THE *MAXFORCE®* CONCEPT - CONSIDERING DYNAMIC FORCES DURING TRANSPORT OF DANGEROUS GOODS

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SUMMARY

A new container concept called the ***MAXFORCE®*** concept is presented which has been developed for transporting dangerous goods. For the first time, dynamic loads have been considered as design requirement for the design of ISO freight containers. Various international rules and regulations have been compared regarding the dynamic load requirements for ISO freight containers and enormous differences were observed. While various regulatory frameworks like the CSC (Convention for Safe Containers) or ISO 1496/1 are satisfied with static loads: 2 g (corresponding to 0.8 g dynamic) in the construction of freight containers, the ST-2 recommend 5 g dynamic and the US CFR 10 g dynamic (without 16 Hz low-pass filtering) as design criteria. Transport is a dynamic process. STM have based its design requirement for the ***MAXFORCE®*** container concept on various switchyard ram tests, a drop test and on numerical computer simulations. STM propose for routine conditions of transport (incident free) a dynamic design load in longitudinal direction of 6 g and for normal conditions of transport (minor mishaps) dynamic design load of 9 g.

INTRODUCTION

The ***MAXFORCE®*** concept stands for a family of special 20 ft ISO containers, which at the time consist of the ***BOXFORCE®*** container (20 ft BOX container) and the ***TOPFORCE®*** container (20 ft OPEN TOP container) including a special load securing system. The containers represent the state of the art technique in transport of radioactive materials with the highest safety standard world wide. The development of the special containers required many years of intensive research like full scale testing (switchyard ram tests, drop test) with container prototypes and developing a dynamic model for calculating the dynamic forces during transport. The ***BOXFORCE®*** container including the load securing system will be described in detail presenting the prototype test results and the results of the numerical simulations and analyses.

CONTAINER DESIGN REQUIREMENTS

The design requirements which a container carrying dangerous goods must satisfy are embodied in numerous international laws and agreements. A selection of the most important ones are shown in Table 1. Of these, the new IAEA Safety Standards ST-1 and ST-2 (Draft) represent regulations and advisory material which are most important, as far as the transport of radioactive materials is concerned. The ST-1 has included at the first time a dynamic impact requirement for freight containers during routine conditions of transport. In ST-2 there are acceleration factors listed which we interpret as recommended values to help designing the freight containers. E.g. the listed acceleration factor for package retention system design is 5g in longitudinal direction for rail transport. The requirements for the resistance of general freight containers to dynamic loads arising during routine transport operations are also established by the various European railway associations (e.g. German Railways, Swiss Federal Railways etc.) with the railway loading procedures RIV who have set a longitudinal acceleration standard of 4 g (see Table 1) with no shunting restrictions.

Based on various switchyard ram tests, a drop test which STM have been performed and based on numerical simulations using an own developed discrete numerical model. STM came up with the following design requirements for the ***MAXFORCE®*** container concept using the the ST-2 definition for a graded transport approach :

1. First general severity level; routine conditions of transport (incident free)
   Dynamic design loads in longitudinal direction : 6 g *

In accordance to the ST-2 recommended values of 5 g for rail transport, the ACTS value of 6 g and the US value of 10 g (the 10 g value is measured at approx. 50 to 60 Hz which equals to 6 g with low-pass filtering of 16 Hz)

2. Second general severity level; normal conditions of transport (minor mishaps)
   Dynamic design loads in longitudinal direction : 9 g *

Based on the approach used by BAM (Federal Institute of Materials Research and Testing) in Germany for the Dangerous Goods Exemption Regulation GGAV No. 49 (see Table 1) we also use a 1.5 safety factor which result in 9 g (6 g x 1.5) dynamic load for the normal conditions of transport.

3. Third general severity level; accident conditions of transport
   Dynamic design loads in longitudinal direction : >9 g *

* with low-pass filtering frequency of fo = 16 Hz

THE *BOXFORCE®* CONTAINER

The 20 ft freight container is qualified as industrial package Type 2, 3 and Type A-package. The ***BOXFORCE®*** is to our knowledge the only container world wide which is designed to take up dynamic loads in longitudinal direction of up to 510 kN which is equivalent to an impact velocity of ca. 15 km/h or an acceleration of ca. 10 g (see Figure 1).
The regular ISO freight container to transport radioactive materials are designed to take only static loads in accordance with ISO standard 1496 Part 1, 1990. For the transport of dangerous goods it is necessary to have the highest safety standard and to use the best technology available on the market. The risk potential transporting dangerous goods needs a detailed contemplation based on the materials which are transported. In this respect it should be mentioned that radioactive materials of the LSA and SCO categories are by far not the dangerous goods to be transported in freight containers.
The safety margin of the ***BOXFORCE®*** is 6 times higher in comparison to the regular used container for the transport of radioactive materials and other dangerous goods. Table 2 summarizes the most important data about the ***BOXFORCE®*** container.

