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MEMORANDUM REPORT ARBRL-MR-02996

POST-SHOT BLAST LOADING PREDICTIONS FOR GERMAN STRUCTURE NO. 2 - DICE THROW EVENT

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March 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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Pressure-time blast loading post-shot predictions are presented for German Structure No. 2 exposed on the Dice Throw Event. Loading curves are shown for front, side, and interior structure locations.

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I. INTRODUCTION

The Defense Nuclear Agency (DNA) requested the Ballistic Research Laboratory (BRL) to predict after the event the pressure-time loading at selected locations for German structure No. 2 exposed on the Dice Throw Event. This structure was one of three located at different distances (and pressure levels) from the detonation of 5.7×10^5 kg of ammonium nitrate-fuel oil mixture (Reference 1) at the White Sands, New Mexico test site in October 1976. Only Structure No. 2 was to be considered for these predictions. Pressure-time profiles were calculated for Structure No. 2 and are presented for a front wall position, two interior room locations, and for a ground position near to the outside of the left side wall. The measured field data obtained for the structure are displayed in graphical form with the predictions for comparison.

II. FRONT LOADING

Sketches of the structure are shown as Figures 1 and 2. They illustrate the two types of construction material used-brick and block for the left room and brick and wood for the right room. Window areas and some pertinent dimensions are shown which are needed for later use in the calculations. The relative location of the transducer P-2 is shown on the front wall (Figure 2) between the two rooms of the structure. A method follows illustrating the calculation of the front loading at this position.

As the blast wave (created from the detonation of the high explosive) reaches the front wall of the structure, reflected pressure covers the front wall. The reflected pressure loads the front wall until rarefaction waves arrive from the windows and wall edges. For the location of P-2, the first rarefaction came from the left window. Later rarefactions (from left edge, roof, right window, and right edge) decayed the remaining pressure to still lower values until stagnation pressure was reached on the front wall. Both reflected pressure and stagnation pressure are time dependent with the decay of the side-on free-field blast wave.

The method used for the loading calculation for transducer location P-2 is illustrated by the following set of equations. Ambient test conditions (Reference 1) were given as a temperature of $T_1 = 9.7^\circ$ C, a pressure $P_1 = 85$ kPa, a density $S_1 = 1.05$ kg/m^3 (calculated), and the side-on peak blast pressure of $P_S = 25.5$ kPa.

