

**VALIDATION OF AIRBLAST DAMAGE PREDICTIONS
USING A MICROCOMPUTER BASED HIGH EXPLOSIVE
DAMAGE ASSESSMENT MODEL (HEXDAM)**

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ABSTRACT

A flexible and easy to use microcomputer program has been developed to predict the damage to facilities resulting from the effects of conventional explosions. This High Explosive Damage Assessment Model (HEXDAM) is intended to provide safety engineering offices and facility designers a tool for rapid evaluation of airblast damage to structures. The model was first reported at the 1988 Explosive Safety Seminar and has received widespread distribution within the U. S. Government and industry. This paper presents additional data which verifies the capability of HEXDAM to accurately predict structural damage for a wide range structure types and explosive events.

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BACKGROUND

There are large numbers of personnel in the Department of Defense (DOD), other Federal agencies and private industry who must manage, operate or regulate the safety of explosively hazardous activities. Examples of such activities within DOD include ammunition production, storage and maintenance; facility siting and master planning; and the assessment of facility vulnerability to terrorism and conventional weapons effects. In private industry similar activities include planning, siting and operation of hazardous industrial or chemical processes. Most of the persons performing these activities do not have the technical background or time to develop a complete grasp of airblast effects and the resultant damage to structures. With the advent and widespread availability of desktop microcomputers, however, a tool is now available to provide this capability. The Facility Army System Safety (FASS) Office recognized the potential benefits of such a microcomputer based system in 1987 and initiated action to develop such a system.

SELECTION OF DAMAGE ASSESSMENT MODEL

An existing computer code, "Enhanced Nuclear Damage Assessment Model" (ENDAM) was developed by the U. S. Army Strategic Defense Command (Reference 1). This code assesses the damage to structures caused by nuclear weapons effects. It was identified as a potential candidate for adaptation to perform the same damage assessment for conventional weapons effects. ENDAM included suitable algorithms for computing airblast effects, assessing structural damage, and correlating statistical data. Input to the program was provided through a graphics tablet with audio prompting via a voice synthesizer. Output included both graphics and tabular data, in both plan and isometric views, with a dynamic display of the nuclear blast wave. The major limitation of ENDAM was the extensive hardware requirements. The program required a multi-component minicomputer system that would not be readily available to a large number of users.

A decision was made to develop a conventional airblast effects code based on ENDAM but simplified to operate on a widely available microcomputer platform. The platform selected was an IBM PC-XT/AT compatible computer with at least 512 kilobytes of memory and a hard disk drive. The result of this effort was the microcomputer program "High Explosive Damage Assessment Model" (HEXDAM), described in detail in References 2 and 3. Additional development has been performed over the past two years to provide more accurate modeling of structures and enhance the user compatibility of HEXDAM. These changes and other planned improvements are described in more detail in References 4 and 5.

CAPABILITIES OF HEXDAM

HEXDAM provides the user with the ability to quickly model a group of structures and compute expected damage to these structures from a conventional explosion. Up to 200 structures may be included in a given problem. These structures can also contain explosives, and HEXDAM can include the effects of secondary explosions. Structures may be drawn from a master list that includes 178 structure types. Additionally, the user can define his own structure types. Structures can be automatically divided into substructures for more detailed analysis. HEXDAM can also account for shielding of one structure by another structure. HEXDAM has been distributed extensively within the government for the last two years. A commercial version is also available to private industry.

Figures 1 through 3 present typical graphical output from HEXDAM. Figure 1 shows the plan for a typical site layout before evaluation of damage. Figure 2 includes the same plan view after analysis by HEXDAM. This plot includes overpressure contours and gross damage levels, in terms of percent damage, for each structure. Figure 3 provides a plot of structural damage contours for one of the structures in the example site plan.

DAMAGE PREDICTION MODEL

An important goal for HEXDAM is the capability to reasonably estimate damage to many different types of structures for virtually any conventional explosion. This requires that the program accurately model the effects of such explosions and the variation in these effects for varying charge weight, or yield. Figure 4 illustrates this type of variation by showing the idealized blast loads for two explosive events, as computed from References 6 and 7. The first load is the result of a detonation of 500 pounds of TNT at a distance of 95 feet from a structure. The second load is from 75,000 pounds of TNT at a range of 506 feet. Both of these pressure-time loads have a scaled range ($\text{distance}/\text{yield}^{1/3}$) of 12. The difference in pulse duration and total impulse is significant. For a given scaled range, the overpressures acting on a structure are fairly constant regardless of the charge weight, or yield. However, the duration of the load on the structure varies directly with charge weight. The dynamic response and resulting damage experienced by a receiver structure will be different for these two loadings. For large yields, the pulse duration and resulting damage will be much higher. Figure 5 shows a typical, one-way, reinforced concrete wall panel and its response to the two blast loadings. The first load results in some permanent deformation but only slight damage. The longer duration loading results in significant permanent deflection and severe damage.

HEXDAM DAMAGE PREDICTION ALGORITHM

The damage algorithm in ENDAM uses a "vulnerability number" to express a structure's basic vulnerability to overpressure or dynamic pressure. It uses a "pulse duration factor" and corresponding "reference yield" to consider structural response. In essence, the combined effect of these parameters is used to derive a single effective pressure loading for which damage is estimated. Details of this damage algorithm can be found in Reference 1. The vulnerability numbers and pulse duration factors for ENDAM were derived from damage observed during actual and simulated nuclear weapons tests. ENDAM provides these parameters in a library of 178 existing structure types. Because of the long duration of overpressures for even the smallest nuclear weapons, the damage estimates from ENDAM are only valid for very large quantities of conventional explosives (roughly greater than 100,000 pounds). Additional data is required to estimate damage for smaller quantities of explosives.

The damage algorithm in HEXDAM is similar to that used in ENDAM. This algorithm uses five vulnerability parameters. The vulnerability numbers from ENDAM are replaced with reference pressure levels. Two pressure levels are used, one for "moderate" damage and one for "severe" damage. Two pulse duration factors for the same damage levels and a reference explosive yield are also used. HEXDAM provides these parameters for the same 178 structure types as ENDAM in a library of existing structure types. It should be noted that the levels of damage are expressed in terms of percentage of damage to the structure, where 0% is no damage and 100% is complete destruction. The "moderate" and "severe" damage levels are somewhat arbitrary, although differing damage percentages will require different reference pressures and pulse duration factors. For structures given in the HEXDAM master structure list, moderate damage is taken as 30% and severe damage as 75%.

