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RHIC PROJECT

Brookhaven National Laboratory

Estimate of High Energy Punch-Through in Shielding Wall Cracks

A. J. Stevens

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I. Introduction

In considering penetrations (holes) in shielding, the excess dose equivalent at the exit of the penetration due to the penetration itself can be considered to have two components; a "low energy" component caused by neutrons of order 1 MeV which come directly through the penetration and a "high energy" component caused by either high energy hadrons which come directly through the penetration or which interact in the shielding near the penetration with resultant (high and low energy) radiation which escapes through the penetration.

This note describes a CASIM calculation of the high energy component *in a specific geometry* which includes an approximation of the STAR Detector. The cracks simulated are *horizontal*, since the directionality of the high energy component implies that (to a good approximation at least) the only effect of (small) vertical cracks would be a slight reduction of the shielding thickness. The results of the CASIM calculations are "fit" to an extremely simple model whose only parameter is a normalization constant. Although perhaps useful as a guide, the degree to which this "model" can be extended to other geometries is not obvious. Clearly, some safety margin should be allowed.

Two additional caveats must be mentioned. The first is that the reader must keep in mind that the total dose caused by cracks must include the low energy component *which may well be the dominant term*. At the time of this writing, MCNP calculations are underway which will hopefully be of use in estimating this component. The second caveat is related to the problem of knowing what volume should be used in dose-averaging. Most exposure criteria are given in terms of whole body dose. However, the volume over which excess exposure occurs behind a small shielding wall crack is itself very small, and the *evaluation* of the dose depends on the volume used for averaging. The final section of this note returns to this problem, but without a suggested solution.

II. CASIM Calculations

Horizontal cracks were explored in the context of a material distribution approximating the STAR detector. A CASIM calculation was performed with 250 GeV/c protons scraping on the DX magnet. The shield wall was taken as a 150 cm. thick region of light concrete at a lateral distance from the beam line between 12.45m and 13.95m. The calculation performed was fully 3-dimensional which makes high statistical precision difficult. At the back of the wall star density was binned in a series of strips of dimension 300 cm. × 4 cm. × 4 cm. The 300 cm. dimension is along the beam line at the downstream end (with respect to the simulated beam fault) of the front

STAR shield wall; the star density had been observed to flat over this region in previous calculations. The strips were placed at various vertical positions where horizontal "cracks" in the wall were simulated.

Fig. 1 shows the star density in the strips as a function of vertical position where no cracks are present as a function of a limited range of the vertical position. The data points here were obtained from 3 CASIM runs with different starting values of the random number generator seed. The errors shown are simply the rms of the three runs. Each run took about 33 hours of computer time on an IBM RS6000 host. The three dimensional nature of the calculation clearly limits statistical precision within reasonable computer time, which in turn implies that *one must explore relatively large cracks and extrapolate the calculations to smaller values.* The average star density in Fig. 1 is 1.0×10^{-9} star/cc-p. In the test material used this corresponds to 417 mrem at 4 times the design intensity which is in good agreement with previous calculations upon which the wall design was based. Clearly a crack size which results in an *excess* star density of about 0.2×10^{-9} star/cc-p is the limit that can be explored directly.

Cracks of 1" and 1/2" width were simulated as a function of the vertical (Y) coordinate over a limited range of Y. Figure 2 shows the results of these calculations superimposed on the "background" (no-crack) results of Fig. 1.

III. A Simple Model as Parameterization

As mentioned immediately above, some extrapolation procedure is required to obtain estimates for any geometry other than the configuration corresponding to the calculations shown in Fig. 2. A simple formula based on direct punch through originating at the beam line axis seems to do fairly well. Fig. 3(a) shows the basis of this model; a ray is shown in this figure which has probability of survival of $e^{-S/\lambda}$ instead of $e^{-S0/\lambda}$ which would be the case if the crack were not present. In these expressions λ is the normal effective transverse attenuation length in concrete, 50.2 cm. Fig. 3(b) shows a situation with a crack closer to the beam line than shown in Fig. 3(a). In this case rays whose transverse angle θ is greater than a critical angle θ_c = atan((H-W/2)/D) have no attenuation. For the case shown in Fig. 3(a), the expression used to "fit" the *excess dose* due to a crack is the following:

$$\textit{Excess Dose} = K \times W \times f \quad \text{where}$$

$$f = \frac{1}{\Delta\theta} \times \int (e^{S(\theta)/\lambda} - e^{-S0(\theta)/\lambda}) d\theta$$

In terms of the variables shown in Fig. 3,

$$S(\theta) = \frac{H - W/2}{\sin(\theta)} - \frac{D}{\cos(\theta)} \quad \textit{and}$$

$$S0(\theta) = \frac{L - D}{\cos(\theta)}$$

The integral is performed (numerically) between the values of θ defined by the crack at the back of the wall, i.e., between θ_1 = atan((H-W/2))/L and θ_2 = atan((H+W/2)/L). The expression for cases where some value of θ is greater than the critical value is essentially the same except that S(θ) is 0 for all theta greater than θ_c.

