Computational Modelling to Predict Waste Package Performance

N.K. Prinja, A. Buckley
AMEC NNC
Booths Park, Knutsford, Cheshire, WA16 8QZ
United Kingdom

ABSTRACT

An important aspect of a safety case for any packaging is its performance under accident conditions. This paper addresses the challenge faced by designers and manufacturers to predict behaviour of waste packages under various transport and emplacement conditions. Previously, performance of waste packages has usually been demonstrated by test. Carrying out a full-scale drop test of a prototype package with the representative simulant wasteform is time consuming, costly, and can lead to variability in the results. Furthermore, these tests are unique for a particular design and cannot be easily applied to other designs. Therefore, predictive modelling based on computational techniques like the finite element analysis (FEA) can be of great benefit.

This paper presents an example of how computational modeling can be used to assess free drop and transportation loads. The example presents FEA of a packaging designed to transport a 50 Te steel pot containing radioactive silicate slag to the UK's Low Level Waste Repository site (LLWR) at Drigg in Cumbria in accordance with the relevant UK legislation. The results from FEA are processed to obtain stress and strain levels to show that there is no likelihood of rupture/leakage. Strain energy distribution in the package is assessed to demonstrate that the impact is absorbed by the packaging.

INTRODUCTION

One of the key principles underlying regulations for performance of a waste package under normal and accident conditions is that activity release should be low and predictable. Structural behaviour of the waste package under given loading conditions need to be predicted in order to estimate any activity release. Advanced computational techniques like the FEA can be used to predict structural response under variety of loading conditions. The scope of this paper is limited to assessment of free drop and transportation loads. Such an assessment involves dynamic analysis involving simulation of the waste package impacting other targets and/or experiencing suddenly applied accelerations.

In the UK, the Transport Container Standardisation Committee (TCSC) is currently considering producing a code of practice on 'FEA of Radioactive Material Transport Packages' [1]. Some of these documents are referenced by the TS-G-1.1 produced by the IAEA [2]. The regulations specify the height of free drop depending on the classification of the packaging. The example presented here is of a packaging designed to transport a 65 Te steel pot containing radioactive silicate slag to the UK's Low Level Waste Repository site (LLWR) at Drigg in Cumbria in accordance with the relevant UK legislation. The material has been classed as Industrial Package 2 (IP2) and is non-fissile. The testing requirements for an IP2 package are a free drop from 0.3m.

The tests need not be a physical test (on a specimen) but could be calculation performed using Finite Element Analysis (FEA). The aim is to demonstrate that following a 0.3m drop there is no loss or dispersal of the radioactive contents and that the shielding integrity limits any increase in radioactivity at any external surface to a maximum of 20%.

METHODOLOGY

Methodology is based on using the FEA results to demonstrate impact withstand capacity. At the start of the analysis, all the features to be modelled are identified. Particular attention is paid to the modelling of the package and the wasteform. The regulations specify the height of free drop but do not specify the orientation. Dynamic analysis is conducted to identify the worst drop orientation. The results from FEA are processed to obtain stress and strain levels to show that there is no likelihood of rupture/leakage. Strain energy distribution in the package is assessed to demonstrate that the impact is absorbed by the packaging. The scope of the work is to generate a computational model of the transport package, and then analyse and assess the performance under the impact conditions for the required drop test. The work covered the following aspects:

- Identification of all the features to be modelled
- Modelling of the package
- Modelling of the wasteform
- Analysis to identify the worst drop orientation
- Obtain strain energy from FEA results
- Structural assessment of the frame and the liner to predict any rupture/leakage
- Assess the results from FE analysis to demonstrate that the impact is absorbed by the packaging.
- Apply engineering judgement and previous knowledge to predict the radioactivity released to the environment

Homogenous wasteform in the slag pot is assumed. Note that a full scale test validation of the waste packaging is out of scope of this study but the FE model produced in this study can be used to analyse a full scale test with a dummy slag pot if required.

All FEA work has been carried out using the general purpose FE code ABAQUS [3]..

EXAMPLE PROBLEM

BACKGROUND

At a facility in the UK which operates a melting shop for the production of stainless steels and downstream processing operations including cold rolling, finishing and distribution, part of the process for the manufacture of stainless steel products involves melting stainless steel scrap. The main by-product of this process is a silicate based slag and there have been incidents when this has been contaminated by an extraneous source of radioactivity present in the scrap brought to the plant. The contaminated slag is contained in four 'slag pots' that were stored on the site and required transporting to the UK's Low Level Waste Repository site (LLWR) at Drigg in Cumbria in accordance with the relevant UK legislation. Each pot is over 3m high, 4m in diameter and weighed up to 65 Te.

