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Stowage during transport: a proposal for harmonization

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Abstract

For stowage and retention during transport, the International Atomic Energy Agency (IAEA) transport regulations (SSR-6) only require that the package shall be securely stowed. Additional information is given in the IAEA guidance material (SSG-26), that includes specific load factors that should be considered in the safety demonstrations.

Nevertheless, applicants commonly use other load factors to justify the design of the packaging attachment points. In particular, acceleration values vary between different countries and this may lead to difficulties during the validation of foreign approval certificates.

Discussions with applicants identified that the load factors presented in the IAEA guidance material are not necessarily relevant for the different transport modes. For some modes, the load factors are representative of situations occurring in routine conditions of transport. For other modes, the load factors are more representative of situations occurring in normal or accident conditions of transport.

Furthermore, the origins of the specified values are not clear.

In this context, some IAEA TRANSSC members decided to review the stowage guidance. An international working group was constituted in 2013, including representatives of competent authorities, technical support organizations, and transport stakeholders. Several topics were discussed and many questions were raised during the two year review. For example, some discussions focused on

the conditions which have to be considered for stowage design, both as relevant to the load factors used for strength and fatigue analysis, as well as the criteria which have to be considered for the package attachment points. In addition, related questions on operational aspects were also discussed. Overall, the working group concluded that new guidance material was warranted as input into SSG-26.

As a result of those discussions, the international working group produced new guidance material for stowage in transport, addressing each of these topics. The proposal to modify the IAEA guidance material (SSG-26, Appendix IV), presented by France to the TRANSSC in the 2015 initiated review cycle of the Regulations, was unanimously accepted and will be implemented in the next edition of the guidance material.

Introduction

It is quite difficult to design attachment points of a package due to the different acceleration values given in Appendix IV of SSG-26 [1]: Tables IV.1 and IV.2. For example, for the lateral acceleration value in rail transport, Table IV.1 gives the value of 2 g. Table IV.2 gives the values of 0.5 g in Europe, 1 g for Uranium hexafluoride, and up to 5 g in the USA for Type B(U), B(M), and fissile material package designs. Others standards give also quite different values.

It is apparent that the hypotheses taken to establish those values are different. Some of those values may also integrate unknown safety factors. Thus, the review of the values appeared necessary!

An international working group was created in 2013, including representatives of competent authorities, technical support organizations, and transport stakeholders (WNTI), from Europe (France, Germany, UK), America (USA, Canada) and Asia (Japan).

Working group steps used for topic clarification

First step: What do we address?

Tie-down and stowage material… the field is wide! It was decided to address, in the new SSG-26, only the design of the packaging. It should be highlighted that the new Appendix IV only addresses the parts of the packaging used for stowage (e.g., trunnions, lugs), referred to as attachment points. Existing regulations or standards for stowage of general cargo on transport means developed for each mode of transport, at international or national level, should be considered as appropriate and sufficient for the design of the stowage equipment which is not part of the package.

For better understanding, the general arrangement of the package stowage components, as used in this paper, are included in Figure 1 below.

The appendix does not focus on package handling loads. However, when an attachment point is used both for lifting and tie-down, then the lifting operation loads, including snatch lifting loads, have to be taken into account in the design.

Second step: What do we consider?

The use of stowage has been extensively discussed in the working group. What should the tie-down sustain? Packages have to be securely stowed in routine conditions of transport (RCT), which is obvious. Stowage does not have to resist in accident conditions of transport (ACT), that is also quite obvious. But what about normal conditions of transport (NCT)?

Considering that NCT are representative for minor mishaps, the working group considered that the attachment points of a package do not have to resist to NCT. But package retention systems have to be designed to perform in a predictable manner under all conditions of transport. However, in normal or accident conditions of transport, a separation between the package and the conveyance is permitted, and may be required as part of the design, by the breakage or designed release of its restraint in order to preserve the package integrity. In all cases, the safety of the package has to be addressed, and the tie-down system shall not reduce its safety.