Fig 4 is a re-run of Fig. 2 together with the above expression (added to the "background" of 1.0×10^{-9} stars/cc/p) where the normalization constant K was set to 8.5×10^{-9} stars/cm^4-p. The fit is reasonably good, better than a factor of 1.5 from the CASIM results over the range explored Note that this "model" contains the thickness of the wall (L-D) and can therefore be extrapolated to walls of different thickness. Distance from the beam line presumably differ from the geometry considered here by $1/R_t^2$ scaling.

Figs. 5-8 show the model results at 4 times RHIC design intensity for the following range of parameters:

D = distance from beam line to inner wall = 40,30, and 20 ft.
W = crack width = 1/4" and 1/8 "
T = wall thickness = 4 ft. and 5 ft.
θ = angle from beam line to center of crack at the back of the wall = 1°,2.5°,5°, and 10°.

Specifically, the numerical results in these figures come from the equation

$$\textit{Excess Dose at } 4 \times \textit{Design Int. in mrem} = 3554 \times \left(\frac{1395}{L}\right)^2 \times W \times f$$

where the crack size W and L (see Fig. 3) are in cm. The lines in Figs. 5-8 are only to guide the eye.

IV. Bin Size Effect

As mentioned in the introduction, the calculation is sensitive to the size of the test detectors. The numerical results given in this note were obtained, as stated, with a 4 cm. high detector volume (± 2 cm.) flush against the backwall. [The cracks are infinitely long, for all practical purposes, and the depth is not an issue — sensitivity in this geometry is only to the height.] For comparison, results were also binned in a 2 cm. high volumes, also centered on each crack. Although statistical precision was even more difficult here, the results were higher, as one would expect, in every calculation. The enhancement ranged from very small values to a factor of about 1.8 for the 1/2 inch crack size on the midplane. However, as stated earlier, it is not clear what volume is relevant since the RHIC criteria are in terms of whole body irradiation. The initial 4 cm. was selected as a rough measure of the size of a typical organ, but no good justification can be given. This uncertainty adds to the model uncertainty in arguing for the application of a safety factor.

