DROP ANALYSIS FOR TRANSPORT CASK OF SPENT FUEL RODS FOR TIANWAN NUCLEAR POWER PLANT

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ABSTRACT

The transport cask for spent fuel rods in Tianwan NPP has been designed for the drop from 9 m height to hard ground. In the following the numerical analysis is carried out for the perpendicular drop of the cask from the height of 26 m on the soil cushion consisting of 10 cm of asphalt, 40 cm of gravel and 4.5 m of soft sand. The results of drop to soil cushion are then compared with results of cask drop from 9 m's height on hard concrete. The cask is steel cylinder with base diameter of 2060 mm and height of 5500 mm and wall thickness of 350 mm. The total weight of the cask is 120 tons. The actual dropping angle of the cask in experiment is about 30 degrees from the vertical.

The straight cask drop on soft soil cushion from the height of 26 m was modeled by finite element method. The model was developed using the twenty node solid elements. The model consisted of the cask, gravel layer and sand layer. The diameter of the soil cushion in the model was 7.2 m and the thickness of gravel layer was 0.4 meters and the thickness of sand layer was 5 meters. The material properties in the nonlinear drop analysis were taken as follows: 1) Steel: von Mises elasto-plastic material model; 2) Gravel: Mohr-Coulomb elasto-plastic material model; 3) Sand: Mohr-Coulomb elasto-plastic material model. The drop height of the cask was 26 meters corresponding to 22.6 m/s initial velocity of the cask. This velocity was given as the initial condition for all steel elements representing the cask. The lowest natural frequency and the corresponding natural period for the cask-soil system were estimated and the value 0.05 seconds was obtained for the natural period. The time step used in the large displacement nonlinear transient response analysis was 0.001 seconds and the length of the analyzed time window was 0.1 seconds representing 100 time steps and approximately two and three quarters of the period of the vibrating system.

The drop height of the cask on hard ground was 9 meters corresponding to 13.3 m/s initial velocity of the cask. The cask is validated by comparing displacement and von Mises stress time histories for drops from 26 m drop on soft soil cushion and from 9 m drop on hard ground. The displacement in hard ground case are only a fraction of displacements in soft soil case and the peak von Mises stress is about 1.5 times as large as that in soft soil drop case. So it can be concluded that the 9 m's validation drop on hard soil ensures the integrity of the cask for 26 m drop on soft soil cushion.

INTRODUCTION

The cask has been designed for the drop from 9 m height to hard ground. In the following the preliminary numerical analysis is carried out for the perpendicular drop of the cask from the height of 26 m on the soil cushion consisting of 10 cm of asphalt, 40 cm of gravel and 4.5 m of soft sand.The results of drop to soil cushion are the compared with results of cask drop from 9m height on hard concrete.

THE GEOMETRY OF THE CASK

The cask is steel cylinder with base diameter of 2060 mm and height of 5500 mm and wall thickness of 350 mm. The total weight of the cask is 120 tons. The actual dropping angle of the cask is about 30 degrees from the vertical. The scheme for the cask drop to soft soil cushion has been depicted in the following Figure 1:

