C 6/7

Impact Tests on Scale Models of a Shock Absorber for a LWR Spent Fuel Transport Packaging

D. Aquaro, G. Forasassi

Università degli Studi di Pisa, Dipartimento di Costruzioni Meccaniche e Nucleari, Via Diotisalvi 2, I-56100 Pisa, Italy

ABSTRACT

The main results of the elaboration of the test data sets,collected during the development of a research program carried out by the Dipartimento di Costruzioni Meccaniche e Nucleari of Università di Pisa, for the study and the characterization of a shell type shock absorber for a LWR spent fuel cask at present under study in Italy,are discussed.

The test program included several impact test series on reduced scale models for pratical and economical reasons, as the prototype weight will be over 64000 kg.

The experimental data were elaborated against the results of a dimensional analysis of the structure dynamic deformation problem. This analysis indicates, in synthesis, for the acceleration an inverse and for deformation a direct proportionality to the scale factor.

Actually the values of the adimensional monomials, derived from the analysis and calculated by means of the experimental values of variables such as acceleration and deformation, are in a fair mutual agreement and seem to form a statistically significative set of data.

Also the overall efficiency of the impact limiter was confirmed by the relatively low expected acceleration values for the prototype.

1. Introduction

The transport of LWR spent fuel elements is performed by means of very large and heavy packagings with suitable structures in order to mantain the necessary safety levels, even in accident conditions.

The performance of such packagings in the above mentioned conditions are actually tested, or theoretically calculated, taking in account several reference test series indicated in the relevant IAEA regulations. Among these tests the 9 m. free drop test against an hardmore plate is the most severe, at least from the structural integrity point of view.

In order to meet the IAEA [1] safety limits for the shelding and containment capabilities in that condition, nearly all the uptodate packagings are provided with various types of impact limiters.

In the case of the cylindrical LWR spent fuel cask, designed in Italy by AGN (fig. 1)[2], two shell type shock absorbers are used for the protection of the bases as well as of the body of the cask it self, for all the possible positions envisaged in the drop test.

Due to the shape and type of the shock absorbers, besides the design numerical calculations, it was considered necessary to set up an experimental research program with the aim of:

a) studying and characterizing the shock absorber behaviour in the relevant impact conditions
b) confirming the design hypotheses
c) actually testing the structure performances from the "licensing" point of view.

In consideration of the dimensions and weight of the cask (over 64000 kg), the program was carried out on reduced scale models by the Dipartimento di Costruzioni Meccaniche e Nucleari (DCMN) of Università di Pisa with the financial support of ENEA.

The experimental data were elaborated in the light of a dimensional analysis of the structure dynamic deformation problem, in order to define the limit, if one, of the possibility of their use for the prototype design.

2. Experimental Program

The experimental program [3] was carried out on 3 types of scale models with scale reduction factors of 1:9, 1:6 and 1:2, with weight ranging from near 90 to 8000 kg. These values were selected taking in account of the availability of suitable commercial materials (of the same types envisaged for the prototype) and the need of attaining results capable to demostrate the reliability of the experimental data extrapolation by means of the scale laws defined within the analysis (cfr.par 3).

The larger part of the models were made out of carbon steel; few 1/6 scale specimens were of AISI 304.

The test series included essentially vertical and lateral drop tests but also inclined axis (30° and 70° on the horizontal plane) drop tests were performed in order to verify the performances of the absorber structure in these impact conditions.

The main components of the test apparatus were the 15 mt. drop tower with integrated target (for the smaller models), the 4x4 mt. reinforced concrete steel plated target (for the larger models) available in the DCMN laboratory, as well as suitable mobile crane and drop devices.

During the tests, accelerations of the model body and dynamic strains on the shock absorbers surfaces were recorded by means of piezoelectric accelerometers and strain gauges connected by suitable amplifiers to multitraces magnetic tape recorders for an off-line computer aided processing.

The overall model deformations too were registered by means an high speed camera.

In fig. 2 and 3 an 1/2 scale model is shown after a vertical and a lateral drop test respectively.

3. Dimensional Analysis

The analysis of the problem was aimed to define several adimensional monomials capable to characterize the behaviour of the shock absorbers in impact conditions taking into account the geometry of the structures, the mechanical characteristics of the materials,the test conditions and parameters interesting from a design point of view as the acceleration of the model body and the deformation of the absorbers.