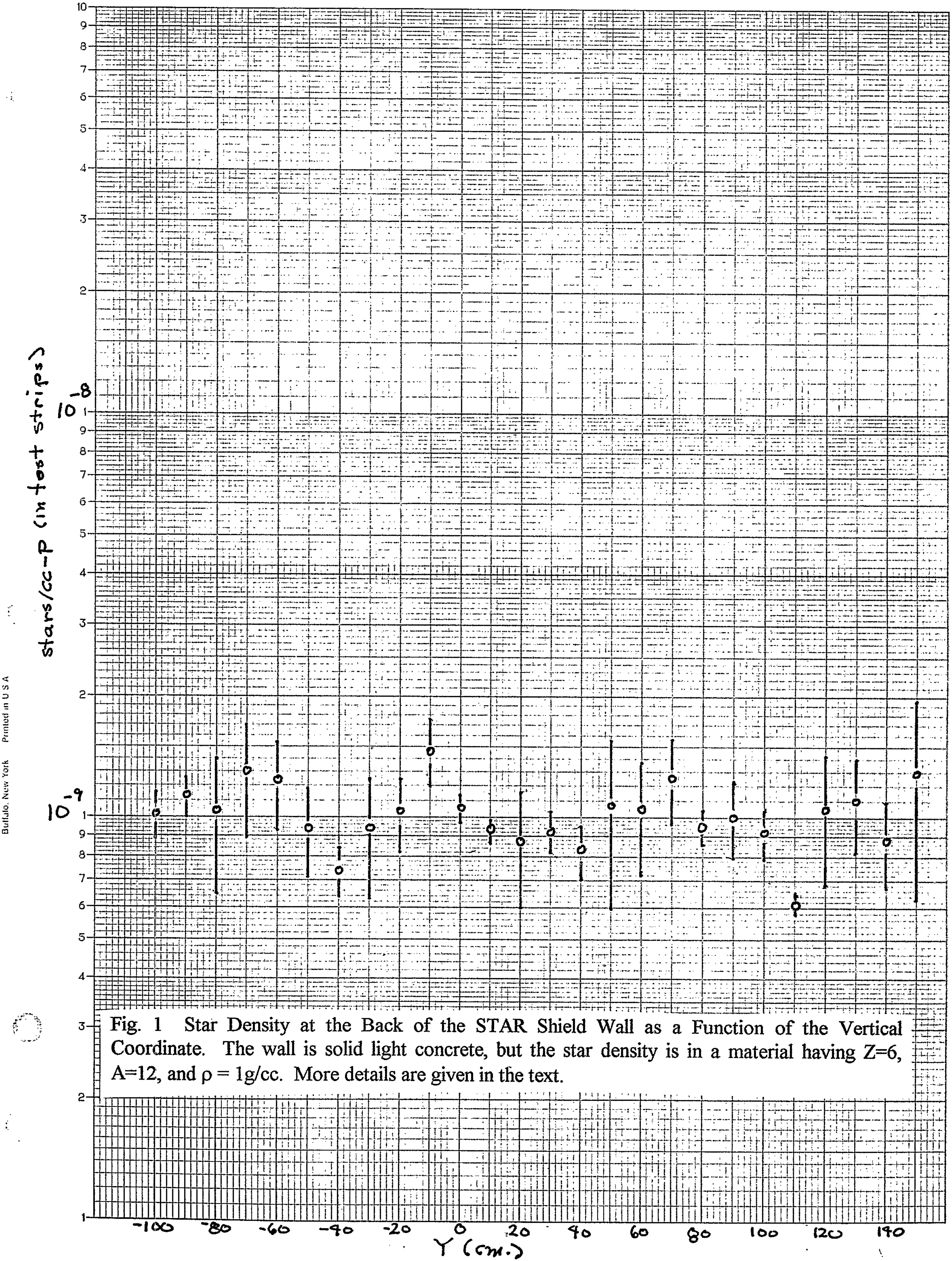

Fig. 1 Star Density at the Back of the STAR Shield Wall as a Function of the Vertical Coordinate. The wall is solid light concrete, but the star density is in a material having Z=6, A=12, and ρ = 1g/cc. More details are given in the text.

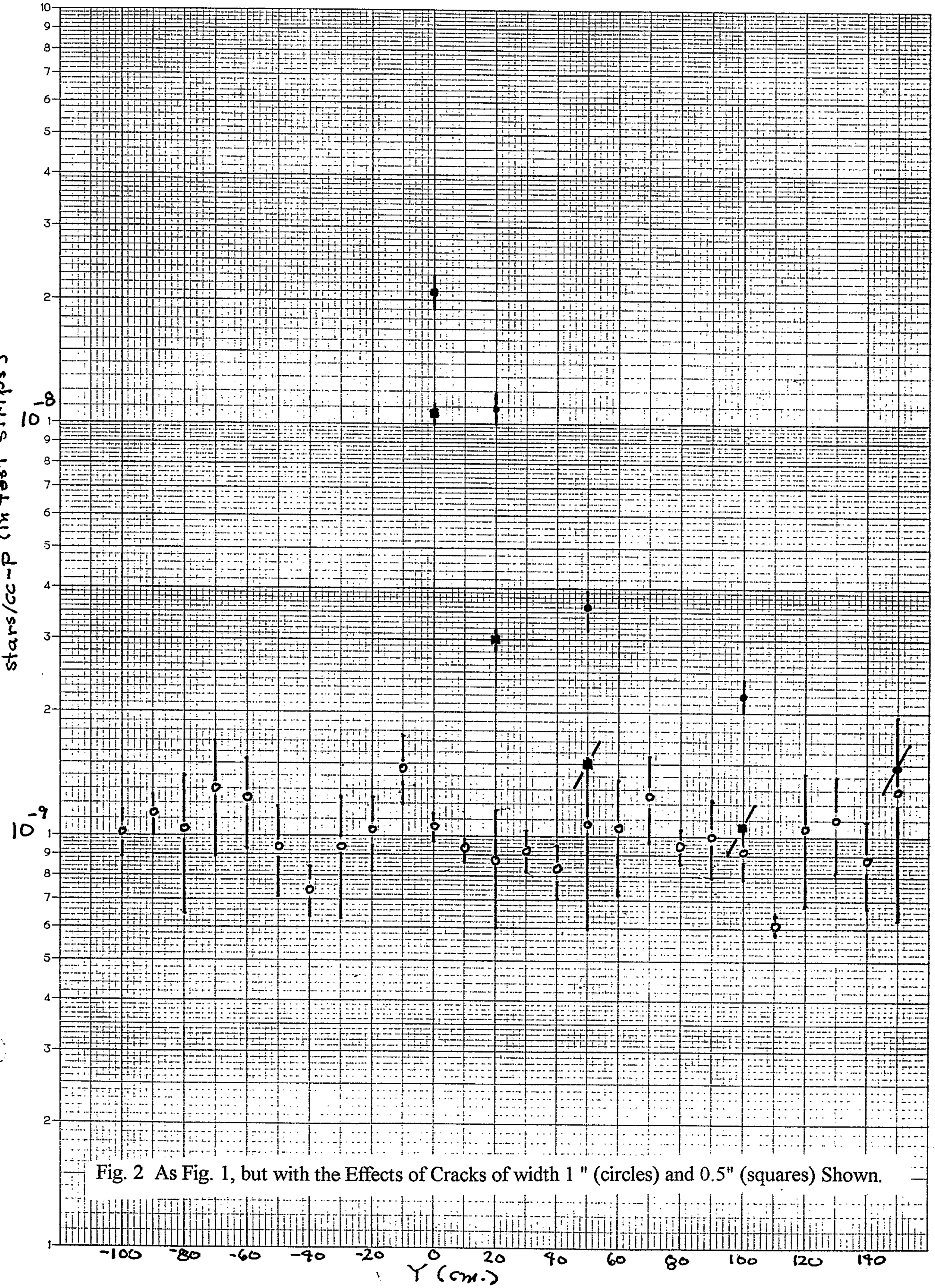

Fig. 2 As Fig. 1, but with the Effects of Cracks of width 1 " (circles) and 0.5" (squares) Shown.

