TORNADO MISSILE IMPACT STUDY

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ABSTRACT

UCRL-15910 specifies wind and tornado missiles for moderate- and high-hazard DOE facilities. Wall-barrier specimens have been tested at the Tornado Missile Impact Facility at Texas Tech University. The facility has an air- activated tornado missile cannon capable of firing 2x4 timber planks weighing 12 lb at speeds up to 150 mph and 3-in-diameter steel pipes weighing 75 lb at speeds to 7 5 mph.

Wall barriers tested to date include reinforced concrete walls from 4-in. to 10-in. thick; 8-in. and 12-in. walls of reinforced concrete masonry units (CMU); two other masonry wall configurations consisting of an 8-in. CMU with a 4-in. clay-brick veneer and a 10-in. composite wall with two wythes of 4-in. clay brick.

The impact test series is designed to determine the impact speed that will produce backface spall of each wall barrier. A set of 15 wall sections has been constructed and tested at this time. Preliminary finding suggest that all cells of CMU walls must be grouted to prevent missile penetration. Walls recommended in the workshop on UCRL-15910 provide acceptable protection if cracking can be accepted.

Tornado missile criteria in UCRL-15910 is based on experience from windstorm damage documentation. The objectives of the study described in this paper are to determine the effects of missile impact according to UCRL 15910 criteria on various wall configurations and to determine the types of walls needed to satisfy the missile criteria. Missile impact tests were conducted in the Tornado Missile Impact Facility at Texas Tech University.

A literature review identified tests that had been conducted previously, including earlier 2x4 timber plank tests at Texas Tech. A testing plan was then developed to determine the threshold effects of the 3-in. diameter steel pipe missile specified in the UCRL 15910 criteria. Both reinforced concrete and masonry wall barriers were tested.

The Rotz Equation, an empirical relationship developed from a series of impact tests conducted by Bechtel Power Corporation, was used for preliminary design of the concrete test specimens. The barrier thickness determined by the Rotz Equation were in relatively good agreement with those predicted by the Modified NDRC equation, which is a modified version based on ballistic tests. Designs of the masonry wall barriers were extrapolated from results of limited tests on masonry barriers at Texas Tech.

The current series of tests consisted of nine concrete test barriers and three masonry barriers. The concrete specimens were 39 in. square with various thickness and percentages of reinforcing steel. The concrete was furnished by a commercial company, while the masonry specimens were constructed by masonry tradesmen.

The Tornado Missile Impact Test Facility consists of a compressed air actuated cannon, a reaction frame and an electronic missile speed measuring gate. The cannon consists of a compressed air tank, a quick opening butterfly

valve and a 20 ft barrel. The reaction frame, which supports the test specimen, is very stiff. It supports the test specimen on all four sides. The timing gate measures the missile speed as the trailing end of the missile leaves the barrel. This gives the speed when the missile is approximately two feet from impact. Although some tests have involved oblique impact angles, the worst case appears to be on end. All tests reported herein are on-end impacts.

Results of the timber plank impact tests are published elsewhere. The results of the impact tests for the 3-in. diameter steel pipe are summarized in Table 1. The 2x4 timber plank will perforate wood, metal panels, and corrugated asbestos panels at speeds of 50 mph or greater. An 8-in. concrete wall with minimum reinforcing on back face is required to stop the 3-in. diameter pipe at 50 mph. Some radial cracks less than 3/16 in. were observed, but no back face spall takes place. The threshold speed for spall on a 9-in. thick reinforced concrete slab in 75 mph. A 10-in. thick wall has no back face spall at an impact speed of 75 mph. The 3-in. diameter pipe perforated an 8-in. masonry wall constructed of 9-in. CMUs with vertical cells reinforced and grouted at 75 mph impact speed. A similar wall constructed with 12-in. CMUs had 1/8 in. hairline cracks on front and back faces, but no perforation or spall. The 9 1/2-in. brick cavity wall was tested at 50 mph impact speed. A 1/4-in. crack appeared on the back face, but there was no perforation or spall.

Preliminary recommendations for minimum barrier requirements to satisfy UCRL 15910 missile impact criteria are as follows:

Moderate Hazard, Straight Wind: Requires minimum of 8-in. CMU wall reinforced with 1 - #3 rebar grouted in each vertical cell and trussed horizontal joint reinforcement @ 16-in. o.c.

Moderate Hazard, Tornado: Timber plank impact at 100 mph requires 8-in. CMU wall reinforced with 1 - #3 rebar grouted in each vertical cell and trussed horizontal joint reinforcement @ 16-in. o.c.; 6-in. concrete wall with #3 rebar @ 12-in. o.c., each way 1 1/2 in. from inside face. 3-in. diameter steel pipe impact at 50 mph requires 12-in. CMU wall reinforced with 1 - #4 rebar grouted in each vertical cell and trussed horizontal joint reinforcement @ 16 in. o.c.; 8-in. concrete wall reinforced with #4 rebar @ 12-in. o.c. each way, and 1 1/2-in. from each face.

