Earth Covered Ammunition Storage Magazines
Quantity-Distance Model, DISPRE2

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ABSTRACT

The building debris hazard prediction model DISPRE has been expanded under an international KLOTZ Club sponsored program. The new version of the model, DISPRE2, covers arch-shaped and rectangular above-ground ammunition magazines storing up to 5,000 kg of TNT equivalent explosives material. Quantity-distance criteria for ammunition magazines have historically been based on the analysis of test data. The tests are usually conducted to expose magazines of specific designs to internal detonations, measure the external blast, and map and analyze the structural debris and weapon fragments. Fragment and debris critical densities are calculated and then used to define safe siting distances between two magazines and between a magazine and an inhabited building or public traffic route. Quantity-distance criteria are set in this way for directions to the front, side, and rear of a donor magazine. When a new magazine design is developed or an existing design is modified, additional testing (scale model or prototype) may be necessary to officially site the magazine. This approach is quite costly, in terms of financing the tests and efficiently getting approval of the design and constructing the new magazines. A more economical and feasible approach is to have a computer model, validated with available data, which can be used to predict the debris density at any given distance from the magazine.

A predictive model for determining safe siting distances for protection from hazardous building debris was developed by Southwest Research Institute (SwRI) in recent years under funding from the U.S. Department of Energy (DOE) with additional contributions from the U.S. Department of Defense Explosives Safety Board (DDESB). This model, termed DISPRE for "dispersion prediction", was approved as a siting tool for explosives processing or handling facilities in November 1990 by both DOE and DDESB.

The DISPRE model has been proven to be quite effective in reducing required siting distances for many explosives material quantities when the model is used within its constraints. Generally, Version 1.0 of the model can be used to predict building debris throw for charge weights up to 120 kg in a rectangular structure. The model was being frequently extrapolated since very few prediction methods have been specifically approved for determining safe separation distances between inhabited buildings and buildings containing explosives. Instead of simply extrapolating the DISPRE model to predict debris dispersion for an

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ammunition magazine, the model has been modified as DISPRE2 to cover the specific differences between the internal loads and breakup of an above-ground, rectangular structure containing no more than 120 kg of TNT equivalent explosives and the arch-shaped and rectangular above-ground magazines storing up to 5,000 kg of TNT equivalent explosives material. Since the safe separation of the magazines depends on external air blast as well as debris throw, DISPRE2 also includes the prediction of air blast around the magazine.   The DISPRE2 model has now been converted to a self-contained software package, including pre- and post-processors designed to run in a Windows environment on an IBM-compatible personal computer. The expanded DISPRE2 software, which is currently in the beta testing phase, is the subject of this paper.

1.0   Introduction

The building debris hazard prediction model DISPRE (Reference 1), which has been discussed in the last two explosives safety seminars (References 2 and 3), has been expanded by Southwest Research Institute (SwRI) under a program sponsored by the international KLOTZ group. The new version of the model, DISPRE2, covers arch-shaped and rectangular above-ground ammunition magazines storing up to 5,000 kg of explosives material. The model can be used to predict safe siting distances for protection from the throw of hazardous building debris following an accidental explosion in an aircraft shelter or other ammunition magazine which fits within these constraints.

Accidents are possible wherever ammunition is stored, causing injury or death to personnel and damage to equipment and property. The risk of an accident is a function of both the frequency of occurrence and the potential consequences of the accident. In some countries, political bodies have made formal decisions concerning the risk level to which the public can be exposed. Exposure levels for peak overpressure and debris density are usually defined for a given politically accepted risk level. Quantity-distance (Q-D) is based on these types of physical parameters and can be determined either theoretically or by properly conducted tests. Because more and more countries are implementing risk analysis as a part of their safety evaluation and decision making, it is paramount that the harmful physical effects of an accident (such as air blast and debris throw) be understood and defined as a function of distance from the donor, as well as the frequency of occurrence of the accident. The DISPRE2 software addresses the prediction of initial debris parameters, debris throw, and air blast following an explosives accident.

The DISPRE2 software is based on the analysis of data accumulated by others and fundamental calculations. SwRI conducted no additional testing during the model development. The software has been validated to a level of accuracy consistent with the existing data (mostly aircraft shelter breakup, debris, and air blast data).

2.0   Model Background

A predictive model for determining safe siting distances for protection from hazardous building debris was developed by SwRI in recent years under funding from the U.S. Department of Energy (DOE) with additional contributions from the U.S. Department of Defense Explosives Safety Board (DDESB). This model, termed DISPRE for "dispersion prediction", was approved as a siting tool for explosives processing or handling facilities in November 1990 by both DOE and DDESB (Reference 4). Three separate computer codes comprise Version 1.0 of the DISPRE model: SHOCK, FRANG, and MUDEMIMP (Reference 1). Intermediate steps in using the model include empirically based calculations used to establish input for and analyze output from the computer codes.

The DISPRE model has been proven to be quite effective in reducing required siting distances for many explosives material quantities when the model is used within its constraints. The constraints of DISPRE are based on the limits of the test data used to validate the model. Generally, Version 1.0 of the model can be used to predict building debris throw for charge weights up to 120 kg in a rectangular structure. The model was being frequently extrapolated since very few prediction methods have been specifically approved for determining safe separation distances between inhabited buildings and buildings containing explosives. Instead of simply extrapolating the DISPRE model to predict debris dispersion for an ammunition magazine, the model is being modified as DISPRE2 to cover the specific differences between the internal loads and breakup of an above-ground, rectangular structure containing no more than 120 kg of TNT equivalent explosives and the arch-shaped and rectangular above-ground magazines storing up to 5,000 kg of TNT equivalent explosives material. Since the safe separation of the magazines depends on external air blast as well as debris throw, DISPRE2 also includes the prediction of air blast around the magazine.   The DISPRE2 model still consists of three main computer codes (BLASTX replaces the SHOCK code) with intermediate calculation and decision modules; however, it has now been converted to a self-contained software package, including pre- and post-processors designed to run in a Windows environment on an IBM-compatible personal computer.

