DESIGN, MANUFACTURE AND TESTING OF THE NIREX 3 CUBIC METER BOX

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ABSTRACT

UK Nirex Ltd is developing a range of standard containers for packaging intermediate level radioactive waste, which is to be disposed of in a deep underground repository. This paper describes the specification, design and prototype testing of one of the company's standard waste containers, the 3 m^3 box. Prototype testing confirmed that the design satisfies the mechanical performance requirements in the Nirex specification. A drop test from 40 m was accurately modeled by the OASYS-DYNA3D finite element code, which includes the facility to model the weakening of cementitious grout under large induced strains.

INTRODUCTION

UK Nirex Limited (Nirex) has the responsibility for developing a deep underground repository for the disposal of solid intermediate and low level radioactive waste arising in the United Kingdom. Most forms of intermediate level waste (ILW) will be immobilized and packaged into unshielded waste containers, and transported to the repository in re-usable shielded transport containers.

The standard waste containers adopted by Nirex are the 500 liter drum, the 3 m^3 box and the 3 m^3 drum, and Nirex is producing specifications to ensure that containers give satisfactory performance. The specifications consider all aspects of container use including filling, handling, interim storage at the waste producer's site, transport to the repository and final emplacement in the repository caverns. Performance is specified under both normal and accident conditions of transport; the specification also addresses both the operational and post-closure phases of the repository.

This paper describes the design, manufacture and testing of one of the Nirex standard waste containers, the 3 m^3 box.

DESIGN CONCEPT

The 3 m^3 box (Fig. 1) will be used to package items of ILW which are too large for the more commonly-used 500 liter drum, for example contaminated steel plates from decommissioned reactors.

The 3 m^3 box consists of a body with a separate lid. Rounded corners allow the box to be transported in a standard re-usable shielded container which was designed primarily to carry four 500 litre drums in a transport frame. Wastes will be placed in the box and immobilized with a cementitious grout, after which the lid will be welded to the top of the body walls.

Four vertical stacking posts allow the box to be lifted and stacked, and also stiffen the walls against hydrostatic pressure while the box is being filled with fluid grout. The box is lifted by ISO-pattern twistlocks which engage in aperture plates welded to the tops of the stacking posts. When boxes are stacked, feet attached to the underside of the stacking posts engage in the twistlock apertures of the box below.

The following two sections describe the performance specification to which the box was designed, and give more details of the design features.

PERFORMANCE SPECIFICATION

Weight

The maximum weight of the filled box is 10 tonnes.

Dimensions

The maximum dimensions are 1720 mm x 1720 mm x 1225 mm high. The corners are rounded to a plan radius of 430 mm. The box must be capable of being filled without distortion beyond the maximum overall dimensions.

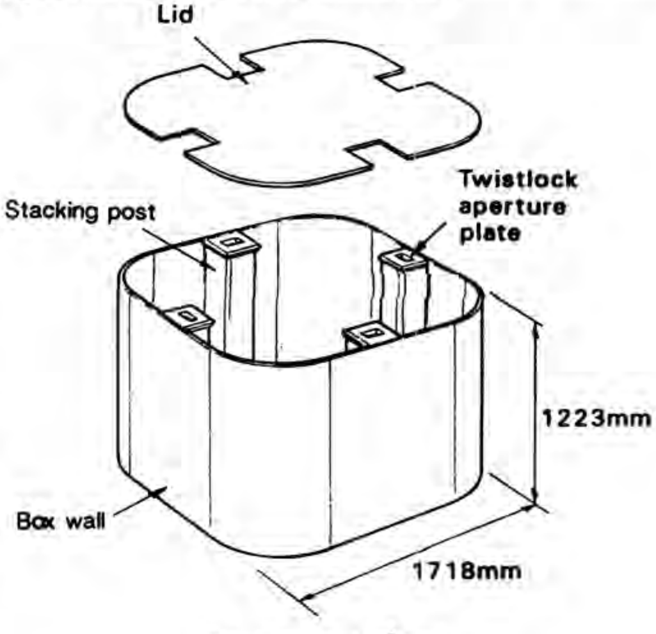

Fig. 1. Nirex 3 m^3 box.