HEXDAM predicts damage by first computing the peak incident overpressures and dynamic pressures imposed on the structures by an explosive event. These computations are based on pressure curves for nuclear blast effects. The curves are scaled to account for the range, height and weight of the charge, and are modified to account for the difference in blast energy generated by conventional and nuclear explosions. (Conventional explosives produce less thermal energy and roughly twice the blast energy as nuclear explosives.) HEXDAM interpolates between these modified curves to determine the peak pressures at the geometric center of each structure. If the structure has been subdivided, the pressure values are computed for each substructure.

The pulse duration factor is used to include the effect of pulse duration on structural damage. The reference pressure levels for moderate and severe damage are adjusted to account for the duration effect, using the pulse duration factor and the reference yield. The predicted damage

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to the structure is then computed using a bilinear relationship between these modified pressures and the corresponding damage levels. If the structure has been subdivided, the damage level for each substructure is computed. The equations defining the HEXDAM damage assessment algorithm can be found in Reference 8.

VALIDATION OF OVERPRESSURE CALCULATION ALGORITHM

As stated above, HEXDAM computes overpressures acting on each structure through an interpolation of existing curves for nuclear weapons effects. This algorithm was evaluated by computing and plotting overpressure versus range for nine different yields. These plots are shown in Figure 6. Comparison to a similar plot for conventional explosives (Reference 10) shows generally excellent agreement between HEXDAM and other methods of computing overpressure. The curves in Reference 10 appear to decay slightly faster than the HEXDAM curves at longer ranges. However, the difference is very small and will have minimal effect on the ability of HEXDAM to reasonably predict structural damage.

VALIDATION OF DAMAGE PREDICTION ALGORITHM

Excellent recent work in the prediction of damage to structures has been performed in References 9 and 10. This work is based on the development of standardized pressure-impulse (P-I) response diagrams for typical components of building systems. A P-I diagram is essentially an isodamage curve for a given structure or component. For any event resulting in a pressure-time loading that falls on the P-I curve, the damage to the structure will be the same. The P-I diagrams in Reference 10 are based on structural theory and have been modified to reflect experimentally observed damage. Figure 7 is a dimensionless P-I diagram for a one-way reinforced concrete slab. An entire family of P-I isodamage curves, corresponding to different damage levels, can be developed for a structural component. These can be used as a basis for estimating building damage. Reference 11 provides a good discussion of the development of P-I diagrams.

The HEXDAM damage prediction algorithm was evaluated in Reference 12 by using P-I diagrams to define the vulnerability parameters for a family of structural components commonly used in building systems. The components considered are listed in Table 1. Figure 5 includes the details of the one-way reinforced concrete wall panel used in this study. The P-I diagrams for each of the 12 components were computed for 0%, 50% and 100% damage. The five vulnerability parameters for each component were computed from these P-I diagrams, using 30% as the moderate damage level and 75% as the severe damage level.

These parameters were evaluated by using them to predict damage with HEXDAM. Three test cases were selected, using explosive yields of 250, 2,500 and 250,000 pounds of TNT. Curves showing the variation of pressure and impulse with scaled distance, for each of the three charge weight cases, were superimposed over the P-I diagrams for each structural component. The intersections of these curves denote scaled ranges for each component at which 0%, 50% and 100% damage could be expected. These scaled ranges were used to determine the location for each component from the charge for HEXDAM models. Three HEXDAM models, one for each charge weight, were prepared and analyzed to produce predicted damage levels.

The results of the tests for all structural components are given in Table 2. Specific pressure-impulse-yield diagrams for the concrete wall, pre-engineered building wall and wooden wall systems are given in Figures 8 through 10, respectively. In these diagrams, the pressure-impulse-distance curves for the three charge weights are superimposed over the P-I curves. Damage levels predicted by HEXDAM are shown in boxes.

The damage levels predicted by HEXDAM agree well with the expected damage levels from the P-I diagrams. For the 0% damage case, HEXDAM predicted damage that is somewhat greater than 0%. This can be attributed to the fact HEXDAM uses no zero-damage threshold. The derivation of P-I diagrams includes a small, non-zero load that will cause no permanent deformation and, therefore, no damage. For the 50% and 100% damage cases, HEXDAM computed damage levels that were in very good agreement with the P-I diagrams. In all cases, the small differences in damage prediction were within reasonable limits. These results clearly indicate that the HEXDAM damage algorithm can predict damage with a degree of accuracy that agrees well with other, more detailed analysis methods.

It should be noted that a slight modification of the equations in the HEXDAM damage prediction algorithm was required to match the shape of normal P-I diagrams. The modified version of HEXDAM is available as an upgrade to all Government users.

CONCLUSIONS

HEXDAM provides a fast, reliable tool to evaluate the potential for damage from conventional explosions. This study has shown that P-I diagrams for building components can be easily adapted to provide damage indexes in HEXDAM to accurately estimate overall damage to structures. Future work planned at this time is to develop a library of structures with suitable vulnerability values derived from P-I diagrams. Table 3 is an example of the structure types being developed. The structure database resulting from this effort will be included in future versions of HEXDAM. Users will only have to select a structure, for example, "single story pre-engineered building", and its necessary parameters will be provided

automatically. The ability to enter customized structure data will continue to be available to users for unique modeling requirements.

It should be clearly recognized that HEXDAM is not intended to be a replacement for the more rigorous methods of analysis required to design structures or evaluate in detail structural damage from blast effects. Rather, it is intended to give the user with limited background a reasonably accurate estimate of probable gross damage from overpressure for a wide range of building types.

HEXDAM is available to all Government agencies through Reference 8. An equivalent code is available to private industry through Reference 13.

