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Tie-Down Assessment of Radioactive Material Packages on Conveyances Approach to Competent Authority Approval Applications in accordance with TS-R 1 (June 2000) and TS-G-1.1 (June 2002)

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1. Introduction

This paper summarizes the authors' findings, during carrying out many package tie-down assessments, regarding the approach to the assessment process, and the issues that may arise. The current regulatory framework, as outlined in the abstract, is considered and possible areas for further development or research are discussed.

The safe transport of a package containing radioactive material requires a secure system of retention on the conveyance during transport. The requirements for the assessment of this tie-down system are covered by International Atomic Energy Authority (IAEA) Regulations, and by the specific regulatory and guidance materials applying in the country of application.

The IAEA regulations have recently been updated in TS-R-1 (June 2000) [1] and TS-G-1.1 (June 2002) [2]. In particular, Appendix V of reference [2] specifically covers 'Package Stowage and Retention during Transport'.

In the United Kingdom the Transport Container Standardisation Committee (TCSC) provides guidance on the application of the IAEA regulations in TCSC 1006 "The securing of Radioactive Materials on Conveyances" [3], and this document has also been revised in December 2003.

The basic requirement of the IAEA regulations is to maintain the integrity of the components of the package and its retention systems during routine operations (TS-R-1 Para 612). In accident conditions the package is permitted and may be required as part of the design (the weak-link approach as discussed later in this paper) to separate from the conveyance, while preserving the package integrity. Any tie-down attachments on the package shall be so designed that, under normal and accident conditions of transport, the forces in those attachments shall not impair the ability of the package to meet the requirements of the Regulations. (TS-R-1 Para 636).

2. Package Tie Down Systems

There are a number of methods of attaching a package to a conveyance. The most common for larger packages is to use the lifting trunnions (figure 2.1) as attachment points. These are already designed for more onerous loadcases for lifting and tilting (these loadcases often bound the loadings for normal transport as the specified design accelerations are usually higher). Using the trunnions avoids or minimizes introduction of other features such as lugs or feet on the flask body. The trunnions are generally designed to be significantly stronger than the rest of the tie down system. This ensures that the trunnions would not impair flask integrity, on detachment from the tie down system, in an accident event.

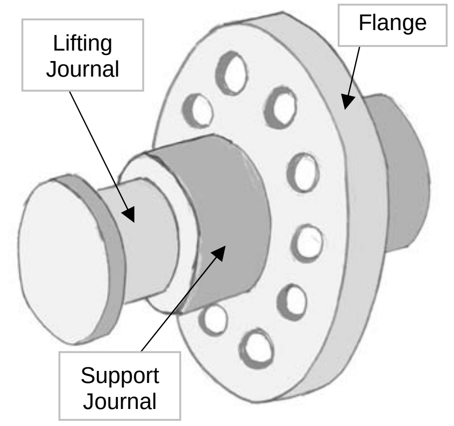


Figure 2.1 Typical bolted Trunnion

A typical transport arrangement using the trunnions is shown in figure 2.2 with the four trunnions supported in trunnion cups on a Transport Frame bolted to the conveyance. For heavier flasks the side frames are likely to be substantial and the detailing needs care to avoid compromising the heat dissipation around the flask. For less substantial flasks this can be alleviated used lighter side members and stiffer bolted corner beams as shown in figure 2.3. The implication of this lighter arrangement is that there will be more significant bending in the corner beams, and the forces in the conveyance attachment bolts are likely to be greater than they would be for a side frame designed to resist bending.

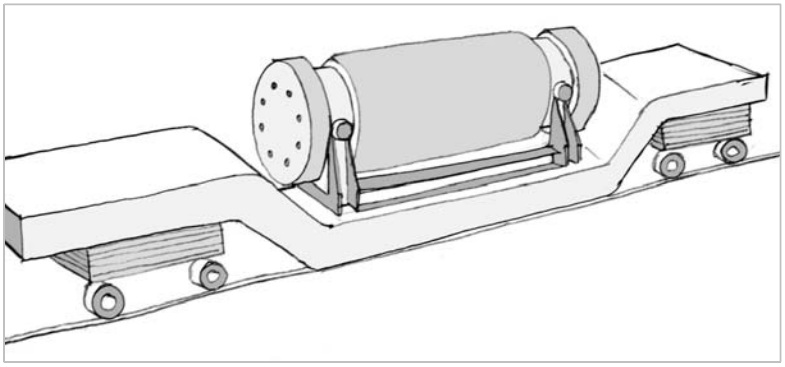


Figure 2.2 Package on Transport Frame supporting Trunnions

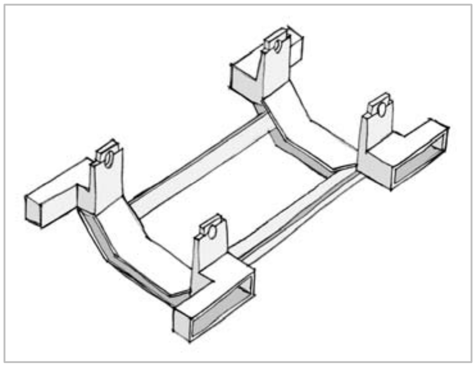


Figure 2.3 Transport Frame with light side beams and corner bolted beams

Some of the alternative arrangements to trunnion support for different package configurations are bolted feet integral with the package (as figure 2.4), or lashings (or twistlocks) attached to the conveyance (figure 2.5). The advantage of a foot welded to the package is that the load is transferred directly to the conveyance at low level and the welded foot can be an integral part of the thermal fins external to the flask. The structural detailing of the attachment of the foot to the flask body therefore requires careful consideration and integration into the fin design. It should be note that two trunnions are generally still required to allow the flask to be tilted into the vertical for lifting. The bolted foot arrangement can be used in conjunction with lateral and longitudinal chocking, to ensure that the bolts are only required to resist tension, and this is preferable to avoid extremely high bolt combined stresses that can lead to a requirement for large bolts, often in non standard higher strength steels.

