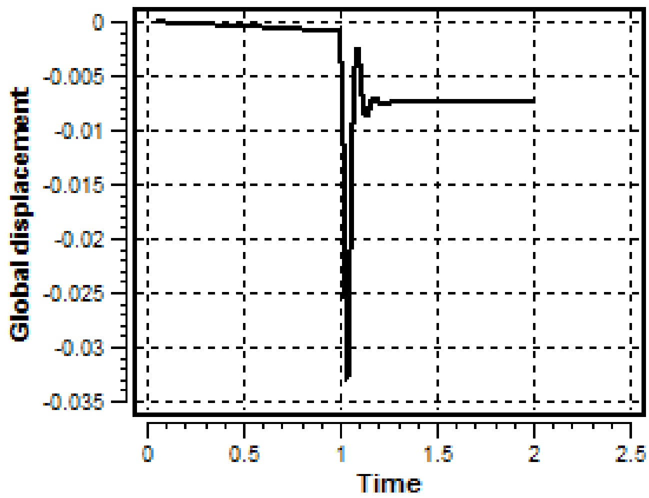

Figure 7.17 Global displacements as function of time in node 1

7.3.4 Plastic utilization

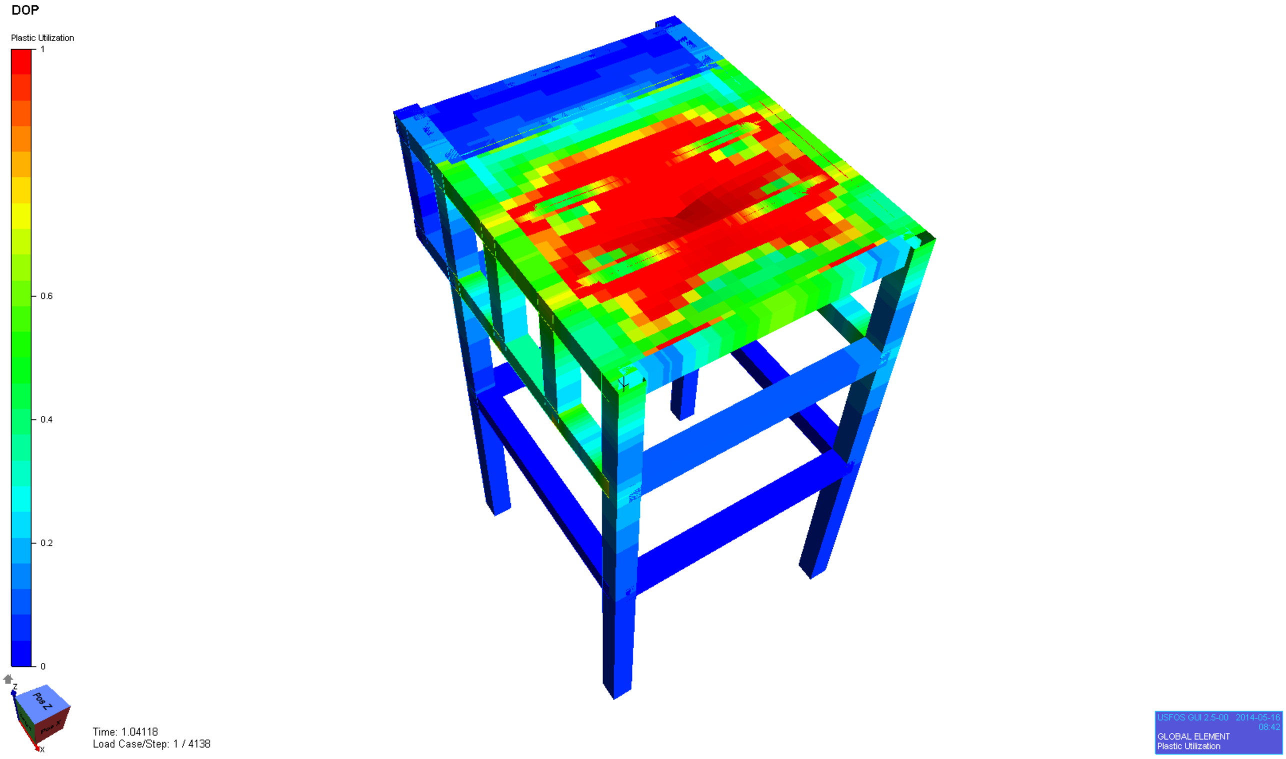

Figure 7.18 Plastic utilization

Figure 7.18 is showing that large area of the plate is fully plastic utilized. This is showing that the plate is absorbing much of the energy from the dropped object.

7.4 Analysis 3 One node mass in node 3

7.4.1 General

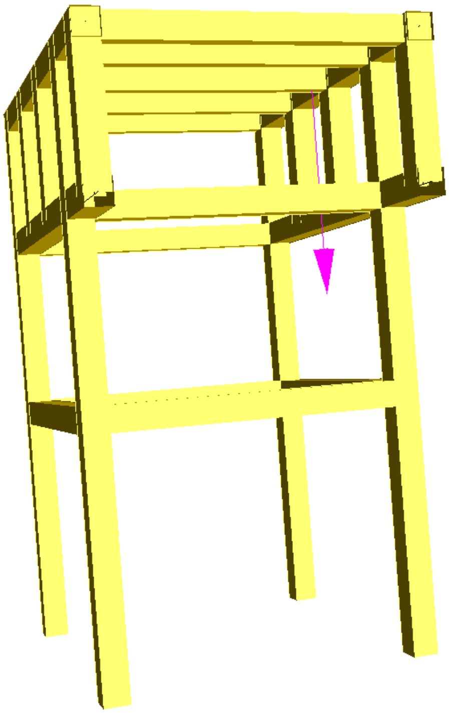

Figure 7.19 Load

In Analysis 3there is a node mass of 7000kg dropped from 3 meters in node 3 at the end of the RHS200x120x8.0. The impact load will create shear forces to the beam. The plate will obtain some of the energy from the dropped object.

7.4.2 Strain

Figure 7.20 Strain

Maximum strain in the end of the beam is 10.4% (Figure 7.20). 10.4% is lower than the maximum strain in the middle of the beam in analyses 1, where the beam strain was 13.6%.

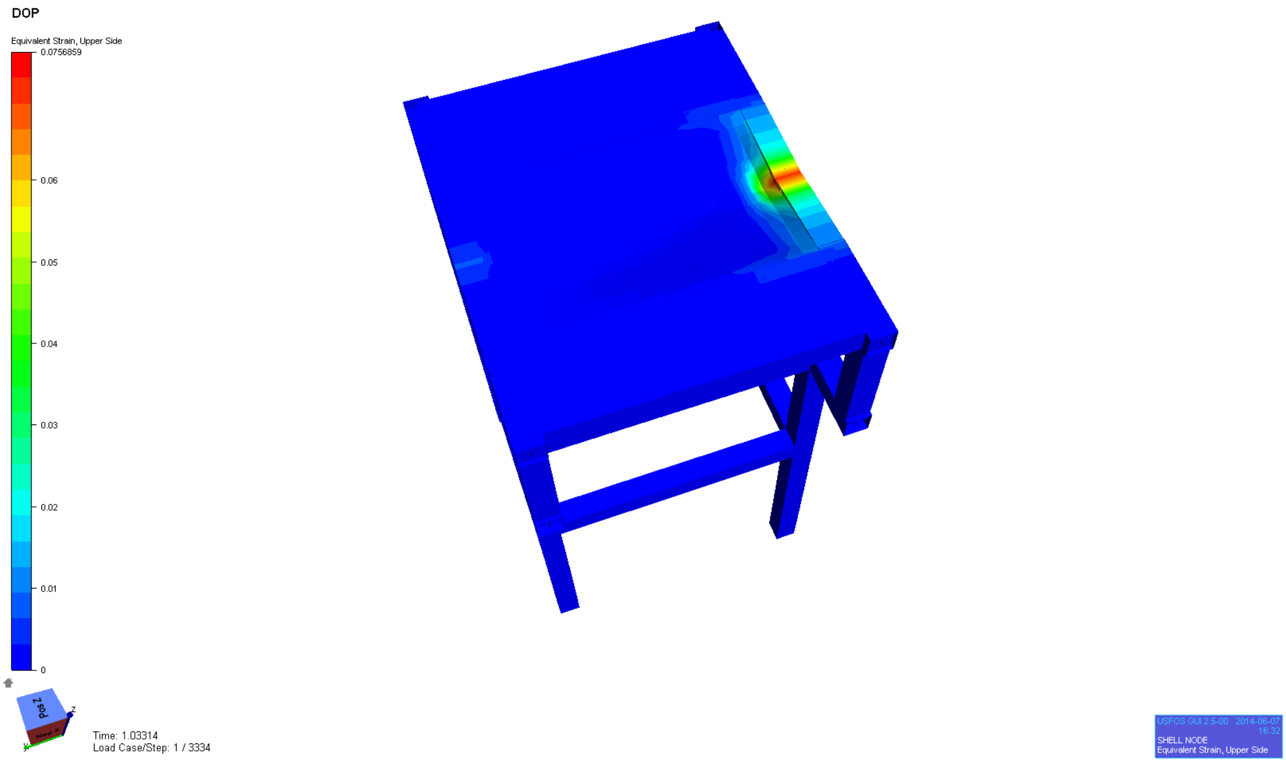

Figure 7.21 Strain

The maximum strain in the plate is 7.6% in figure 7.21 which is lower than the limit of 10% according to NORSOK N-004.

7.4.3 Displacement

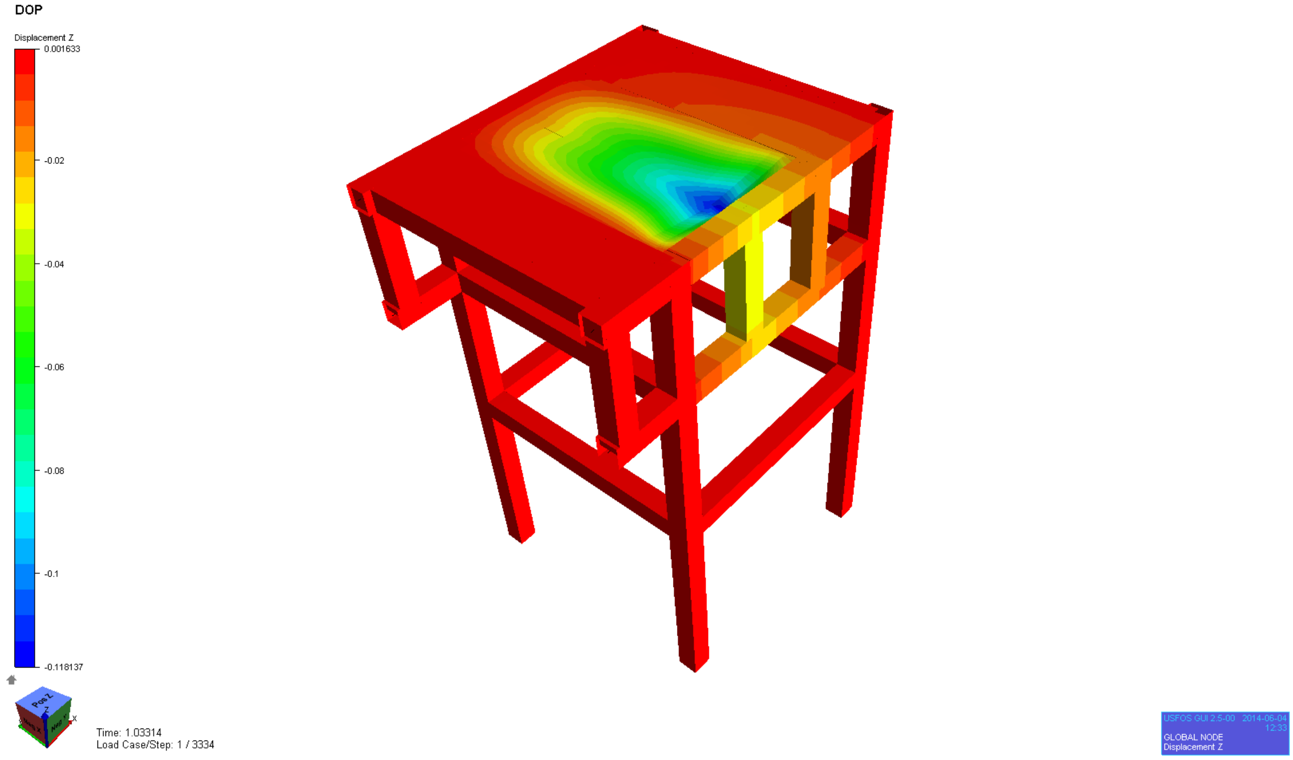

Figure 7.22 Displacement

The load creates maximum displacement in the end of the beam as shown in Figure 7.22. The maximum displacement is 11.8 cm.

7.4.4 Plastic utilization

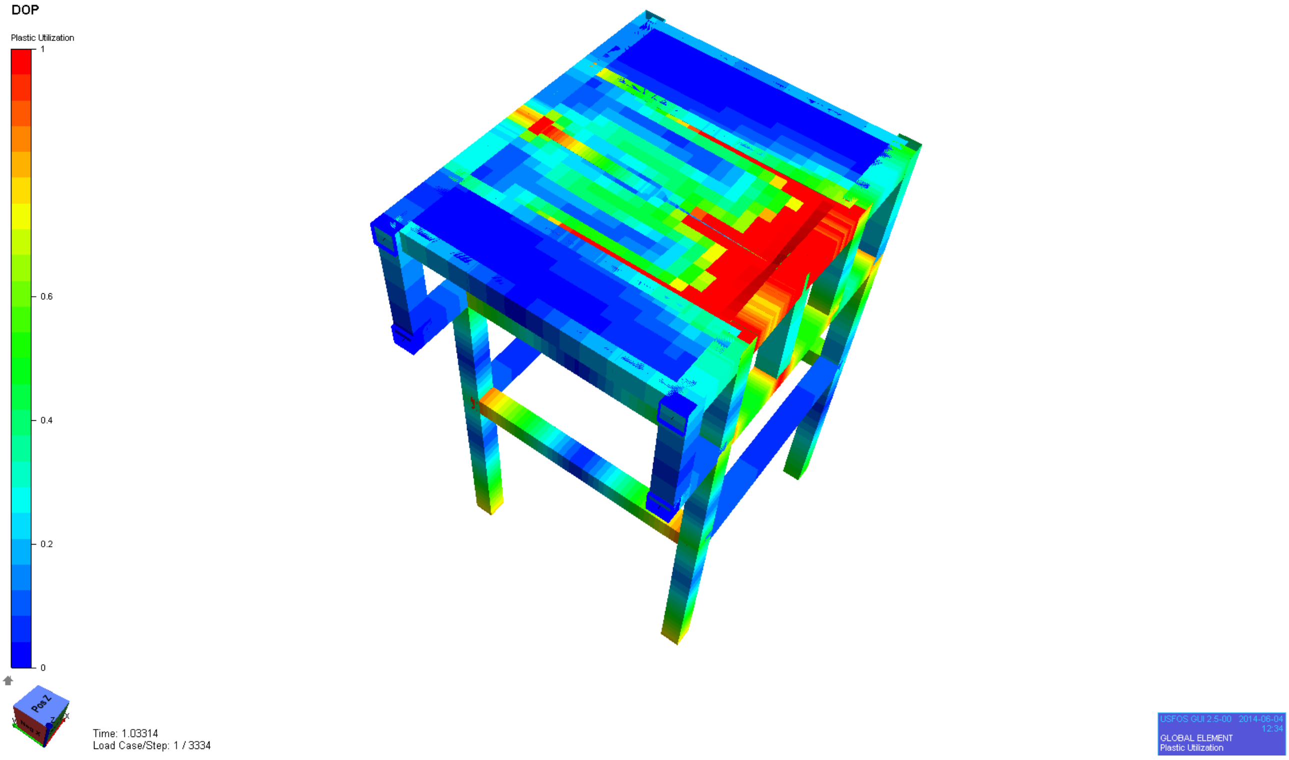

Figure 7.23 Plastic utilization

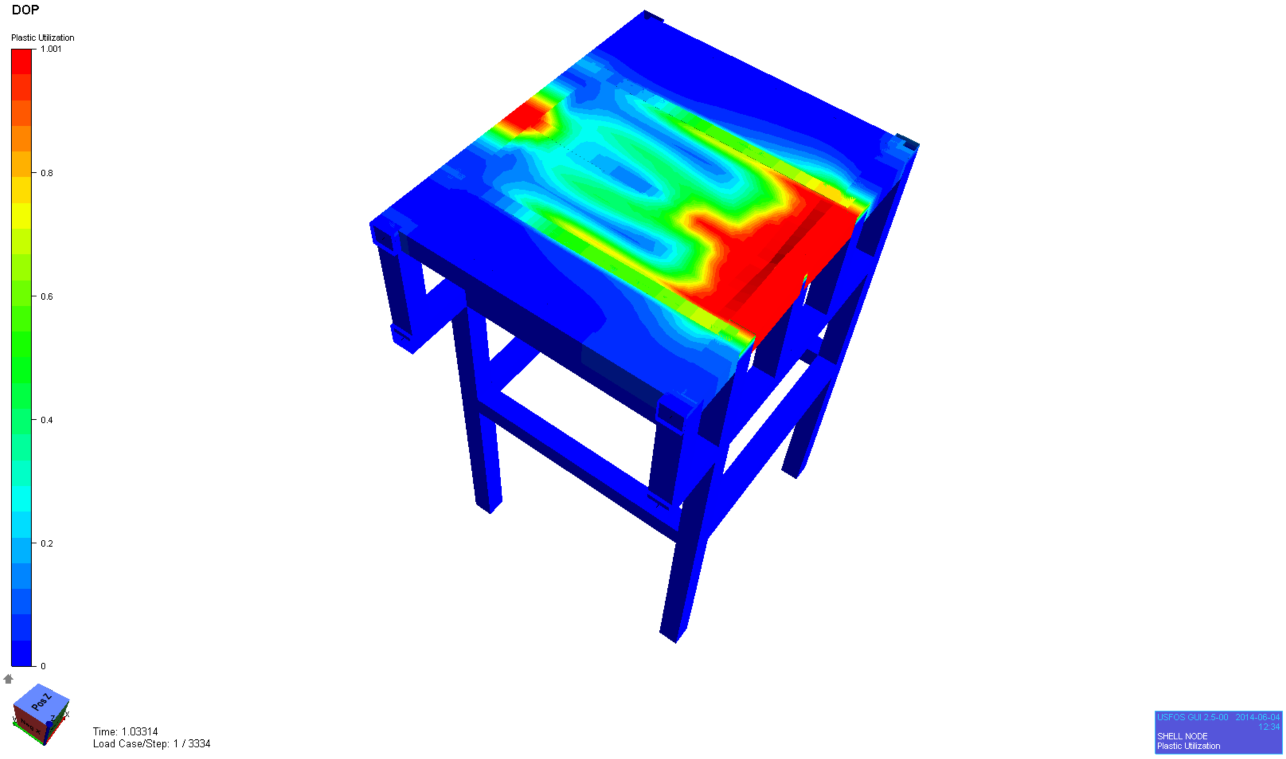

Figure 7.24 Plastic utilization

Figure 7.23 show the plastic utilization for the entire structure and figure 7.24 shows the plastic utilization smother for the plate surface. These figures are showing that the area around the impact is fully plastic utilized.

7.5 Analysis 4 One node mass in node 4

7.5.1 General

Analysis 5 have impact loads on the edge beam of the structure, there will be less membrane effect from the plate, since the plate is only on one side of the impact. The larges moment force will occur in the middle of the beam.