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Table 1: Building Components for HEXDAM Validation

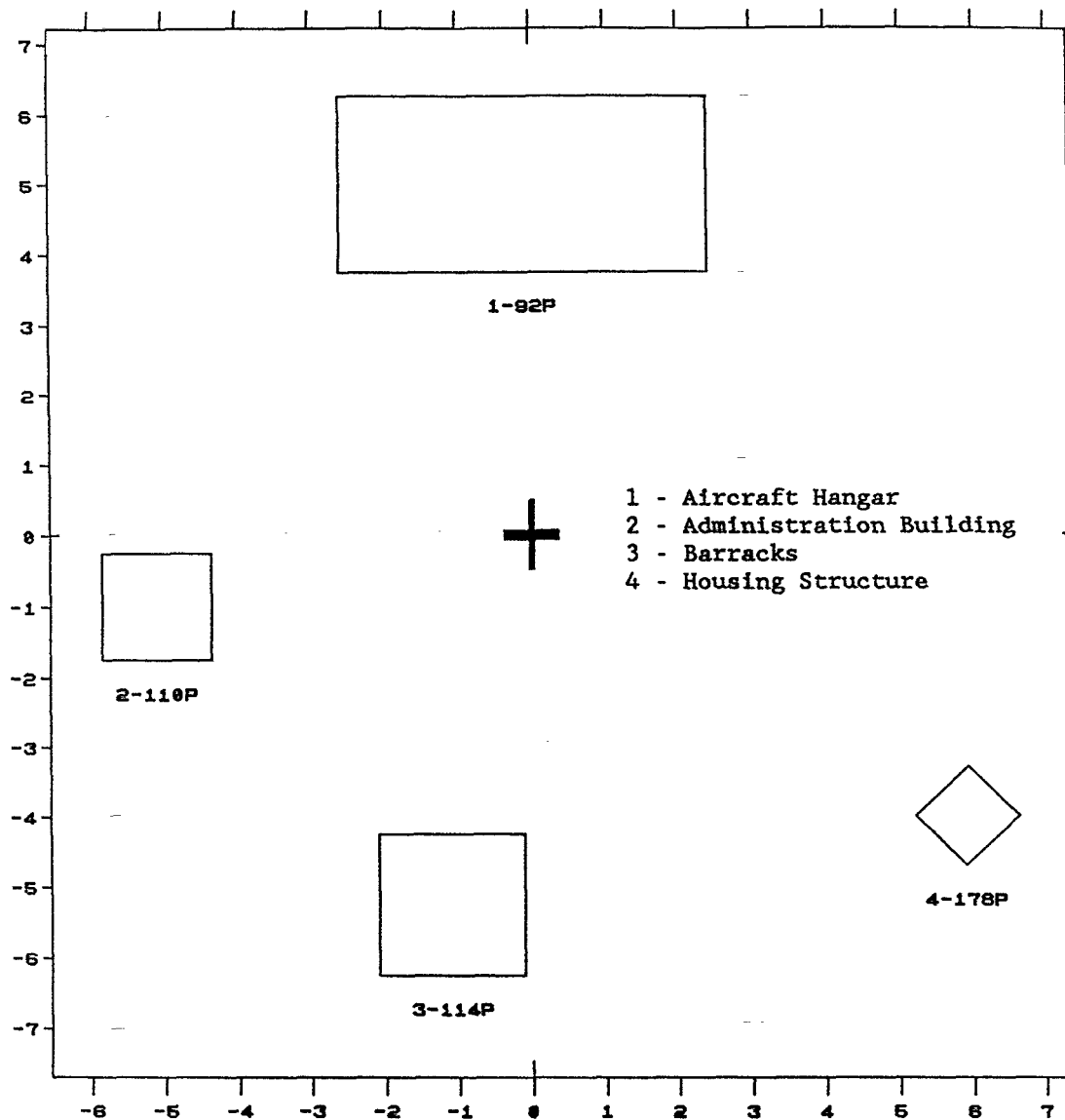
Structure Description	Structural Components
Wood Building	Wall: Lightweight wooden wall, 2"x6" wood studs on 16" centers, 1/2" wood sheathing on both sides Roof: Wood trusses, 40'-0" span, 2"x10" truss members, 1/2" wood sheathing on top side only
Metal Frame Building CMU In-Fill Walls	Wall: 8" concrete masonry unit wall with nominal reinforcement Roof: Lightweight concrete slab, 4" thick, reinforcement ratio 0.0056
Metal Frame Building	Wall: Insulated 1-1/2" corrugated steel sandwich panels, 26 gauge, spanning 4'-0" Roof: 1-1/2" corrugated steel roof panels, 26 gauge, spanning 4'-0"
Pre-Engineered Metal Building	Wall: 1-1/2" corrugated steel wall panels, 26 gauge, spanning 4'-0" Roof: 1-1/2" corrugated steel roof panels, 26 gauge, spanning 4'-0"
Reinforced Concrete Building	Wall: 8" thick concrete walls, one-way, reinforcement ratio 0.002 Roof: Lightweight concrete slab, 4" thick, reinforcement ratio 0.0056
Concrete Tilt-Up Building	Wall: 6" thick concrete wall panels, reinforcement ratio 0.02 Roof: Lightweight concrete roof slab, 4" thick, reinforcement ratio 0.0056

TABLE 2: Comparison of Damage Prediction for P-I Diagrams and HEXDAM

Structure Component	Structure Description	Damage Levels Predicted by HEXDAM (% damage)									
		Yield	25 lbs			2,500 lbs			250,000 lbs		
		P-I Damage	0	50	100	0	50	100	0	50	100
Wall Roof	Wood Building		.61	49.9	100	7.5	50.9	100	7.7	52.9	100
			5.33	43.1	100	15.1	40.1	97.7	16.4	47.3	100
Wall Roof	Metal Frame Building CMU In-Fill		.06	43.0	100	7.3	37.8	100	11.1	46	100
			1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9
Wall Roof	Metal Frame Building		.10	55.3	93.7	4.6	57.3	99	4.7	61.7	100
			1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
Wall Roof	Pre-Engineered Building		1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
			1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
Wall Roof	Reinforced Concrete Building		.70	51.1	92.6	.2	49.9	100	4.7	55.1	100
			1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9
Wall Roof	Tilt-Up Concrete Panel Building		.70	56.7	98.3	.5	44.5	100	4.1	50.7	100
			1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9

Table 3: Proposed Structures for Future HEXDAM Development

- Reinforced concrete general purpose buildings, single and multiple stories
- Steel frame, concrete floor slab, general purpose buildings, single and multiple stories
- Steel arch magazine for ammunition and explosive storage
- Timber mobilization-type military structures
- Petroleum, oil and lubricant facilities
- Pre-engineered metal buildings, single story
- Civil defense shelters
- Residence structures

