COMPUTER ENHANCEMENTS FOR DETERMINING EXPLOSIVE FRAGMENTATION Q-D

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ABSTRACT:

Operations involving the manufacture, storage and maintenance of explosives and munitions create an unusual risk to people and unrelated facilities. To reduce this risk to acceptable levels Department of Defense Explosive Safety Regulations define minimum separation distances. Required safety zones are based on a 670 foot separation distance for quantities of explosive less than 100 pounds and 1250 feet minimum for higher quantities. The land encumbered by these safety zones restricts flexibility in the effective use of total installation assets. In many cases the arbitrary separation distances required by regulation are overly conservative. The Department of Defense Explosives Safety Board (DDESB) has recently approved the use of specific fragmentation/debris prediction analyses procedures that can be used to reduce the required safety zones. These analyses procedures are available in a computer model named DISPRE. This paper discusses the prediction model and provides examples of how default driven explosive quantity safety zones can be substantially reduced. A preprocessor called DISPRE1 which greatly enhances the usefulness of the DISPRE code is also demonstrated.

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BACKGROUND

Department of Defense (DoD) installations that manufacture, store and maintain explosives, munitions and propellants create a significant risk to unrelated personnel facilities in the vicinity of the hazardous operations. Accidental explosions generate blast overpressures, primary fragments from munitions, and secondary debris from the destruction of the operating facility. Empirically developed criteria and observations of past explosive accidents have been the basis for defining minimum separation distances from these hazardous operations. Safety distances are intended to reduce the risk to what is generally acceptable to society. The governing DoD regulations contain two separation distance criteria, one for overpressure and one for fragmentation and debris. Separation distance required for primary fragmentation of cased weapons is defined by munitions hazard classification. This paper will discuss the criteria related to secondary fragmentation and debris from building breakup. This risk often governs safe separation distances for smaller quantities of explosive materials.

REGULATIONS

DoD 6055.9-STD "Ammunition and Explosive Safety Standards" (Reference 1) establishes uniform standards applicable to DoD ammunition and explosive facilities. The standard is also used by the Department of Energy and the National Aeronautics and Space Administration. The governing requirements for fragmentation and debris specify minimum Inhabited Building Distance (IBD) separations of 670 and 1250 feet for Net Explosive Weights (NEW) less than and more than 100 lbs respectively. The 1250 foot value will control over overpressure up to 30,000 lbs NEW. These minimum default separation distances are intended to provide reasonable protection from exposure to hazardous fragments. A hazardous fragment is defined in the as one with kinetic energy greater than 58 ft-lbs. The DoD standard requires a hazardous fragment density of not more than one per 600 square feet of impact area beyond the inhabited building distance.

FACILITY MANAGEMENT REQUIREMENTS

The application of the standards to operations involving many small uncased explosive quantities (a few ounces to several hundred pounds) can restrict substantial amounts of real estate. In actual operational situations, the default distances are frequently conservative. When it can be shown that engineered facility designs, constructed barricades or natural terrain mitigate hazardous fragmentation, then reduced distances can be used for explosive safety siting. In addition, whenever the facility housing the explosive operation is sufficiently robust, the expected range for hazardous fragments is often reduced. Any of these methods can conserve real estate, reduce costs, and still meet explosive safety requirements. The DDESB has accepted detailed analyses which demonstrates that the fragmentation or debris threat distance is less than the default values. Use of these special analyses is not unusual for significant facilities or projects. However, they demand special expertise, can be fairly expensive and require an extensive regulatory review period.

DISPRE ANALYSIS PROCEDURE

In the past, the lack of a standardized analysis procedure for demonstrating reduced building debris throw distances limited the ability of facility users to take advantage of this option in expanding the use of their facilities. However, in 1991 the Department of Energy completed an extensive experimental program which provided sufficient data to develop a standardized analytical model for predicting building debris ranges for explosive limits up to 250 lbs NEW. The new procedure with necessary empirical data was combined in the computer code DISPRE. After extensive review by the DDESB the procedure and data contained within DISPRE were certified as a "pre-approved" method for obtaining reduced separation distances for building debris and fragmentation. The DISPRE model is formally documented in DDESB Technical Paper 13 "Prediction of Building Debris for Quantity Distance Siting" (Reference 2)

The DISPRE Model predicts debris impact ranges and densities for the building construction materials that were evaluated in the DOE test program. Fortunately, most of the materials tested were common to DoD explosive material facilities. The test program provided empirical data on debris size, shape, drag characteristics, trajectory launch angles for typical facility configurations, probability distribution functions for different types of debris properties, and launch velocities. It also provided data to determine contribution of internal gas pressure impulse to the shock loading used to determine initial energy.

The DISPRE model uses input data from several computer models already approved by the DDESB. These models are automated procedures derived from the basic principles given in TM5-1300, "Design of Structures to Resist the Effects of Accidental Explosions" (Reference 3). The DISPRE model substantially reduces the time and resources required to complete an analysis to demonstrate reduced safety separation distances. It thus provides an opportunity to evaluate many smaller facilities and storage conditions and gain additional use or planning flexibility.