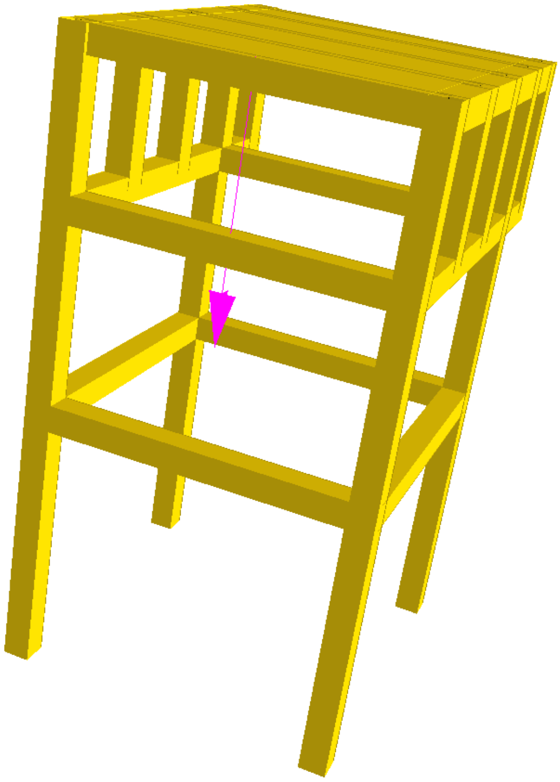

Figure 7.25 Load

7.5.2 Strain

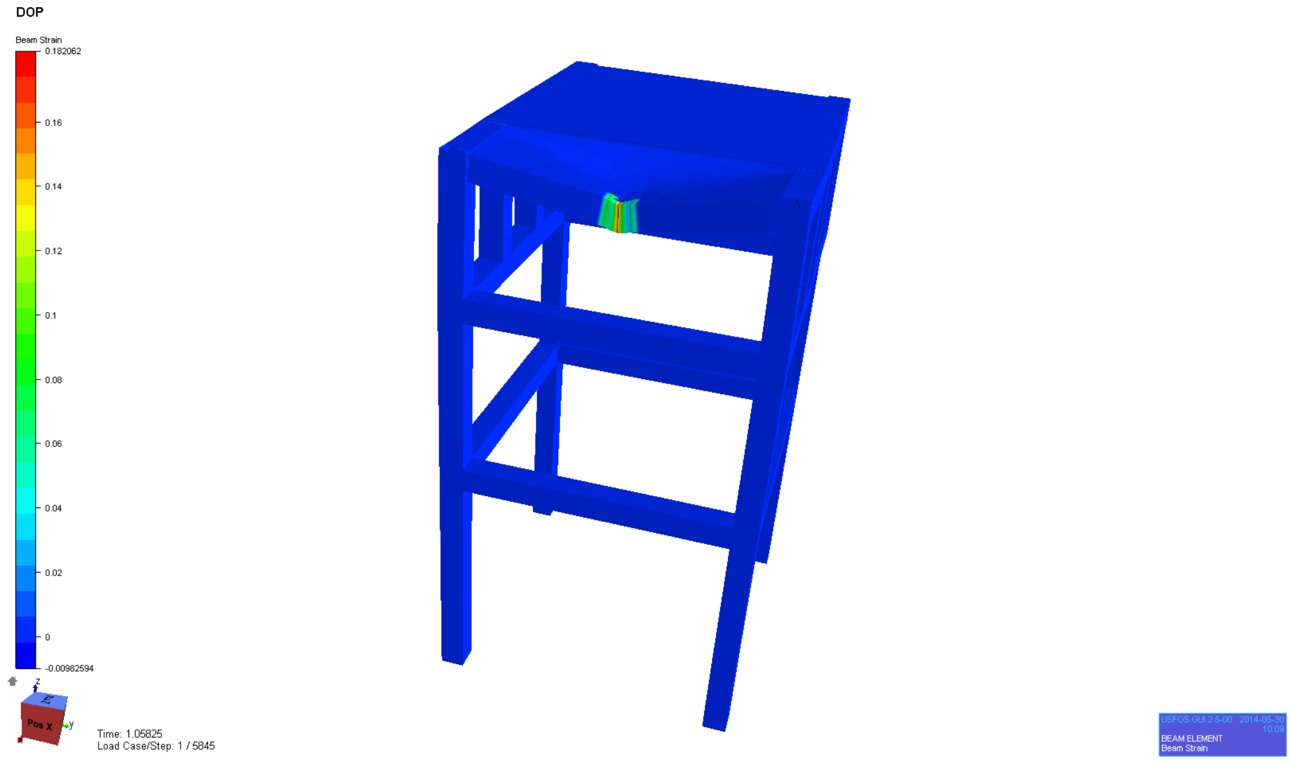

Figure 7.26 Strain

When the impact loads is applied to the edge beam at the end of the structure the maximum strain in the beam is 18.2%. The requirement for S355 is 15% according to NORSOK N-004. Since this is a point load in one node this is a conservative approach for the calculations.

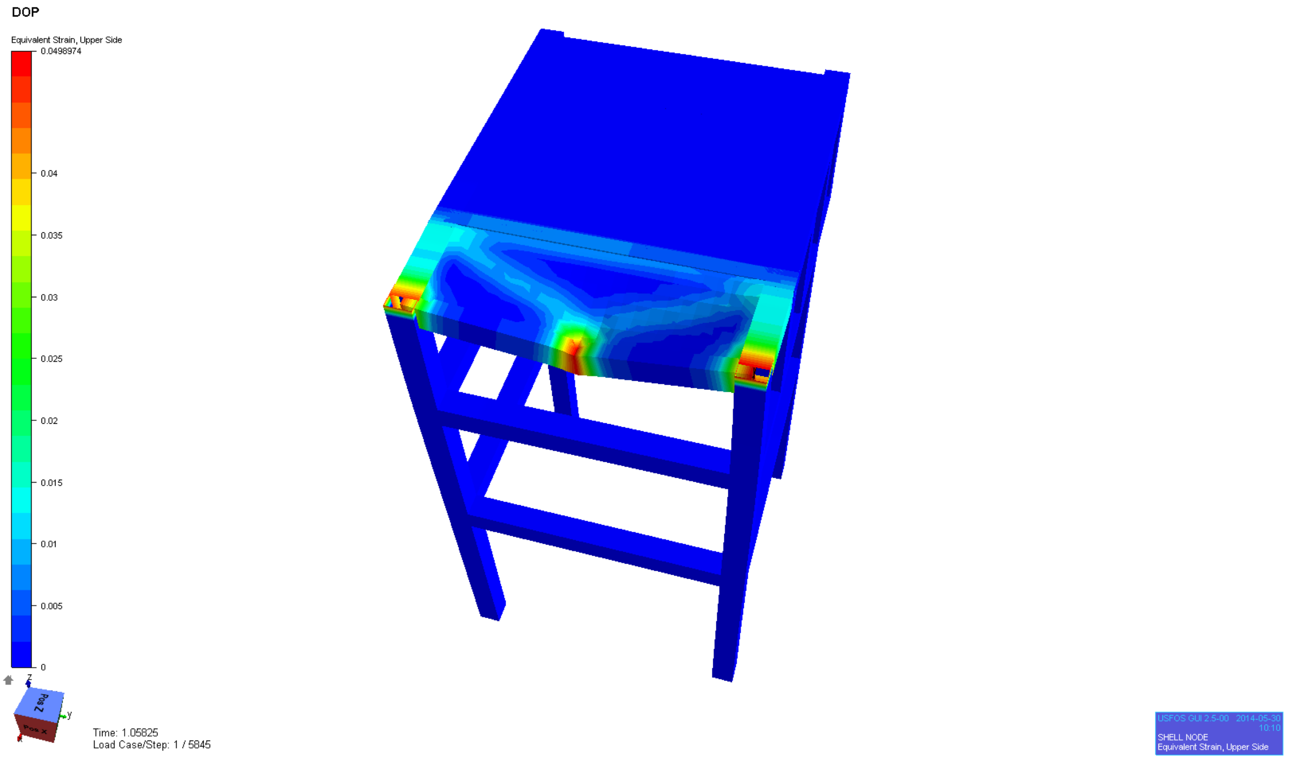

Figure 7.27 Strain

Figure 7.27 is showing the strain in the plate. The maximum strain in the plate is 4.9 % and figure 7.27 is showing yield lines are starting to be created from the impact point towards the corners.

7.5.3 Displacement

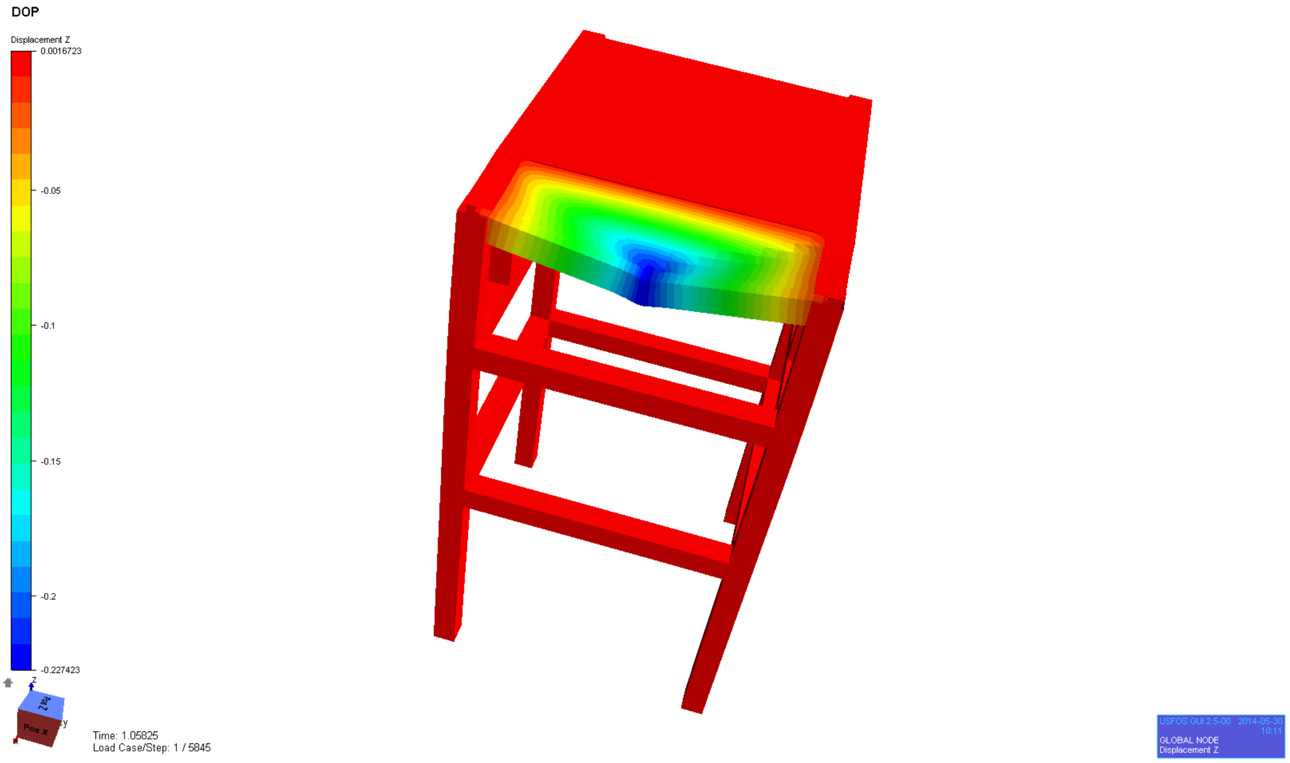

Figure 7.28 Deflection

The maximum deflection in z direction is 22.7cm according to figure 7.28, this is in the allowable limit of 25cm for not damage the equipment.

7.5.4 Plastic utilization

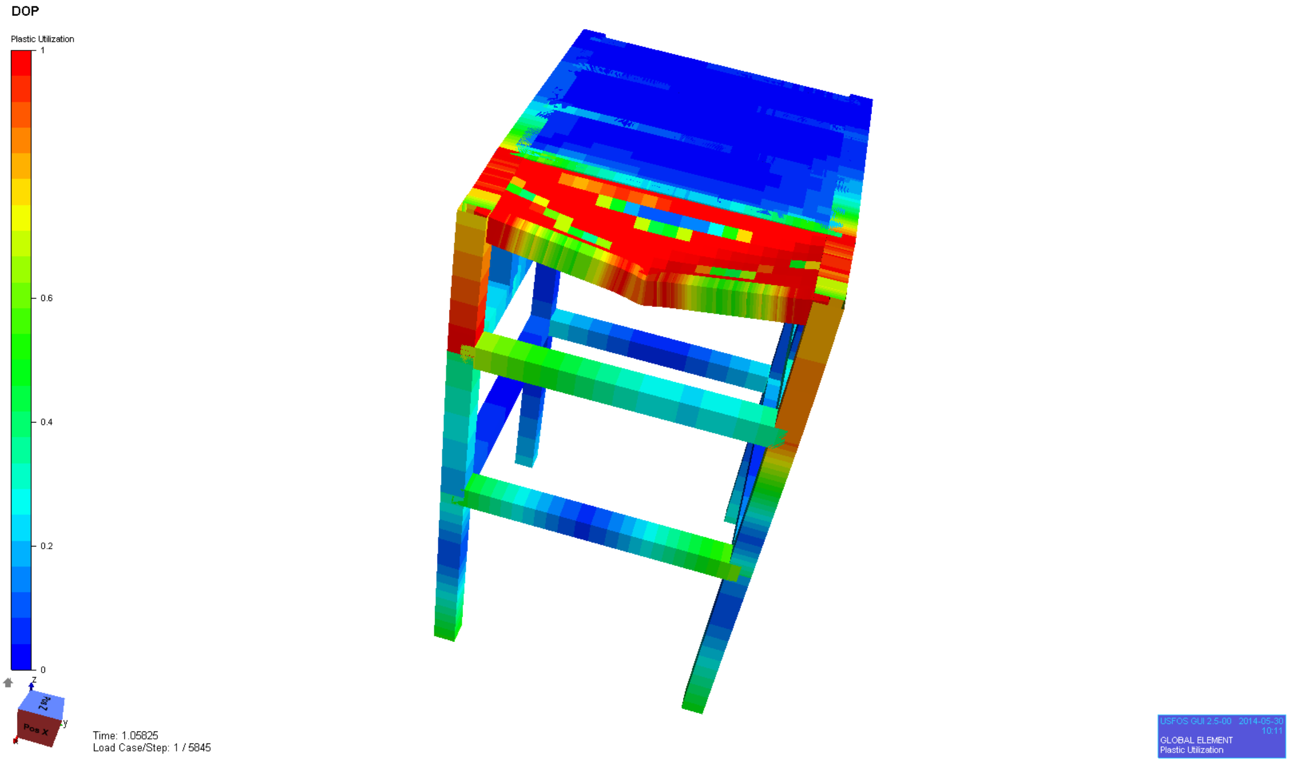

Figure 7.29 Plastic utilization

The beam is creating plastic hinges in the start, middle and end of the beam (Figure 7.29). The plate is almost fully plastic utilized until the next RHS200x120x8.0.

7.6 Analysis 5 Three node masses in node 4 area

7.7.1 General

In Analysis 5 there is a load in the middle of the end beam in node 4 area, but the impact loads are distributed on three nodes with equally mass. The total mass in the node mass is 7000kg. There is one load in the middle of the beam and on each side of the middle load as shown in figure 7.30 with a distance of 10cm for each. The plastic utilization of the structure will be similar to figure 7.29.

7.7.2 Strain

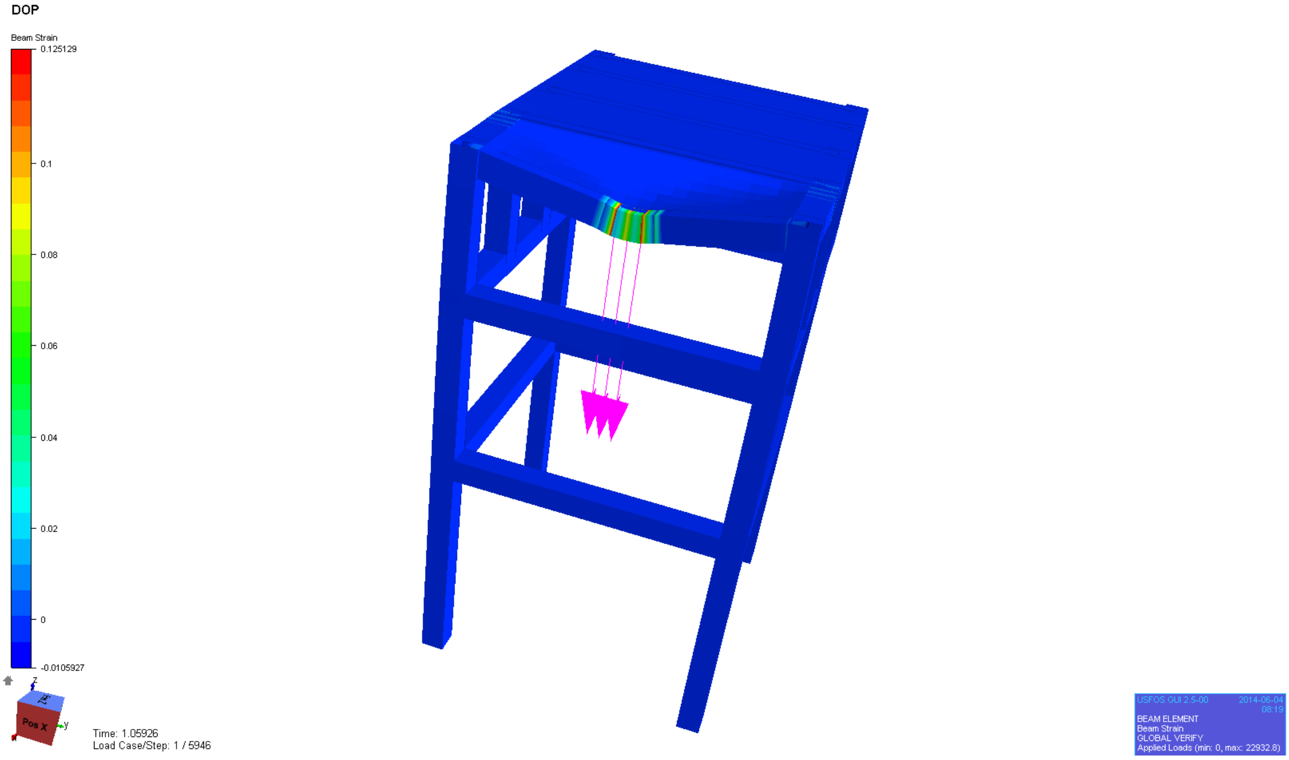

Figure 7.30 Strain

With the force divided into three points load the maximum strain have been reduced to 12.5% in the beam, which is acceptable. In analysis 5 the maximum strain was 18.2% for comparing.