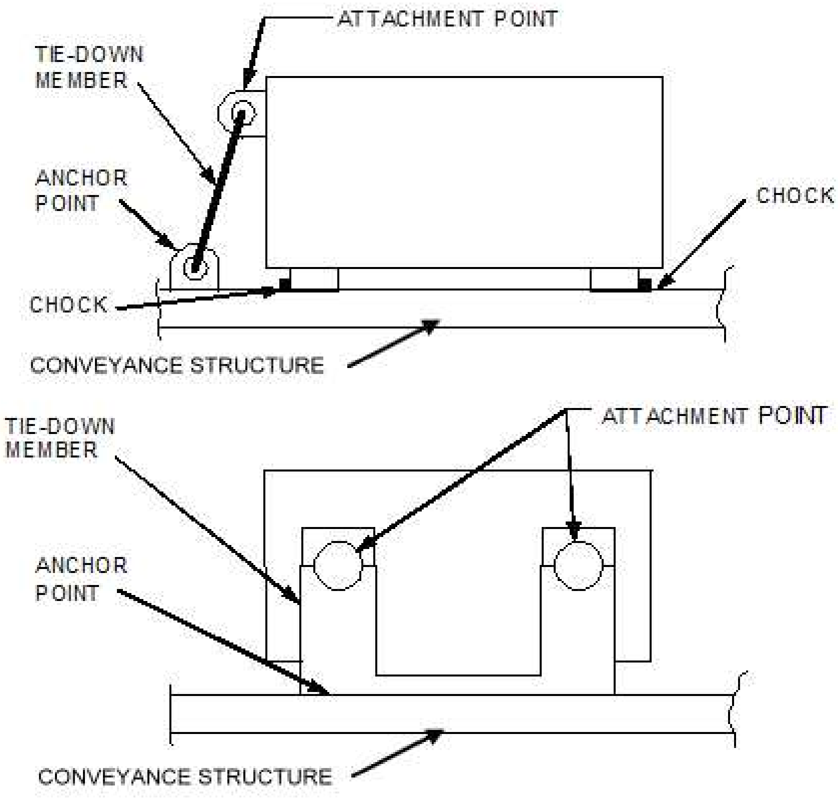

Figure 1: General Package Stowage Components

Third step: What are RCT?

Both RCT and NCT are included within SSR-6, but they are not defined in detail and deriving real loads for stowage is not clearly explained. However, the tests for demonstrating the ability of a package to withstand NCT are described and included within SSR-6. We needed a set of transportation conditions that corresponded to RCT in the new appendix. So the working group considered that inertial forces due to uneven road or track, vibration during transport, braking and accelerations, direction changes, rail shunting (when permitted), motions of a ship in heavy seas and turbulence in air transport are considered as RCT. The inertial forces that act during minor impacts with vehicles and obstacles, rail shunting (when not permitted), very exceptional seas and emergency landings (in air transport) are not considered as RCT.

Fourth step: What should the attachment points withstand?

To gain consistency in the understanding and usage of stowage provisions, the working group members provided related operational experience in various presentations and discussions, which resulted in a general set of existing norms, guidelines and standards. The working group determined that there were very few differences noted within the standards amongst the countries represented (European countries, Japan, USA), including those issued by international bodies (IMO, ILO, UNECE, UIC, ISO, …) or countries not represented in the working group (Australia).
Most of the standards address strength analysis of the tie-down members. They provide acceleration values; the tie-down members have to restrain the package when the acceleration is applied to the package. Most of the standards also give safety factors to be applied on the result. The working group collected the basic acceleration values, for all modes of transport, in different guidelines and standards. As a basic acceleration value, we understand the value without any safety factors. For each mode of transport, and for each direction, the highest basic acceleration value was selected.
To increase the confidence that the proposed range of loading will not be exceeded, a safety factor of 1.25 was applied on all the basic values.
It is well known that a repeated stress, even far below yield, could lead to a failure of the material by fatigue. Obviously, such a failure cannot be allowed and a fatigue analysis of the attachment point has to be performed. But the acceleration values to be considered for the fatigue analysis are not necessarily the same as the maximum ones considered for the stress analysis.

Results

Acceleration values for strength analysis

For strength analysis, the final values (including the safety factor of 1.25 mentioned above) for common cases are given in Table 1 below. Those values include gravity.

Table 1: Acceleration values for strength analysis

Mode	Longitudinal	Lateral	Vertical
Road	1 g	-	1 g down ± 0.3 g
	-	0.7 g	1 g down ± 0.3 g
Rail	1.3 g/5 g		1 g down ± 0.4 g
		0.7 g	1 g down ± 0.4 g

Mode	Longitudinal	Lateral	Vertical
Sea/water	0.5 g	-	1 g down ± 1 g
	0.3 g	1 g	1 g down ± 0.6 g
Air	1.3 g	-	1 g down
	-	1.3 g	1 g down
	-	-	2.5 g up, 2.5 g down

Directional load combination for strength analysis

The new Appendix IV stipulates: “The analyst should first consider application of each directional acceleration value separately and then all combinations for each line in Table 1 for the relevant transport mode.” Combination of longitudinal and lateral accelerations is not demanded (excepted in sea mode of transport). This position is also the position of most guides or standards, and is due to statistical reasons of non-simultaneous occurrences and envelopes provided by the other cases. The separate analyses, direction by direction, are requested for precaution to cope with non-linear effects (for which one direction could give higher responses than a combination).

Acceleration values for fatigue analysis

For fatigue analysis, the working group reached a consensus only on rail transport. The acceleration values given in Table 2 below may be used, in accordance with the conditions and criteria of the standard DIN EN 12663-2:2010-07 [3].

Table 2 Acceleration values for fatigue analysis

Mode	Longitudinal	Lateral	Vertical
Rail	± 0.3 g	± 0.4 g	1 g down ± 0.3 g

What is the expected behavior of the attachment points?