DISPRE uses a computer program called MUDEMIMP. MUDEMIMP is a Southwest Research Institute (SwRI) modification of a program developed by the Naval Civil Engineering Laboratory (NCEL). The original program was designed to predict fragment throw distances and overall fragment densities based on statistical distributions. SwRI included a refined fragment density calculation and calibrated the fragment roll on impact with test data. MUDEMIMP uses a Monte-Carlo type randomization along with default statistical distribution to predict hazardous building debris densities in fragments per 600 square feet of impact ground area. Fragments are assumed to roll if the impact angle from horizontal is less than 50 degrees. Five thousand fragment simulations are used. The program outputs the critical distance for hazardous fragment density, the distance to the extreme fragment, the fragment densities in each cell, and the throw data for each fragment simulation.

While DISPRE has provided a much more economical DDESB pre-approved model for calculating reduced separation distances, the methods used and the execution of the model are still complex. It requires knowledge of fundamental principles of fragmentation and debris generation, structural dynamics, statistical applications and computer code usage. In addition, the code provided in Reference 2 requires careful preparation of data to avoid errors and has limited diagnostics.

DISPRE has several limitations for its use. The scaled standoff must be a minimum of 0.5 ft/lb$^{1/3}$ and the actual standoff must be at least 1.5 ft. The general use is limited to debris velocities of less than 1000 fps with the exception of corrugated metal walls or roofs. The explosive charge is limited to 250 pounds NEW. DISPRE is limited to the construction materials covered in the research which are lightly reinforced concrete, unreinforced CMU, unreinforced clay tile or brick, steel, and cemestos. Wood, fiberglass, and other materials are not covered by this model.

- DISPRE Input Requirements

  Blast Load

  The computer programs SHOCK (Reference 4) and FRANG (Reference 5) are used to determine the shock and quasistatic gas pressure loads. The shock load can be averaged over the whole surface, over part of the surface, or at a point on the surface. Which load is used depends on the type of material and the explosive standoff.

  Fragment Velocity

  The model requires the initial velocity characteristics for the fragments. The maximum velocity, average velocity and the standard deviation must be calculated. These are based on the material and blast load characteristics.

  Fragment Weight

  The average fragment weight must be calculated. The methods used to calculate the weights differ greatly between the types of construction material.

  Fragment Trajectory

  Input the initial fragment trajectory angle. This is usually normal to the surface measured relative to horizontal.

  Effective Destroyed Weight

  The DISPRE model requires the input of the total destroyed weight. This is, the portion of the building surface which will be destroyed in an explosion and will contribute debris.

  Grid Areas

The value of the 'GRIDL' term must be calculated. This term is used by the model in determining the size of the grid area used in calculating the hazardous fragment density. 'GRIDL' is calculated based on the total effective destroyed weight and the weight per unit area of the element.

MUDEMIMP

The computer program MUDEMIMP is then run. MUDEMIMP is a fragmentation density computer simulation program. It requires a formatted input file where correct data placement is essential.

The flow chart for the DISPRE model is shown in Figure 1.

ž DISPRE1

DISPRE can be difficult to use with numerous hand calculations, engineering decisions, and a formatted data file required. In order to simplify the process, the Huntsville Division of the U.S. Army Corps of Engineers developed the computer program DISPRE1 for the DDESB. It uses a menu driven "shell" code to input the raw data required by the DISPRE model. The main menu is shown in Figure 2. DISPRE1 then makes many of the calculations which DISPRE required be done by hand. DISPRE1 uses this information to create the formatted data file, 'min.dat', required by MUDEMIMP. After MUDEMIMP is run, DISPRE1 renames and saves both the input file and the output files under the file names that were selected on the DISPRE1 main menu. This aids in book-keeping if many runs are to be made. All functions such as running SHOCK, FRANG, MUDEMIMP, and an ASCII editor can be accessed from the main menu of DISPRE1.

