New Box-Container System for Waste Drums: Dynamic Tests and Qualification

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INTRODUCTION

In this paper we present a new 20' box container, designed by the firm CORROBESCH for the transport of radioactive and other dangerous wastes, and having a carrying capacity of 22 tons. The container itself weighs only 4 tons, and it incorporates a proprietary corrosion finish that is highly resistant to mechanical wear, deformation, and radioactive contamination. Recently, the container was subjected in Germany to a series of collision and drop tests, as specified by the International Atomic Energy Agency (IAEA) , and it passed these tests to complete satisfaction. As a result, the container received certification by agencies such as the Germanischer Lloyd (GL), the Deutsche Bahn A.G. (DB), and the Bundesanstalt für Materialprüfung (BAM). At the same time, the writers have also developed a mathematical model of the container to predict its dynamic behavior during service loads, and have been able to make motion predictions that are in good agreement with signatures recorded during tests.

BOX CONTAINER

The German firm CORROBESCH, with corporate offices in Hamburg, has recently developed a 20 foot ISO box-container of type M-CB 49, intended for the transport of highly radioactive wastes and other dangerous products stored in liquid and granular form within steel drums. While the container weighs only four tons, it can carry up to 22 tons of cargo in various configurations. The container is made of stiffened steel plates, and is closed at one end by two doors with latches and bolts. All interior and exterior surfaces are covered with a highly resilient paint developed and patented by CORROBESCH, which is resistant to chemical corrosion, to mechanical deformation and wear, to scratches and tear, and to radioactive contamination. Indeed, the anti-corrosion finish can sustain radiation levels as high a 30 MGy without damage or permanent contamination, and painted steel plates can be bent by up to 140 degrees without obvious fissures in the corrosion finish. As a result of these characteristics, the container can easily be cleaned, decontaminated and reused.

SUPPORT TRAYS AND MOTION RESTRAINING DEVICES

One of the aims in the development of this container was to achieve a system that could transport cargoes with variable numbers of drums stacked in changeable configurations — including an only partially filled container— while ensuring the safety of the container for accidental dynamic forces and vibrations that could conceivably arise during transport. This goal led CORROBESCH to the design of an interchangeable tray system for the drums that can easily be handled and loaded into the container, together with passive restraining devices that prevent this assembly from moving inside the container when solicited by dynamic forces. Another important consideration was the fact that after loading and sealing of the container, it is not possible to inspect or adjust the contents until after it has arrived at its destination. Since the transport can last days, weeks or even months, it was deemed necessary to avoid the use of restraining devices on the drums that rely on initial set forces, such as tension straps, because with time such devices can loose their tension, and thus their effectiveness.
Hence, CORROBESCH developed passive restraining devices that adjust themselves as the drums vibrate back and forth, see Fig. 1.

Fig. 1

The drums are stacked in two layers, and rest on light flexible trays within grooves that have been carved out in the shape of the drum heads. There are three layers of trays: one on the bottom surface, one between the two drum layers, and one on the top covering the drums. These trays are not continuous at a given elevation, but consist of individual trays having the width of the container, with space for up to three drums; these are placed, one at a time, into the container. Between each individual tray lies a removable restraining bar that is anchored elastically to the side walls of the container. A remaining clearance space above the top tray layer of about 50 cm, which is needed to load or unload the drums using forklifts, is then secured with passive restraining devices consisting of masses and springs that lock the trays into place, and which adjust themselves as the container is shaken by vibrations during transport.

DYNAMIC TESTS

On June 29, 1994 the fully loaded container with a total weight of 26 ton was subjected to a series of controlled collisions tests at the experimental facilities of the German Railroads (Deutsche Bundesbahn, DB) in Minden, FRG. The container was loaded and anchored onto a 20 ton flat car, which was subsequently rammed by an 80 ton car at varying speeds. The speed was adjusted in steps so as to achieve prescribed levels of acceleration of up to four times the acceleration of gravity at the anchoring points of the container. Acceleration signatures were recorded at various points in the container, and extensive measurements were made of the motions experienced by the drums. The container withstood these tests without external damage, no drums were broken, and no fill material was spilled. Following these test, the container received certification by the Deutsche Bahn, the Germanischer Lloyd, and the Bundesanstalt für Materialprüfung as being fit for the transport of dangerous goods.