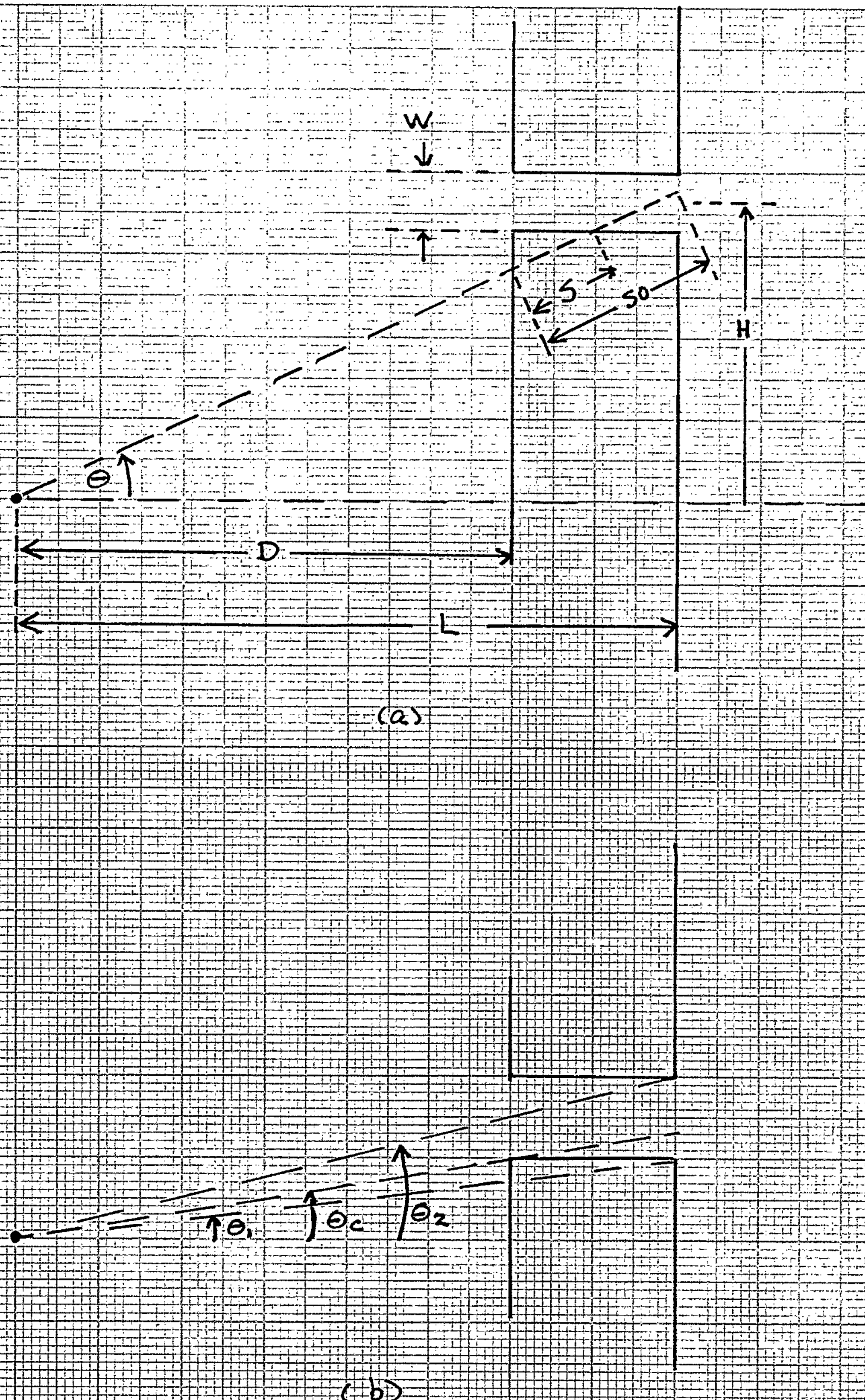

Fig. 3 Geometry of the Simple Model Described in the Text.