FIGURE 1

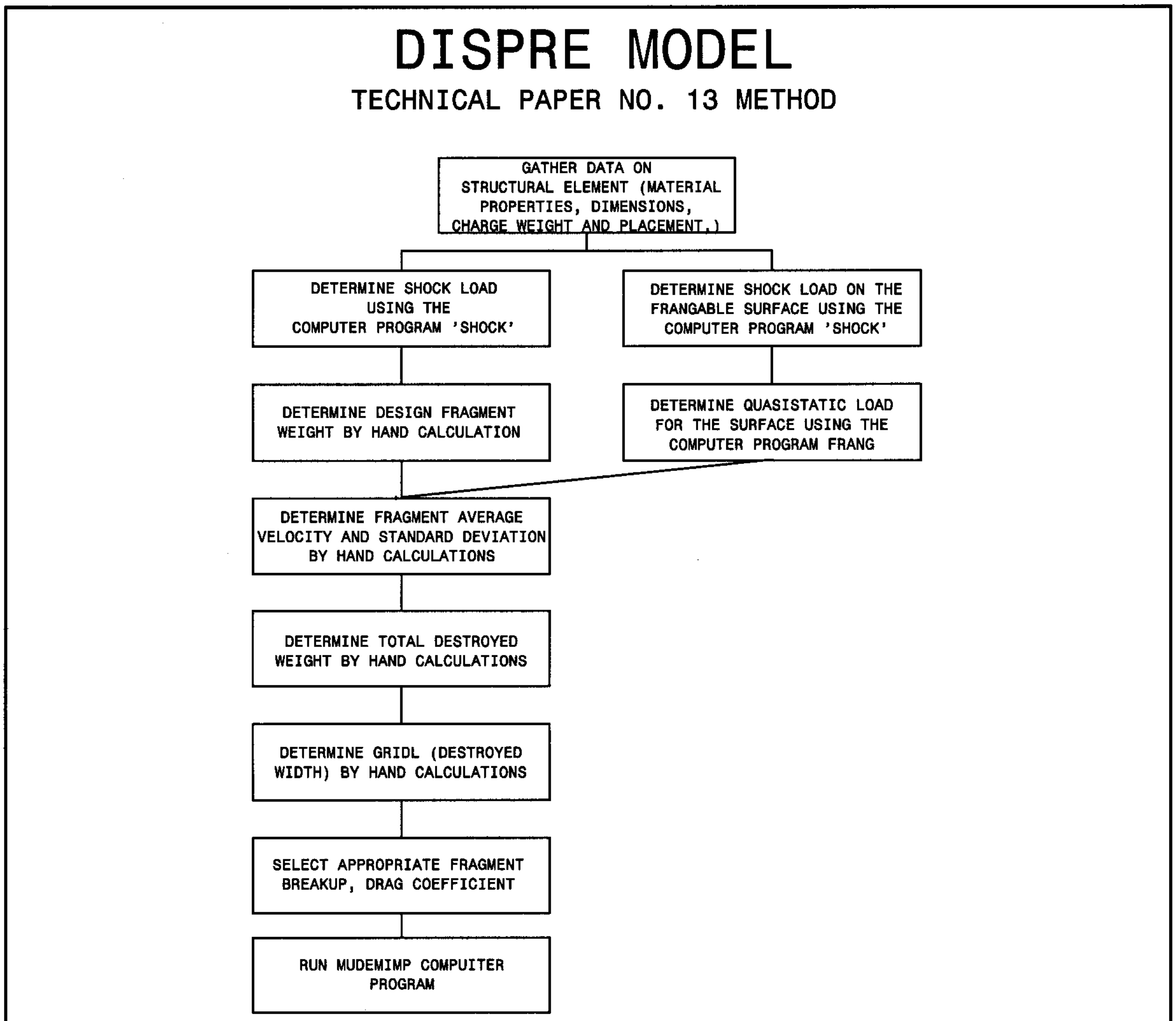

Figure 1

ž DISPRE1 Input Requirements

Explosives Information

Input the charge weight and the its standoff distance from the surface.

Material Type

Input the construction material of the surface to be analyzed. The DISPRE model uses sub-menus to ensure that all of the information required is input. The information for reinforced concrete, for example, includes thickness, clear cover, reinforcing spacing, and concrete strength.

FIGURE 2

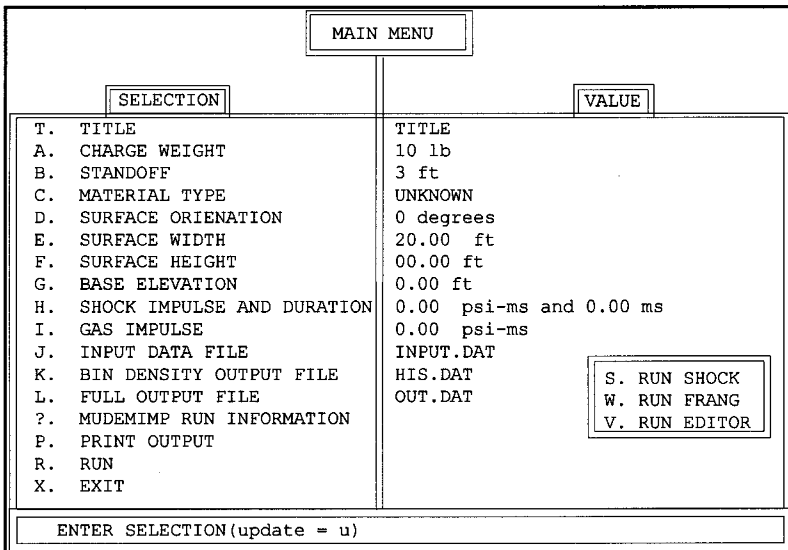

Figure 2

Surface Geometry

Input the height and width of the surface and the initial fragment height, usually the charge height.