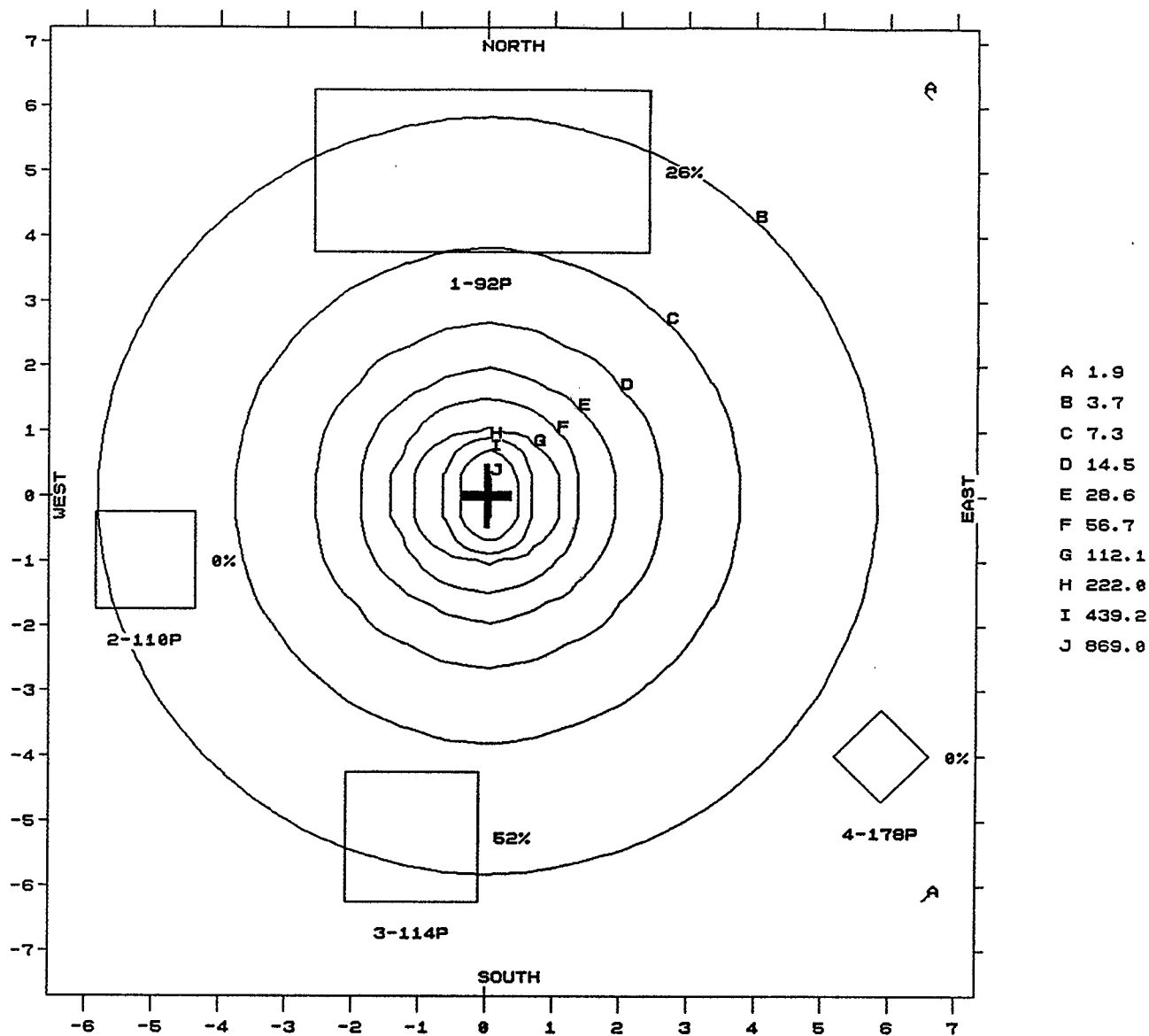


(Distances in 100's of ft)

PLAN VIEW PRIOR TO STRUCTURE DAMAGE (RELATIVE TO DETONATION POINT)

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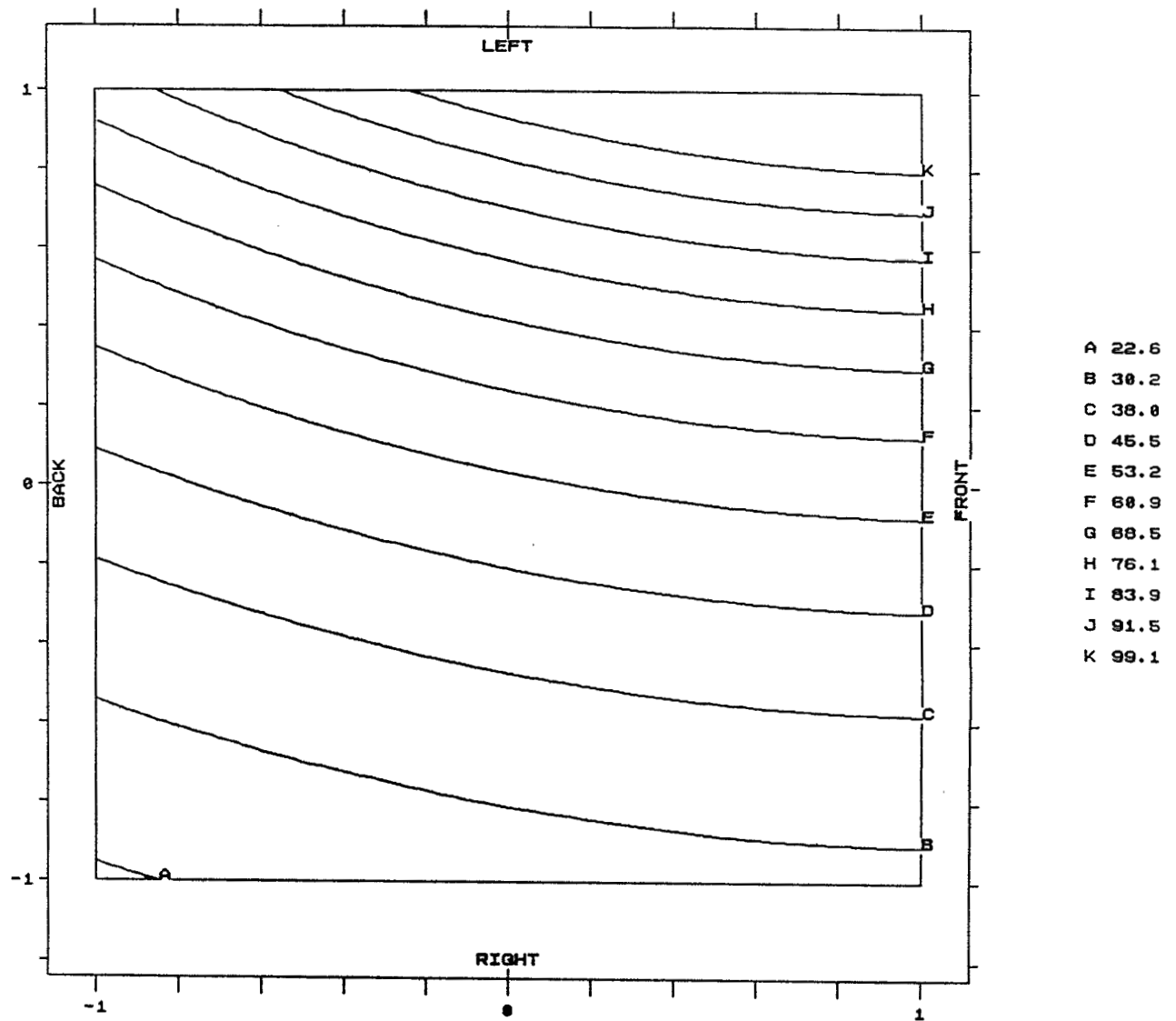
Figure 1: HEXDAM Before Damage Site Plan Plot