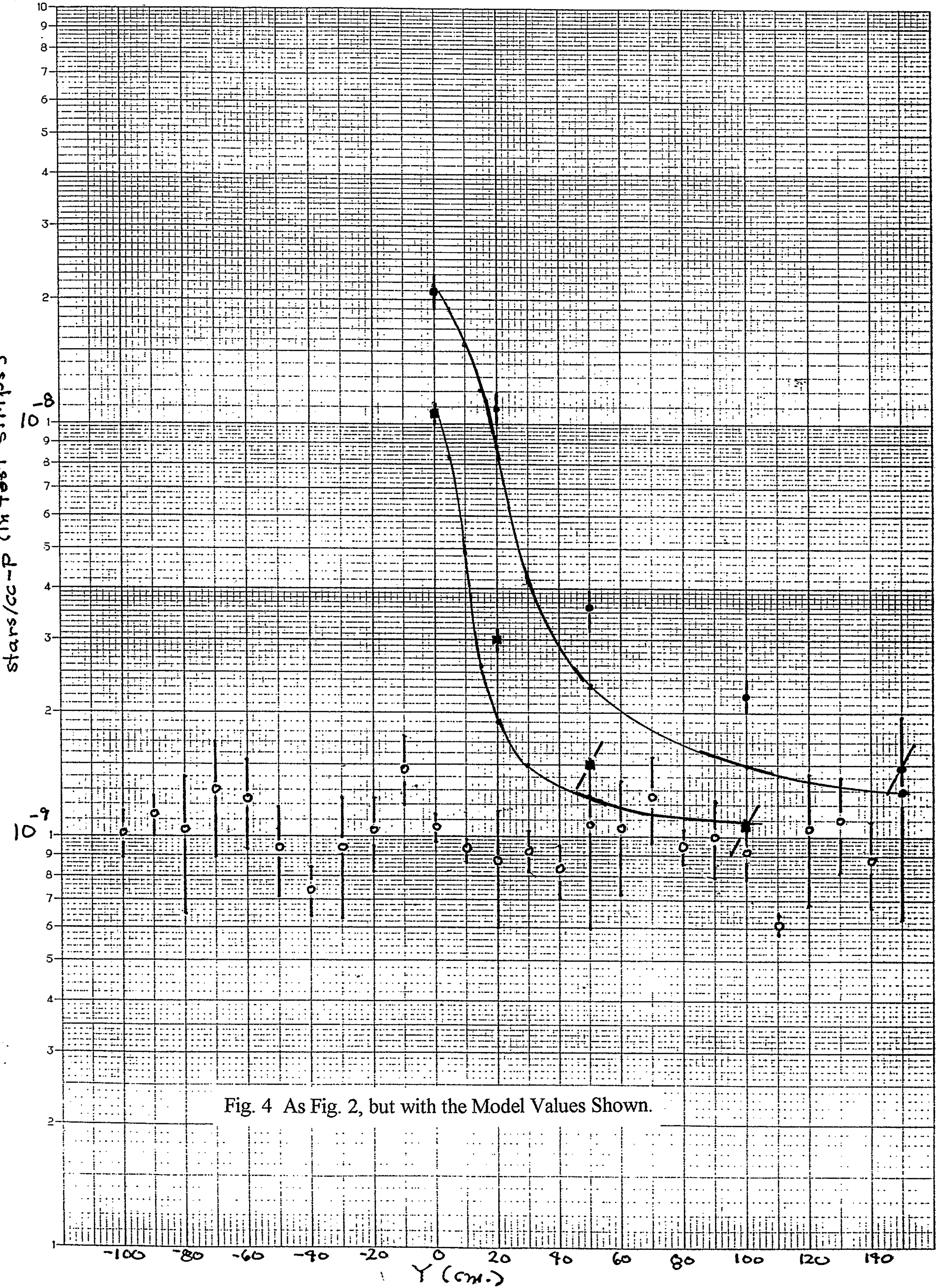

Fig. 4 As Fig. 2, but with the Model Values Shown.