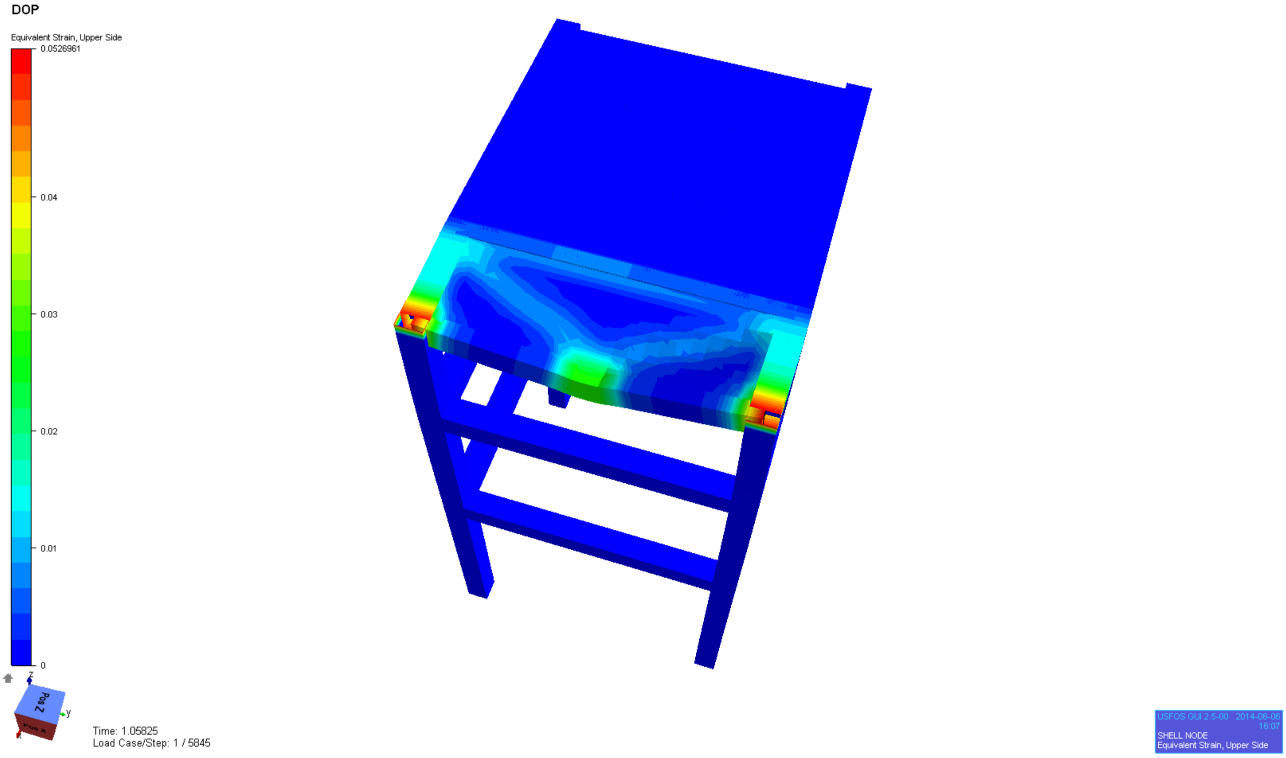

Figure 7.31 Strain

Maximum strain in plate is 5.2% according to Figure 7.31.

7.7.3 Displacement

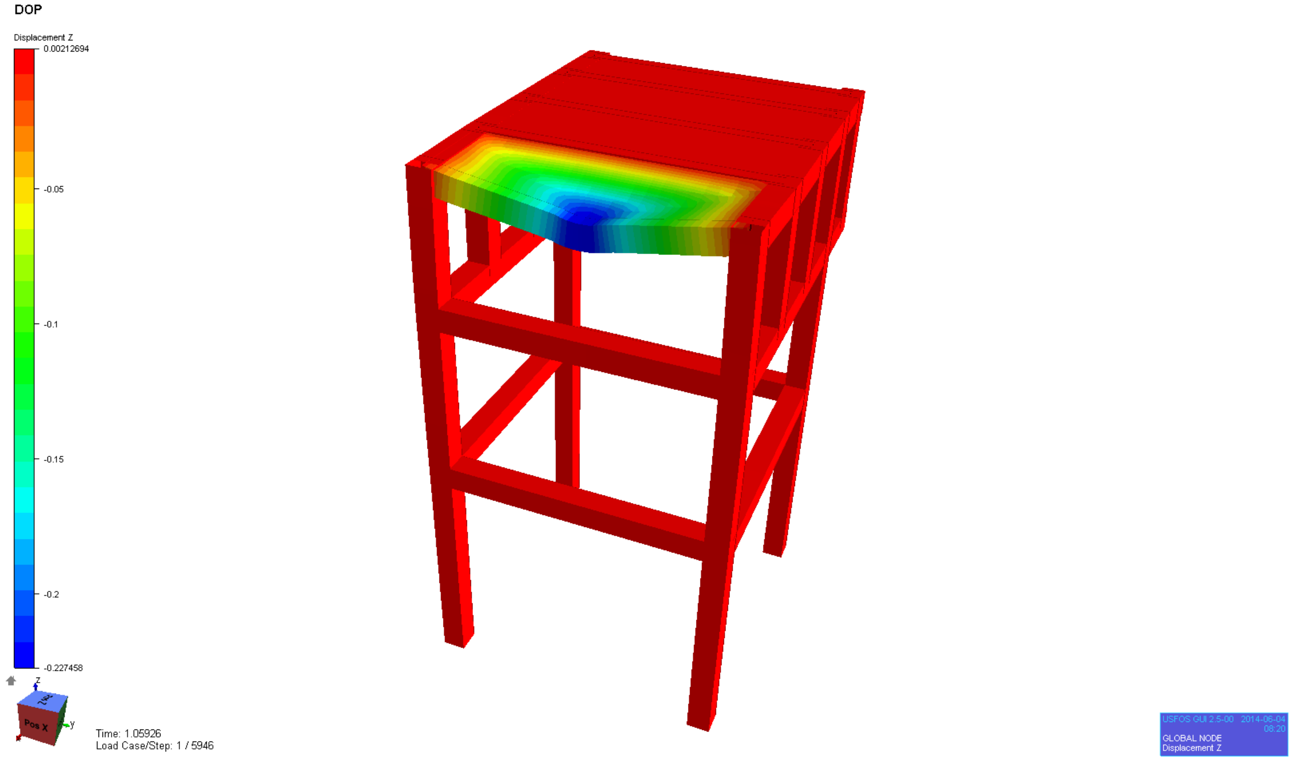

Figure 3.32 Displacement

Distributed load in the middle of the end beam result in 22.7cm displacement.

7.7 Analysis 6 Nine node masses in node 1 area

7.7.1 General

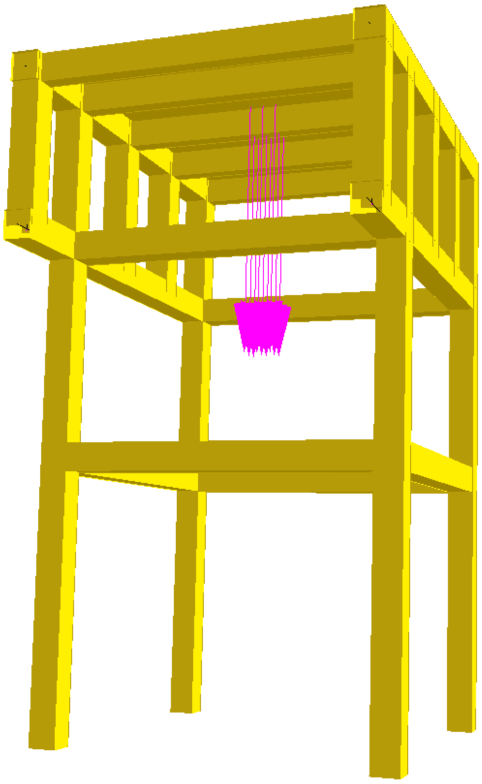

Figure 7.33 Load

In Analysis 6 there are distributed impact loads on the beam (figure 7.33), for simplification the mass is distributed on nine node massed. There is one load in the middle and the others 8 node loads are distributed in the corner and in the middle of the square around. The distances between the nodes are 10cm. The load area is then a square with 30cm for each side, some of the load is not directly on the beam, but on the plate.

7.7.2 Strain

Figure 7.34 Strain

According to figure 7.34 the maximum strain is 8.5%. Not all of the node load is directly in the beam and will reduce the strain. Since the impact loads is distributed and not all in the middle of the beam, the strain will be reduced compared to analysis 1 with 13.6 % strain in beam.

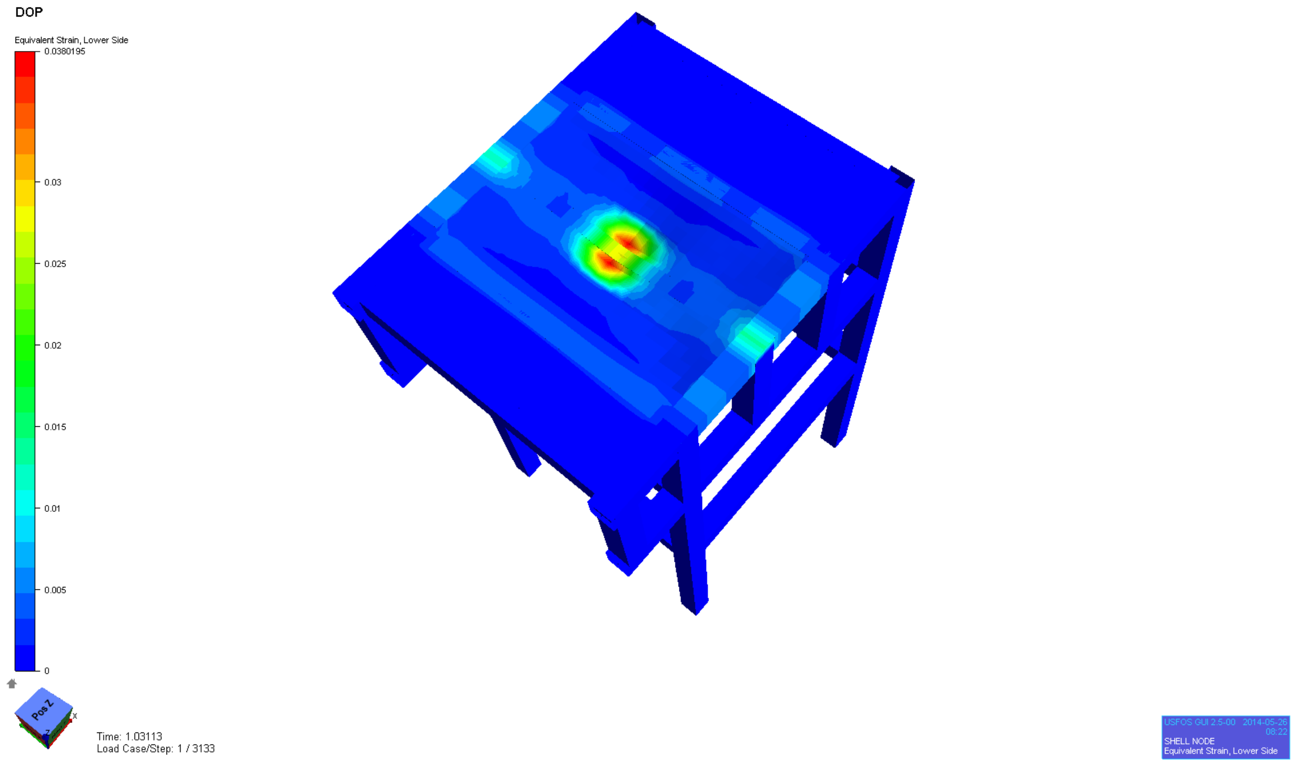

Figure 7.35 Strain

Figure 7.35 show the strain in plate, it is shown that the maximum strain is close to the centre of the beam. The maximum strain is 3.8% in the plate.

7.7.3 Displacement

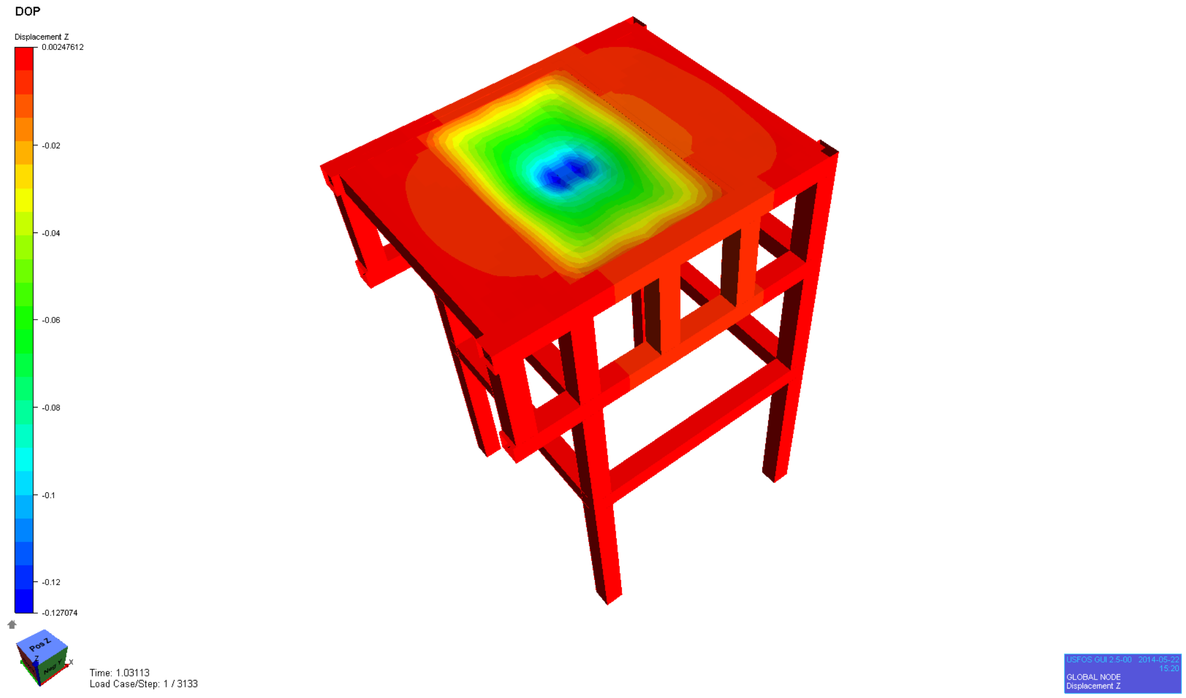

Figure 7.36 Displacement

Since some of the point loads are positioned on the plate field and not on the beam, the maximum deflection is in the plate as shown in figure 7.36. The maximum deflection is then 12.7cm in the plate. For the beam the maximum deflection is 11.7cm (Figure 7.37).

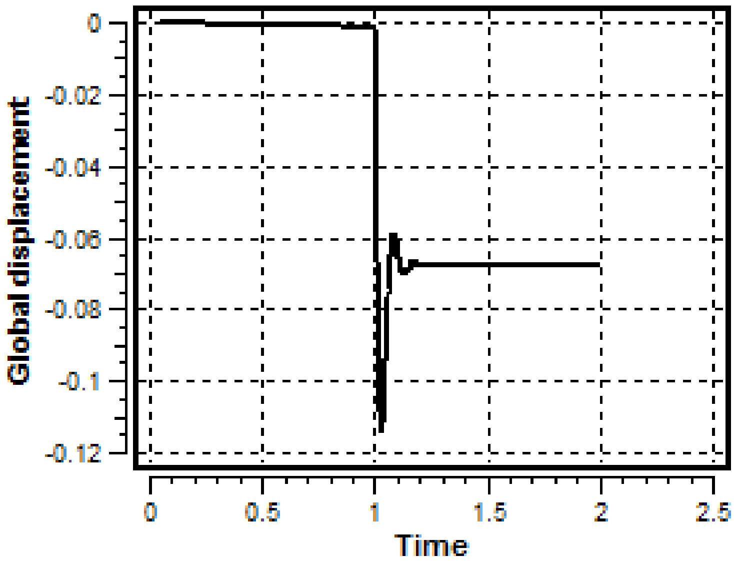

Figure 7.37 Global displacements as function of time in node 1

7.7.4 Plastic utilzation

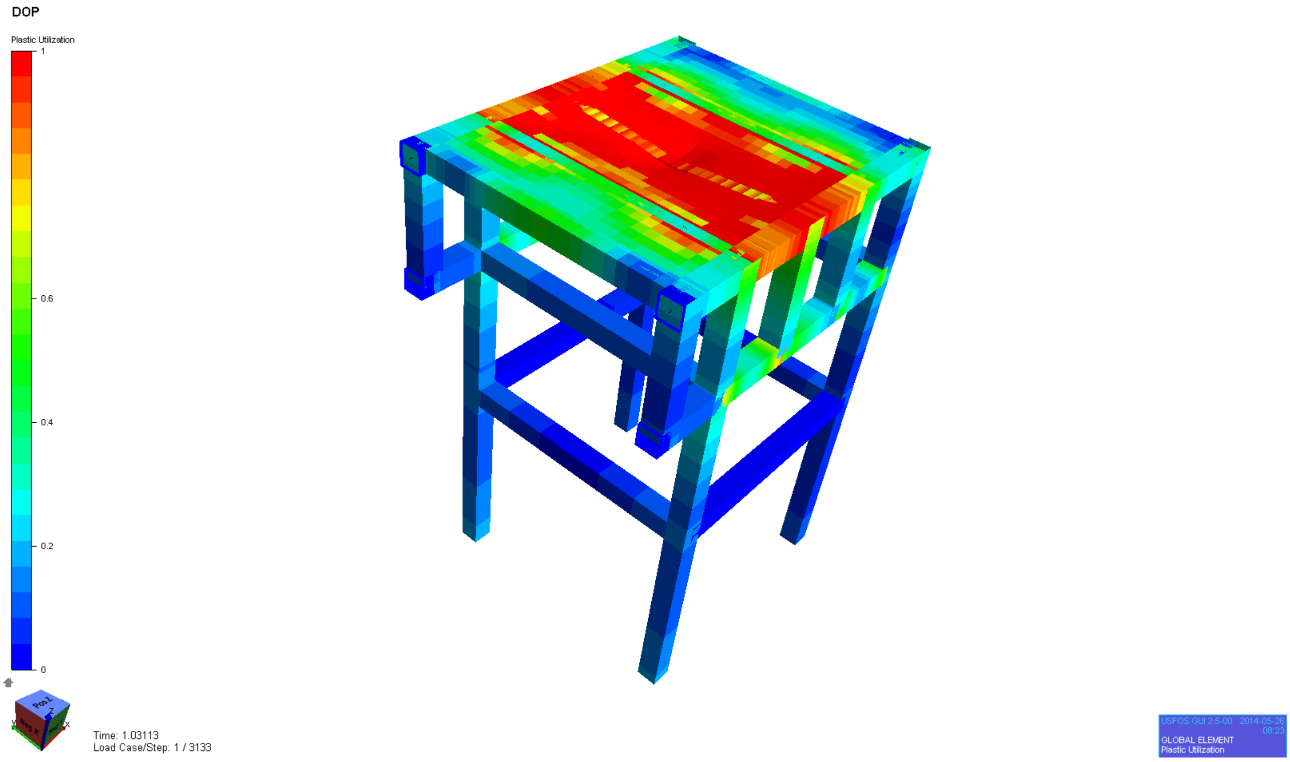

Figure 7.38 Plastic utilization

The load is more distrubated over the plate and will therefore create full platic utilzation over a larger area compared to in analysis 1 with one node load in the centre of the middle beam.

7.8 Analysis 7 Nine node masses in node 2 area

7.8.1 General

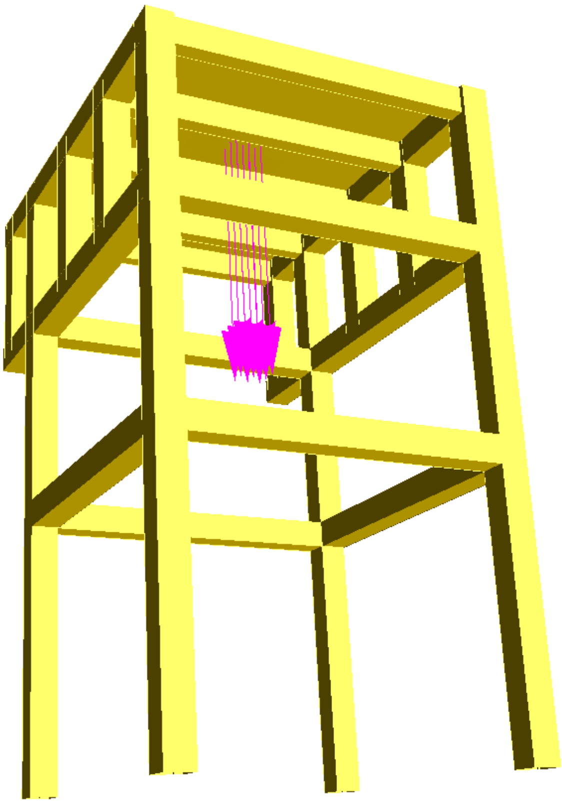

Figure 7.39 Load

Analysis 7 is similar to analysis 6, but the impact loads in analysis 7 are in the center of the plate instead of in the beam. There are 9 node load distrubated like Analysis 6 in a square with an areal of 0.09m^2.