Blast Load

Input the shock and quasistatic gas pressure load on the surface. As with the DISPRE model, this information is obtained from the SHOCK and FRANG programs. DISPRE1 will calculate and indicate the type shock loading that is required. Both SHOCK and FRANG can be accessed directly from the DISPRE1 main menu.

File Names

DISPRE1 allows the user to name the input and output files from the main menu. This aids in bookkeeping when doing multiple runs. DISPRE1 changes the name of the input file to 'min.dat' for running the MUDEMIMP code.

MUDEMIMP

Run the computer program MUDEMIMP. The DISPRE1 processor creates the formatted data file required by the MUDIMIMP code.

Output

After the run DISPRE1 renames the output files to the what the user has input. The output files may be viewed directly from DISPRE1 using the editor which may be accessed from the main menu.

FIGURE 3

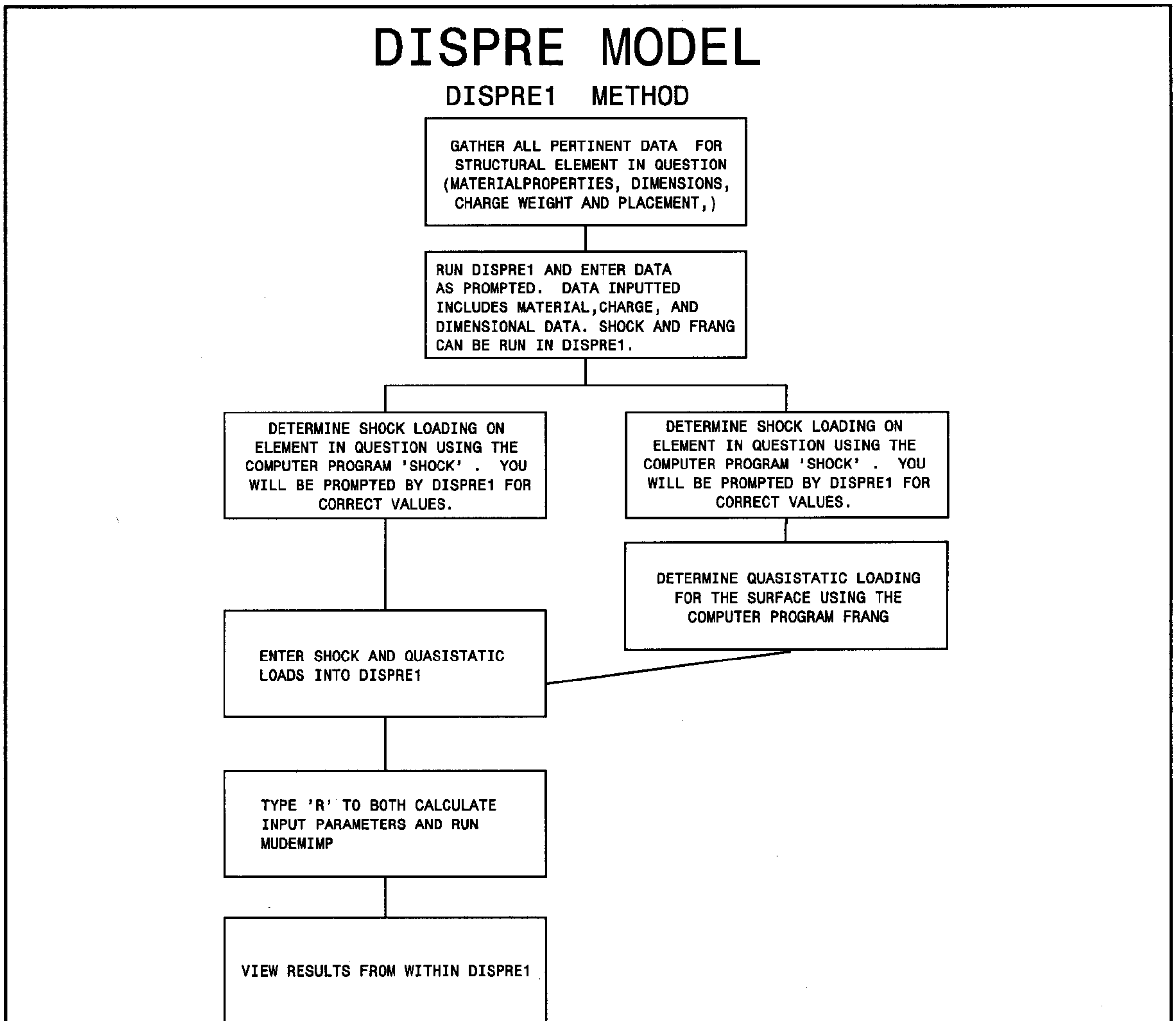

Figure 3

EXAMPLE

The following example is provided to illustrate the advantages of using DISPRE1 computer program and the DISPRE model to determine the alternate fragment distance per Reference 1. Figure 4 shows the plan and section of a 30' by 30' by 15' bay containing an explosive charge of 90 pounds of TNT. For this example the concrete wall opposite the frangible wall will be analyzed. The concrete wall has the following properties;

f'_c	= 4000 psi
thickness	= 12 inches
rebar spacing	= 12 inches
clear cover	= .75 inches