3.0   DISPRE2 Development

The development of the DISPRE2 model has occurred in two phases. Since a significant amount of data had been collected in recent years for debris throw and air blast from hardened aircraft shelters (HAS) exposed to internal detonations, the first phase was to modify the DISPRE model to be able to analyze a single ammunition storage configuration, namely an arch-shaped HAS, containing up to 5,000 kg of explosives. This configuration was the most complex due to the internal loading surface and breakup characteristics, but it was also the situation for which the most data exist. The revised model was then expanded in the second phase to treat arch-shaped and rectangular magazines, with and without earth cover, for the same charge amounts.

The overall development (for both phases) has included several tasks: data review, data analysis to expand the DISPRE model, addition of air blast or leakage pressure prediction, software modifications, development of pre- and post-processors and conversion of the model to a Windows based program, and model validation with data. The first three tasks are discussed within this section, with the latter tasks being covered in Sections 4.0 and 5.0. Final validation of the DISPRE2 model using available data is in progress. The software is undergoing beta testing and is expected to be completed in October 1994.

3.1   Review of Existing Data

The largest amount of available data for ammunition storage structures exposed to internal detonations has been collected within the last thirteen years. The most significant tests on which the model is based are described in References 5-10. Much of the data concentrates on two types of HAS -- the third generation Norwegian/US aircraft shelter (mainly, Reference 5) and the third generation US aircraft shelter tested recently in the Aircraft Shelter Upgrade Program (ASUP, Reference 6) and in the earlier DISTANT RUNNER test series (References 7 and 8). There are also limited data on various other magazine types. The data have been used to provide loading and breakup information for expanding and refining various aspects of the DISPRE model. Unfortunately, not all the reports contain data on all three key data requirements -- internal loads, measurements of debris initial conditions including debris velocity, and external loads. However, what data were available have been utilized to the maximum possible extent. Detailed summaries of all test data used in the development of the DISPRE2 model can be found in Reference 11.

3.2   Data Analysis for Model Expansion

Debris parameters can be predicted either by the use of an empirical approach or from the application of governing fundamental scientific principles. The empirical approach relates relevant properties of the applied blast loading and the tested component to the measured breakup parameters in a manner which applies to all the test data. An understanding of the basic physical phenomena which are controlling breakup is not gained although empirical relationships may provide insight into the physics of the problem. A fundamental approach yields general predictive methods and provides a physical understanding of the breakup process. If an empirical approach is used, the trends within the empirical relationship should agree with trends predicted by applicable fundamental principles. If a fundamental approach is used, the results should match most test data or be conservative. Less test data are required to validate predictions from a fundamentally based model than to generate an empirically based model. For these reasons, this approach was preferable although significant portions of the model are empirical.

The major modifications to the original DISPRE model concerned the internal loads prediction method (to address arch-shaped structures as well as rectangular ones); the treatment of explosive charge weights up to 5,000 kg; the effect of adding mass (soil, sand, or

rock rubble) to the sides, at the rear, and on top of a shelter or magazine; and the inclusion of external loads prediction to the model. Since only existing data were used to expand and validate the model and since much of that data is from scaled tests, a simplified scaling procedure for breakup and debris distribution had to be formulated.

3.2.1   Internal Loads Prediction

A considerable amount of time was devoted to the prediction of internal loads for arch-shaped structures such as a HAS. The internal loads prediction is a key aspect of the model since several debris parameters, such as velocity and mass, depend heavily on the applied blast pressures. Several HAS test series conducted in recent years have included internal load measurements, including measurements along the arch and in the door. The largest amount of internal loads data was obtained from the PAS test series (Norwegian/US 1:3 scale tests with scaled up charge amounts ranging from 100 to 2,700 kg, Reference 5) and the HAS-QD test (full scale U.S. shelter with MK84, Reference 6). The data analysis conducted to establish an appropriate method to use to predict internal loads concentrated on these two series of tests, with the most useful information coming from the PAS series.

Definition of a complete loading history for key locations on the internal structure surface was required. This history needed to include both shock and gas pressure loading. The reviewed test data did indicate the presence of a gas loading phase, although this phase becomes less pronounced as the loading densities become very high. The internal load prediction codes used in the original DISPRE model are SHOCK and FRANG. The SHOCK code only applies to rectangular structures so another code was necessary for predicting the shock phase loading for the revised DISPRE2 model, which covers arch-shaped shelters and magazines as well as rectangular magazines. The BLASTX code (Reference 12) is used for predicting shock loads in the modified model. Reasonable agreement was obtained between BLASTX pressure histories and measured histories for the PAS and HAS-QD series for the shock phase. Although BLASTX can predict gas loading as well as shock loading, the comparison for this phase was not as good. The BLASTX code does not model the mass of the vent cover and, therefore, allows venting to begin immediately after an input pressure or impulse failure criterion is exceeded. The vent cover (e.g. the front door and various percentages of the structure, depending on the loading density) simply disappears when internal venting begins. Comparisons between gas pressure decay predicted by BLASTX and measured pressure histories in the PAS, HAS-QD and several other tests show that BLASTX significantly underestimates the actual gas decay time and, thus, the gas impulse.