(Distances in 100's of ft)

OVERPRESSURE CONTOUR PLOT - ELEVATION = 0.00 FT

Figure 2: HEXDAM Overpressure Contour and Gross Damage Plot



(Distances in 100's of ft)

3-114P DAMAGE CONTOUR PLOT - ELEVATION = 0.00 FT

Figure 3: HEXDAM Damage Contour Plot for Barracks Structure

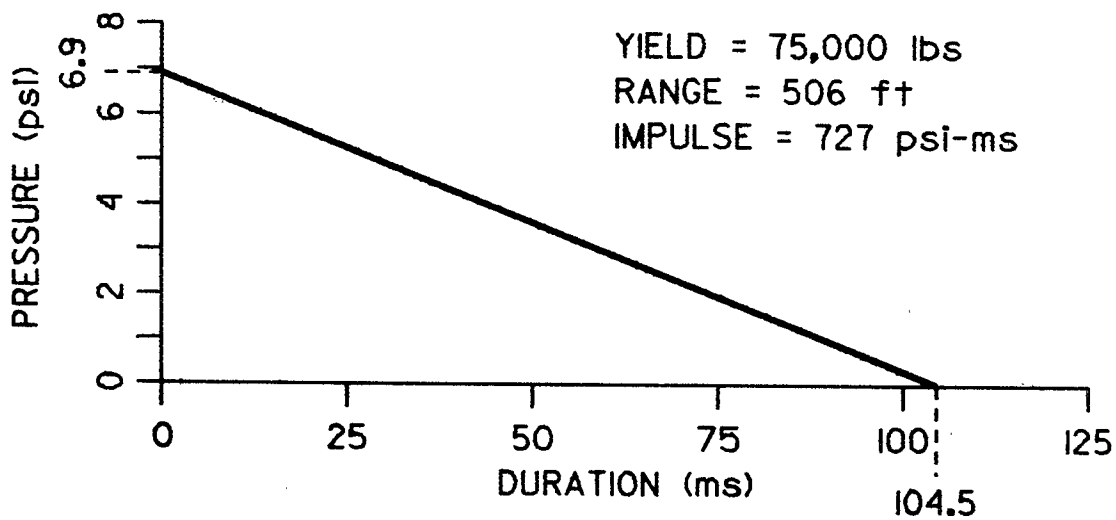
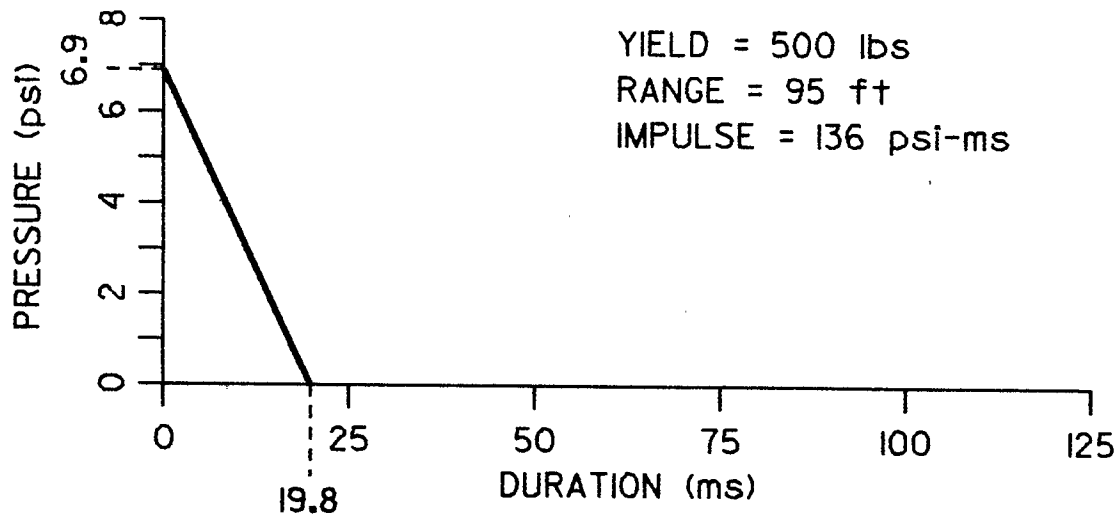
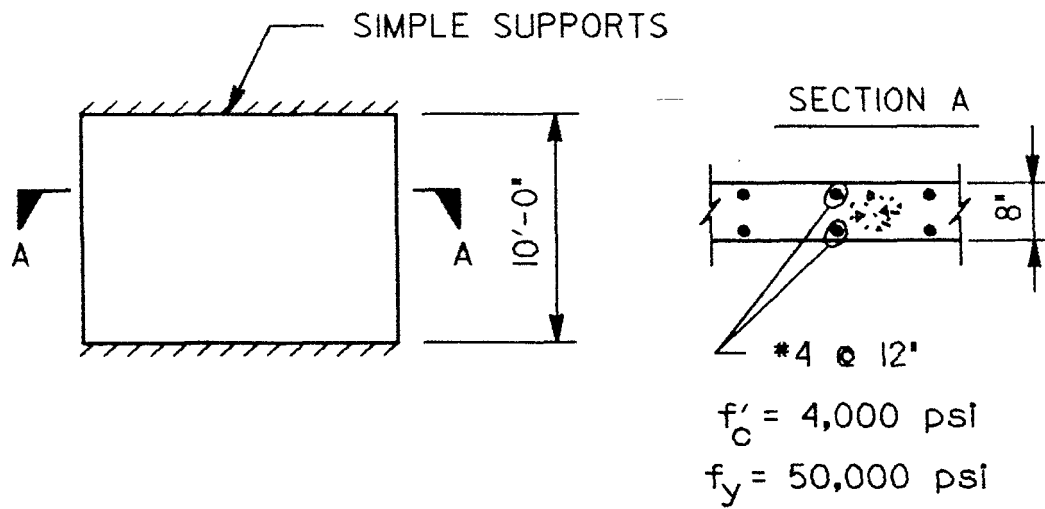


