HIGH EXPLOSIVE DAMAGE ASSESSMENT MODEL
ADVANCED INDUSTRIAL VERSION (HEXDAM-D+)

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ABSTRACT

HEXDAM-D+ represents the fourth industrial version of the High Explosive Damage Assessment Model. Like its predecessors this software has been designed to allow the rapid evaluation of damage experienced by each structure within a facility as a result of a primary explosion, and any accompanying secondary explosions. Its primary application is siting analysis of explosive storage and manufacturing facilities. The code can also be used to evaluate terrorism and sabotage threats to an industrial or military facility. The program has the capability to model an unlimited number of structures, and each with different dimensions and structural properties. The Parametric Analysis of Single Structures (PASS) capability allows the user to determine the influence of various important independent variables on damage to an individual structure within a facility. As with its predecessors, HEXDAM-D+ utilizes widely accepted dynamic pressure and overpressure curves to predict the pressure level at each structure location. Structure shielding based on an advanced shielding algorithm, and secondary explosion effects are calculated and damage levels are determined for each structure. HEXDAM-D+ produces output in the form of damage tables, before-damage and after-damage displays, pressure and damage contour plots, and damage-versus-distance graphs, all in color. Advanced graphical features include three-dimensional graphics in the form of oblique projections, as well as two-dimensional horizontal and vertical cross sections for overpressure, dynamic pressure, and damage contour plots. To ensure the software is usable by installation engineering, planning, and safety offices, the hardware requirements for HEXDAM-D+ have been kept at a modest level. An IBM PC-XT/AT/386/486, or compatible, with a color monitor, a dot matrix printer, and a color plotter (for hardcopy of screen graphics) are sufficient to execute HEXDAM-D+.

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INTRODUCTION

The HEXDAM-D+ software represents the fourth industrial version (color added) of the High Explosive Damage Assessment Model (HEXDAM), developed by Engineering Analysis, Inc. (EAI). Like its predecessors this software has been designed to allow the rapid evaluation of damage experienced by each structure within a facility as a result of a primary explosion, and any accompanying secondary explosions. Its primary application is siting analysis of explosive storage and manufacturing facilities. The code can also be used to evaluate terrorism and sabotage threats to an industrial or military facility.

The program has the capability to model an unlimited number of structures, and each with different dimensions and structural properties. The Parametric Analysis of Single Structures (PASS) capability allows the user to determine the influence of various important independent variables on damage to an individual structure within a facility. As with its predecessors, HEXDAM-D+ utilizes widely accepted dynamic pressure and overpressure curves to predict the pressure level at each structure location. Structure shielding based on an advanced shielding algorithm, and secondary explosion effects are calculated and damage levels are determined for each structure. HEXDAM-D+ produces output in the form of damage tables, before-damage and after-damage displays, pressure and damage contour plots, and damage-versus-distance graphs, all in color. Advanced graphical features include three-dimensional graphics in the form of oblique projections, as well as two-dimensional horizontal and vertical cross sections for overpressure, dynamic pressure, and damage contour plots.

To ensure the software is usable by installation engineering, planning, and safety offices, the hardware requirements for HEXDAM-D+ have been kept at a modest level. An IBM PC-XT/AT/386/486, or compatible, with a color monitor, a dot matrix printer, and a color plotter (for hardcopy of screen graphics) are sufficient to execute HEXDAM-D+.

APPLICATIONS

HEXDAM-D+ can be used as a damage assessment tool to determine the amount of blast damage done to individual structures in a certain geographical area due to the detonation of explosives at ground-level or at a specified height above the ground. This type of information would be helpful in determining the potential for destruction of an industrial facility where significant amounts of explosives are manufactured, handled, and/or stored. Such information should also be useful in evaluating the risk represented by acts of terrorism or sabotage to any commercial building or industrial complex. Other information may be useful in determining whether structures subject to explosion (magazines, storage tanks, and fule stockpiles, etc.) received enough damage to explode, and if so, how much additional damage was done to other structures in the vicinity of the explosion.

CAPABILITIES AND LIMITATIONS

HEXDAM-D+ is a useful tool for making blast damage assessments resulting from an explosion on a localized area. Specific capabilities include:

1. Prediction of blast damages to 104 basic structures types, plus any user-defined structure types.
2. Compatibility with Vulnerability Assessment of Structurally Damaging Impulses and Pressures (VASDIP) software [1]*.
3. Prediction of blast damages to both overpressure-sensitive and dynamic pressure-sensitive structures.
4. Prediction of shielding** effects by each structure on surrounding structures based on advanced algorithm.
5. Prediction of blast damage resulting from secondary explosions triggered by the initial (primary) blast.
6. Capacity to model an unlimited number of individual structures within a facility.
7. Automatic or user-specified subdivision of structures.
8. Generation of pressure and damage contours (3-D oblique projections, 2-D horizontal and vertical cross sections).
9. Zoom feature for all graphical displays.
10. Parametric Analysis of Single Structure (PASS)

The 104 basic structure types are summarized in Table 1.

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* Numbers in brackets refer to references cited.

** The user has the option to perform damage computations with and without shielding.

Table 1. Types of Structures Covered

1. Structural Elements (7 different types)
   a. Aluminum
   b. Asbestos
   c. Brick
   d. Concrete
   e. Glass
   f. Steel
   g. Wood
2. Composite Structures (97 different types)
   a. Bridges
   b. Buildings
      (1) Commercial/Administrative
      (2) Industrial
      (3) Residential
   c. Hangars
   d. Magazines
   e. Shelters
   f. Underground Structures
   g. Transportation Equipment
      (1) Aircraft
      (2) Railroad
      (3) Earth-moving
      (4) Naval Vessels
      (5) Vehicles
   h. Communications/Electrical Equipment
   i. Industrial Equipment
   j. Gas and Oil Storage Tanks
3. User-Defined Structures
   a. Compatible with VASDIP
   b. Unlimited Number of Choices

The HEXDAM-D+ model has certain limitations, primarily due to the amount of memory available. The following restrictions apply:

1. single primary explosion,
2. blast effects only are considered,
3. multiple reflections are not considered,
4. no terrain considerations,
5. no meteorological considerations, and
6. all structures must be on the ground.

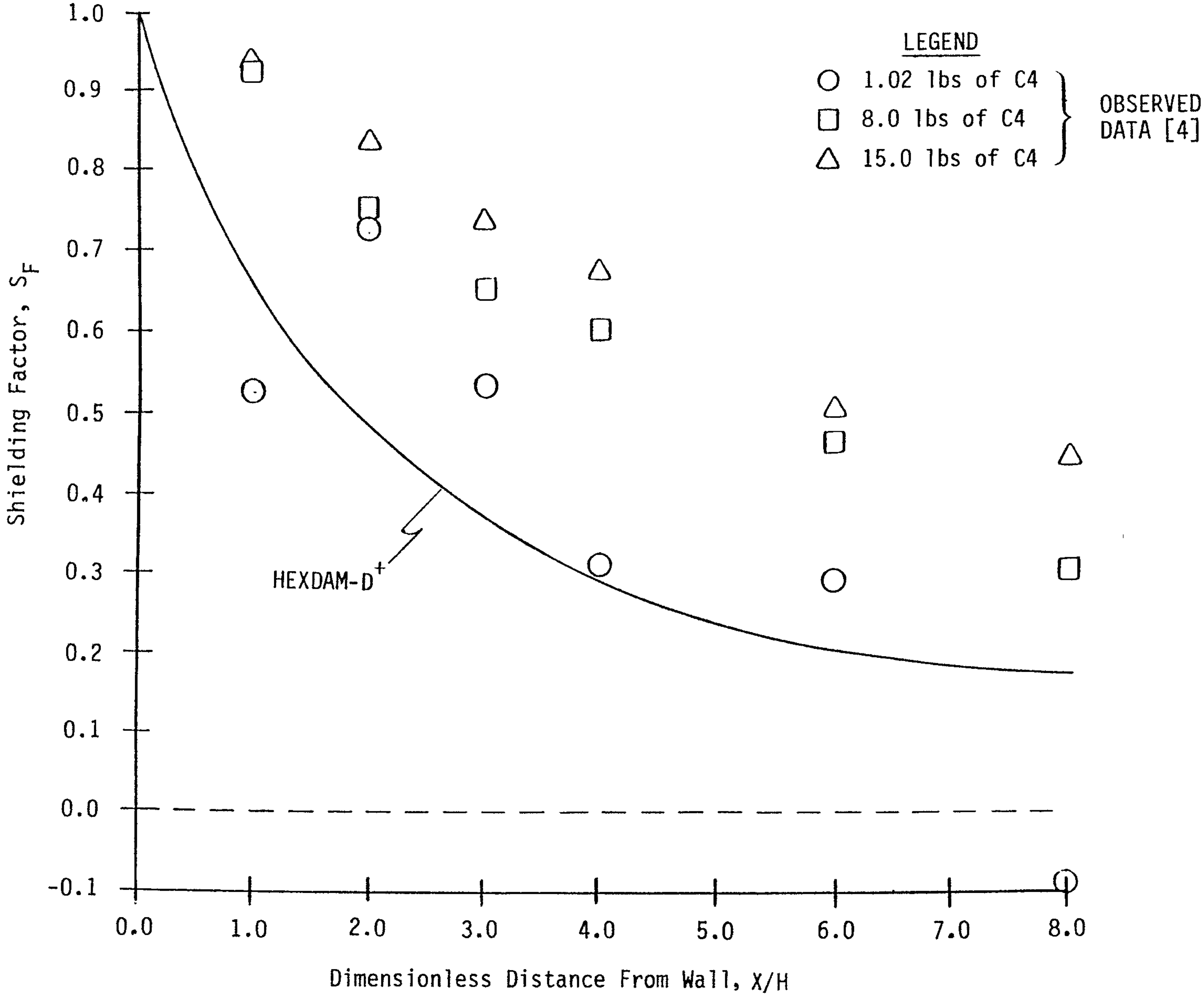
Notice should be taken that HEXDAM-D+ has not been fully validated with all available blast data, nor has it been officially certified by any government agency. The pressure versus distance models are in general agreement with standard tables [2], and the pulse duration model compares favorably with available theory and data [3]. As shown in Figure 1, the shielding model agrees reasonably well with limited observations [4]. The secondary explosion model represents a technical concept for which insufficient data are currently available to permit rigorous validation. Because multiple shock reflections are not considered, HEXDAM-D+ cannot accurately predict damage caused by confined explosions occurring within strongly reinforced structures. For the reasons noted, good engineering judgment must be exercised in interpreting the results generated by HEXDAM-D+, especially when making critical decisions pertaining to personnel safety.