7.8.2 Strain

Figure 7.40 Strain

Maximum strain in the beams is 1.6%. In analysis 2 the beam stain was 0.7%, but in analysis 7 the impact loads are closer to the beam, therefore higher beam strain.

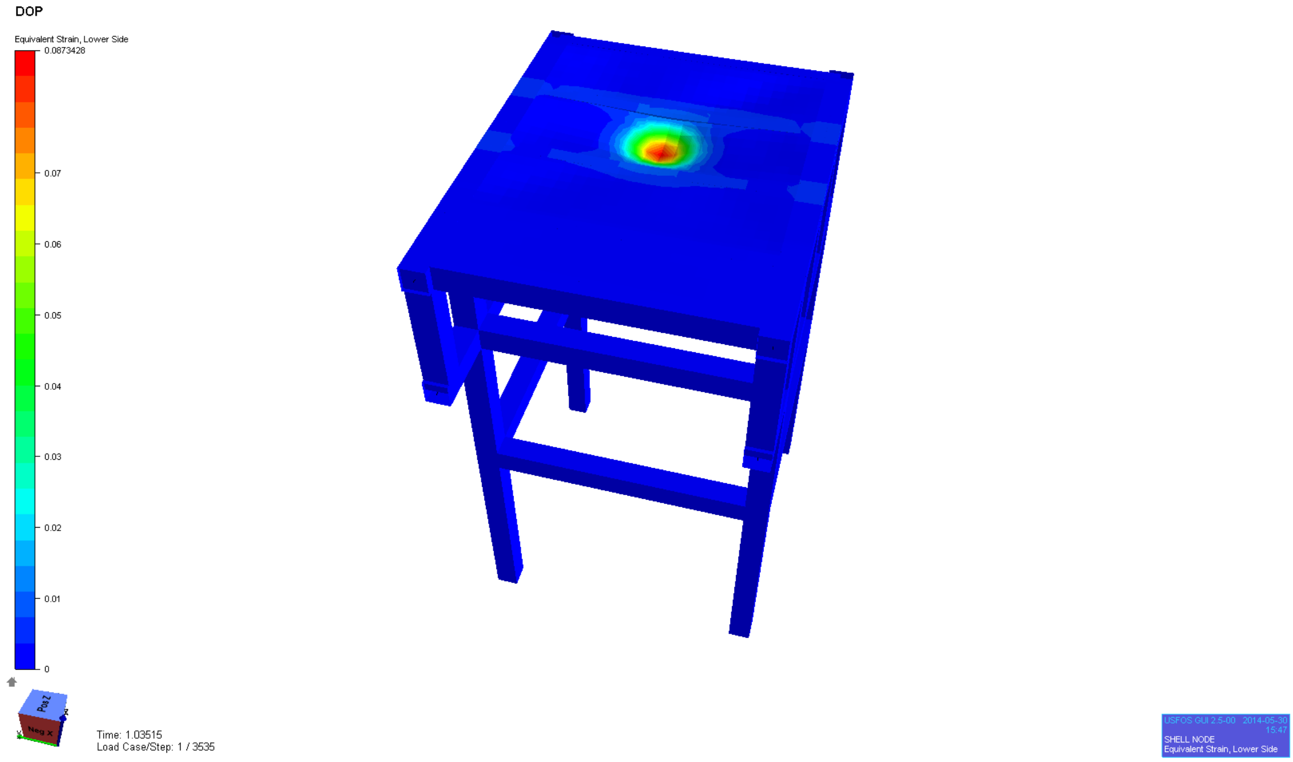

Figure 7.41 Strain

8.7% is the maximum strain in the plate which is in the acceptable range. Compared to one consentrated impact load in Anlysis 2 which gave 17.9%, which was over the acceptable limit.

7.8.3 Displacment

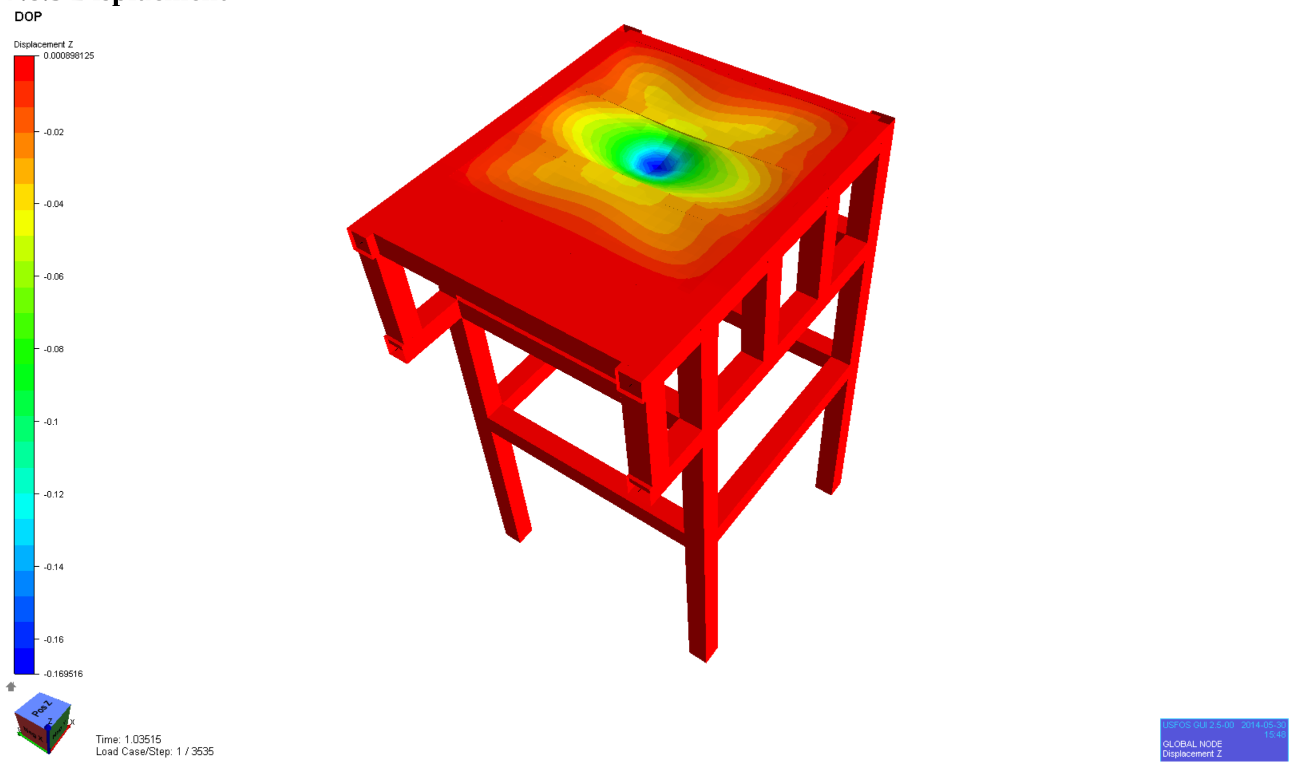

Figure 7.42 Displacment

The maximum displacement in the center of the plate is 17.0cm as shown in figure 7.42. The beam reach maximum delection right after the impact. The maximum deflection in z-direction is 4.2cm(Figure 7.43)

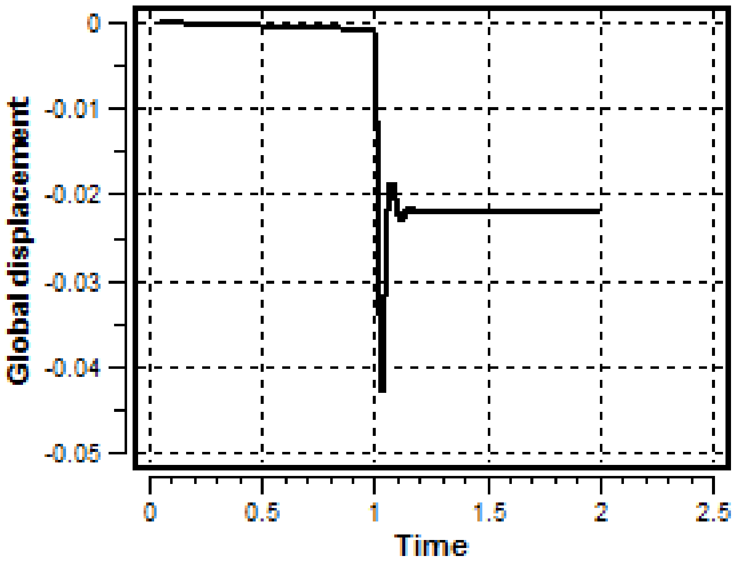

Figure 7.43 Global displacements as function of time in node 1

7.8.4 Plastic utilization

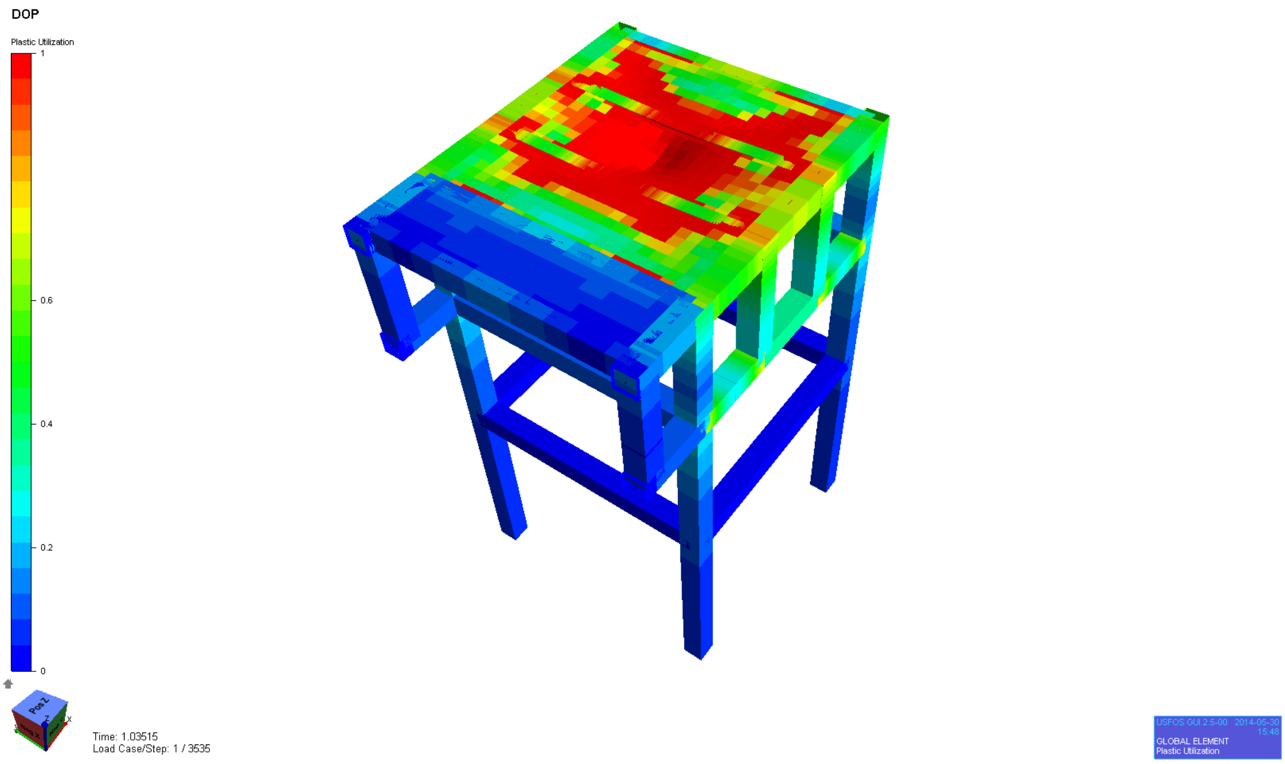

Figure 7.44 Plastic utilzation

A large area of the plate is fully plastic utilized as shown in figure 7.44. The plastic utilization is similar to analysis 2 with one node load as shown in figure 7.18.

7.9 Analysis 8 16 node masses in node 2 area

7.9.1 General

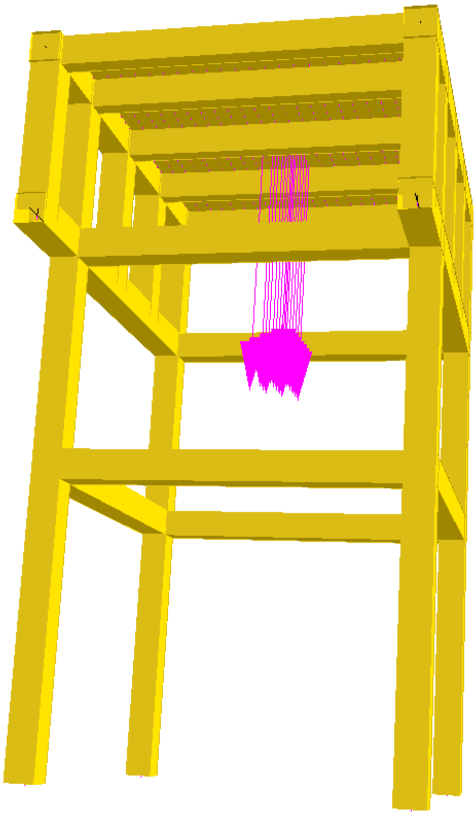

Figure 7.45 Load

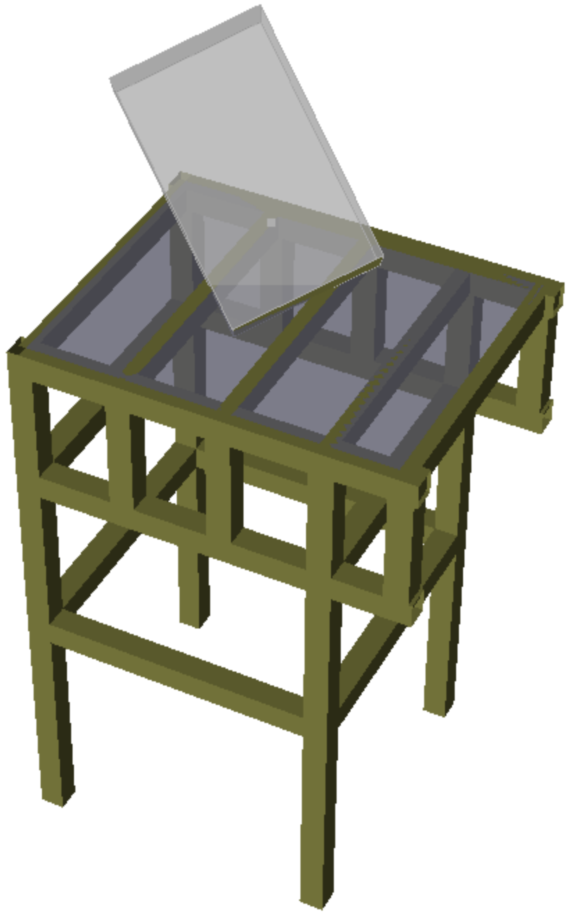

Figure 7.46 Load

In analysis 8 there are distributed mass in the in node 2 area for the impact loads (Figure 7.45), for simplification the node mass is distributed into 16 node masses shapes as a triangle. This situation simulates a container falling down on the structure with one of the corners first as shown in the figure 7.46. The situation can occur if a container is lifted and one of the slings snaps and the container fell down.

7.9.2 Strain

Figure 7.47 Strain

As can be seen in Figure 7.47 the maximum strain is 2.7% and is located in the mid-section of the two beams close to the impact. In analysis 7 the maximum strain in beam is 1.6%, this is lower because load is closer to the beams in Analysis 8.

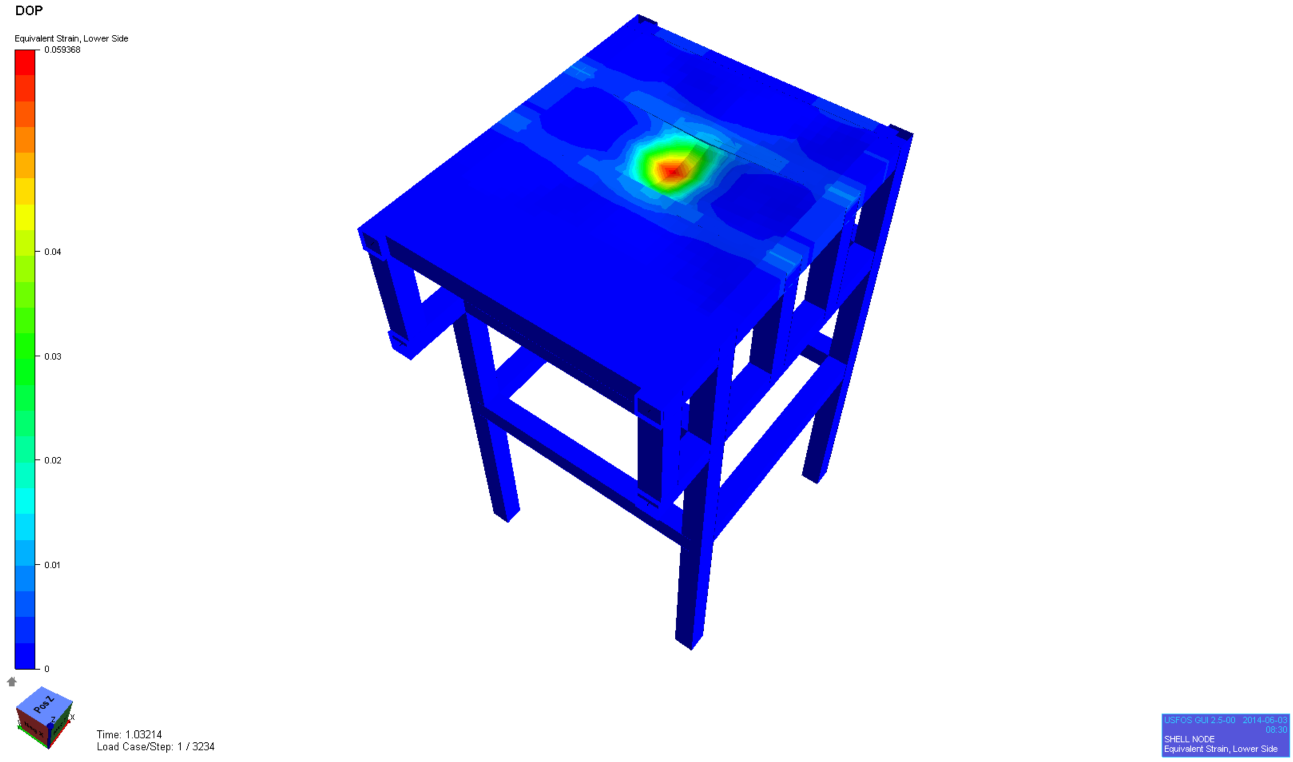

Figure 7.48 Strain

The impact load is distributed over a larger area than in Analysis 7, hence the maximum strain is lower. As shown in Figure 7.48 the maximum strain for the plate is 5.9%, which is acceptable.

