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TECHNICAL REPORT ECOM C-0423-1

GASEOUS PLUME DIFFUSION CHARACTERISTICS WITHIN MODEL PEG CANOPIES

TASK IIB RESEARCH TECHNICAL REPORT

DESERET TEST CENTER

BY

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SEPTEMBER 1968

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UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH, N. J.

CONTRACT DAAB07-63-C-0423
FLUID DYNAMICS AND DIFFUSION LABORATORY
FLUID MECHANICS PROGRAM
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Technical Report ECOM C-0423-1 September 1968

Wind Tunnel Studies and Simulations of Turbulent Shear Flows Related to Atmospheric Science and Associated Technologies

TECHNICAL REPORT

GASEOUS PLUME DIFFUSION CHARACTERISTICS WITHIN MODEL PEG CANOPIES

TASK IIB RESEARCH TECHNICAL REPORT
DESERET TEST CENTER

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CER68-69RNM-DK-TY-3

ABSTRACT

A point source of an air-helium mixture was released continuously at various positions within a simulated canopy composed of 9 cm high pegs, 0.48 cm diameter, spaced in several arrays (2.54 x 2.54, 3.55 x 3.55, and 5.08 x 5.08 cm). Variations of the vertical location of the source revealed the strongly nonisotropic character of diffusion within a canopy with respect to the relative diffusion rates in the lateral and vertical directions. When the source was placed at various downstream distances from the edge of the canopy, it displayed a tendency to exhale the plume near the front of the model canopy and to inhale the plume at distances further downstream. Calculations of the turbulent diffusion coefficient, K, within and above the canopy from the experimental data, reveal both a constant region and a region of linear increase with height increase as suggested by previous authors.

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GASEOUS PLUME DIFFUSION CHARACTERISTICS WITHIN MODEL PEG CANOPIES

by

R. N. Meroney*, D. Kesic**
and T. Yamada**

INTRODUCTION

Agricultural meteorologists, atmospheric scientists, and many hydrologists are interested in the evaporation and exchange processes which occur in vegetative canopies. Such information permits calculation of the efficiency of water, energy, and CO_2 transport in plant metabolism and the penetration of foreign additives into or their escape out of the bulk of a canopy. As early as 1937 experimenters have made measurements of velocity, temperature, evaporation rates, and energy balance within and above such configurations [1, 2, 3, 4] These measurements have provided a rough picture of a highly complex and turbulent flow field within the vegetation. Today, there exists a definite need for more elaborate and extensive measurements for different types of simple geometry crops.

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Past measurements of diffusion from point or line sources in such configurations seem to have been limited to measurements of an instantaneous line source by Bendix[5] over a tropical rain forest, of point and line source distributions over a deciduous forest by Litton Systems,[15] of instanteous point sources in a jungle-like deciduous forest by Melpar,[16] and of rates of particulate dispersion in a forest canopy at Brookhaven.[6] These measurements are extensive and well documented; however, they must be normalized to some simplified geometry in order to determine the universal characteristics and governing parameters of vegetative penetration by a diffusing plume.

Since field measurements are not easy to obtain because of the cost of providing a perfect measuring station and the difficulty of obtaining cooperative weather, a laboratory program of modeling the flow in and above plant covers has been initiated at the Fluid Dynamics and Diffusion Laboratory at Colorado State University. Previous results from this program have been published by Quarishi and Plate, Yano, Hsi and Nath, and Kawatani.[7,8,17,18]

The purpose of this report is to discuss some measurements of diffusion from a continuous point source in and above a model peg canopy. The results of this study will consist of:

1) A description of the diffusion processes in and above the simulated canopy,

2) A description of the vertical dispersion of the tracer materials,

3) A determination of the effect of the initial fetch of the peg canopy on tracer dispersion, and, finally,

4) A determination of the vertical distribution of the eddy diffusion coefficients in and above the modeled canopy.

MODELING OF A VEGETATIVE CANOPY

The wind tunnel, long a research tool of the aerodynamicist, has recently proven its worth in atmospheric science through the success of an extensive sequence of programs to study modeling feasibility for micro-meteorological research.[9, 10] As a result, it is now possible, for those conditions where Coriolis effects are secondary, to model many important features of the atmosphere. Suggestions concerning the applicable modeling criteria for vegetative canopies have been made by Quarishi and Plate.[7]

The intent of this program was to scale the nature of gaseous plume penetration at different points above a model crop, to determine the dispersion characteristics of a plume in such circumstances, and then to calculate and compare eddy diffusion coefficients with prototype data. Rather than model specifically all the complex characteristics of a live vegetative cover, it was proposed to retain the character of the flow while avoiding its minute complexity. Hence, short dowel pegs, approximately 0. 5 cm in diameter and 9 cm long, were chosen as model elements and arranged in various geometrical patterns. This rough boundary arrangement produced turbulent flow at even small velocities; a constant drag coefficient, independent of wind speed*; and, hence, a flow independent of Reynolds' number.

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*Measurements of canopy drag force were made by a shear plate described in Army Quarterly Report No. 11, 1 Nov 67-31 Jan 68, grant DA-AMC-28-043065-G20.

A logarithmic velocity profile similar to that typically found in the vertically stratified atmospheric boundary layer was reproduced in the wind tunnel by an upstream fetch of 20 meters of test section floor. It has been repeatedly shown that such an upstream boundary condition is critical for the quivalent kinematic character of a modeled flowfield.[9, 10, 19]

A careful study of the mean velocity profiles, turbulent intensities and shear stress in and above the model peg canopy has been completed by Kawatani.[18] These data were compared with prototype measurements in forests and agricultural crops. The marked functional agreement between the dynamic and kinematic behavior of the peg canopies and the live vegetative canopies provided a confirmation of the assumption of general similarity.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

The experimental data were obtained in the low speed Army Meteorological Wind Tunnel in the Fluid Dynamics and Diffusion Laboratory at Colorado State University.[11] This tunnel was specifically designed to study fluid phenomena of the atmosphere. It has a 2 meter square by 26 meter long test section with an adjustable ceiling to provide a zero pressure gradient over the canopy crop. Model elements consisted of 0.48 cm diameter by 9 cm long dowel pegs inserted in holes in aluminum plate sections and arranged in geometric arrays the width of the test section extending for 11 meters downstream from the middle of the length dimension of the tunnel. All the various arrangements studied are summarized in Fig. 1.

A single and a cross-wire constant temperature anemometer was used to measure velocity, turbulent intensity, and shear. In addition, pitot-static tube measurements were made at each section. The sending elements of the anemometer circuit were platinum wire 0.2 mil in diameter and approximately 0.25 cm long. The bridge circuit utilized was a CSU Solid State Anemometer and the pitot tube output went to a Transonic Model A, Type 120 electronic pressure meter. Turbulence signals were interpreted by means of a CSU designed sum and difference circuit and a Bruel and Kjaer RMS meter, Model 2416.

Helium gas was used as a tracer for the turbulent diffusion experiments. The gas was released continuously at a constant rate of 630 cc/min from a 2 mm nozzle located in or above the canopy. The sampling probe, manufactured from small diameter hypodermic tubing, was mounted on a traversing carriage, the horizontal and vertical positions of which were controlled remotely from outside the tunnel. Helium concentration was measured at ground level along a line normal to the axis of the plume and vertically at the plume centerline.

Samples were drawn into the probe at a constant rate and passed over a standard leak into a mass spectrometer (Model MS9AB of the Vacuum Electronic Corporation). Output of the mass spectrometer was an electrical voltage proportional to concentration. The mass spectrometer was calibrated periodically be a set of pre-mixed gases of research grade. Fig. 2 shows the experimental arrangment.

Since a closed-circuit wind tunnel was used, the ambient concentration level of helium built up in the wind tunnel with time. Eventually, most of the gas did leak out; therefore the amount of helium in the ambient flow was never higher than 60 parts per million. Nevertheless, an ambient concentration measurement was taken after each profile. The relative concentration was obtained by subtracting the corresponding ambient concentration from the absolute concentration. All data presented in the figures or tables are relative concentrations.

Due to the slow response of the mass spectrometer, a period of one to two minutes was allocated for the stabilization of each reading before it was recorded. Usually, the concentration signal itself was averaged over at least 60 seconds. This method gave results that compared favorable with the average of signals taken over a period as long as 250 seconds by graphical means.

EXPERIMENTAL RESULTS

All measurements were taken at a free stream velocity of 12 m/sec. The ceiling of the test section was adjusted for zero pressure gradient, and the upstream velocity profile was measured and found to be logarithmic. And, because the temperature condition was constant, neutral stability existed.

1. Typical Velocity, Streamline, and Shear Results

Velocity and shear measurements have been compiled for pegs positioned in 1.27 x 1.27 cm diagonal, 2.54 x 2.54 cm square, 2.54 x 2.54 cm diagonal and 5.08 x 5.08 cm square arrays. In the downwind direction, the typical transformations of the wind profiles in the vertical direction are shown in Figs. 3 and 4 for flow in and above the crop respectively. Velocity profiles within the canopy agree qualitatively with prototype measurements,[1,2,3,4] and approximate the exponential profiles suggested by Inoue, Saito and Cionco, (et al).[2,12,13] The profiles above the canopy are logarithmic and follow the displacement law $u/u^* = 1/k \, \ell n \left[(y-d)/z_o\right]$ utilized for rough surfaces since the time of Rossby and Montgomery (1935).

Typical intensity and shear profiles shown in Figs. 5, 6 and 7 indicate the growth of the inner boundary layer over the rough surface. The shear profile growth compares favorably with the measurements of transition made by Schlichting for flow from a smooth to a rough surface.[14] Values of intensity from 0.5 to 0.8 within the canopy correspond to field measurements in crops and forests but suggest that a linearized interpretation of the hot-wire anemometer output is extremely doubtful. Hence, measurements of velocity, intensity or shear may err as much as 20% at the lower velocities.

Streamline calculations over the model canopy as shown in Fig. 8 indicate the tendency for the approach flow to initially accelerate upward away from the floor and then to subsequently re-penetrate the canopy ceiling. This flow behavior was also evidenced in the diffusion measurements. It was concluded that the flow field was probably quasi-established within 60 h of the inception of the canopy. The dynamic behavior of the flow over the peg canopies is described in greater detail in Reference 18.

2. Diffusion Plume Results

Diffusion measurements were made over pegs positioned in the 2.54 x 2.54 cm square, 2.54 x 2.54 cm diagonal (3.60 x 3.60 cm) and 5.08 x 5.08 cm square arrays (see Table I). The plume source was located either at the canopy inception ($x_s = 0$) or six meters downstream ($x_s = 6$ m). It was located at various times at heights of 1cm, 4.5 cm, 9 cm and 13.5 cm ($z_s = 1$ cm, h/2, h, 3/2 h). Vertical and horizontal traverses along the plume were made at varying distances downstream.

Source and sampling tube locations studied are summarized in Table 1. The most extensive data are available for the 2.54 x 2.54 diagonal (or center filled square) matrix. Unfortunately, the program of diffusion measurements was instituted some time after the inception of the dynamic measurements (mean velocity, turbulence, etc.), and therefore only a limited number of data are presented for the other peg matrices.

Figures 9 to 18 display the longitudinal variation of the vertical profiles for the 2.54 x 2.54 cm peg matrix. Figures 15 to 27 display the longitudinal variation of the vertical profiles for the 2.54 x 2.54 cm diagonal peg matrix. The lateral profiles for the 2.54 x 2.54, 2.54 d x 2.54 d and the 5.08 x 5.08 cm peg matrices are displayed as isoconcentration lines on Figs. 37-38, 39-40 and 41-42, respectively.

The more extensive concentration data for the 2.54 x 2.54 diagonal peg matrix have been converted into isoconcentration profiles for a longitudinal section along the plume centerline. Figures 30 to 32 indicate the tendency of a point source to exhale out of the canopy when the source is located at half canopy height or above and near the inception of the vegetative cover. Farther downstream, the plume tends to dip down into the vegetative cover when released above the canopy, as is shown in Figures 33 to 36.

Figures 28 and 29 show how the plume maximum concentration rises abruptly upward at the canopy inception and subsequently is displaced downward slightly as the flow re-penetrates the canopy ceiling. In the same figures, the maximum concentration line is compared with the meandering of the streamlines passing through the source position.

TABLE I

Summary of Data Collection Program

Peg Array	Source Release x_s m	Source Release z_s cm	Vertical profiles at longitudinal distances x m	Longitudinal distances at which lateral profiles measured m
2.54 x 2.54 cm	0	0	0.3, 0.6, 0.9	
		4.5	0.3, 0.6, 0.9	
		9.0	0.3, 0.6, 0.9	
	6	1.0	0.3, 0.6	0.3
		9.0	0.3, 0.6	0.3
		18.0	0.3, 0.6	
3.60 x 3.60 (2.54 x 2.54 diagonal)	0	1.0	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	
		4.5	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	
		9.0	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	
	6	1.0	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	0.25
		4.5	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	
		9.0	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	0.50
		13.5	0.25, 0.5, 0.75, 1.0, 1.5, 7.0, 7.5	
5.08 x 5.08	0	1.0	0.3, 0.6	0.3, 0.6
		9.0	0.3, 0.6	0.3, 0.6

The consequences of this effect on crop dusting penetration are obvious. Yano has suggested this effect may be accelerated by differences in eddy diffusion coefficient profiles; however, calculations of K from velocity data do not suggest that any large changes do occur.[8] It was found that the vertical position of the maximum concentration of plumes released at $x_s = 6$ m tended to drift downward. This is probably a joint effect of streamline repenetration and the gradient in K.

The growth in the characteristic width of the vertical dispersion of a continuous point source plume has frequently been found to be proportional to a power function of the longitudinal downstream distance, x^n. Similarly, it is generally observed that the maximum concentration at ground level decreases at a rate proportional to x^{-m}. For a plume dispersing in or above the vegetative canopy, the rate of dispersal appears to be a function of the fetch distance from the canopy inception position (see Table II). This marked variation is evident near the canopy edge as is shown in Figs. 43 and 44. These rates of dispersion may be compared with values of $x^{0.7}$ and $x^{-1.5}$ for plumes dispersing over a smooth surface.[20]

The nonisotropic character of the horizontal versus vertical plume dispersal is evident in cross-sections of the plume plotted as isoconcentration lines (see Figs. 37 to 42). For a source located

TABLE II

Coefficients of Concentration Dispersal Rate for Canopy*

x_s	n	-m
0	1.66	3.6
6	1.42	2.5

*2.54 x 2.54 diagonal case

z_s = 1 cm only

within the canopy, lateral diffusion is very strong, while for a source at the top of the canopy, vertical dispersion predominates. Rapid diffusion in the vertical direction is very evident within the canopy since gradients in concentration are quickly reduced to a uniform vertical distribution.

3. Eddy Diffusion Coefficient

The concept of a macroscopic equation of turbulent dispersion of some property C results generally in the equation

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x_i}(u_i C) = \frac{\partial}{\partial x_i}\left(K_{x_i}\frac{\partial C}{\partial x_i}\right) \tag{1}$$

where K_{x_i} is the coefficient of turbulent diffusion. The coefficient K_{x_i} incorporates within itself the complexities of the actual transport process. Hence, most analytical studies of fluid mechanics require some theoretical or empirical expression for the variation of K_{x_i} with other parameters. Several scientists have studied the nature of K_{x_i} for plant communities, but further data are still needed.[1, 2, 3, 8, 12, 13]

The eddy diffusion coefficient for transport of the injected gas in the model canopy has been determined utilizing concentration and velocity profiles and a finite difference interpretation of Equation (1). In order to accomplish the calculations with the limited data, it was assumed that K_y and K_z were equal at all levels. Calculations were performed on a CDC 6400 computer at Colorado State University using input data taken from lines fared through the concentration measurements, from vertical velocities calculated from the slope of streamlines, and from the following equation:

$$K(x, z) = \frac{u\left(\frac{\partial C}{\partial x}\right) + v\left(\frac{\partial C}{\partial z}\right) + \left(4K(x, z-\Delta z) - K(x, z - 2\Delta z)\right)\left(\frac{\partial C}{\partial z}\right)}{\left(\frac{\partial^2 C}{\partial z^2}\right) + \frac{1.5}{\Delta z}\left(\frac{\partial C}{\partial z}\right)} \tag{2}$$

The resulting profiles in K(z) are displayed on Fig. 45. Three distinct regions of variation of K are noticeable. Immediately adjacent to the wall is a zone where K increases exponentially. In the area from 2 to 5 cm, K remains essentially constant; and, finally, K increases linearly with z in the region beyond 5 cm.

A number of authors have suggested that K should remain constant in vegetative cover; others have suggested that K should vary linearly.[2,3] It is interesting to note that for the case of the model peg canopy, both conditions of K exist, although in different regions. Figure 47 compares the distribution of K within the canopy with typical results of the distribution of K for a corn crop as measured by Uchijima and Wright.[3]

The momentum vertical eddy transport coefficient K_m has been calculated from the velocity and shear data found in Reference 18 by use of

$$K_m = \frac{-\overline{u'w'}}{\left(\frac{du}{dz}\right)} \tag{3}$$

Figure 46 compares the variation of the momentum, K_m and mass K_c eddy diffusion coefficients in and above the artificial canopy. Above the canopy, K becomes proportional to (z-d) where d is a displacement height. Similar behavior has been observed for prototype canopies.[1, 2, 3, 12, 13, 21]

As a result of calculations by Denmead, the eddy diffusivity in a pine forest might also be interpreted to behave in a similar manner.[21] Wright and Lemon reported K distributions in a canopy of corn; however, they reported results in terms of a wind profile classification which does not permit direct comparison.[22] Finally, these K profiles may also be described as qualitatively similar to the peg data.