Figure 4: Example Blast Loads for Scaled Range of $12 \text{ ft/lb}^{1/3}$



Yield	500 lbs	75,000 lbs
Overpressure	6.9 psi	6.9 psi
Duration	19.8 ms	105.4 ms
Maximum Deflection	0.36 in	6.3 in
Support Rotation	0.34°	6.0°
Damage Level	Slight	Severe

Figure 5: Response of One-way Reinforced Concrete Wall to Example Blast Loads

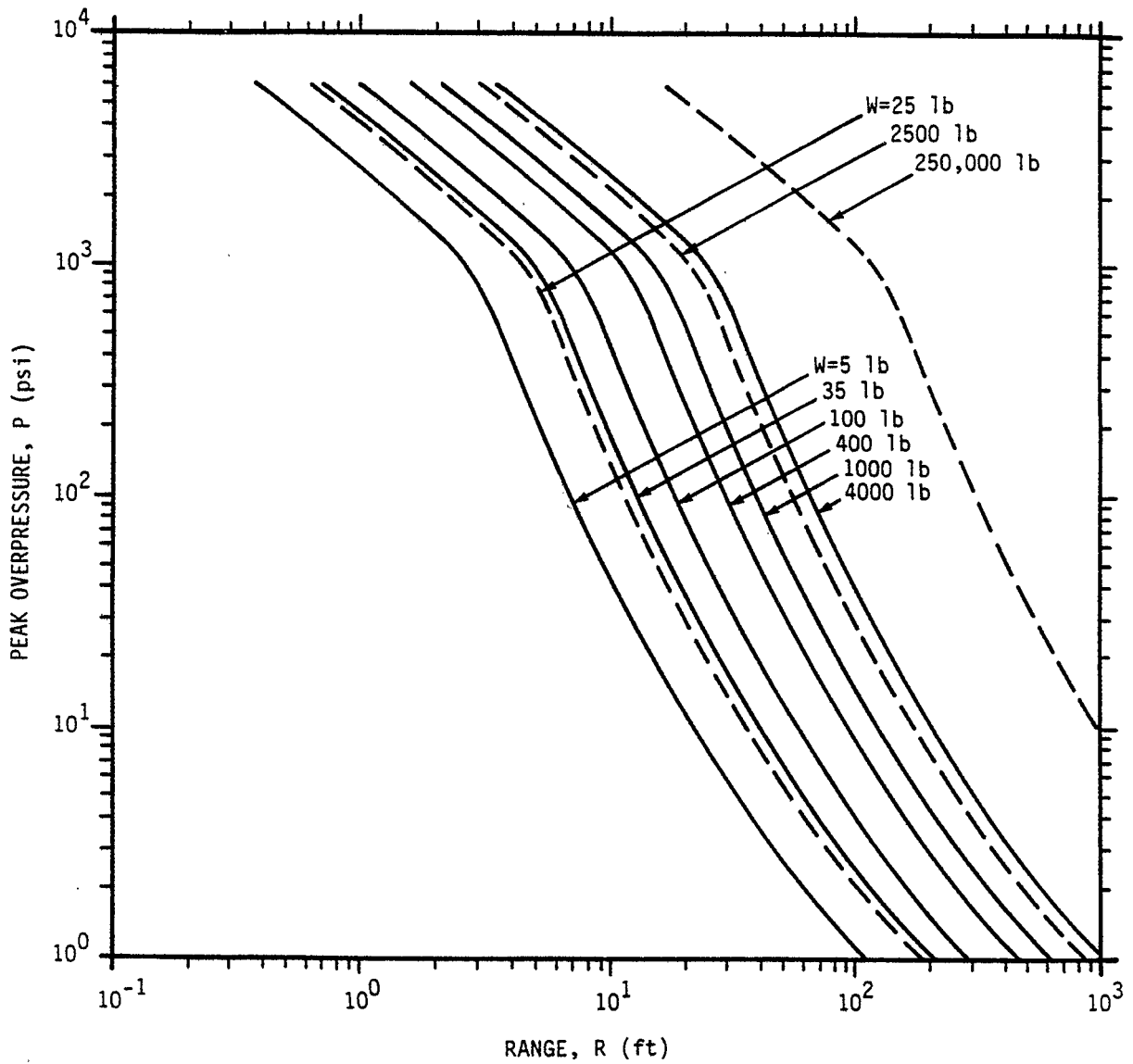


Figure 6: HEXDAM Overpressure vs. Range Curves

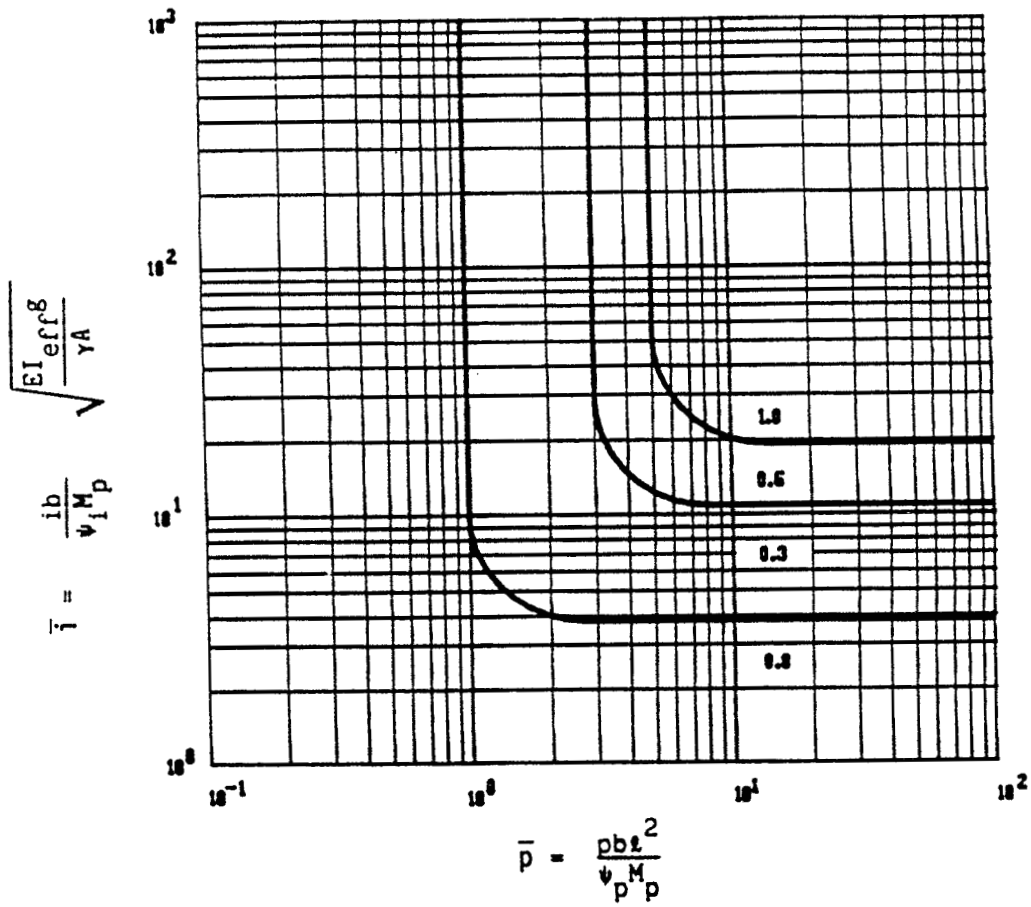


Figure 7: Example Dimensionless P-I Diagram

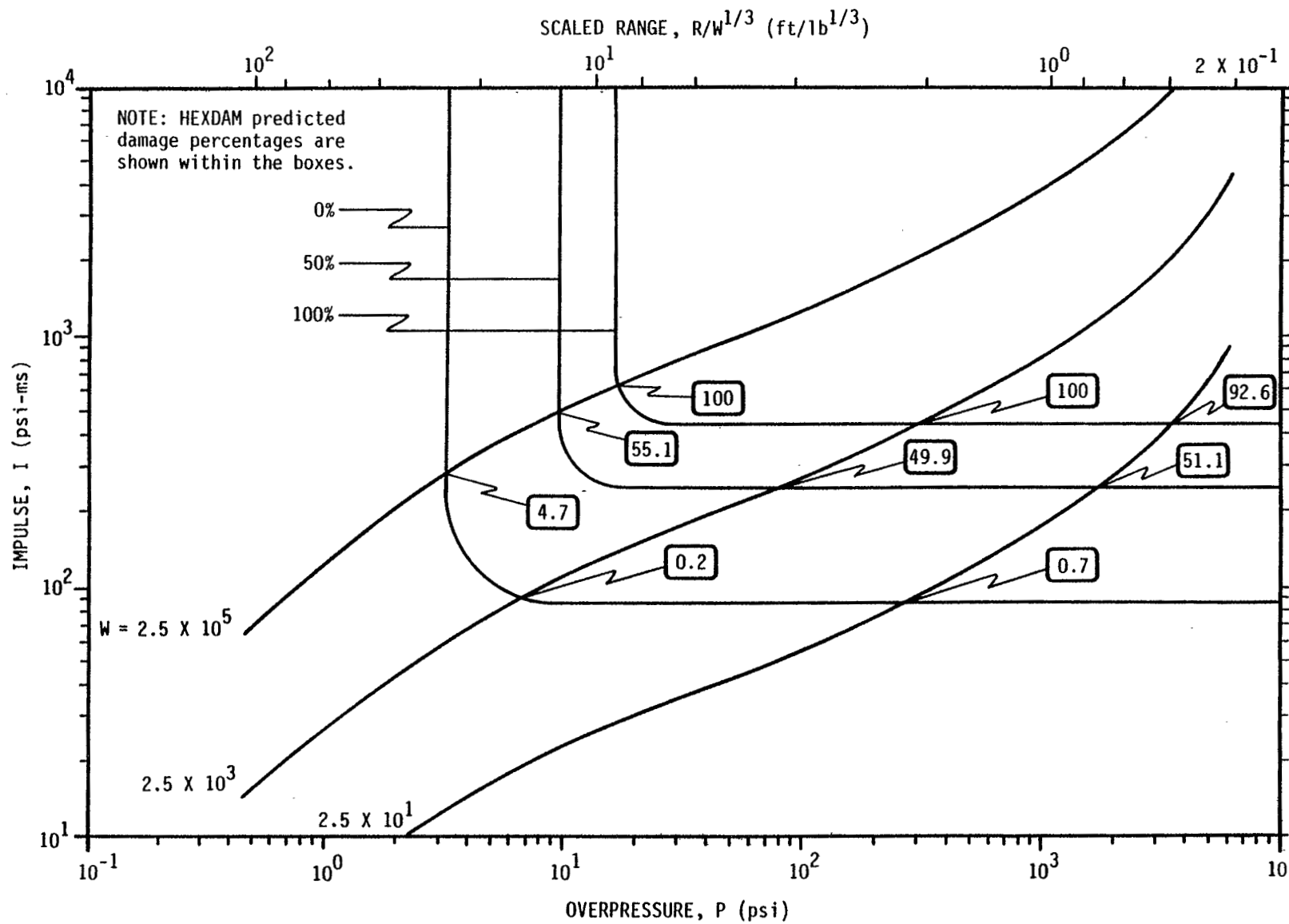


Figure 8: Pressure-Impulse-Yield Diagram for Reinforced Concrete Wall