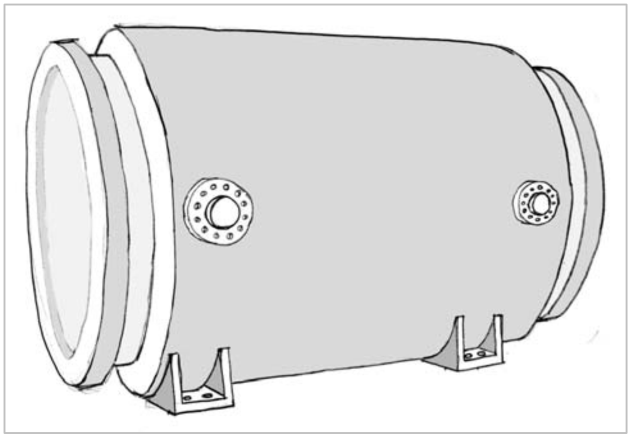


Figure 2.4 Flask with bolted feet welded to body

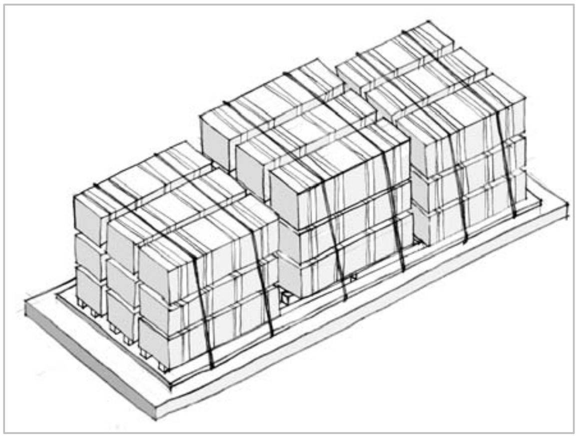


Figure 2.5 Stacked cuboidal packages with ties

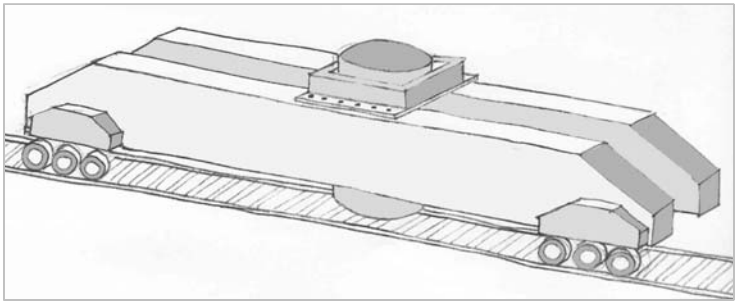


Figure 2.6 Vertical Flask mounted between rail wagon beams

Figure 2.6 illustrates a vertically mounted flask arrangement, requiring a special purpose rail conveyance with beams between which the flask is suspended. This is not now a commonly used design in the United Kingdom, but revalidation to the latest regulations of a package using a configuration similar to this has been carried out by the authors. The flask is held in position either with bolts, or with ties and chocks to prevent lateral movement. This arrangement differs from the others considered in that the centre of the flask mass is below the attachment point on the conveyance.

3. The Design Assessment Process

In considering the safety and security of the retention system, it is important that there is a clear understanding of the load paths between the package and the conveyance. These load paths may vary depending on the forces that the tie-down system is subjected to (i.e. if friction operates at lower levels of acceleration, but is then overcome, or if a component can only be designed to resist forces applied in a particular direction, such as a chock or bolt). The package tie-down designer should both clearly understand and document the intended behaviour in each case.

The method of assessment is generally to adopt a static model of the loadpath and to consider the effects of applying specific accelerations to the package. The components in the loadpath are considered in turn for the combination of stresses that result.

The applied accelerations are set out in the regulatory and guidance documents, and may vary depending on:

- The type of package (i.e. type IP, A, B, C etc. - reference [12], and whether unilaterally or multilaterally approved – the consignor of a unilaterally approved package cannot guarantee how the package will be treated once it has left the consignors control and therefore higher levels of acceleration are often applied)
- The mode of transport (Road, Rail, Sea or Air)
- The loadcase being considered (a routine acceleration encountered during everyday transport, or a minor mishap event with a relatively moderate likelihood of occurrence, as distinct from an accident condition that would terminate the useful life of the package)
- Whether the loadcase is quasi-static or fluctuating, to be considered for fatigue potential.

In each case both the applied accelerations, and the acceptance criteria need to be clearly understood and agreed with the relevant competent authorities. References [2],[3] and [11] give specific guidance on accelerations to be applied. Packages designed for use in different countries and which will be transported by different modes need to be designed using the most onerous combinations of acceleration factors that may apply.

A number of assumptions are generally made in carrying out such an assessment:

- It is assumed that the design accelerations are static and are applied simultaneously about all three axes. The accelerations are combined in the least favourable orientation (reference [4]). In the vertical accelerations it is important to be very clear that 1g downward due to gravity is additional to the applied acceleration figures given (or to specifically state if it has been included in any quoted acceleration figure).
- It is assumed that the forces can be modelled by applying the accelerations to the package mass at it's centre of gravity.
- It is assumed that the full magnitude of the resulting forces needs to transfer through the tie-down load path to the conveyance, modelled as if the conveyance were a rigid external support.
- It is often assumed that, for a package secured at four points using trunnions, only two of the trunnions act for each direction of applied force. A similar assumption may be applied when a package has a bolted foot type arrangement, with only a proportion of bolts considered to act due to fit up tolerances etc.

The applicability of the assumptions made should be carefully considered by the package designer. In the case of the last assumption listed above, particularly with respect to longitudinal accelerations, this can introduce an extremely onerous degree of conservatism into the design. By careful consideration of the tie-down frame, considering fit up tolerances (at bolts, trunnions cups etc.), thermal effects, local deformations etc. it can be possible to show by simple calculation that the frame is able to spread longitudinal load more evenly to the package support points (i.e. this was shown by the authors in assessment of a frame similar to the configuration in figure 2.3). This aspect of the design is considered in more detail later in section 6. of this paper in the case of a rail package with a relatively stiff Transport Frame.