Thus, a better approach is to use BLASTX to calculate the initial shock phase and the FRANG code (as used in the original DISPRE model) to calculate the gas phase of the loading. An empirically based rule is used for determining the vent characteristics required as input for FRANG. The pressure trace is estimated by "adding" a modified gas phase history

predicted by FRANG to the shock phase history predicted by BLASTX, beginning at the time at which the peak gas pressure would occur for any given location in the magazine. The time of peak gas pressure, t_g, is predicted using the method used to calculate this parameter in the BLASTX code. To simplify the creation of this summed pressure history (and account for differing time steps for which data is saved by each code), the gas phase pressure history predicted by FRANG is simplified by assuming a linear decay from the peak gas pressure to a duration, t_d, which will result in the predicted peak gas impulse.

3.2.2 Debris Breakup and Dispersion

The DISPRE2 model, like the original DISPRE model, must be able to predict the manner in which a structure breaks into debris when exposed to internal explosive loading and how that debris is dispersed. The breakup of a magazine is defined by predicting initial debris launch parameters for each component, such as debris velocity, mass, and angle, and by representing these parameters with appropriate probability distributions as required by the MUDEMIMP trajectory and dispersion code used by DISPRE2. The MUDEMIMP code determines debris throw distances by first using a Monte Carlo simulation to randomly combine initial conditions from the probability density functions for each piece of debris, and then using a trajectory code to calculate the corresponding debris throw distance. Debris areal densities are calculated using a procedure similar to that described in Reference 13. A brief discussion on how the probability density functions for the initial parameters are determined in the software follows.

Referring to the previous section on the prediction of internal loads, debris velocity is calculated using the gas impulse up until the time of critical venting, t_A, when the debris are far enough from the magazine so that they are no longer significantly loaded by gas pressure inside the structure, or the gas pressure in the structure decays to zero. Also, only the portion of the shock pressure history from BLASTX up to the time ($t_g + t_A$) is used to calculate shock impulse applied to debris. It is assumed that when the debris are no longer loaded by gas pressures in the magazine, they are also no longer loaded by shock pressures in the magazine. The maximum debris velocity is calculated as i/m, where i is the total summed shock and gas impulse described above and m is the mass per unit area of the component from which the debris originate. As in DISPRE, DISPRE2 uses a normal probability distribution defined by a calculated average velocity and standard deviation to define initial debris velocities for reinforced concrete debris.

Another task necessary in expanding the DISPRE model was to determine the effect of soil cover on the debris velocities, masses, and throw distance. Many of the aircraft shelters and magazines used in the KLOTZ group countries have some sort of soil cover and/or soil or rock rubble berms on the sides; thus, the DISPRE2 model must be able to treat these cases. The approach used by the DISPRE2 model to account for the effect of soil cover over shelters or magazines on debris velocity and mass is based on the available data from two sets of vented explosion tests in earth covered magazines (References 14 and 15). Basically, soil

mass is included in i/m to calculate initial velocity.   Data from the tests described in References 14 and 15 indicate maximum debris velocity can be predicted well with i/m considering the following factors: 1) the recessed depth and increased areal weight of the roof panel caused by the soil cover must be considered when calculating gas impulse with the FRANG code; and, 2) the shock impulse from multiple reflections off reflecting surfaces contributes significantly to the velocity of debris from structures with high loading densities (near 1.0 kg/m^3). The overall effect of added soil mass is to reduce the calculated initial debris velocities and throw distances.

Two other key initial parameters necessary to define debris throw distance are the debris mass and the launch angle. The mass for any given debris is selected from an exponential distribution defined by an empirically determined average mass, in a similar manner as was done in the original DISPRE model. The selection of the launch angle for any given debris is component dependent. For an arch-shaped HAS, for example, the launch angles for debris out the front are represented by a normal distribution with a mean of 45 degrees and a standard deviation of 10 degrees. The reason the normal to the front (0 degrees) is not used as the mean of the distribution is explained by the special treatment of debris thrown out the front of a HAS. The doors on these structures are very large and compose much, if not all, of the front wall. As exceptionally large debris, these doors are considered hazardous entities regardless of where any other debris is thrown out the front; i.e., the doors are not included in debris density calculations. Debris density out the front of a magazine is determined by considering any other concrete debris, most of which originates from where the door meets the roof. This is why the higher angle of 45 degrees is chosen to define the angle distribution. The hazardous debris density out the front is then the larger distance of the calculated debris density or the calculated door throw distance. The door throw distance is determined from an empirical curve fit based on the calculated initial velocity of the door. The same type of distribution is used to define angles for debris thrown to the rear of a HAS. In this case, the large mass of the rear is believed to cause most of the significant debris to be thrown from the roof-rear wall intersection area at high angles.

A uniform distribution is used to define launch angles for debris thrown to the sides of an arch-shaped HAS or magazine. The angles are allowed to fluctuate between a minimum angle, which is defined by the extent of any soil or rock rubble berm (generally around 10 degrees for a HAS with a rock rubble berm), and a maximum angle of 90 degrees. For earth covered, arch-shaped magazines, where the thickness of the earth berm varies greatly between the top and bottom of the arch, the launch angle and debris velocity are not randomly selected independently of each other. In this case, the debris velocity, which is calculated using the concrete and soil cover mass, varies according to its origin on the magazine. This variance must be directly related to the launch angle used for a given debris piece.