High Hazard, Straight Wind: Requires minimum of 8-in. CMU wall reinforced with 1 - #3 rebar grouted in each vertical cell and trussed horizontal joint reinforcement @ 16-in. o.c.

High Hazard, Tornado: Timber plank at 150 mph requires 8-in. CMU block wall reinforced with 1 - #4 rebar grouted in each vertical cell and trussed horizontal joint reinforcement @ 8-in. o.c.; 6-in. concrete wall with #4 rebar @ 12-in. o.c., each way, 1 1/2-in. from each face. 3-in. diameter steel pipe at 75 mph requires 10-in. reinforced concrete wall with #4 rebar @ 12-in. o.c. each way, 1 1/2 - in. from each side.

Consideration of the 3000 lb automobile at an impact speed of 25 mph requires structural response calculations that are beyond the scope of this project.

TABLE 1. TORNADO MISSILE IMPACTS TESTS

Missile: 3 in. diameter. Schedule 40 Steep Pipe weighing 75 lb

Test	Impact Speed mph	Target Description	Damage Description
CR-6.1	36	6-in concrete wall reinforced with #3 rebar @ 9 in. o.c. each way, 1 1/2in. from front face.	Vertical crack on front face, radial cracks on back face that propagate thru thickness of slab. Max. width of tensile crack 3/16 in. Missile penetration 1/4 in., no back face spall.
CR-6.2	37	6-in. concrete wall reinforced with #4 Rebar @ 12 in. o.c. each way, 1 1/2 in. from back face.	Radial hairline cracks on front & back face. Missile penetration 3/8 in., no back face spall.
CR-6.3	38	6-in. concrete wall reinforced with #3 rebar @ 6 in. o.c. each way, 1 1/2 in. from back face.	Small radial cracks on front face larger radial cracks on back face, max. width of crack 1/8 in. Missile penetration 3/8 in., no back face spall.
CR-8 1	44	8-in concrete wall reinforced with #4 rebar @ 9 in. o.c. each way in the middle of wall.	One horizontal crack on front face. Radial cracks on back face, max. width of crack 1/16 in. Missile penetration 3/8 in., no back face spall.
CR-8.2	44	8-in. concrete wall reinforced with #4 rebar @ 12 in. o.c. each way in the middle of wall.	Vertical crack on front face, radial cracks on back face. Max. width of crack 1/8 in. Missile penetration 5/8 in., no back face spall.
CR-8.3	50	8-in concrete wall reinforced with #3 rebar @ 12 in. o.c. each way, each face 1 1/2 in. from each face.	No cracks on front face. Radial cracks on back face, max width of crack 3/16 in. Missile penetration 11/16 in., no back face spall.
CR-9.1	50	9-in. concrete slab reinforced with #4 rebar @ 12 in., o.c. each way, each face 1 1/2 in. from each face.	No cracks on front face. Hairline radial cracks on back face. Missile penetration 7/16 in., no back face spall.

TABLE 1. TORNADO MISSILE IMPACTS TESTS (Con't)

Missile: 3 in. diameter. Schedule 40 Steep Pipe weighing 75 lb

Test	Impact Speed mph	Target Description	Damage Description
CR-9.2	78	Same wall as CR-9.1	Extensive radial cracks on back face, impact appears right spall threshold. Missile penetration 1 1/2 in., max. width of crack 1/8 in. Small (1 in. x 1/2 in.) chips of concrete spalled from back face.
CR-10.1	74	10-in. concrete wall reinforced with #4 rebar @ 12 in. o.c. each way, each face, 1 1/2 in. from each face.	No cracks on front face, radial hairline cracks on back face. Missile penetration 13/16 in., no spall.
CBM-(9.5).1	50	52 in. wide x 48 in. high clay brick masonry cavity wall, 9 1/2 in. thick. Cavity reinforced vertically with #3 rebar @ 8 in. o.c. Horizontal joint reinforcement placed @ 16 in. o.c.	Discontinuous vertical hairline crack on front face, vertical on back face, max. width of crack 1/4 in. Missile penetration 1 1/8 in., no back face spall.
CBCMU-12.1	50	48 in. wide x 48 in. high masonry wall constructed of 8-in. CMUs and 4-in. clay bricks. CMU cells reinforced with #4 rebar and grouted. Horizontal joint reinforcement placed @ 16 in. o.c.	Two cracks on front face, one rising vertically from the impact point and the other running horizontally from the impact point to the right side of the wall. Vertical cracks on both front and back face are 3/8 in. wide. Missile penetration 2 1/8 in. Impact at threshold of back face spall.