Six months later, on December 6, 1994, a fully loaded container was subjected to a drop test at the port facilities of Blohm+Voss in Hamburg. The container was hung by one edge 30 cm above the ground and dropped with some inclination onto a concrete mat overlain by a thick steel plate. The container crashed first onto a corner, then pivoted about this point and slammed onto the surface with great violence. The motion signatures were recorded at various points with triaxial devices; additionally, the test was captured on video. While the container suffered some external damage, no fill material was spilled to the exterior.

MATHEMATICAL MODELS

Clearly, full scale dynamic tests are very expensive and time consuming. Even though a number of essential tests are prescribed by the licensing agencies and must unavoidably be carried out, it is also true that these test may often not be exhaustive enough. One can easily imagine — or postulate — scenarios not covered by the tests. Thus, it is desirable to supplement the physical tests with mathematical models that can be used to make predictions about hypothesized accidental conditions. Such tools can be invaluable for the prediction of the behavior of the container during such conditions, and can also be used to interpret any measurements made during actual tests. These considerations moved the writers to develop a discrete numerical model for the analysis of the container when subjected to dynamic conditions. In essence, the authors implemented a finite element model with discrete elements that allow for large motions of the components. The technical details will not be presented in this paper, however, not only because of the limited space available, but also because the theoretical details of such discrete models are generally well understood. Thus, we shall describe only in very general terms some of the characteristics of the model used to predict the behavior during collisions.

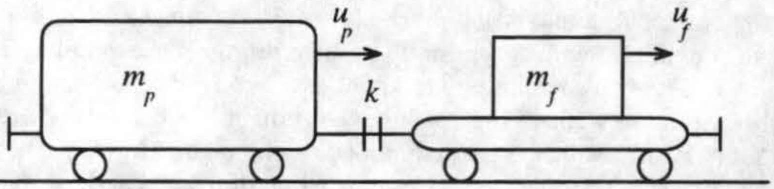

Fig. 2: Ram car and flat car with container

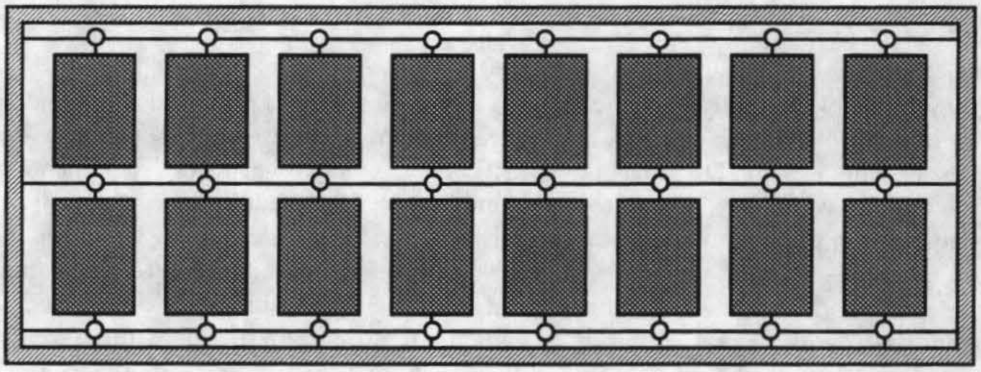

Fig. 3: Container with finite masses

Consider a container loaded onto a flat car, which is in turn impacted from the rear end by another heavy car (Fig. 2). The container is loaded with two layers of drums on trays, and there are eight rows with three drums in each (Fig. 3). Thus, the container contains a total of 2x3x8=48 drums. To a first approximation, such a collision elicits mostly longitudinal horizontal forces within the container, so it suffices to represent this system in terms of a plane (two-dimensional) geometry. In such model, we have made the following assumptions:

- Both the ramming and flat cars as well as the container itself — but not its contents — are infinitely rigid separate bodies of known masses.