3.2.3   Debris Roll

As discovered in the test program associated with development of the original DISPRE model

(Reference 1), if debris thrown after an explosion impacts the ground at a shallow angle, it will roll after impact. Predicting the first impact location as the final resting place is very inaccurate in this case. Logic to calculate debris roll distance from curve fits to test data is incorporated in the MUDEMIMP code. The test data includes tests on masonry and concrete walls from both severe close-in loading and severe gas loading. According to the roll logic built into the DISPRE code, the total debris throw distance is the sum of the distance to the first impact and the roll distance. The roll distance is calculated from the debris angle and velocity at first impact. Debris angle is considered only to the extent that debris with an impact angle less than 55 degrees from the horizontal are assumed to roll, whereas those debris impacting at higher angles are assumed not to roll. The debris impact velocity is used with curve fits from test data (described in Reference 1) to calculate roll distance.

Although there were no roll measurements or definitive roll observations reported for the shelter and magazine tests analyzed for this study, trajectory calculations indicate some type of roll must be occurring. Internal loads and debris initial velocities are being predicted reasonably well, yet the predicted first impact distance can be much less than reported final resting location. There is, however, a big difference in trajectories (and impact angles) between debris thrown off a vertical wall from a rectangular building or magazine and debris from an arch-shaped aircraft shelter or magazine. Thus, the roll logic used in DISPRE was modified for use in DISPRE2 so that only the horizontal component of the impact velocity is used in the empirical formulas to calculate concrete debris roll.

3.3   External Air Blast Prediction

The external loads prediction method included in the model is based on the data for aircraft shelters and magazines reviewed as part of the DISPRE2 development and on data analysis by Swisdak (Reference 16). Air blast data from all the HAS tests which included these type measurements were compared to magazine air blast data described in Reference 16. Measurements in all cases included gauges to the front, side, and rear of a HAS or magazine. Figures 1-3 show the HAS data compared to Swisdak's least squares curve fits for predicting pressure to the front, side, and rear of a magazine. Table 1 indicates the loading densities represented by each test series on these figures. The data for higher loading densities (> 0.1 kg/m^3) compare reasonably well to the magazines curve (Reference 16) for each direction, given that the magazines curve is a least squares fit to numerous data points from earth covered magazines. However, lower loading densities (< 0.1 kg/m^3) would result in overly conservative blast pressure predictions. For this reason, at least two regimes will be used within the software for air blast prediction in each direction based on an observed separation of data sets defined by the loading density.

Swisdak (Reference 17) has recently completed a study in which he specifically examines hazard ranges (both from air blast and debris) for small net explosive quantities in hardened aircraft shelters. The maximum charge weight considered in Reference 17 is 500 kg, which corresponds to a loading density of about 0.1 kg/m^3 for a HAS. As a result of this study,

modified quantity-distances (Q-D) are being proposed as changes for both NATO and U.S. Q-D standards for charge weights up to 500 kg. DISPRE2 (which analyzes both HAS and other magazines) will use methods described in Reference 17 to predict air blast pressures for loading densities less than 0.1 kg/m^3 and methods similar to those in Reference 16 for larger loading densities.

4.0   Microsoft$^®$ Windows$_{TM}$ Based Software

DISPRE2 (Reference 11) uses the BLASTX Version 2.2 (as adapted in BLASTX for Windows, Version 0.8), the FRANG Version 1.0, and the MUDEMIMP Version 1.3 codes. The FORTRAN executables for these codes are embedded in a Visual Basic program which controls all steps of the model for the user. Intermediate steps of the model are conducted within separate FORTRAN modules which are integrated in the Visual Basic structure. A brief outline of the general software flow for predicting hazardous debris distances around a magazine follows.

1) Run BLASTX to obtain shock pressure histories. This is donefor a number of "target" locations for the arch (or roof and side walls of a rectangular magazine), door (or front wall), and rear wall.

2) Determine the total charge weight from all the charge locations input to BLASTX.

3) Calculate the time of peak gas pressure, t_g, for each target location.

4) Determine the vent characteristics based on the structure being analyzed and the loading density.

5) Run FRANG. This is only done twice, once to calculate gas impulse applied to the door or front wall and once to calculategas impulse applied to debris from the arch (or side walls) and rear wall.

For each of three components for an arch-shaped structure or up to five components for a rectangular structure:

6) Sum the applicable portion of the shock and gas pressure histories for each target location.

7) Integrate the summed pressure history for each target location to obtain the total impulse applied to debris at each location.

8) Determine the impulse to use as the load on the entire component.

9)   Define parameters needed for the probability density distributions for the following debris initial conditions as required by the MUDEMIMP code: velocity, mass, drag coefficient, angle, drag area. Other input data for this code,   such as total destroyed mass, are also determined.

10)   Run MUDEMIMP and extract calculated hazardous debris dispersion distances and debris masses for creating desired output.

11)   Calculate appropriate external pressures for graphical output as requested by the user.

Since there are several standard aircraft shelters and magazines in use by the countries represented in the KLOTZ group, the DISPRE2 software contains a number of standard input scenarios which can be selected by the user. When the user accesses the software, the initial screen will allow him/her to select one of four standard icons (three aircraft shelters and a rectangular magazine) or two generic icons (an arch-shaped and a rectangular structure) for analysis. If a standard icon is chosen, the input required by the user is limited to a title and the description of the charge(s). A maximum of twenty charges containing any of the explosives allowed by the BLASTX Version 2.2 code can be specified through program menus. All other input to describe the structure will already be set up within the software. If a generic icon is selected, the user will need to supply some general dimensions of the structure as well. Items such as location of the "targets" for BLASTX are determined internally, but the user is given the option of modifying these target locations. Figure 4 illustrates an initial input screen and a processing screen for DISPRE2.

When DISPRE2 calculations have been completed, the user can select the output option menu. This menu offers the user the following graphics options: number of debris as a function of debris mass; debris density as a function of distance (to front, side, and rear directions); external pressure versus distance (from front, side, or rear direction); air blast contours; target internal load histories; and debris density contours. The DISPRE2 output options screen with an example output plot of debris density vs. distance is illustrated in Figure 5. Some additional example output plots are shown in Figure 6.