4. Weak Link Performance

To ensure that during normal or accident conditions the permitted failure of the tie-down system (Reference [2] Appendix V) does not impair the integrity of the package, a designed weak link may need to be introduced.

This is usually an element in the tie-down system loadpath that is designed always to fail before the attachment point, or its connection to the package, would fail.

For a new package design, an element of the tie-down can be given a specifically engineered strength capacity to achieve this (i.e. by careful selection of material and engineering of the component size and detail – an example of this would be the use of a bolt shank machined to a precise required size). For an existing package, however, it can be possible to show that, while not explicitly 'designed in'; a most likely mode of failure always exists that does not impair the package or the attachment point. In the case of packages attached at trunnions this is often found to be by local deformation at the keep plate retaining the trunnions and by failure of the retaining bolts.

The weak link needs to function in the case of upward, lateral or longitudinal accelerations, and the expected behaviour in each case, and in their combinations, needs to be appraised by the package designer.

Provision of a designed weak link, by implication, means designing a component with the intent that it will fail at a specific load, or load combination. Predicting the behaviour at failure is not straightforward. Differences in the detailed stress strain performance of adjacent components, load shedding once yielding has commenced, and tolerance variations make this difficult. Often a practical balance needs to be adopted by the package designer between achieving required stress limits in weak link components under routine and normal accelerations, while not over strengthening them to the degree that they would not operate as intended under accident conditions.

5. Particular Transport Mode Considerations

There are some issues which need to be considered specifically in the context of the Transport Mode.

For transport by sea the orientation of the package when stowed may be with the long axis of the flask alongship or athwartship. For a package designed to be stowed in either orientation a further set of loadcases needs to be considered with the a_x and a_y accelerations swapped. Similar considerations may be needed for other modes of transport. This, in combination with load reversals, can lead to a large number of cases requiring assessment and care is needed to ensure that all of the bounding cases are fully considered.

For transport by road the possibility of providing a degree of shock absorption between the package and conveyance may be considered (i.e. into a system similar to that shown in figure 2.5). The detailing of this and its behaviour in relation to the weak-link performance needs to be very carefully designed, so that the intended point of detachment can be achieved, and so that any weak link can operate as intended.

References [9] and [10] include detailed consideration of forces for each transport mode, and results of measurement of accelerations actually experienced during routine transport in rail, road and sea modes. These papers conclude that the accelerations experienced by packages in routine transport are low and within the bounds of the common design cases used. Reference [10] also considered the effects of a minor rail impact (normal conditions), and this paper further considers the modelling of such an incident in section 6.

6. Revalidation of Existing Tie-Down Arrangements

Revalidation of existing packages is required when the conditions of an original application are no longer valid (for instance the mass of the package may be increased by introduction of new shock absorbers). In the case of a revalidation it is necessary to gain a full understanding of the original design intent, and to have full geometric and fabrication information on the tie-down arrangement under consideration. This may involve carefully scrutiny of original drawings and calculations along with measurement, recording and testing of the tie-down components.

Frequently the design assumptions originally adopted may differ from the current regulations and this is likely to mean that the original design basis assumptions need to be fully reassessed.

7. Modelling of the Performance of a Frame under Combined Accelerations

The majority of tie down assessments can be readily carried out using simple hand calculations. Such calculations rely, however, on assumptions as listed in section 2. There is some research into the validity of the assumptions for routine conditions, but relatively little work has been done on the validity of the assumptions in normal events – minor collisions and mishaps - although covered to some degree in reference [10].

Arup have carried out a preliminary evaluation of the behaviour of a transport frame during a minor collision using the non-linear transient finite element code LS-DYNA. The purpose of the analysis was to evaluate the magnitude and timing of lateral and vertical accelerations, corresponding to an impact that generates a longitudinal acceleration of 2g, and to assess load share between the four trunnions during such an event.

The model is shown in figure 7.1, with an inset showing the trunnion interface to the trunnion cups on the frame. The model was of a 120 tonne flask, on a 6 tonne frame, attached to 60 tonne rail wagon. The details were based on an actual flask and its transport frame in use in the UK.

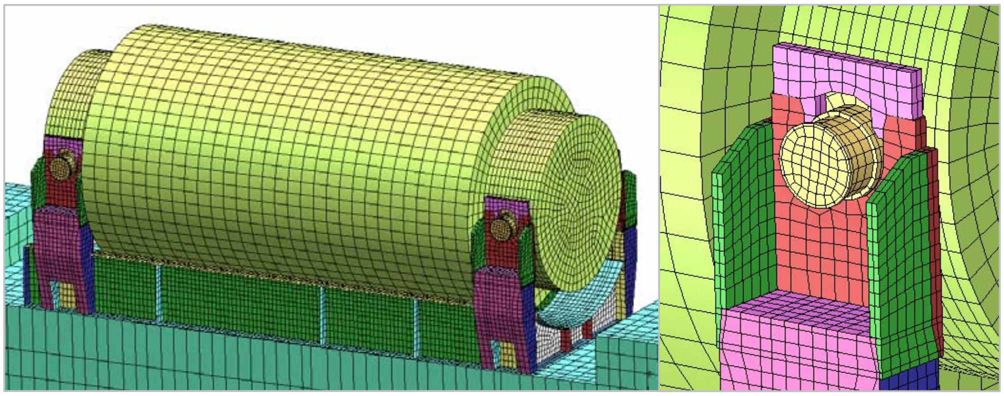


Figure 7.1 FE Model of the 120 tonne Flask and 6 tonne Transport Frame

The base of the transport frame was 1085mm above the rail and 485mm above the wagon buffers. The flask was modeled as undeformable, but was given the correct geometric and inertial properties. The transport frame was modeled with a mixture of shells and solids with appropriate material properties for the specified steel grades. The rail wagon was also modeled as undeformable, except for the buffers.