- The shock absorbers between the cars are modeled as a linear spring-damper system, which may neither exceed a maximum elongation, nor be subjected to tension. Upon reaching its maximum elongation, the ensuing collision is assumed to be of negligible duration (the time required for a shock wave to travel through the flat car is between one and two orders of magnitude smaller than the response time of the container with the drums inside).

- The drums in the container are rigid bodies connected by elastic springs (the trays and the restraining devices); each drum can both translate as well as rotate about a transversal axis.

- The longitudinal motion of the bottom edge of the inferior row of drums is impeded by friction against the bottom of the container. Upon exceeding its maximum frictional value, each drum may slide independently.

- Inelastic damping forces are neglected.

Using these assumptions, we have then made motion predictions for tested configurations considering three mechanical models of increasing sophistication:

- First, the two colliding cars were assumed to be perfectly rigid and obeying the physical laws governing an elastic-plastic collision (conservation of momentum and energy balance). This is the very simplest model that we used to make predictions about the abrupt change in velocity that takes place when the shock absorbers between the cars have reached their maximum deformation (21 cm).

- Secondly, we considered the collision of two rigid bodies separated by a spring. This model can be evaluated in closed form, it supplements the previous model, and allows one to make simple predictions about the orders of magnitude of the response (accelerations, forces, etc.).

- Finally, we developed a complex numerical model in which the contents of the container are discrete masses separated by springs that can move, rotate, or slide relative to each other. The resulting system of non-linear equations were then solved numerically by means of a special computer code written in the FORTRAN language. Motion signatures were then evaluated at various points and compared to those recorded at the Minden facilities.

After the two cars make contact, momentum begins being transferred through the shock absorber to the flat car with the container, which in turn transfers some of its kinetic energy to the drums in the form of a wave propagating through them in both a horizontal as well as vertical direction. If and when the maximum elongation of the shock absorbers is reached, an elastic plastic collision ensues, which changes abruptly the momentum, and thus the velocity of the flat car. This collision is associated with very large accelerations, which do not immediately affect the drums, since the compliance of the trays and the sliding capability of the drums on the bottom of the container limit the forces that can be transferred to them. A shock wave then develops which again propagates through the system eliciting translations, rotations, and sliding. Each drum experiences then different motions, and must be analyzed in turn.

Fig. 4 depicts the maximum acceleration of one of anchor points of the container as computed with the aid of the second elementary model (the spring-mass system), and shows also values recorded during the actual tests at the DB Minden facilities (where the actual mass ratio was 0.625). As can be seen, the simple model provides excellent estimates of the maximum acceleration, even though the actual system exhibits a more complex (non-linear) behavior due to the changing participation of the contents of the container with the impact velocity.