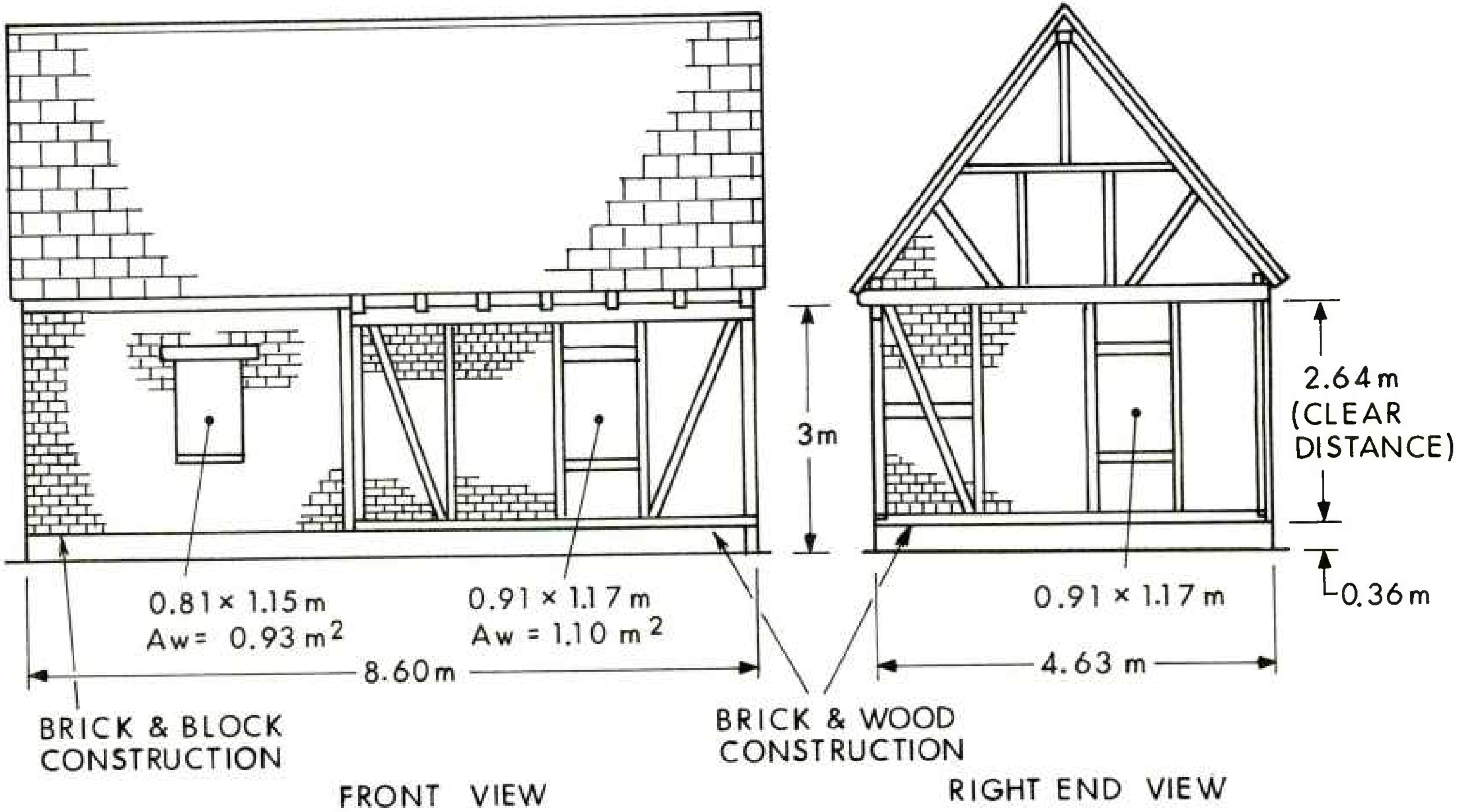

Figure 1. German structure - Dice Throw Event.