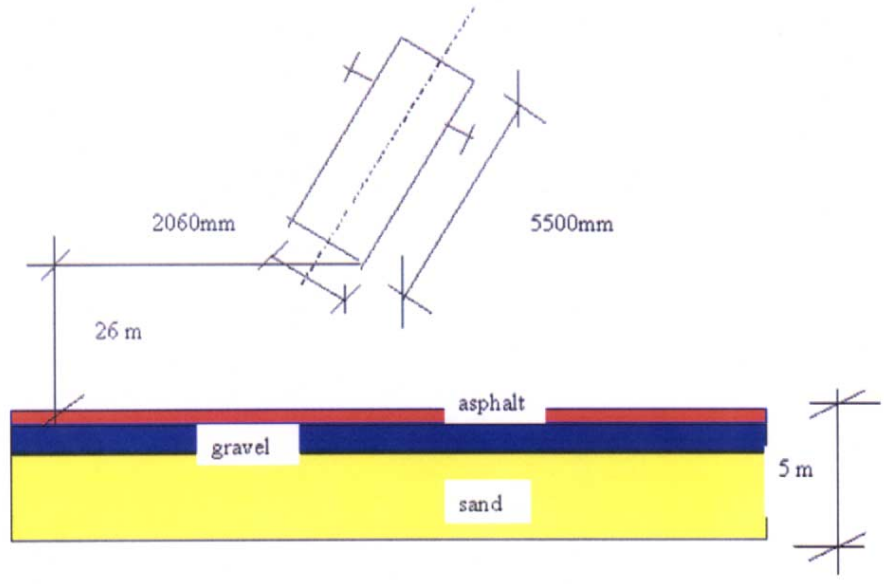

Figure 1 Drop of the transport cask on soft soil cushion

FINITE ELEMENT ANALYSIS OF THE DROP

The straight cask drop on soft soil cushion from the height of 26 m was modeled by finite element method. The model was developed using the twenty node solid elements available in MSC/NASTRAN [1]. The model consisted of the cask, gravel layer and sand layer. The dimensions of the cask are already given in Figure 1. The diameter of the soil cushion in the model was 7.2 m and the thickness of gravel layer was 0.4 meters and the thickness of sand layer was 5 meters. The boundary conditions, and model geometry and element mesh are shown in the following two figures

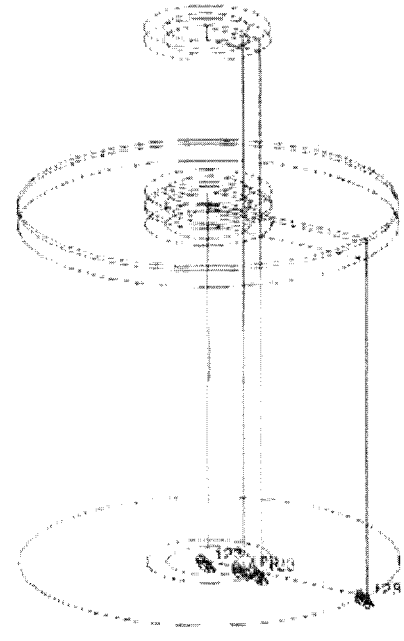

Figure 2 Geometry and boundary conditions of the finite element model

Figure 3 Element mesh of the calculation model

COMPLETED ANALYSES

Linear Analysis of Drop on Soft Soil Cushion

In order to gain insight to the problem linear transient analysis was carried out first. The material properties in the linear analysis were taken as follows:

- Steel
  - E = 200 000 MN/m^2
  - ν = 0.3
- Gravel
  - E=10 000 MN/m^2
  - ν = 0.3
- Sand
  - E =2500 MN/m^2
  - ν = 0.3

The drop height of the cask was 26 meters corresponding to 22.6 m/s initial velocity of the cask. This velocity was given as the initial condition for all steel elements representing the cask. The lowest natural frequency and the corresponding natural period for the cask-soil system was estimated and the the value 0.05 seconds was obtained for the natural period. The time step used in the transient response analysis was 0.005 seconds and the length of the analyzed time window was 0.05 seconds representing one whole period of the vibrating system. The following two figures depict the vertical displacement time history for node 258 located in the lower edge of the cask and the von Mises stress time history for element 27 also in the lower edge of cask:

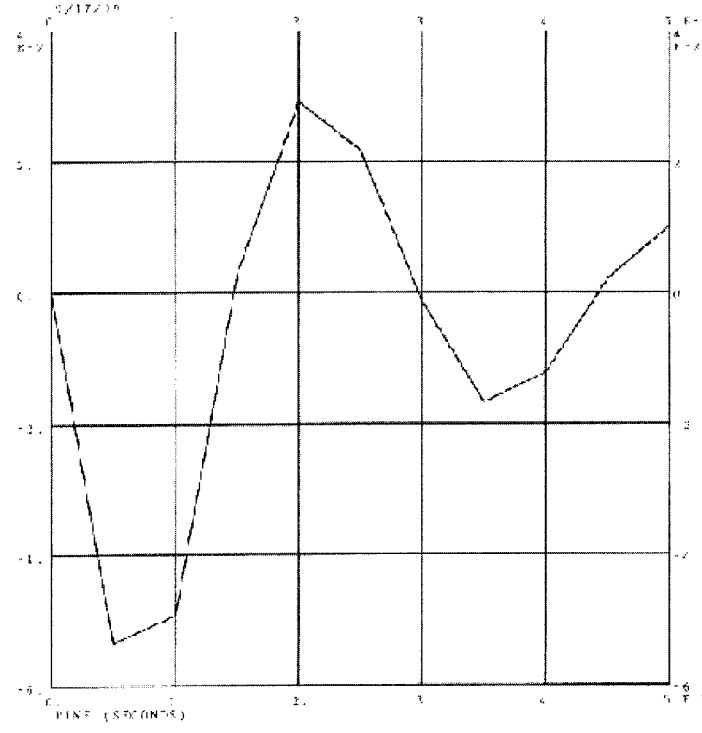

Figure 4 The vertical displacement history of node 258 of drop on soft soil cushion