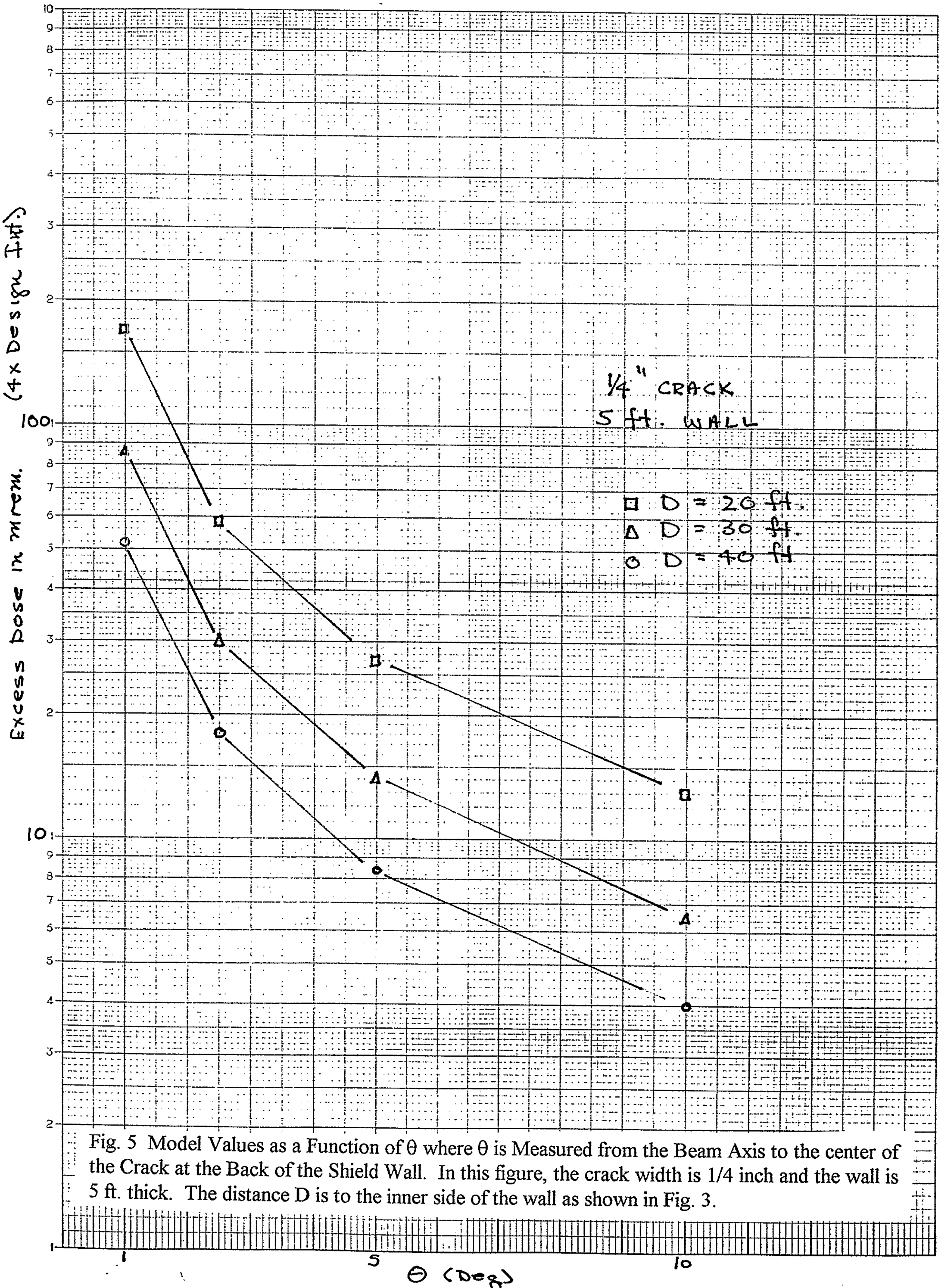

Fig. 5 Model Values as a Function of θ where θ is Measured from the Beam Axis to the center of the Crack at the Back of the Shield Wall. In this figure, the crack width is 1/4 inch and the wall is 5 ft. thick. The distance D is to the inner side of the wall as shown in Fig. 3.