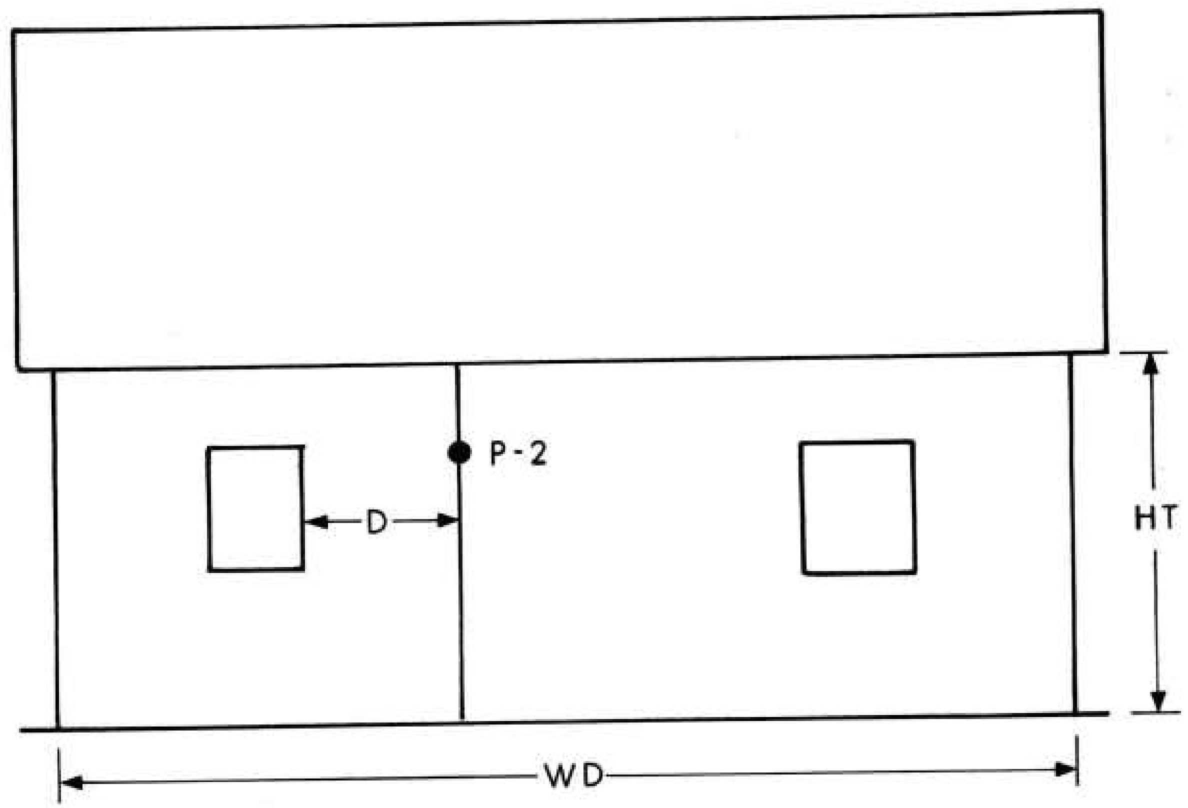

Figure 2. Sketch for front loading.

From these, an ambient sound speed, A_1, is calculated from Equation 1:

$$A_1 = 331.62 \left(1 + \frac{T_1}{273.16}\right)^{\frac{1}{2}} = 337.4 \text{ m/s.} \tag{1}$$

The first rarefaction will arrive from the window edge (D = 1.34 m) after a time,

$$TR = D/C_{ref} = 3.7 \text{ ms}, \tag{2}$$

where the sound velocity, C_{ref}, in the reflected pressure is obtained from Equation 3 (derived from Reference 2 for $\gamma = 1.4$ for air).

$$C_{ref} = A_1 \left[\frac{\left(8 \frac{P_S}{P_1} + 7\right) \left(2 \frac{P_S}{P_1} + 7\right)}{7 \left(7 + 6 \frac{P_S}{P_1}\right)} \right]^{\frac{1}{2}} = 363.4 \text{ m/s.} \tag{3}$$

The loading during the period of reflected pressure is given by Equation 4,

$$P = P_{ref}(T), \; 0 \leqslant T \leqslant TR, \tag{4}$$

where

$$P_{ref} = 2P_s \left[\frac{7P_1 + 4P_s}{7P_1 + P_s} \right] = 57.3 \text{ kPa} \tag{5}$$

at T=0. As the side-on blast wave pressure decays during this time, so does the reflected pressure. The value of P_{ref} at time TR is assumed to equal the reflected value for the side-on value existing at the time TR. See the tables in Reference 3 or use Equation 5 for $P_{ref}(TR)$. $P_{ref}(TR) = 54$ kPa. Equation 6 is next used (Reference 4):

$$P = P_{ref}(TR) \; e^{-[0.232(T-TR)/TR]} \tag{6}$$

for $TR < T < 2.5$ TR.

As later rarefactions cause additional pressure decay, Equation 7 is used:

$$P = 0.70 \; P_{ref}(TR) \; e^{-[0.36(T-2.5TR)/(TC-2.5TR)]} \tag{7}$$

for $2.5\ TR \leqslant T \leqslant TC$, where the clearing time, TC, is given by Equation 8.

$$TC = 2.5\ DR/C_{ref} = 20.6\ \text{ms} \tag{8}$$

where,

$$DR = \text{least of } WD/2 \text{ or } HT, \tag{9}$$

and $DR = HT = 3.0\text{m}$.

After the clearing time, the front loading pressure follows the stagnation pressure of the input blast wave:

$$P = P_{stag}\ (T) \tag{10}$$

for $T > TC$.

Figure 3 shows a plot of the predicted pressure-time loading (for P-2) as calculated by the above steps. The predicted loading is compared with the side-on input blast wave for free-field and the measured loading (from P-2) from the Dice Throw Event (Reference 5).

The predicted initial reflected pressure was not reached by the transducers. The predicted decay follows the data well until later rarefactions arrive and cause still lower pressure than predicted. After about 50 ms it is belived that the transducer began to leak internally and behaved in a differential manner at times after the transducer mount on the structure began to be loosened. This would account for a positive loading duration considerably shorter than the free-field blast wave.

III. INTERIOR FILL LOADING

Pressure-time profiles for transducer locations P-3 and P-8 (Figure 4), one in each room, were chosen for comparison to the fill predictions.

A BRL filling code reported in Reference 6 was used for the fill predictions shown in Figures 5 and 6. Input values needed for the code are ambient conditions, blast stagnation pressure (calculated from Reference 2 for input values), window openings, and volume of the rooms.

The filling code takes the stagnation pressure as a reservoir of pressure over the front wall which is the driving pressure source that fills the two rooms. The filling rate is proportional to ratio of the room volume to window area. Figure 4 lists these values for the two rooms of the structure. An orifice coefficient is included in the program to take into account choking of the flow through the openings.

