BRICK MODEL TESTS OF SHALLOW UNDERGROUND MAGAZINE

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BRICK MODEL TESTS OF SHALLOW UNDERGROUND MAGAZINES

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INTRODUCTION

A considerable amount of research has been performed in the last two decades to develop data and prediction methods for airblast and debris hazards from accidental explosions in underground magazines. Much of this work is concerned with detonations in magazines so deep that venting does not occur. For the shallow magazines, the effect of cover venting on reduction of external airblast was initially investigated in small-scale tests (1:25) performed in the United Kingdom (Millington, 1985). More recently, the Shallow Underground Tunnel/Chamber Explosion Test (Joachim, 1990), sponsored by the KLOTZ Club*, provided full-scale airblast and debris/ejecta data for a shallow underground magazine containing 20,000 kg, net explosive weight (NEW).

Previous explosive cratering tsts by the U.S. Army Engineer Waterways Experiment Station (WES) has indicated a definite effect of rock strength and structure (jointing) and terrain surface slope, as well as the charge cover depth, on the size and shape of the crater produced, and on the amount, direction, and velocity of ejecta thrown out (Davis, 1981, Smith, 1989 and Joachim, 1988). These results strongly imply that, at large scales where extensive volumes of rock must be moved during the venting process, the gross (as opposed to unit) strength and structure of shallow rock covers may be important factors in predicting the extent of rupture of the cover, and the ejecta hazard ranges, from site to site. This is in addition to the known problem of accounting for the variations in cover thickness and surface slope.

The 1988 Shallow Underground Test provided data for a single set of test conditions. In actual practice, however, such magazines have been constructed at sites having a wide range of rock strengths and cover thicknesses. In addition, the loading densities of the magazines differ from site to site. This paper describes a series of model tests conducted to investigate the influence that these variations would have on the external blast hazards from an accidental explosion in shallow underground magazines. This work was sponsored by the Directorate of Health and Safety, Ministry of Defence,

* The KLOTZ Club is an ad hoc committee, representing the defense agencies of France, Germany, Norway, Sweden, Switzerland, the United Kingdom, and the United States, which sponsors research to improve the safety of ammunition storage.

United Kingdom; the Norwegian Defence Construction Service; and the Department of Defense Explosives Safety Board.

OBJECTIVE

The overall objective of the Brick Model test program was to determine the hazardous effects (airblast and debris) produced by an accidental detonation of explosive stores which ruptures the overhead cover of an underground magazine. Specific test objectives were to evaluate the effects of explosive loading density (kg of explosive per m^3 of chamber volume) and the thickness and strength of the rock cover on the external blast hazards.

DESCRIPTION OF TESTS

Three magazine models were tested, each consisting of a single storage chamber and access tunnel constructed in a large testbed of paving brick, simulating a jointed rock mass. The dimensions of the storage chamber and access tunnel corresponded to a 1:25-scale model of those constructed for the 1988 Shallow Underground Tunnel/Chamber Explosion Test. The model storage chamber was 72 cm long, with a cross-sectional area of 294.4 cm^2 (20 cm wide by 16 cm high; see Figure 1). The access tunnel was 1.0 m long with a cross-sectional area of 84.4 cm^2 (9.6 cm in height and width; see Figure 2).

Three tests were conducted. Test 1 modeled the cover depth and explosive loading density of the 1988 Tunnel/Chamber Test. Test 2 had the same cover depth, but a reduced loading density. For Test 3, the loading density was the same as Test 2, but the cover depth was increased from 48 to 86 cm.

Dynamic measurements on all tests included: (1) chamber pressures, (2) access tunnel pressures, (3) external airblast pressures, and (4) motion (acceleration) of the simulated rock mass above the chamber. The airblast and ground-motion gage locations are shown in Figure 3. Passive measurements consisted of post-test surveys of debris distributions for Test 3, and observations of the extent of cover rupture and debris throw on all three tests.

MODEL CONSTRUCTION

All models were constructed with solid paving bricks (without mortar) inside a reinforced concrete containment structure, as illustrated in Figure 4. Dimensions of the bricks were 5.8 by 9.3 by 19.7 cm. As shown in Figure 4, the bricks were laid with the wide face (9.3 by 19.7 cm) in the vertical plane, and with the long axis rotated 30° from the vertical, in the direction of the portal. Thus, the overburden surface slope of the models was 30 degrees. A thin layer of sand was placed over the surface of the bricks to simulate soil overburden.

The chamber and access tunnel were formed around galvanized steel sheet metal, shaped to the required cross-sections (Figures 1 and 2). A layer of mortar approximately 4 cm thick was placed around the top and sides of the chamber form to fill voids between the form and the bricks, and bricks were placed around the assembly. The same procedure was used to form the access tunnel in the model. The chamber was constructed first, and the sheet metal form removed prior to installation of the tunnel section.

INSTRUMENTATION

Two accelerometers were positioned in the overburden above the tunnel/chamber centerline to measure the motions of the cover material for each test. Four internal airblast pressure gages (two in the chamber wall and two in the access tunnel floor) recorded the internal pressure environment. Six free-field pressure gages were permanently installed in front of the tunnel portal, along the extended tunnel/chamber centerline. The gage mounts were cast into a 10-cm thick concrete slab. The concrete slab was 1.8 m wide and extended a distance of 6 m from the tunnel portal. The surface of the pavement was level out to a distance of 1.5 m, where a downward slope (11 degrees) began.

EXPLOSIVE CHARGES

The explosive charges were assembled from 0.085-kg/m (400-grain per foot) PETN detonating cord, cut in 48-cm lengths and inserted through the access tunnel into the chamber. Charge weights, chamber loading densities, and dimensions of the explosive charges are given in Table 1.

EJECTA/DEBRIS COLLECTION

Previous test experiences and analytical studies have clearly shown that, while debris throw ranges and relative distributions can be scaled by model tests, the areal density (impacts per m^2) cannot. This is because the model material which comprises the debris source does not break up with the same size distribution as does the prototype material. Consequently, for Tests 1 and 2, only the maximum range of ejecta/debris was recorded. However, a more detailed ejecta survey was made after Test 3. The locations of the sample areas are shown in Figure 5. The debris distribution data was broken down into the number of pieces smaller than half of a brick, and those larger than half.

RESULTS AND DISCUSSION

The free-field airblast peak pressure predictions for the brick model are presented in Figure 6. These predictions were developed from the prototype, large-scale Shallow Underground Test, and small-scale concrete model (Norwegian Defence Construction Service) data. The corresponding model (Test 1) data are included for comparison. The distances from the model portal were multiplied by the 1:25 scale factor in this plot to match the prototype scale. As shown here, the brick model data clearly falls within the band spread of the predictions.

In Figure 7, the ratio of calculated exit pressure (i.e., peak airblast pressure at the tunnel portal) to measured free-field (external) overpressure is plotted versus normalized distance from the tunnel portal, for all available data from previous tests of underground magazines. The Brick Model Tests (WES Model (1:25)) are included, along with six other model series and two full-scale tests, including the Shallow Underground Test (KLOTZ (88)). The exit pressures were calculated from the relation given by Vretblad, 1988:

$$P_w = 17.7 \, (Q / V_T)^{0.45}$$

where P_w is the exit pressure, bars
Q is the TNT-equivalent explosive weight, kg
and V_T is the total volume of the underground facility, m^3.

