DEVELOPMENT OF A LARGE UNYIELDING TARGET FOR PACKAGING TESTS*

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Abstract

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A large, essentially unyielding, target for nuclear transportation package testing has been developed at Sandia National Laboratories in Albuquerque, New Mexico. The target was designed, and its performance predicted, using computer modelling methods. The performance was verified by conducting a high-speed impact test of an experimental package onto the target and analysing data from instrumentation installed within the target.

INTRODUCTION

Impact testing is frequently used to demonstrate compliance with radioactive material packaging regulations [1] [2]. For Type A and Type B packages, a test specimen must free drop onto an unyielding target from a specified height so as to suffer maximum damage. Drop heights range from 0.3 m (1 ft) for a normal condition of transport test on a package with a mass of greater than 15 000 kg to 9 m (30 ft) for hypothetical accident tests on Type B packages. In the United States, packages for shipment of plutonium by air must also withstand impact at a velocity of not less than 129 m/s (422 ft/s) at a right angle onto a flat, essentially unyielding surface [3]. The impact surface for all of these tests is frequently referred to as an 'unyielding target'. The target is expected to be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the test specimen would not significantly increase the damage to the specimen.

The proposed revision to Safety Series No. 37 provides an example of an unyielding target to meet testing requirements. An acceptable target consists of a steel plate bonded to the upper surface of a concrete block whose mass is at least

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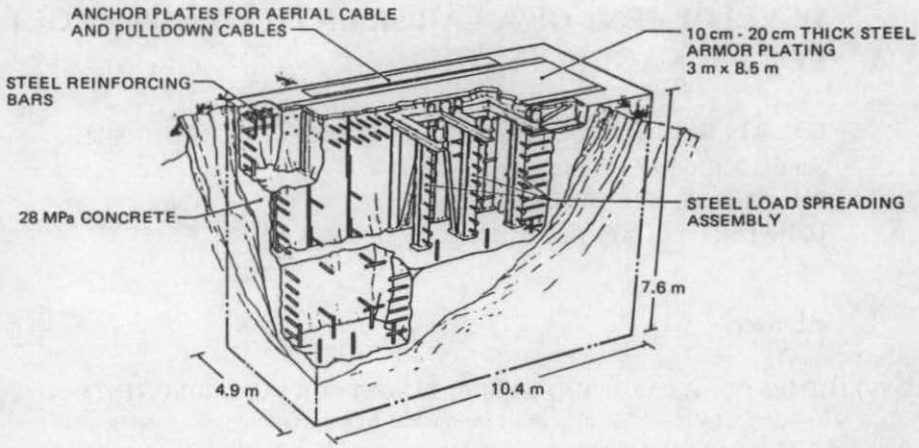

FIG. 1. 910 t armoured target at Sandia National Laboratories.

10 times that of the specimen to be dropped on it. The steel plate should be larger than the package being tested and the target mass should be as close to cubical or cylindrical in form as possible. Analysis and extensive testing experience at Sandia National Laboratories (SNL) have supported the validity of using an 'unyielding target' as described in Safety Series 37 for Type A and B package testing. However, experience has shown the reaction mass ratio of ten to one is insufficient for the higher speed impacts required for testing plutonium air-transportable packages. Although each case needs to be evaluated individually, reaction mass to specimen mass ratios of $\geq$400 have been used for high-speed impact tests conducted at SNL.

Unyielding targets do 'wear out' with frequent and extended use and may require periodic repairs. The most common failure mode is a debonding between the steel surface plate and the concrete mass. Loss of a close structural coupling between the two can adversely affect the validity of impact tests being conducted. As a result of one recent target failure and as part of a continuing program to upgrade test facilities, a new unyielding target has been developed at SNL under the direction of the Transportation Technology Center. The target has been constructed at the SNL Sol Se Mete cable site and will be used for testing Type B and plutonium air-transportable packages.

As shown in Fig. 1, the target is 10.4 m (34 ft) in length, 4.9 m (16 ft) in width and 7.6 m (25 ft) deep with a mass of 910 000 kg (2 000 000 lb). The steel armor plate is 3.1 m (10 ft) by 8.5 m (28 ft) and varies in thickness from 20 cm (8 in) to 10 cm (4 in). Given the large forces reacting on the target and the goal of using it repeatedly without failure, a considerable effort was required to design a structure that would keep the surface plate bonded to the concrete and effectively transmit loads into the mass without causing major compressive failure in the concrete.