CONCLUSIONS

It is apparent that the general character of flow in and above vegetative canopies may be satisfactorily simulated in the meteorological wind tunnel. In addition, these new data suggest that even the micro-sctucture transport phenomena behave in a manner similar to that of the prototype. Therefore, it is possible to conclude that:

1) The basic trends of the dynamic and kinematic behavior of a complex vegetative cover may be simulated by a simple porous geometry in a wind tunnel.

2) The initial fetch of the peg canopy affects tracer dispersion of a continuous point source in a unique manner: Vertical convective motions exhale the gases released at the beginning of the canopy, and subsequently, the canopy appears to re-inhale the products farther downstream.

3) The dispersive characteristics of the canopy are non-isotropic. For a source near ground level, lateral mixing is strong; for a source located at the top of the canopy, vertical transport predominates.

4) The eddy diffusion coefficient varies linearly as (z-d) above a vegetative cover and has a growth rate proportional to ku*.

5) The eddy diffusion coefficient, K , within the artificial vegetative cover, appears to develop into three regions: Initially K

grows exponentially, next it remains constant, and, finally, K grows at a linear rate.

6) The experimental law for attenuation of boundary concentration was obtained as $x^{-2.5}$ for gas source releases far from the canopy inception. (Rates of dispersion are somewhat larger near the edge of the vegetative cover.)

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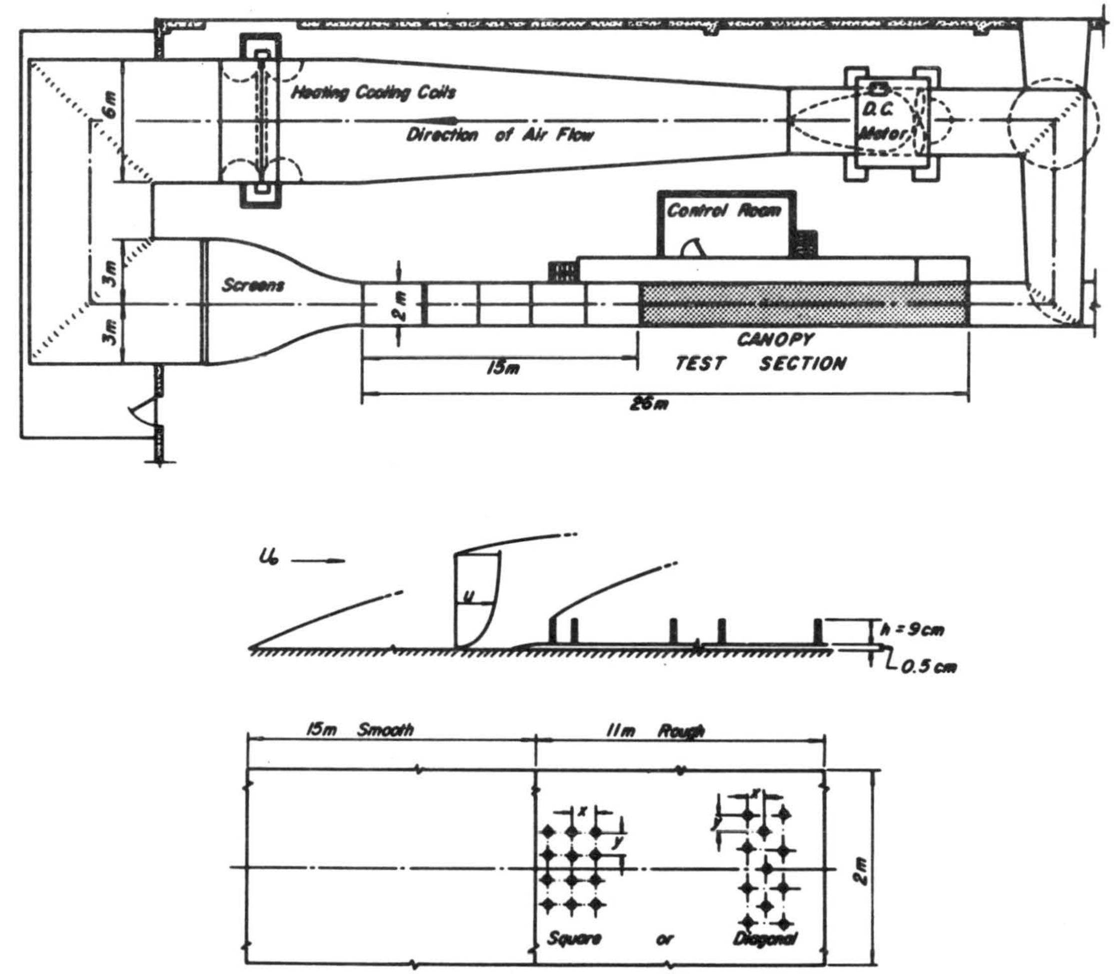


PEG ARRAYS STUDIED

x, cm	y, cm	ARRAY
1.27	1.27	DIAG.
2.54	2.54	SQ.
2.54	2.54	DIAG.
5.08	5.08	SQ.

Fig. 1. Wind tunnel and artificial canopy configuration

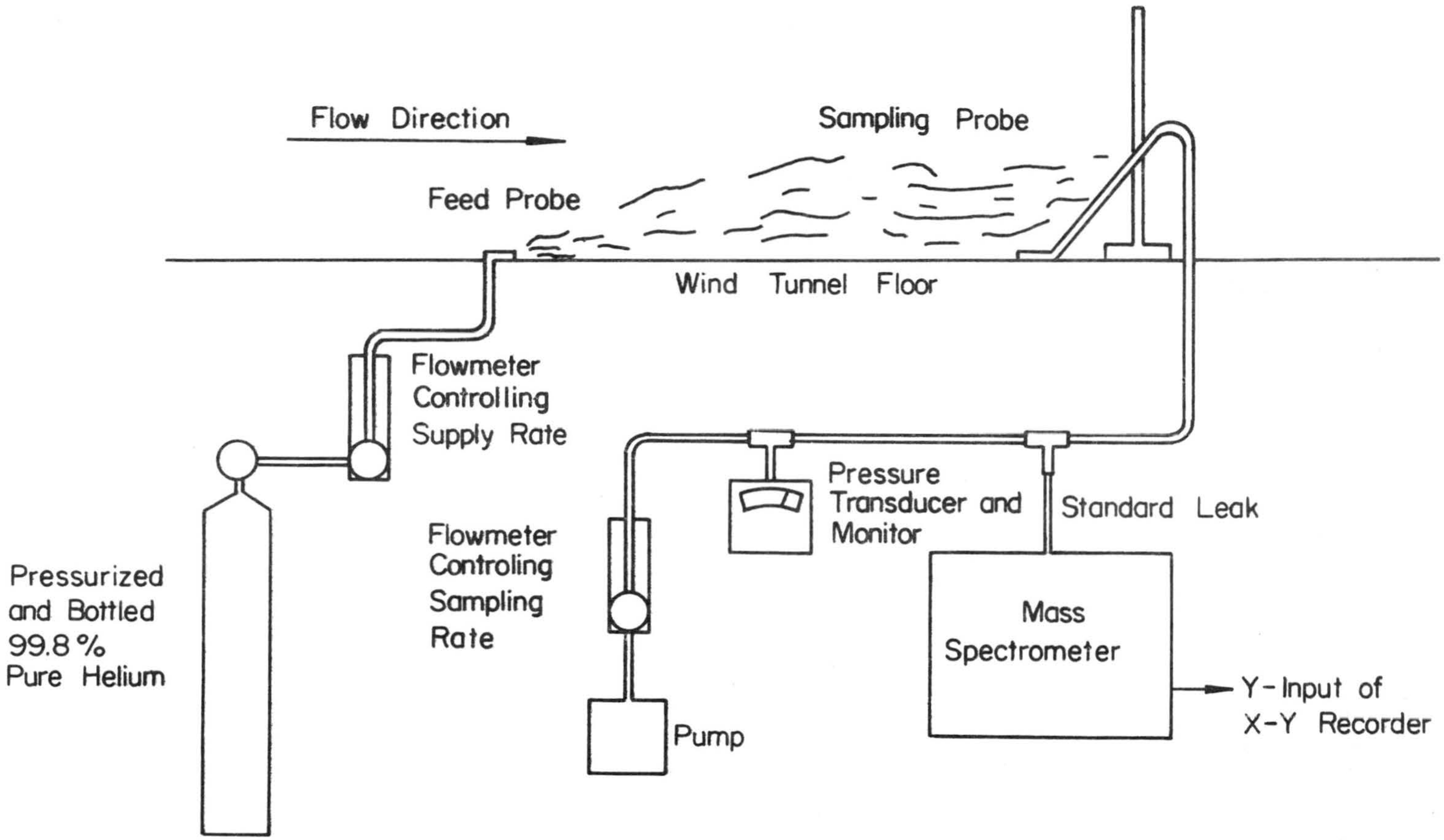
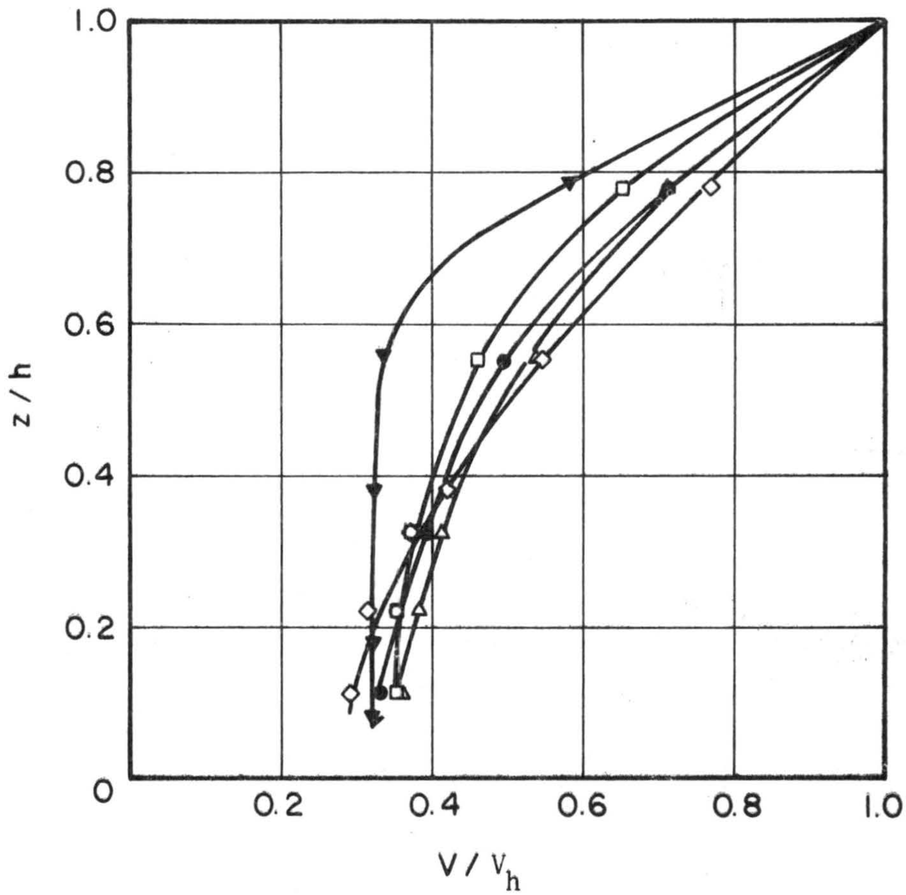


Fig. 2. Continuous point source feed and sampling system



▼ $\frac{x}{h}$ = 11.1 △ $\frac{x}{h}$ = 94.5

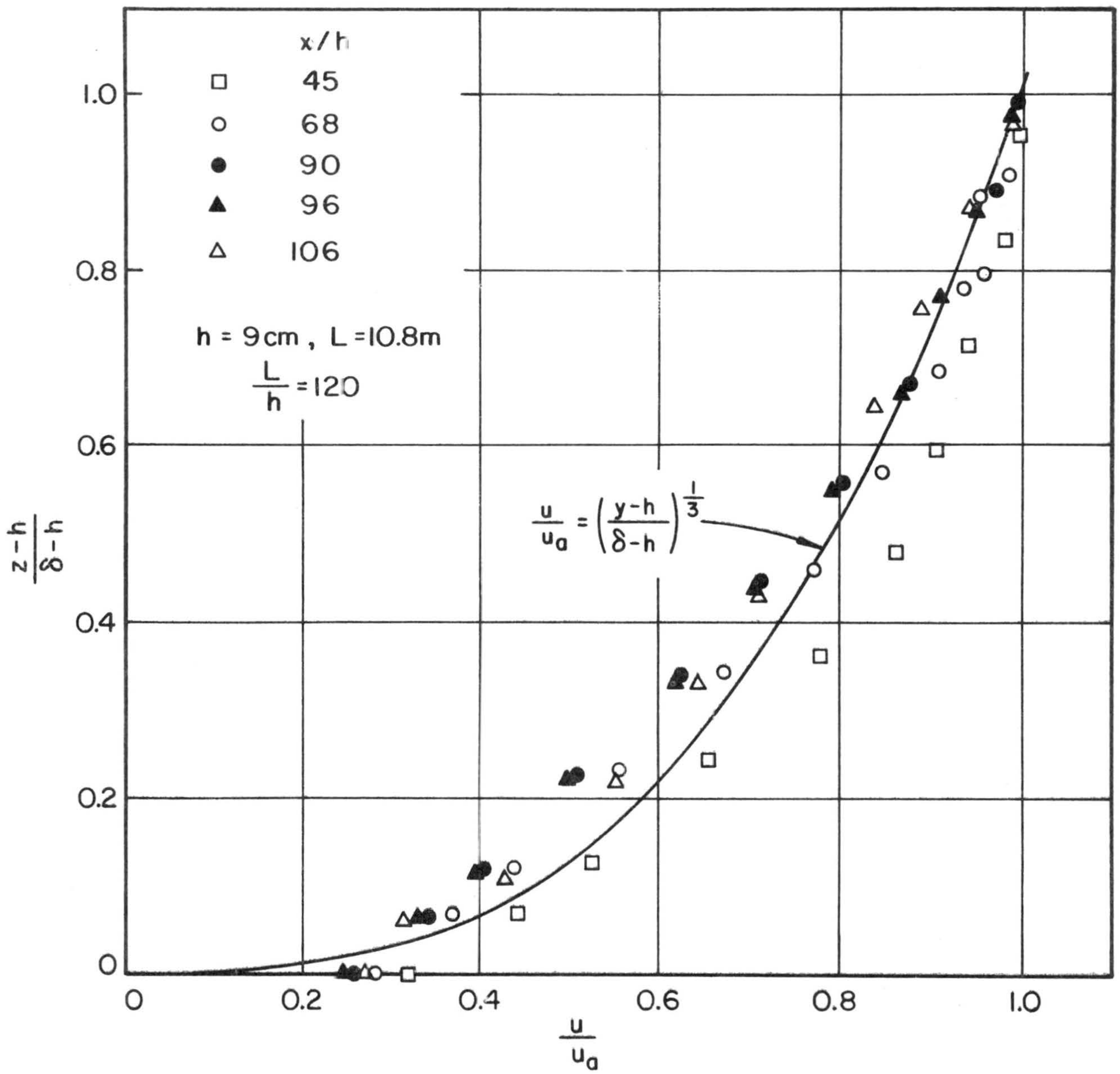
● $\frac{x}{h}$ = 44.4 ◇ $\frac{x}{h}$ = 111.0