The ***BOXFORCE®*** container is designed to transport dangerous goods including low radioactive wastes or materials e.g. LSA II/III. In addition, the container is capable of

transporting SCO materials as well as other hazardous solids in granular form. When using 200 liter drums, the container may contain up to 48 drums for a total net weight of 22 metric tons. The ***BOXFORCE®*** is made of special sheet metal and bracing members forming the box. The materials used for construction of the containers is suitable for outdoor temperature range from – 40 °C to +70 °C . While the lateral walls are corrugated, the floor and roof are flat. The longitudinal and transverse support beams together with the floor are made up in the form of a basin. The front wall is formed by a pair of hinged doors with sockets for a forklift. The ***BOXFORCE®*** is watertight from the outside and gastight from the inside to outside using an inner and outer door seal. The leak tightness of the door is tested using the bubble test. The container includes a valve (automatic pressure relief) with a filter near the roof whose purpose is to contain aerosols while impeding the possible build-up of overpressure.
The entire container, both the outer and inner surfaces, are coated with a special paint, a highly resistant anti-corrosion, anti-scratch finish; this enamel not only confers excellent abrasion, chemical thermal and radiation resistance to the wall surfaces, but it also allows easy decontamination of the container.

THE LOAD SECURING SYSTEM

An other important advantage is the drum support and bracing system which allows the ***BOXFORCE®*** to be loaded in various configurations, including not only a variable number of drums, but also drums or other loads of different dimensions. The support and bracing system contains of a special elasto-plastic support trays with grooves for holding the drums in place (see Figure 2), which are light, interchangeable, and can be easily installed and removed from the container for cleaning and decontamination. Together with additional bracing elements, this system impedes the sliding of the drums within the container and exhibits important shock and vibration- absorbing characteristics and drastically improves the safety of the transport system .

VERIFICATION TESTS

The following tests were carried out to certify the container as worthy of industrial package Type 2, 3 and Type A-package:

(1) Drop test with a fully loaded prototype container from a height of 0.3 m onto a rigid surface
(2) Switchyard ram test with 48x200 liter drums (26 tons total) up to an acceleration of 4 g (this is the design limit of the Switchyard ram test facility in Minden/Germany)

Drop test

Prior to the test, the prototype container was loaded up to its maximum allowable weight of 26 tons. The impact surface was a large concrete block weighing about 800 tons, which was overlain with a 35 mm steel plate. The container was lifted in place and dropped from a height of 0.3 m so as to cause an initial impact on the upper edge of the doors, followed by a rotation and crash down onto the roof (Figure 3). The 20 ft BOX container withstood successfully the drop test with no damages at recorded accelerations up to 140 g and received certification to that effect.

Switchyard ram tests

In June 1994, a prototype container fully loaded with 48x200 liter drums was subjected to a series of ram tests at the testing facilities of the German Railway in Minden/Germany (see Figure 4). The 26 ton container was mounted and anchored centered onto a flat car with a self-weight of 20.5 ton, which was in turn rammed by a heavy 80 ton car in sequential tests at progressively increasing speeds, until peak accelerations of 4 g were observed in the flat car. In each case , the motion signatures were measured and recorded at 34 discrete points in the drums, the container, and the cars by means of sensors connected to a data acquisition system. The tests were conducted in both longitudinal directions, that is, with the container doors in either proximal or distal position relative to the end being rammed. Since the facilities of the German Railways at Minden are set up to test only up to 4 g, it was not possible to carry on the experiment to the 9 g level which is the design criteria of the ***BOXFORCE®*** container considering normal conditions of transport . Additional numerical simulations and analyses had to be performed to proof this design criteria.
The container withstood all tests without external damage, and while a few drums exhibited slight indentations, none ruptured or lost its seal.

NUMERICAL SIMULATIONS AND ANALYSES

The previously described Switchyard ram tests served, and were used, to establish the safety and show the compliance with the international rules and regulations and to obtain the requisite certification. However, to show the dynamic load behavior of the container and its content above 4 g up to the STM design limit of 9 g for the normal conditions of transport , we had to supplement the physical ram tests with mathematical experiments which could be tested and evaluated. Among the advantages of such numerical tests are not only the greatly reduced costs, but also the possibilities of making reasonable assessments on the affects of changes in design. Models such as these were used to predict that the container could indeed have sustained, without damage, ramming tests with accelerations of at least 9 g.