Target Construction

The location chosen for construction of the new target was the Aerial Cable Facility at Sol Se Mete Canyon. This facility consists of two parallel cables which span a mountain canyon. The cables are 30 m (100 ft) apart and each has a clear span of 1460 m (4800 ft) and a maximum height above the test area at mid-span of 180 m (600 ft). One cable is the trolley cable and the other is the pull-down cable. The new target was constructed under the pull-down cable. A package to be tested under simulated aircraft crash conditions is suspended above the target and wire rope towing cables are attached. The towing cables travel downward through high speed sheaves attached to the sides of the target and horizontally to a rocket sled where they are terminated. The package to be tested is then accelerated to the desired impact velocity by the rocket sled using multiple rockets and can achieve impact velocities of $\geq$129 m/s (422 ft/s) to simulate an airplane crash. A package may also undergo the regulatory 9 meter drop to simulate hypothetical accident conditions for surface transport by suspending the items to be tested from the aerial cable, a mobile crane, or a temporary test stand and releasing the package so that it impacts onto the target in the desired orientation.

The general location evaluated for the target was an area under the pull-down cable more than 100 m (300 ft) in length along the canyon floor. The final site was chosen after a shallow seismic refraction survey was performed throughout the area. In addition, three test borings were made to depths of 13 m (43 ft) and the soil type and density characterized. No bedrock was encountered under the target. In order to make the steel armored surface of the target level with the surrounding terrain, the area was excavated to a depth of approximately 8 m (26 ft) to allow forming of the structure.

The bottom 4 m (13 ft) was formed and reinforced with #8 rebar on .3 m (1 ft) centers around the perimeter and 1.2 m (4 ft) centers throughout the section. The concrete for this section was poured in October 1985. A steel load spreading structure, consisting of thirteen steel W10x19 columns with anchor studs and base plates, was constructed and positioned on the top of the 4 m (13 ft) base section. The forming

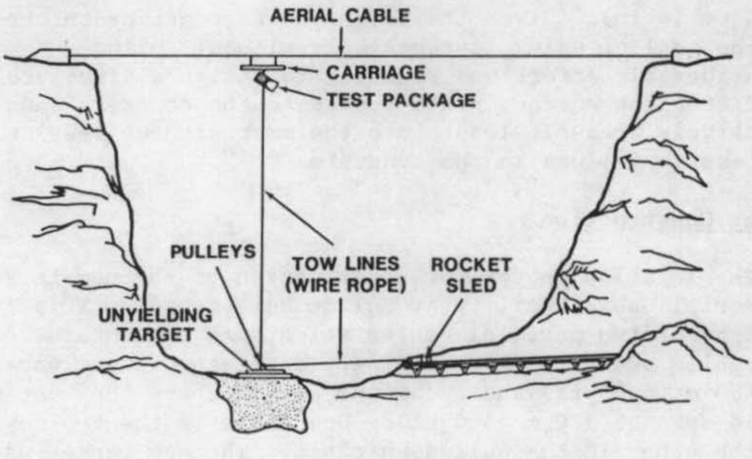

FIG. 2. Rocket Pulldown Facility.

materials were then repositioned for construction of the next two sections of concrete. After form removal from the lower section, the exposed concrete surfaces were covered with 5 cm (2 in) of Styrofoam insulation to minimize the temperature differential from the center to the exterior surfaces resulting from the heat of hydration in the still curing concrete. The excavation surrounding the base section was then backfilled and recompacted. Reinforcing steel for the second section was installed on the same spacing as the base section and the concrete was poured. Reinforcing bars were installed on .3 m (1 ft) centers in the top 1 m (3 ft) of the last concrete section. The top plate which was a section of battleship armor varying from 20 cm (8 in) to 10 cm (4 in) in thickness was welded to the load spreading assembly. The third and last section of concrete was poured and a high-strength grout was pressure injected the same day to assure all areas under the steel plate were filled. The forms were removed within 24 hours and rigid insulation installed on the sides of the structure. The excavation was then backfilled and recompacted to the original elevation.