□ $\frac{x}{h}$ = 66.7 ~ 83.0

Pegs ϕ = 0.48 cm, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120

Spaced 2.54 x 2.54 cm, V_∞ = 12 m/s

Fig. 3. Velocity profiles within model canopy



Canopy Study: Flow Above Canopy
Pegs ϕ 0.48, Spaced 2.54 x 2.54 cm

Fig. 4. Velocity profiles above model canopy

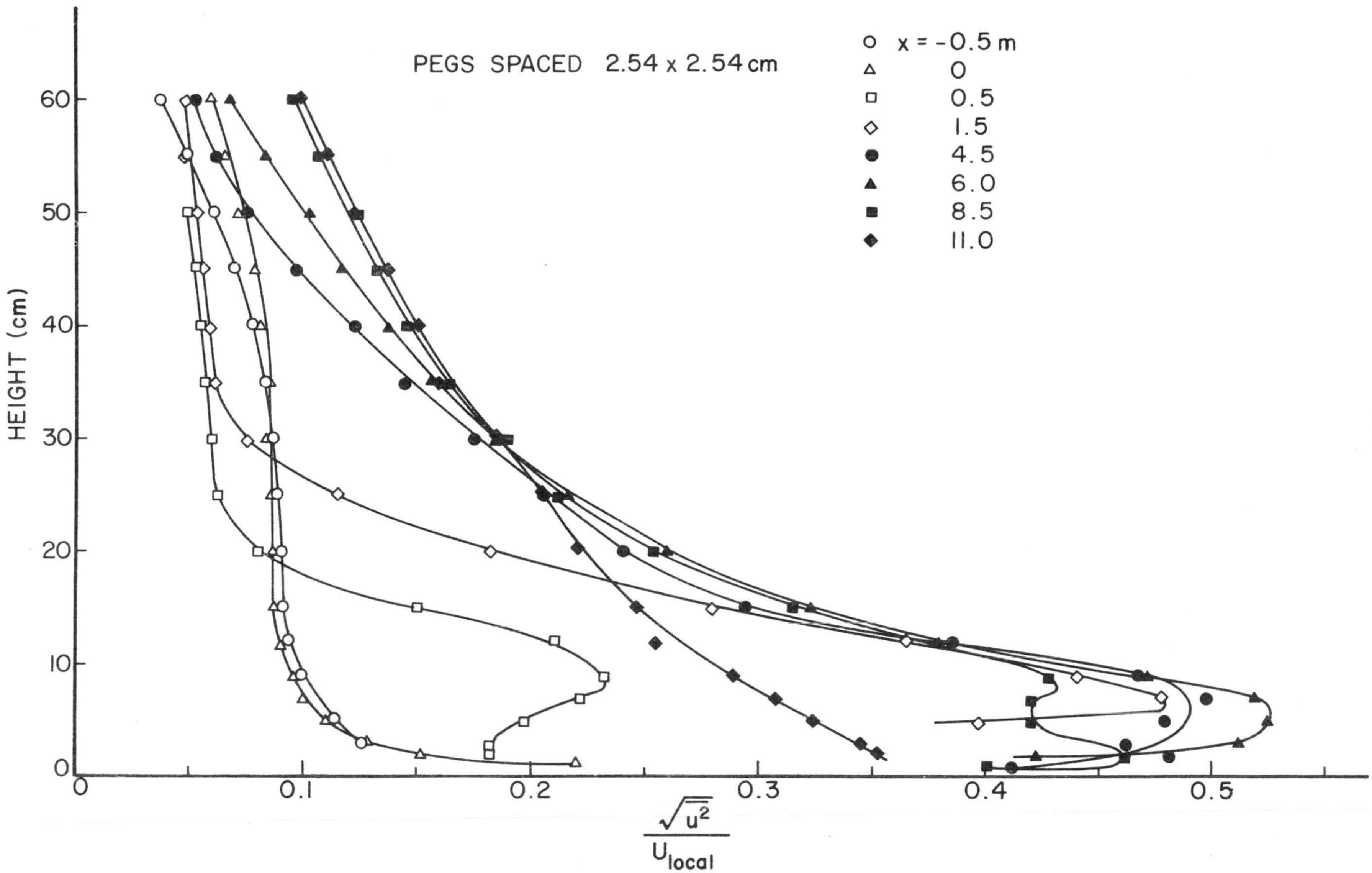


Fig. 5. Longitudinal turbulent intensity for model canopy

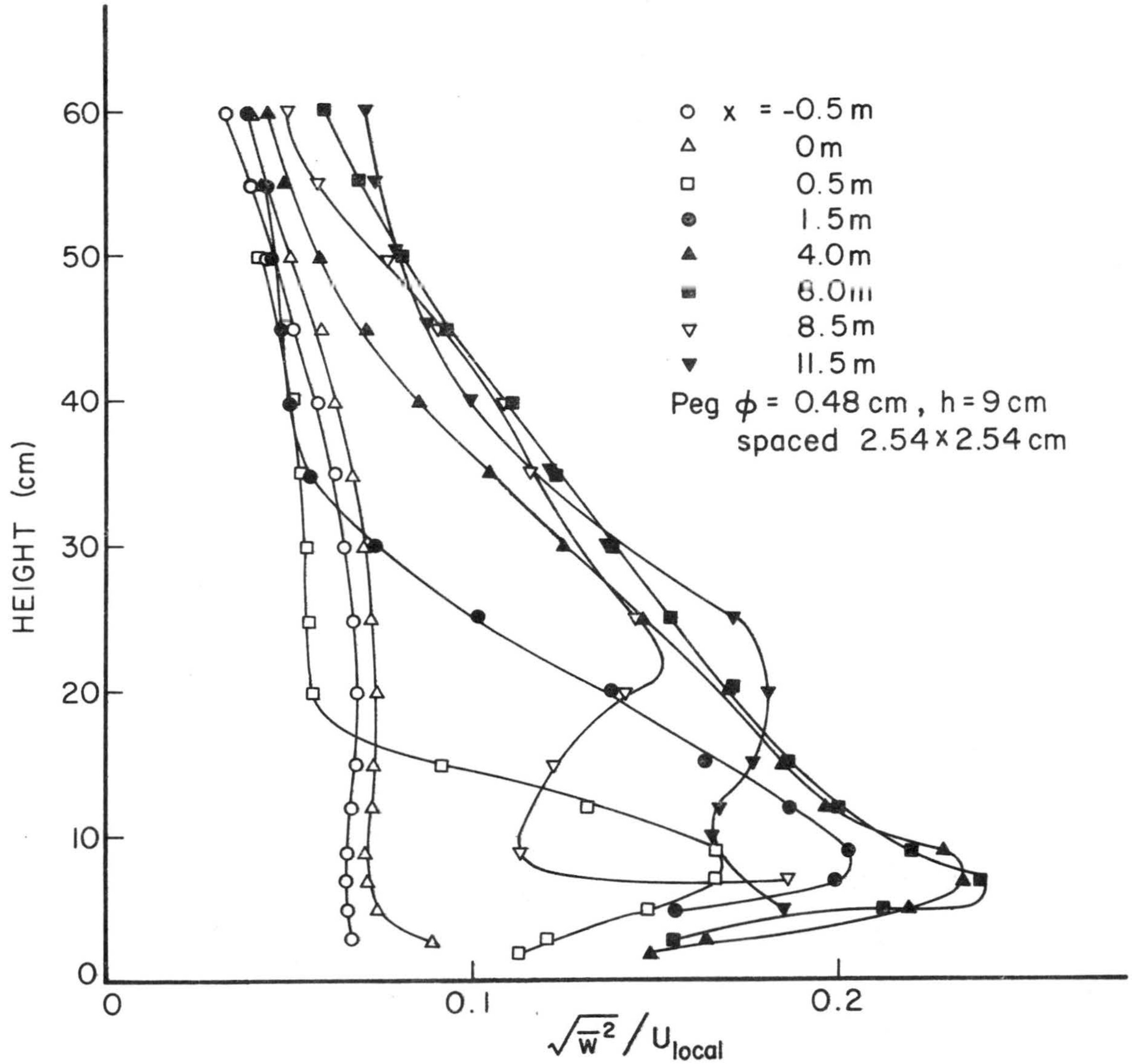


Fig. 6. Vertical turbulent intensity for model canopy

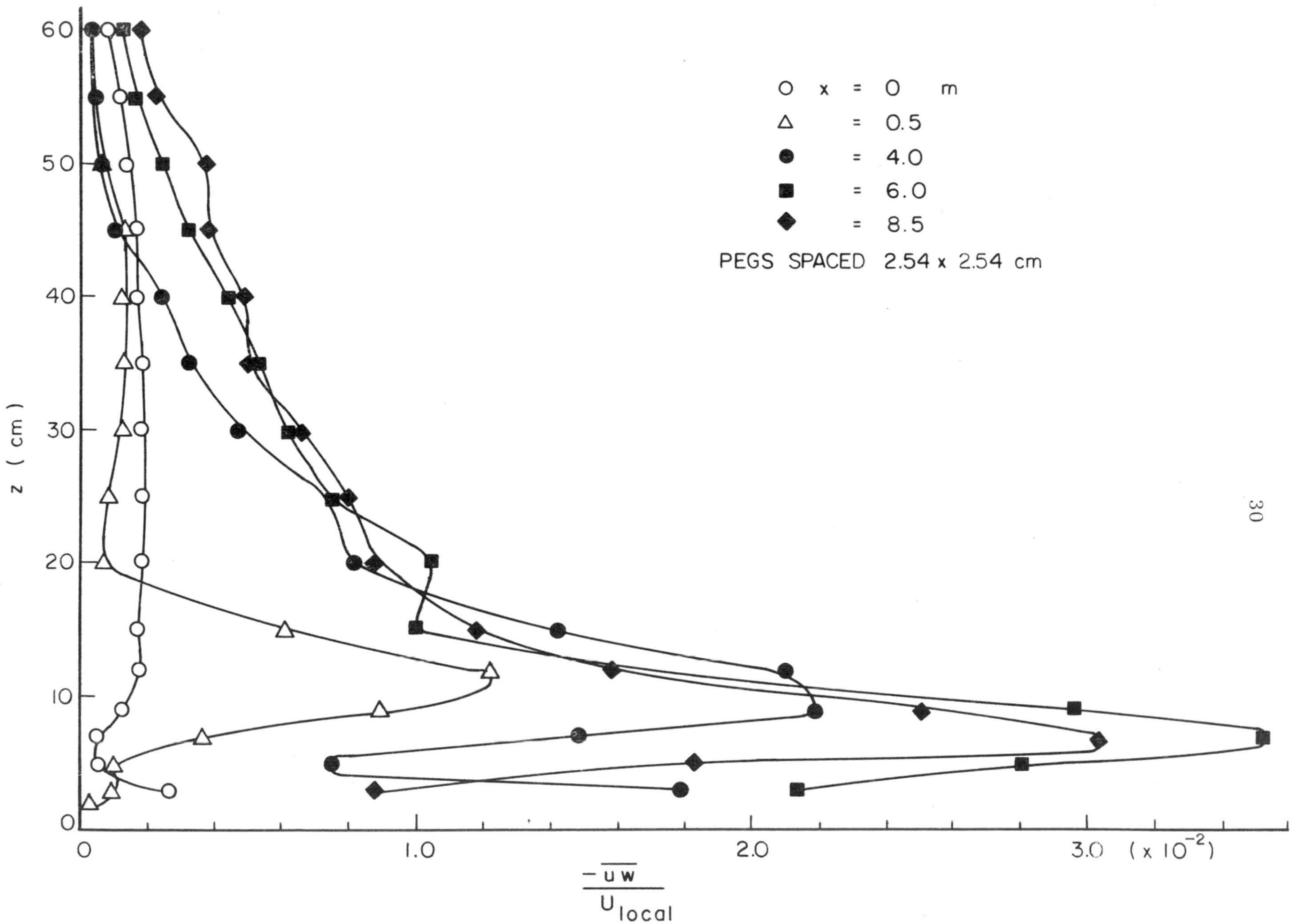


Fig. 7. Shear profile for model canopy

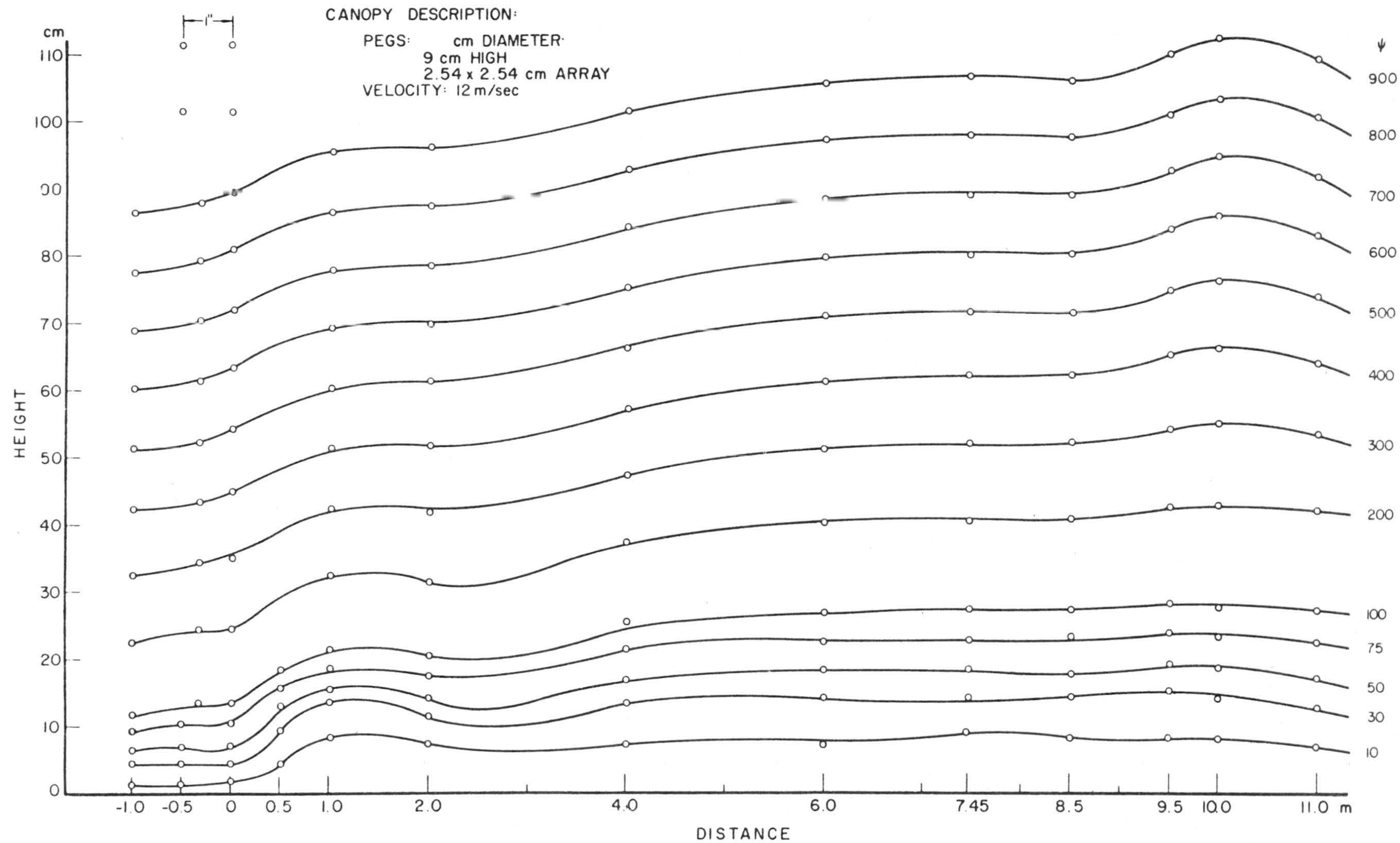


Fig. 8. Streamline flow in and above a model canopy

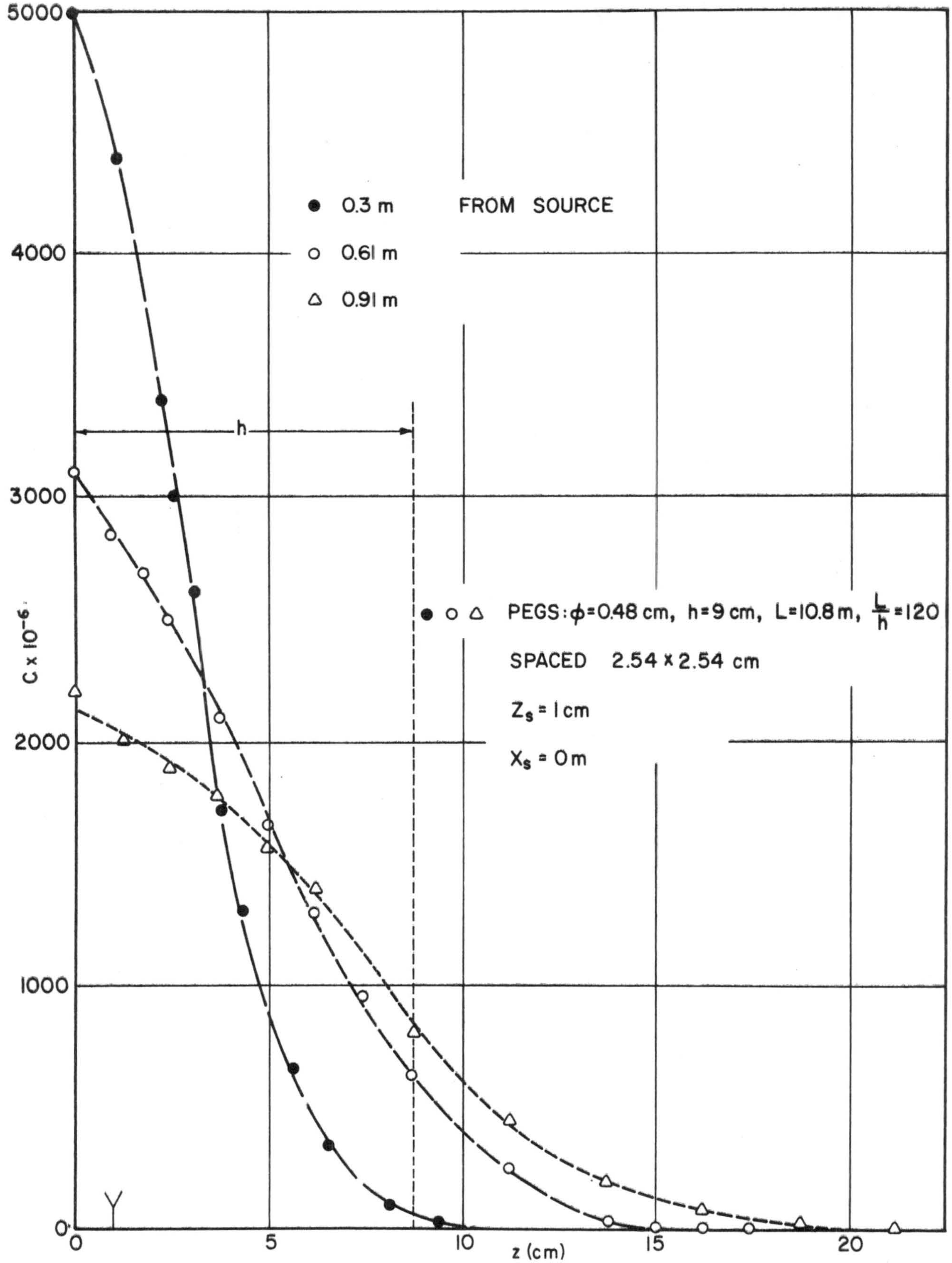


Fig. 9. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). $x_s = 0$, $z_s = 1$ cm