If the bay is sited as shown in Figure 5, the 670 foot fragment distance arc extends past other inhabited buildings. The corresponding inhabited building distance arc for overpressure ($40(90)^{1/3}$ ~ 180 feet) does not infringe on the other building. A reduction in fragment distance is greatly desired.

- The first step is to start DISPRE1.

- Change the title, charge weight (90 lbs)), and standoff (3 ft) in the Main Menu.

- Select the option to change the material type.

- From the Materials Menu, Figure 6, select reinforced concrete ('A').

- On the Reinforced Concrete Data menu, Figure 7, change the thickness (12 inches), concrete unit weight (150 pcf), concrete clear cover (.75 inches), steel reinforcement spacing (12 inches), f'_c concrete compressive strength (4000 psi), and the top surface condition (option 'F' = Y).

- Return to Materials Menu (type 'X') and then return to the Main Menu (type 'X' again).

- Change the surface orientation (90 degrees), surface width (30 ft), surface height (15 ft), and initial fragment elevation.

- Select 'H' to change the shock impulse and duration. Make a screen print (shift-print screen) of the window that pops up with instructions on the screen. Hit enter three times. This will put zero values in the shock impulse and duration.

- Select 'I' to change gas impulse (quasistatic). Make a screen print (shift-print screen) of the window that pops up with instructions on the screen. Hit enter twice. This will put a zero value in the gas impulse .

ž Select 'S' to run SHOCK. Run SHOCK as directed by DISPRE1. Perform an additional run to determine loadings on the frangible surface.

ž Select 'W' to run FRANG. Run FRANG as directed by DISPRE1.

ž Select 'V' to open the DOS editor. When running SHOCK and FRANG be sure to write down the output file names. A suggested naming practice is to name all SHOCK output files file.shk and all FRANG file.frg. The files for this example are named DDESB1.shk, DDESB2.shk, DDESB1.frg, and DDESB2.frg. This practice makes it easier to keep track of files. Either write down the necessary information from the files or print them from the editor.

ž Select 'H'. Press return to clear the shock impulse. Input the shock impulse and press enter. Enter the shock duration and press return.

ž Select 'I'. Press return to clear the gas impulse. Input the gas impulse and press enter.

ž Change the input and output file names. The names for this example are DDESB.dat, DDESB.his, and DDESB.out.

ž Press 'R' to begin MUDEMIMP execution. The screen will clear and 4 lines of text will appear on the screen. These are from MUDEMIMP and should be ignored. When MUDEMIMP is finished a window with the start and stop times for the MUDEMIMP run shown. Press enter to return to DISPRE1 Main Menu.

ž Press 'P' to print or view the output files.

The critical distance for hazardous fragments is determined from 'DDESB.his' to be .208e3 feet or 208 feet. This is a reduction in the fragment distance of almost 70%. Figure 8 illustrates the advantages of the alternate fragment distance. The bay was in violation with the default fragment distance but is sited adequately based upon the DISPRE1 hazardous fragment distance calculation.