Small diameter (63 mm) holes were drilled in the armor plate on .5 m (18 cm) centers and a high-strength epoxy grout was pressure injected under the plate to assure all cracks, separations, and voids resulting from construction or concrete shrinkage during curing were completely filled. The concrete was vibrated throughout each pour to minimize voids. A bonding agent was applied on the top surface of the first and second concrete sections to ensure a good bond at the 'cold joints' between sections. The concrete was specified to have a minimum compressive strength of 28 MPa (4000 psi) and tests performed

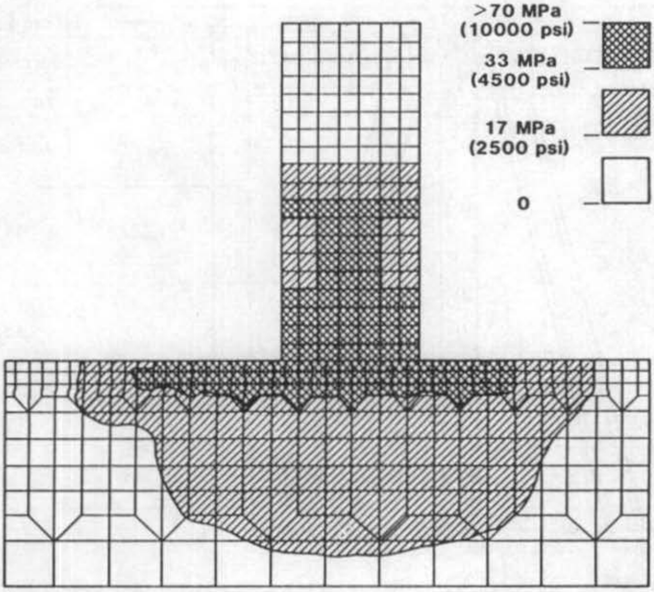

FIG. 3. Von Mises' stress in target and test unit calculated by DYNA2D finite element code.

on samples of each section of concrete indicated a compressive strength of 34 MPa (5000 psi) or greater. The cement grout used was tested to have a compressive strength of approximately 54 MPa (7800 psi). The epoxy grout had a compressive strength of 110 MPa (16 000 psi).

Analytical and Experimental Evaluation

The target was evaluated both experimentally and analytically to determine its effectiveness. DYNA2D [4] an explicit integration finite element code, was used to perform the analytical calculations. For experimental verification, a 2040 kg (4500 pound) package was impacted onto the target in March 1986 at a velocity of 134 m/s (440 ft/s). Fig. 2 illustrates the experimental test setup. Strain gauges attached to internal members of the target provided experimental results for comparison with computer calculations. Correlation between the experimental and analytical results proved quite good.

Given the complexity of the problem, simplification of the steel load spreading structure within the target mass was required for computer modeling (Fig. 3). The concrete was modeled as an elastic-perfectly plastic material. While a more realistic concrete material model that properly simulates cracking and spalling does not exist in present finite element

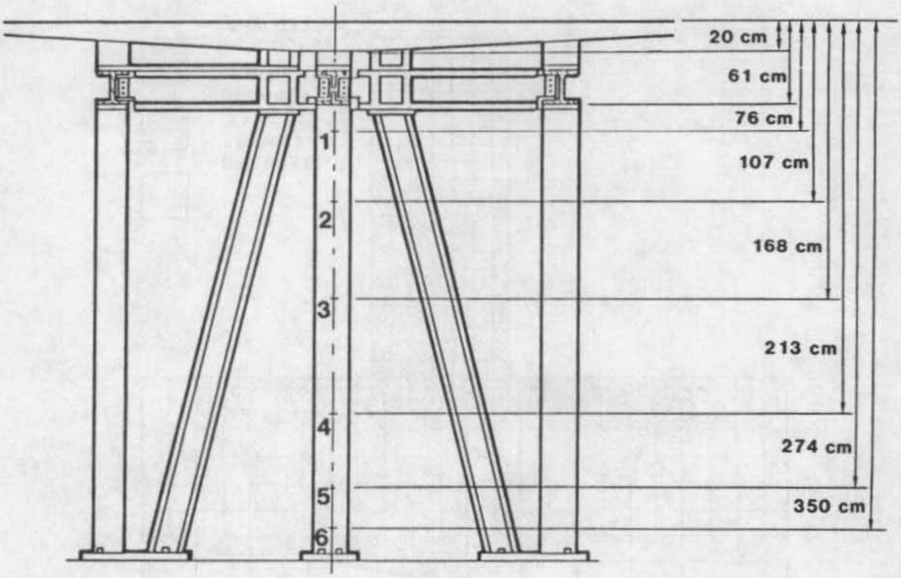

FIG. 4. Strain gauge locations on centre load spreading column.

codes, the use of an elastic-perfectly plastic analysis produced results indicative of the experimental data. DYNA2D results show the steel plate and load spreaders do absorb the given load. However, this load is also directly transmitted to the concrete below the target (Fig. 3). Independent of the concrete mass of a particular target, the concrete directly below the point of impact will experience stresses in proportion to the load applied. As the initial load is absorbed into the concrete, the load spreading capabilities of the entire structure and concrete mass come into effect. The analysis showed that the concrete under the load would experience high stresses to the point of cracking. The exact amount or depth of cracking was not clearly evident from the analysis, only that localized cracking could occur.