EQUIPMENT SPECIFICATIONS

The execution of HEXDAM-D+ requires the computer equipment and operating system listed in Table 2. All equipment listed is essential to the correct execution of the program.

TABLE 2. HEXDAM-D+ EQUIPMENT REQUIREMENTS

ITEM	DESCRIPTION
PROCESSING UNIT	IBM PC-XT/AT/386/486 OR COMPATIBLE
DISK DRIVE	1 HARD DISK DRIVE
PRINTER	(WITH GRAPHICS CAPABILITY)
MONITOR	MONOCHROME OR COLOR
PLOTTER	
GRAPHICS CARD	CGA, EGA, or VGA
OPERATING SYSTEM	DOS 3.2 OR LATER
RAM	MINIMUM OF 640 KILOBYTES


LEGEND
1.02 lbs of C4
8.0 lbs of C4
15.0 lbs of C4
OBSERVED DATA [4]
HEXDAM-D+
Shielding Factor, S_F
Dimensionless Distance From Wall, X/H
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

SOFTWARE COMPONENTS

HEXDAM-D+ software consists of three separate parts: a preprocessor (HEXDAM1), processor (HEXDAM2), and postprocessor (HEXDAM3). Each part executes independently from the others. All of the data necessary for HEXDAM-D+ are input in the preprocessor, which creates output files which are fed into the processor. Upon execution of the processor, output files are created which are fed into the postprocessor. The postprocessor generates the output data in forms of graphs, displays, contour plots, and tables.

MODES OF OPERATION

The software can be used in two modes as follows:

- o Scenario Analysis (SA)
- o Parametric Analysis of Single Structure (PASS)

In the Scenario Analysis mode, a primary explosion is specified within or about a facility consisting of one or more structures. Pressures received by each structure in the facility are calculated based on each structure's location relative to the primary explosion, as well as, any secondary explosion. The effects of structures shielding one another may also be taken into account. The damage occuring to each structure is then calculated based on the magnitude of the pressure it received and its ability to withstand the pressure. In addition to the calculations of pressures and damages occuring at the structures within the facility, the SA mode allows the user to overlay a grid (either 2-D or 3-D) over the facility and to calculate pressures which occur at these locations. In a similar manner, the SA mode allows the user to overlay a grid within specific structures in order to analyze the distribution of damage within the structures.

In addition to the Scenario Analysis capability, HEXDAM-D+ provides a second mode of operation, referred to as Parametric Analysis of Single Structure (PASS), which takes a somewhat different approach. For the PASS mode the parameters which constitute a description of the explosion (i.e., location and/or magnitude) are treated as independent variables, which are systematically varied. The pressures and damages which would occur at a single "structure-of-interest" are treated as dependent variables, which are calculated as functions of the independent variables. These calculations can be made independent of all other structures in the facility (referred to as a scenario-independent PASS), or can be made where the shielding of other structures and possible secondary explosions are taken into account (referred to as a scenario-dependent PASS).

The scenario-independent PASS involves varying the magnitude and/or location of an explosion relative to a structure-of-interest. The actual (absolute) locations of the structure and the explosion are never defined. This version of PASS is best used for answering questions such as:

> "How much damage does a given wall sustain from an explosion one foot off the ground and twenty feet away when the amount of explosive is varied from ten to one hundred pounds?"
>
> "What overpressures would a structure be subjected to if the location of a 100-pound explosion on the ground was varied from 10 to 100 feet away in 10-foot intervals?"

The scenario-dependent PASS mode is equivalent to performing many SA's except pressures and damages are only calculated for the structure-of-interest. This type of PASS involves varying the location and/or magnitude of an explosion within a scenario and analyzing the resulting pressures and damages predicted at the structure. Scenario-dependent PASS is useful for answering questions such as:

> "How much explosive can be safely stored in a storage area if the user wants to ensure that persons in a certain building are not harmed, if detonation somehow occurs in the storage area?"
>
> "Where are the most vulnerable locations outside the barriers surrounding a compound?"
>
> "How much damage will occur to a given building in a compound if an explosives-laden truck located at some location were to explode, where the amount of explosive in the truck is varied from 100 to 1000 pounds?"

INPUTS/OUTPUTS

The inputs and outputs to HEXDAM-D+ are dependent upon the mode of operation, Scenario Analysis, (SA), or Parametric Analysis of Single Structure (PASS).

Scenario Analysis Inputs/Outputs

The basic inputs to HEXDAM-D+ in the Scenario Analysis (SA) mode are designed to provide a description of a primary explosion and one or more structures located in the vicinity as follows:

1. Primary explosion
   a. location (including height)
   b. yield
2. Individual structures
   a. location
   b. dimensions (length, width, height)
   c. orientation
   d. structure type
      (1) 104 basic types
      (2) user-defined types
   e. explosion threshold for secondary explosions
   f. yield for secondary explosions

The basic SA outputs of HEXDAM-D+ are designed to provide descriptions (both tabular and graphical) of the structure(s), which have been exposed to the primary explosion. Such outputs include the following:

1. Before-Damage Display - Provides 3-D oblique projection in color of all structures being modeled.

2. Damage Table - For each structure provides pressure level and damage assessment.

3. After-Damage Display - Provides same 3-D oblique projection in color as Before-Damage but also indicates damage level to each structure.

4. Damage vs Distance Graph - Provides color-coded plot of damage levels to all structures versus distance from primary explosion.

5. Pressure Contours - Provides 3-D oblique projections and 2-D horizontal and vertical cross sections in color of overpressure and dynamic pressure contours.

6. Damage Contours - Provides 3-D oblique projections and 2-D horizontal and vertical cross sections in color of contour plots of damage levels to any structure.

7. Data Tables - Provides tabulation of overpressure, dynamic pressure, and/or damage level for each grid point used in contour plots.