The buffers were modeled with springs. Their stiffness was chosen so that the peak longitudinal deceleration of the flask was around 2g in a 5mph (2.2 m/s) impact onto a rigid wall target. The analysis was in two phases, a dynamic relaxation phase during which gravity loading was applied and a transient phase. At the beginning of this transient phase, the model was given an initial velocity of 5mph towards a rigid wall target which was oriented perpendicular to the direction of impact. The event was analysed from initial impact through to complete rebound.

The acceleration-time history, velocity-time history and displacement-time history of the flask in the longitudinal direction are shown in Figures 7.2, 7.3 and 7.4. Positive velocity is movement towards the target; positive vertical displacement is upward. The vertical acceleration-time history and displacement-time history are shown in Figures 7.5 and 7.6. Contact force-time histories showing the interface reaction forces at the trunnion-frame interface in the longitudinal and vertical directions are shown in Figure 7.7.

As this is a front-on impact, with complete symmetry about a plane perpendicular to the lateral direction, there is no gross lateral displacement or acceleration in the lateral direction.

As the buffers compressed against the target, the wagon and frame decelerated, and tried to restrain the inertia of the flask. The moment arm between the flask inertia and the buffer caused the flask to tilt during deceleration. The contact point between the trunnions and the trunnion cups also shifted as the trunnions tried to “ride-up” in the cup. The flask’s inertia loading onto the upstands of the transport frame caused the upstand to deflect elastically in bending and compression.