As a general consensus, the working group agreed that for both strength analysis and fatigue analysis, the attachment points shall not be damaged during RCT.

For strength analysis, the package and its attachment points shall not be stressed beyond yield. No permanent deformation is allowed in RCT. The analysis should include additional justified safety factor. This point is specifically discussed below.

For fatigue analysis, several approaches may be considered, including infinite endurance, fatigue life of the attachment point, and control in service. For infinite endurance in rail transport, the working group recommended to consider standard [3]. For other situations, the working group listed useful references. Criteria have to be chosen in accordance with the approach.

Discussion of some points

Longitudinal acceleration in rail transport

In rail transport, trains may be constituted with wagons from different geographical origins and with different geographical directions. At some points on the way, the wagons have to be sorted. Rail shunting is a technique used for wagon sorting. That technique induces high accelerations to the wagon (up to 5 g), much higher than the accelerations "on the road", of 1.3 g. That explains the two values given in Table 1 for the longitudinal acceleration in rail transport: 1.3 g or 5 g.

1.3 g may be used in either of the following cases:

- rail shunting is not permitted; or
- the wagon is equipped with long-stroke shock-absorbers.

In all other cases, the acceleration value of 5 g should be used.

Fatigue damage

Fatigue damage refers to both initiation and growth of a macroscopic fissure by cyclic loadings. Consequently it can be described as a "local" damage, and depends on the stress applied on each point of the attachment point. This should be taken into account in the stress analysis (e.g., through refined finite element models or introduction of adequate stress concentration factors).

Strength analysis

For strength analysis, the acceleration values given in Table 1 are applied at the package center of gravity in order to produce equivalent quasi-static forces of inertial effects. The package and its attachment points shall not be stressed beyond yield. No permanent deformation is allowed in RCT. The analysis should include appropriate safety factor.

If a specific design code is used in the analysis, an additional safety factor consistent with the applied code may be required. For example, some codes consider that the threshold value for a continuous usage is 2/3 of the yield strength. If no specific design code is used, then a safety factor should be considered in the analysis. In France, a safety factor in the order of 1.5 on the acceleration values (or of 2/3 on the criteria, i. e. the yield strength) is considered as appropriate. In all cases, the analyses have to be agreed on by the relevant competent authorities.

Stress linearization in strength analysis

The strength verification refers to an elastic behavior of the attachment point in RCT. So the damage aimed for strength verification is no longer "local" in the sense the attachment must "globally" remain elastic, which is ensured by no permanent deflection after unloading. Some design codes, like ASME [4] or RCC-M [5] codes, may consider linearized stresses (membrane and bending) in the strength analysis. In fact, very localized plasticity may theoretically be allowed, but under strict conditions. In particular, the plastic zone shall be confined by extended elastic zones, and so shall have no significant

impact on the permanent global deformation. The geometry of the load attachment point shall also permit the stress linearization in unambiguous manner.
In all cases, an evaluation of the allowance of linearization is necessary and the analyses have to be agreed on by the relevant competent authorities.

Ways forward

Some difficulties have not been solved so far. Some of them are clearly identified, but the data have not been considered as sufficient to be implemented in the new Appendix IV. In particular, a lack of consistent data has been noted for light packages in road transport (packages transported in vehicles less than 3,500 kg), and generally for fatigue analysis.
France is working on those topics. A working group composed of members of competent authority, technical support organization, and industry is considering the potential ways for having relevant values in those fields. The working group is also working on guidelines in the field of human factors applied on stowage, emphasizing the importance of the training requirements, operators skills and relevant documents. In particular, with the help of cargo securing training experts, typical content of training programs for people in charge of designing or carrying out the stowage of radioactive packages onboard vehicles, wagons of freight containers is under development. This will include recommendations on the duration, the share between theory and practice, the training recycling periodicity, and the qualification of the trainers.

Conclusions

It is not easy to harmonize each of the respective points of view of so many different working group members. Additionally, there is also some lack of data, most notably in the field of fatigue analysis, that made the task more difficult. As a result, the working group’s final product provides a starting point for future improvements. But each working group member trusts that Appendix IV of the new edition of SSG-26 [2] will be easier to use than the current one, that a wide utilization of the new information will support harmonization of the stowage practices throughout the world, and that this new guidance material will support smooth transportation of packages, and more efficient design approvals and validations.

References

[1] IAEA Safety Standards, Specific Safety Guide No. SSG-26, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)

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[3] DIN EN 12663-2:2010-07 Railway applications-Structural requirements of railway vehicle bodies-Part 2: Freight wagons

[4] AMERICAN SOCIETY OF MECANICAL ENGINEERS (ASME), Boiler and Pressure Vessel Code, 2015

[5] Design and Construction Rules for Mechanical Components of PWR Nuclear Islands; Règles de conception et de construction des matériels mécaniques des ilôts nucléaires REP (RCC-M), 2012, AFCEN