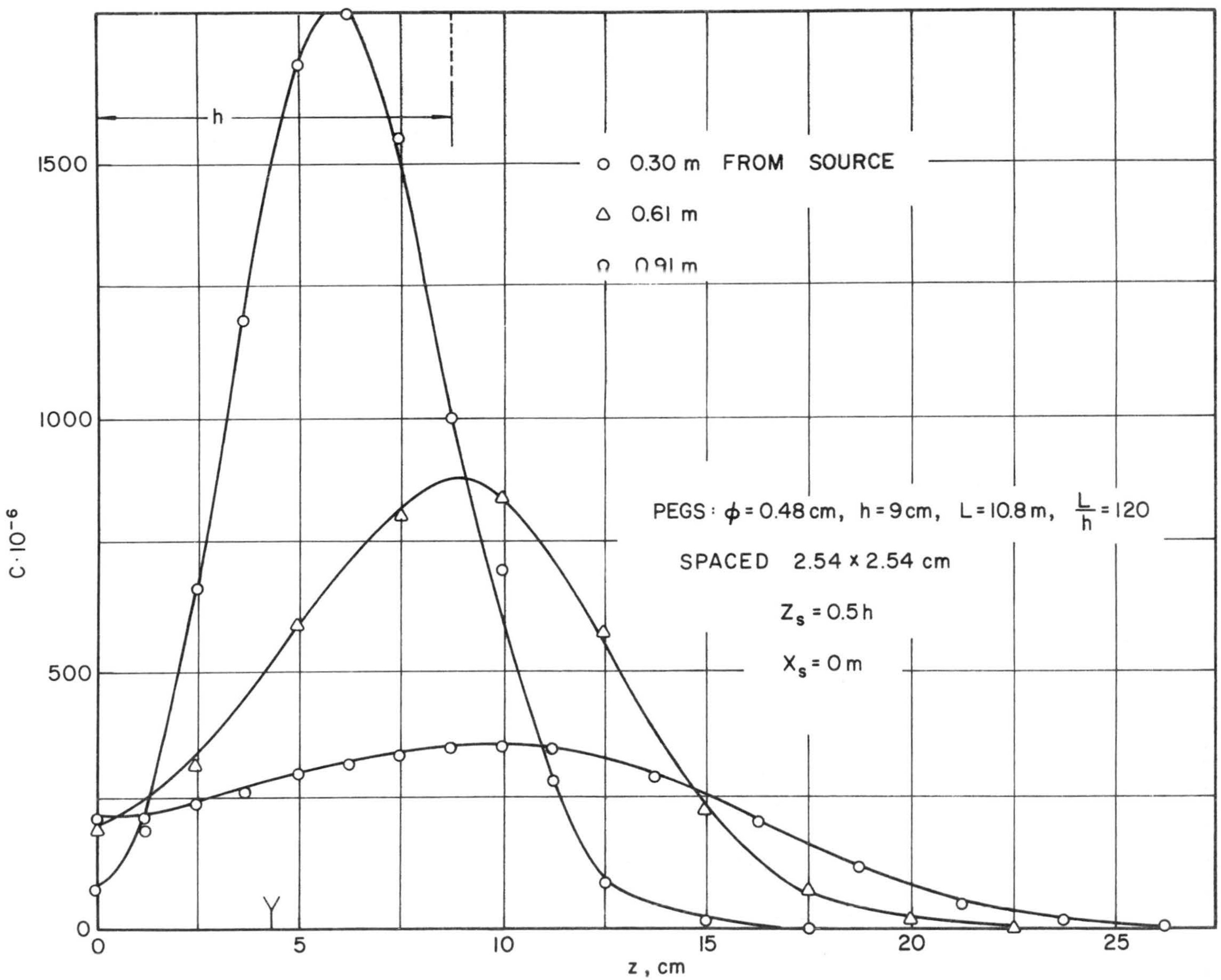


Fig. 10. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). $x_s = 0$, $z_s = 0.5$ h

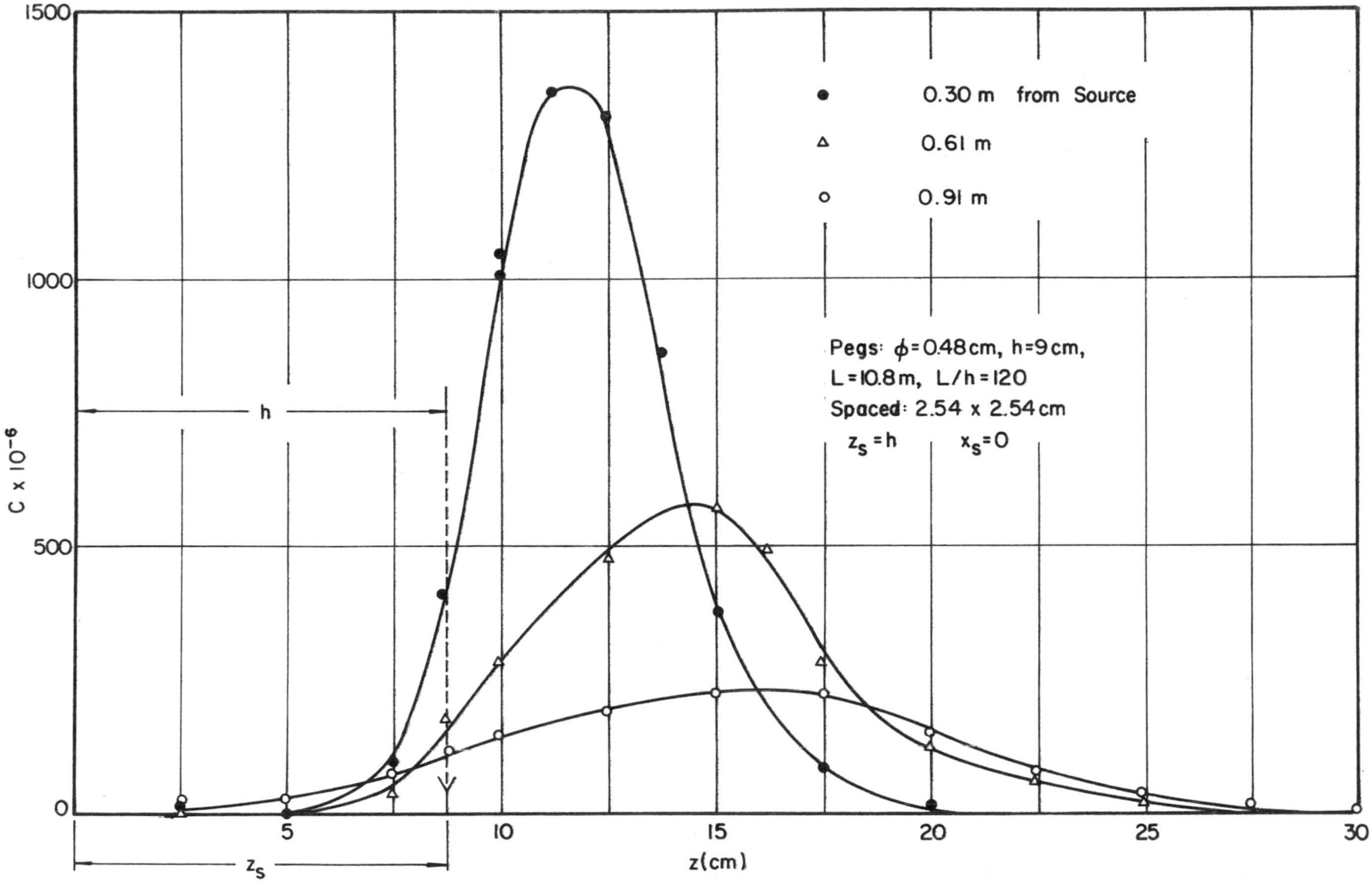


Fig. 11. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). $x_s = 0$, $z_s = h$

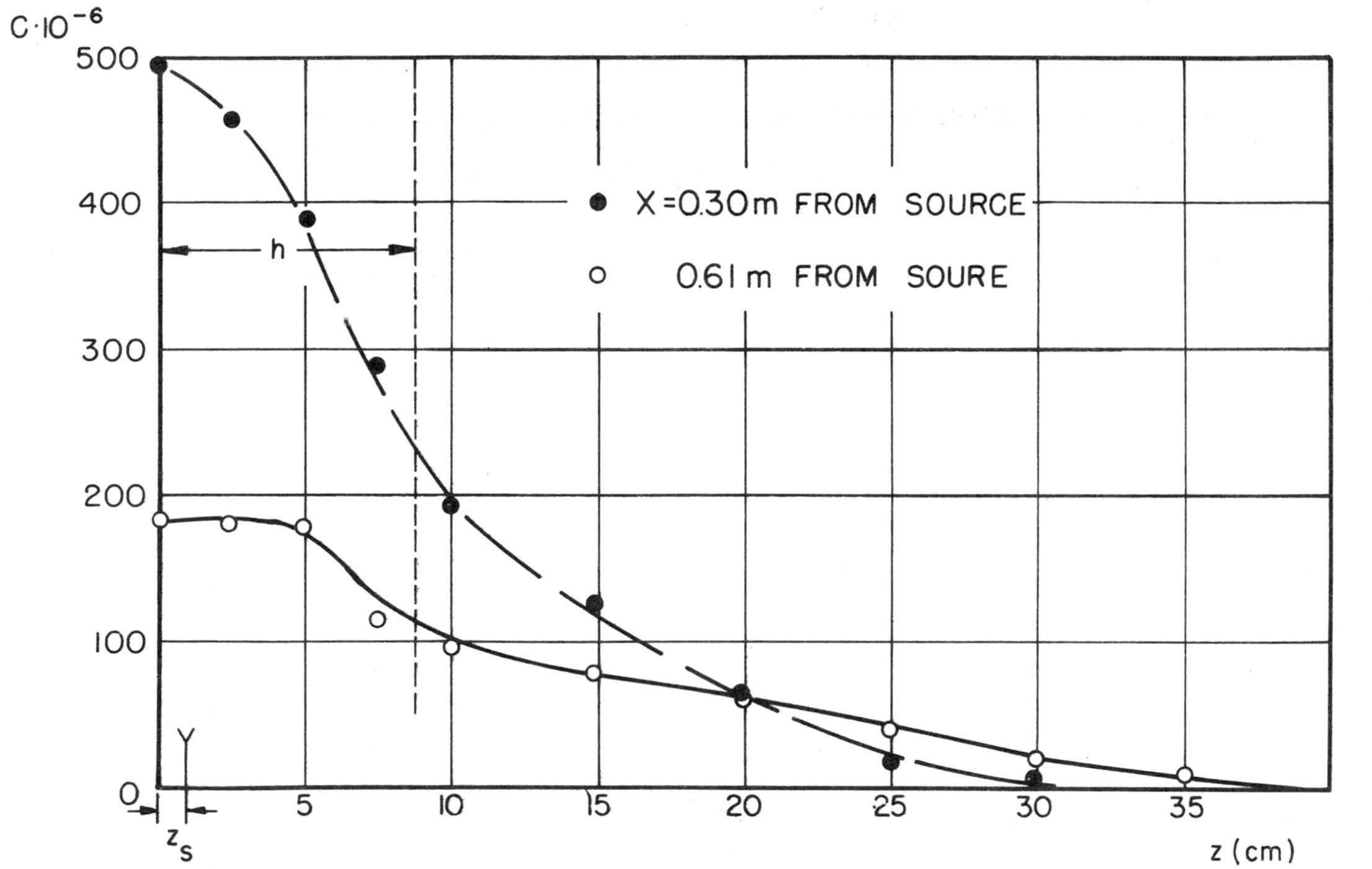


Fig. 12. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = 1 cm

PEGS: ϕ = 0.48cm, h = 9cm, L = 10.8m, $\frac{L}{h}$ = 120, SPACED 2.54 x 2.54 cm

Z_s = 1 cm

X_s = 6

V_∞ = 12 m/sec

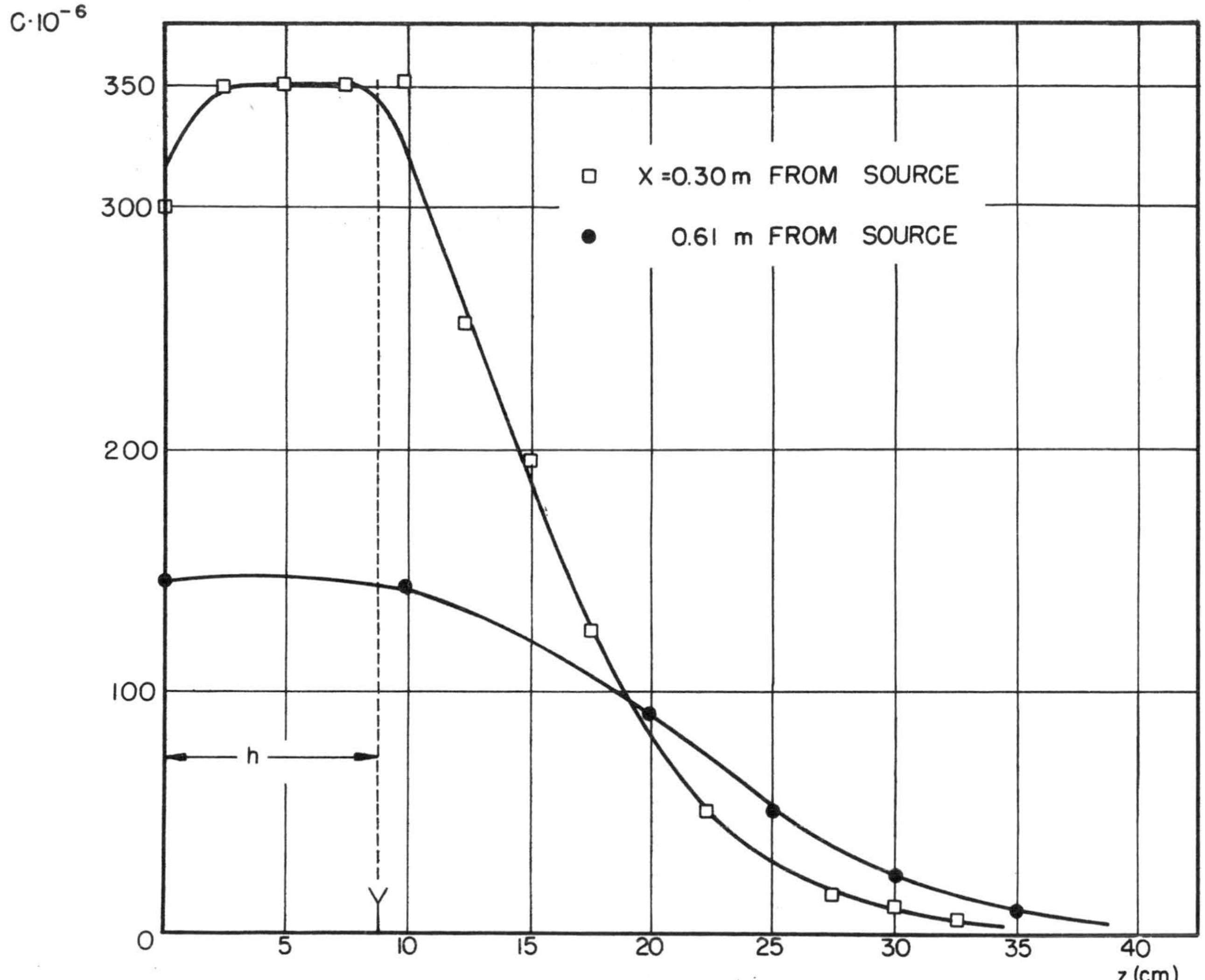


Fig. 13. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = h

PEGS: ϕ = 0.48 cm, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120, SPACED 2.54 x 2.54 cm