Design Life

The box must provide effective containment for up to 50 years of storage at the site of the waste producer, followed by a minimum of 50 years in a backfilled disposal cavern.

Lifting

If one of the twistlocks fails when lifting a loaded box, it must be possible to continue to lift the box safely.

Stacking

It must be possible to stack six loaded boxes on top of one another without causing permanent structural deformation. Such a stacking arrangement may be adopted in the repository caverns.

Impact Performance

The loaded box must be capable of withstanding a free drop of up to 25 m on to a rigid target in the worst-case impact attitude; the specification includes a range of drop heights with limits upon the permitted releases of particulate radioactive materials after impact. The maximum of 25 m is determined by the planned height of the repository caverns.

DESIGN DETAILS

Carbon steel, stainless steel and concrete were considered as candidate materials for the 3 m^3 box. Although the alkalinity of concrete offers good resistance against chemical attack, the wall thickness required to provide adequate structural performance would unacceptably reduce the payload volume. Consequently concrete was rejected, leaving carbon steel and stainless steel to be evaluated against the following criteria.

Corrosion

Carbon steel would require additional corrosion protection, which could be provided either by applying a protective coating or by adding a corrosion allowance to the plate thickness so that the structure would still be mechanically adequate at the end of its design life of 100 years. Since coatings have limited life, they were rejected in favor of increasing the plate thickness. Stainless steel would have sufficient inherent corrosion resistance that the plate thickness could be determined only by mechanical performance considerations.

Following a comparative cost study, carbon steel was selected as the material for further design development.

Filling

When the box is filled with fluid grout, hydrostatic forces will cause deformations which become permanent when the grout sets. The stacking posts contribute significantly to the stiffness of the box walls, and the maximum calculated wall deflection of 0.1 mm is well within the dimensional tolerances.

Lifting

The lifting force is transmitted by the bearing contact stress between the twistlock and the underside of the twistlock aperture plate, and thence in bending and shear to the top of the stacking post.

Failure of a twistlock during lifting would impose high bending stresses on the aperture plate, because almost the entire load would be transferred to two of the remaining twistlocks (the third providing only a balancing force). A further safety factor of 2 is applied to allow for dynamic loading effects, so that each aperture plate must be capable of supporting 10 tons. The necessary plate thickness is 39 mm, including 4 mm of corrosion allowance.

Stacking

The box is designed to transmit all the weight of its contents to the stacking posts. Feet on the lower ends of the stacking posts are arranged to transfer axial loads into the stacking posts of the box below (Fig. 2) without significantly stressing the twistlock aperture plates.

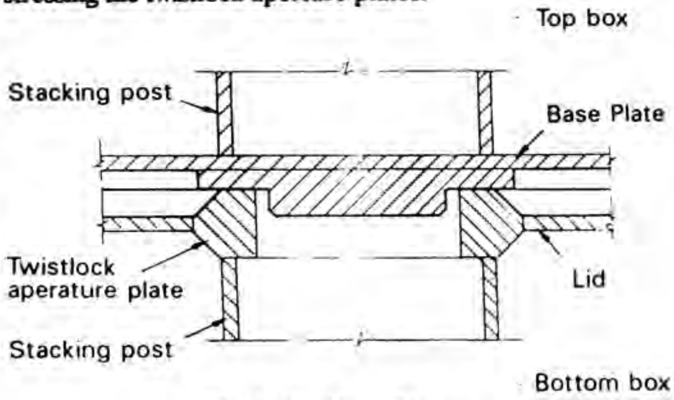

Fig. 2. Stacking of boxes.

Impact-related Features

During the design stage, the OASYS-DYNA3D finite element code (1) was used to predict the performance of the filled box in the specified impact tests. Both lid-corner and lid-edge impact attitudes were analyzed to establish the worst case (Figs. 3 and 4). The following changes were made as a result of the impact analyses.

It was found that the plate material from which the box is constructed must have high ductility in all three directions: parallel and transverse to the direction of rolling, and also through the thickness. A suitably-specified grade of commercial carbon steel plate was identified.

Weld details in the vicinity of the twistlock aperture plate were modified to be capable of accommodating large deformations.