PASS Inputs/Outputs

For a scenario-independent PASS, the basic inputs are as follows:

1. Primary explosion*
   a. ground distance from structure-of-interest
   b. height of burst
   c. slant range to structure-of-interest
   d. yield
2. Structure-of-Interest Type
   a. 104 basic types
   b. user-defined types

For a scenario-dependent PASS, the basic inputs are similar to those for a Scenario Analysis, except the structure-of-interest must also be identified. These inputs are as follows:

1. Primary explosion*
   a. X-coordinate of detonation
   b. Y-coordinate of detonation
   c. height of burst
   d. yield
2. Individual Structures
   a. location
   b. dimensions (length, width, height)
   c. orientation
   d. structure type
      (1) 104 basic types
      (2) user-defined types
   e. explosion threshold for secondary explosions
   f. yield for secondary explosions

---

* The user may vary up to three of the parameters defining the explosion. HEXDAM-D+ ensures that the combination of parameters varied is not illogical.

Regardless of the type of PASS, the user can generate up to four different plot types in the HEXDAM-D+ postprocessor. These four plot types are:

1. conventional 2-D plot - dependent variable plotted versus one independent variable
2. conventional 3-D plot - dependent variable plotted versus two independent variables
3. 2-D contour plot - dependent variable contours plotted on grid of two independent variables
4. 3-D contour plot - dependent variable iso-surfaces plotted onto grid of three independent variables

SOFTWARE PERFORMANCE

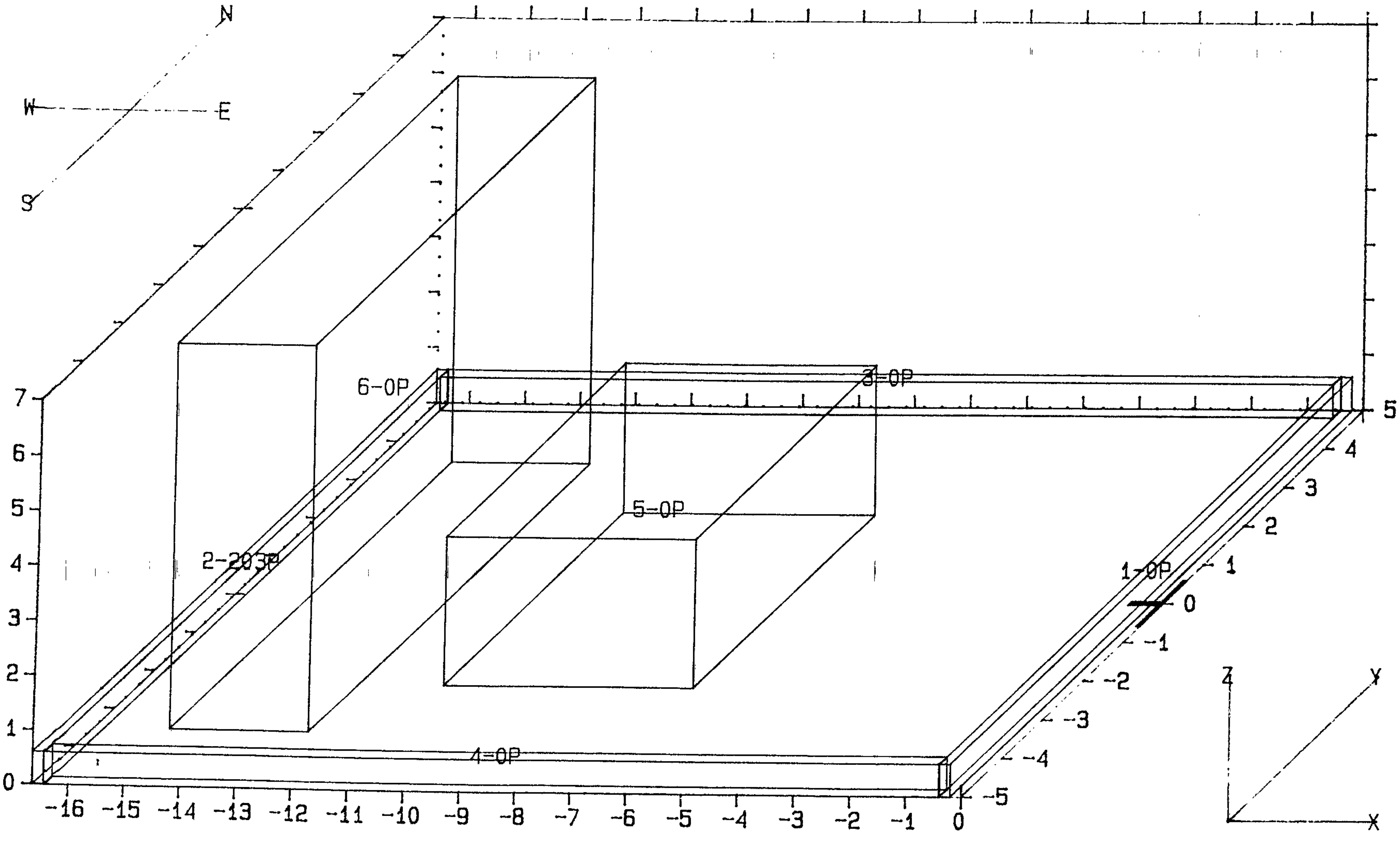
The preprocessor (HEXDAM1) calculates parameters needed by the processor (HEXDAM2), and provides before-damage graphics displays, to permit the user to verify the explosion scenario being modeled. Most of the interface between the HEXDAM-D+ software and the user is associated with the inputs required by the preprocessor. Examples of the Before-Damage Display generated by the preprocessor are presented in Figure 2 (without subdivision) and Figure 3 (with subdivision).

The HEXDAM-D+ processor (HEXDAM2) reads data files containing data preprocessed by HEXDAM1, processes the data, and writes to data files to be used by the postprocessor (HEXDAM3). Data processing by HEXDAM2 includes computation of

- overpressure and dynamic pressure,
- shielding effects,
- secondary explosions, and
- damage levels.

The only interface between the processor and the user involves the initiation of the program.

The HEXDAM-D+ postprocessor (HEXDAM3) is designed to read the data output by the processor and present the data in the form of tables and graphical displays of overpressure, dynamic pressure, and damage. The interface between the program and the user is limited to program initiation and selection of output options.

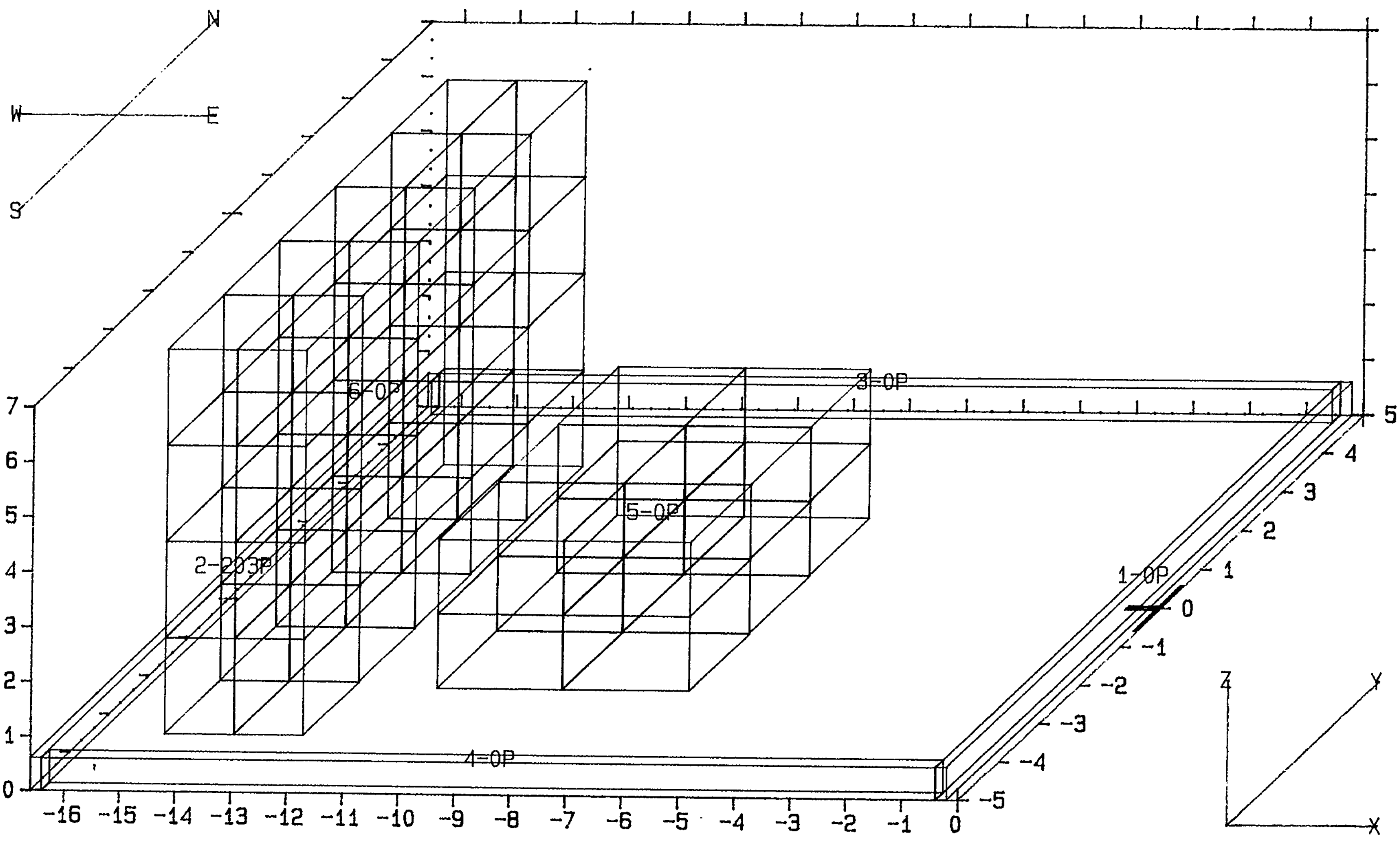


(Distances in 10's of ft)