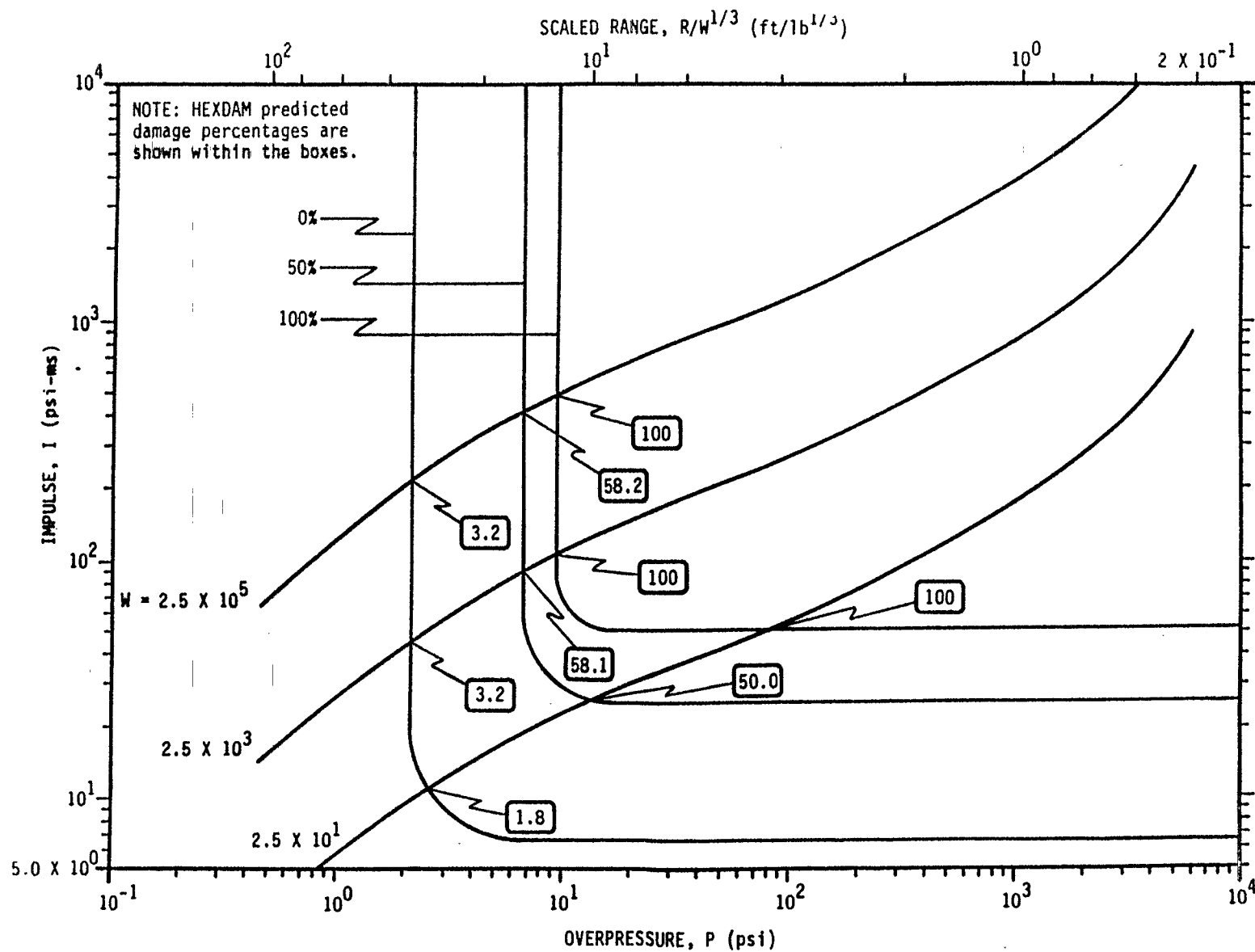


Figure 9: Pressure-Impulse-Yield Diagram for Pre-Engineered Building Wall

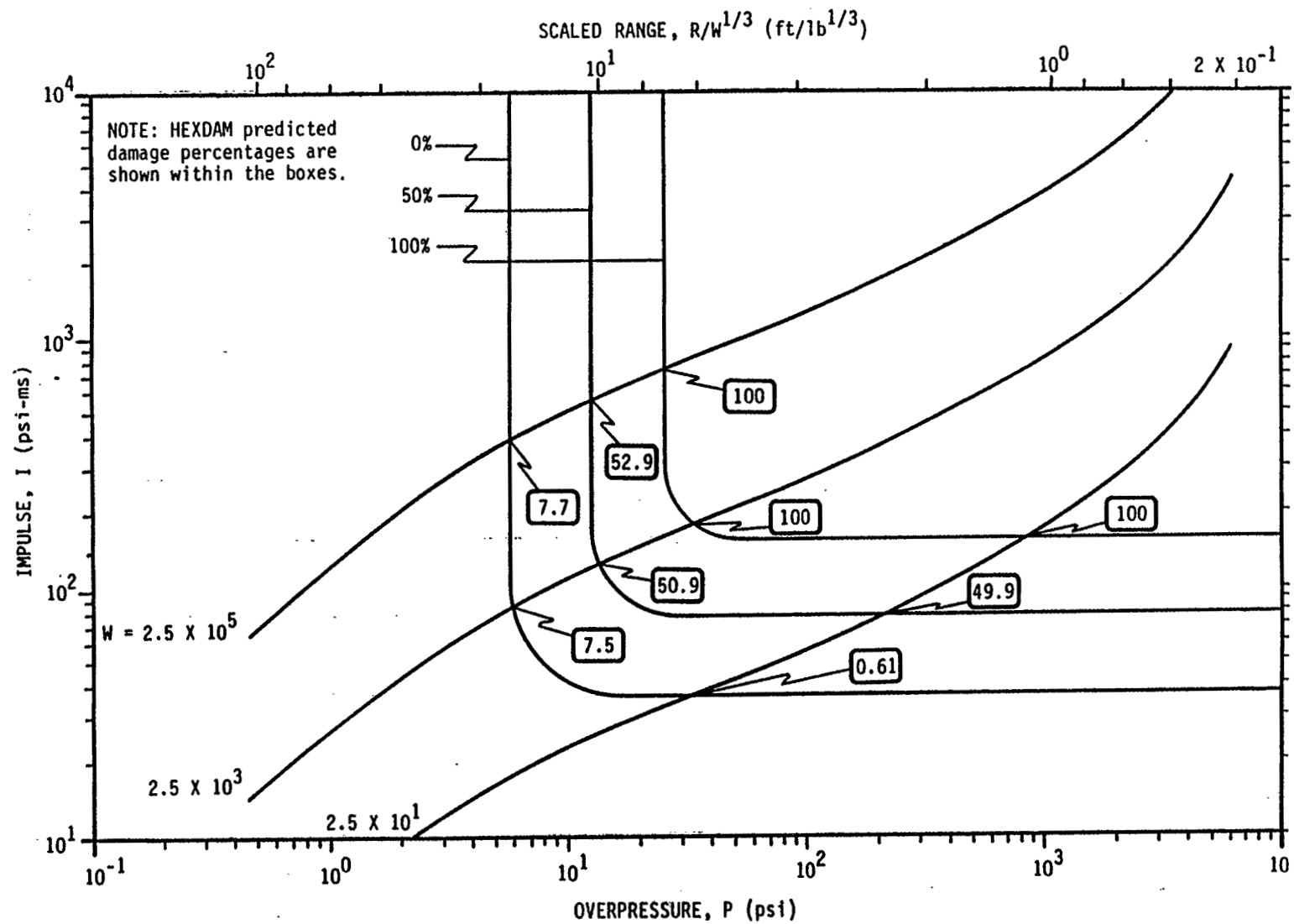


Figure 10: Pressure-Impulse-Yield Diagram for Wooden Wall System

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