A reference line through the data in Figure 7 can be expressed by the equation

$$P_w / P_{so} = 1.0 \, (R / D)^{1.35}$$

and $$D = 4 \, A / p$$

where P_{so} is the free-field overpressure, bars
R is the horizontal distance from the portal, m
D is the hydraulic diameter of the tunnel (for turbulent flow), m
A is the minimum cross-sectional area of the tunnel, m^2
and p is the perimeter of the minimum cross-sectional area, m

As shown in Figure 7, the data exhibits considerable scatter, with many of the points lying above the reference line. Note however, that the results of the Brick Model tests and the Shallow Underground Test (solid data points) fall well within the scatter band, near the reference line.

Table 2 lists the Inhabited Building Distances (scaled up to full-scale ranges) derived from five model tests with similar loading densities, but withdifferent scaled cover depths and cover material strengths. There is a clear trend in the effect of the overall integrity of the chamber cover on the IBD. With similar cover thicknesses and loading densities, the heavily-jointed brick model produced about the same long-range blast pressures as did the Norwegian model having a sand cover. Based on the IBD's, however, the Norwegian model having concrete cover material produced a long-range blast pressure equivalent to a heavily-jointed brick model with almost twice the cover thickness.

Measured peak pressures from all three Brick Model tests are plotted in Figure 8. The DDESB airblast prediction equation and the curve fit to the peak overpressure data of the Shallow Underground Test are included in Figure 8 for comparison. Although there is some data scatter, certain trends are indicated. When the cover depth was held constant and the loading density was reduced from 60 to 10 kg/m^3 (Test 2 versus Test 1), the portal pressure was reduced by a factor of about four, and the long-range external pressures were about halved. When the <u>scaled</u> cover depth of the brick models was increased from 0.44 to 0.79 m/kg$^{1/3}$ (Test 3 versus Test 1), and the chamber loading density held constant at 60 kg/m^3, the side-on overpressures outside the tunnel portal increased an average of 30 percent. The peak pressure midway down the access tunnel increased by about 130 percent. When the scaled cover depth was held constant at 0.8 m/kg$^{1/3}$, an increase in chamber loading density from 10 to 60 kg/m^3 (Test 3 versus Test 2) produced an average of 250 percent increase in the free-field side-on overpressure outside the portal.

From Figure 8, it is interesting to note the degree to which the internal and external airblast overpressures measured on the large-scale, Shallow Underground Test were reproduced in the 1:25-scale brick model (Test 1). In general, the model provided a good representation of the prototype results. The tunnel exit pressures match very closely, but external overpressures were low by a factor of approximately three in the free-field. However, these lower pressures may have been due to the downward slope of the ground surface constructed for the model (see Figure 3) at the far-field gage stations.

The peak impulse values from the model tests, obtained by integrating the overpressure-time histories, are plotted versus distance from the charge initiation point in Figure 9. The peak impulse data curve from the Shallow Underground Test are included in Figure 9 for comparison. Although peak impulse shows more scatter than the overpressure data, the model and prototype data clearly follow the same trends.

Figure 10 is a plot of IBDistance (distance to the 5.0 kPa pressure level) versus loading density for selected tests, where the loading density is based on the total volume of the storage facility (i.e., the volume of the chamber plus the access tunnel). A curved line has been drawn through the data points for the WES 1:75-scale model test (Smith, et al, 1989). These small-scale tests were conducted in a model chamber and access tunnel formed with steel pipe and cast in a heavily reinforced concrete block. Therefore, this model represents a totally non-responding magazine structure. The data from the large-scale 1987 KLOTZ test at Alvdalen, Sweden (Vretblad 1988) fall very close to the WES 1:75-scale model curve. The Alvdalen tests were conducted in rock chambers with sufficient overburden to prevent rupture and cover venting, and therefore also represent non-responding structures.

The remaining data presented in Figure 10 are from tests where the overburden ruptured (responding magazines), allowing release of the detonation gas pressures in the storage chamber through the cover venting. The full-scale IBD's derived from the Shallow Underground Test, the Brick Model Tests, and the Norwegian model tests (Jenssen and Krest, 1988) all fall well below the IBD curve for the non-responding magazine tests, by about a factor of four.

While the IBD's for the responding magazines may at first appear unrelated, certain trends are indicated. For example, the Brick Model Tests show an increase in IBD of 25 percent (from 212 to 266 m in full-scale) when the scaled cover thickness was increased from 0.44 to 0.79 $m/kg^{1/3}$. Similarly, increasing the total loading density (mass of explosives divided by total volume of the underground facility) from 7.1 to 42.9 kg/m^3 increased the IBD by 77 percent (from 150 to 266 m), when the scaled cover depth was held constant at about 0.8 $m/kg^{1/3}$.

DEBRIS THROW

The maximum ranges of debris observed on the Brick Model Tests were 91 m for Test 1, and 32 m for Test 3 (Joachim, 92). Using $W^{1/6}$ scaling, the range for Test 1 is less than half the maximum range observed on the large-scale test. On Test 3, the explosive charge was larger than that of Test 2, but the cover thickness was also greater, resulting in the same (or nearly so) scaled cover thickness of 0.8 $m/kg^{1/3}$. All of the debris moved outward from the surface slope over the tunnel and chamber, within a sector extending about 30 degrees to each side of the extended tunnel axis (see Figure 11). The vast majority of debris pieces were fragments less than 1/2 brick in size, indicating that the initial shock shattered most of the bricks near the surface.

Figure 12 shows a series of curves (from Helseth, 1982) relating debris launch velocity to the scaled cover thickness and the magazine loading density. The data sources range from aircraft shelters, which had very shallow cover thicknesses and loading densities, to buried cratering charges, which had very deep covers and very high loading densities. Underground magazines would typically fall between two extremes.

Dimensional analyses show that the ratio of velocities measured in a model test to those occurring in a full-scale test is equal to the square root of the model scale factor. Therefore, the peak velocity measured by Gage GM-2 in Test 2 of the Brick Model Tests was multiplied by 5, and plotted in Figure 12 along with launch velocities recorded on the large-scale Shallow Underground Test. While this single data point from the Brick Model Tests appear to almost exactly match the curves and other data of Figure 12, it must be remembered that the Gage GM-2 was not at the cover surface, but at mid-depth in the cover. The actual launch velocity for Test 2 (small though it was, as evidenced by the short debris travel) was no doubt somewhat greater than at the gage point.

Also shown in Figure 12 is the launch velocity based on the ballistic calculation for Test 1. The value, which was also multiplied by a velocity scaling factor of 5 for plotting on Figure 12, appears to be somewhat low in comparison to the full-scale Shallow Underground Test.

Figure 13 shows the debris areal density (number of impacts per square metre), as a function of range from the tunnel portal, for Brick Model Test 3 compared to that of the large-scale Shallow Underground Test. In accordance with accepted scaling procedures for ejecta/debris (Rooke, 1980), the distances in the model case have been scaled up by multiplying by the sixth root of the ratio of the model-versus-prototype charge weights, i.e., $(20{,}000\ \mathrm{kg}/1.27\ \mathrm{kg})^{1/6}$.

It is not possible to quantitatively compare the debris densities of the Brick Model Tests with those of the full-scale test, since the number of fragments produced by the cover breakup does not scale. Therefore Figure 13 should be regarded only as a comparison of the relative debris densities recorded on Brick Model Test 3 as a function of range and azimuth, with similar relations from the large-scale test. To provide such a comparison, the entire grouping of the model data has been arbitrarily positioned with respect to the ordinate scale of Figure 13. Considering this limitation, the comparison is actually quite good. the attenuation of the model impact densities with distance closely matches the shape of the curves from the large-scale data. The relative differences between the debris densities along the extended tunnel axis (0-degree azimuth) and the densities "off-axis" also compare quite well with the large-scale results.