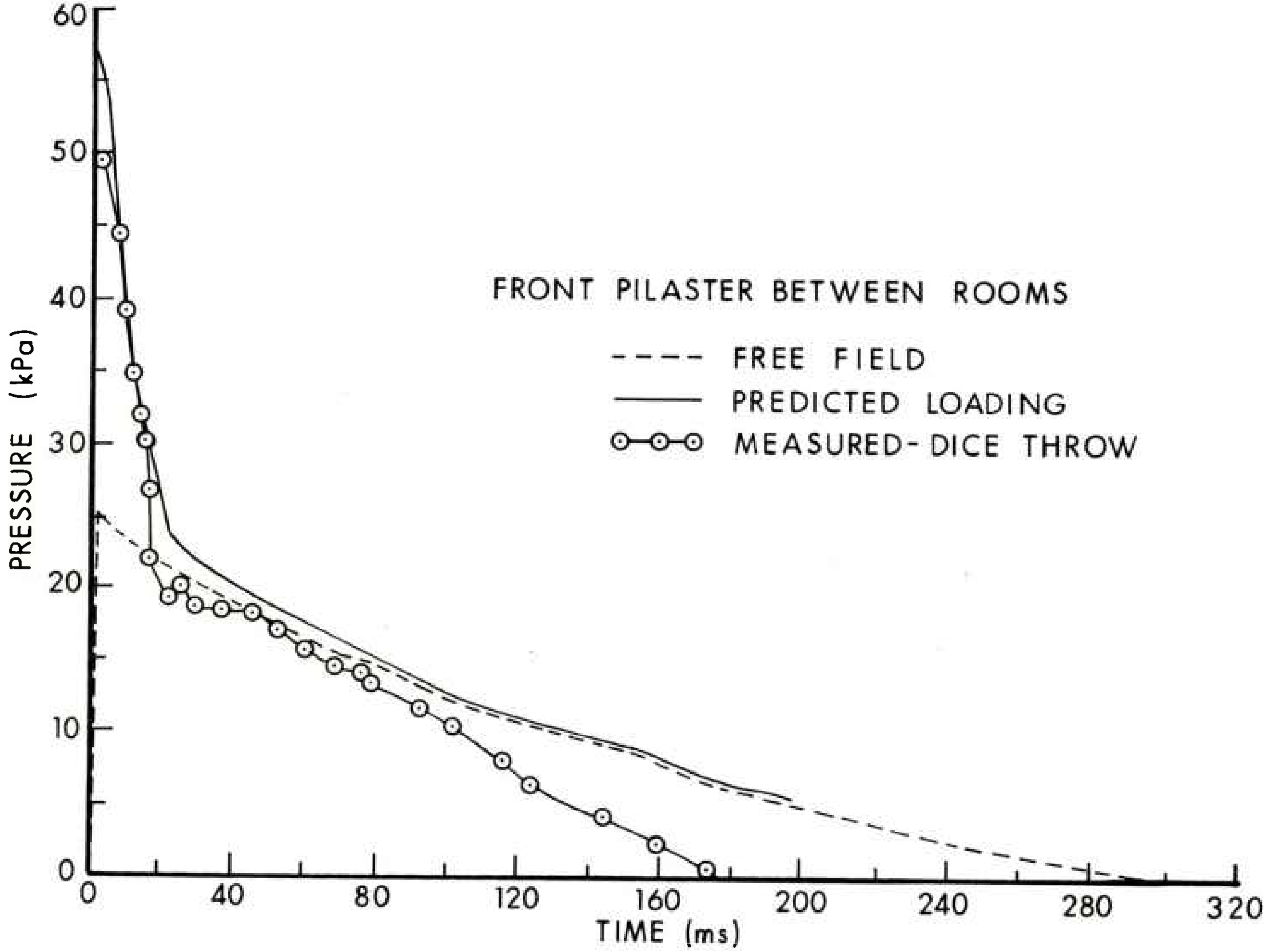

Figure 3. Front loading prediction for P-2 on German structure No. 2, Dice Throw Event.