5.0   Model Validation

Comparisons of model predictions with data was an ongoing process throughout the development of DISPRE2. The available data were used to create and validate methods for determining individual parameters, such as debris mass or initial velocity, as well as to test the linkage of these parameters to provide final results. Procedures were generally not incorporated into the model until they had been tested against data. However, a significant amount of effort was still necessary in the end to compare predictions made by the complete model with the data. The model can only be validated with actual data; thus, the validation is limited to the extent of the available data.

The hazardous debris distance predicted by the model has been compared to values measured in a number of the HAS tests. The hazardous distance is defined as the distance from the shelter to the center of the nearest "zone" which is not exposed to an areal debris density of more than one hazardous fragment per 55.7 m^2. A hazardous fragment is defined as one having an impact kinetic energy greater than 79 Joules. Debris densities for the tests are calculated considering only the hazardous debris in a triangular sector centered on the perpendicular line from the center of the HAS out each side of the structure. This triangular sector is defined by a debris spread angle off the normal to each side. The sector is divided into trapezoidal zones with edges defined by the spread angle and a constant width along the direction of the normal. The debris density at the center of each zone is calculated by dividing the number of debris landing in, or passing through, each zone by the area of that zone. For any given set of mapped debris, the calculated densities are sensitive to the chosen spread angle and the width of the zones (height of the trapezoids). Once these two parameters are set, the debris density is calculated in an initial zone, defined by this width and angle, which includes the furthest hazardous debris out the side, front, or rear of the structure. The center of the zone is then moved toward the structure by some fraction of the zone width, and the debris density is again calculated. This process is repeated until the densities increase to a value which is sufficiently greater than the hazardous density. Since the calculated debris densities are functions of the spread angle, zone width, and debris distribution, the triangular sector must be defined based on the observed, or expected, debris distribution.

Aircraft shelter test data are available for tests conducted at several different scales. Only three full scale tests can be used with loading densities ranging from 0.08 to 0.8 kg/m^3. These data are considered the most reliable. Scaled tests do not properly scale gravity forces, which affects the debris throw or the effect of strain rate on damage and breakup of brittle materials. The model can be validated against scaled data at a representative critical areal density by simply using the model to predict the hazardous distance for the scaled shelters. This is considered more straight forward, and thus more reliable, than comparing it to data where the debris distances have been "scaled up" based on a number of assumptions. Typically, "scaling up" the debris distribution is done using a trajectory code, assuming the initial launch conditions (which are not significantly affected by gravity forces) do represent properly scaled values. When a structure is overwhelmed by the explosive loading, any error in the scaling of the structural breakup of the model is expected to be less significant. At low loading densities, where the strength of the structure affects debris formation to a greater extent, scaled up debris distributions may not provide a representative estimate of the full scale debris distribution and hazardous distances.

A comparison of predicted hazardous debris distance to measured hazardous distance for various loading densities is shown in Figure 7. As shown, the model predicts hazardous debris density, and thus hazardous distance, reasonably well. It should be noted that model predictions for the 1/3 scale PAS series (Reference 5) had to be adjusted to be able to compare with measured debris densities. The researchers collected data in 5 degree sectors

to a certain distance, then just mapped large debris. The model was adjusted for these cases to predict debris density in the same fashion. Thus, predicted hazardous distance for these scaled shelters will not necessarily match predictions for a comparable full scale Norwegian/US shelter analyzed by the model. Maximum debris distances can be underpredicted by DISPRE2 for low loading densities, but the hazardous distances are more important in meeting or setting safe siting criteria for aircraft shelters or magazines.

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Table 1. Loading Densities for HAS Tests

Test Series	Scale	Loading Density (kg/m^3)
DISTANT RUNNER Event 1 (DR-1)	Full	0.004
PAS-1	1/3	0.021
PAS-2	1/3	0.062
HAS-QD	Full	0.08
PAS-3	1/3	0.18
DISTANT RUNNER Event 4 (DR-4)	Full	0.20
PAS-4	1/3	0.56
DISTANT RUNNER Event 5 (DR-5)	Full	0.80
1:10 Scale ASMT	1/10	0.80

Table1. Loading Densities for HAS Tests

Figure 1. External Blast Pressure Out the Front
and
Figure 2. External Blast Pressure to the Side
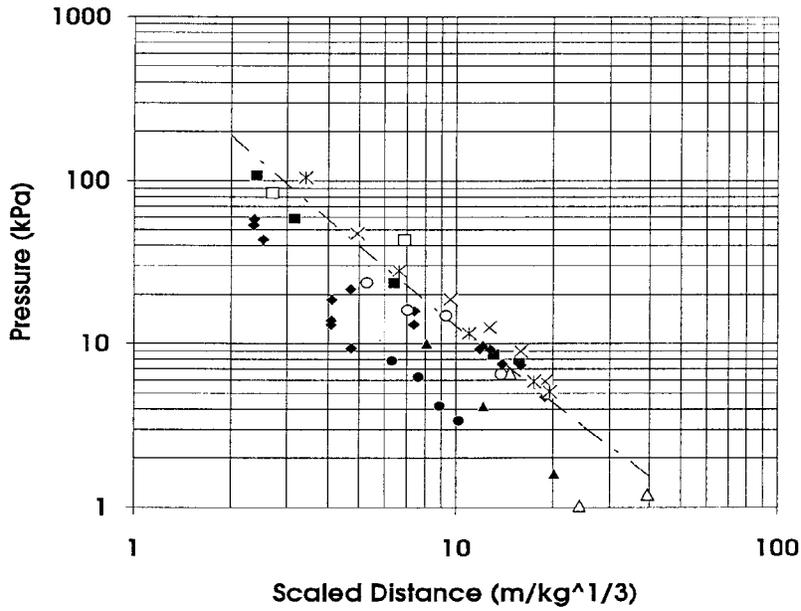
Figure 1. External Blast Pressure Out the Front