CONCLUSIONS

Peak airblast overpressure and impulse values measured on the Brick Model Tests at the tunnel exit and in the near-field (just outside the portal) closely match the results of the corresponding large-scale test. The model pressure data in the far-field was somewhat lower than measured in the large-scale test, possibly due to the gravity and inertial effects resulting from our inability to properly scale the overburden. A comparison among the model test results shows an increase in pressure of a factor of 4 to 6 when the chamber loading density was increased from 10 to 60 kg/m^3. An overpressure increase on the order of 90 percent was seen when the scaled overburden thickness was increased from 0.44 to 0.79 $m/kg^{1/3}$. The Inhabited Building Distance indicated by the model tests was significantly less than for the cooresponding large-scale Shallow Underground Test, but this was also attributed to overburden scaling deficiencies.

Ejecta impact data collected from Brick Model Test 3 demonstrate the feasibility of modeling the basic nature of overburden ejecta throwout. Because the breakup of the cover material does not scale, however, ejecta sizes in the model tests were much too large to accurately define the ejecta hazard range, in terms of impacts-per-square meter.

ACKNOWLEDGEMENT

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REFERENCES

1. Davis, Landon K.; and McAneny, Colin C.; 1981, "Project SPERRE, Report 5, Summary Report: Road Cratering Tests in Rock With Preemplaced Charges," Technical Report SL-81-5, U.S Army Engineer Waterways Experiment Station, Vicksburg, MS.

2. Helseth, Einar S.; "Underground Ammunition Storage, Model test in scale 1:100 in Sand," Fortifikatorisk Notat NR 160/82, Progress Report to KLOTZ Club Meeting, Norfolk, VA.

3. Jenssen, Arnfinn; and Krest, Ottar; 1988, "Shallow Underground Ammunition Magazine Trials at Naval Weapons Center (NWC), China Lake, Ad Hoc Model Tests, Approximate Scale 1:24.8," FORTIFIKATORISK NOTAT NR 192/88, Norwegian Defence Construction Service, Oslo Norway.

4. Joachim, Charles E.; and Smith, Dennis R.; 1988, "WES Underground Magazine Model Test," Twenty Third DOD Explosives Safety Seminar, Atlanta, GA.

5. Joachim, Charles E.; 1990, "Shallow Underground Tunnel/Chamber Explosion Test Program, Summary Report," Technical Report SL-90-10, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

6. Joachim, Charles E.; 1992, "Brick Model Tests of Shallow Underground Magazines," Miscellaneous Paper SL-92-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

7. Millington, Charles, 1985, "The Ernestettle Report," Preliminary AWRE Report UK(ST)IWP 205, O/1/85, AWRE (Foulness), Ministry of Defence, United Kingdom.

8. Rooke, Allen D., Jr., 1980, "Crater-Ejecta Hazard Predictions in Cohesive Soils, The Middle Gust 1 Event," Thesis, Master of Science, Mississippi State University, Mississippi State, MS.

9. Smith, Dennis R.; Joachim, Charles E.; Davis, Landon K.; and McMahon, Gordon W.; 1989, "Effects of Explosions in Underground Magazines," Technical Report SL-89-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

10. Stromsoe, E.; 1969, "Underground Explosion Trials at Raufoss 1969, Measurement of Airblast Outside The Tunnel," Intern Rapport X-124, FORSVARETS FORSKNINGSINSTITUTT, Norwegian Defence Research Establishment, Kjeller, Norway.

11. Vretblad, Bengt; 1988, "Data from the 1987 KLOTZ Club Tests In Sweden, Report C3:88, FORTIFIKATIONSFORVALTNINGEN, FORSKNINGSBYRAN, Eskiltuna, Sweden.

Table 1. WES Brick Model Tests: Explosives Charges, and Chamber Cover Thicknesses							
	Explosive Charge					Minimum Scaled	
Test No.	Total Mass (kg)	Loading* Density (kg/m^3)	No. of** Strands	Length (cm)	Diameter (cm)	Chamber Cover ($m/kg^{1/3}$)	Portal Cover ($m/kg^{1/3}$)
1	1.27	60	31	48	5	0.44	0.034
2	0.21	10	5	48		0.80	0.062
3	1.27	60	31	48	5	0.79	0.49

* Mass of explosives divided by chamber volume.

** 0.085 kg/m (400 grains/foot) detonation cord

Table 2. Effects of Magazine Cover Resistance on Airblast

Model Test	Model Scale	Cover Type	Scaled Cover Depth $m/kg^{1/3}$	Loading Density $m,kg^{1/3}$	Airblast Effects: Portal Pressure MPa	Airblast Effects: Full-scale IBD m
NDCS Sand	1:24.8	Sand	0.33	58.3	6.2	208
Brick Model 1	1:25	Bricks	0.44	60	5.0	205
NDCS Concrete	1:24.8	Concrete	0.33	58.3	103	250
Brick Model 3	1:25	Bricks	0.79	60	5.0	250
WES Concrete	1:75	Concrete	>2.0	60*	-	1000

* Extrapolated from Figure 12.

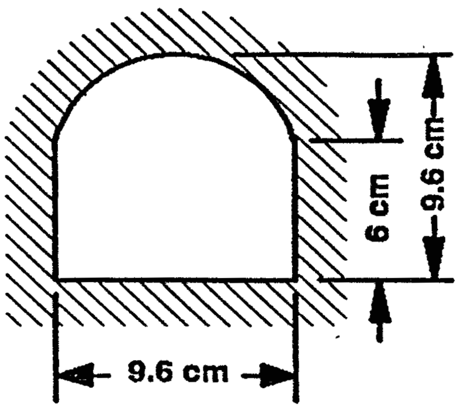

Figure 1. Access tunnel cross-section for 1:25-scale WES Brick Model Tests

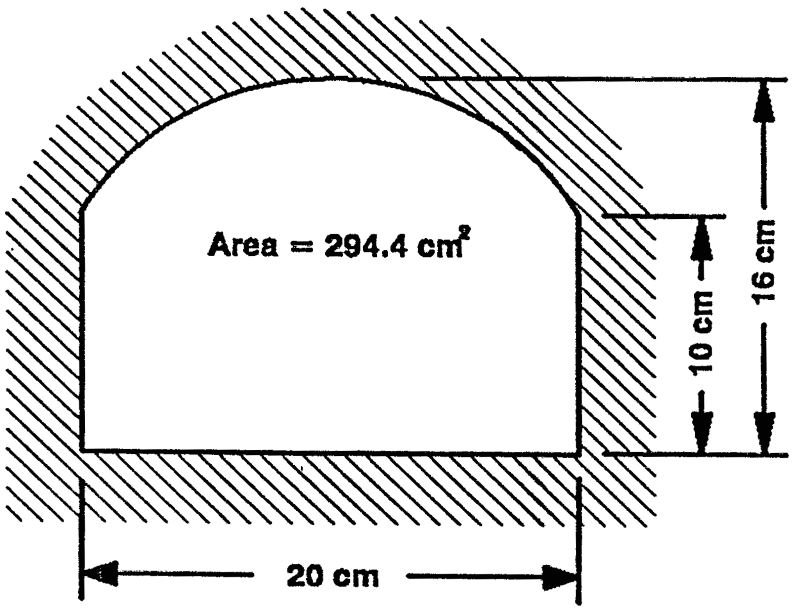

Figure 2. Storage chamber cross-section for 1:25-scale WES Brick Model Tests.