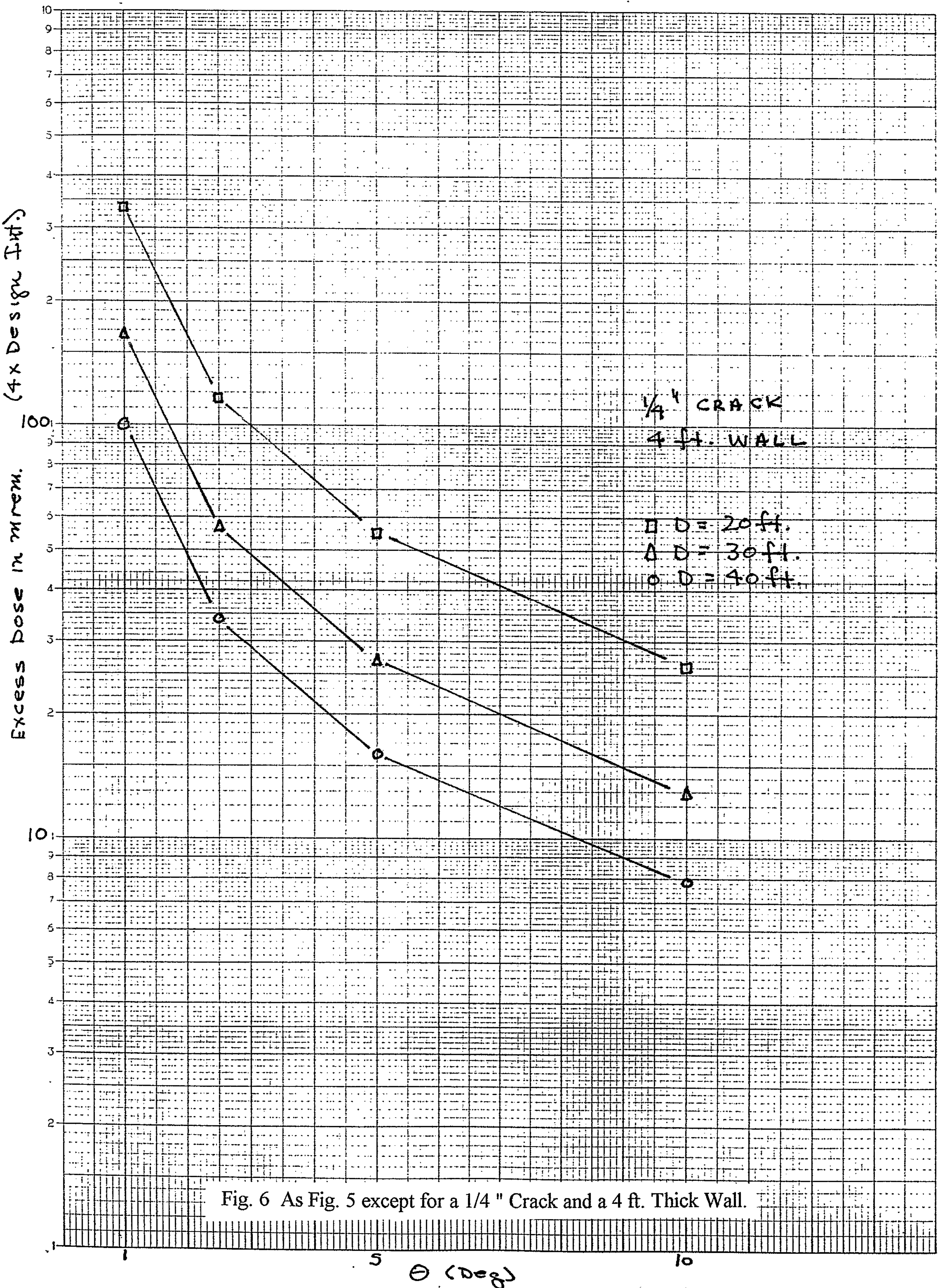

Fig. 6 As Fig. 5 except for a 1/4 " Crack and a 4 ft. Thick Wall.