Figure 2. External Blast Pressure to the Side

Legend:
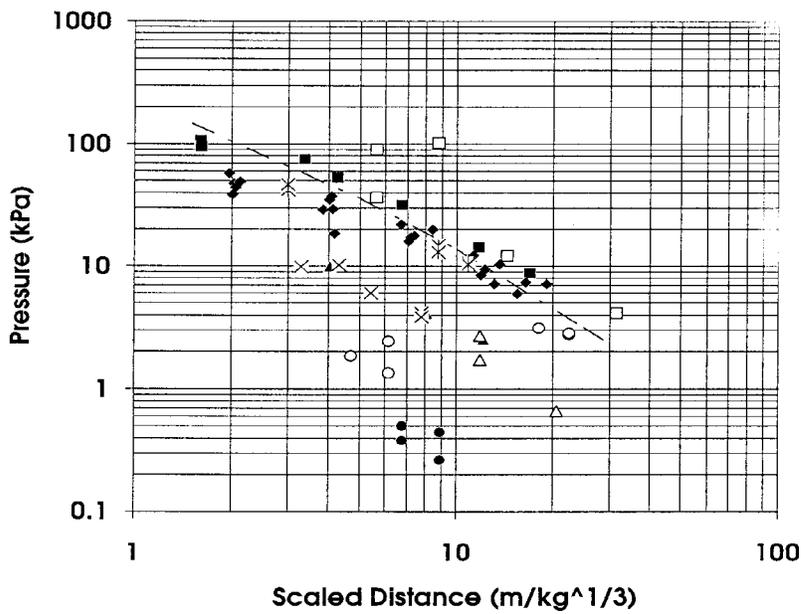
- ■   DR-5 (Ref. 7)
- □   DR-4 (Ref. 7)
- ◆   1/10 ASMT (Ref. 8)
- — · —   Magazines (Ref. 15)
- ▲   HAS-QD (Ref. 6)
- △   DR-1 (Ref. 7)
- ●   PAS-1 (Ref. 5)
- ○   PAS-2 (Ref. 5)
- ×   PAS-3 (Ref. 5)
- ✳   PAS-4 (Ref. 5)

Figure 3. External Blast Pressure to the Rear
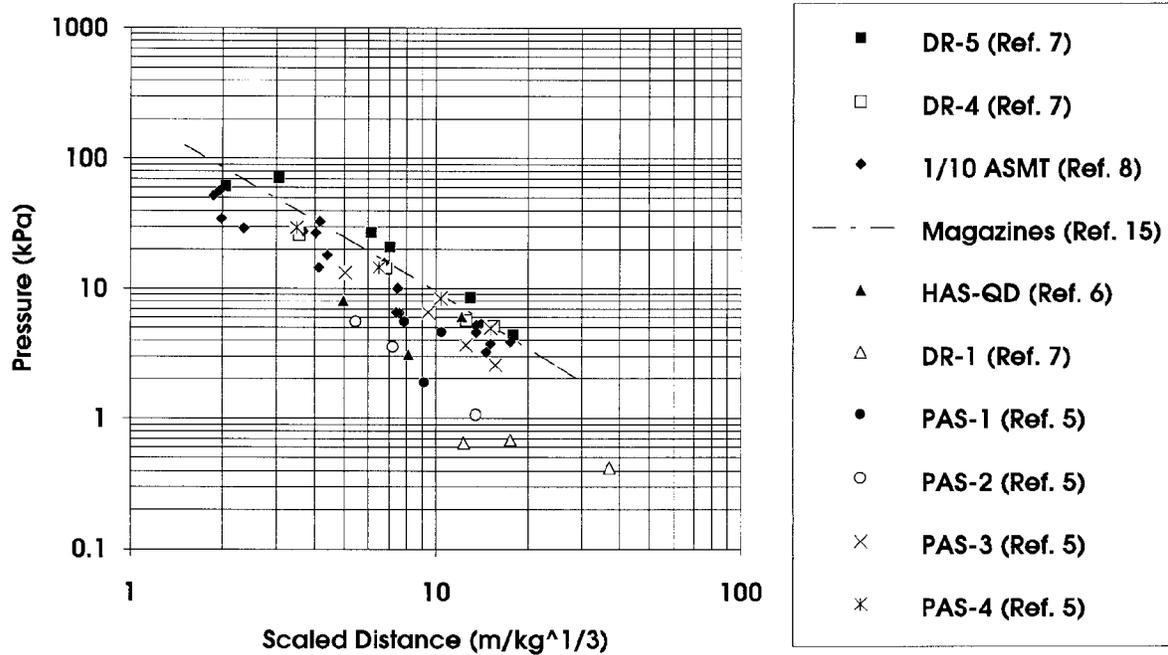
Figure 3. External Blast Pressure to the Rear