Working in cooperation with the University of Hamburg (Prof. Dr. H. C. Flessner) and the Massachusetts Institute of Technology (Prof. Dr. E. Kausel) , a discrete numerical model was developed, implemented in a computer code, and used to determine the dynamic behavior of the container and the load securing system during the different stages of the ramming test up to accident conditions. This analytical model is based on a finite element (e.g. spring-mass) idealization of the container, the drums the supporting trays, and can be used to obtain the complete vibration signatures at strategic points in the system. As it turns out, when the experiments at Minden were simulated by means of this computer code, the computed signatures were found to be in excellent agreement with the measured ones. In addition, it was possible to confirm the superior shock-absorbing characteristics of the elasto-plastic trays. Indeed, one of the most important conclusions obtained from these simulations is that the mechanical properties of the trays play a crucial role in cushioning both the drums and the container walls from damage (see Figure 1). Stiff, inflexible trays allow large forces (exceeding 900 kN, see Figure 1) to be transmitted to the walls at collision speeds of about 13 km/h (approx. 6 g). Such high loads would surely rupture or even destroy the walls or doors of the container. By contrast, a flexible support system goes a long way in absorbing the dynamic impact forces arising during collision.

CONCLUSIONS

An appropriate consideration of dynamic loads in the design of freight containers, intended for the transport of dangerous goods has gained in urgency in recent years. For example, impact acceleration exceeding 6 g could be expected during normal switchyard operations at collisions speeds of about 13 km/h. Indeed, a freight container should be able to withstand such forces without damage. The load securing system for the cargo has been found to play a crucial role in the ability of the container to sustain dynamic loads, which has motivated the development of a novel system of elasto-plastic trays and restraining devices. The transport of hazardous materials is understandably an issue of great concern to the public, and while accident statistics do not give so far cause for preoccupation, such concerns should and must be heeded.

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Table 1. Comparison of Various International Rules and Regulations for 20 ft Freight Containers Regarding Dynamic Loads and Demanded Tests

	ISO 20 ft Freight Container	**Longitudinal**	**Lateral**	**Vertical up**	**Vertical down**	**Tests**
1	International Convention for Safe Containers (**CSC**) 2.12.1972, 2.8.1985, 4.11.1993	2 g (static)	-	-	-	static load, 0.4 P** to end walls static load, 0.6 P** to side walls
2	**ISO 1496** part1, 1990	2 g (static)	-	-	-	static load, 0.4 P** to end walls static load, 0.6 P** to side walls
3	**UIC**-Code 592-1 International Union of Railways 1.1.1979; Reprint 1.7.1985	2 g (static)	-	-	-	static load, 0.4 P** to end walls static load, 0.6 P** to side walls
4	Dangerous Goods Exemption Regulation - **GGAV No. 49** class 7 materials 20.12.1995, Bonn/D canceled July 1, 1997	3 g	1,5 g	1,5 g	3 g	switchyard ram test
5	Technical Rules (**TR Dioxine 001**) for B, E, S* Bonn/D, March 11,1997	3 g	3 g	2 g	-	tests not mentioned
6	Railway Loading Procedures **RIV**, Attachment II, Volume 1 (SBB R 352.1), 28.5.1995; no shunting restrictions	4 g	0,5 g	0,3 g	-	switchyard ram test
7	**IAEA** Safety Standard Series No. ST-2 (Draft), class 7 - rail - road	 5 g 2 g	 2 g 1 g	 2 g 2 g	 2 g 3 g	tests are recommended
8	**UK Railtrack,** England railway	5 g	2 g	2 g	-	switchyard ram test
9	**ACTS** *** Test Procedures for Dangerous Goods UIC-Code 591-1, Attachment 1, 1995	ca. 6 g	-	-	-	switchyard ram test
10	US Federal Register, Vol. 60, No. 188, 28.9.1995 **10 CFR 71.45** ; Lifting and tie-down standards for all packages	10 g	5 g	2 g	-	free fall test, vibration test

g = acceleration due to gravity = 9,81 m/s^2 ; * B = inland waterways, E = rail, S = road
** maximum payload of the Container ; ***Roll-off Container Transport System;

Table 2. Specification for the BOXFORCE® Container Qualified as Industrial Package Type 2, 3 and Type A-Package

	ISO 20 ft Freight Container BOXFORCE®	
1	Packaging Type	IP-2, 3, Type A
2	Solid radioactive materials and dangerous goods	LSA I, II, III; SCO I, II
3	Maximum overall weight (R)	26,000 kg
4	Tare weight (T), empty container weight	4,100 kg
5	Maximum payload (P)	21,900 kg
6	External dimensions	6058 mm x 2438 mm x 2591 mm
7	Inner and outer surfaces	Anti-corrosion finish with easy decontamination (10 years warranty)
8	Load securing system	Elastic braces with shock-absorbing trays and self-tensioning wedges
9	Sealing capacity	Gastight from inside to outside, watertight from the outside
10	**Dynamic design loads** (with low-pass filtering of f_0 = 16 Hz)	
	Longitudinal	9 g
	Lateral	3 g
	Vertical, upwards	3 g
	Vertical, downwards	9 g

Figure 2. The *BOXFORCE®* Container being Loaded with 200 liter Drums Showing the Elasto-Plastic Support Trays

Figure 3. The *BOXFORCE®* Container after the 0.3 m Drop Test

Figure 4. Testing Facilities of the German Railway in Minden/Germany Showing Ram Car and Ramp Pull-up Winch