Earlier impact analyses of 500 liter drums had shown that the energy absorption capability of cement grouts reduces as the package deformation increases (2). This is due to 'strain softening' of the grout, an effect which could not be modeled by OASYS-DYNA3D at that time. Since the deformations in the impact of a 3 m^3 box would be significantly greater than those in a 500 liter drum, it was decided to verify the design of the box by drop-testing, the results of which could also be used to improve the techniques of impact analysis.

PROTOTYPE MANUFACTURE

Two prototype boxes were manufactured, one for each drop attitude (Figs. 3, 4). The curves in the walls of the box and stacking post were cold-formed and all joints were MIG welded.

Since large strains were expected in the impact tests, it was important that the welds were of sufficient quality to transfer the strains into the parent material. A wide range of tests were carried out on the welded joints including bending tests, all-weld and transverse tensile tests, hardness tests, Charpy toughness tests and non-destructive tests. In all respects the properties of the welds and of the heat-affected zone were at least as good as those of the parent material.

MECHANICAL PERFORMANCE

In preliminary tests to simulate the filling, lifting and stacking operations, the performance of the boxes was well within the specified limits. The boxes were filled with 5 tonnes of steel scrap to simulate the waste, plus approximately 4 tonnes of grout to give a total laden weight of 10 tonnes.

Two drop tests were carried out, one in the lid-corner impact attitude (Fig. 3) and one in the lid-edge attitude (Fig. 4). The boxes were dropped on to an essentially unyielding target consisting of a large concrete block faced with a 150 mm thick steel plate. In order to provide more information on the strain softening effect in the grout, the original drop height of 25 m was increased to 40 m. Accelerometers were placed on the boxes to measure the acceleration-time history of the two impact events; by processing the acceleration measurements it was possible to deduce how the boxes would perform in the corresponding 25 m drop tests.

The boxes performed very well in both drop tests from 40 m. In the lid-corner impact attitude some minor weld failures occurred at the twistlock aperture but no material was released. In the lid-edge impact attitude, weld failure occurred at the twistlock aperture; but the quantity of material released (0.5 kg of capping grout) was more than an order of magnitude within the limit specified for a lesser drop of 25 m.

IMPACT SIMULATION

The lid-edge impact was the more severe of the two impact attitudes tested, and was therefore subjected to a post-test finite element analysis using the later Version 5.1 of OASYS-DYNA3D which could model the strain softening effect.

Finite Element Model

Taking advantage of symmetry, only half of the container was modeled (Fig. 5). Using the finite element scheme shown in Table I, the following material properties were assumed.

Cement Grout

The grout was assumed to have a peak compressive strength of 32 N mm^{-2} and a tensile strength of 3.2 N mm^{-2}.

Strain softening reduces the shear strength of a material as the strain increases; in practical terms the grout material crumbles. Typical triaxial compressive test results on concrete indicate that after failure at the peak axial load, the sustainable axial load falls to a much smaller fraction of the peak value, typically 10-20%. Parametric studies carried out on this variable showed that the best correlation was achieved with a value of 20%. The plastic strain at this residual shear strength was assumed to be 5.0 times that at the peak shear strain.

Steel plate and Welds

Tensile tests carried out prior to manufacture of the boxes showed that the selected steel plate could develop a transverse reduction in area of about 66% at failure, which is well in excess of the specified minimum of 35%. The plastic strain at failure was calculated as follows:

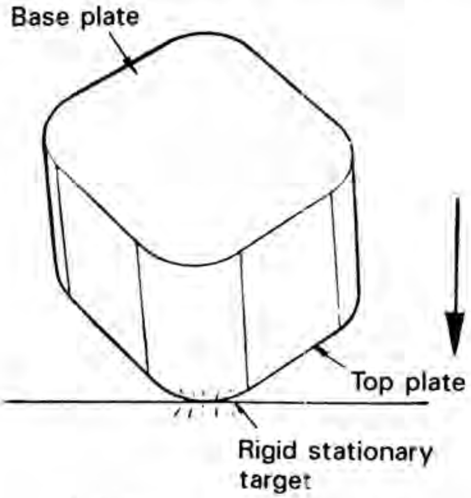

Fig. 3. Lid-corner impact attitude.