Six strain gauges were used to instrument the target to determine any movement of the steel plate subjected to impact loading. The gauges were placed along the internal load spreading beam situated directly under the center of the steel plate (Fig. 4). Table 1 shows the response experienced by the gauges when the target was subjected to its first impact. The first four strain gauges registered strains high enough to cause permanent deformation. Fig. 5 shows the strain versus time plot for the gauge 76 cm (30 in.) below the top of the plate. A permanent strain reading of 130 microstrains corresponds to plastic deformation of 10% over the yield stress.

TABLE I. STRAIN GAUGE TEST DATA

Strain gauge	1	2	3	4*	5*	6*
Maximum Microstrain	1800	850	540	600	600	75
Permanent Microstrain	130	130	130	80	0	0

*Stress Wave

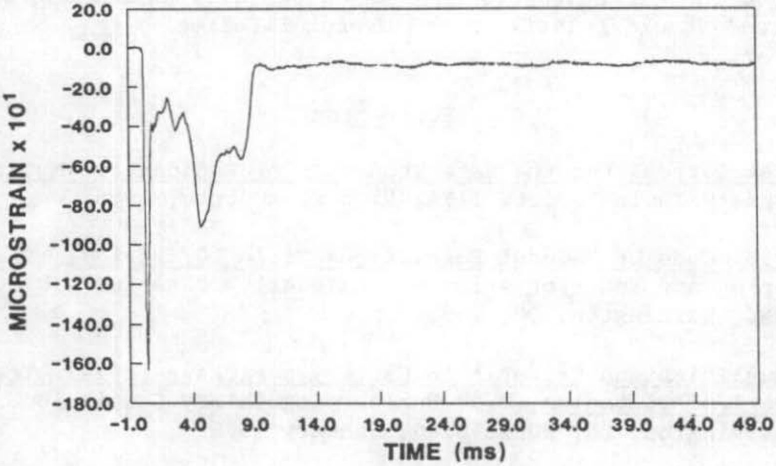

FIG. 5. Strain gauge signal at 76 cm below top of armour.

Judging by the strain readings, the load began to dissipate as it traveled away from the plate surface. This is evident from the signal in strain gauges 4, 5 and 6. These gauges were excited due to a stress wave rather than a direct loading. Thus, the target's load spreading capability proved effective. As predicted in the analysis, experimental results showed that directly under the impact point of the unyielding target, the center beam experienced some permanent deformation and some concrete cracking may have occurred. However, no surface cracks are visible and no apparent 'de-bonding' has occurred between the steel plate and the concrete mass. A second impact with a similar package produced no additional permanent deformation in the load spreading member. Thus, the load spreading capabilities of the target remain intact. While some cracking may have taken place, it has not had an adverse affect on target performance.

CONCLUSION

The completion of a new unyielding target at Sandia National Laboratories provides a significantly upgraded capability for radioactive material package testing. Particular emphasis was made to bond the steel plate to the concrete block via the use of I-beam load spreaders. Both an analysis and test showed that the concrete directly below the plate surface would experience stresses above the yield limit. However, the combination of the bonding and load spreading techniques insured the target represented an essentially unyielding surface and should greatly extend useful lifetime.

References

[1] Regulations for the Safe Transport of Radioactive Material, Safety Series No. 6, IAEA, Vienna, Austria, 1985.

[2] U.S. Code of Federal Regulations-Title 10, Part 71, "Packaging and Transportation of Radioactive Material", U.S. NRC, Washington, DC, 1983.

[3] Qualification Criteria to Certify a Package for Air Transport of Plutonium, U.S. Nuclear Regulatory Commission, Washington, DC, NUREG-0360, January 1978.

[4] J. O. Hallquist, User's Manual for DYNA2D -- An Explicit Two-Dimensional Hydrodynamic Finite Element Code with Interactive Reasoning, UCID - 18756 - Rev. 2, Lawrence Livermore Laboratory, Livermore, California, January 1984.