FIGURE 4

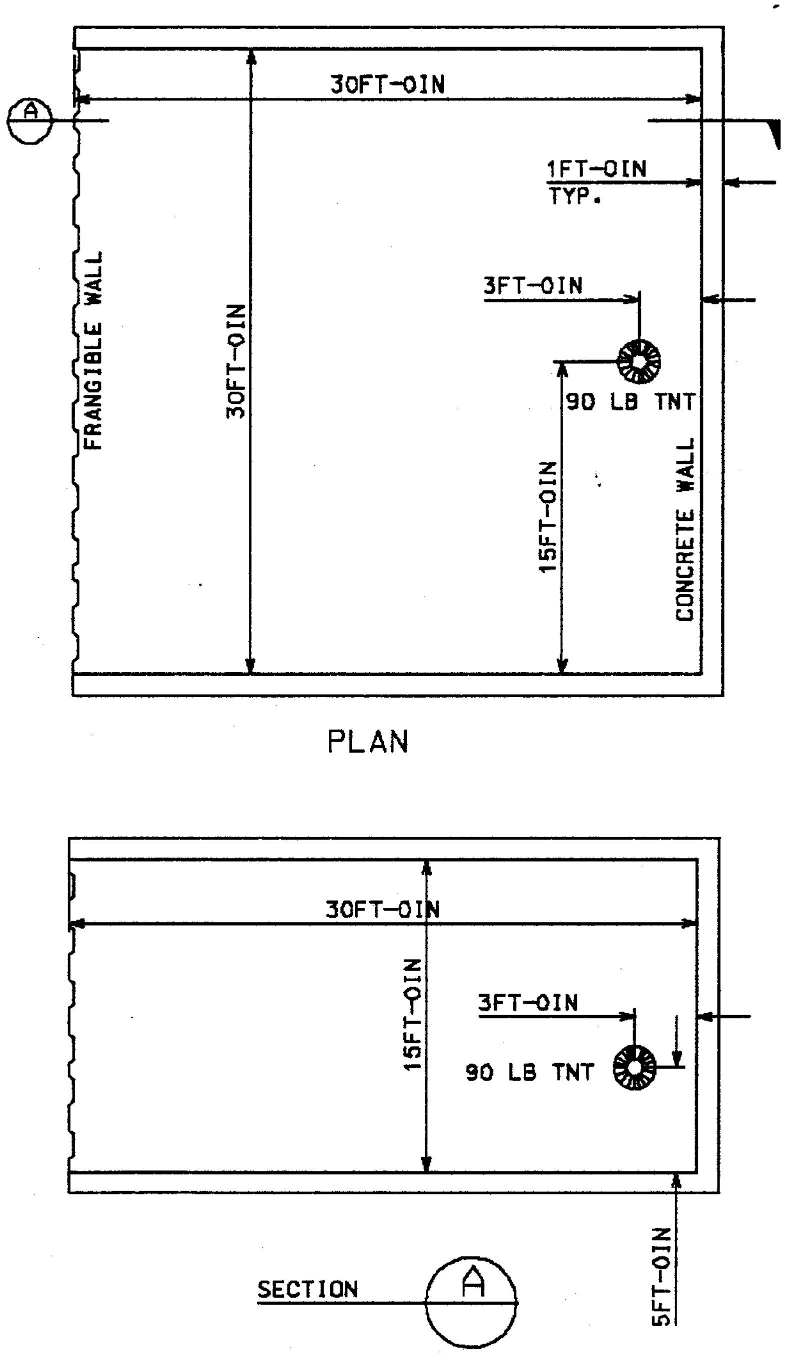

Figure 4

FIGURE 5

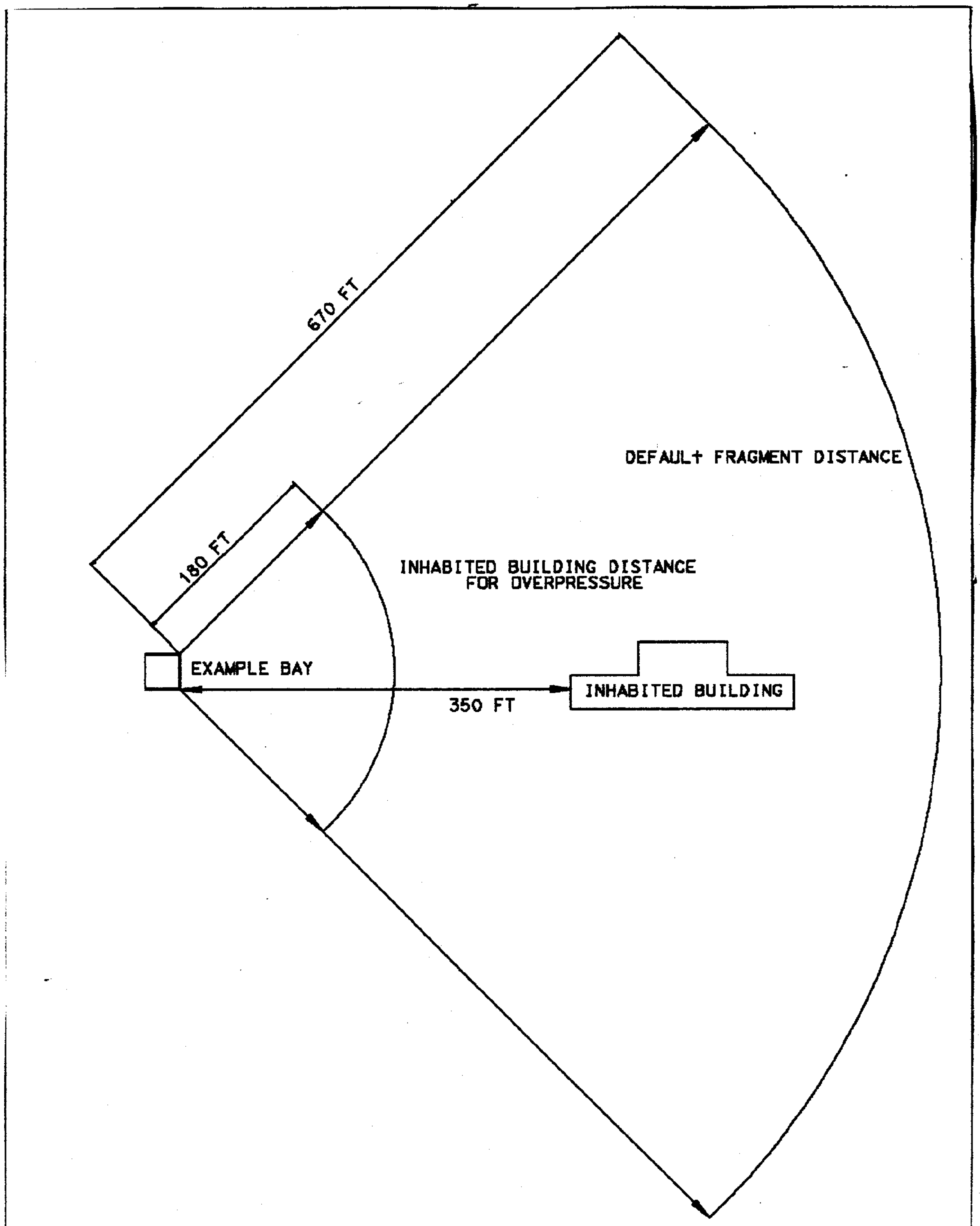

Figure 5

FIGURE 6

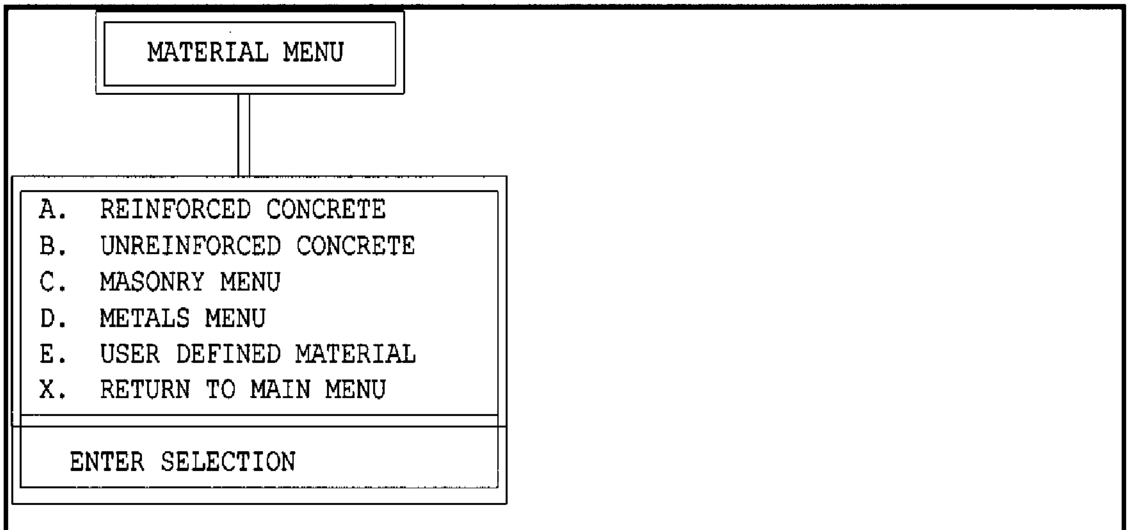

Figure 6

FIGURE 7

```
                REINFORCED CONCRETE DATA

      SELECTION                                          VALUE
A.  THICKNESS                                       10.00     inches
B.  CONCRETE UNIT WEIGHT                            150.00    pcf
C.  CONCRETE CLEAR COVER                            0.75      inches
D.  STEEL REINFORCEMENT SPACING                     12.00     degrees
E.  f'c CONCRETE COMPRESSIVE STRENGTH               3000.00   psi
F.  IS THE SURFACE RESTRAINED AT THE TOP (Y OR N)   N

X.  RETURN TO PREVIOUS MENU

  ENTER SELECTION(U -->UPDATE)
```