Z_s = h V_∞ = 12 m/sec

X_s = 6 m

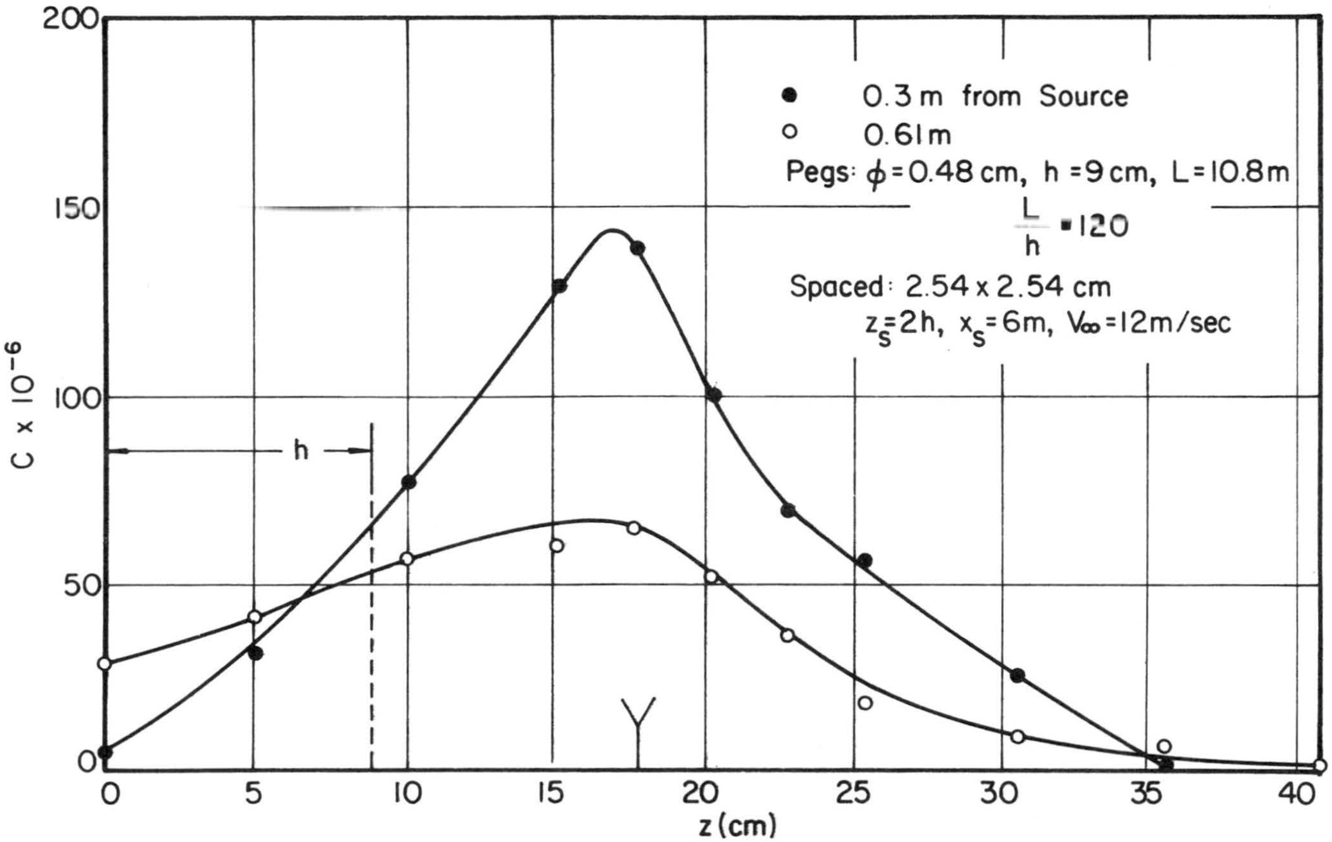


Fig. 14. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = 2 h

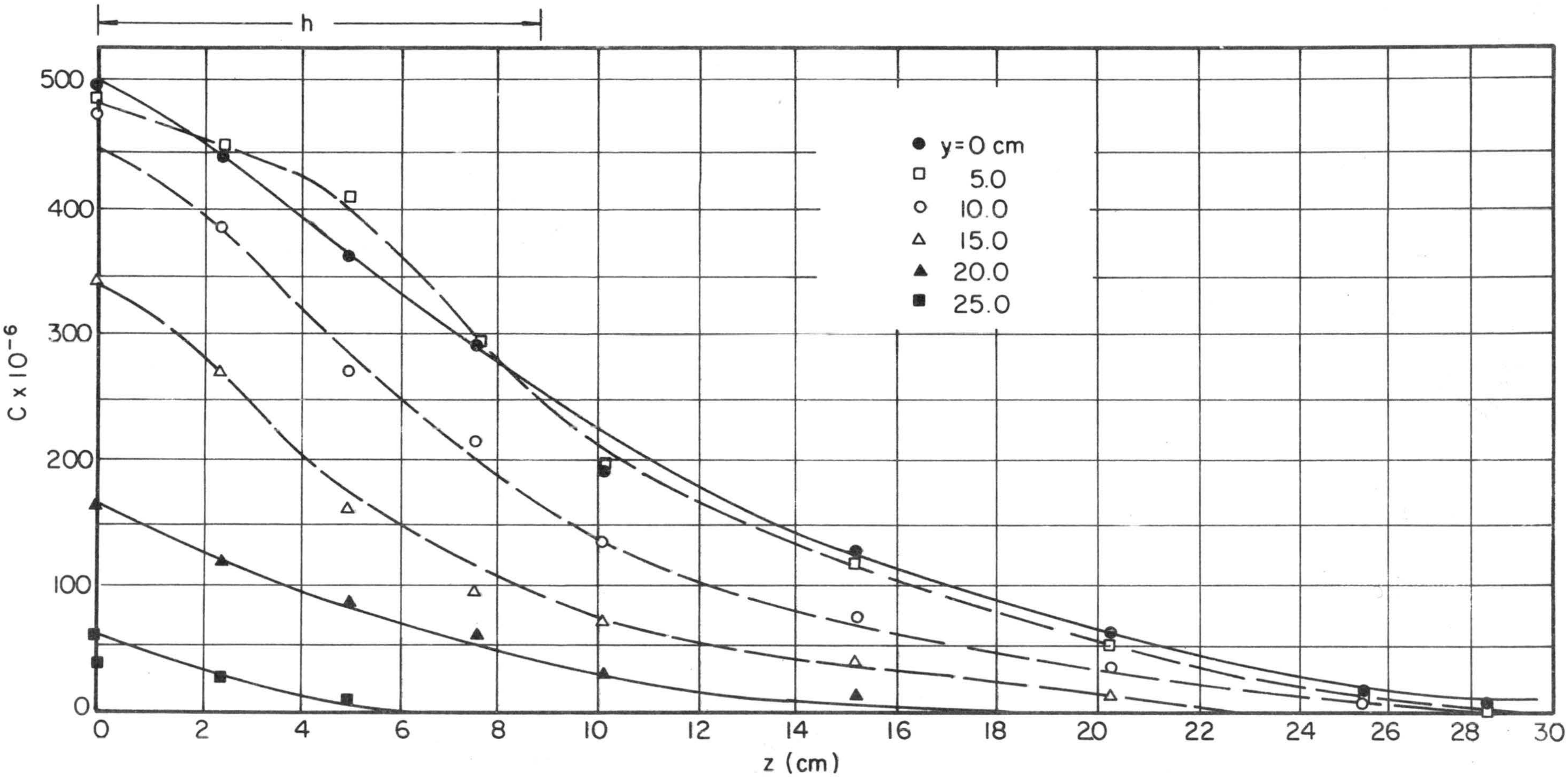


Fig. 15. Lateral dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = 1 cm

Pegs: ϕ = 0.48 cm, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120

Spaced: 2.54 x 2.54 cm

z_s = 1 cm

x_s = 6 m

$\dot{x}$ = 0.3m

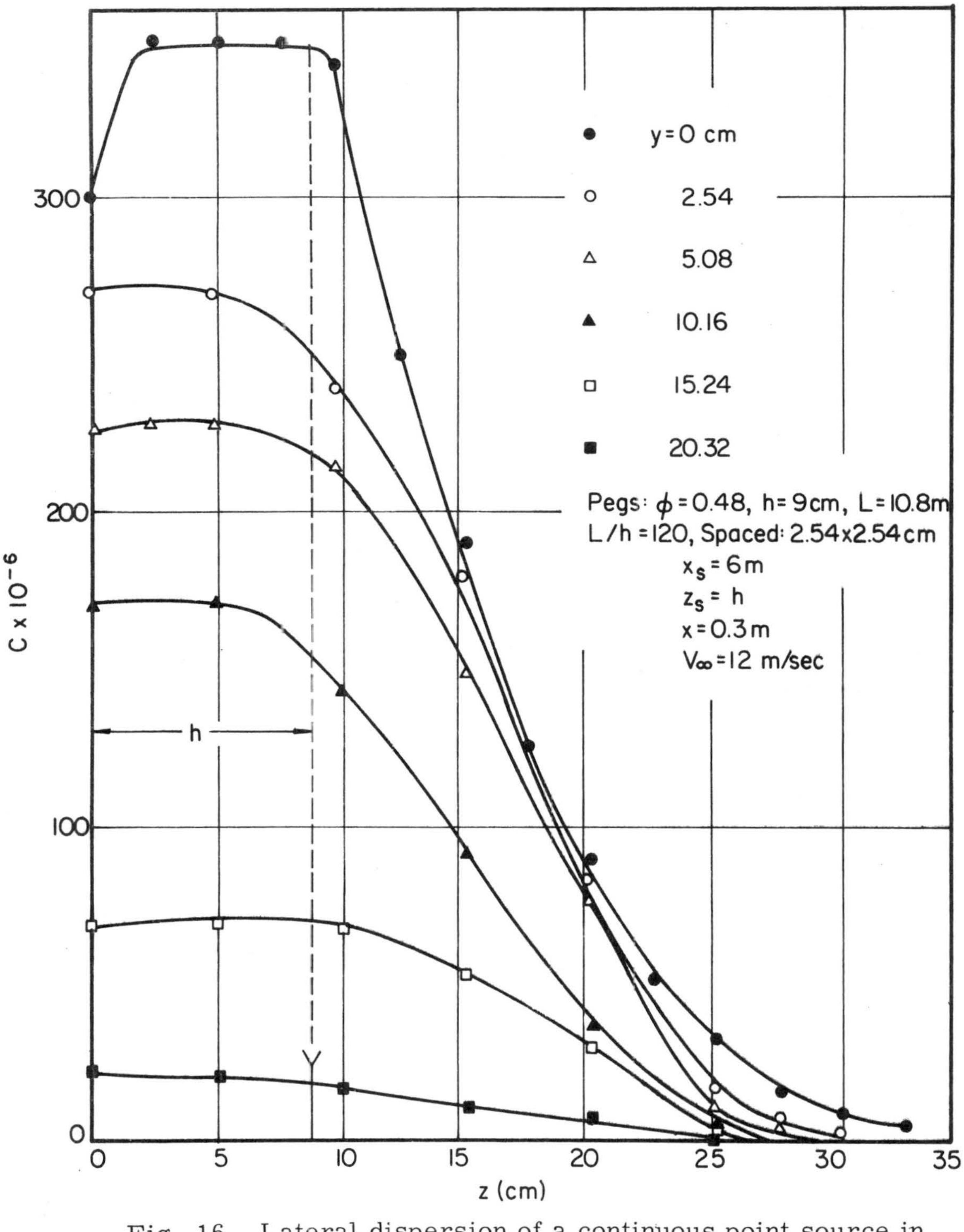


Fig. 16. Lateral dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = h

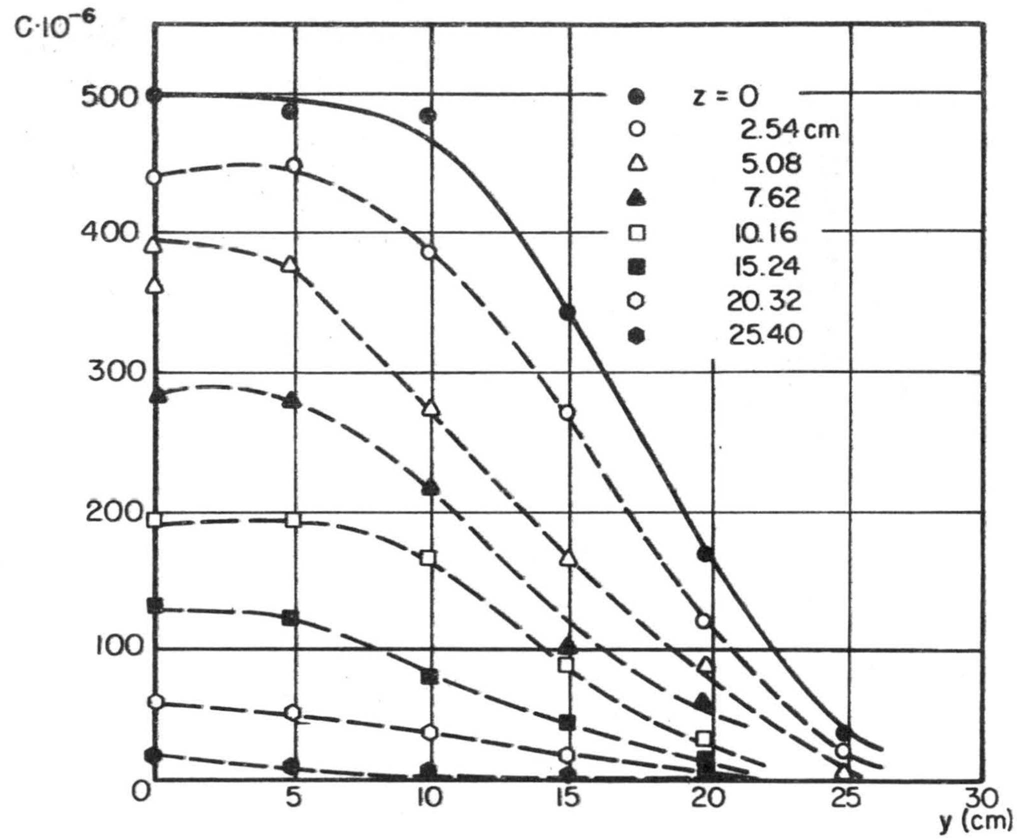


Fig. 17. Lateral dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = 1 cm

PEGS: ϕ = 0.48 cm, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120, SPACED 2.54 x 2.54 cm

Z_s = 1 cm
X_s = 6 m
V_∞ = 12 m/sec

0.30 m FROM SOURCE

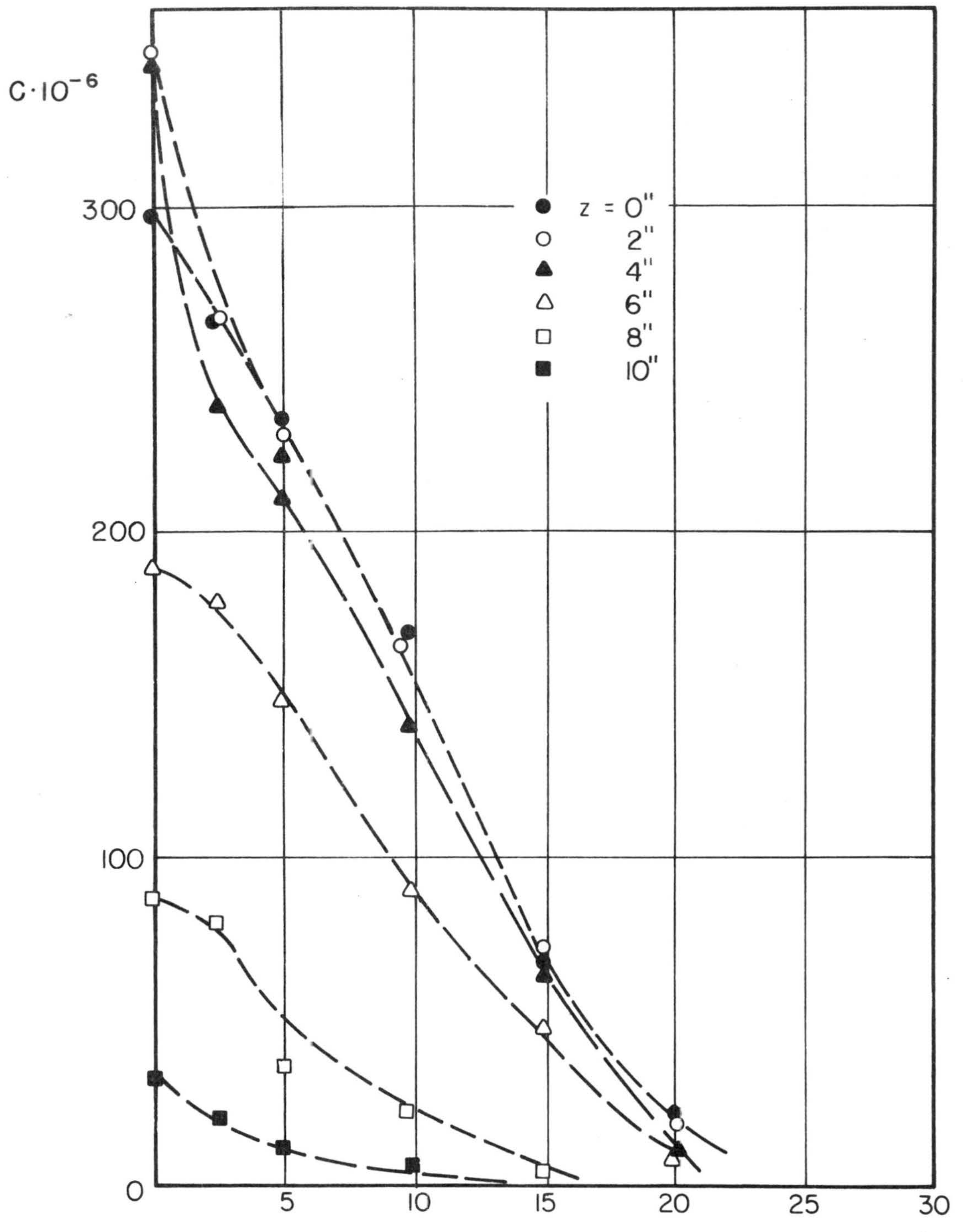


Fig. 18. Lateral dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = h

PEGS: ϕ = 0.48 cm, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120, SPACED 2.54 x 2.54 cm