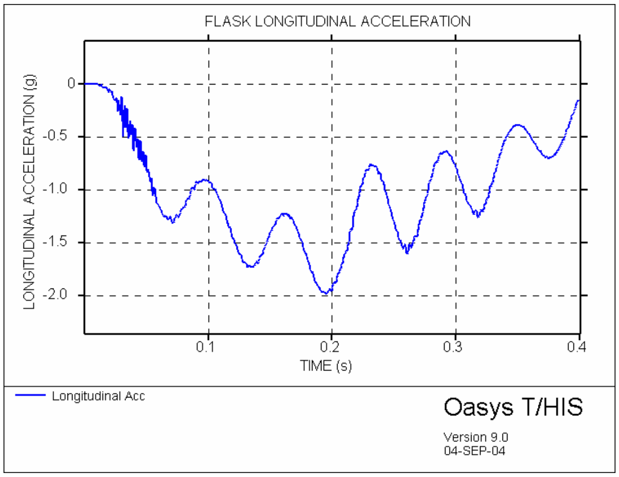


Figure 7.2 Flask longitudinal acceleration-time history

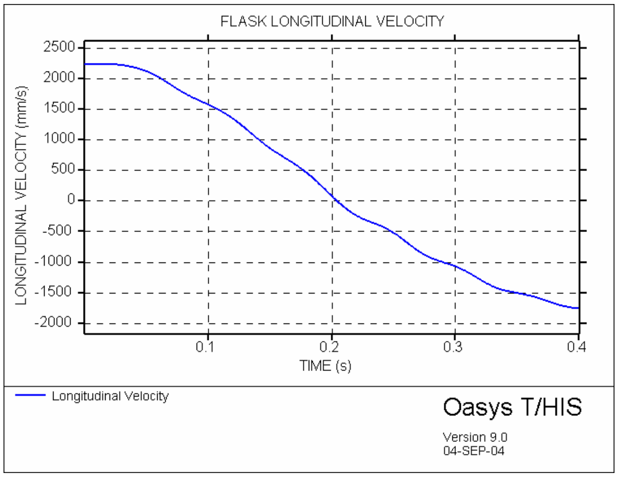


Figure 7.3 Flask longitudinal velocity-time history

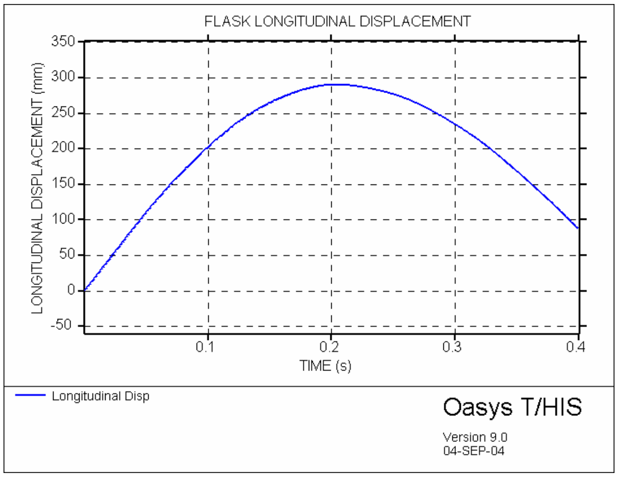


Figure 7.4 Flask longitudinal displacement-time history

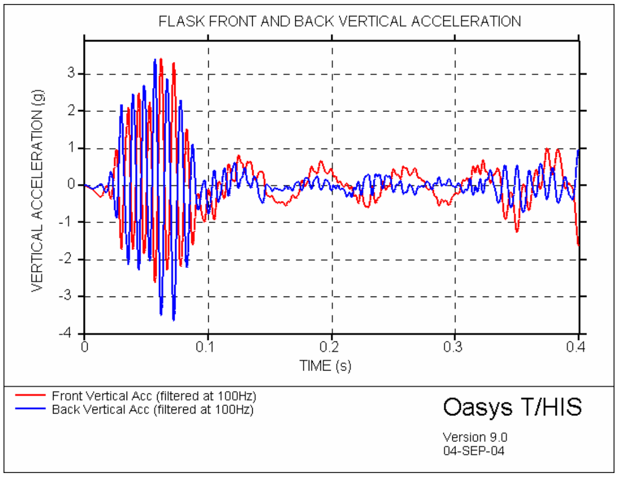


Figure 7.5 Flask vertical acceleration-time histories

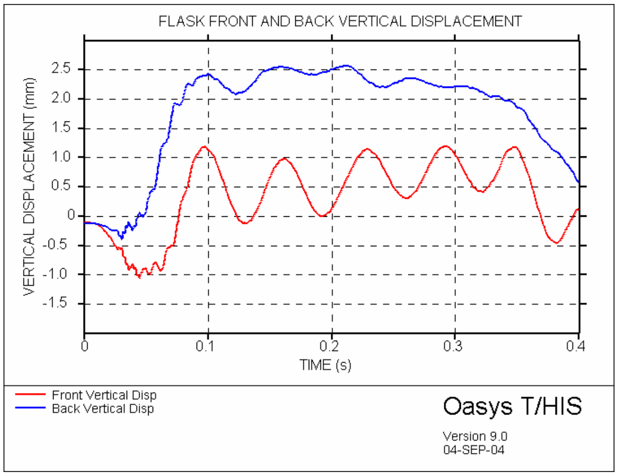


Figure 7.6 Flask vertical displacement-time histories

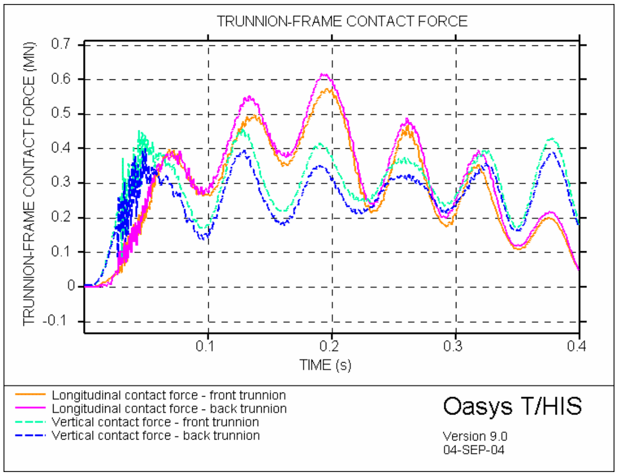


Figure 7.7 Contact force time histories at flask to transport frame interface

There were high frequency oscillations in the vertical acceleration-time histories during the first 0.1s, accompanying deflection and compression of the upstands. Using a 100Hz filter, the peak was about 3.5g, although with very short duration. These high vertical accelerations did not happen at the same time as the longitudinal peak. At the point of maximum vertical acceleration, the longitudinal acceleration was about 1g, half the maximum.

Contact force time histories at the trunnion to frame interfaces show a maximum longitudinal force of 0.6MN, with a maximum difference between the front and the back interfaces of 5%. In the vertical direction, the maximum contact force was 0.45MN. There was a 15% difference between the vertical contact force at the front and the back. In comparison, using the normal conservative assumptions the design forces taken into the frame would be approximately 1200kN from longitudinal (2g on two trunnions), coexistent with 1800kN downward (3g on two trunnions). At these design accelerations reference [3] requires the material stresses in the Transport Frame to remain within the stress allowables of reference [5] which are typically at about 60% of material yield.

Figure 7.8 is a minimum principal stress plot and shows the compressive loading in and around the back upstands, taken at t=0.192s when the longitudinal deceleration was at it's highest. The highest Von Mises stress in the structure occurring at the back of the transport frame is shown in Figure 7.9.

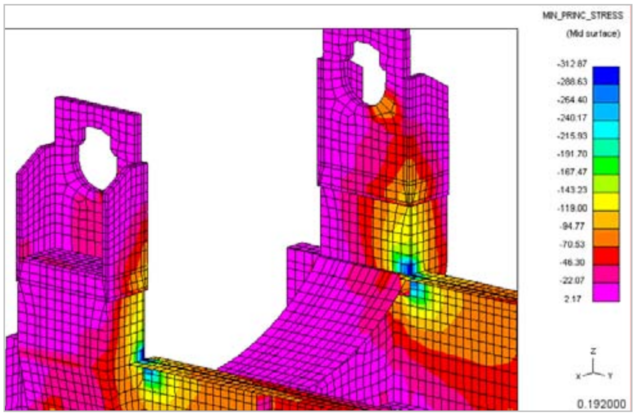


Figure 7.8 Minimum principal stress in the back upstands of transport frame

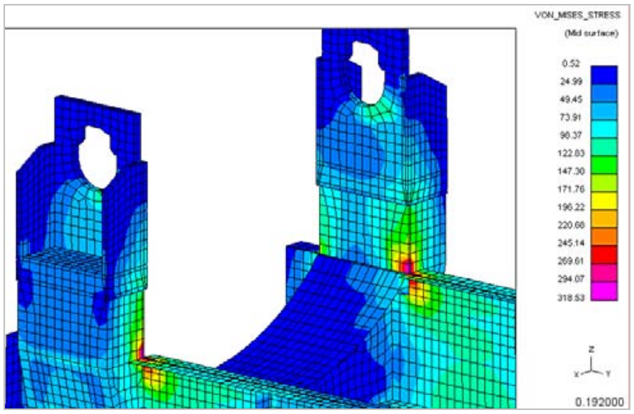


Figure 7.9 Von Mises stress in the back upstands of transport frame

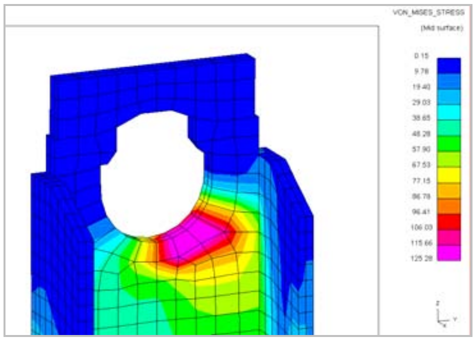


Figure 7.10 Concentration of Von Mises stress at Trunnion Cup

These plots show the elastic flexural behaviour of the upstands, which contributes to the oscillations in the system. The highest Von Mises stress local to the trunnion is shown in more detail in figure 7.10. The modeling carried out indicates that there are conservatisms in the common assumptions for frame design over load shed to trunnions, and the fact that in the head on minor impact the coexistent lateral and vertical accelerations, at peak longitudinal acceleration, would be likely to both be much lower than 1g.