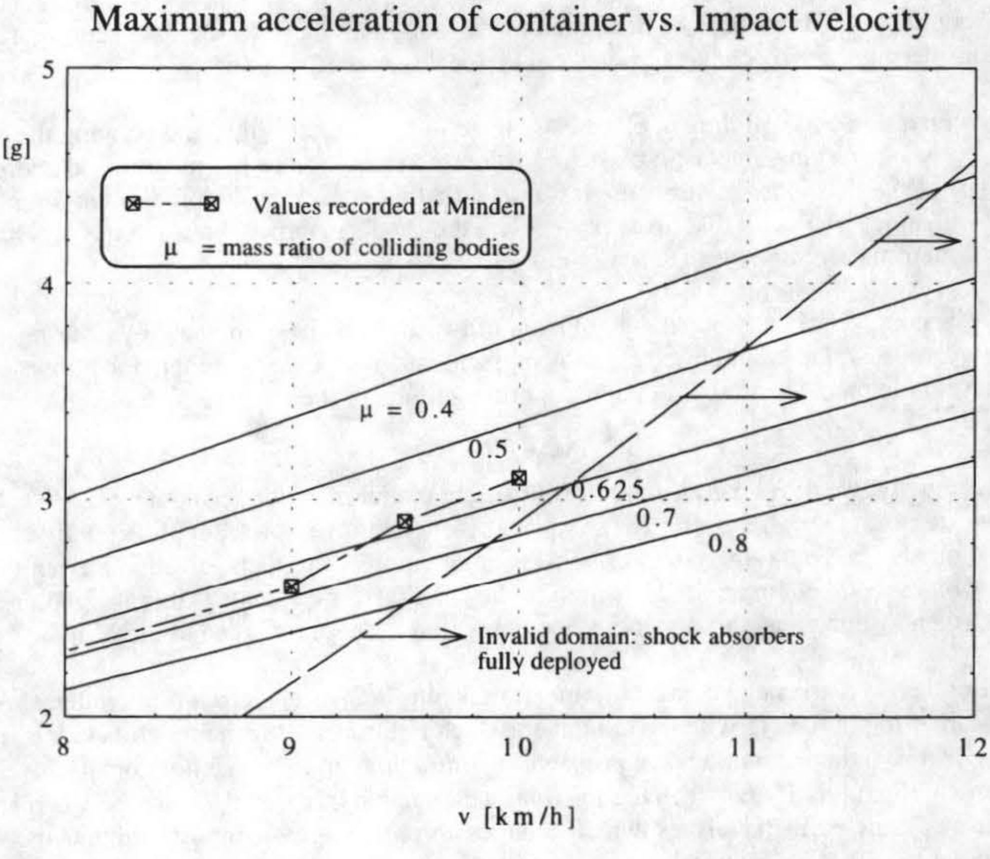

Fig. 4

Figs. 5 and 6 show a comparison of the motions in the front left row of barrels in the container, as computed with the discrete model and as recorded at the Minden test facilities, for a collision velocity of 10 km/hr. Fig. 5 gives the motion at the bottom of the lower layer of barrels (similar to the container's motion), while Fig. 6 provides the acceleration at the top of the upper layer of barrels. In both cases, the synthetic signatures have been low-pass filtered to match the filtering used during the tests (although this made little difference in the computed motions). While the computed and recorded motions are clearly not the same, they exhibit similar overall trends, the orders of magnitude of the acceleration are similar, and there is general concordance in the duration of the process and in the frequencies of oscillation. Indeed, the differences in these figures is no worse than the variations that were observed in actual motions recorded at the left, center, and right barrel columns (not shown), which on account of symmetry could have been expected to be very similar, or even the same. This experimental observation indicates that the trays supporting the barrels may not have had symmetric stiffness/geometric properties, and/or that non-linear processes (e.g. local yielding of materials etc.) played an important role. Nonetheless, the numerical model provided useful results concerning overall physical behavior.

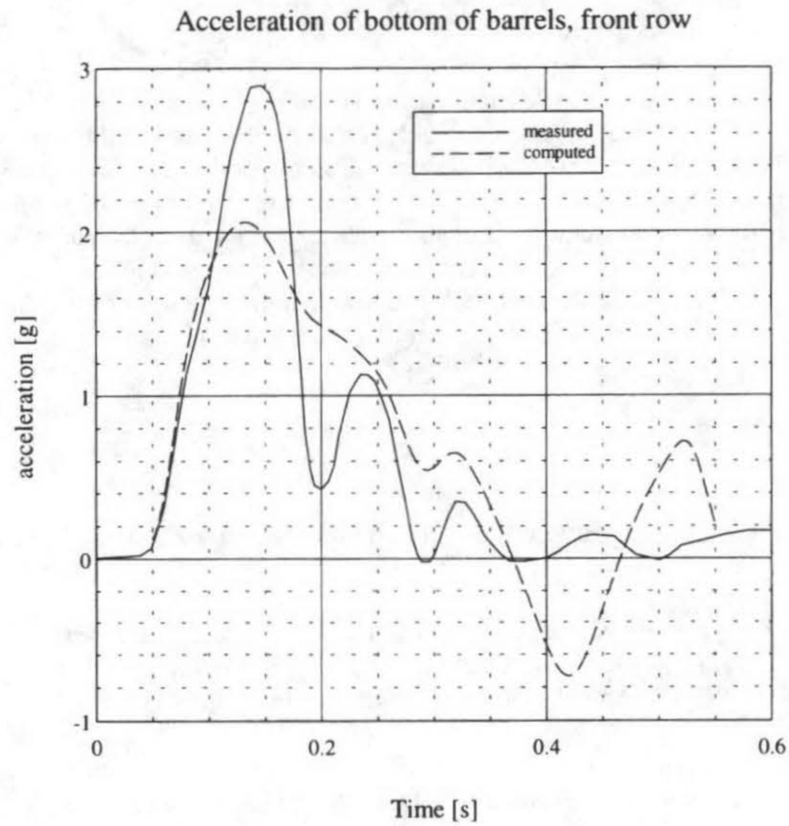
Acceleration of bottom of barrels, front row
measured
computed
acceleration [g]
3
2
1
0
-1
0
0.2
0.4
0.6
Time [s]