3D Oblique Projection Before Damage (Relative to Burst)

flyer2.dat 08/13/92 15:58 Yld=1000 Lbs HoB=0.00 Ft Ah=None Av=None

Figure 2. Three-Dimensional Before Damage Display, 0° View Angle (S-N)



(Distances in 10's of ft)

3D Oblique Projection Before Damage (Relative to Burst)

flyer2.dat 08/13/92 16:03 Yld=1000 Lbs HoB=0.00 Ft Ah=None Av=None

Figure 3. Three-Dimensional Before-Damage Display with Subdivision, 0° View Angle (S-N)

Outputs from the postprocessor are in the form of tabular data and graphical displays (both two-dimensional, and three-dimensional) of overpressure, dynamic pressure, and damage as follows:

- o Structure Damage Table
- o After-Damage Display
- o Damage-vs-Distance Graph
- o Overpressure Contour Plots
- o Dynamic Pressure Contour Plots
- o Structure Damage Contour Plots
- o Parametric Analysis of Single Structure Plots
- o Grid Description(s)
- o Data Tables

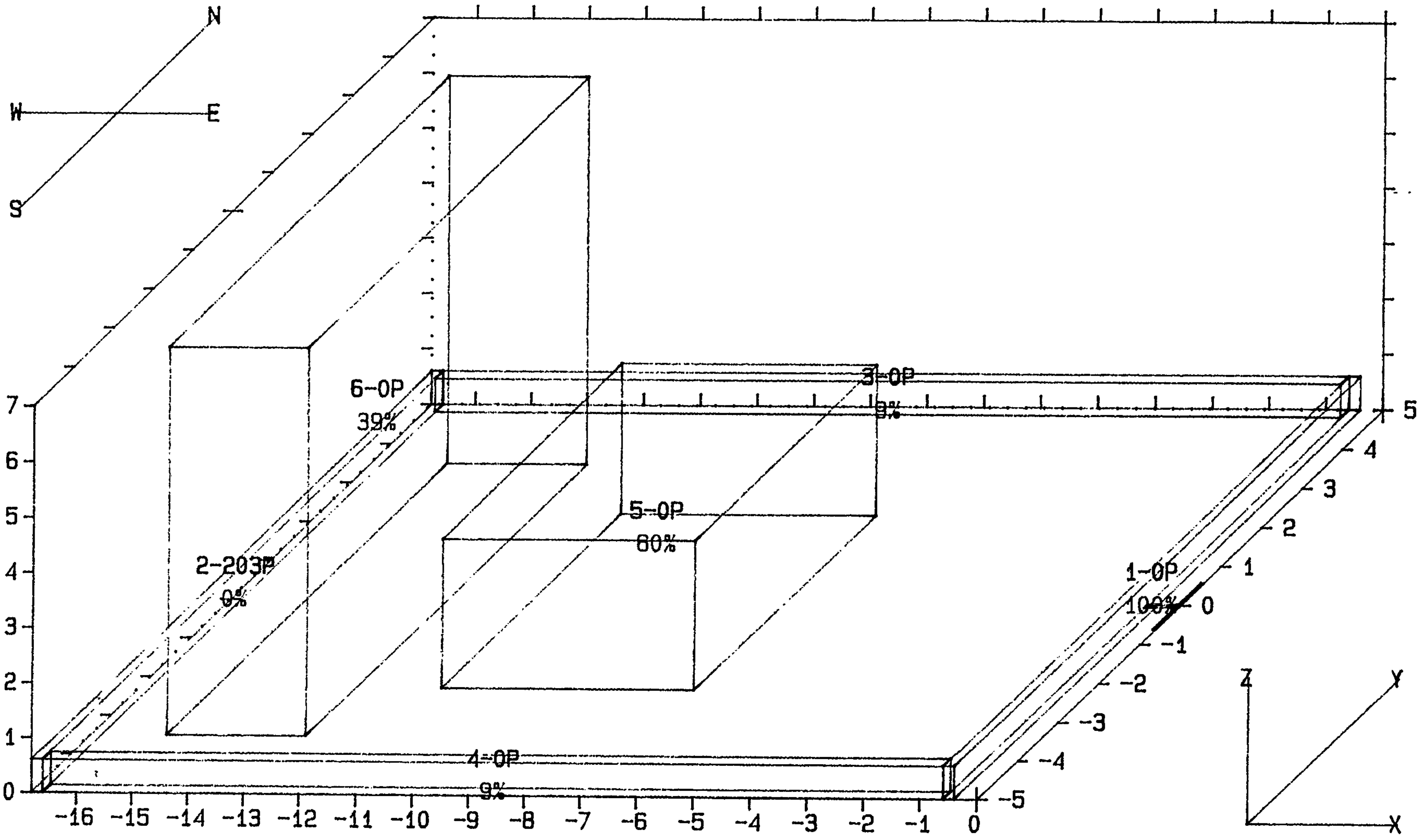
In the case of graphical displays, the user is given the option of displaying each output on the screen, generating a color copy by means of the printer or the plotter.

An example of an After-Damage Display is shown in Figure 4, corresponding to the same case as shown in the Before-Damage Display. Immediately below the label for each structure the calculated damage is displayed.

Figure 5 provides are example of the Damage-vs-Distance Graphs. By means of preprocessor inputs the user can adjust the limits for "slight", "moderate", and "severe" damage levels shown in the figure.

An example of an Overpressure Contour Plot is presented in Figure 6, while an example of a Dynamic Pressure Contour Plot is presented in Figure 7. These plots are three-dimensional oblique projections, for which four different viewing angles are available (0°, 90°, 180° and 270°). Figure 6 represents the 0° viewing angle while Figure 7 represents the 270° angle. Two-dimensional contour plots in the horizontal, vertical-lateral or vertical-longtudinal plane can also be generated for overpressure and dynamic pressure.

Examples of the two types of Structure Damage Contour Plots are presented in Figures 8 and 9. In Figure 8 the structure damage contours to the taller building on the left are displayed, with all other structures, as well as the primary detonation location, included in the plot. In Figure 9 the structure



(Distances in 10's of Ft - Percentages represent mean percent damage.)