Figure 4a. Initial DISPRE2 Imput Screen Example
and
Figure 4b. DISPRE2 Processing Screen Example
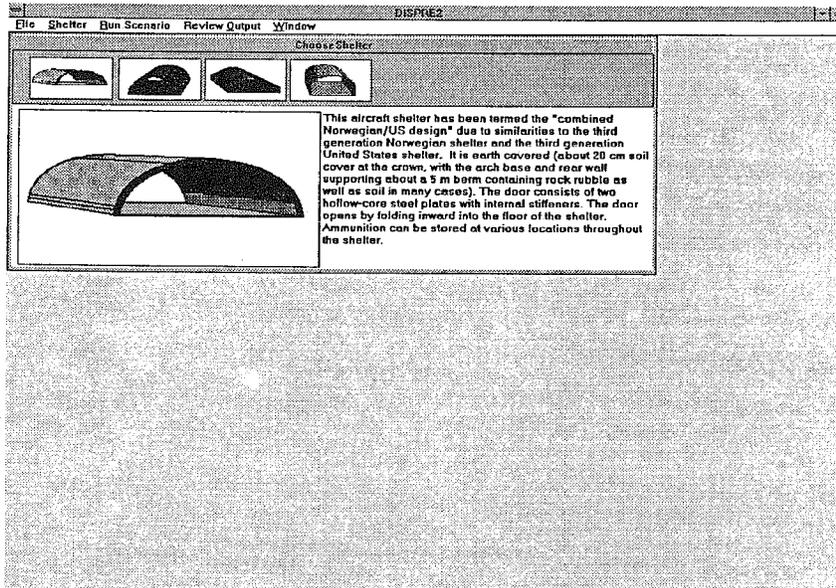
Figure 4a. Initial DISPRE2 Input Screen Example
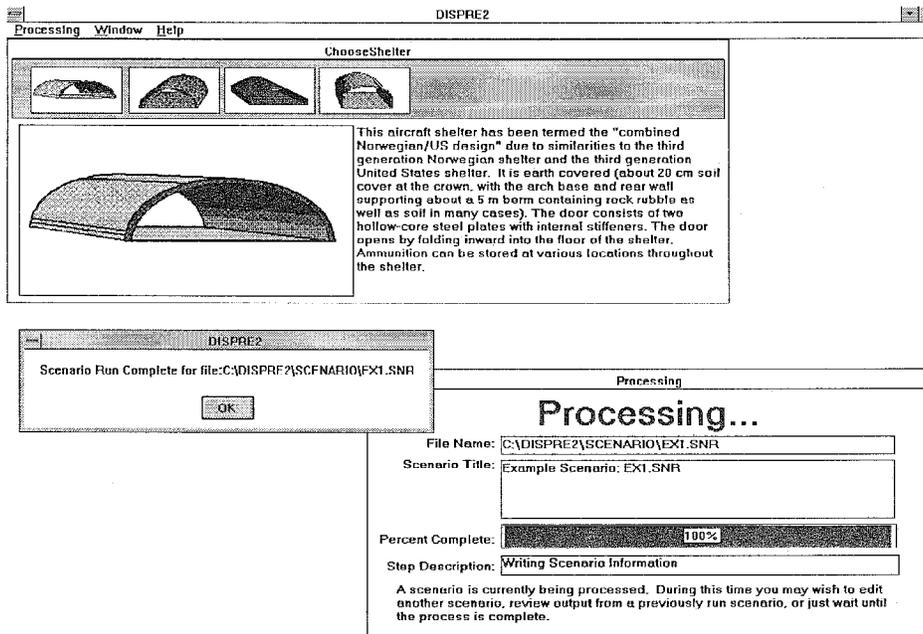
Figure 4b. DISPRE2 Processing Screen Example

Figure 5. DISPRE2 Output Options Screen
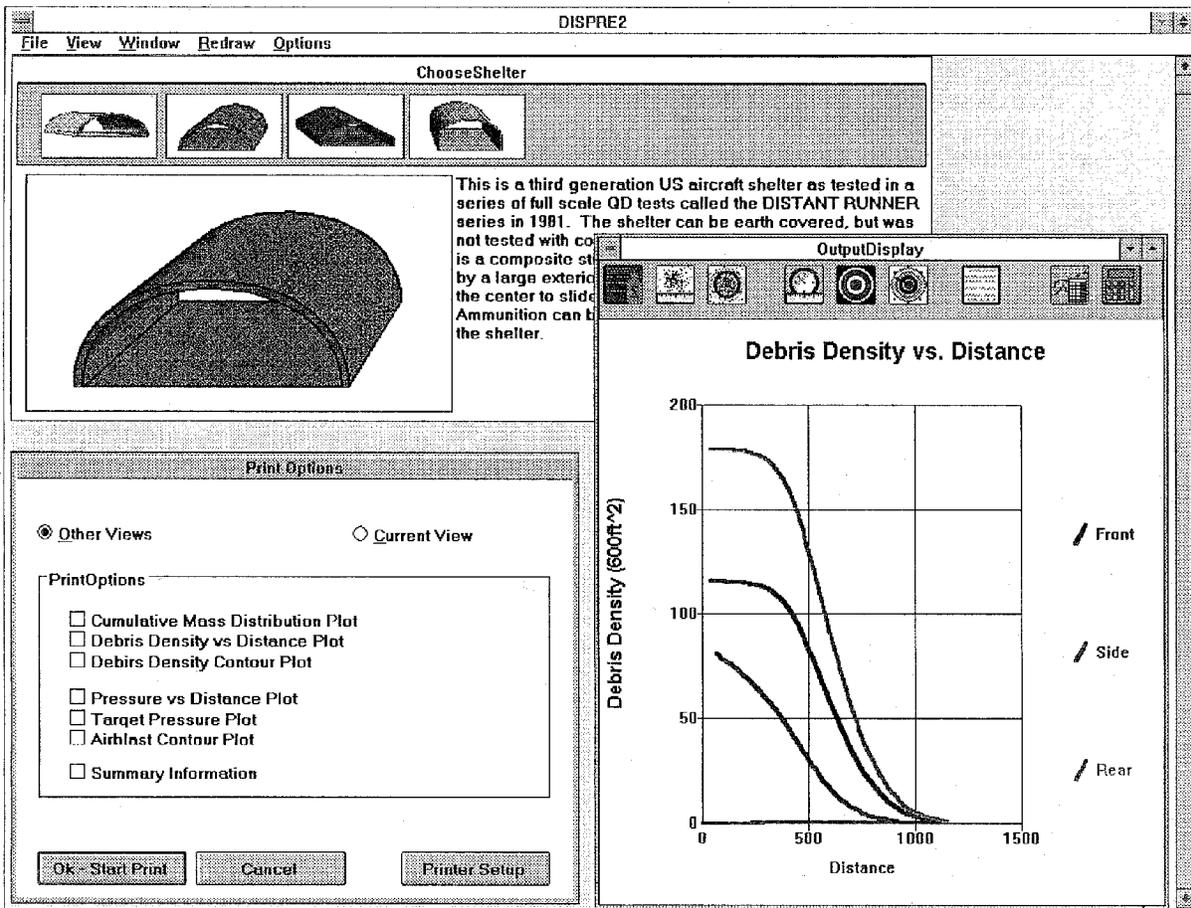
Figure 5. DISPRE2 Output Options Screen