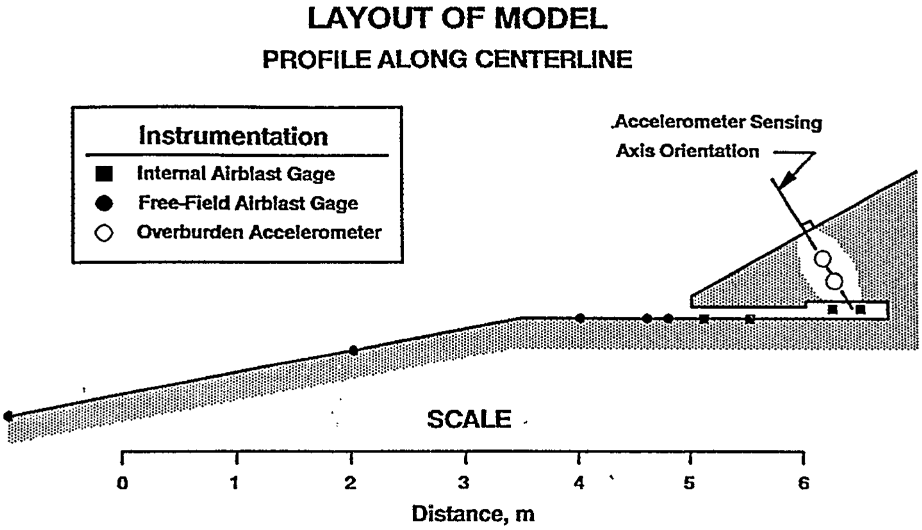

Figure 3. Layout (centerline profile) of 1:25-scale WES Brick Model.

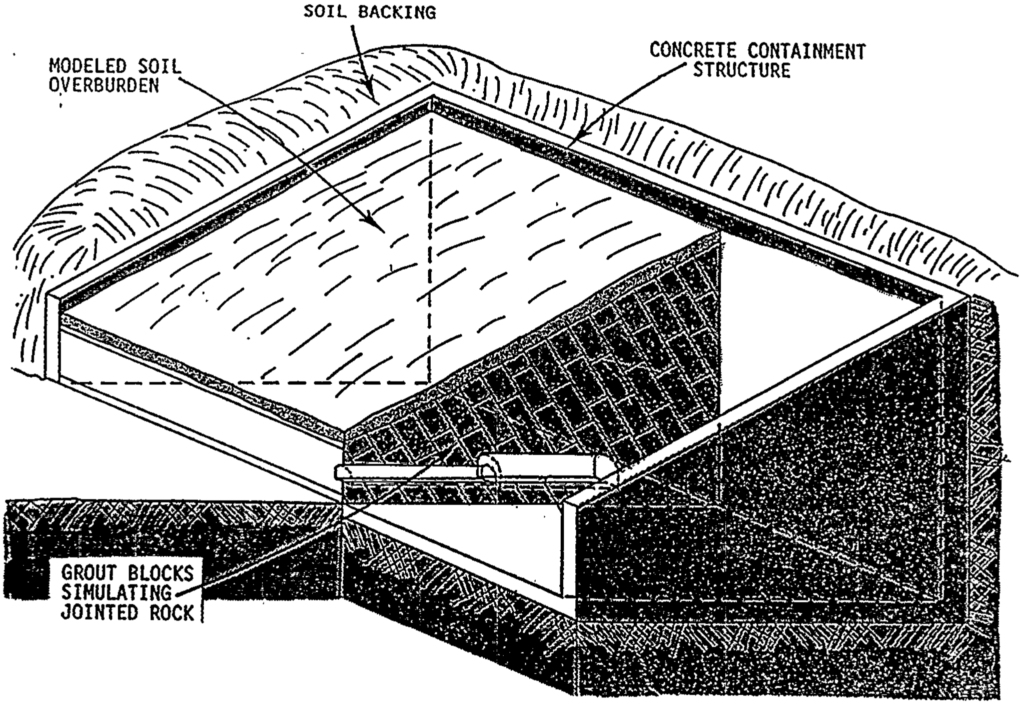

Figure 4. Testbed design for 1:25-scale tests of influence of cover rock characteristics on venting, ejecta, and internal/external airblast levels for shallow underground magazines.

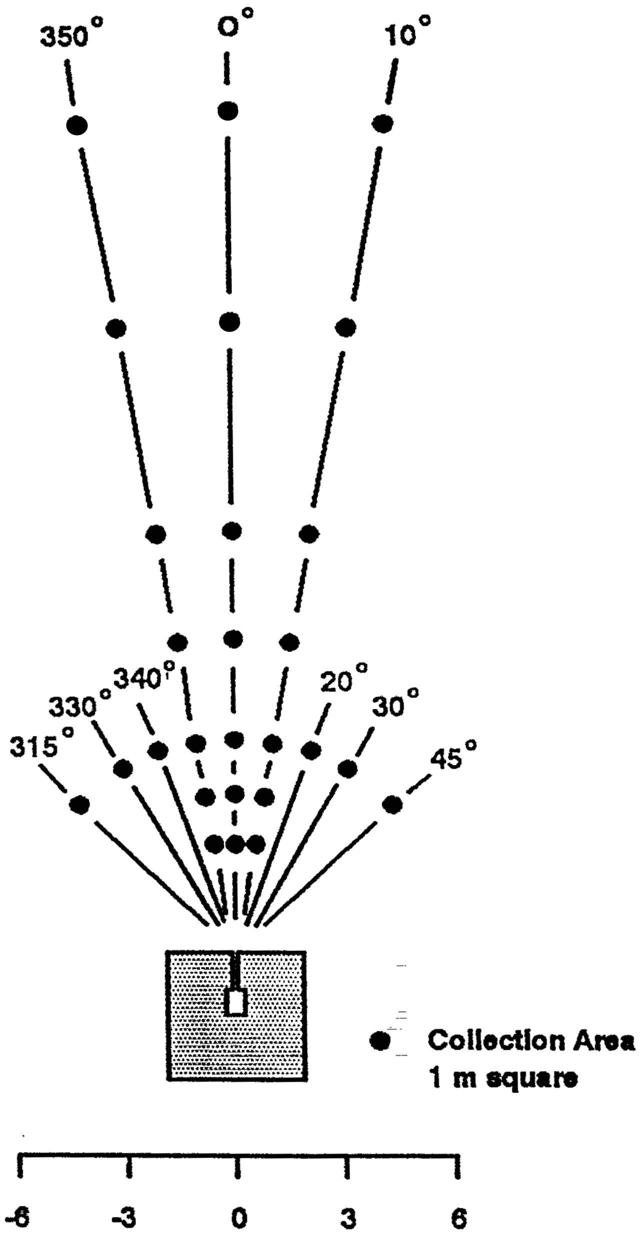

Figure 5. WES Brick Model Test 3: location of ejecta collection areas.