Fig. 5

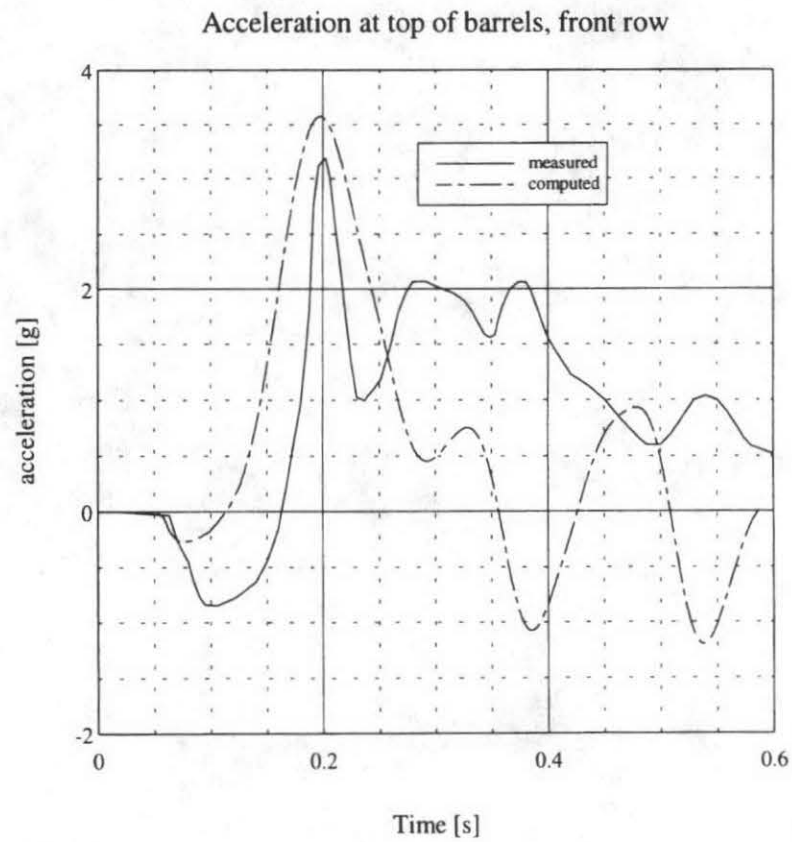
Acceleration at top of barrels, front row
measured
computed
acceleration [g]
4
2
0
-2
0
0.2
0.4
0.6
Time [s]

Fig. 6

CONCLUSION

Discrete numerical models for the dynamic analysis of box containers intended for the transport of drums filled with radioactive products, such as that briefly described herein, can provide valuable insight in the behavior of such systems during hypothesized accidental conditions. More importantly, they can be used to supplement and expand the results obtained in actual testing, to help in their interpretation, and above all, to test for design changes in the computer without the need for expensive experiments. The model considered in the context of the new 20' box container designed by CORROBESCH has yielded prediction numbers that were in reasonable agreement with the signatures recorded during actual tests.

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