The model included the diameters of the trunnions and trunnion cups, but does not fully explore the potential variability of tolerances due to fit up and the thermal variations of flask and frame at these locations. There is therefore considerable scope for further investigation into these variations and their effect on the predicted load sharing.

8. Fatigue Performance

Fatigue loading can be assessed in a number of ways. There are several papers (ref [3], ref [4] which give data on instantaneous accelerations measured during transport of packages, giving actual longitudinal vertical and lateral accelerations experienced. Data on accelerations for lower mass (10-20 tonne) packages is also given in reference [3]. Statistical data can then be collected on the number of cycles at which each level of acceleration occurred during the journey and this can be extrapolated over the design life of the package being assessed. The appropriateness of the source data should be reviewed in the context of the package being considered as the acceleration data will be dependent on the precise transport modal arrangement, journey conditions, and peak fluctuating accelerations would be anticipated to vary with package mass.

The data can then be used with a recognised code covering fatigue (ref's [5], [6] & [7], with reference [7] providing the more comprehensive and recent UK basis) to sum the cumulative damage corresponding to each stress level, and determine whether the component has an acceptable fatigue life.

A more simple method may be appropriate in which a single average fatigue acceleration is considered about each axis and the cycle capacity at the stress levels corresponding to these is calculated for each tie-down component. Taking the reciprocal of the summed reciprocal cycle capacities then gives the component design life.

From assessments in which both methods have been used, the simplified approach is normally sufficient, and provided the average acceleration taken about each axis is appropriate (i.e. table 3 of reference [3]) will be likely to bound the results that would be obtained from a more thorough statistical approach.

9. Mathematical Methods and Retention of Design Data

Assessment of the loadpath for a flask tie down system involves investigation of all of the component parts, plate elements, bolts and welds etc. for both static accelerations and fatigue loads. All of the calculations are dependant on the flask mass, which is liable to vary during the development of the flask design for thermal, impact and other practical aspects. The outcome of the initial tie down assessments may also influence the geometry, materials, masses and loads resulting in an iterative process of revisiting calculations.

Flask and tie down designs are often in use for many years, and modifications to the base design may well be needed during the life of the package to accommodate regulatory or operational change.

It is therefore suggested that the calculation base for the design should be managed, so that designs can easily be rerun, modified and reviewed.

Calculation management, using commercially available mathematical software packages (such as MathCAD) allows the design process (and subsequent reappraisal of design) to develop using a standardised set of calculations that can readily be modified.

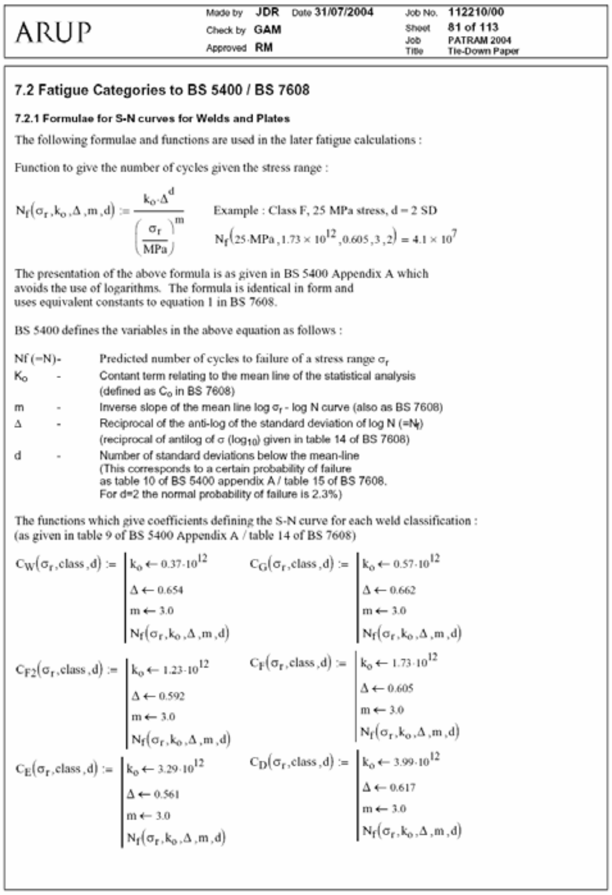
Examples of this approach to managed calculation sets are shown on the following page.

Figure 9.1 shows a standard set of validated calculation routines used to assess fatigue life in components on the basis of references [6] and [7]. Figure 9.2 is an extract from the calculation set for a Typical Transport frame explaining the loadpath assumptions used in the design. Figure 9.3 is a sample calculation of varying bending forces and stresses along a Transport Frame side beam, and the calculation is dynamically linked to the flask mass and geometry variables.

The final figure 9.4 shows a typical results summary, with tabulated output of design stresses, stress allowables and reserve factors. Use of a Calculation Management approach allows this tabulated data to be linked to the calculations, and to automatically update when parameters such as the flask mass or centroid position are altered. Building the calculation model in this way allows for a managed approach to changes during the design process, and parametric studies of the effects of changing elements of the design can rapidly be carried out.

10. Conclusions

The revised IAEA regulations set out a framework for the design of tie down systems, and it is incumbent upon the package designer to work with the relevant competent authorities to achieve the objectives set out in TS-R-1. The area of routine transport has been reasonably well researched, and considerable attention is paid to the accident condition and implications of flask drop. The area of design for minor mishaps and collisions and the acceptability criteria applied to these conditions have been less well investigated, and the regulatory requirements in this area can be more open to interpretation. There is therefore scope for further research into what would be the realistic behaviour of packages and their tie-down systems during minor mishap events.