Z_s = h
X_s = 6m
V_∞ = 12 m/sec

0.3m FROM SOURCE

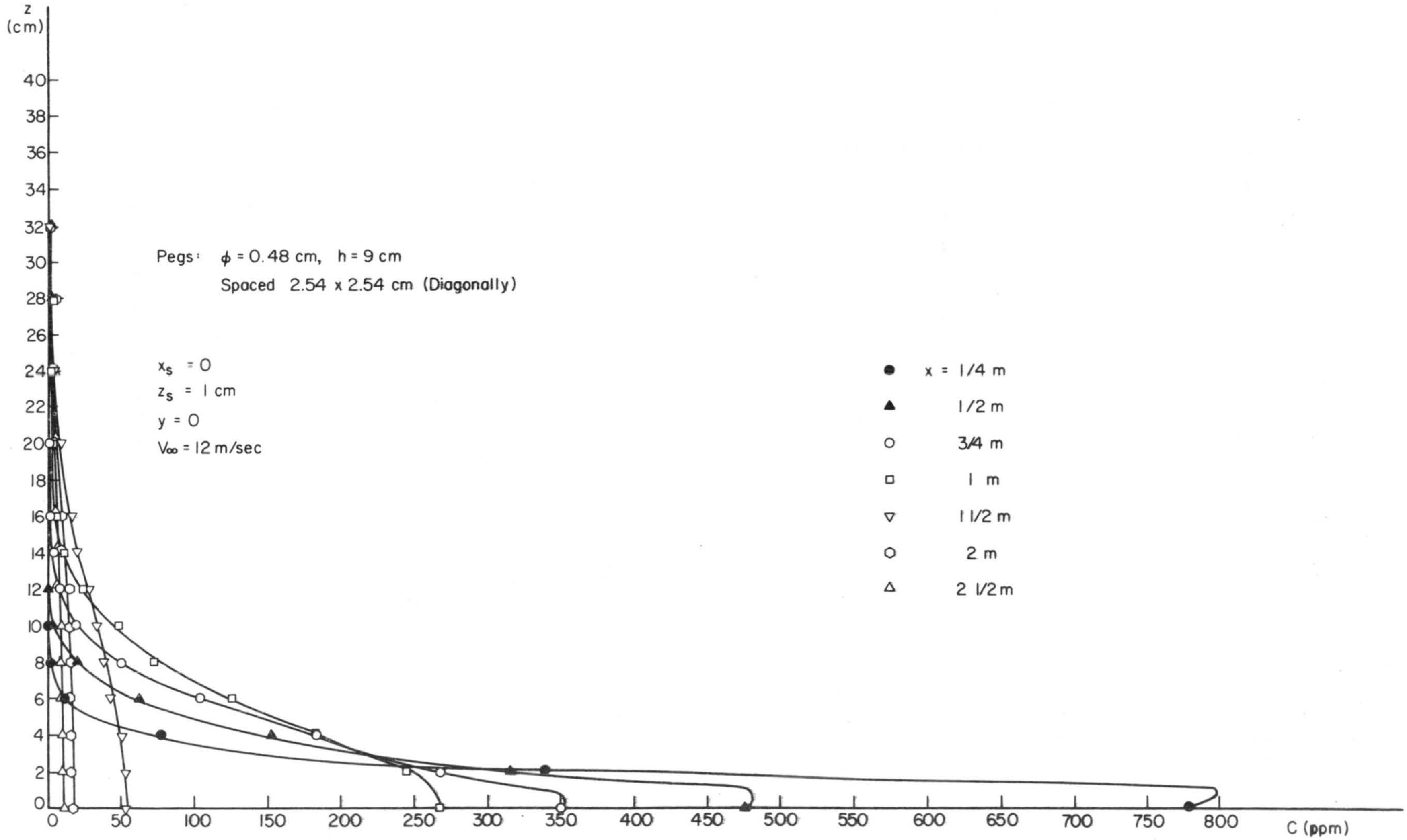


Fig. 19. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 cm diagonal). $x_s = 0$, $z_s = 1$ cm

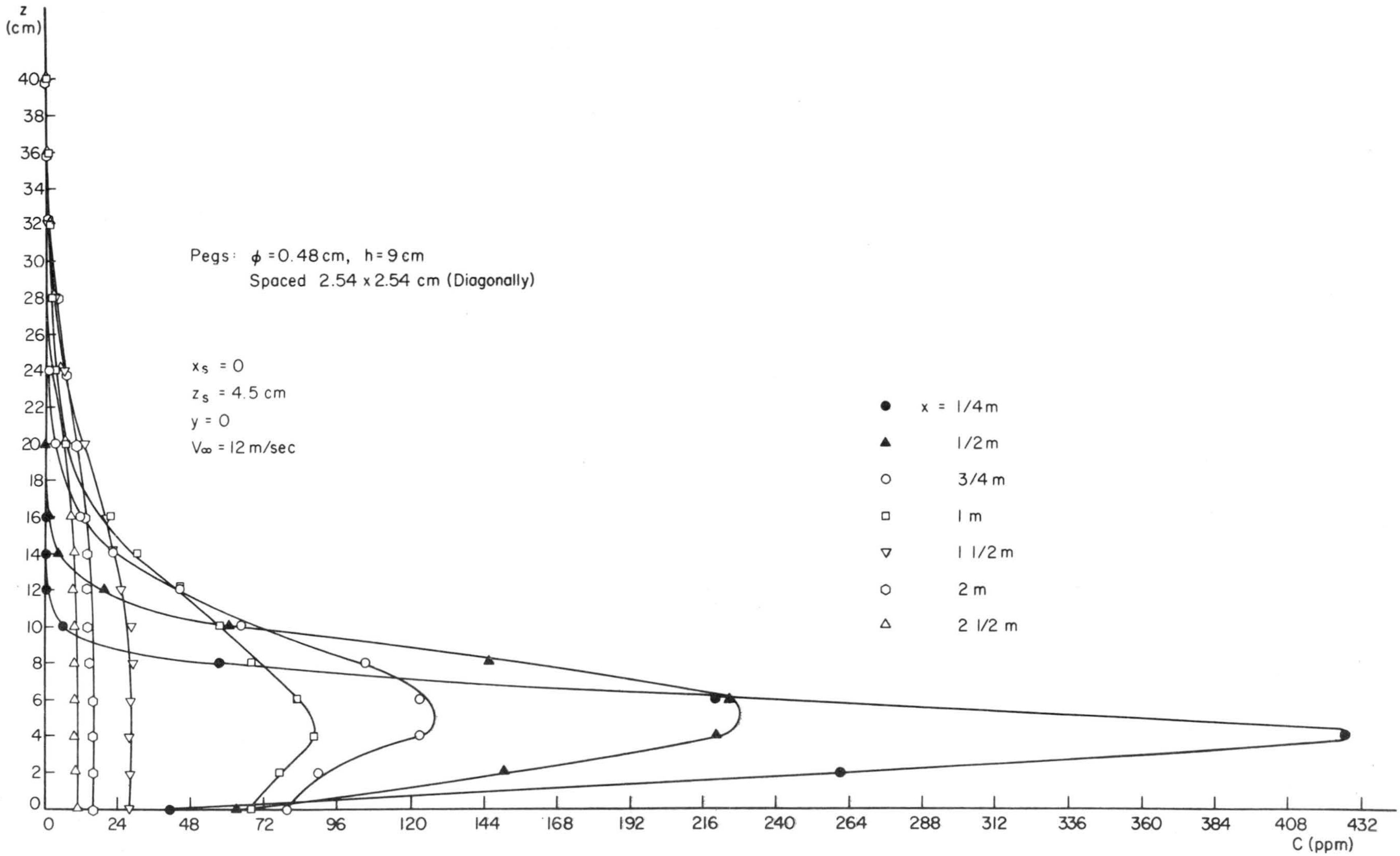


Fig. 20. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). $x_s = 0$, $z_s = 0.5$ h

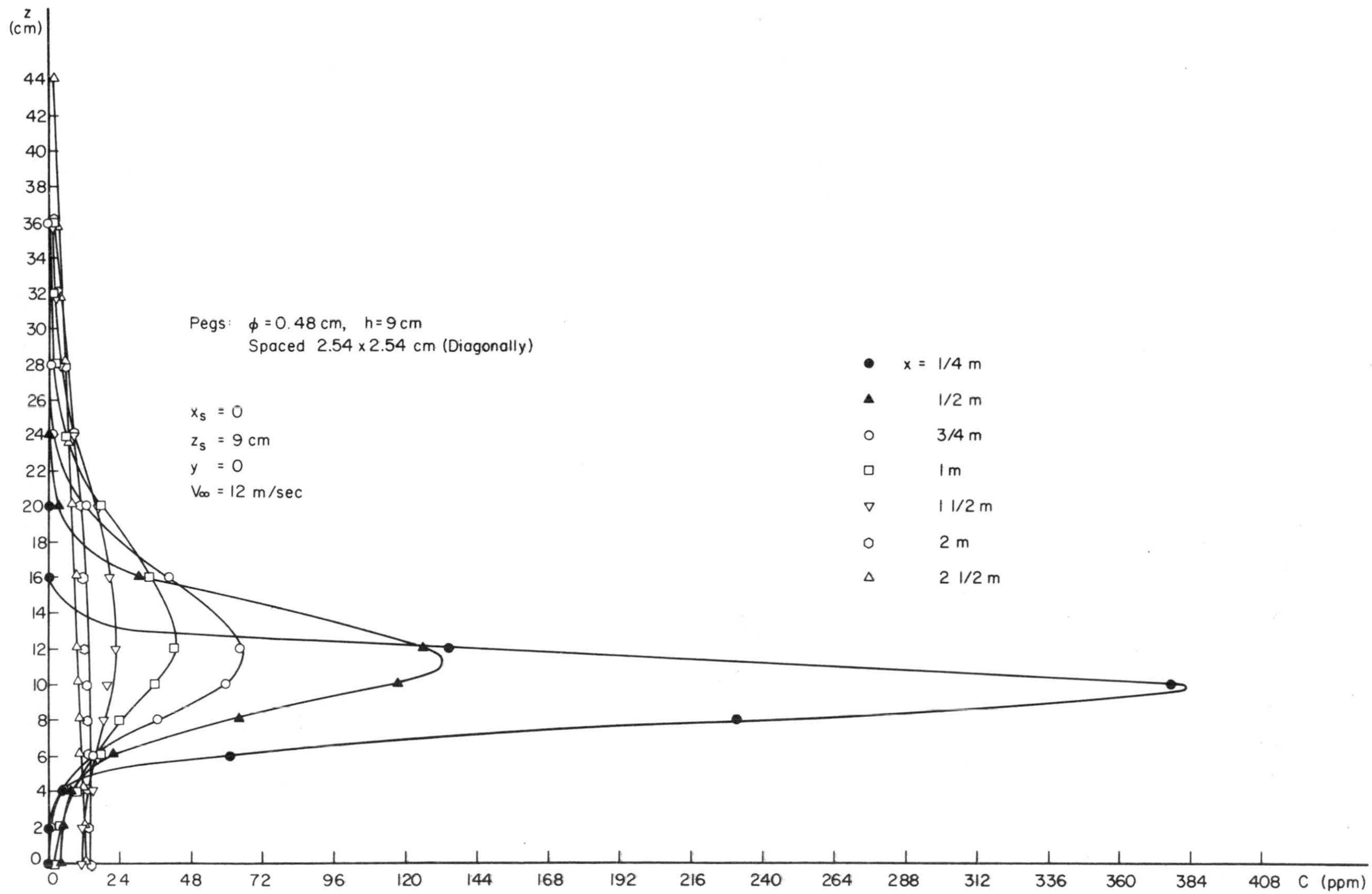


Fig. 21. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). $x_s = 0$, $z_s = h$

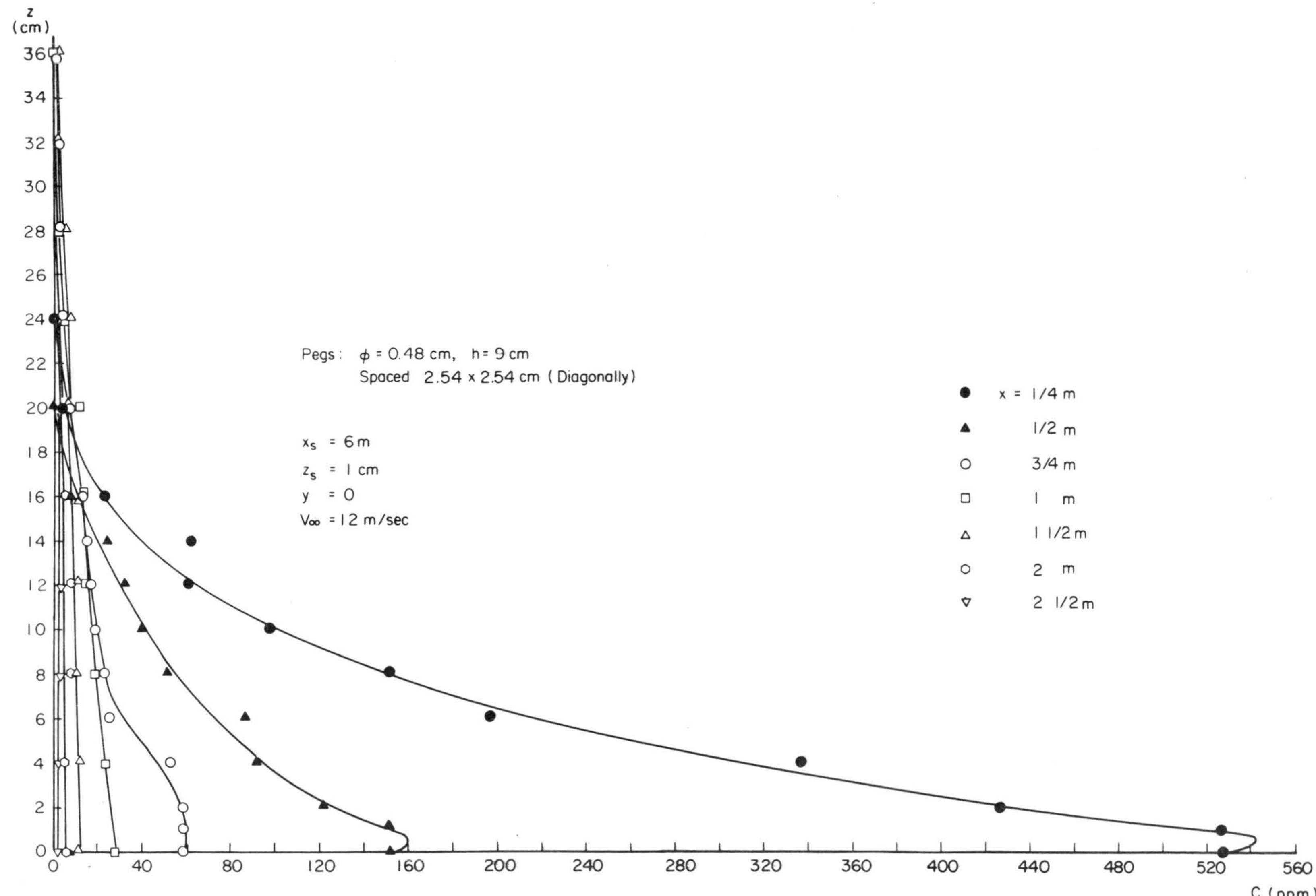


Fig. 22. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). x_s = 6 m, z_s = 1 cm

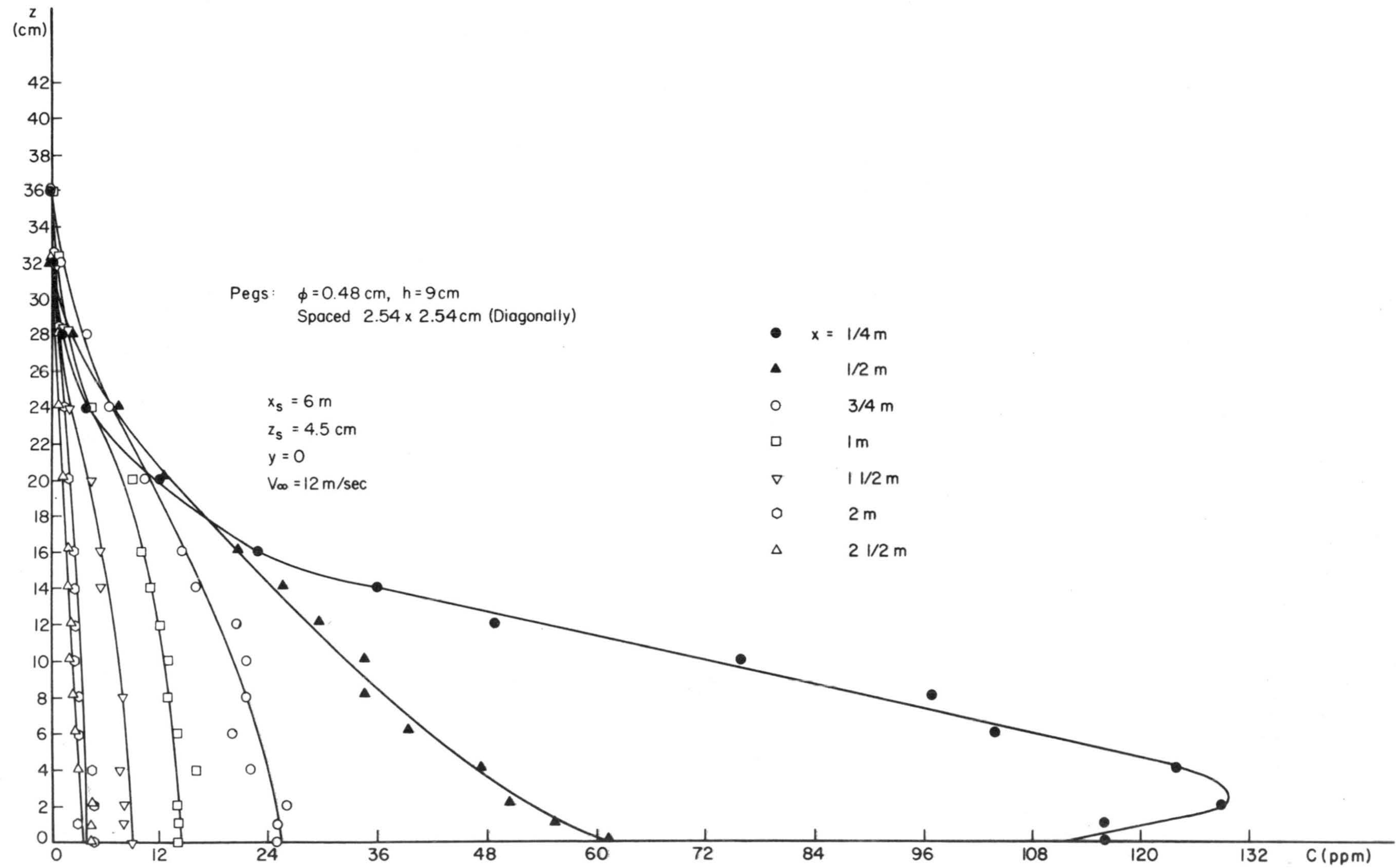


Fig. 23. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). x_s = 6 m, z_s = 0.5 h