The material was classed as a Industrial Package 2 (IP2) and non-fissile. A transport package was designed for the pots. It comprised of a 4.8m x 4.8m x 3.8m main steel frame with lifting lugs, a steel plate liner, support ring and concrete base to support the slag pot and hold it in place. The gap was to be filled with a lightweight concrete based grout. The total transportation package weighed close to 120 Te. However, the testing requirements for an IP2 package required the package to withstand a free drop from 0.3m and it was not practical or easy to perform detailed physical testing of prototype. Therefore, FEA was used to used to demonstrate that following a 0.3m drop there was no loss or dispersal of the radioactive contents and that the transport package remained intact.

ANALYSIS

Finite Element Model

A 3D finite element model of the transport frame and slagpot was generated based on the proposed design and used analyse and assess the performance of the frame when dropped from 0.3m as required by the regulations. The finite element model generated is shown in Fig. 1.

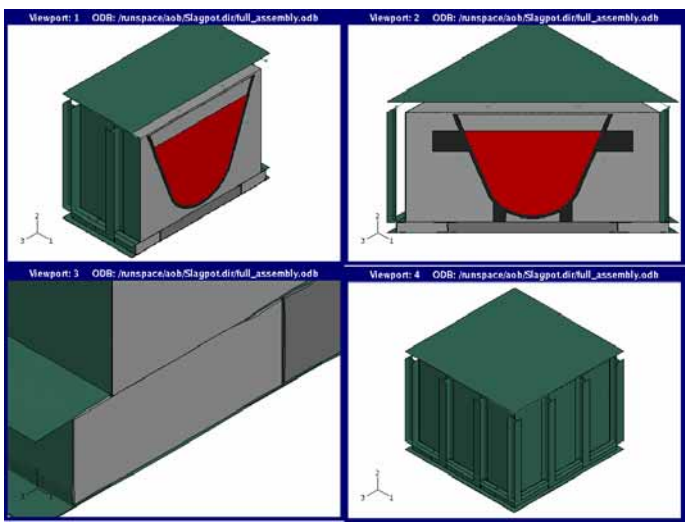

Fig. 1. FE Model of the Transport Package

The model was generated in four modules:

- The Steel Frame Work and Liner Plates (Green)
- The Concrete Base Support (Dark Grey)
- Slagpot and Slag (Black/Red)
- Lightweight Concrete in-fill (Light Grey)

Each of these modules were then combined to produce the full FE model shown in Fig. 1. This allowed flexibility in both the modelling techniques and the final package design, for example, analysis could easily be performed with and without the lightweight concrete grout. In developing each module, the geometry, connections and properties of the components were represented in the FE model.

For the main steel frame work, consistent with the design intent, full moment connection have been assumed at all bolted and welded joints. Noting that the bolts and welds were not explicitly modelled. Shell elements were used for majority of FE model; this allowed the deformation of the flanges and webs local to the impact to be accurately captured. Away from impact area beam elements have been used for the support ring and top framework. Note that Lifting eyes and transport anchor points were modelled but implicitly represented by boundary conditions at nodes, when appropriate.

The concrete base was modeled using solid elements and non-linear material properties to capture the crushing strength of the concrete. The interface between the steel frame and the concrete base was included using contact surfaces and assuming no bonding between the steel and concrete. The lightweight concrete based grout in-fill was modeled in a similar manner. Again, the interfaces between the various materials were captured using contact surfaces and no bonding was assumed.

Although each of the slag pot differed slightly in terms of dimensions and mass, conservatively, the largest and heaviest pot was chosen for the analysis and modeled. The FE model was constructed in solid elements and both the slag and slagpot were given representative material properties so that the total mass and stiffness of the slag and pot was reasonable.

The full assembled model also included a rigid impact surface onto which the transport frame assembly was dropped.

For each module and the full assembly, basic validation and verification of FE model was carried out. The dimensions were been spot checked and the mass of each module confirmed. The total mass of the fully assembled FE model was in excess of 110 Te.