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7.2 Fatigue Categories to BS 5400 / BS 7608

7.2.1 Formulae for S-N curves for Welds and Plates

The following formulae and functions are used in the later fatigue calculations :

Function to give the number of cycles given the stress range :

$$N_f(\sigma_r, k_o, \Delta, m, d) := \frac{k_o \cdot \Delta^d}{\left(\frac{\sigma_r}{MPa}\right)^m}$$

Example : Class F, 25 MPa stress, d = 2 SD

$$N_f(25 \cdot MPa, 1.73 \times 10^{12}, 0.605, 3, 2) = 4.1 \times 10^7$$

The presentation of the above formula is as given in BS 5400 Appendix A which avoids the use of logarithms. The formula is identical in form and uses equivalent constants to equation 1 in BS 7608.

BS 5400 defines the variables in the above equation as follows :

Nf (=N)-		Predicted number of cycles to failure of a stress range σ_r
K_o	-	Contant term relating to the mean line of the statistical analysis (defined as C_o in BS 7608)
m	-	Inverse slope of the mean line log σ_r - log N curve (also as BS 7608)
Δ	-	Reciprocal of the anti-log of the standard deviation of log N (=N_f) (reciprocal of antilog of σ ($\log_{10}$) given in table 14 of BS 7608)
d	-	Number of standard deviations below the mean-line (This corresponds to a certain probability of failure as table 10 of BS 5400 appendix A / table 15 of BS 7608. For d=2 the normal probability of failure is 2.3%)

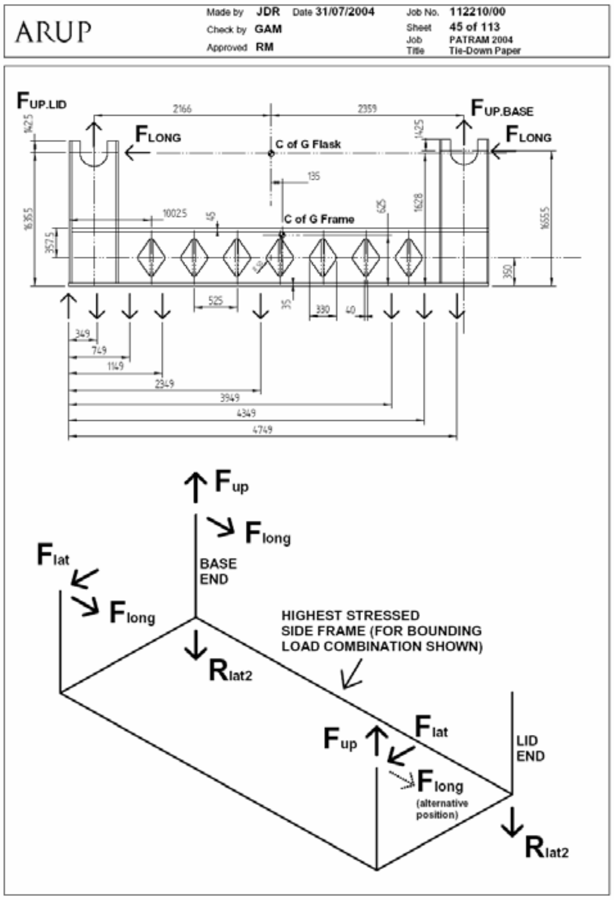
The functions which give coefficients defining the S-N curve for each weld classification :
(as given in table 9 of BS 5400 Appendix A / table 14 of BS 7608)

$$C_W(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 0.37 \cdot 10^{12} \\ \Delta \leftarrow 0.654 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right. \qquad C_G(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 0.57 \cdot 10^{12} \\ \Delta \leftarrow 0.662 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right.$$

$$C_{F2}(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 1.23 \cdot 10^{12} \\ \Delta \leftarrow 0.592 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right. \qquad C_F(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 1.73 \cdot 10^{12} \\ \Delta \leftarrow 0.605 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right.$$

$$C_E(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 3.29 \cdot 10^{12} \\ \Delta \leftarrow 0.561 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right. \qquad C_D(\sigma_r, class, d) := \left| \begin{array}{l} k_o \leftarrow 3.99 \cdot 10^{12} \\ \Delta \leftarrow 0.617 \\ m \leftarrow 3.0 \\ N_f(\sigma_r, k_o, \Delta, m, d) \end{array} \right.$$

Figure 9.1 Example fatigue assessment calculation



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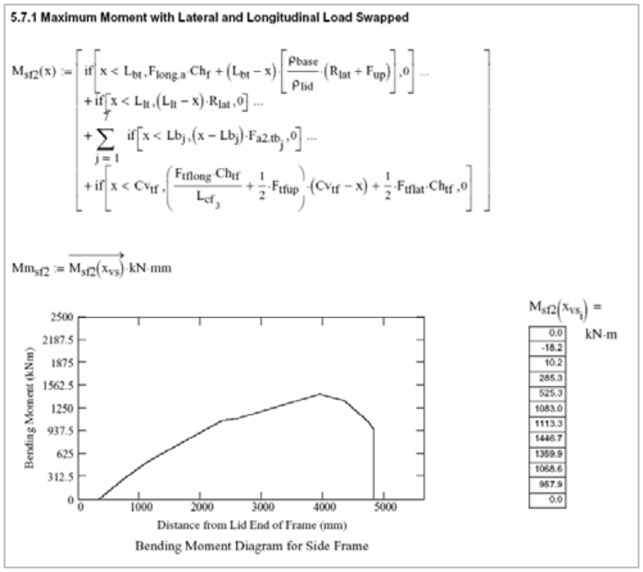
Job No. **112210/00**
Sheet **45 of 113**
Job Title **PATRAM 2004 Tie-Down Paper**