Among the variables characterizing the fenomenon were considered:

- m = mass of the model $|M|$
- g, a = gravity and model acceleration $|LT^{-2}|$
- H = drop height L
- σ_y = material yield strength $|ML^{-1}\ T^{-2}|$
- $z, \Delta z$ = absorber characteristic dimension, variation $|L|$
- s = absorber thickness $|L|$
- Δt = impact duration $|T|$

According to the Buckingham theorem [4] the following complete set of adimensional monomials was chosen in the above mentioned hypotheses:

$$\Pi_1 = \frac{\bar{a}\ m}{\sigma_y\ s^2} \qquad (1)$$

$$\Pi_2 = \Delta t\ \sqrt{\frac{\sigma_y\ s}{m}} \qquad (2)$$

$$\Pi_3 = \Delta z\ \frac{\sigma_y\ s^2}{m\ g\ H} \qquad (3)$$

$$\lambda_1 = \Delta z/s \qquad (4)$$

$$\lambda_2 = a/g \qquad (5)$$

$$\lambda_3 = s/z \qquad (6)$$

Indicating with K the geometric scale reduction factor, the similarity laws derived for the scale factors K_i pertaining to the more relevant variables are

$$K_a = K^{-1}$$

$$K_{\Delta t} = K$$

$$K_{\Delta z} = K \qquad (7)$$

$$K_a = K_{\bar{g}}$$

assuming that the material and the drop height are the same for the models and the prototype ($K_{\sigma y} = K_H = 1$).

As $K_g = 1$, the first and the last of the (7) cannot be verified simultaneously; from this consideration the necessity arises to verify experimentally, in the specific case, the limits of the errors connected to the application to the prototype design of the first three of the (7).

4. Experimental Results elaboration

In the tables I and II the values of some adimensional monomials are reported as calculated on the experimental results basis for vertical and lateral drop tests.

As it is possible to see also from the absolute and relative values of the standard deviation, the results show a consistent repeatability, with $\sigma/\bar{x}$ overall values under the 16% and 11% for the vertical and lateral drop tests respectively. Moreover the larger dispersion for the vertical drop test may be due to some deviations in the 1/9 scale model geometry.

It is worthwhile to note that the Student test for the experimental data indicated that the probability that the difference, between the actual and the calculated mean value, may be greater than 16% is egual to 10% and 1% for the vertical and the lateral drop test respectively.

In the fig. 4 a, b are reported the acceleration diagrams for the prototype as extrapolated by means of the relations (7) from the ones registered and digitally processed for the scale models. Also in this case it is possible to see that the agreement among the curves is well within acceptable limits from a practical design point of view.

5. Conclusions

The experimental results and the analysis carried out confirmed that it is possible to obtain usefull design information for this type of shock absorbers by means of reduced scale model testing with evident economical and practical advantages.

Moreover the relatively low deviations observed in the test values seems to be at least partially due to the inconsistencies in the geometry of models assembled with commercial, even if well controlled, materials and procedures.

The shock absorber structure was shown to be suitable for the envisaged use as mechanical impact protection for the LWR spent fuel transport cask under study.

References

/ 1 / IAEA - "Regulations for the safe Transport of Radioactive Materials". safety series n° 6 - IAEA - 1979 - Vienna

/ 2 / A. OLIVIERI, G. POCHINI, "Calculation and testing of a New conception Impact limiter for irradiated fuel shipping Cask" 6th Int. Simposium on Packaging and trasportation of radioactive Materials - November 10-14-1980 Berlin.

/ 3 / D. AQUARO, G. FORASASSI, "Analysis of the Behaviour under Impact Loads of a shell Type Shock Absorber for a LWR spent Fuel transport Packaging". 7th Int. Simposium on Packaging and Transportation Radioactive Materials. May - 15 - 20, 1983 - New Orleans.

/ 4 / H. LANGHAAR, "Dimension Analysis and Theory of models" - J. Wiley & Sons-New York 1951.

Tab. I - Adimensional monomials calculated for the vertical drop tests

Scale factor K	Shock absorber material	Π_1 (*) $a\, m/\sigma_y\, s^2$	Π_1' (*) $\bar{a}\, m/\sigma_y\, s^2$	Π_2 (*) $\Delta t \sqrt{\frac{\sigma_y\, s}{m}}$	Π_3 (*) $\Delta z\, \frac{mgH}{\sigma_y\, s^2}$
1:9	carbon steel	67,860	43,501	1,020	2,30 10^{-2}
1:6	AISI 304	50,649	36,784	1,188	3,27 10^{-2}
1:6	AISI 304	51,853	36,530	1,196	3,08 10^{-2}
1:6	carbon steel	47,860	31,870	1,165	3,12 10^{-2}
1:2	carbon steel	48,880	29,10	1,261	3,37 10^{-2}
mean value $\bar{x}$ (-)		53,42	35,56	1,16	3,02 10^{-2}
standard deviation σ (-)		8,22	5,50	0,09	0,42 10^{-2}
σ / $\bar{x}$ (%)		15,38	15,46	7,64	14,9