Figure 7

FIGURE 8

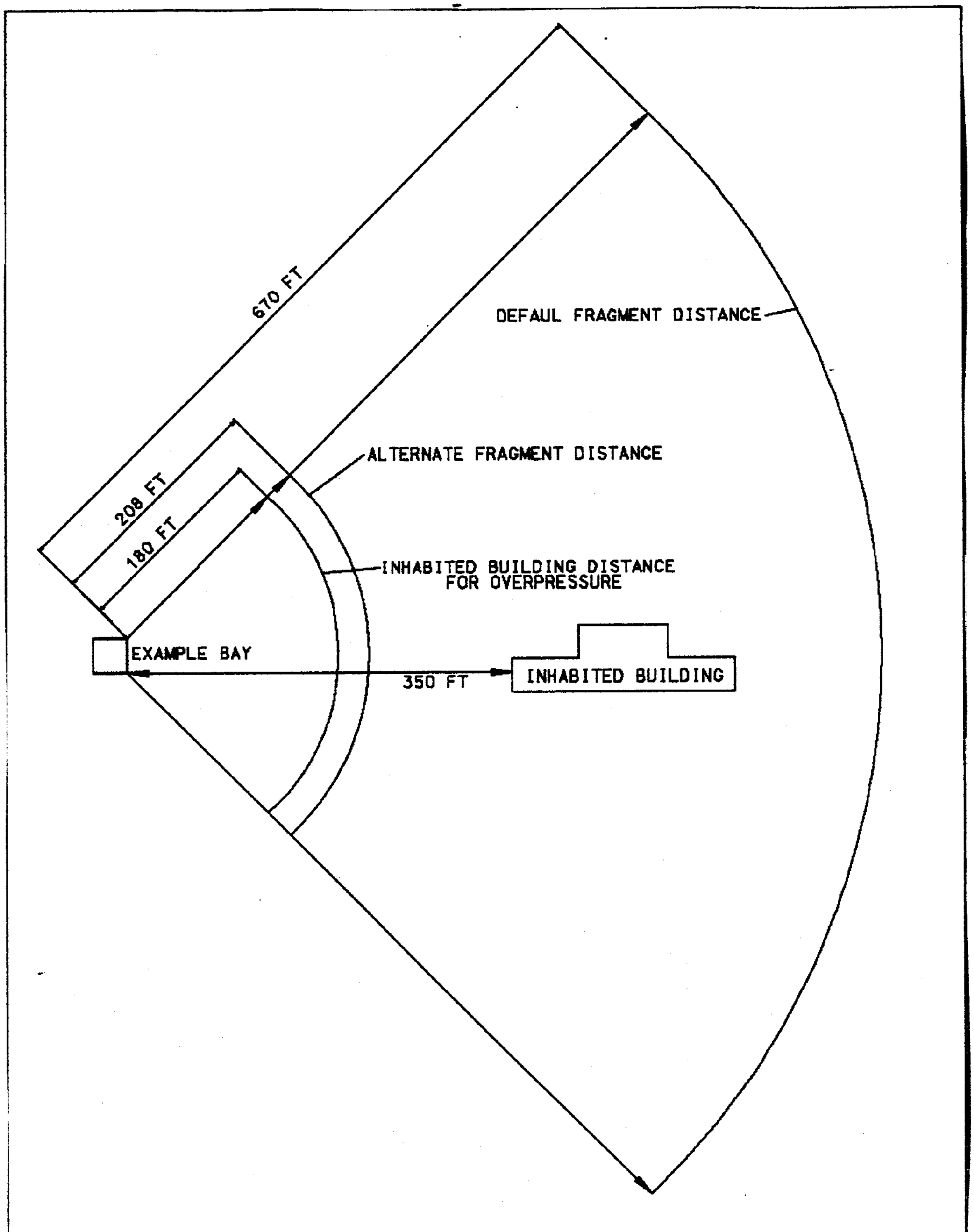

Figure 8

CONCLUSIONS

The default fragmentation debris separation distances required by DoD 6055.9 STD are often unduly conservative for quantities of uncased explosives less than a few hundred pounds. The computer model DISPRE approved by the DDESB provides the means to analyze these situations and obtain potentially significant reduction in encumbered land area. However as a first generation code, DISPRE is labor intensive in data preparation and presents a risk of results invalidated by unrecognized input errors or assumptions. The DOS based model DISPRE1 was developed to provide a more user friendly input, error diagnostics, and to integrate the input from other codes required to execute DISPRE.

The use of the DISPRE/DISPRE1 model allows an order of magnitude improvement in the preparation of reduced separation distance analyses for operations with less that 250 lbs NEW. The Huntsville Division has successfully used it on numerous Army facilities with great benefit to the using installation. There is potential that this methodology will be extended to higher quantities in the future. A final comment is in order. As codes such as these become more user friendly it is much easier for an inexperienced person to exercise them. Such individuals may not have the grasp of fragmentation, structural dynamics, trajectory analysis etc, to recognize valid initial conditions or questionable output. Until Artificial intelligences inference systems are developed for this field, the user must have appropriate technical experience or a quality control review by such an individual.

REFERENCES

1. DOD 6055.9-STD, DOD Amunition and Explosives Safety Standards, Assistant Secretary of Defense (Production and Logistics), US Department of Defense, Washington, DC.

2. Technical Paper No. 13, Prediction of Building Debris for Quantity-Distance Siting, Department of Defense Explosives Safety Board, Alexandria, VA.

3. Tri-Service Manual, US Army TM 5-1300 / Navy NAVAC P-397 / Air Force AFR 88-22, Structures to Resist the Effects of Accidental Explosions, Departments of the Army, Navy, and Air Force, Washington, DC, November 1990.

4. "SHOCK Users Manual", Naval Civil Engineering Laboratory, Port Hueneme, CA, 1988.

5. "FRANG Users Manual", Naval Facilities Engineering Command, Alexandria, VA, 1989.