Figure 9.2 Typical loadpath diagrams for a frame



5.7.1 Maximum Moment with Lateral and Longitudinal Load Swapped

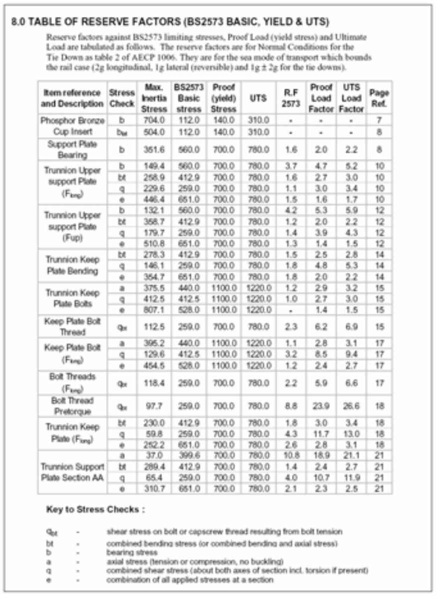
$$M_{sf2}(x) := \left[\begin{array}{l} \text{if}\left[x < L_{bt}, F_{long.a} \cdot Ch_f + (L_{bt} - x) \cdot \left[\frac{\rho_{base}}{\rho_{lid}} \cdot (R_{lat} + F_{up})\right], 0\right] \ldots \\ + \text{if}\left[x < L_{lt}, (L_{lt} - x) \cdot R_{lat}, 0\right] \ldots \\ + \sum_{j=1} \text{if}\left[x < Lb_j, (x - Lb_j) \cdot F_{a2.tb_j}, 0\right] \ldots \\ + \text{if}\left[x < Cv_{tf}, \left(\frac{F_{tflong} \cdot Ch_{tf}}{L_{cf_3}} + \frac{1}{2} \cdot F_{tfup}\right) \cdot (Cv_{tf} - x) + \frac{1}{2} \cdot F_{tflat} \cdot Ch_{tf}, 0\right] \end{array} \right]$$

$$Mm_{sf2} := \overrightarrow{M_{sf2}(x_{vs})} \cdot kN \cdot mm$$

$M_{sf2}(x_{vs_i}) =$ kN·m

$M_{sf2}(x_{vs_i})$
0.0
-18.2
10.2
285.3
525.3
1083.0
1113.3
1446.7
1359.9
1068.6
957.9
0.0

Figure 9.3 Calculating bending along a Transport frame



8.0 TABLE OF RESERVE FACTORS (BS2573 BASIC, YIELD & UTS)

Reserve factors against BS2573 limiting stresses, Proof Load (yield stress) and Ultimate Load are tabulated as follows. The reserve factors are for Normal Conditions for the Tie Down as table 2 of AECP 1006. They are for the sea mode of transport which bounds the rail case (2g longitudinal, 1g lateral (reversible) and 1g ± 2g for the tie downs).

Item reference and Description	Stress Check	Max. Inertia Stress	BS2573 Basic stress	Proof (yield) Stress	UTS	R.F 2573	Proof Load Factor	UTS Load Factor	Page Ref.
Phosphor Bronze Cup Insert	b	704.0	112.0	140.0	310.0	-	-	-	7
	b_{bt}	504.0	112.0	140.0	310.0	-	-	-	8
Support Plate Bearing	b	351.6	560.0	700.0	780.0	1.6	2.0	2.2	8
Trunnion Upper support Plate (F_{long})	b	149.4	560.0	700.0	780.0	3.7	4.7	5.2	10
	bt	258.9	412.9	700.0	780.0	1.6	2.7	3.0	10
	q	229.6	259.0	700.0	780.0	1.1	3.0	3.4	10
	e	446.4	651.0	700.0	780.0	1.5	1.6	1.7	10
Trunnion Upper support Plate (Fup)	b	132.1	560.0	700.0	780.0	4.2	5.3	5.9	12
	bt	358.7	412.9	700.0	780.0	1.2	2.0	2.2	12
	q	179.7	259.0	700.0	780.0	1.4	3.9	4.3	12
	e	510.8	651.0	700.0	780.0	1.3	1.4	1.5	12
Trunnion Keep Plate Bending	bt	278.3	412.9	700.0	780.0	1.5	2.5	2.8	14
	q	146.1	259.0	700.0	780.0	1.8	4.8	5.3	14
	e	354.7	651.0	700.0	780.0	1.8	2.0	2.2	14
Trunnion Keep Plate Bolts	a	375.5	440.0	1100.0	1220.0	1.2	2.9	3.2	15
	q	412.5	412.5	1100.0	1220.0	1.0	2.7	3.0	15
	e	807.1	528.0	1100.0	1220.0	-	1.4	1.5	15
Keep Plate Bolt Thread	q_{bt}	112.5	259.0	700.0	780.0	2.3	6.2	6.9	15
Keep Plate Bolt (F_{long})	a	395.2	440.0	1100.0	1220.0	1.1	2.8	3.1	17
	q	129.6	412.5	1100.0	1220.0	3.2	8.5	9.4	17
	e	454.5	528.0	1100.0	1220.0	1.2	2.4	2.7	17
Bolt Threads (F_{long})	q_{bt}	118.4	259.0	700.0	780.0	2.2	5.9	6.6	17
Bolt Thread Pretorque	q_{bt}	97.7	259.0	700.0	780.0	8.8	23.9	26.6	18
Trunnion Keep Plate (F_{long})	bt	230.0	412.9	700.0	780.0	1.8	3.0	3.4	18
	q	59.8	259.0	700.0	780.0	4.3	11.7	13.0	18
	e	252.2	651.0	700.0	780.0	2.6	2.8	3.1	18
Trunnion Support Plate Section AA	a	37.0	399.6	700.0	780.0	10.8	18.9	21.1	21
	bt	289.4	412.9	700.0	780.0	1.4	2.4	2.7	21
	q	65.4	259.0	700.0	780.0	4.0	10.7	11.9	21
	e	310.7	651.0	700.0	780.0	2.1	2.3	2.5	21

Key to Stress Checks :

q_{bt} - shear stress on bolt or capscrew thread resulting from bolt tension
bt - combined bending stress (or combined bending and axial stress)
b - bearing stress
a - axial stress (tension or compression, no buckling)
q - combined shear stress (about both axes of section incl. torsion if present)
e - combination of all applied stresses at a section

Figure 9.4 Tabulated stresses and reserve factors with automatically updated links to calculations

12. References

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for radioactive material in transport. DETR/RMTD/0003 January 2001.

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[13] Transport Container Standardisation Committee TCSC (93) P1072
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