7.9.3 Displacement

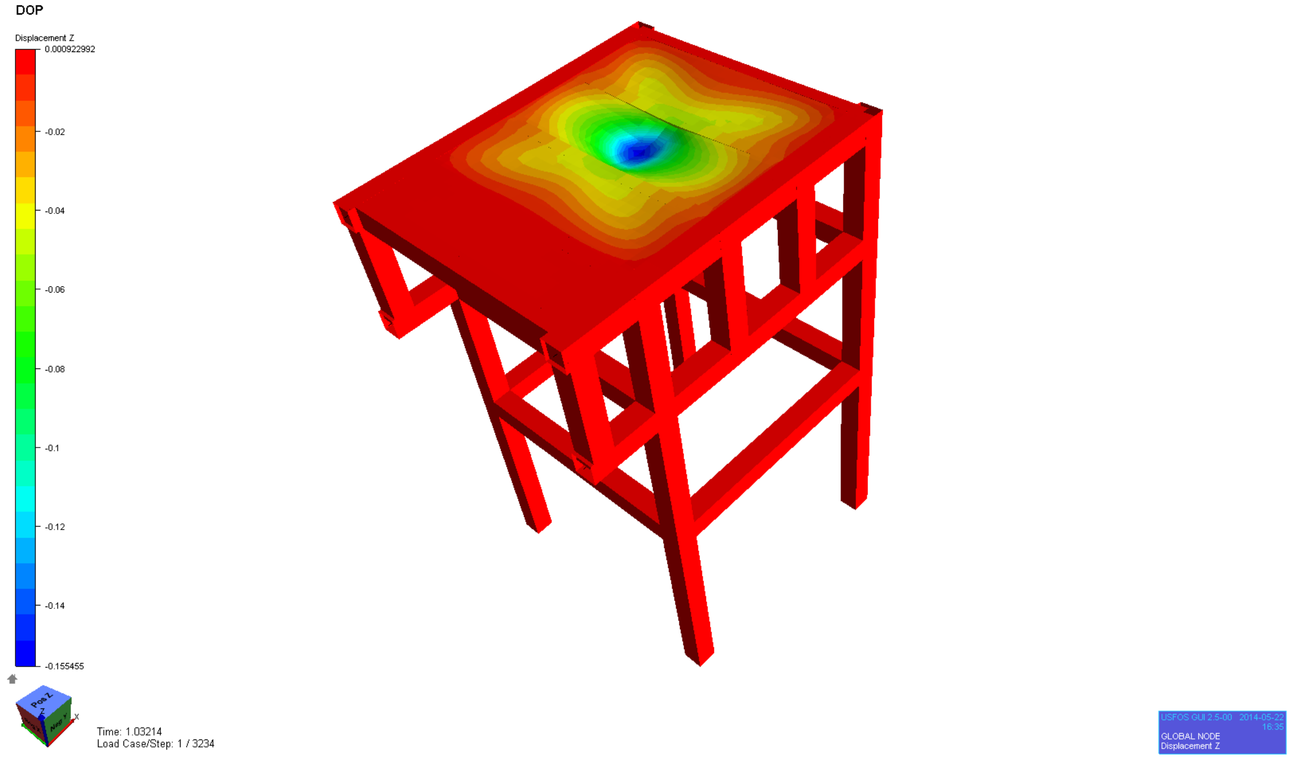

Figure 7.49 Displacement

A more distributed impact load on the plate give as expected a lower maximum displacement. The maximum displacement when using 16 evenly node masses are 15.5cm compared with Analysis 8 which had 17cm.

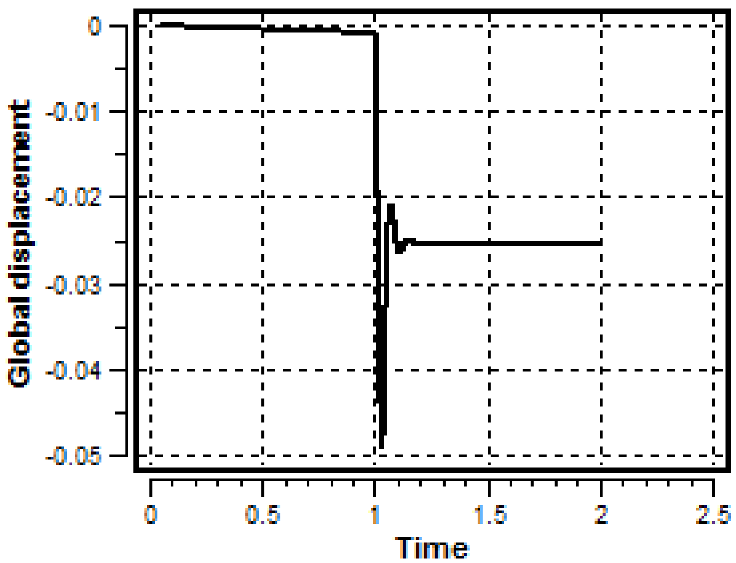

Figure 7.50 Global displacements as function of time in node 1

The maximum displacement on the beam will be 5.0 cm right after the impact from the dropped object. It will reach the maximum deflection right after the impact because of the inertia in the structure.

7.9.4 Plastic utilization

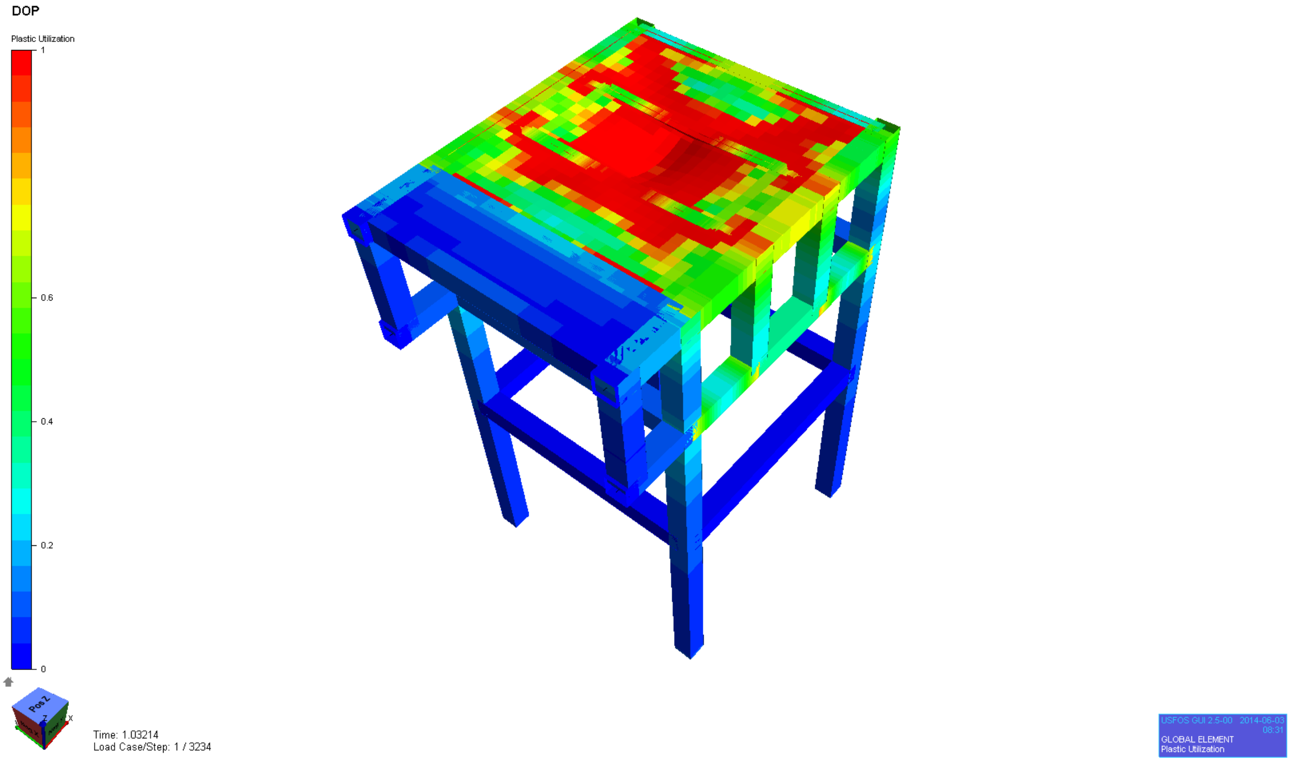

Figure 7.51 Plastic utilization

The plastic utilization in analysis 8 is shown in figure 7.51 has a similar pattern as analysis 7 figure 7.44.

7.10 Analysis 9 One node mass in node 1 and with extra beams

7.10.1 General

Six additional beams have been included to reinforce the DOP structure with the purpose of reducing the strain (Figure 7.52, beams marked red). When including additional beams the structure will be heavier and more expensive.

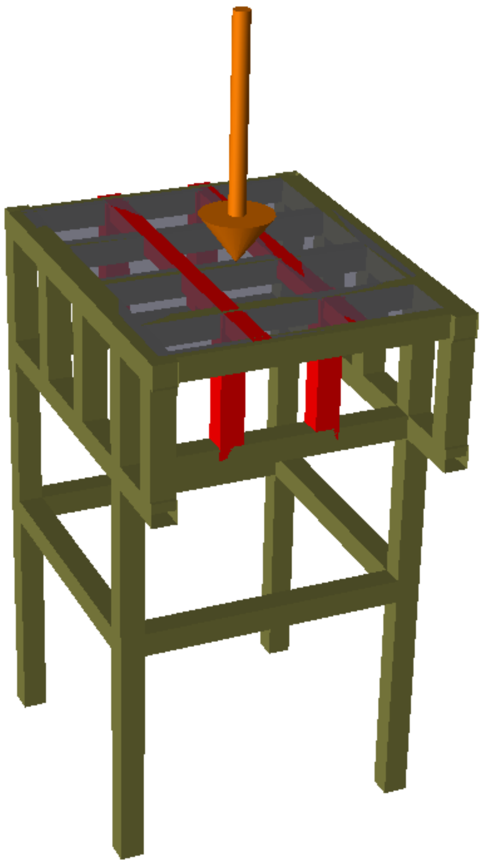

Figure 7.52 Load

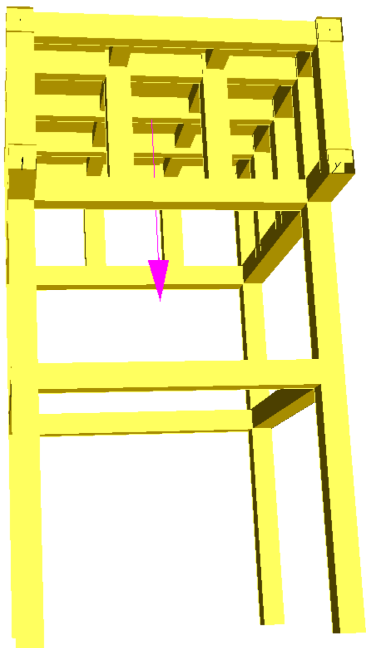

Figure 7.53 Load

7.10.2 Strain

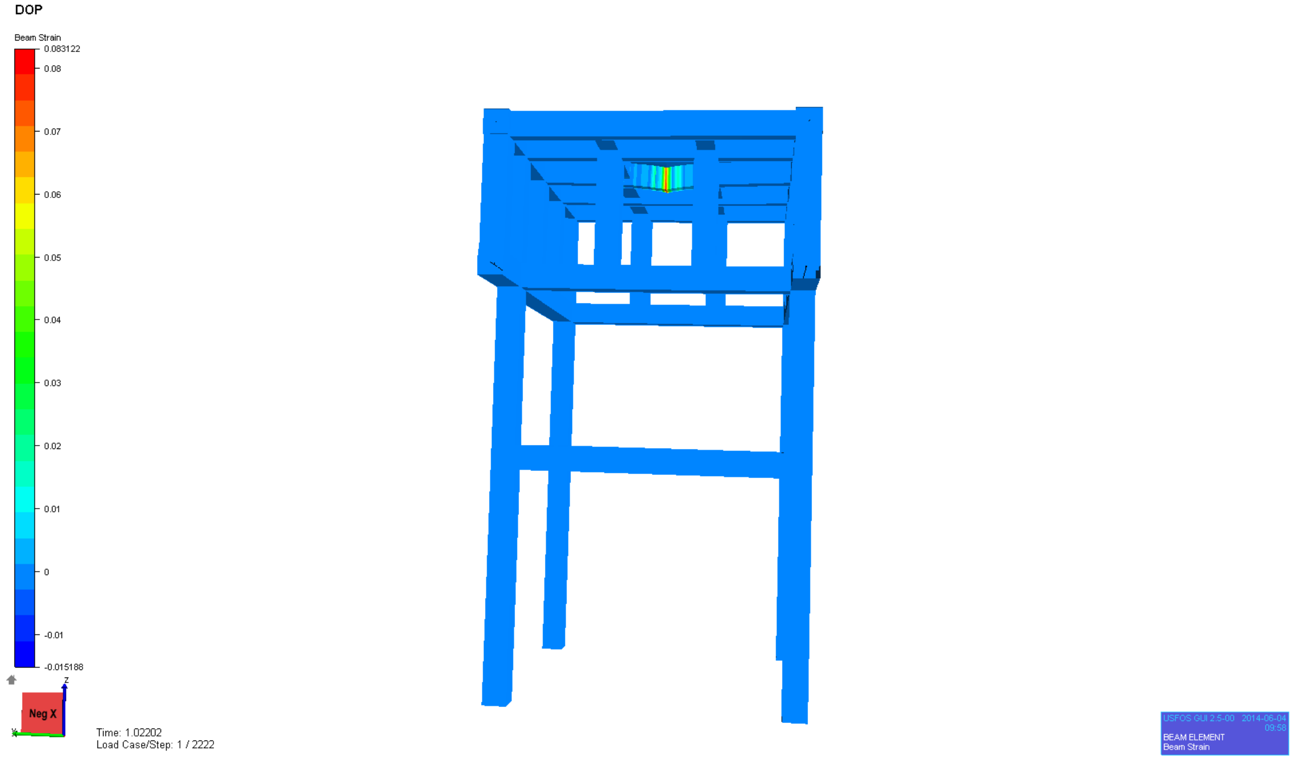

Figure 7.54 Plastic utilization

According to figure 7.54 the beam strain have been reduced to 8.3%. Without the extra beams the maximum strain was 13.8 %.

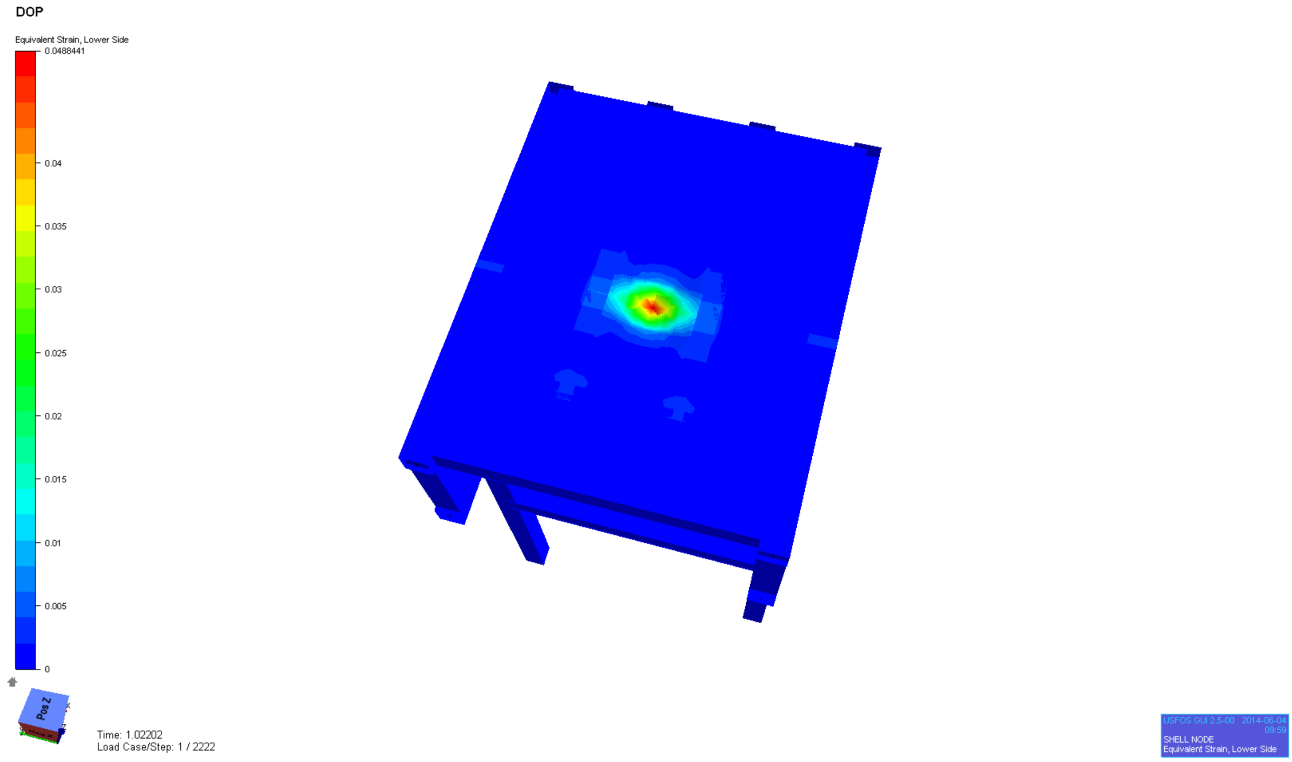

Figure 7.55 Plastic utilization

The maximum strain in the plate is 4.8% in figure 7.55.

7.10.3 Displacement

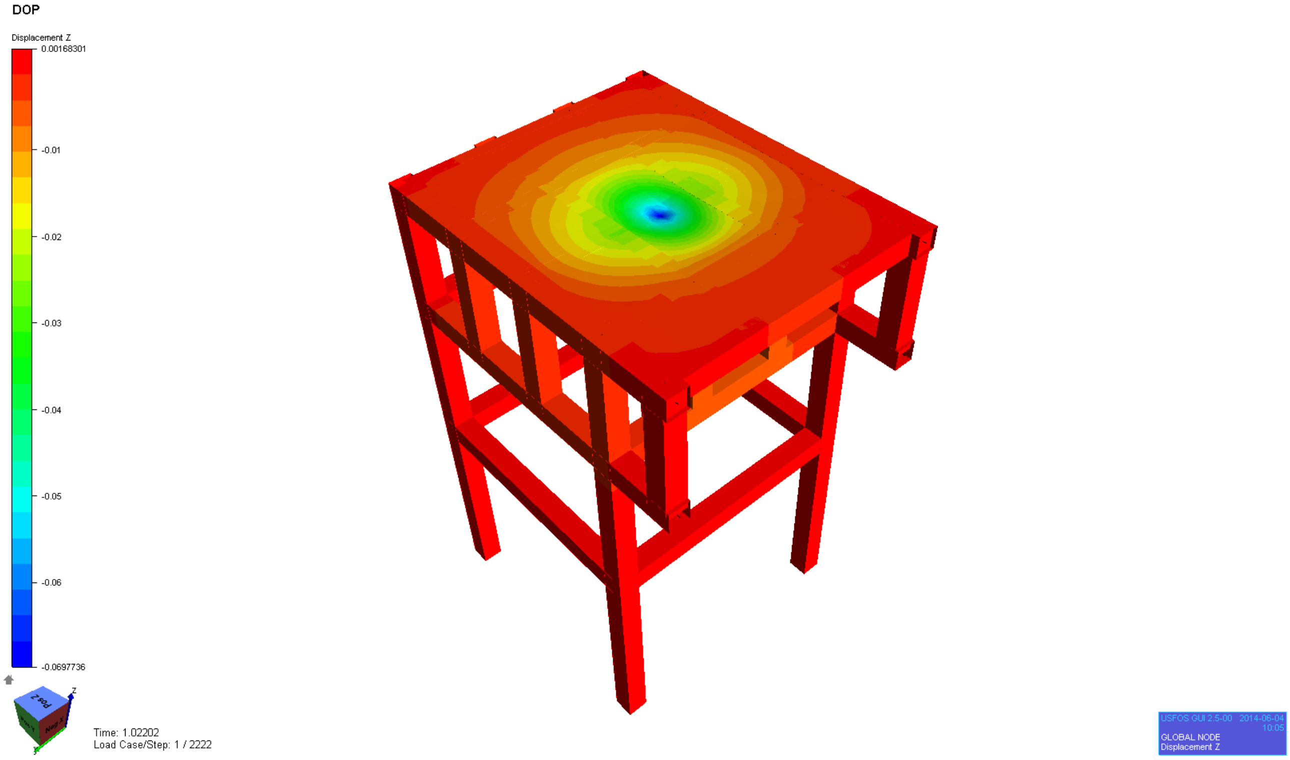

Figure 7.56 Displacement

Figure 7.57 Displacement

In figure 7.56 and 7.57 the maximum displacement in z-direction 7.0 cm which is reduced from 13.3cm with the original design in analysis 1.