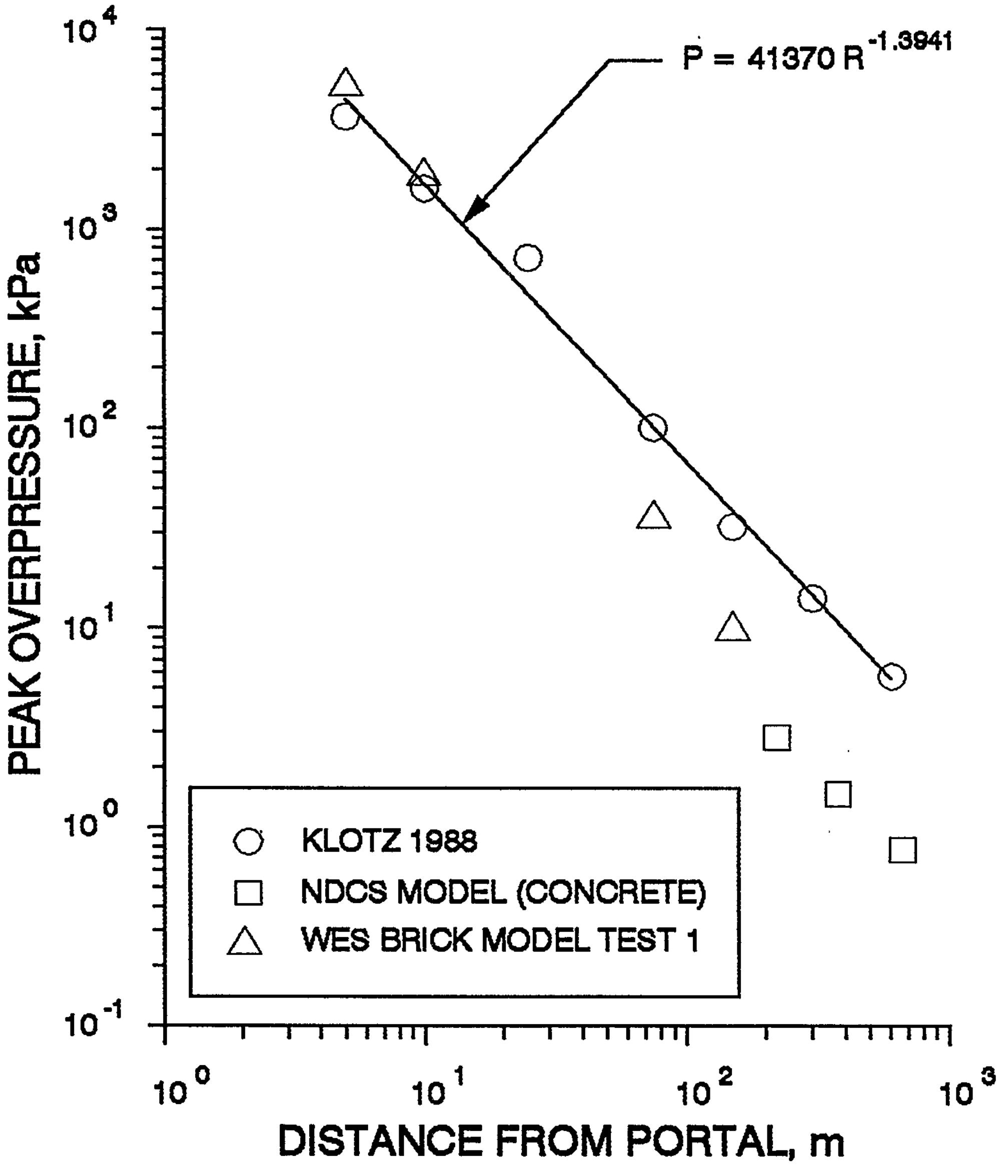

Figure 6. Free-field side-on overpressure scaled to the Shallow Underground Tunnel/Chamber Explosion Test (KLOTZ 1988) parameters.

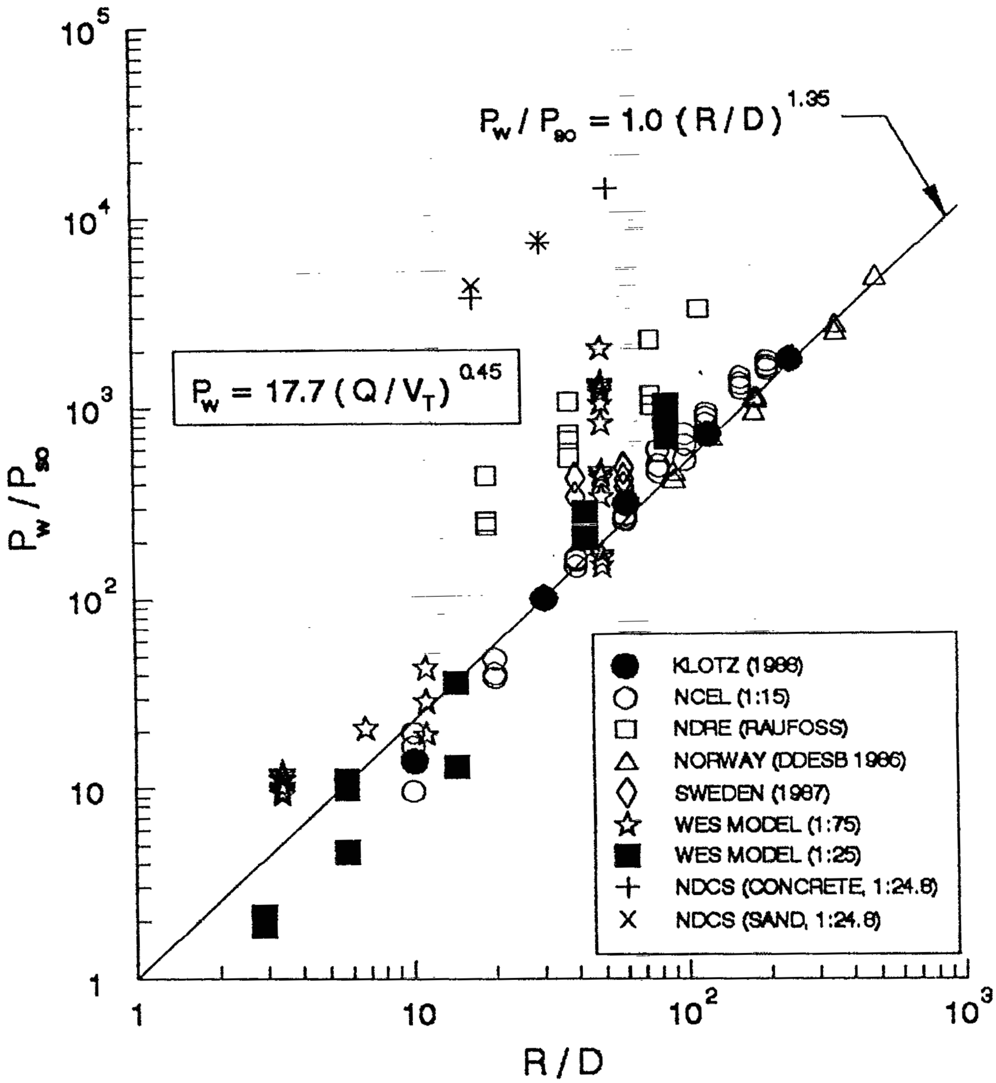

Figure 7. Pressure-distance comparisons from existing data on model and large-scale detonations in underground magazines. The ratio of calculated exit pressure (P_W) to measured free-field side-on overpressure (P_{so}) is plotted versus distance (R) from the tunnel portal along the tunnel/chamber centerline. The distance is normalized by dividing by the hydraulic diameter (for turbilent flow) of the access tunnel cross-section