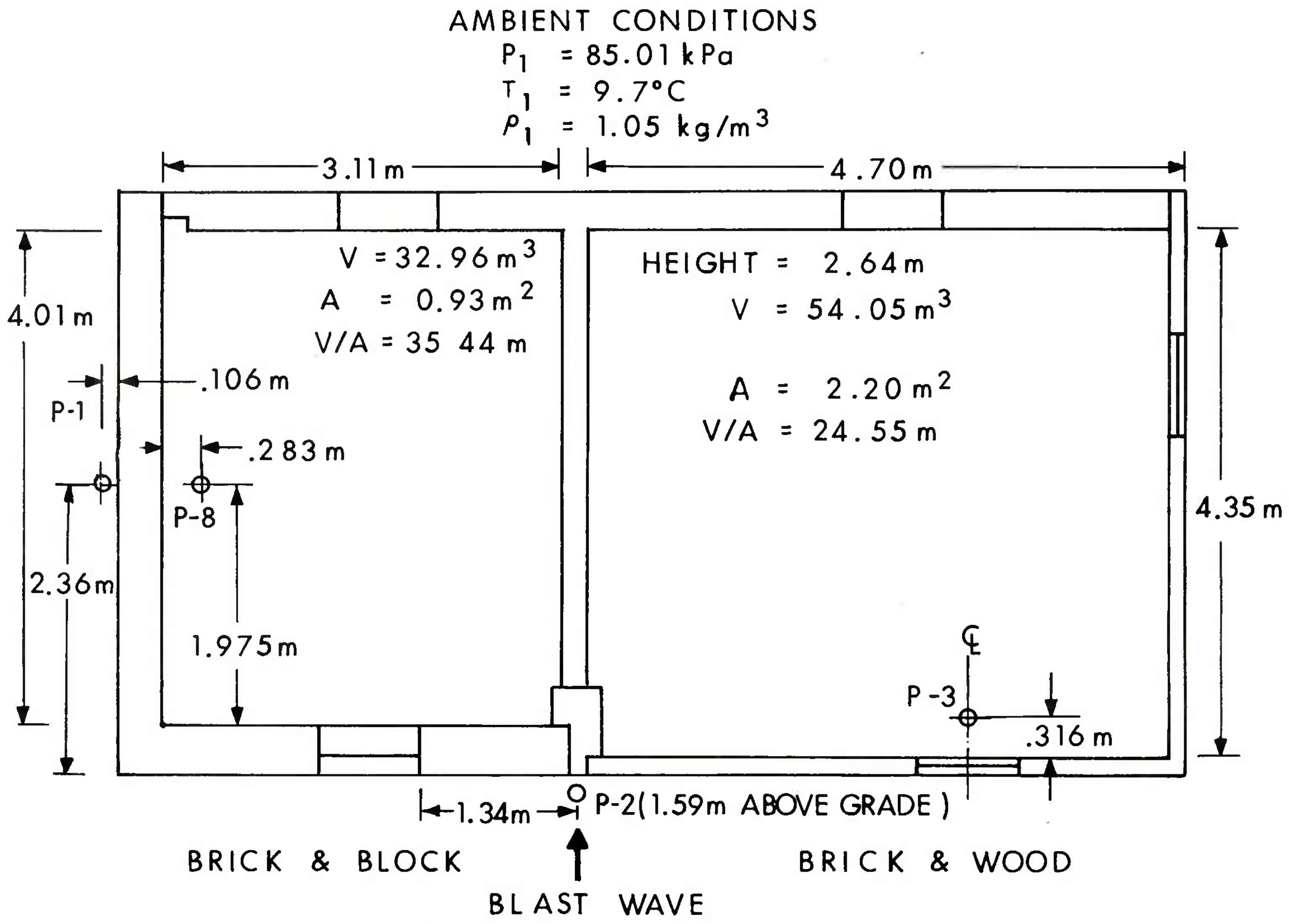

Figure 4. Floor plan for German structure No. 2 on Dice Throw Event.