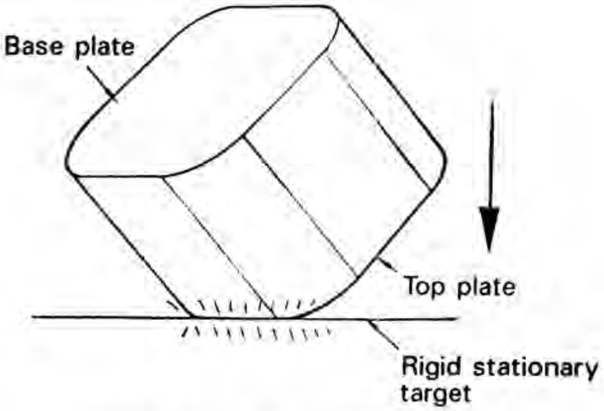

Fig. 4. Lid-edge impact attitude.

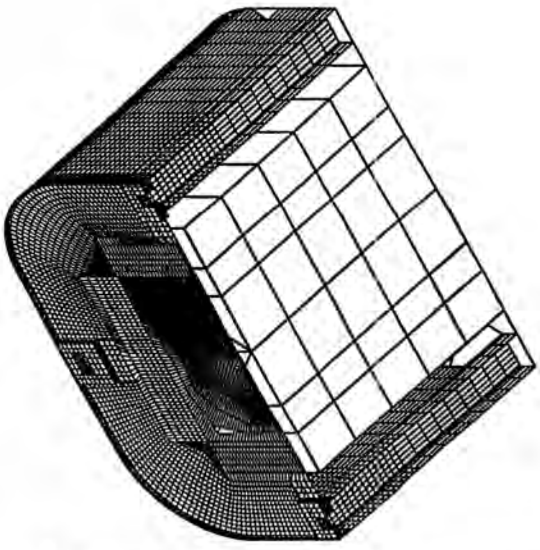

Fig. 5. Finite element mesh for lid-edge impact model.

TABLE I
Finite Element Model for Lid-Edge Impact Analysis

Component	Elements Used	Material Type
Cement grout	16184 8-node solids	'Soil and crushable foam' with strain softening
Box walls, stacking posts and lid	7904 4-node shells	'Isotropic elastic plastic' with failure
Welds	328 4-node shells	'Isotropic elastic plastic' with failure
Waste (steel scrap)	100 4-node solids	'Isotropic elastic'
Twistlock aperture plates	480 8-node solids	'Rigid'

Failure plastic strain = $\ln(A_0/A)$

where

A_0 = original area of tensile test specimen

and

A = reduced area of specimen at failure.

Assuming a reduction in area of 66%, the plastic strain at failure would be 1.08; a conservative value of 1.00 was assumed for modeling purposes. The yield stress was assumed to be 355 N mm^{-2} and the hardening modulus 1000 N mm^{-2}.

The same properties were assumed for the welds as for the steel plate.

RESULTS OF IMPACT SIMULATION

Figure 6 shows the predicted deformation of the box, which agreed well with that produced by the drop test. Weld performance was accurately predicted: all welds remained intact, except for the local failure of the joint between the twistlock aperture plate and the stacking post.

Figures 7, 8 and 9 compare the calculated and measured acceleration, velocity and knockback displacement as functions of time. The main reason for the good agreement is the correct prediction of the rate at which energy is absorbed,

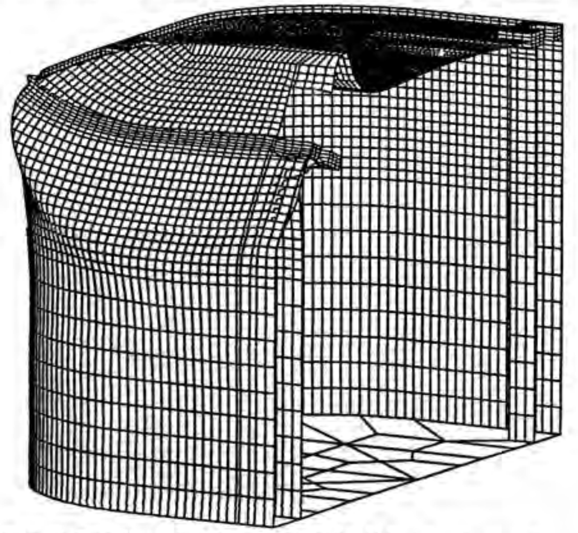

Fig. 6. Predicted deformation by lid-edge impact.