7.10.4 Plastic utilization

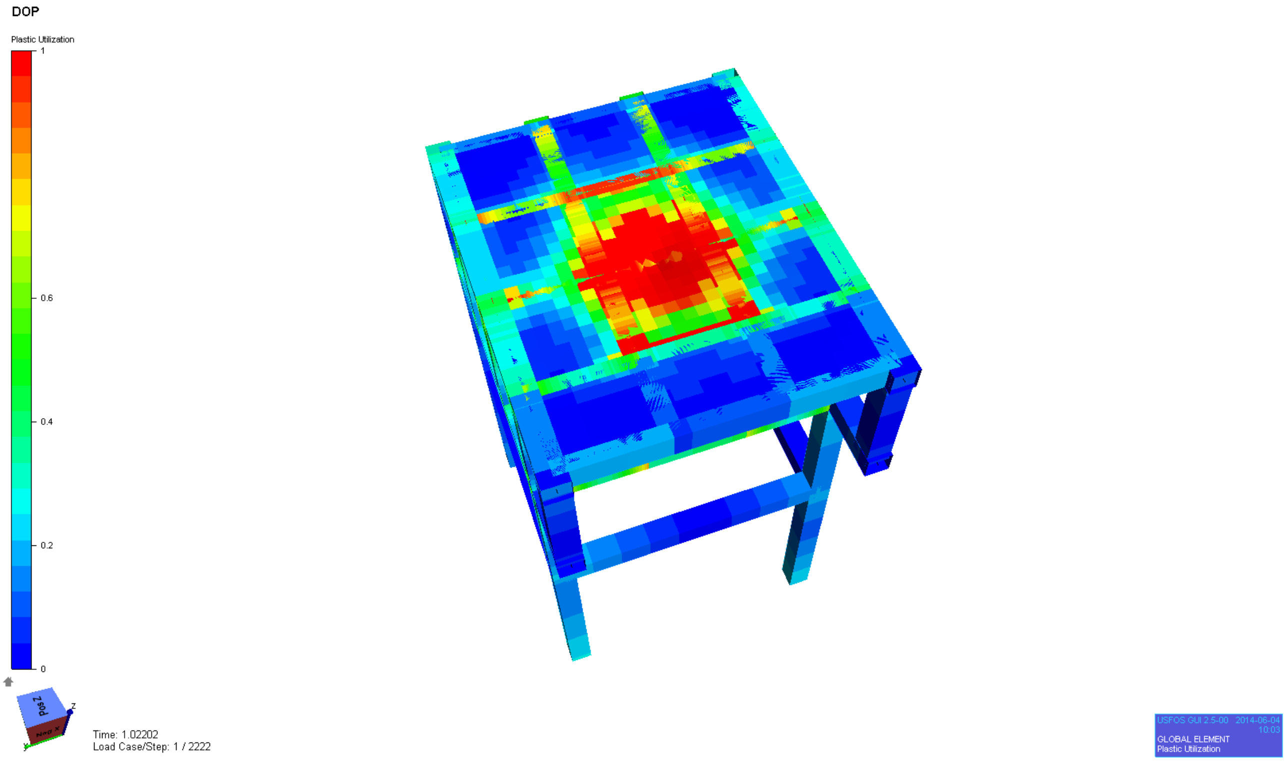

Figure 7.58 Plastic utilization

The plastic utilization is high around the impact location according to figure 7.58. Without the extra beams as in analysis 1 the fully plastic utilized area is extended to the sides as in figure 7.9. In analysis 9 the new beams absorb energy from the dropped object.

7.11 Analysis 10 One node mass in node 4 and with extra beams

7.11.1 General

In Analysis 10 the impact load is simulated as a node mass with velocity acting on the edge beam as in Analysis 5, but the DOP structure is reinforced with 6 extra beams as in Analysis 9. The extra beams reduces the span length hence the strain and deflection is reduced.

7.11.2 Strain

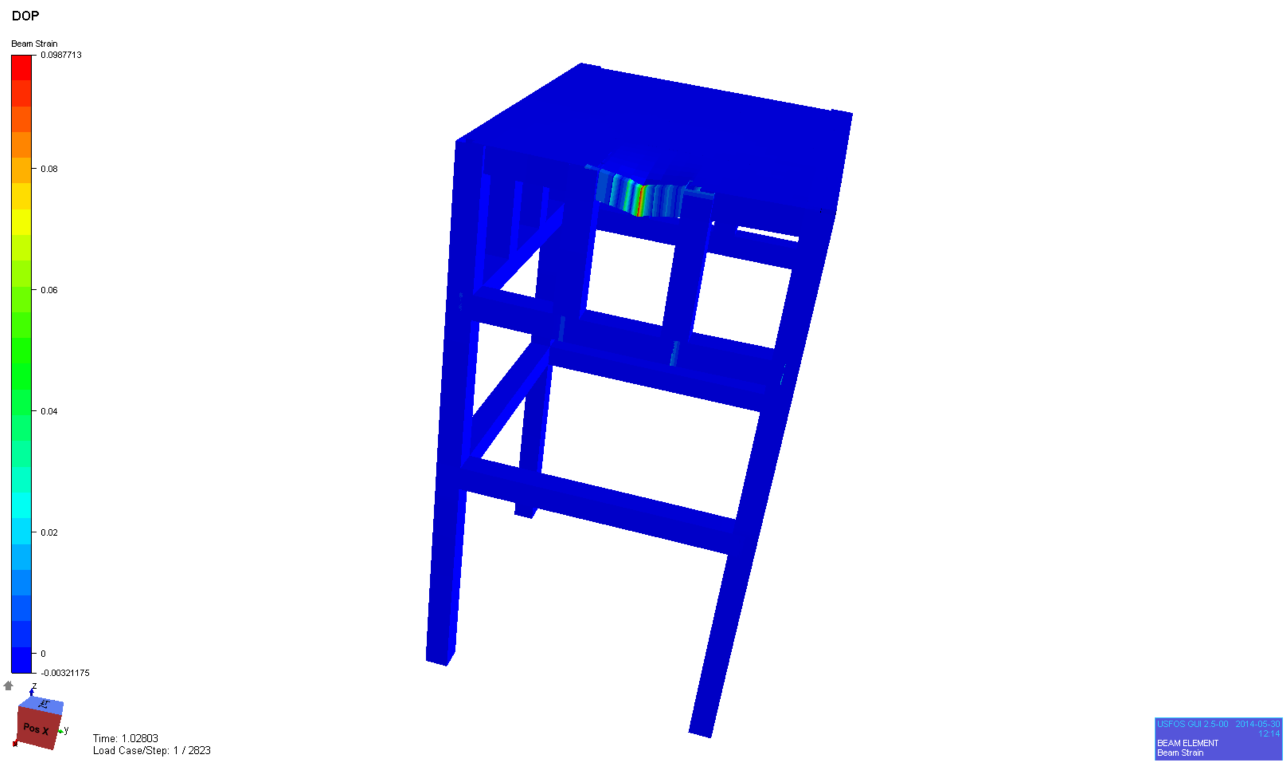

Figure 7.59 Strain

The maximum beam strain is 9.9% with the new reinforced, and is now in the acceptable range. In analysis 5 without the extra beams, the maximum beam strain was 17.6% which was over the limit.

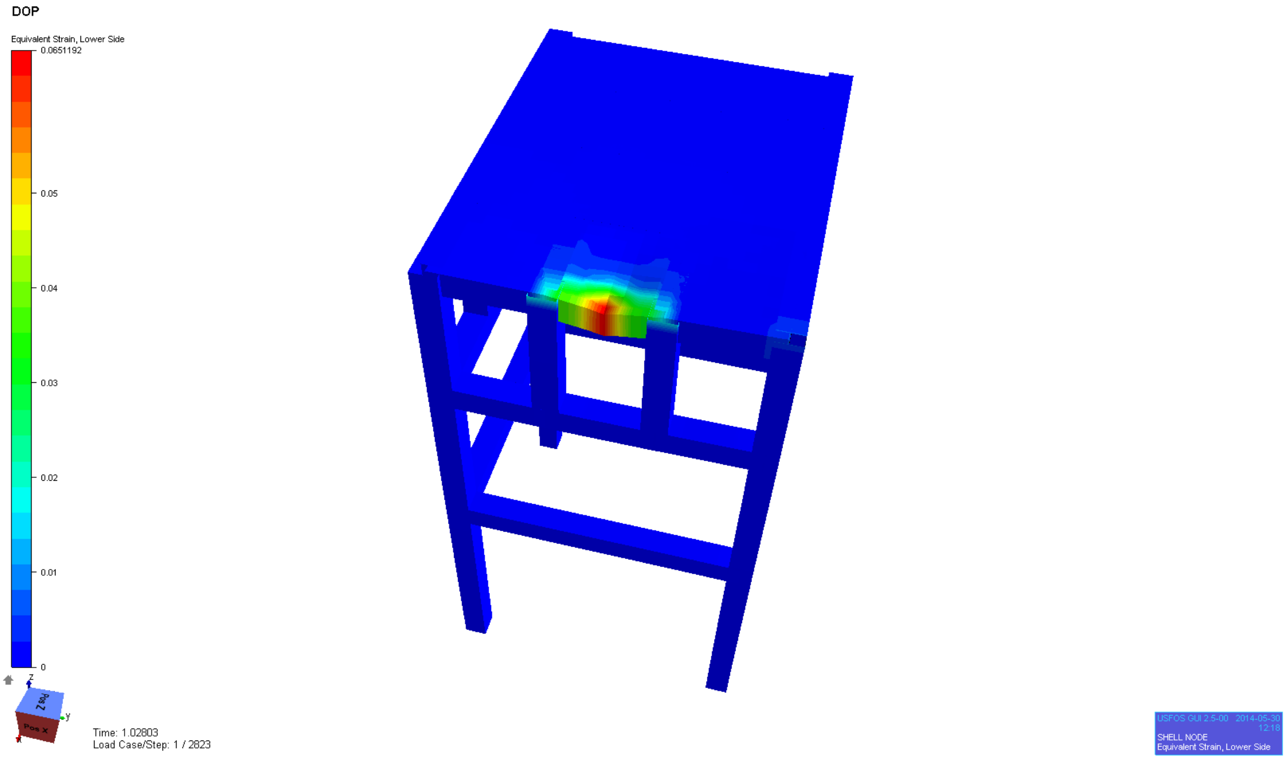

Figure 7.60 Strain

In figure 7.60 the maximum strain is 6.5% in the plate.

7.11.3 Deflection

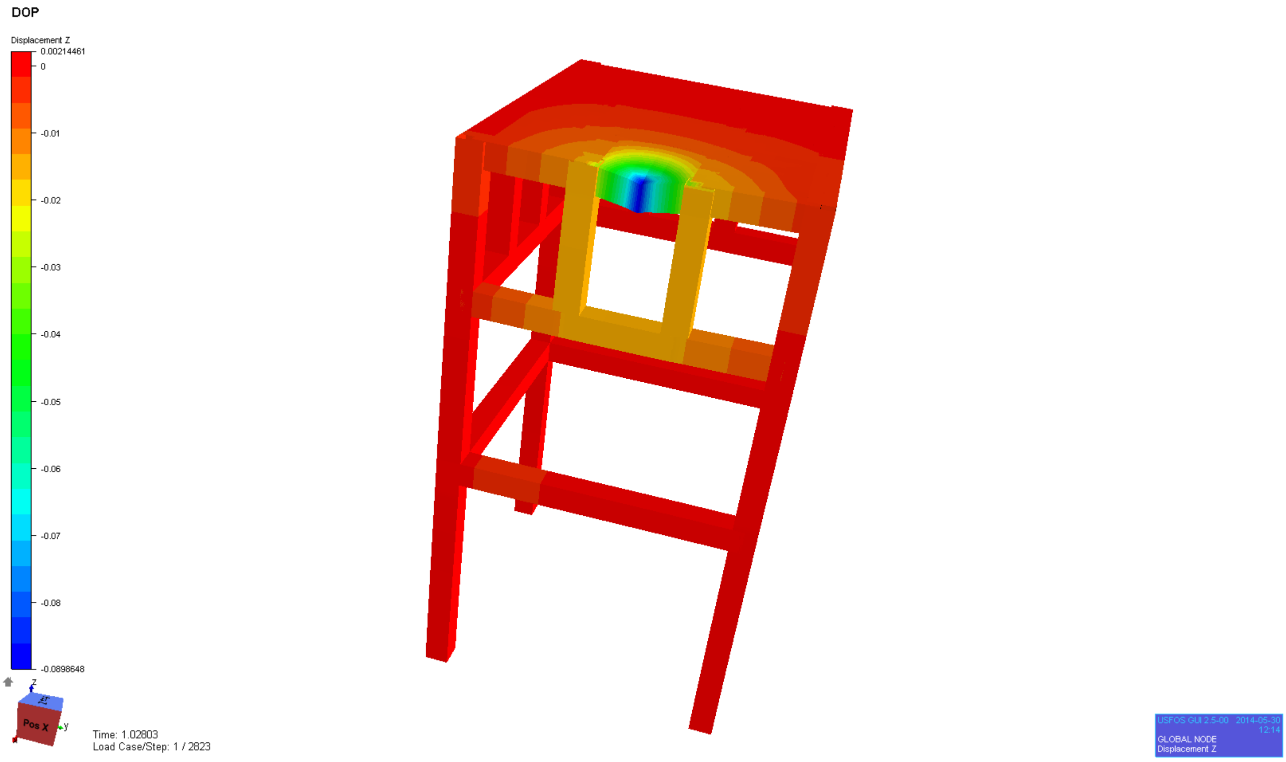

Figure 7.61 Deflection

Maximum deflection in z-direction has been reduced to 8.9cm. In analysis 5 without the extra beams the deflection was 22.7 cm.

7.11.4 Plastic utilization

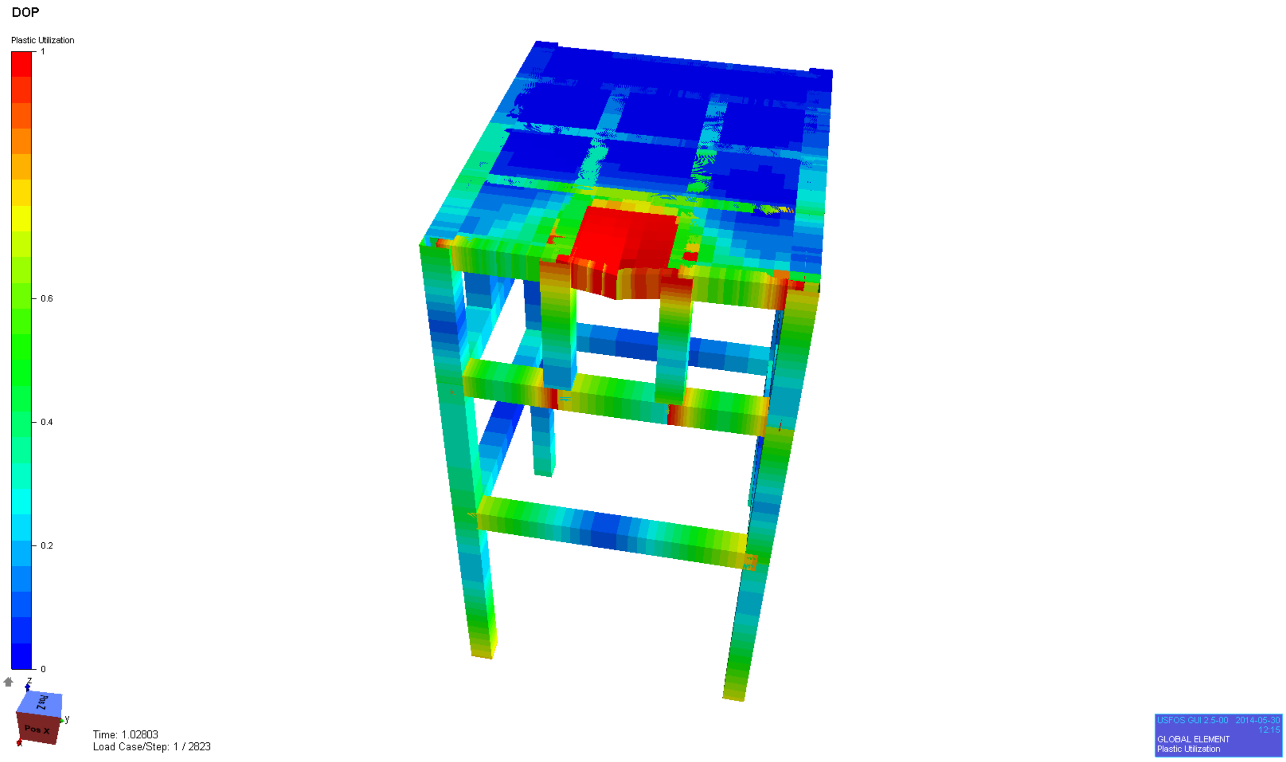

Figure 7.62 Plastic utilization

The plate is fully plastic utilized in between the new beams as shown in figure 7.62. Figure 7.62 also show where the plastic hinges are created in the beams.

7.12 Analysis 11 One node mass in node 1 without plates

7.12.1 General

In Analysis 11 the structure is without plates on top (Figure 7.64). Without the plates with the membrane effect the structure will get to high strain in the beam. Therefore the load is reduced to 2000kg before running the analysis.

7.12.2 Kinetic energy

Mass of the dropped object has been reduced from 7000 kg to 2000 kg therefore the kinetic energy has been reduced. The velocity is still 7.672 m/s.

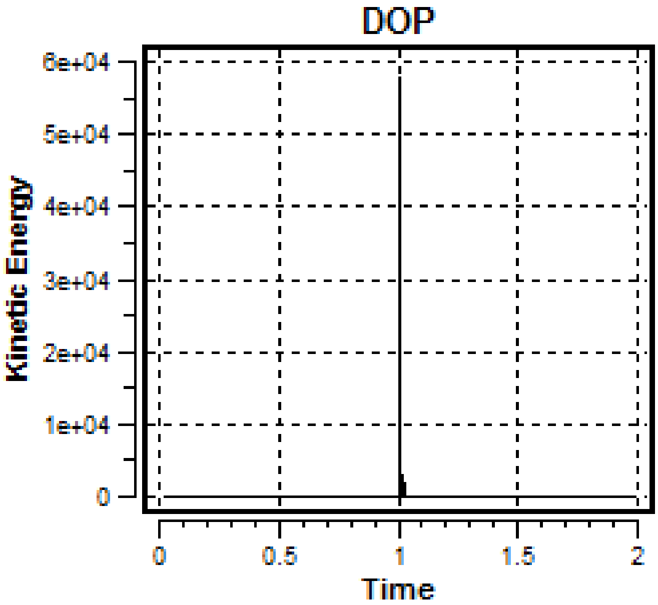

Figure 7.63 Kinetic energy

Table 7.3 Kinetic energy

1.001	2.23525e-013
1.001	2.23705e-013
1.001	58593.3
1.001	58357.6
1.001	58227.3

The maximum kinetic energy according to USFOS is 58.59kNm (Table 7.3) right after the impact.

Calculation for kinetic energy from equation (1.2):

$$E_k = \frac{1}{2} m v^2$$

$$E_k = 58.86\ kNm$$

The hand calculation is slightly higher than the calculation from USFOS. The inaccuracy is probably as in 7.2.2 where the results is some inaccurate, but since this analysis do not have plates which creates many nodes it is easier to run an analysis with more steps. Therefore the result here is closer to the hand calculation with a step length of 0.000001s compared to 7.2.2 where 0.00001s is used.