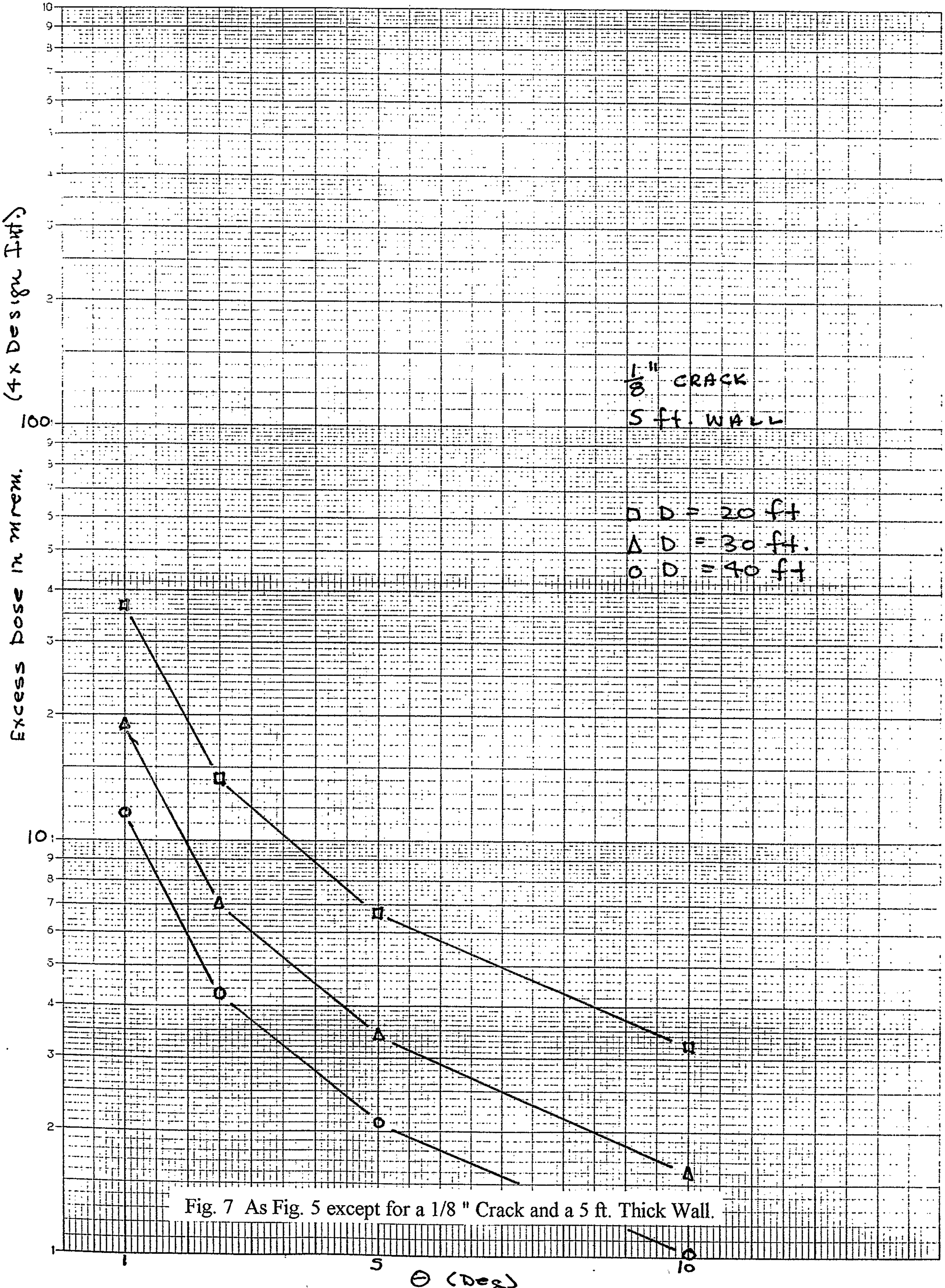

Fig. 7 As Fig. 5 except for a 1/8 " Crack and a 5 ft. Thick Wall.

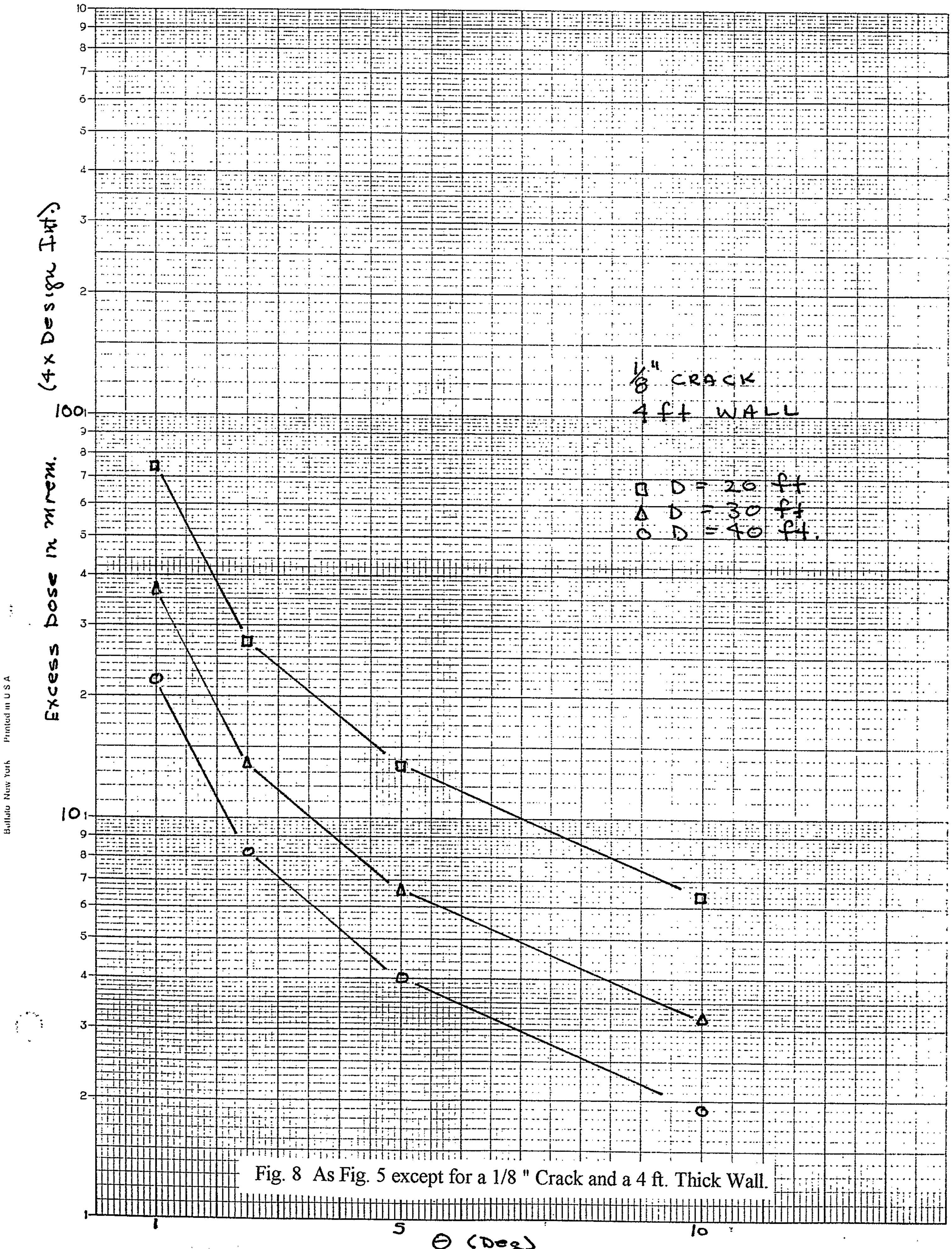

Fig. 8 As Fig. 5 except for a 1/8 " Crack and a 4 ft. Thick Wall.