# Figure 6a. Example Output for Internal Load Histories and Figure 6b. Example Output for Debris Density Contours
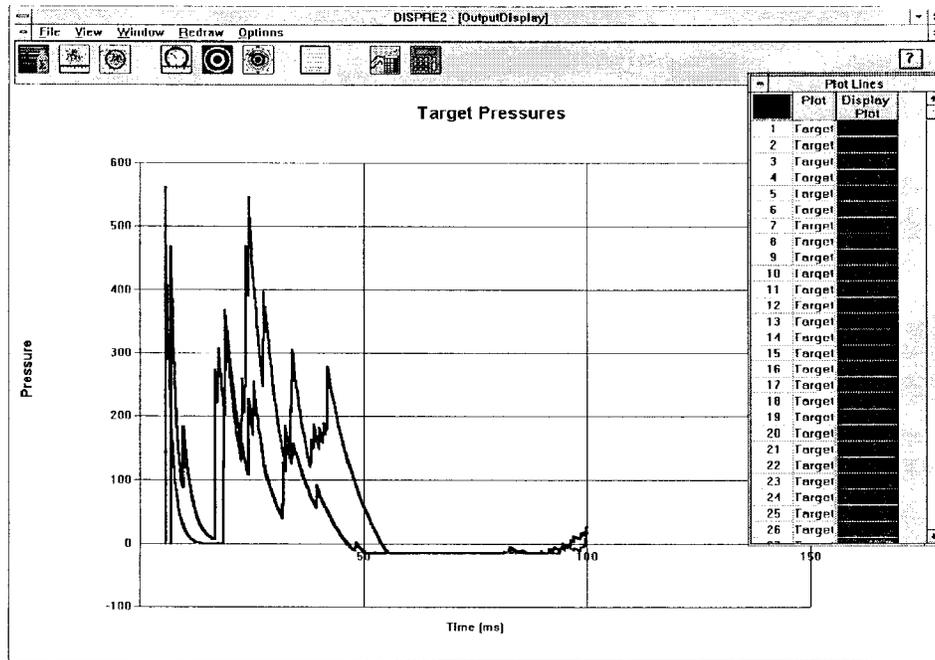
Figure 6a. Example Output for Internal Load Histories
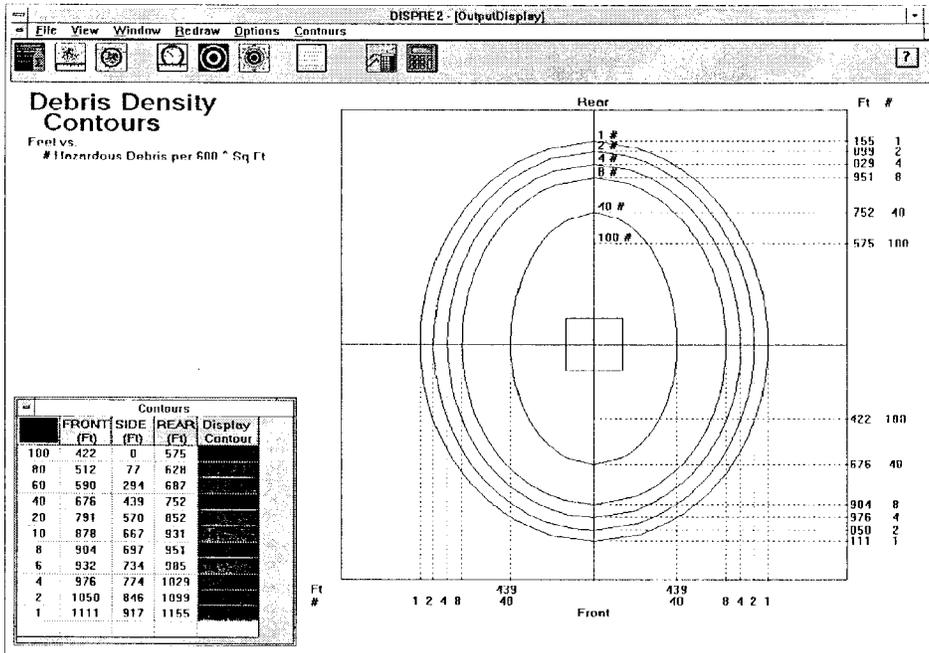

Figure 6b. Example Output for Debris Density Contours

Figure 7. Comparison of Predicted to Measured Hazardous Debris Distance

Figure 7. Comparison of Predicted to Measured Hazardous Debris Distance