7.12.3 Strain

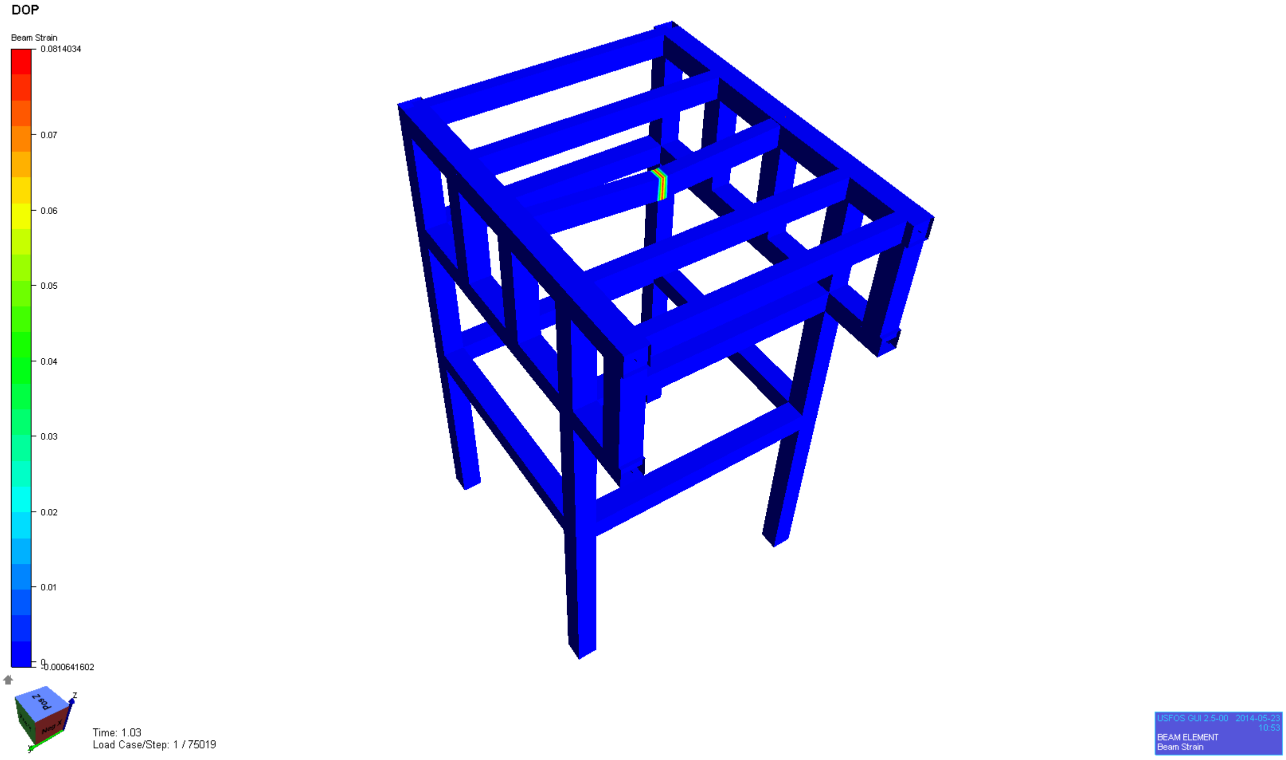

Figure 7.64 Strain

The structure with no plates will get maximum beam strain 8.1% in the middle of the beam from the dropped object with a mass of 2000kg.

7.12.4 Displacement

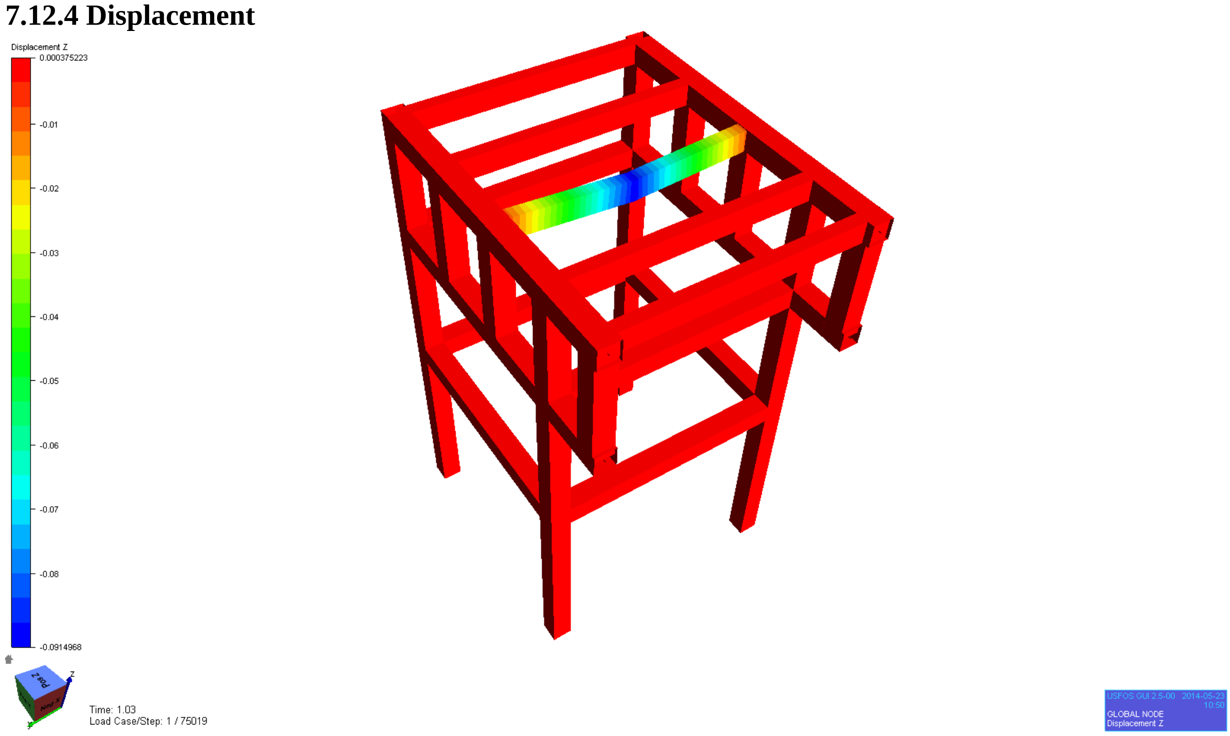

Figure 7.65 Displacement

The displacement is 9.1cm according to figure 7.65

Compered to simply hand calculation on a frame:

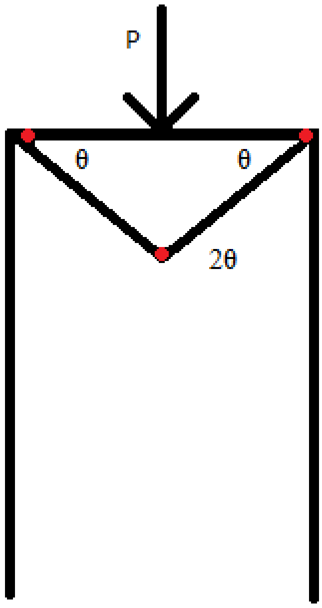

Figure 7.66 Plastic hinges

$W_p = 310*10^3 mm^3$ for RHS 200x120x8

The plastic moment capacity is defined as:

$$M_p = \sigma_y W_p \quad (7.1)$$

Where $\sigma_y = 355 N/mm^2$

$M_p = 110.05 kNm$

Figure 7.67 shows that the plastic hinges are created in the start, mid and end of the RHS200x200x8.0.

External work equals internal work

$$W_e = W_i \quad (7.2)$$

$$P_c \delta = \theta M_p + 2\theta M_p + \theta M_p \quad (7.3)$$

$$\theta = \frac{\delta}{\frac{L}{2}} \quad (7.4)$$

When

$$tan\theta \approx \theta \quad (7.5)$$

$$P_c = \frac{8M_P}{L} \quad (7.6)$$

$L = 2.2\, m$

$$E_k = P_c\delta = W_e \qquad (7.7)$$

The deflection is then:

$$\delta = \frac{E_k L}{8M_p} \qquad (7.8)$$

δ=14.7cm

The deflection from hand calculation is 14.7 cm and from USFOS analysis it is 9.1cm. Some of the forces in the structure are obtained from the rest of the structure, not only the simplified frame used in the hand calculation. The kinetic energy is also a little lower for the USFOS analysis compared to the hand calculations, which will give a lower deflection for USFOS calculations.

7.12.5 Plastic utilization

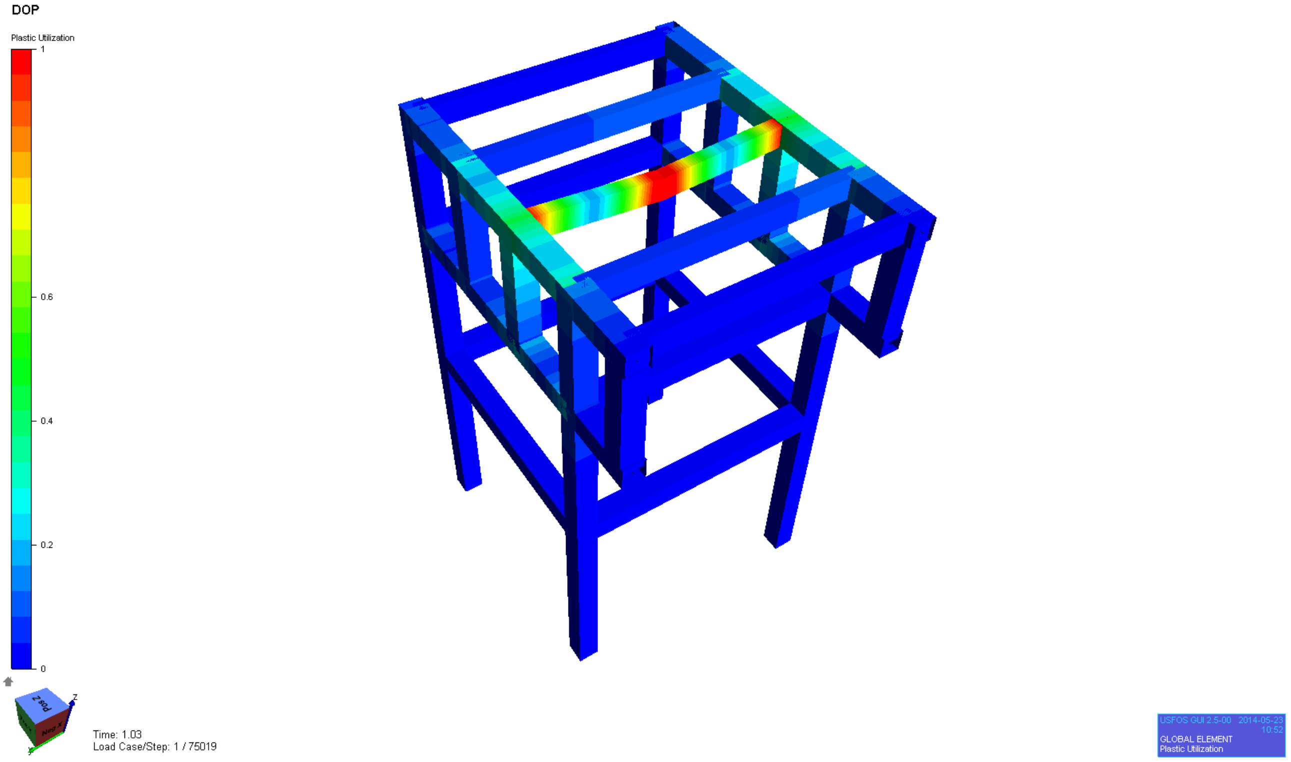

Figure 7.67 Plastic utilization

Figure 7.67 show that the plastic hinges are created in the start, middle and at the end of the beam. It also shows that the structure obtain the energy in the beams close to the beam with the impact of the dropped object.

7.13 Analysis 12 One node mass in node 1

7.13.1 General

For compering the result from the structure without plates, a new analysis is run using a plated structure exposed for an impact load corresponding to an object with a mass of 2000kg dropped from a 3 meter height. The impact load is simulating as in analysis 11 by using node mass with velocity in node 1. The kinetic energy is 58.86kN.

7.13.2 Strain

Figure 7.68 Strain

With a dropped object with a mass of 2000kg in node 1, the strain in the beam will be 6.1% at maximum. In analysis 12 without plates the maximum strain was 8.1%

7.13.3 Displacement

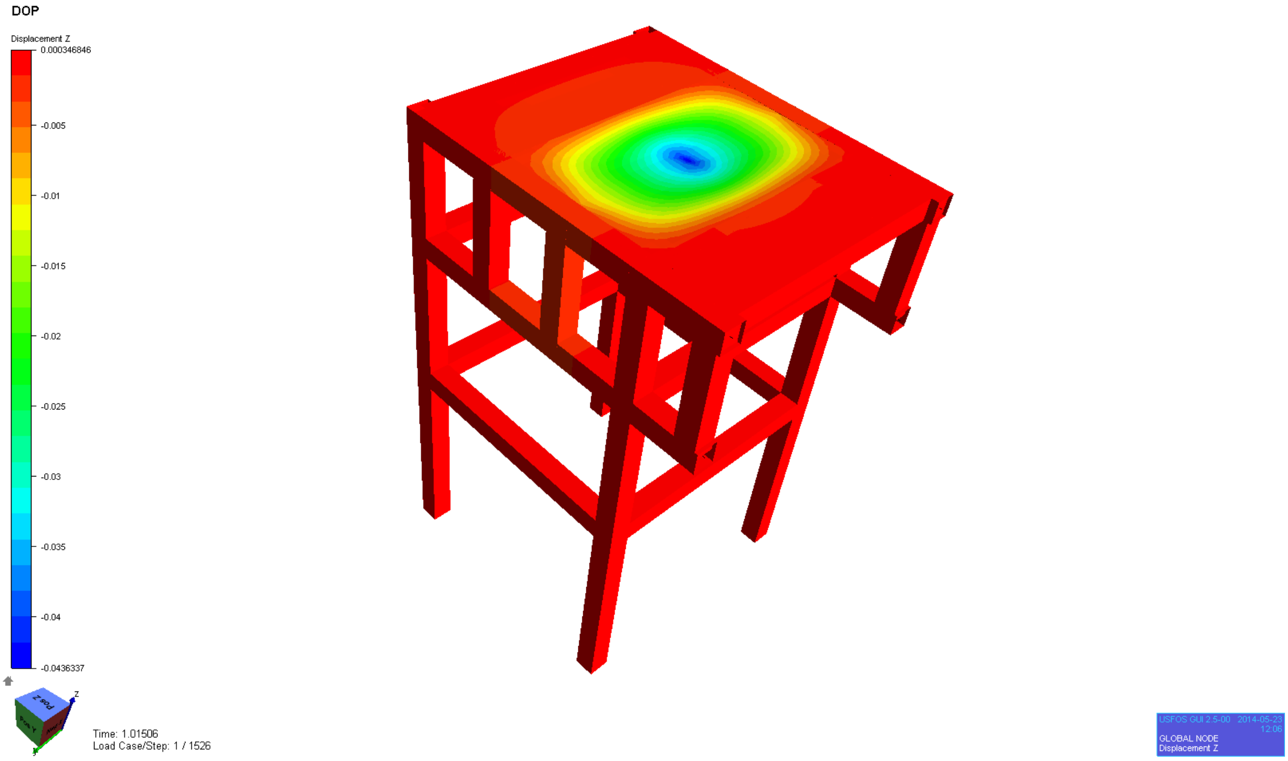

Figure 7.69 Displacement

The deflection will be 4.4cm in the centre of beam according to Figure 7.69, for compering the deflection in Analysis 12 was 9.1cm.

7.13.4 Plastic utilizations

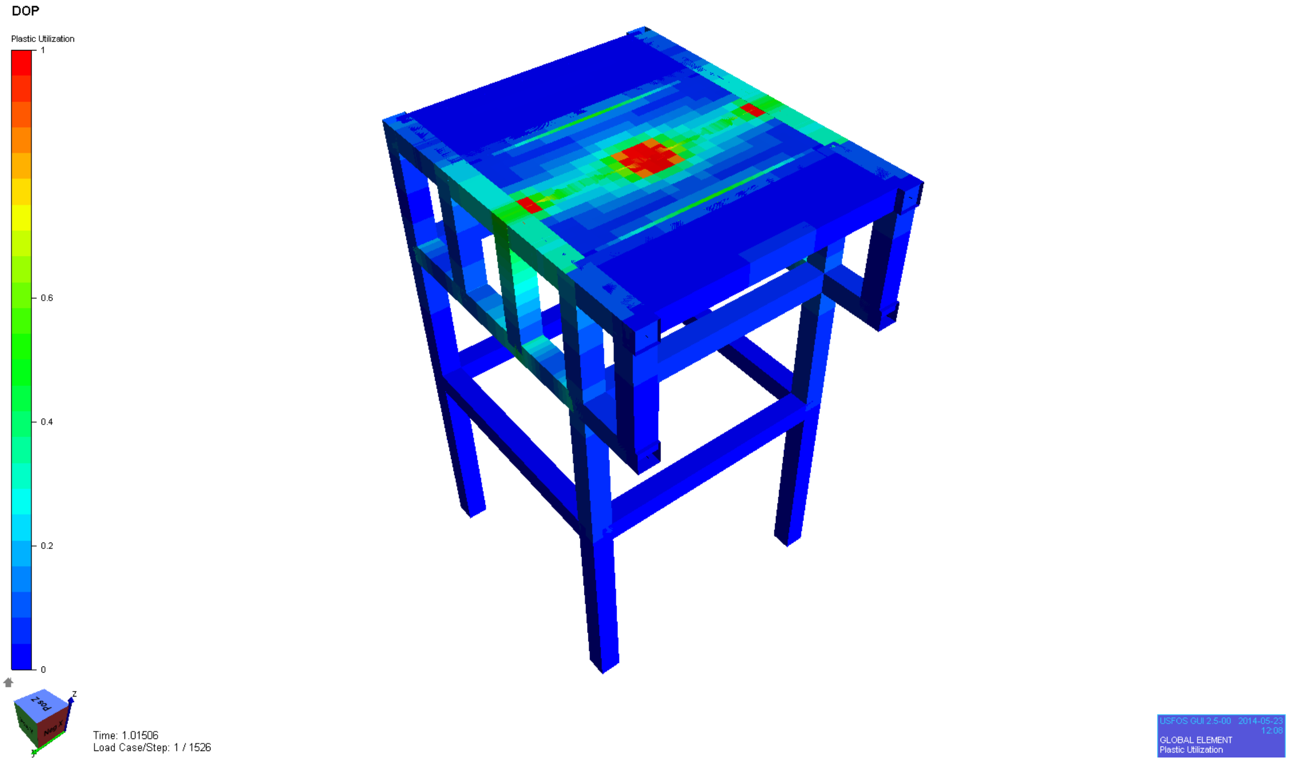

Figure 7.70 Plastic utilization

Since the mass of the dropped object is reduced the plate is not as fully plastic utilized as in analysis 1. There is still full plastic utilization at start, middle and end of the beam.

7.14 Analysis 13 with aluminium and one node mass in node 1

7.14.1 General

In Analysis 13 aluminium is used instead of steel. Aluminium can be an option for steel for a lighter structure. The density for the alumimum is almost 1/3 of the weight of steel. Alloy 5083 T6 is used for the plate and 6082 T6 for the beams. The materials is selected are selcted after the guidelines for selctions in NORSOK M121 where both the alloys are recommended.

E-modul for the alumimium is 70 GPa for plates and beams. Yield strengt is 250 Mpa for the plates and 260 Mpa for the profiles. Since the structure have a lower yield strengt it will be loaded with a mass of 2000kg.