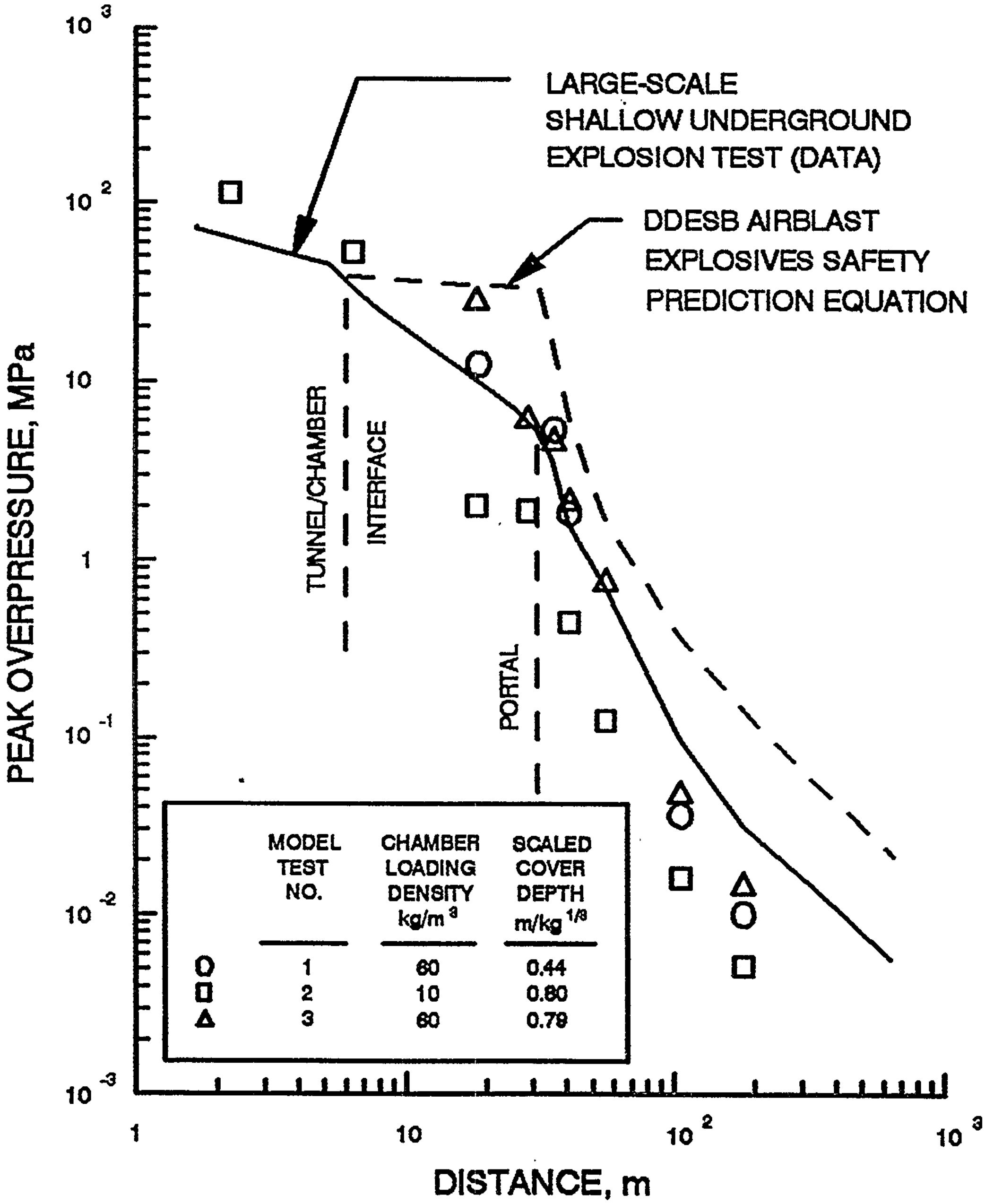

Figure 8. Peak side-on overpressure versus distance from the charge initiation point. A comparison is shown between the prototype (Shallow Underground Tunnel/Chamber Explosion Test, loading density 60 kg/m^3) and the WES Brisk Model Test data.

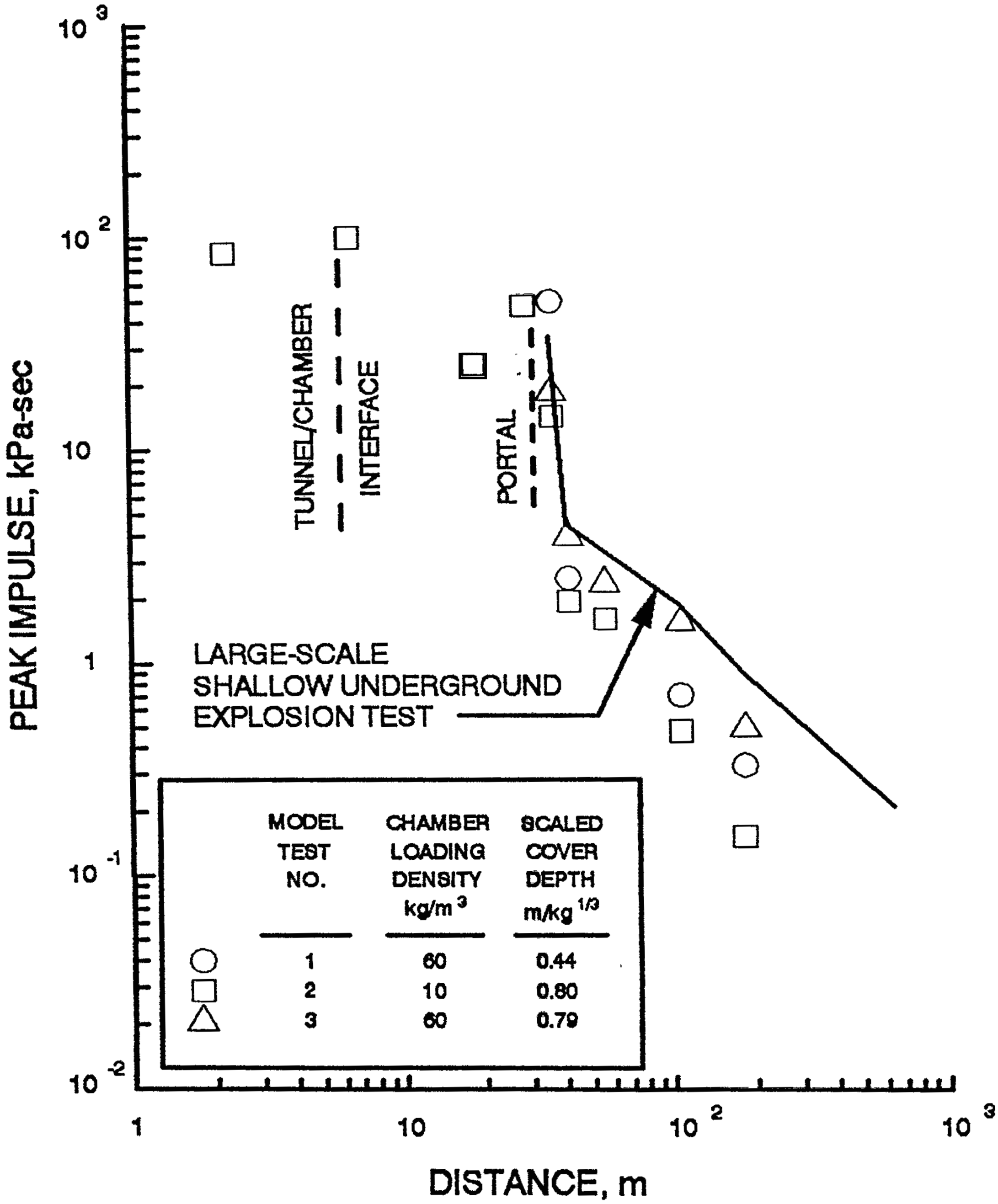

Figure 9. Peak side-on impulse versus distance from the charge initiation point. A comparison is shown between the prototype (Shallow Underground Tunnel/Chamber Explosion Test, loading density 60 kg/m^3) and the WES Brisk Model Test data.