3D Oblique Projection After Damage (Relative to Burst)

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 4. HEXDAM-D+ Three-Dimensional After-Damage Display, 0° View Angle (S-N)

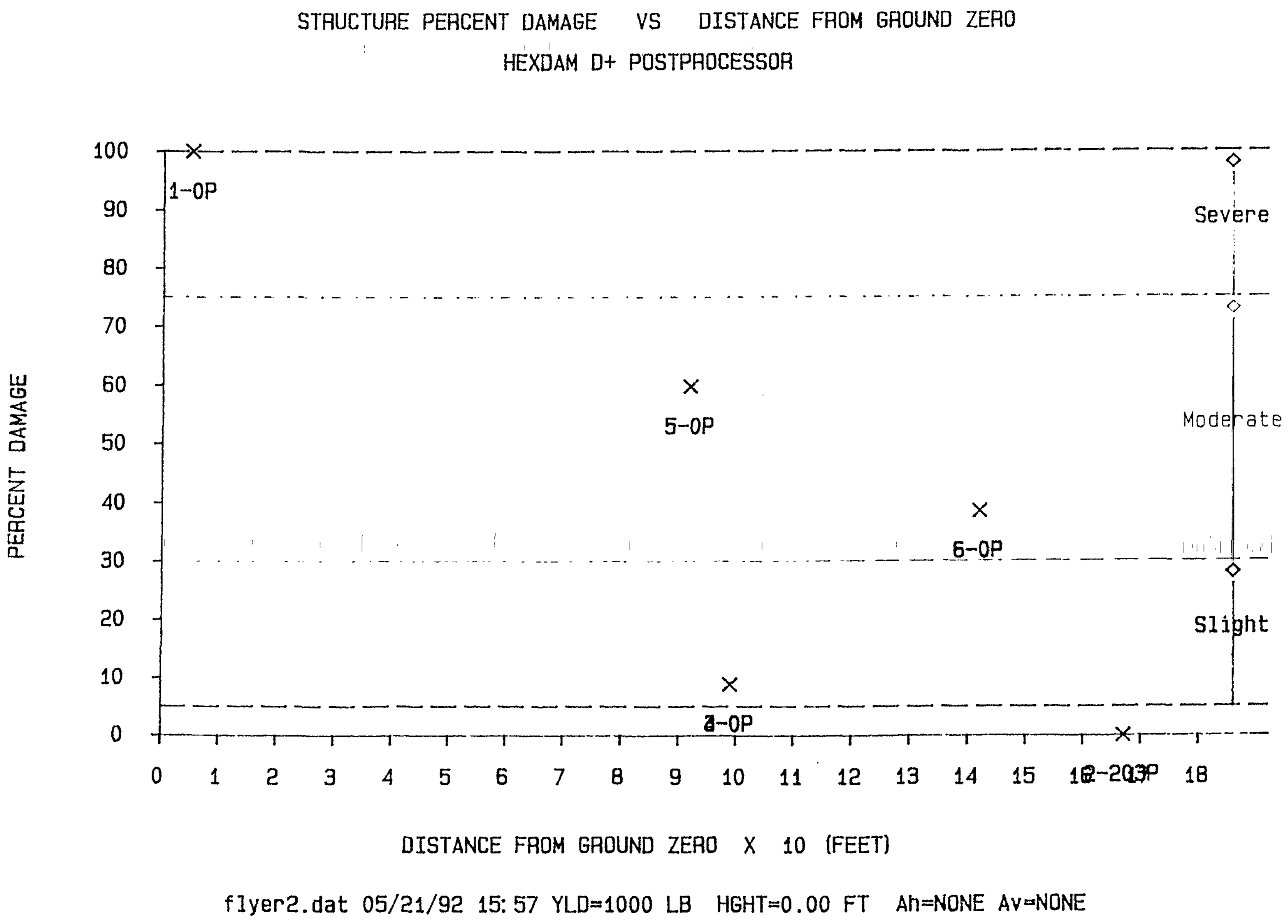
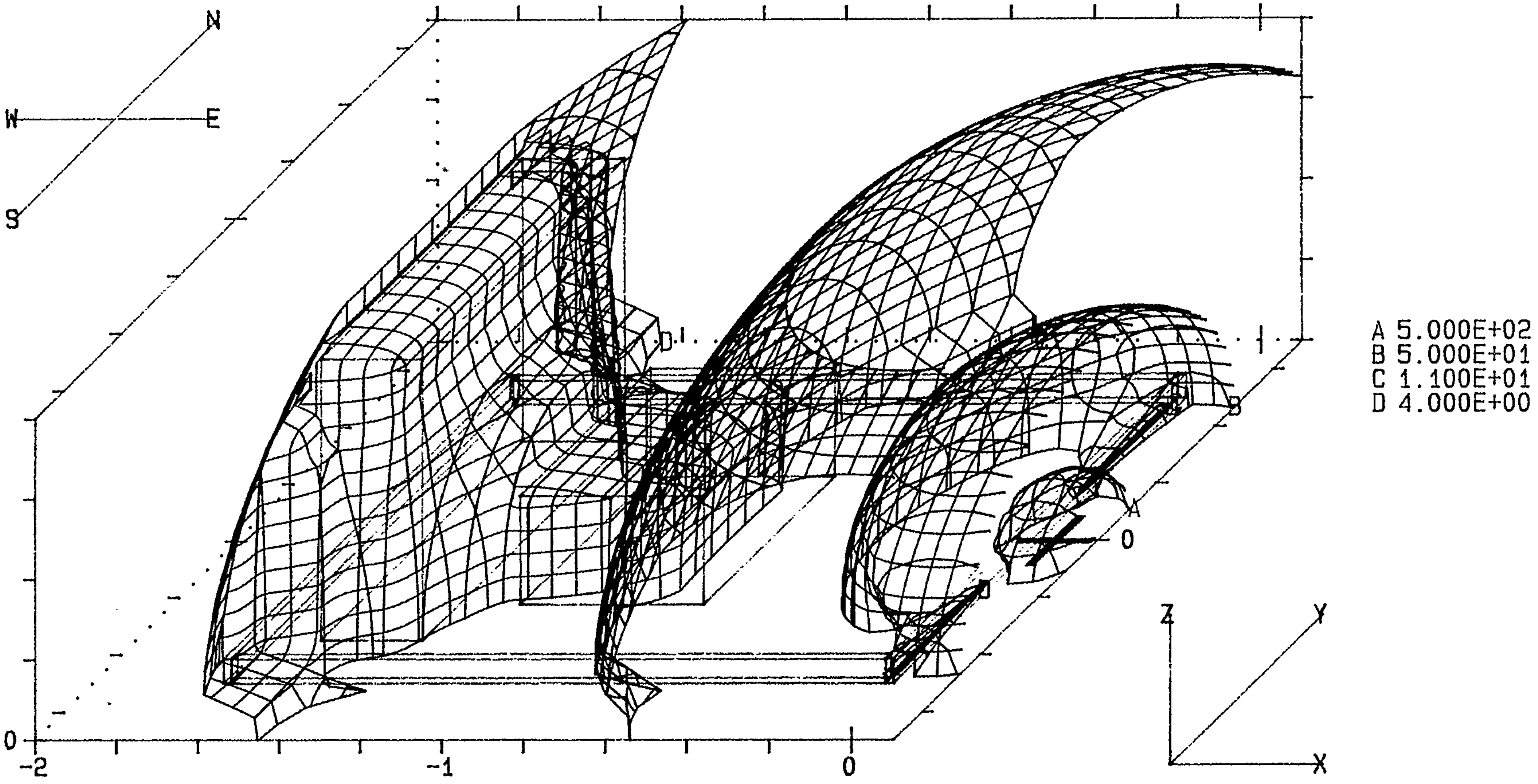