Tab. II - Adimensional monomials calculated for the lateral drop tests

Scale factor K	Shock absorber material	Π_1 (*) $a\, m/\sigma_y\, s^2$	Π_1' (*) $a\, m/\sigma_y\, s^2$	Π_2 (*) $\Delta t \sqrt{\frac{\sigma_y\, s}{m}}$	Π_3 (*) $\Delta z\, \frac{mgH}{\sigma_y\, s^2}$
1:6	carbon steel	94,550	71,910	0,515	1,370 10^{-2}
1:6	carbon steel	104,040	74,470	0,501	1,157 10^{-2}
1:6	AISI 304	-	-	-	1,147 10^{-2}
1:2	carbon steel	96,327	69,129	0,576	1,245 10^{-2}
1:2	carbon steel	103,126	80,461	0,476	1,392 10^{-2}
1:2	carbon steel	90,660	74,795	0,526	1,490 10^{-2}
mean value $\bar{x}$ (-)		97,74	74,15	0,52	1,30 10^{-2}
standard deviation σ (-)		5,72	4,20	0,037	0,139 10^{-2}
σ / $\bar{x}$ (%)		5,85	5,66	7,14	10,68

(*) a, $\bar{a}$ = max, mean model body acceleration; Δt = impact duration; Δz = characteristic deformation.

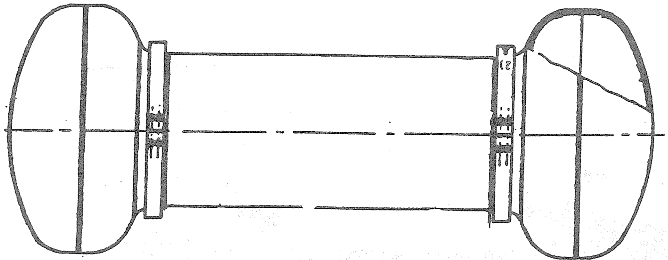


Fig. 1: LWR spent fuel cask model

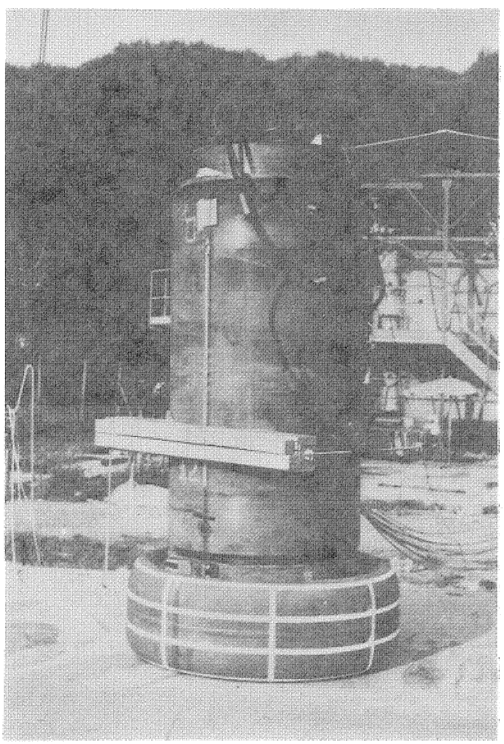


Fig. 2: 9 mt. vertical drop test on a 1/2 scale model

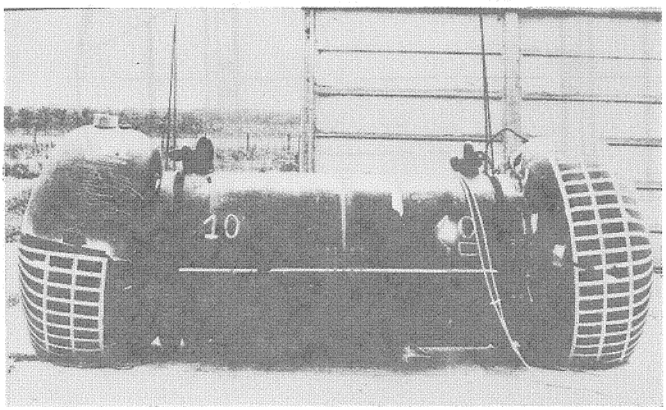
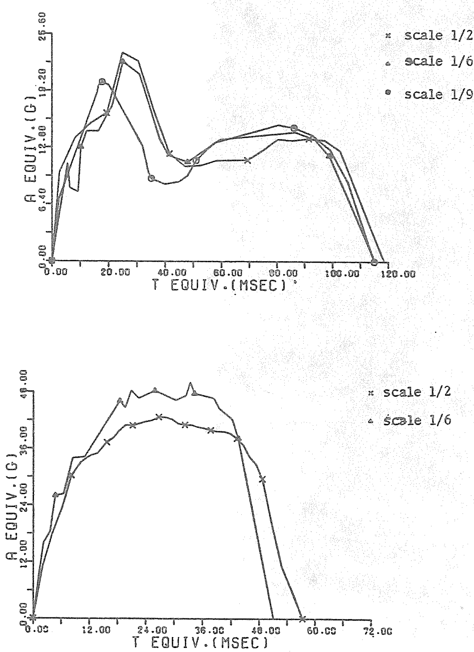


Fig. 3: 9 mt. lateral drop test on a 1/2 scale model



a)

b)

Fig. 4: Acceleration diagrams comparison as extrapolated for the cask prototype from the scale model test results.

a) vertical drop

b) lateral drop