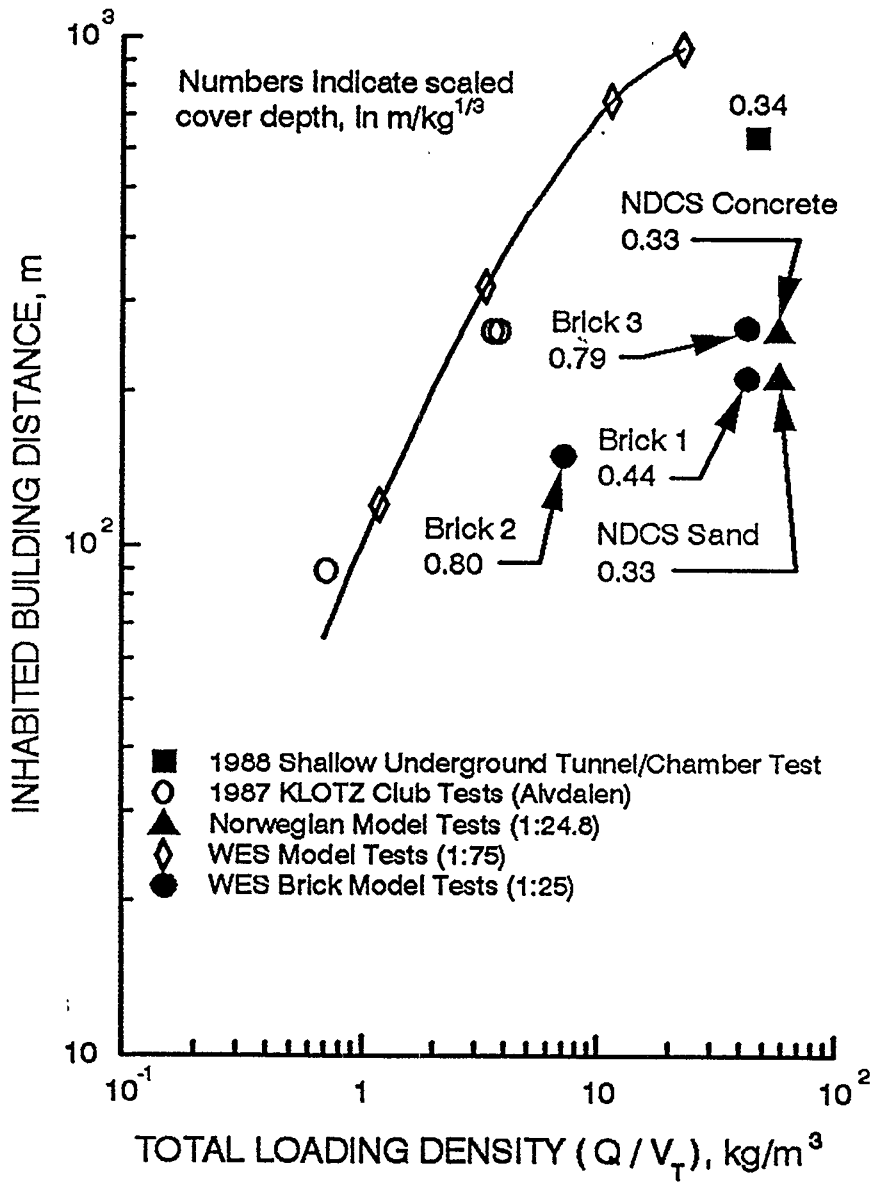

Figure 10. Airblast Inhabited Building Distance versus total loading density (charge mass divided by total internal volume) for selected model and large-scale tests. Solid symbols are for "responding" magazines, and open symbols for "non-responding" magazines.

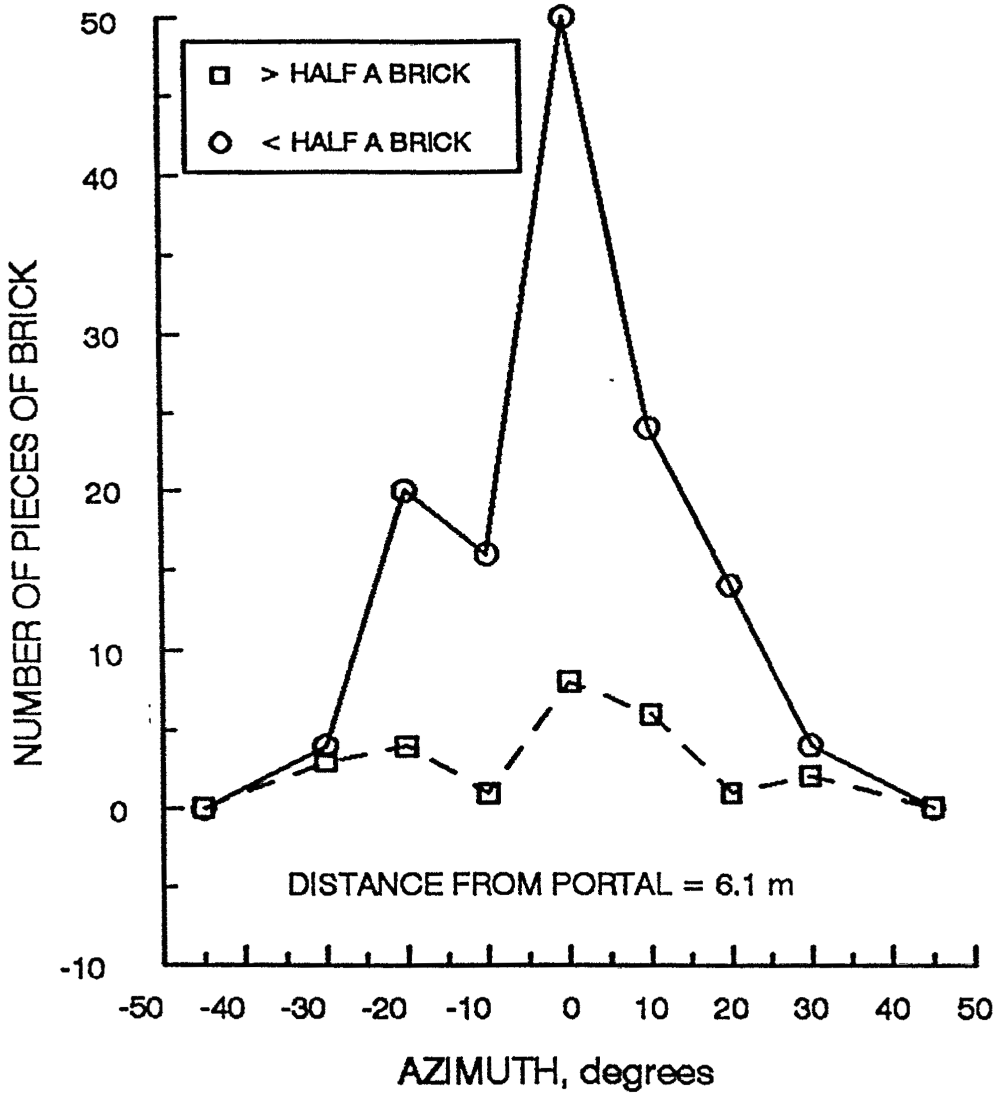

Figure 11. Ejecta distribution as a function of azimuth along the 6.1 m arc, WES Brick Model Test 3.