Figure 5. HEXDAM-D+ Damage VS. Distance Graph

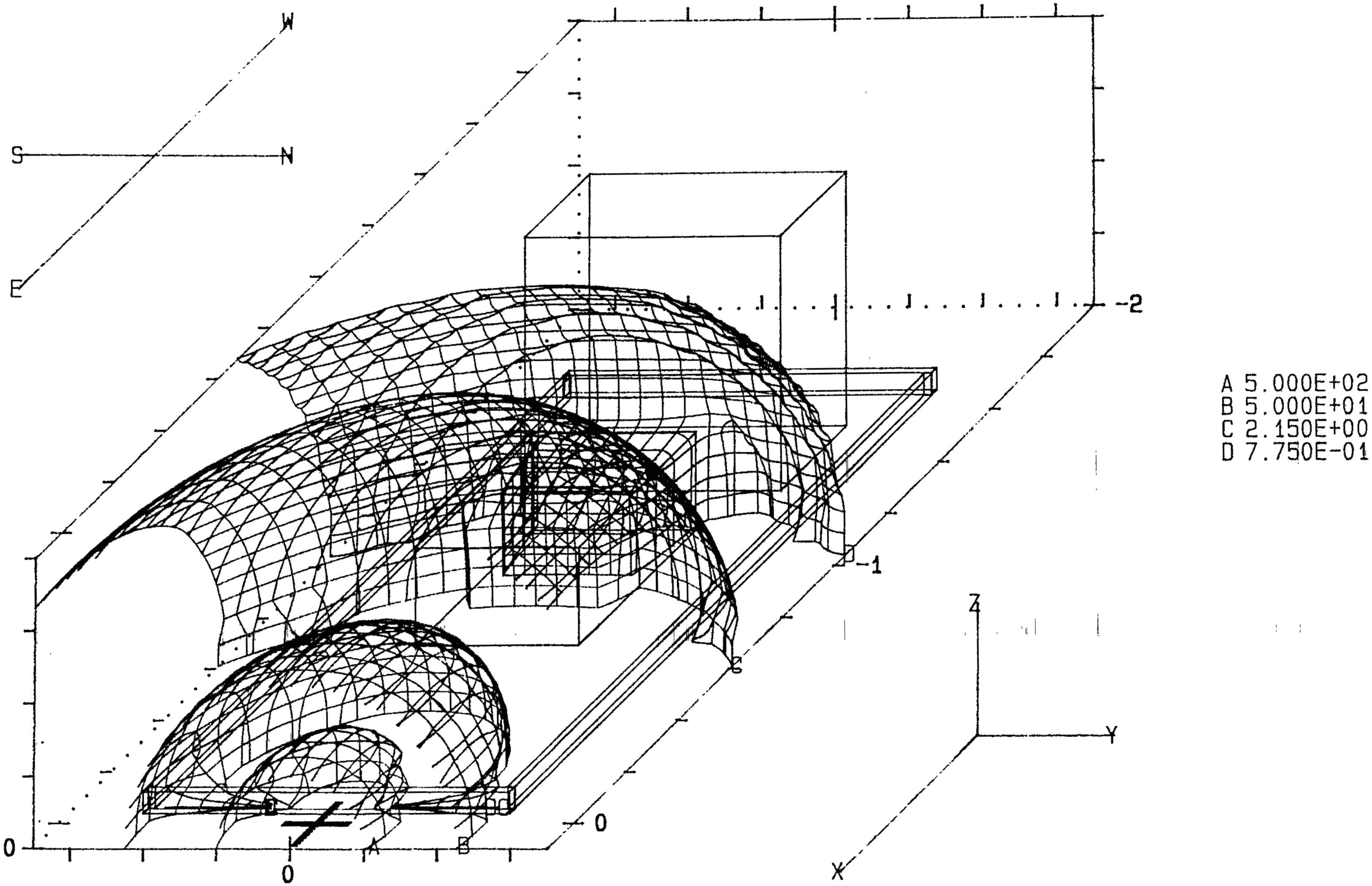


(Distances in 100's of Ft, Contours in Psi)

3D Overpressure Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 6. HEXDAM-D+ Three-Dimensional Overpressure Contour Plot, 0° View Angle (S-N)

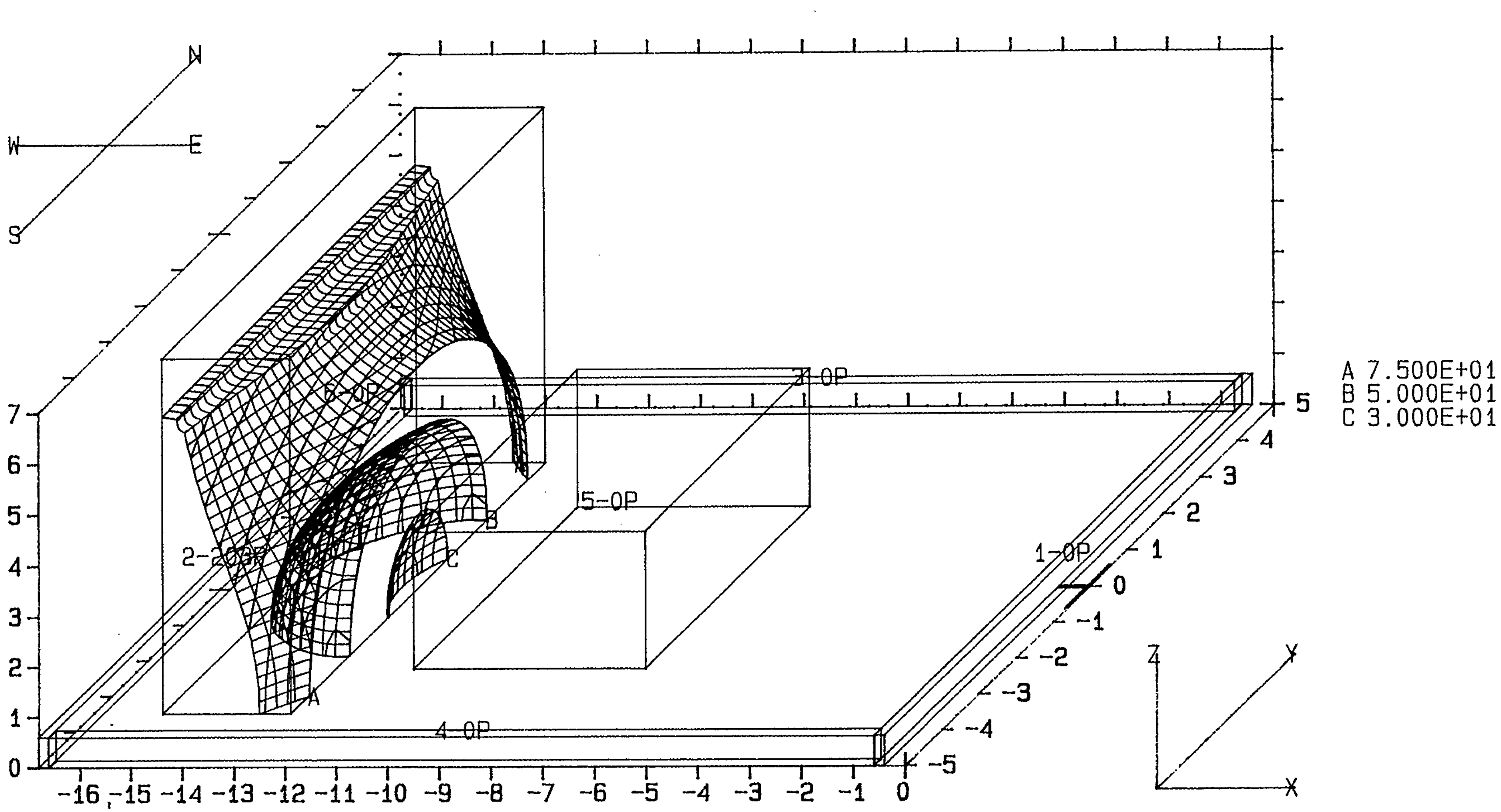


(Distances in 100's of Ft, Contours in Psi)

3D Dynamic Pressure Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 7. HEXDAM-D+ Three-Dimensional Dynamic Pressure Contour Plot, 270° View Angle (E-W)