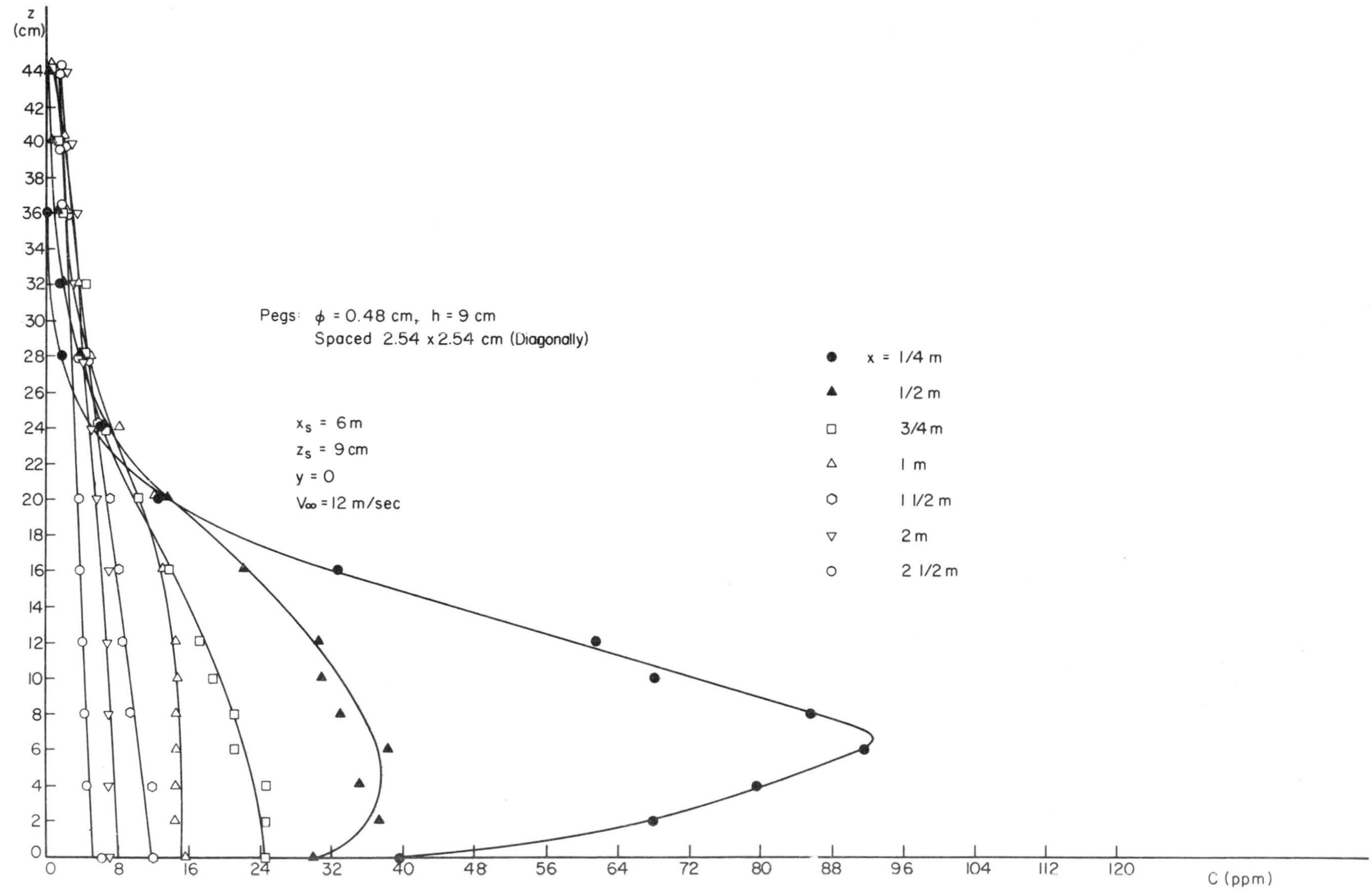


Fig. 24. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). x_s = 6 m, z_s = h

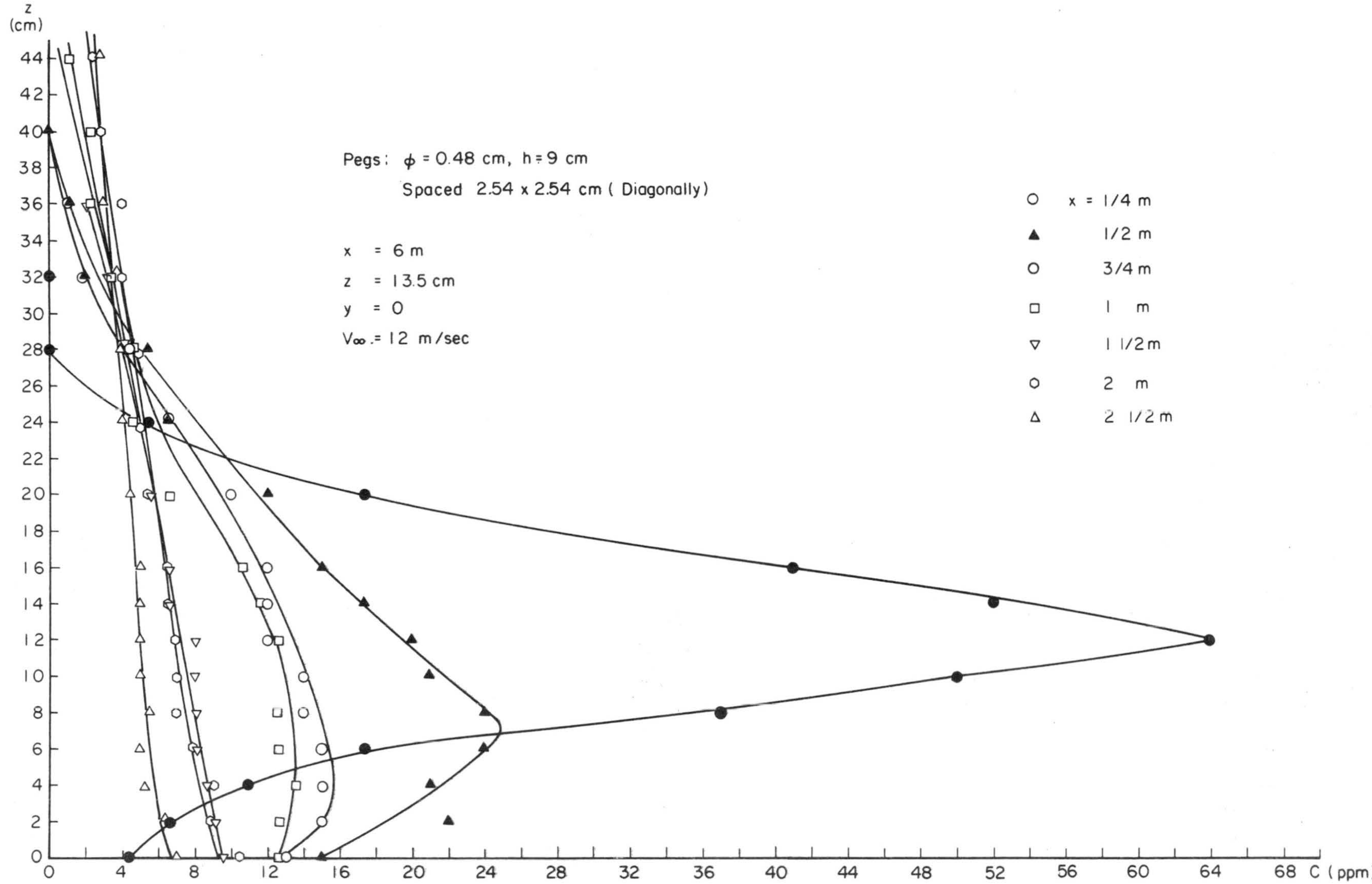


Fig. 25. Vertical dispersion of a continuous point source in a model peg canopy (2.54 x 2.54 diagonal). $x_s = 6$ m, $z_s = 1.5$ h

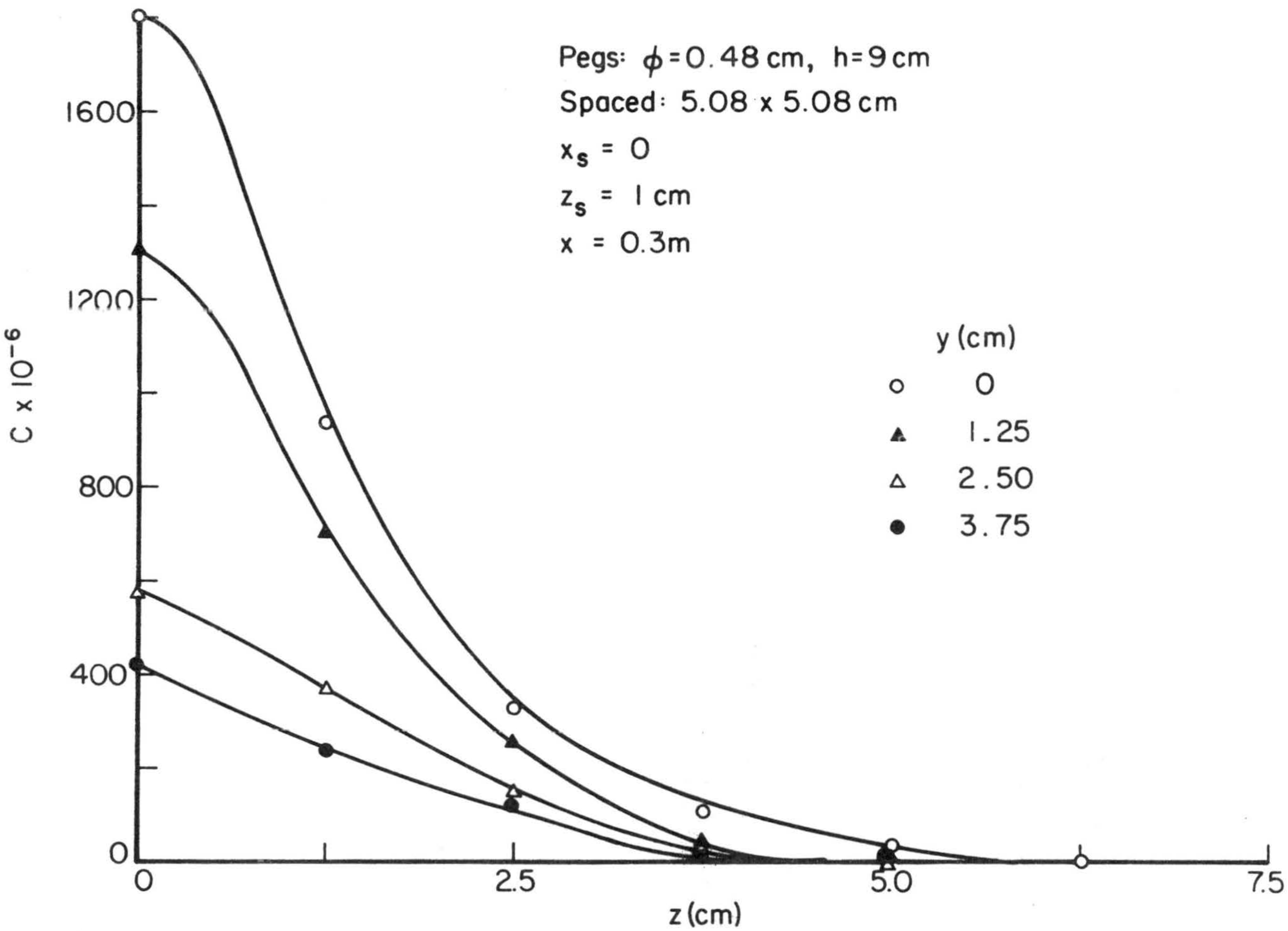


Fig. 26. Vertical dispersion of a continuous point source in a model peg canopy (5.08 x 5.08 cm). x_s = 0, z_s = 1 cm, x = 0.3 m

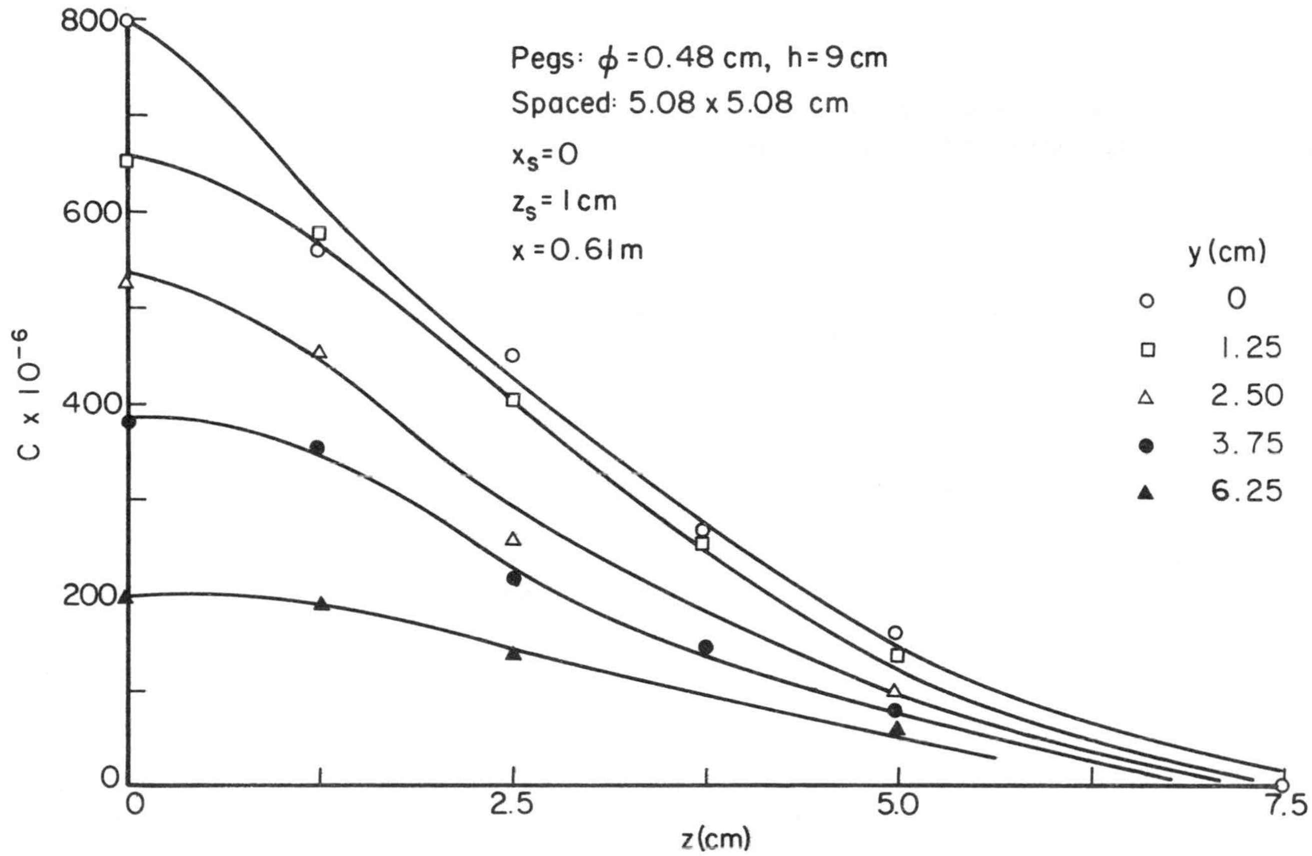


Fig. 27. Vertical dispersion of a continuous point source in a model peg canopy (5.08 x 5.08 cm). $x_s = 0$, $z_s = 1$ cm, $x = 0.6$ m

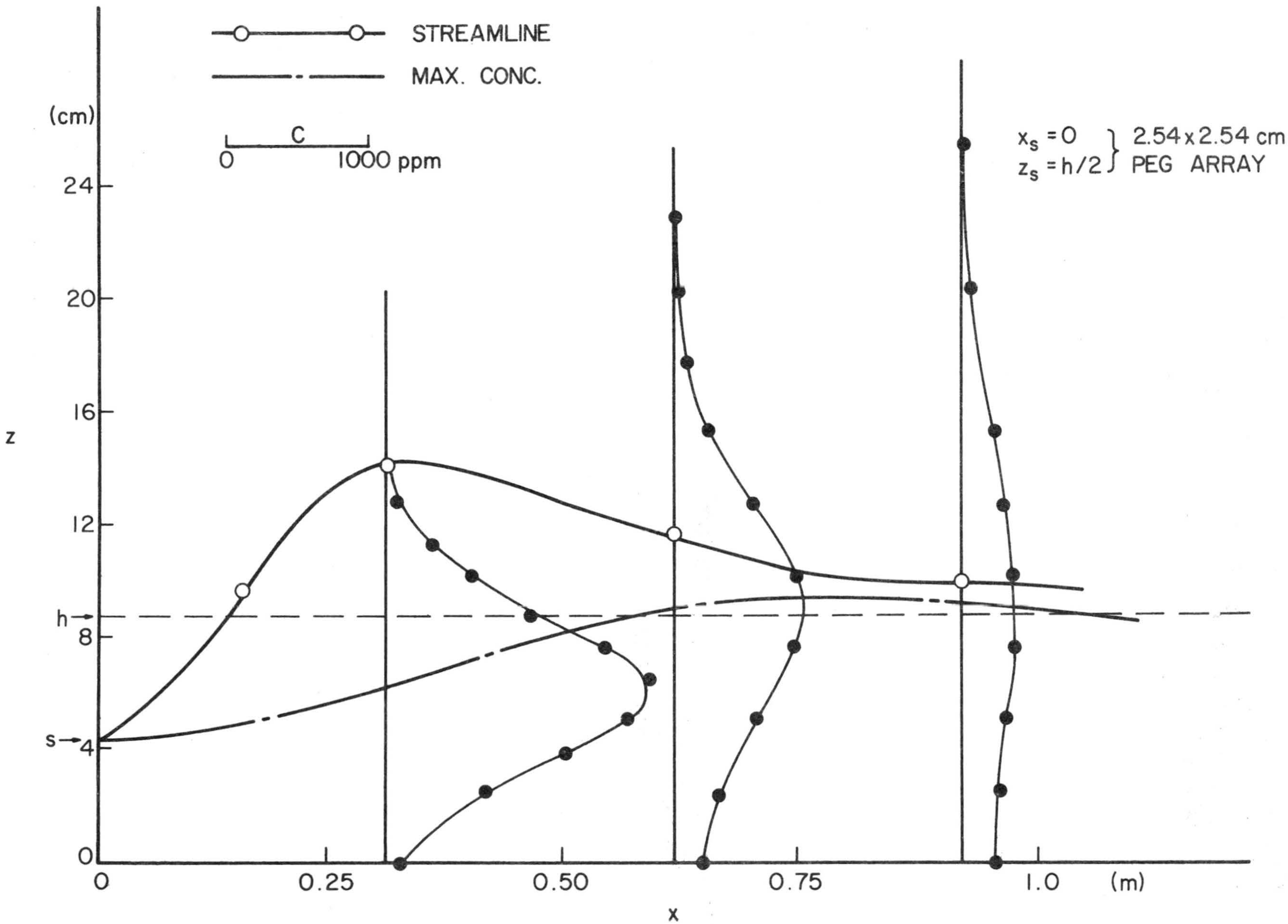


Fig. 28. Traces of maximum concentration from a point source (2.54 x 2.54 cm). $x_s = 0$, $z_s = 0.5$ h.