Analysis Performed

A total of three impact cases were performed. These were:

- Flat Base Drop from 0.3m
- Edge Drop from 0.3m (likely to generate the maximum 'slap' force and rebound)
- Corner Drop from 0.3m (likely to cause the maximum 'knock back' deformation)

To verify the model was working correctly, a further initial analysis was carried out. This was a flat drop on to the base from 0.3m with linear elastic properties (no energy absorption). This analysis was part of the validation and verification of the combined model and establishes that the model was performing as expected. It was also used to help establish the likely areas of plastic deformation in the steel and any potential areas of concern. An initial velocity of 2.4m/s was applied to all nodes to represent the velocity at impact. Fig. 2 presents the von Mises stress distribution in the steelwork and pot at the point of impact during this analysis.

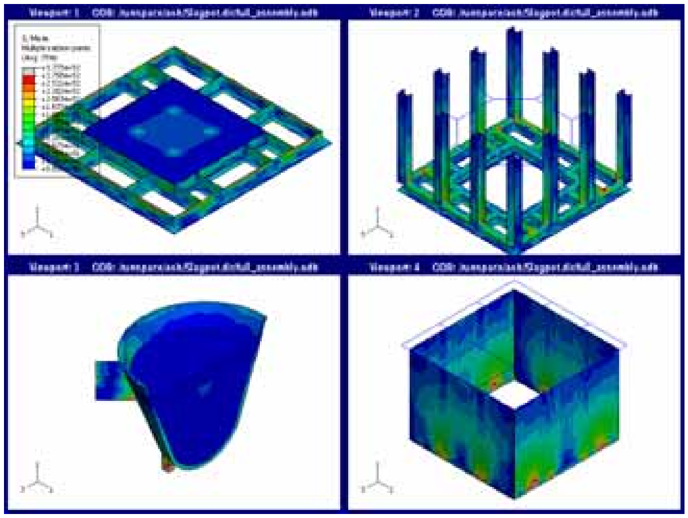

Fig. 2. Von Mises stresses in the Transport Package at the point of impact

The subsequent analyses have been carried out with elasto-plastic material properties for the steel and concrete. This allowed the energy absorbed during the impact by the deformation (strain) of the steel and concrete to be monitored and the levels of strain and stress in the package and the slag pot to be measured.

Results

For each of the dropped/impact loads cases considered, a detailed review of the demand imposed on the various components of the transportation assembly was carried out. The kinetic energy (KE) for the model has been monitored and compared against the strain energy in the system during and after impact, as shown in Fig. 3.

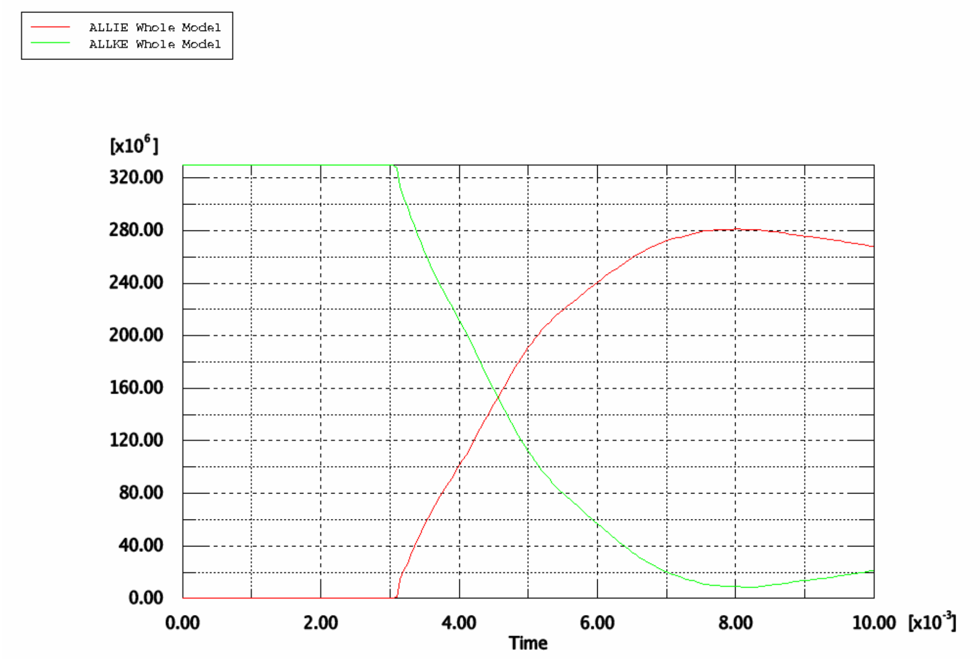

Fig. 3. Kinetic energy/ strain energy for flat base impact from 0.3m

The strain energy in the various components was then plotted (Fig. 4) to demonstrate the majority of the energy in the impact was absorbed by the concrete base and the lightweight concrete grout in-fill crushing (approximately 70%), as per the design intent.