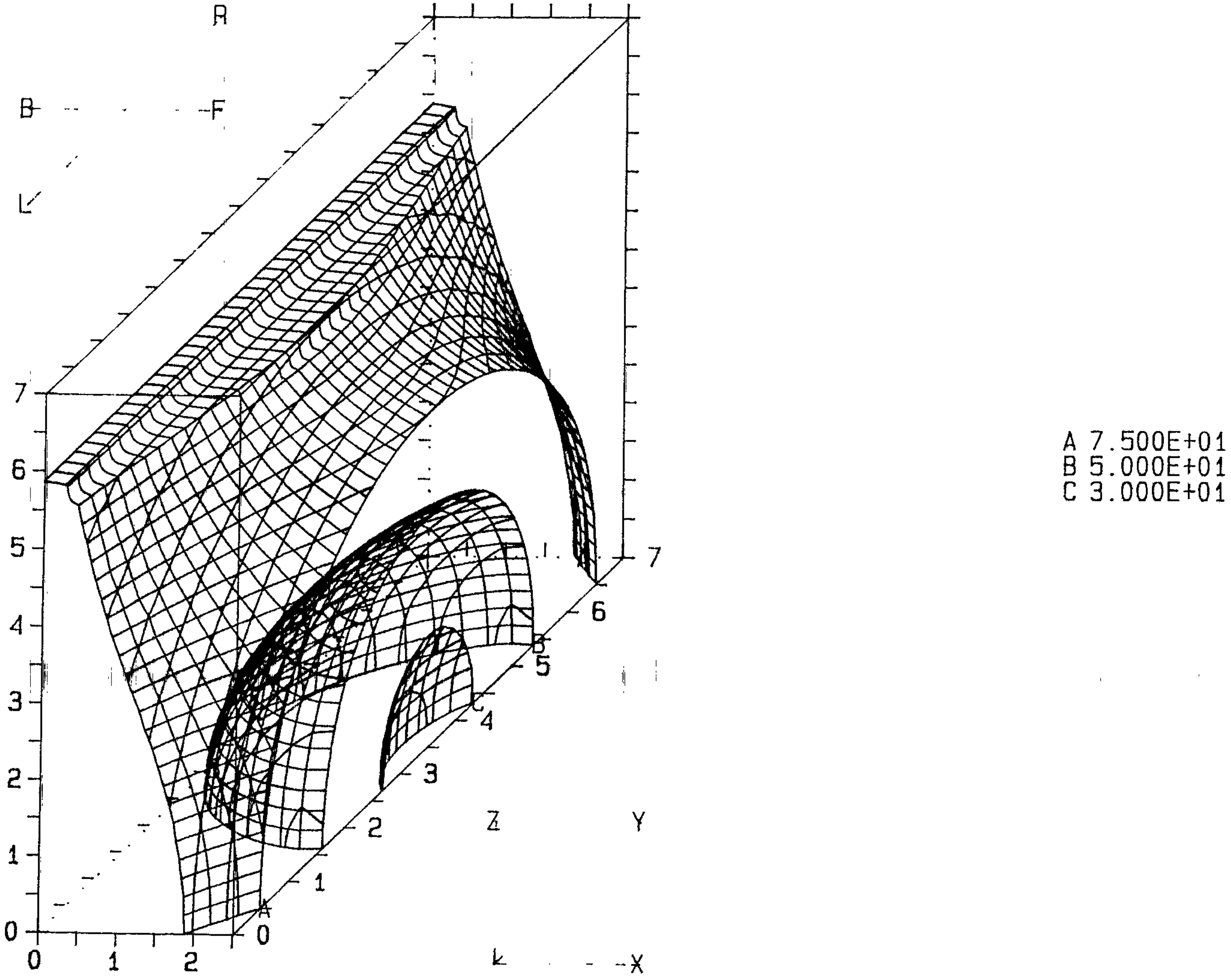


(Distances in 10's of Ft, Contours in %)

6-0P 3D Damage Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 8. HEXDAM-D+ Three-Dimensional Structure Damage Contour Plot (Display relative to Blast), 0° View Angle (S-N)



(Distances in 10's of Ft, Contours in %)

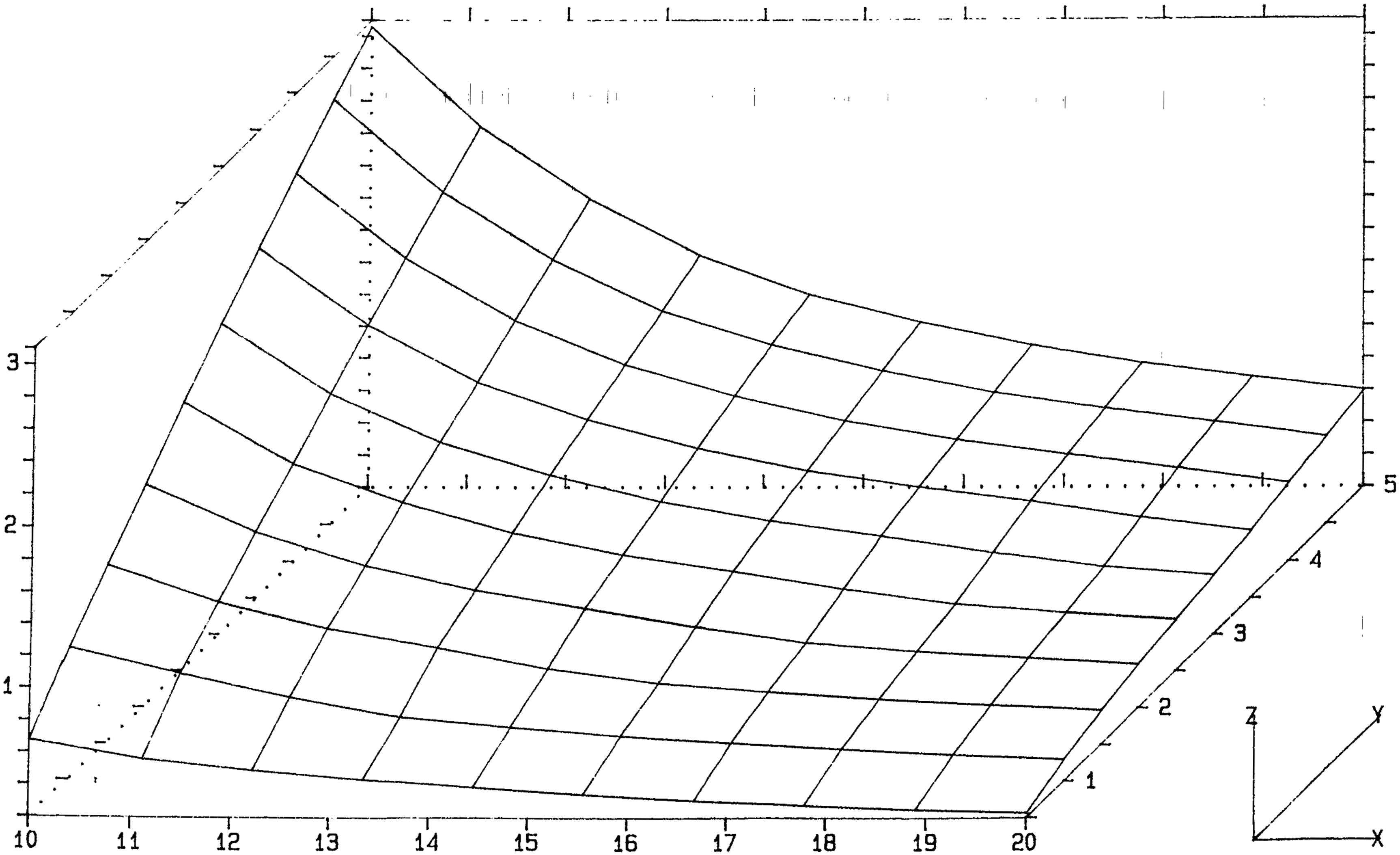
6-OP 3D Damage Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE damage contours to the same building are plotted, but the other structures are omitted, as is the primary detonation.

For the Parametric Analysis of Single Structure (PASS) output, Figures 10, 11, and 12 provide examples of a conventional three-dimensional plot, a two-dimensional contour plot, and a three-dimensional contour plot, respectively. In Figure 10 the independent variables, distance and yield, are plotted on the X- and Y-axes, respectively, while the dependent variable, overpressure, is plotted on the Z-axis. In Figure 11, the independent variables, distance and height of burst, are plotted on the X- and Y-axes, respectively, forming a plane on which contours corresponding to constant values of the dependent variable, damage, are plotted. In Figure 12, the three independent variables, distance, yield, and height of burst, are plotted along the X-, Y- and Z-axes, respectively, forming a rectangular volume. Iso-surfaces of the dependent variable, overpressure, are plotted within the volume.

CONCLUSIONS

HEXDAM-D+ represents a powerful yet flexible engineering software tool for use by safety/security engineers and analysts. Because of its modest hardware requirements, it has the potential for widespread use. The ability of the software to model an unlimited number of structure represents a significant advance over its predecessors. The new shielding algorithm appears to compare reasonably well with observation. By means of the Parametric Analysis of Single Structure (PASS) feature, the effects on a specific structure-of-interest, due to a change in distance or explosive yield, can be rapidly evaluated. The use of oblique projection graphics to produce three-dimensional displays further enhances the software.