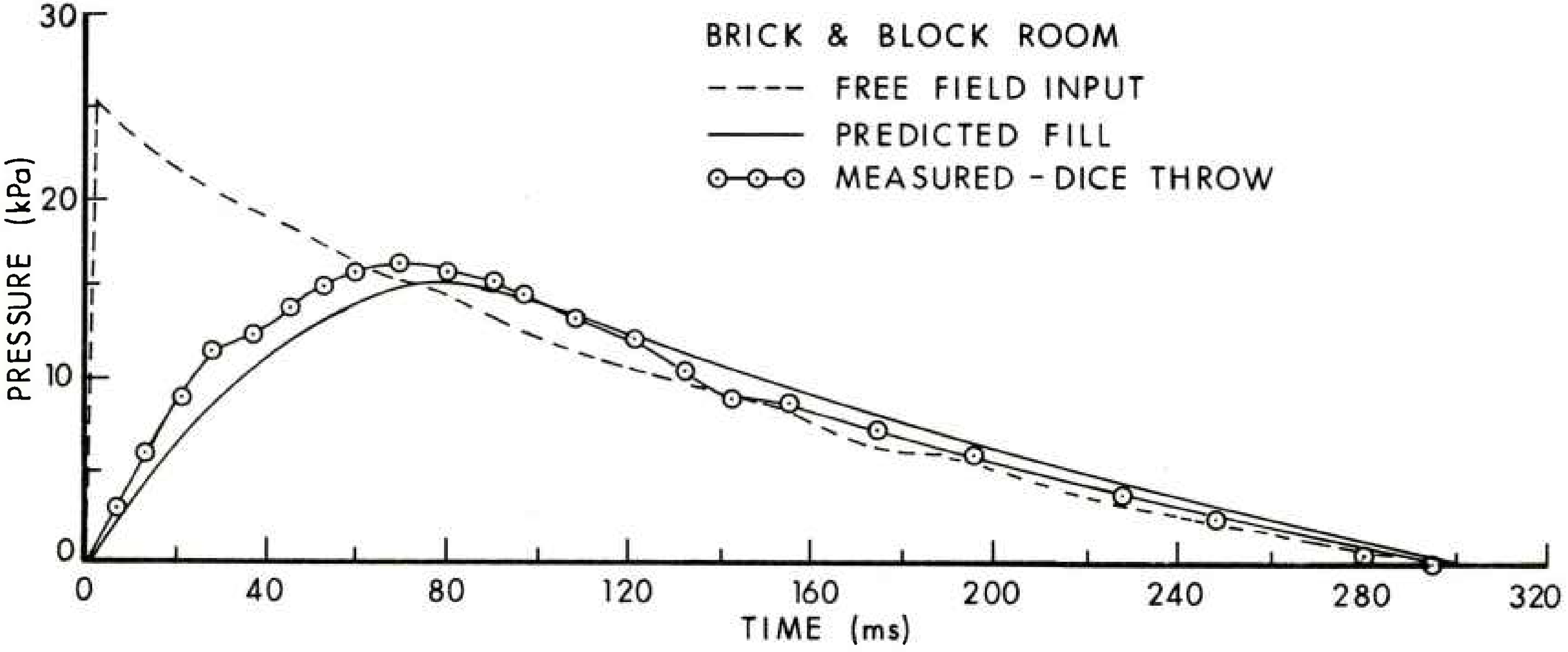

Figure 5. Fill prediction for P-8 in German structure No. 2, Dice Throw Event.