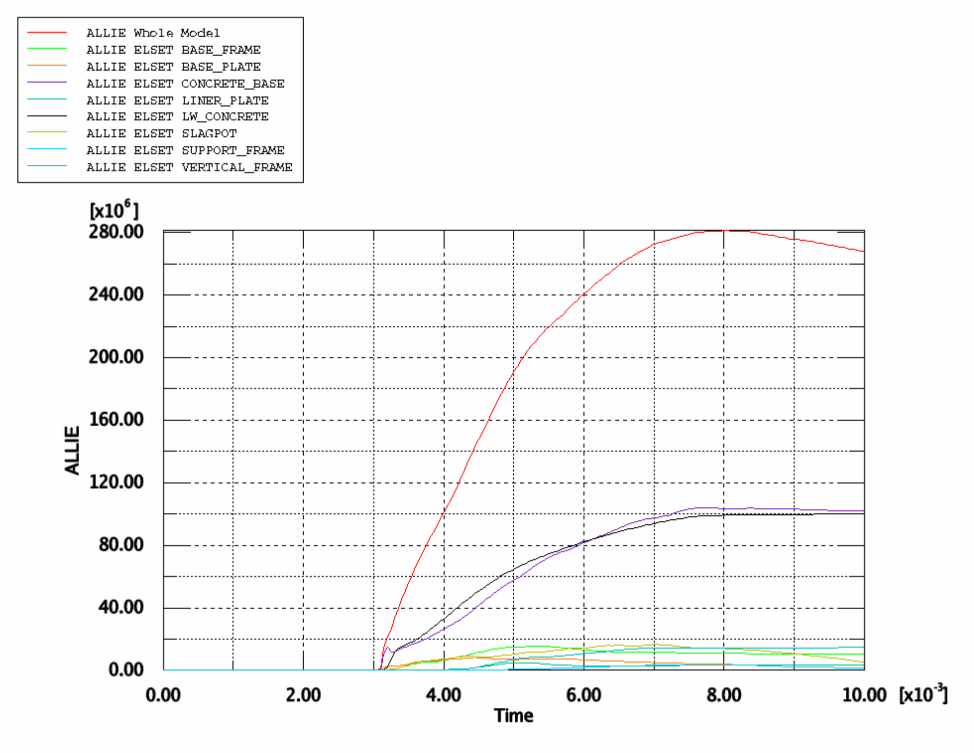

Fig. 4. Strain energy breakdown for flat base impact from 0.3m

At the point of the minimum KE/maximum strain energy the demand on imposed on the structure has been reviewed. The review of the analysis results indicated that, during the flat drop load case, the structural integrity of the frame and the pot is not threatened. Some crushing of the concrete support base and the infill grout will occur but the demand in steelwork and pot is not sufficient to cause rupture.

The FE model was also adapted and used to justify the package during transportation and lifting, static analysis was used and the pot and concrete was not explicitly included in the FE model. The mass of the pot and concrete was smeared across the steelwork. For the vertical and lifting load cases the additional mass was added to the base frame and plate, which provides the support. For the other load cases, the additional mass was distributed across the liner plate and vertical columns.

The following load cases were analysed using this simplified model:

- Case 1: Lifting Loads (1.25g) – Supported by Lifting Lugs
- Case 2: Transportation – 2g Longitudinal

- Case 3: Transportation – 1g Lateral
- Case 4: Transportation – 2g Vertical (Up)
- Case 5: Transportation – 3g Vertical (Down)

In load case 1, to ensure redundancy, only two out of the four lifting lugs were assumed to support the frame. For the lateral and longitudinal load cases (2 and 3) self-weight has also been included. In each case, the reaction forces at the support points were extracted for comparison against the capacity of the bolts.

CONCLUSION

An example has been presented to demonstrate how static and dynamic FEA can be conducted to assess performance of a waste package under free drop and transportation loading conditions. The regulations specify the height of the free drop but do not specify the orientation. FEA has been used to identify the worst case and strain energy distribution obtained from FEA is used to judge the effectiveness of the packaging.

REFERENCES

1. N.K.Prinja and I Davidson, "A Review of FEA Technology Issues Confronting the Power Industry", FENet Meeting Proceedings, Malta, May 17-20 2005, NAFEMS, (2005)

2. Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Waste, TS-G-1.1, Int. Atomic Energy Agency, Vienna.

3. ABAQUS/Standard version 6.6, ABAQUS Inc., USA.