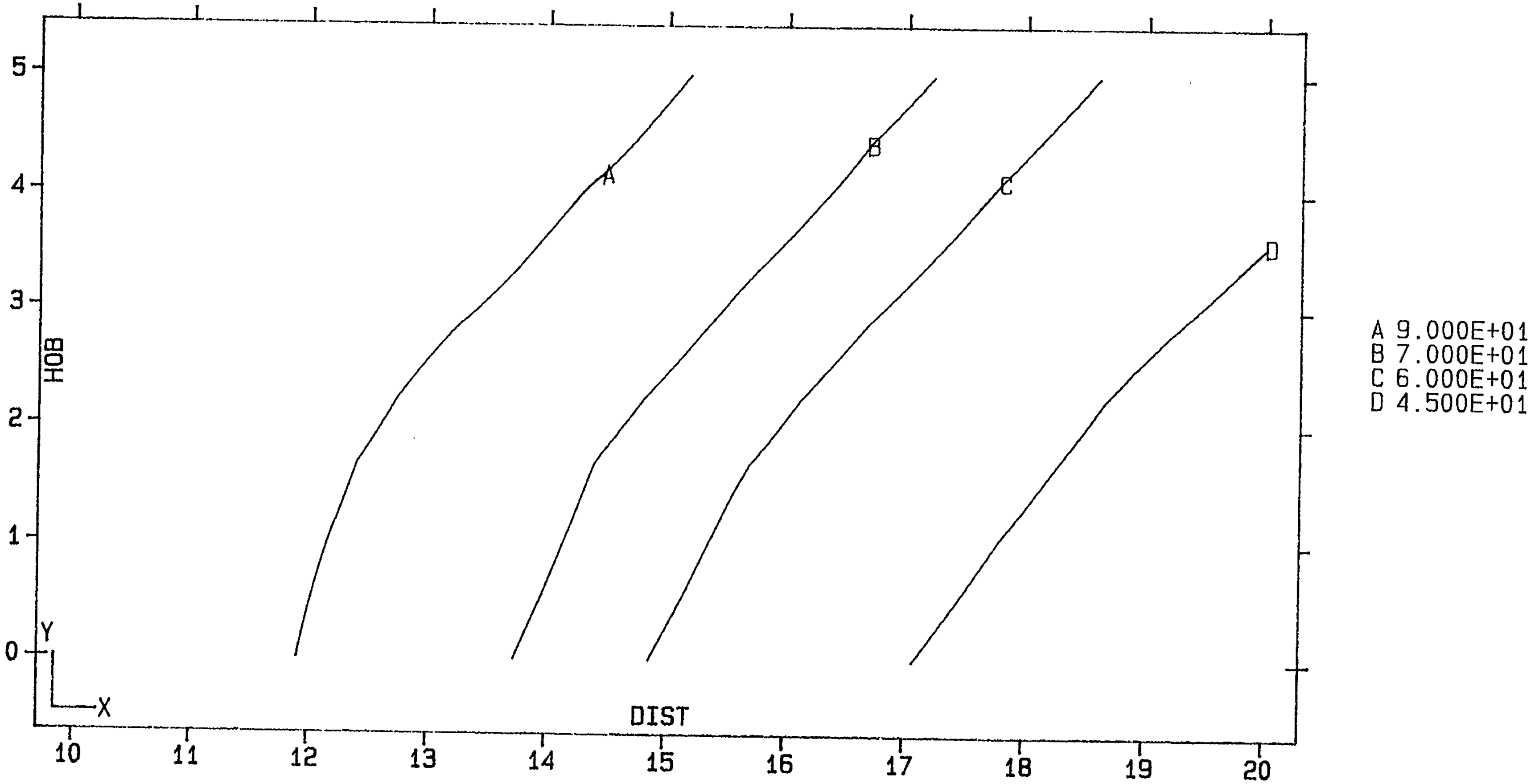


(Pressure in 10's of Psi, Yield in 1000's of Lbs, Distances in 10's of Ft)

3D Plot [X=Dist, Y=Yld, Z=OverP], HoB= 0.000E+00

Parametric Analysis of 6-OP flyer2.dat 05/21/92 15:57 SI

Figure 10. HEXDAM-D+ PASS Three-Dimensional Plot (Conventional)

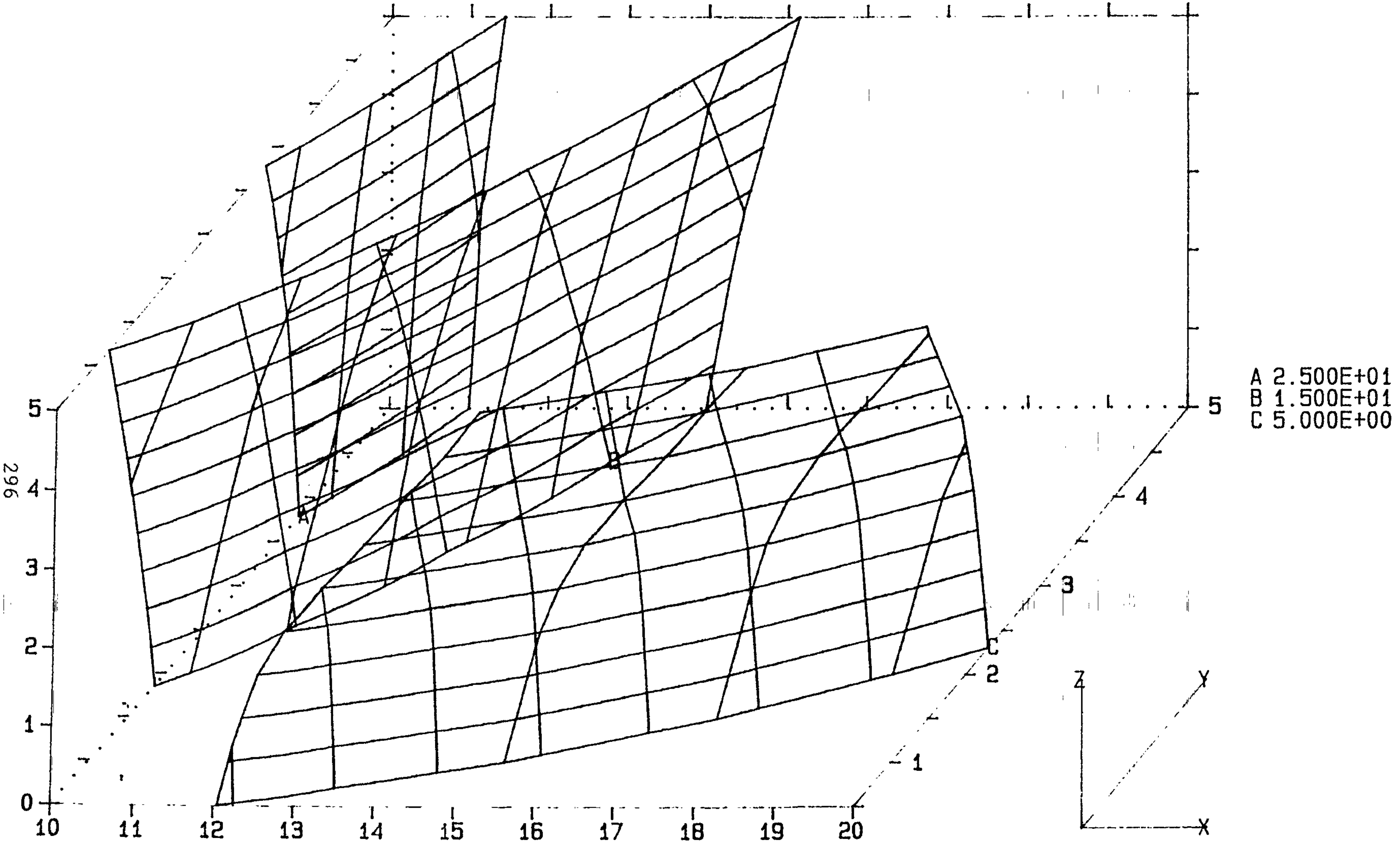


(Yield in Lbs, Distances in 10's of Ft, Contours in %)

2D Damage Contour Plot [X=Dist, Y=HoB], Yld= 5.000E+02

Parametric Analysis of 6-OP flyer2.dat 05/21/92 15:57 SI

Figure 11. HEXDAM-D+ PASS Two-Dimensional Contour Plot



(Yield in 1000's of Lbs, Distances in 10's of Ft, Contours in Psi)

3D OverP Contour Plot [X=Dist, Y=Yld, Z=HoB]

Parametric Analysis of 6-OP flyer2.dat 05/21/92 15:57 SI

Figure 12. HEXDAM-D+ PASS Three-Dimensional Contour Plot

REFERENCES CITED

1. Tatom, Frank B., "Vulnerability Assessment of Structurally Damaging Impulses and Pressures - Color Added (VASDIP+) User's Manual", EAI-TR-90-012, Engineering Analysis, Inc., Huntsville, Alabama, November 1990.

2. Department of Defense Explosive Safety Board, DoD 6055.9-STD, Washington, D.C., 25 November 1983.

3. Polcyn, Michael A. "Preliminary Evaluation of Damage Algorithm Used in the Computer Program HEXDAM (High Explosive Damage Assessment Model)", Contract No. DACA 87-89-D-0021, Southwest Research Institute, 8 December 1989.

4. Beyer, Mary E., "Blast Loads Behind Vertical Walls" Twenty-Second DoD Explosives Safety Seminar, Anaheim, California, 26-28 August 1986.