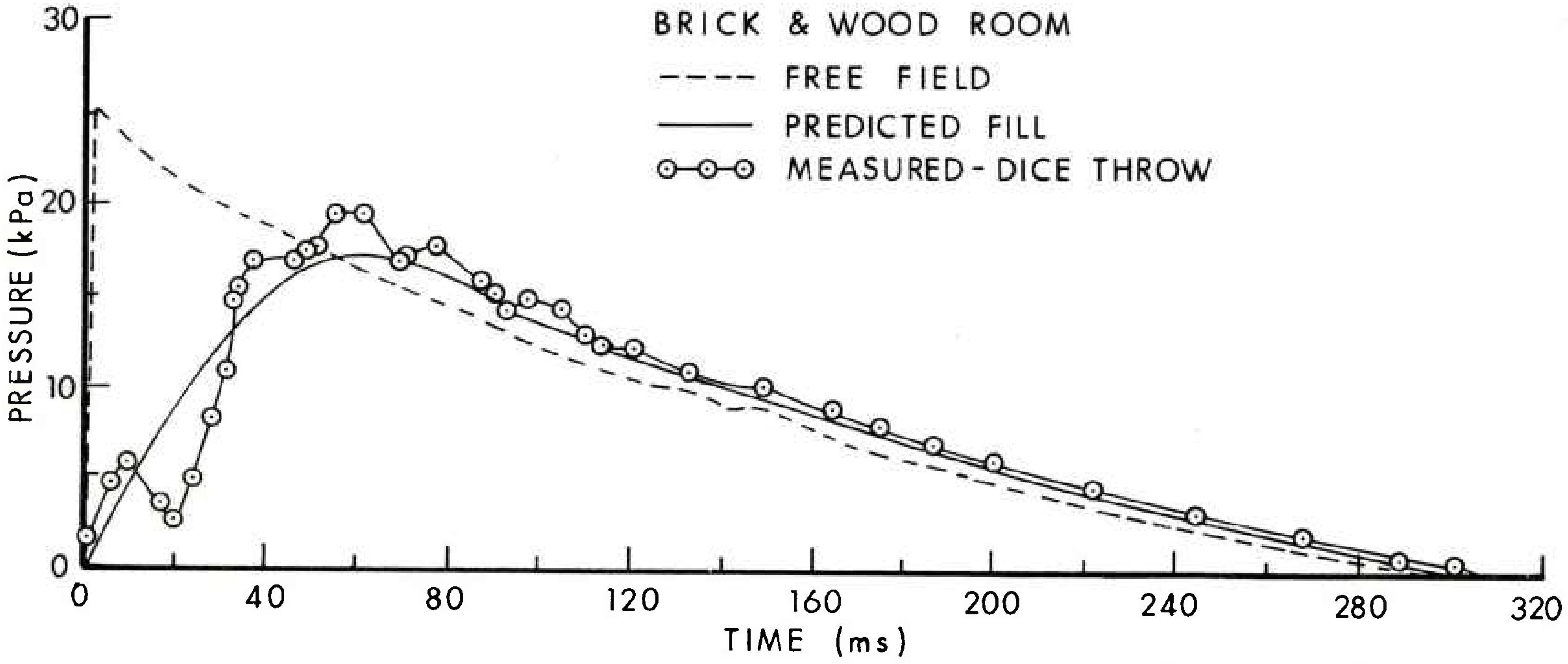

Figure 6. Fill prediction for P-3 in German structure No. 2, Dice Throw Event.

As the pressure reservoir level changes, both sonic and subsonic flows are allowed for in the program. An average fill pressure is calculated for the incremented time chosen. A smooth filling curve is produced by this prediction code.

For brick and wood room (left side), the prediction follows fairly well the measured curve obtained at P-8 (Figure 5). The location was far enough into the room so that a smooth experimental filling curve resulted and matched the prediction.

A similar smooth prediction, Figure 6, made for the brick and wood room at P-3 did not match as well as before for P-8. The transducer for this room was quite close to the window opening. Diffracted waves from the original blast wave entering through the window created a non-smooth filling curve and did not agree with the prediction as well as before.

IV. SIDE LOADING

The prediction method for transducer location P-1 was taken from Reference 7. The assumption was made that this station would be representative of loading on the side wall near the ground. The side-loading pressure follows quite closely that of the free-field input blast except that a vortex from the front wall edge lowers the pressure at a given location as the vortex crosses the area. The equations below, taken from Reference 6, illustrate how this effect is taken into account.

The minimum pressure, P_{side}, caused by the vortex at a time, t_m, is given by Equation 11:

$$P_{side} = P_s(t)[\,4(P_s/P_1)(\frac{L'}{L} - 1) + 1] \quad , \qquad (11)$$

where $P_s(t)$ is the free-field pressure at the front wall as a function of time; P_s is the peak free-field pressure, 25.35 kPa; P_1 is the ambient pressure, 85 kPa; L' is distance to the location of P-1, 2.36m; and L is the length of the side wall, 4.63m.

$$P_{side} = 10.13 \text{ kPa} \quad , \qquad (12)$$

at a time:

$$t_m = L'/v = 64 \text{ ms} \qquad (13)$$

where v is the vortex travel velocity and is calculated from Equation 14.

$$v = (0.042 + 0.108 \frac{L'}{L})U_o = 36.7 \text{ ms}, \quad (14)$$

where U_o is the blast wave front velocity. Equation 15 gives this value.

$$U_o = A_1 (\frac{6}{7} \frac{P_s}{P_1} + 1)^{\frac{1}{2}} = 378.3 \text{ ms} \quad (15)$$

The pressure loading will begin to decay when the decreasing effect of the vortex is just beginning at a time (measured from arrival at front wall),

$$\tfrac{1}{2}(t_d + t_m) = 35 \text{ ms} \quad (16)$$

where,

$$t_d = L'/U_o = 6 \text{ ms} \quad (17)$$

The effect of the vortex is felt until a time defined to be:

$$t_m + 15\, h'/U_o = 182 \text{ ms}. \quad (18)$$

$h' = 3.0$ m the clearing height, taken as the minimum of HT or WD/2.