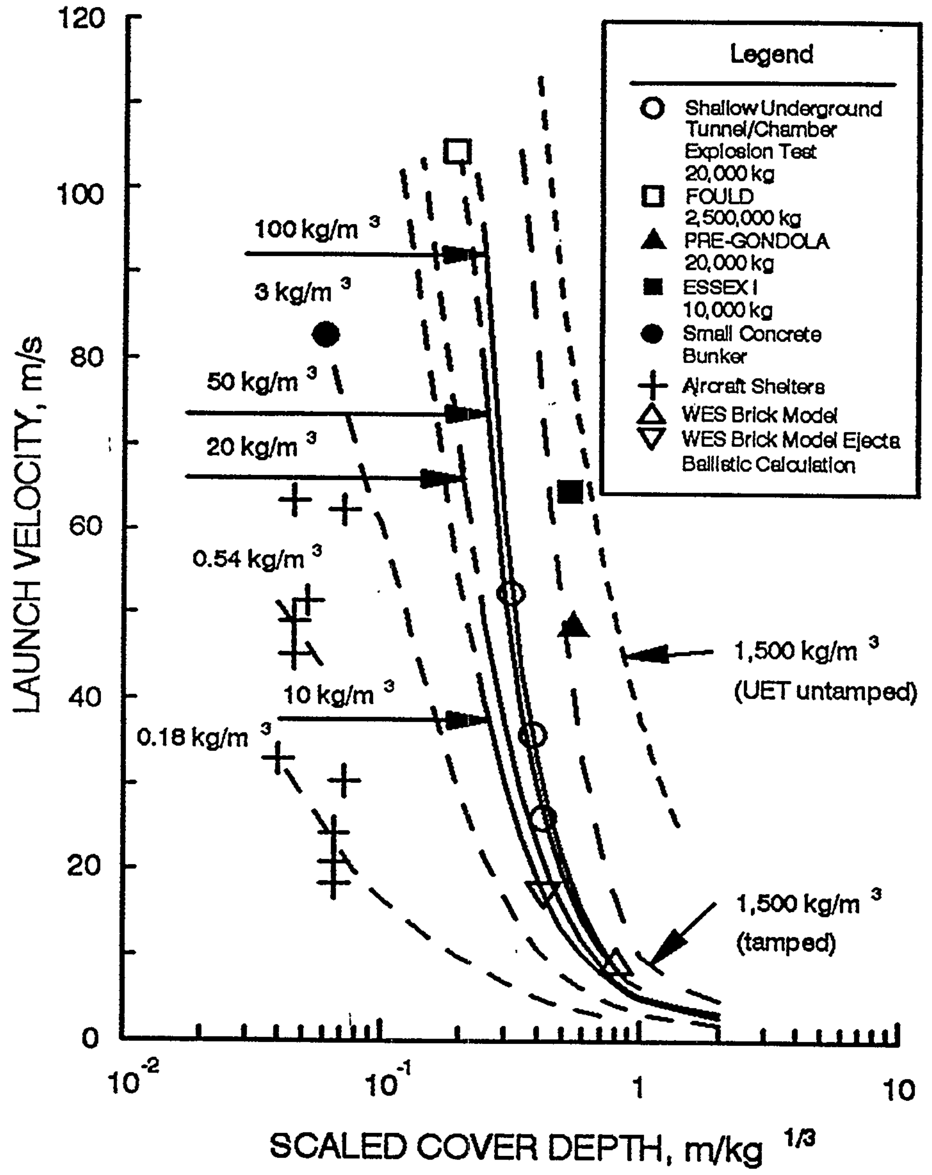

Figure 12. Launch velocity of cover rock ejecta from WES brick model test; compared to ejecta velocities from Shallow Underground Tunnel/Chamber Explosion Test (Joachim, 1990) and other sources (Helseth, 1982) on previous explosion tests.

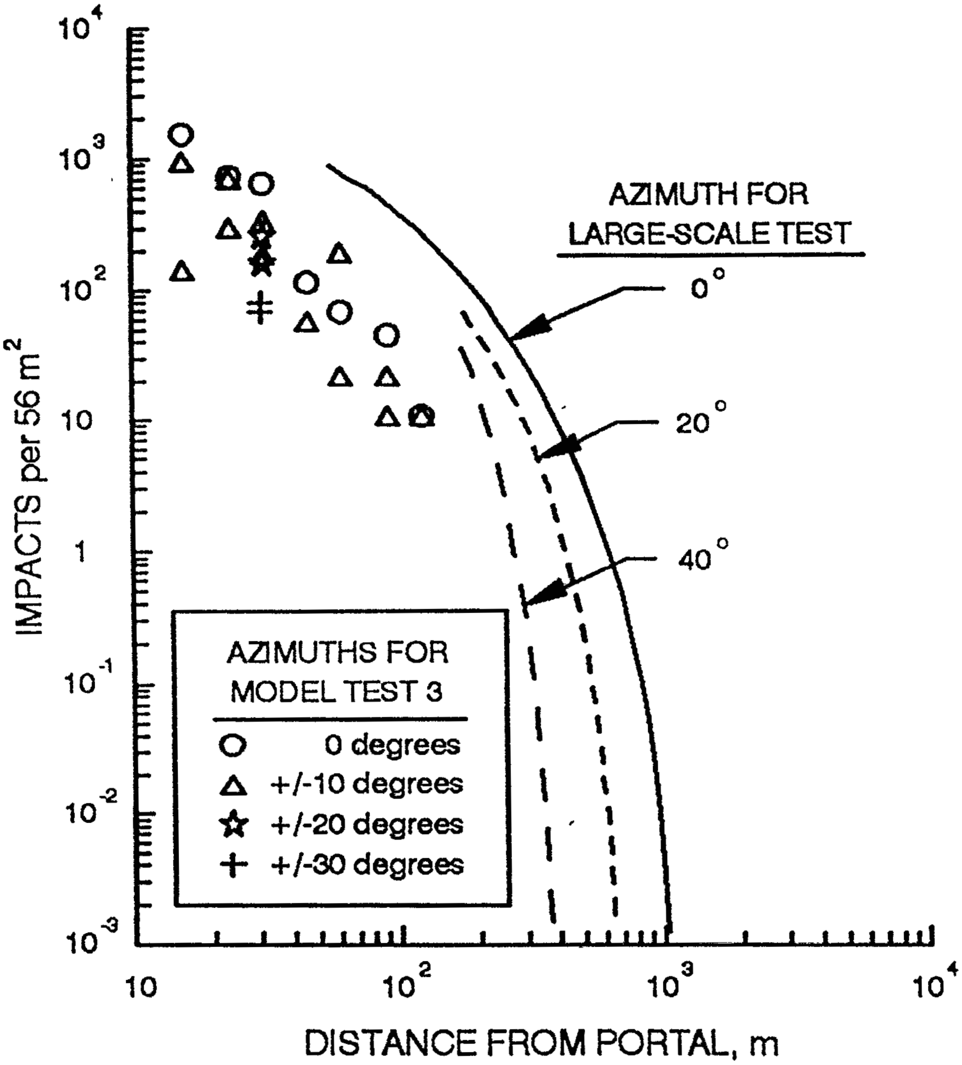

Figure 13. Relative comparison of debris densities from WES Brick Model Test 3 with Shallow Underground Tunnel/Chamber Explosion Test (KLOTZ 1988) data curves. Distances in the model were scaled by the ratio of the charge weights taken to the one-sixth power.