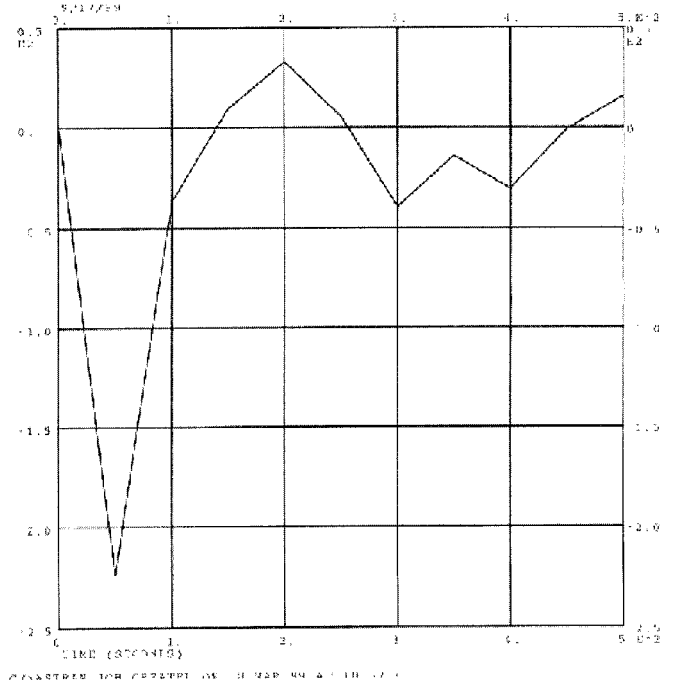

Figure 5 Von Mises stress history of element 27of drop on soft soil cushion

As can be seen from Figures 4 and 5 the maximum displacement in the lower edge of the cask is about 6 centimeters and the maximum stress in the center of element 27 is very small. These results are base on the linear analysis and in case of von Mises stresses the location of the monitoring point is in center of the element and do not represent the maximum that is in the edge of the element.

Nonlinear Analysis of Drop on Soft Soil Cushion

The material properties in the nonlinear analysis were taken as follows:

- Steel: von Mises elastoplastic material model
  - E = 200 000 MN/m^2
  - ν = 0.3
  - Strain hardening slope 0.001
  - Yield stress σ_Y = 220 MN/m^2
  - Damping ratio 2% from critical
- Gravel: Mohr-Coulomb elastoplastic material model
  - E=10 000 MN/m^2
  - ν = 0.3
  - Strain hardening slope 0.001
  - Yield stress 10 MN/m^2
  - Friction angle 38 degrees
  - Damping ratio 10% from critical
- Sand: Mohr-Coulomb elastoplastic material model
  - E =2500 MN/m^2
  - ν = 0.3
  - Strain hardening slope 0.001
  - Yield stress 2.5 MN/m^2
  - Friction angle 30 degrees

The drop height of the cask was 26 meters corresponding to 22.6 m/s initial velocity of the cask. This velocity was given as the initial condition for all steel elements representing the cask. The lowest natural frequency and the corresponding natural period for the cask-soil system were estimated and the the value 0.05 seconds was obtained for the natural period. The time step used in the large displacement nonlinear transient response analysis was 0.001 seconds and the length of the analyzed time window was 0.1 seconds representing 100 time steps and approximately two and three quarters of the period of the vibrating system. The following two figures depict the vertical displacement time history for node 258 located in the lower edge of the cask and the von Mises stress time history for element 27 also in the lower edge of cask:

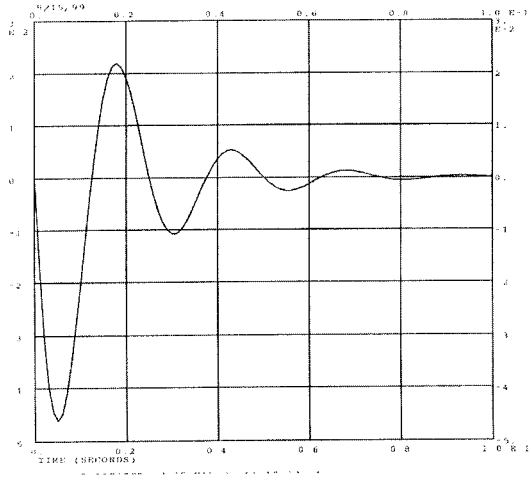

Figure 6 Displacement time history of node 258 calculated from nonlinear transient response analysis of drop on soft soil cushion

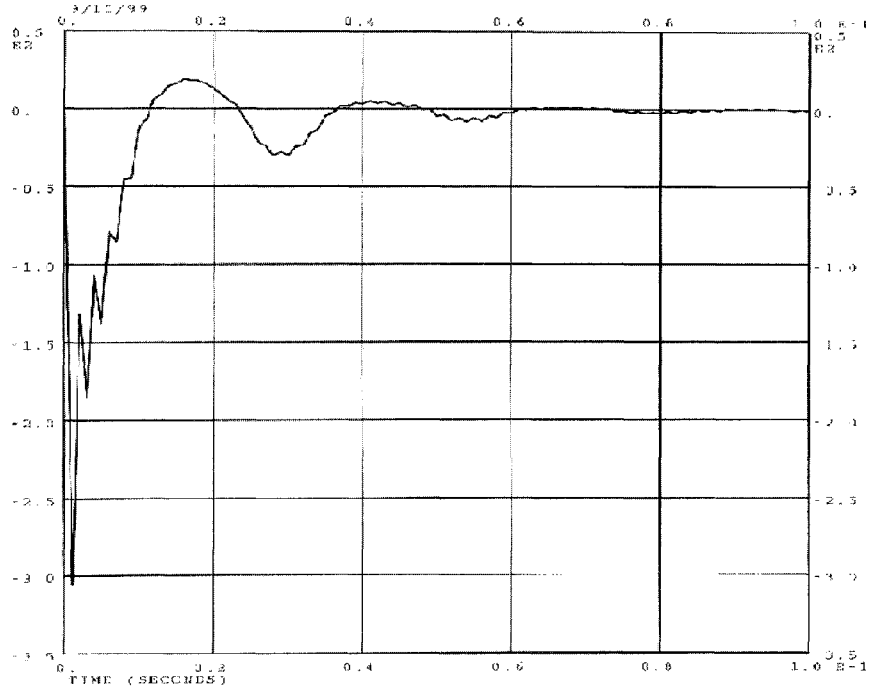

Figure 7 Von Mises stress time history of the edge node point of element 7 at lower edge of the cask calculated by the nonlinear transient response method of drop on soft soil cushion

Nonlinear Analysis of Drop on Hard Ground

The material properties in the nonlinear analysis of cask drop on hard groundwere taken as follows:

- Steel: von Mises elastoplastic material model
  - E = 200 000 MN/m^2
  - ν = 0.3
  - Strain hardening slope 0.001
  - Yield stress σ_Y = 220 MN/m^2
  - Damping ratio 2% from critical
- Concrete: Mohr-Coulomb elastoplastic material model
  - E=30 000 MN/m^2
  - ν = 0.3
  - Strain hardening slope 0.001
  - Yield stress 30 MN/m^2
  - Friction angle 38 degrees
  - Damping ratio 5 % from critical

The drop height of the cask was 9 meters corresponding to 13.3 m/s initial velocity of the cask. This velocity was given as the initial condition for all steel elements representing the cask. The lowest natural frequency and the corresponding natural period for the cask-soil system were estimated and the the value 0.01 seconds was obtained for the natural period. The time step used in the large displacement nonlinear transient response analysis was 0.001 seconds and the length of the analyzed time window was 0.1 seconds representing 100 time steps and approximately two and three quarters of the period of the vibrating system. The following two figures depict the vertical displacement time history for node 258 located in the lower edge of the cask and the von Mises stress time history for element 27 also in the lower edge of cask:

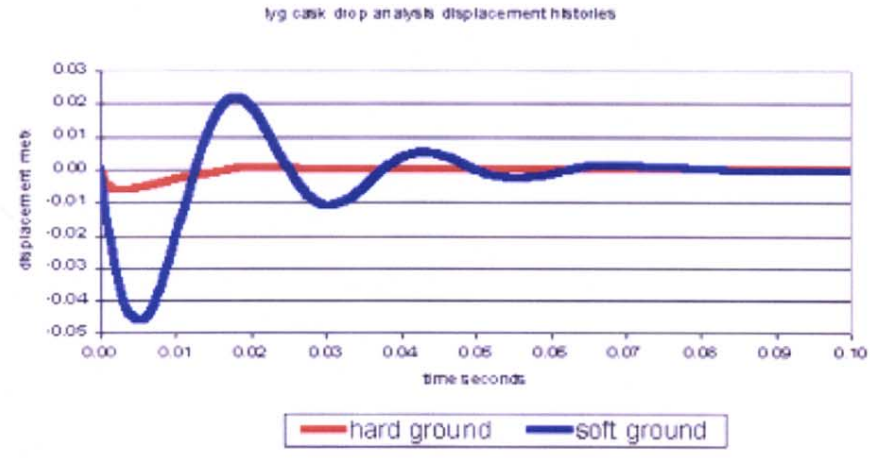

Figure 8 Comparison of vertical displacement histories of node 258 in soft and hard ground drops

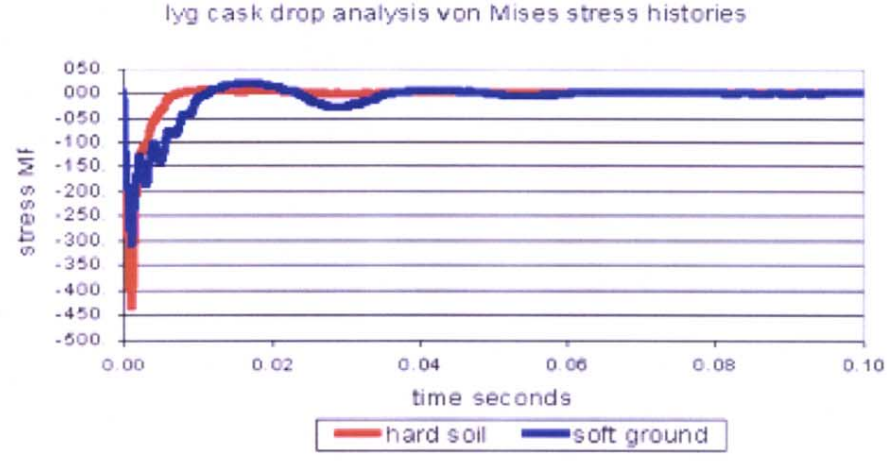

Figure 9 Von Mises stress time histories of the edge node point of element 7 at lower edge of the cask drop on soft and hard grounds calculated by the nonlinear transient response method

CONCLUSION

Based on the analyses performed above and on the results depicted in Figures 4, 5, 6 and 7 the following concluding remarks can be made. Displacements obtained for vertical drop on soft soil cushion were the same order of magnitude for both linear and nonlinear analysis. It can be expected that for skew drop on soft soil for instance in 30 degrees axis angle with the vertical produces displacements that are twice as large as for straight drop and could be about 10 cm. As for the equivalent von Mises stress it can be seen for from the Figure 7 that the stress at the edge point for vertical drop on soft soil exceeds the yield stress for extremely short time less than one millisecond. In case of skew drop on soft soil it could be expected that the yielding will last longer, say, the length of the compression phase of the first period or about 10 milliseconds. Even in this case the yield will be localised to the impacting edge zone and could be expected to occur within a radius of few centimeters from the impacting tangent point. The highly local nature of the yield will ensure that tightness of the cask is preserved for the case under consideration

The above discussion is confirmed by the comparison on displacement and von Mises stress time histories for drops from 26 m on soft soil cushion and from 9 m on hard ground. The displacement in hard ground case in Figure 8 are only a fraction of displacements in soft soil case and the peak von Mises stress is about 1.5 times as large as in soft soil case. So it can be concluded that the 9 m validation drop on hard soil ensures also the integrity of the for 26 m drop on soft soil cushion.

REFERENCES

[1] MSC/NASTRAN User's manual, McNeal-Schwendler Corp., Los Angeles,1998.