7.14.2 Strain

Figure 7.71 Strain

Maximum strain is 12.25 at the middle of beam according to Figure 7.71 with the whole structure in aluminium. In analysis 12 the maximum strain was 6.1%

7.14.3 Displacement

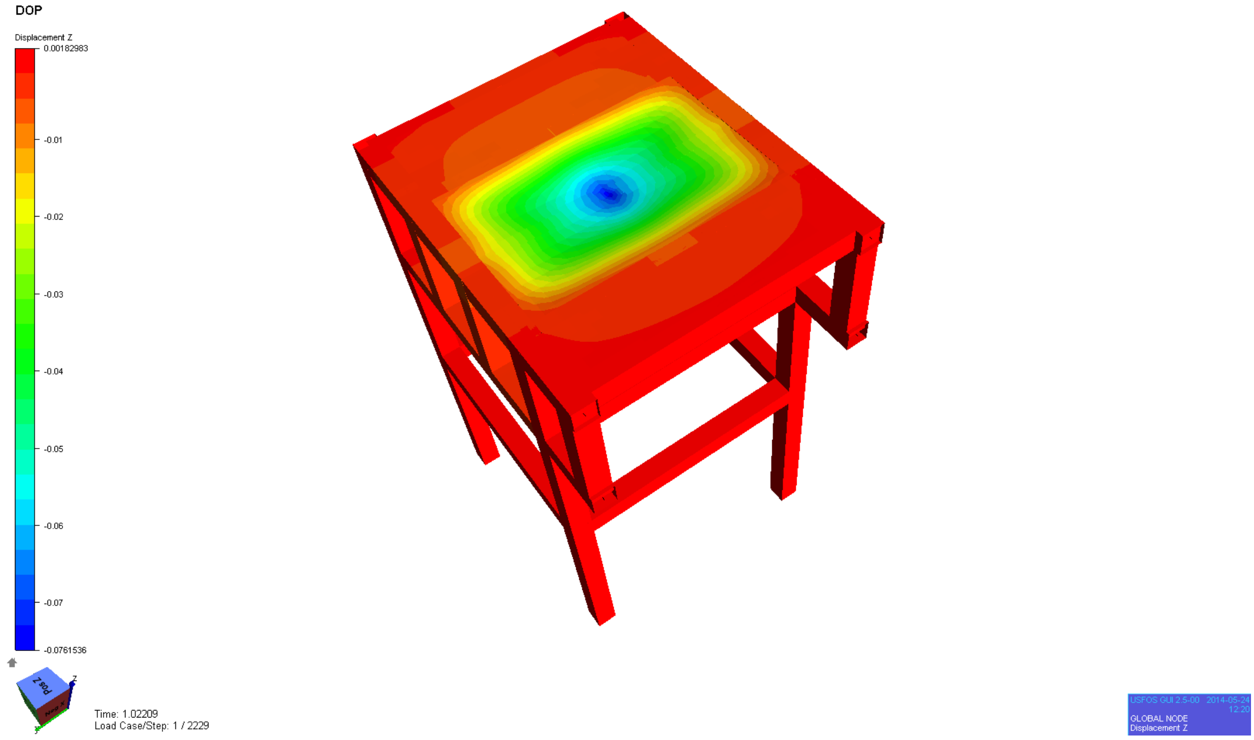

Figure 7.72 Displacement

Displacement is 7.6 cm in node 1. In analysis 12 the displacement is 4.4cm.

7.14.4 Plastic utilization

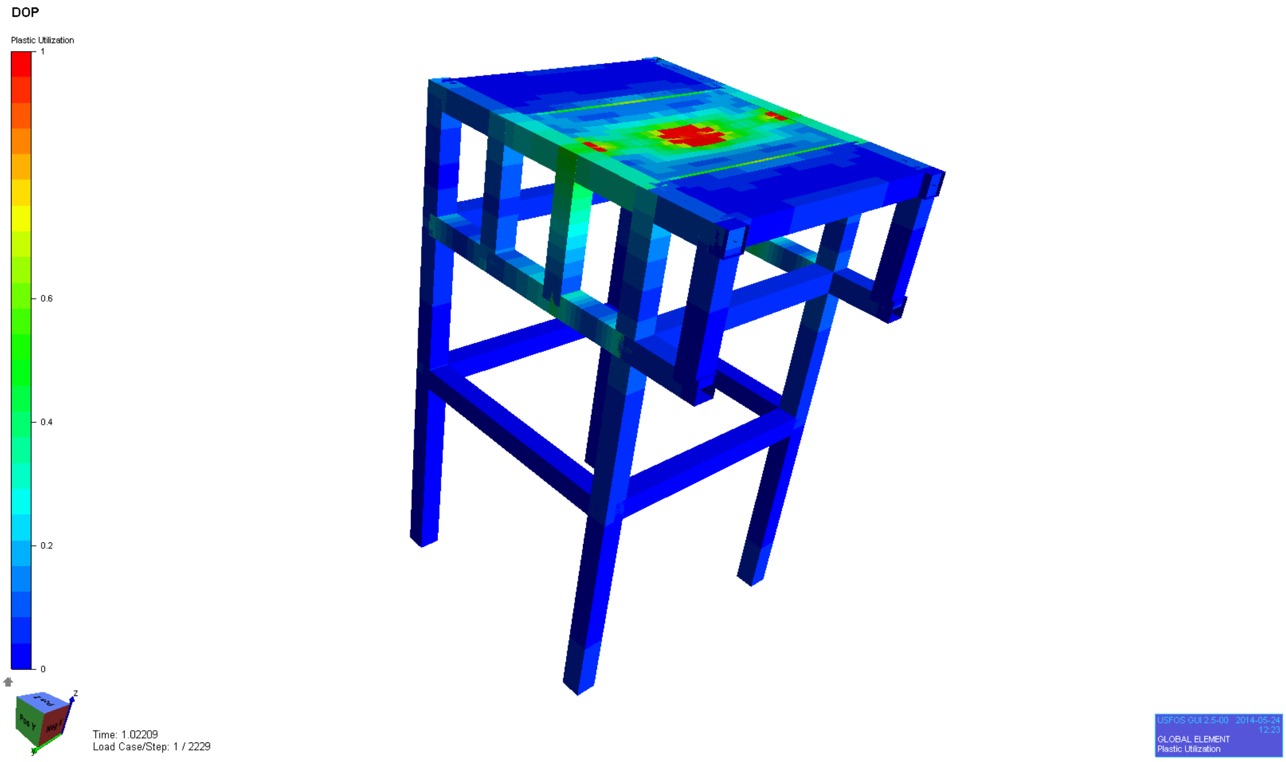

Figure 7.73 Plastic utilazation

The DOP strucrue have a area around the impact loaction and at start and end of the beam where it is fully plastic utilzed according toi Figure 7.73.

8 Comparison and discussion

8.1 Comparison for 7000kg DO

Table 8.1 Strain and deflection

	Beam		Plate	
Analysis	Strain [%]	Deflection [cm]	Strain [%]	Deflection [cm]
Analysis 1 One node mass in node 1	13.6	13.3	7.1	13.3
Analysis 2 One node mass in node 3	0.7	3.3	17.9	19.1
Analysis 3 One node mass in node 4	10.4	11.8	7.6	11.8
Analysis 4 One node mass in node 4 area	18.2	22.7	4.9	22.7
Analysis 5 Three node masses in node 4 area	12.5	22.7	5.2	22.7
Analysis 6 Nine node masses in node 1 area	8.5	11.7	3.8	12.7
Analysis 7 Nine node masses in node 2 area	1.6	4.2	8.7	17.0
Analysis 8 16 node masses in node 2 area	2.7	5.0	5.9	15.5
Analysis 9 On node mass in node 4 and with extra beams	8.3	7.0	4.8	7.0
Analysis 10 One node mass in node 4 and with extra beams	9.9	8.9	6.5	9.9

Table 8.1 is showing the maximum strain in beam in analysis 1 is 13.6% in node 1, the limit for NORSOK N-004 is 15% for S355. In node 1 there is large moment forces in the beam, but membrane effect from the plate obtain energy. In analysis 6 with distributed loads around and in node 1 is the maximum strain 8.5%. The deflection has also been reduced from 13.3cm in analysis 1 to 11.7cm in analysis 6. The deflection in plate is 12.7cm because of there are some point loads in the plate which is not directly over the beam. In analysis 9 the strain has been reduced to 8.3%, compared to 8.5% in analysis 6. The deflection in the beam has been reduced to 7cm which is significant less than in both in analysis 1 and 6.

In analysis 2 an impact load in node 2 create 17.9% strain in the plate, which is over the limit from NOROSK N-004 of 10% for S460. One alternative to reduce the strain in the plate is to increase the thickness of the plate, but this will result in a heavier and more expensive structure. The plate thickness must be increased to 1.8cm for be in the acceptable range. In analysis 7 with the distributed load in and around node 2, the strain in the plate has been reduced to 8.2% which is in the acceptable range. The maximum displacement in analysis 2 is 19.1cm and reduced to 17.0cm in analysis 7. In Analysis 8 node masses with velocity are distributed in a triangular form and have more node masses than in analysis 7. In analysis 8 the maximum strain in the plate is 5.9, which is lower than the maximum strain in analysis 7. In analysis 7 maximum strain is 8.7%, but some of the node masses are directly over beams, which will obtain more energy, and create more strain in the beams.

In analysis 3 is a point load in node 3 for checking the shear load in the beam. The maximum strain in analysis 3 in the beam is 10.4%, which is lower than the maximum strain of 13.6 in analysis 1. The deflection in analysis 3 is 11.8cm which also is less than the deflection in analysis 1, which was13.3. In the area around node 3 there are less membrane effect compared to the area around node 1. The membrane effect obtains some of the energy, hence reduce the strain and deflection.

In analysis 4 the maximum beam strain is 18.2, which is over the 15% limit from NOROSK N-004. The deflection is 22.7cm for the beam. In analysis 5 the node mass is distributed into 3 node masses with velocity in the beam, and reduced the strain to 12.5% which is acceptable. The deflection is maximum deflection is 22.7cm. In analysis 9 there is node mass but extra beams have been added. The maximum strain in node 4 is 9.9% in analysis 9 which also is in the acceptable range. The deflection has been reduced to 8.9cm. In analysis 9 has only 39.2% of the displacement compared to analysis 1 and 10.

Sources of errors in the analysis can be that the mass is attached to the node in impact and creates some extra energy when it vibrates after the impact. It will create some larger vibration after the impact, but can be damped with extra damping. Another source of error can be the kinetic energy was a little lower than the calculated kinetic energy.

8.2 Comparison for 2000kg DO

Table 8.2 Strain and deflection in beam

Analysis	Strain [%]	Deflection [cm]
Analysis 11 One node mass in node 1 without plates	8.1	9.1
Analysis 12 One node mass in node 1	6.1	4.4
Analysis 13 With aluminium and on node mass in node 1	12.3	7.6

The strain in analysis 12 is in the plate 6.1% compared to 8.1% for analysis 11 without plates as seen in table 8.2. The deflection is also 4.4 cm in analysis 12 and 9.1cm in analysis 11. This is a 107% increase in the deflection in the beam. Mostly the increase in the beam and strain is because of the membrane effect created in the plates. Figure 7.70 show how the plate is plastic utilized by the dropped object. There will also be a small increment of the moment capacity in the beam because of the beam will be 200mm + 8mm from the plate.

In analysis 13 the maximum strain is 12.3% and the deflection is 7.6cm. In analysis 13 the DOP structure is designed in aluminium. The yield strength for aluminium is lower than the S355 and S420. The yield strength in aluminium is 260Mpa for the beam and 250Mpa for the plate. The DOP structure can therefore obtain a smaller amount of energy compared to a structure designed in steel.

9 Conclusion

9.1 Conclusion of the results

In this master thesis a DOP structure have been subjected to different impact loads. The dropped objects have varied in size, shape and weight. The impact locations have also been varied for finding the most critical positions. Analysis 4 with a 7000kg mass falling 3 meters with an impact in node 4 created a beam strain of 18.2% which is over the 15% limit for S355. All impacts will have some distributions of the loads. Node mass with velocity in one node will be a conservative simplifying of the model. The less distributed impact forces are the more correct is the result. In analysis 5 there was three impact loads along the beam, with total distance of 20cm of the impact loads. Here was maximum beam strain reduced to 12.5% which is in the acceptable area. The reduction of the strain is because of the impact loads is distributed into three node compared to one node. The impact load is not all in the idle will also reduce the moment force. In analysis 10 with the added beams the strain was 9.9%. The strain has been reduced here because of the extra support from the beams and the reduced span length for the beam.

In analysis 2 the maximum plate strain is 17.9% in node 2, which is over the limit of 10% for S460. The steel is S420 which can have higher maximum strain, but to follow the limit from NORSO N-004 10% is used. This is also conservative because of only load in one node. For example a pipe can fall vertical down and hit the structure with low impact area, but the impact loads will still have some distributing of the impact forces. In analysis 7 the beam maximum beam strain have been reduced to 8.7% which is acceptable. The impact force is distributed on 10 nodes here. With a mass of 7000kg a total area of 30cm x 30cm sees reasonable, but an object can hit with corner or a very stiff item. For handle the impact force in one node the plate can be increased to thickness of the plate from 0.8cm to 1.8cm to get the plate strain in the acceptable limit.

In analysis 11 without the plate and in analysis 12 with the plate are both subjected with mass of 2000kg falling from 3 meters. Here is the maximum strain reduced from 8.1% to 6.1% and maximum deflection is reduced from 9.1cm to 4.1cm. This shows that the plate and its membrane effect have a large effect for the structure. Analysis 4 which is on the edge with only plate on one side have a larger strain than analysis 1 which have plate on both sides of the impact, 18.2% compared to 13.6, but here can the beams around obtain more energy in analysis 1 because it is in the middle of the structure.

According to the result from the analyses the most vulnerable accident situation is when the DO has very low load distributions. The most vulnerable positions are in the middle of the plate and in the middle of the beam at the edge of the DOP structure.

9.2 Future Work

For future work it would be interesting to test the USFOS result compared to another method. The mass of the dropped object could be attached to a spring that will simulate the fall of the object until impact.

It could also be interesting to prepare new model of aluminium which could handle a mass of 7000kg of the dropped object falling 3 meters. The new analysis model must have stronger structure because of the reduced strength in the aluminium compared to the steel.

The connection between the DOP structure and deck it is connected to could be interesting to analyse.

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Appendix A- input files in USFOS – Original structure

A.1-Control file

```
HEAD              DOP
                  USFOS
                 Ingve Nilsen

'      mcods
CNODES       1
'      nodex   idof    dfact
          196     3        1  #1
'         495     3        1  #2
'         186     3        1  #3
'         596     3        1  #4



'
'      T_end      dt      dT_res       dT_pri
Static     1.0      0.050     0.050       0.050
Dynamic    1.2      0.00001   0.001       0.001
Dynamic    2.0      0.01      0.01        0.01
'
'
'

'
TIMEHIST  2 Points
'       Time   factr
          0       0
          1       1
          2       1

'         node_Id  Mass
'Nodemass    196     0 0 2000
 Nodemass    196     0 0 7000
'Nodemass    495     0 0 7000
'Nodemass    186     0 0 7000
'Nodemass    596     0 0 7000
'Nodemass    595     0 0 7000/3
'Nodemass    596     0 0 7000/3
'Nodemass    597     0 0 7000/3

'Analysis 6
```

'Nodemass 196 0 0 7000/9
'Nodemass 363 0 0 7000/9
'Nodemass 364 0 0 7000/9
'Nodemass 365 0 0 7000/9
'Nodemass 195 0 0 7000/9
'Nodemass 197 0 0 7000/9
'Nodemass 425 0 0 7000/9
'Nodemass 426 0 0 7000/9
'Nodemass 427 0 0 7000/9

'Analysis 7
'Nodemass 495 0 0 7000/9
'Nodemass 471 0 0 7000/9
'Nodemass 472 0 0 7000/9
'Nodemass 473 0 0 7000/9
'Nodemass 494 0 0 7000/9
'Nodemass 496 0 0 7000/9
'Nodemass 517 0 0 7000/9
'Nodemass 518 0 0 7000/9
'Nodemass 519 0 0 7000/9
'
'Analysis 8
'Nodemass 425 0 0 7000/16
'Nodemass 448 0 0 7000/16
'Nodemass 471 0 0 7000/16
'Nodemass 494 0 0 7000/16
'Nodemass 517 0 0 7000/16
'Nodemass 540 0 0 7000/16
'Nodemass 563 0 0 7000/16
'Nodemass 449 0 0 7000/16
'Nodemass 472 0 0 7000/16
'Nodemass 495 0 0 7000/16
'Nodemass 518 0 0 7000/16
'Nodemass 541 0 0 7000/16
'Nodemass 473 0 0 7000/16
'Nodemass 496 0 0 7000/16
'Nodemass 519 0 0 7000/16
'Nodemass 497 0 0 7000/16

' Type Time Vx Vy Vz rVx rVy rVz Id_1 Id_2
Ini_velo Node 1.001 0.0 0.0 -7.672 0.0 0.0 0.0 196
'Ini_velo Node 1.001 0.0 0.0 -7.672 0.0 0.0 0.0 495
'Ini_velo Node 1.001 0.0 0.0 -7.672 0.0 0.0 0.0 186
'Ini_velo Node 1.001 0.0 0.0 -7.672 0.0 0.0 0.0 595
'Ini_velo Node 1.001 0.0 0.0 -7.672 0.0 0.0 0.0 596

```
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  597

'Analysis 6
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  196
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  363
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  364
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  365
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  195
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  197
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  425
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  426
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  427

'Analysis 7
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  495
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  471
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  472
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  473
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  494
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  496
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  517
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  518
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  519

'Analysis 8
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  425
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  448
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  471
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  494
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  517
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  540
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  563
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  449
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  472
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  495
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  518
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  541
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  473
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  496
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  519
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  497

'           Load_case     Time_hist
'
 Loadhist        3            2
```

```
Loadhist     10       2

Dynres_G Wint
Dynres_G Wext
Dynres_G Wplast
Dynres_G Wtot
Dynres_G Wkin


RAYLDAMP   0.0094    0.0095
```

A.2 Model file

The USFOS model file are saved in the CD

Appendix B- input files in USFOS – Structure with extra beams

B.1-Control file

```
HEAD              DOP
                  USFOS
                 Ingve Nilsen
'
'          mcods
CNODES       1
'          nodex   idof    dfact
'           259     3        1 #1
            659     3        1 #4

'
'       T_end      dt      dT_res       dT_pri
Static     1.0      0.050     0.050        0.050
Dynamic    1.2     0.00001     0.002        0.002
Dynamic    2.0      0.002     0.005        0.005

'
'         node_Id  Mass
'Nodemass    259     0 0 7000
 Nodemass    659     0 0 7000


'         Type  Time    Vx   Vy   Vz   rVx  rVy  rVz  Id_1  Id_2
'Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  259
 Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  659
'

TIMEHIST  2 Points
'        Time   factr
          0       0
          1       1
          2       1

'            Load_case     Time_hist
'
 Loadhist         3            2
 Loadhist        10            2

Dynres_G Wint
Dynres_G Wext
```

Dynres_G Wplast
Dynres_G Wtot
Dynres_G Wkin

RAYLDAMP 0.0094 0.0095

B.2 Model file

The USFOS model file is saved in the CD

Appendix C- input files in USFOS – Structure without plates

C-1-Control file

```
HEAD              DOP
             USFOS
            Master

'      mcods
CNODES      1
'      nodex   idof    dfact
         297     3       1  #1
'


'      T_end      dt      dT_res       dT_pri
Static     1.0      0.050     0.050        0.050
Dynamic    1.2      0.000001   0.0001        0.0001
Dynamic    2.0      0.01      0.010        0.010
'
'
'


'
TIMEHIST  2 Points
'       Time   factr
         0       0
         1       1
         2       1

'         node_Id  Mass
 Nodemass    297     0 0 2000

'         Type  Time  Vx  Vy  Vz    rVx  rVy  rVz     Id_1  Id_2'
 Ini_velo   Node   1.001  0.0 0.0 -7.672 0.0  0.0  0.0  297

'           Load_case     Time_hist

'
 Loadhist         3            2
 Loadhist        10            2

Dynres_G Wint
Dynres_G Wext
Dynres_G Wplast
Dynres_G Wtot
```

Dynres_G Wkin

RAYLDAMP   0.0094   0.0095

C.2 Model file

The USFOS model file is saved in the CD