Figure 7 shows the pressure lowering vortex effect (solid line) plotted from arrival at P-1, together with the experimental vortex effect measured and the free-field blast wave profile. It is seen from a comparison of the curves that the prediction technique considerably over predicts the effect of the vortex at this location.

V. SUMMARY AND CONCLUSIONS

Predictions of pressure-time loading were made at several locations on German structure No. 2 exposed to the 25.35 kPa overpressure level on the Dice Throw Event. The front loading predictions and average fill loading compared favorably to the experimental records. The fill code used did not have the capability to predict the internal reflections superimposed on the average fill curve. It differed from the experimental curve obtained from the location near the window of the right room (brick and wood). The side wall prediction showed much more of a vortex effect than was measured.

In conclusion, the front loading and average fill curves can be predicted quite well, whereas the side loading prediction method needs some adjustment to account more accurately for the vortex effect.

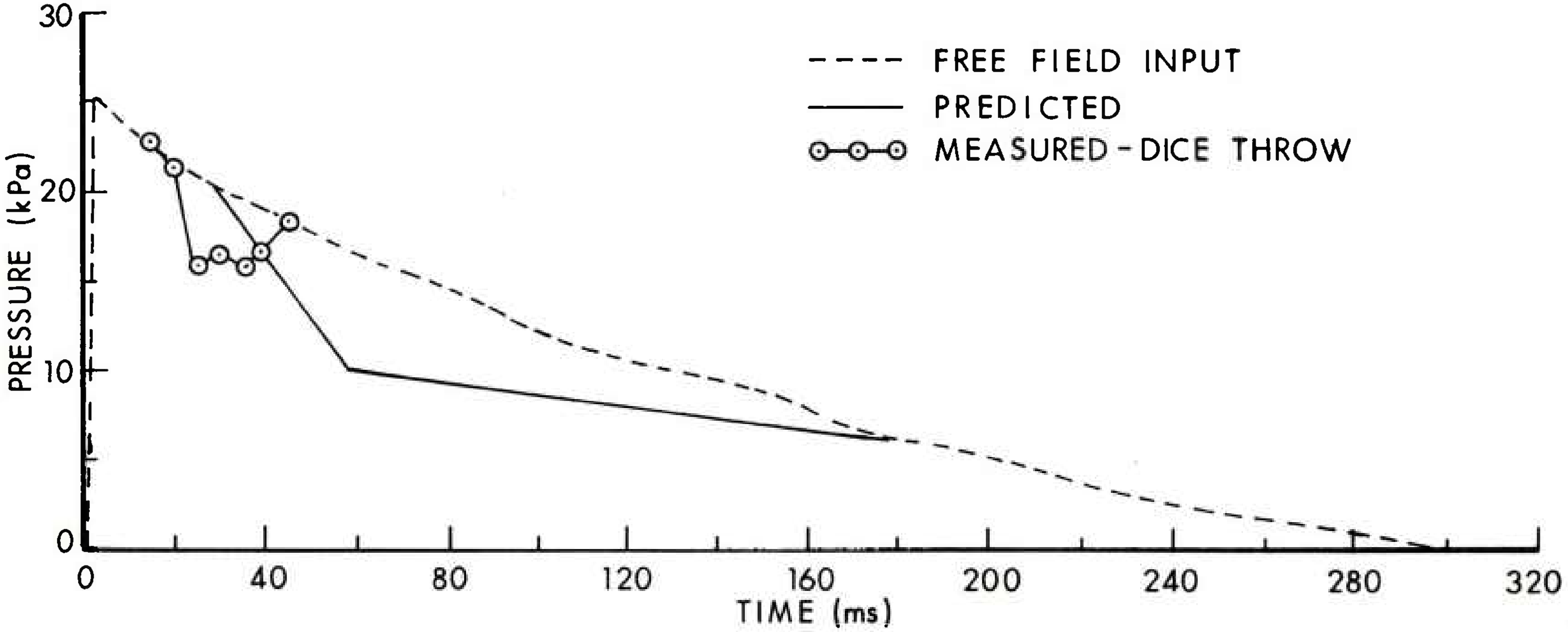

Figure 7. Prediction for P-1 outside of wall of German structure No. 2, Dice Throw Event.

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