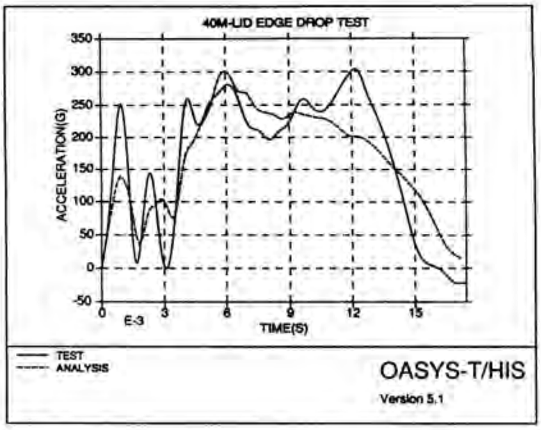

Fig. 7. Accelerations in lid-edge impact.

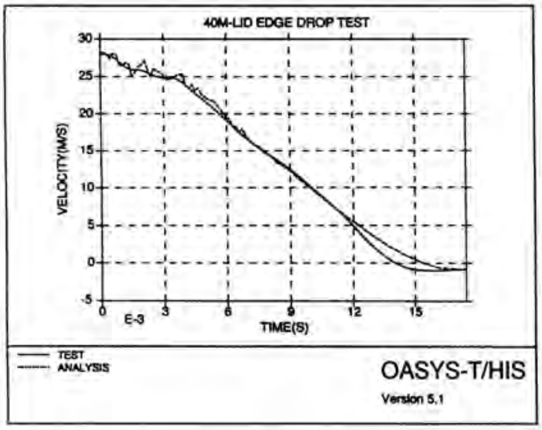

Fig. 8. Velocities in lid-edge impact.

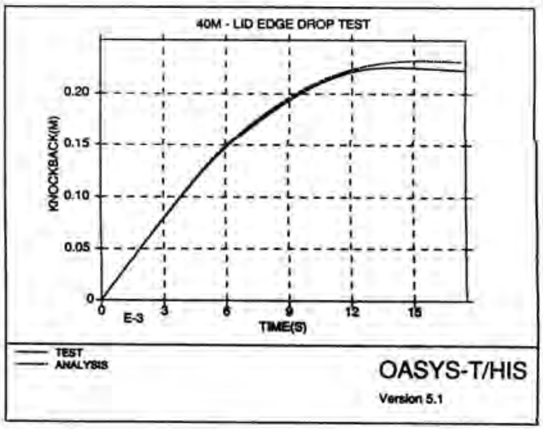

Fig. 9. Knockback distortion in lid-edge impact.

and this was only possible because the model incorporated the strain softening characteristic of the grout.

The design aim is that the energy of an impact upon the lid edge should be absorbed by deforming the corner joint between the lid and the body wall, as shown in Fig. 6. This was achieved successfully over most of the impact edge without breaching the joint. However, the stacking post prevented the twistlock aperture plate from rotating with the rest of the lid; hence the local breach at the joint between the two. Impact energy was also absorbed in generating large strains in the joint between the twistlock aperture plate and the top of the stacking post, although these strains were accommodated by the ductility of the aperture plate.

CONCLUSIONS

Prototype 3 m^3 boxes have been manufactured and tested to confirm that the design satisfies the mechanical performance requirements in the Nirex specification. It was also demonstrated that the selected carbon steel has sufficient ductility and that adequate quality can be achieved in the fabrication welding.

The 40 meter impact test on to the lid edge was accurately modeled, thanks to the strain softening algorithm available in OASYS-DYNA3D Version 5.1. The model accurately predicted the localized weld failures that were observed.

REFERENCES

1. OASYS-DYNA3D Version 5.1 Users Manual, September 1992. (OASYS Ltd, 13 Fitzroy Street, London W1P 6BQ, United Kingdom)
2. P DONELAN, C MILLOY, J C MILES AND B MARLOW, "Mechanical Properties of Immobilized Intermediate Level Waste", PATRAM '86.