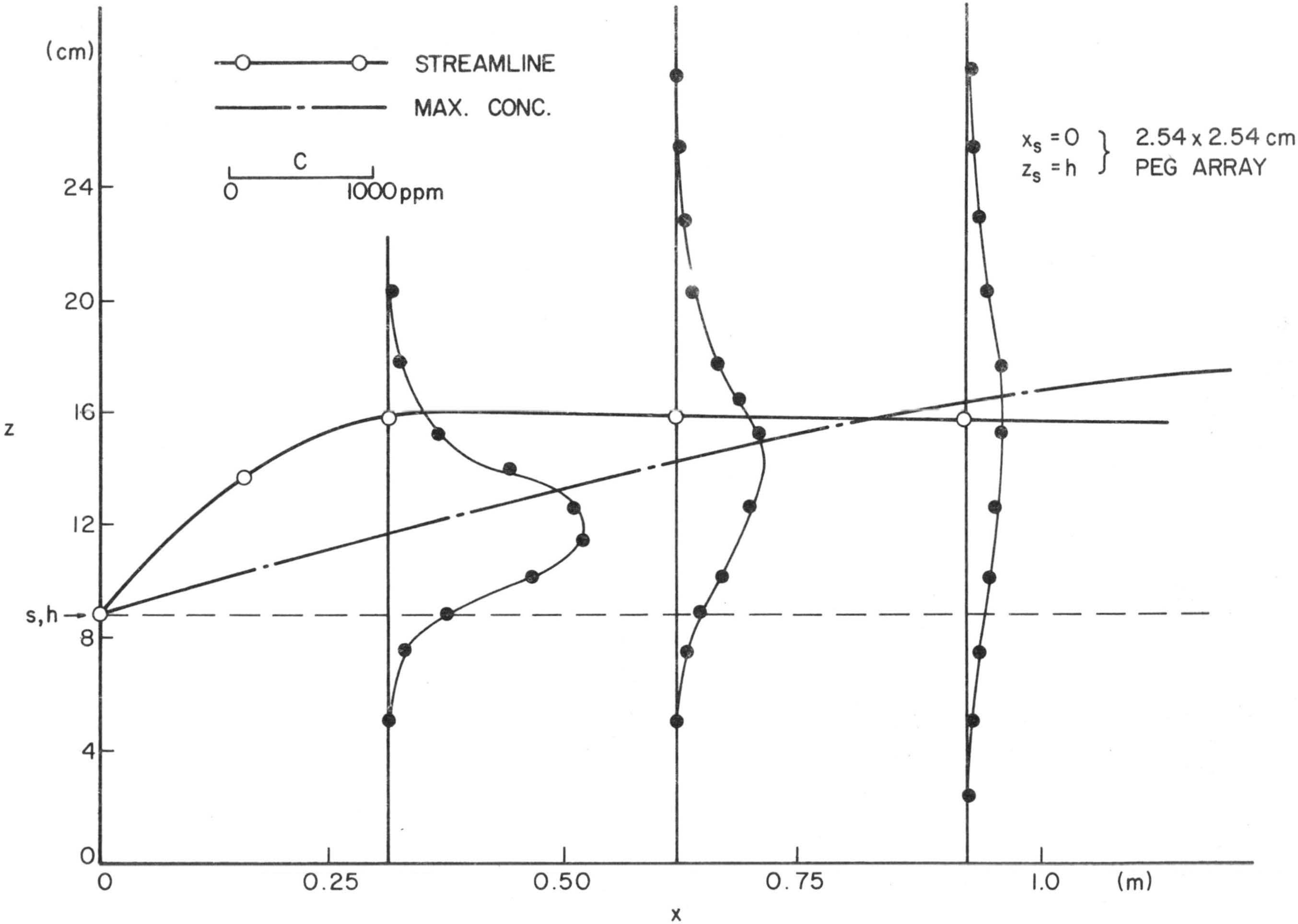


Fig. 29. Traces of maximum concentration from a point source (2.54 x 2.54 cm). $x_s = 0$, $z_s = h$

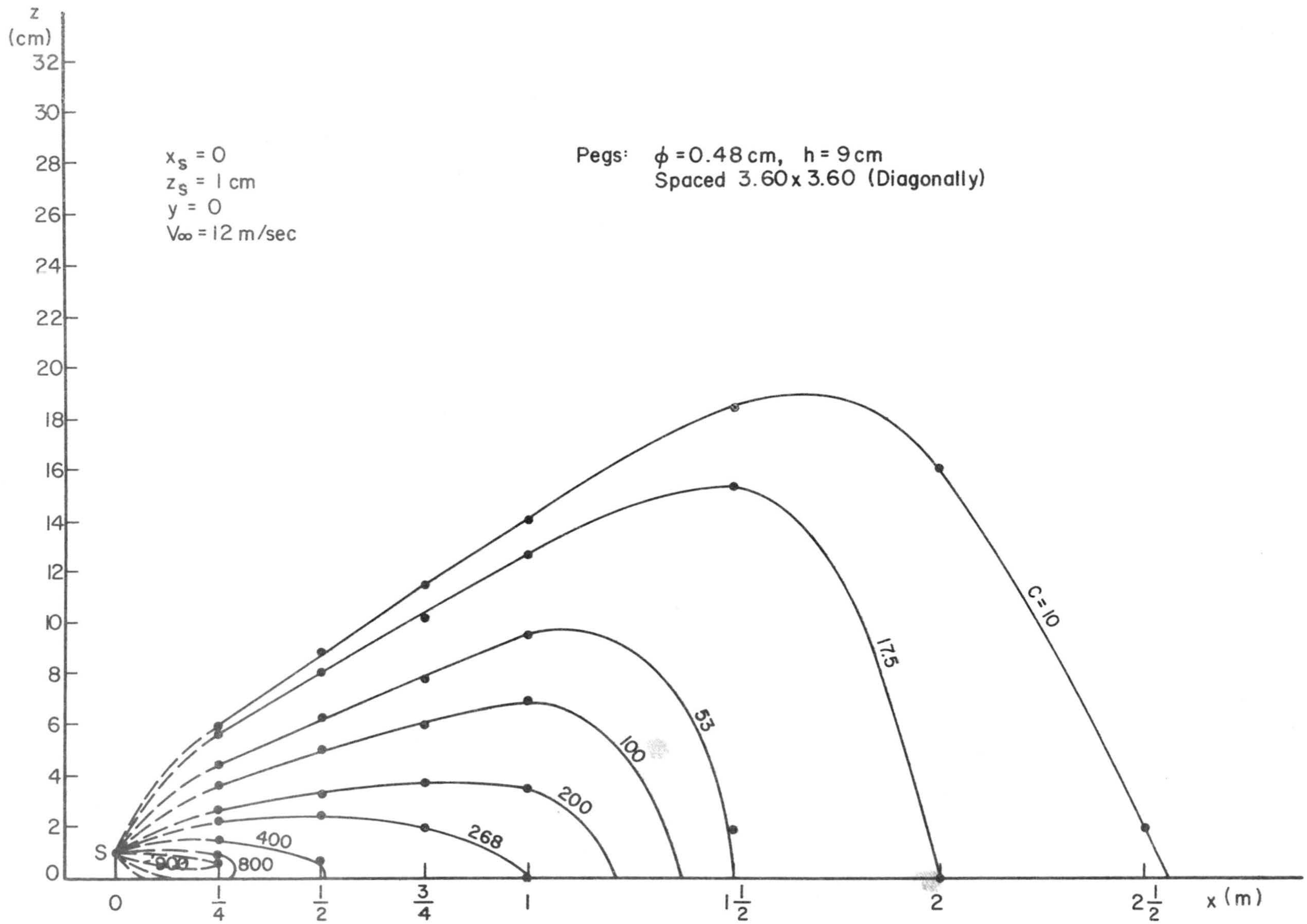


Fig. 30. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal). $x_s = 0$, $z_s = 1$ cm

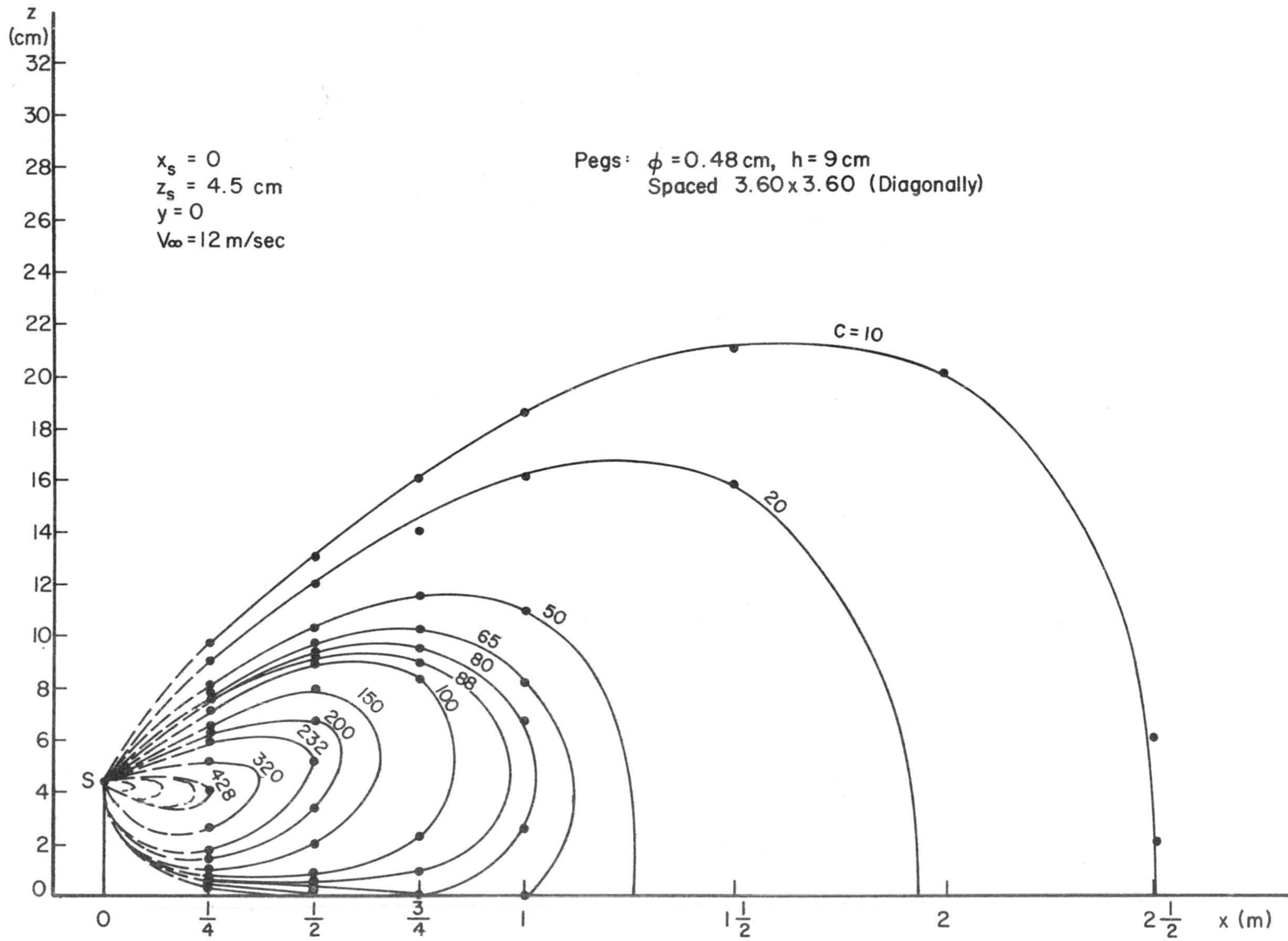


Fig. 31. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal).
x_s = 0, z_s = 0.5 h.

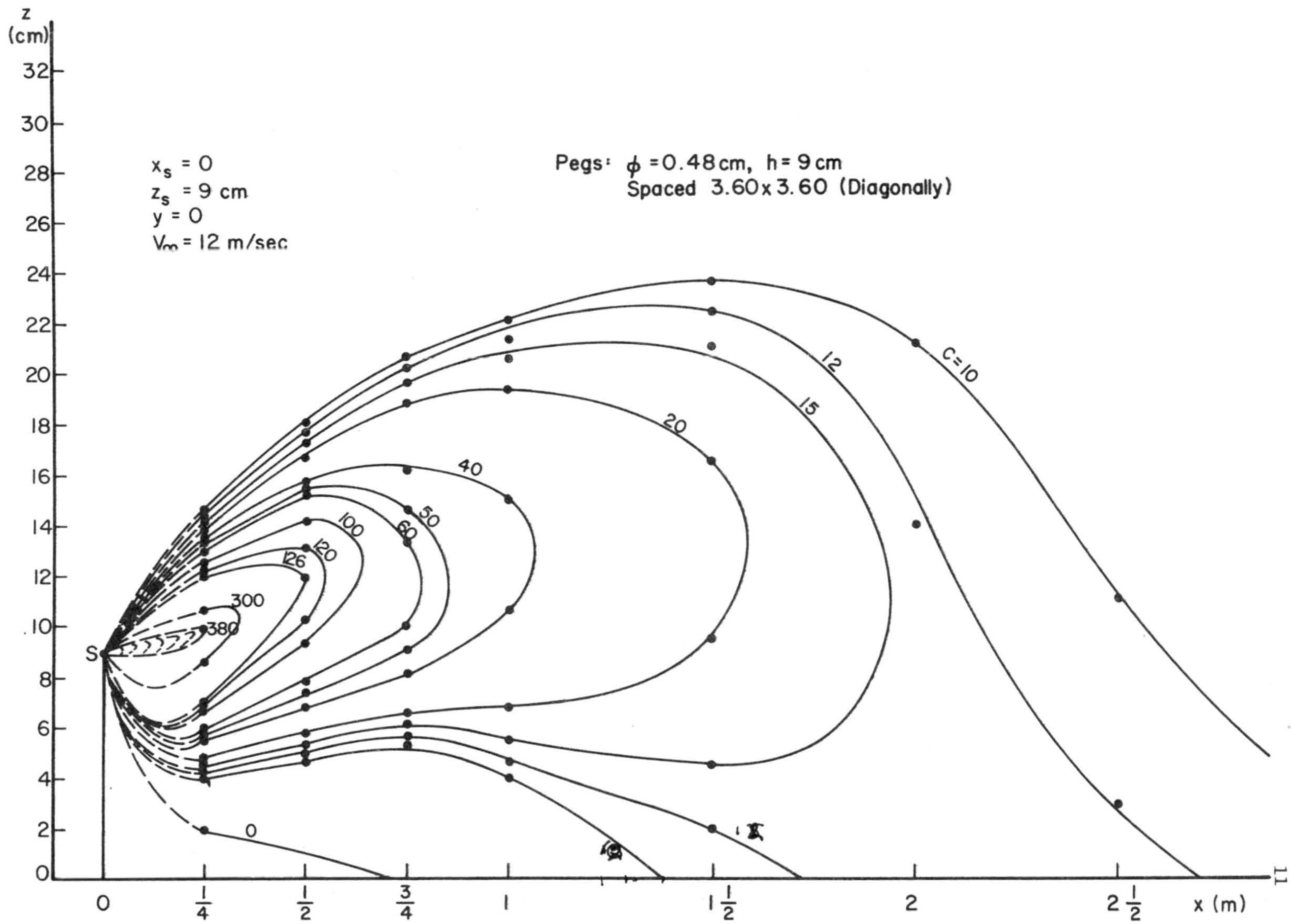


Fig. 32. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal).
$x_s = 0$, $z_s = h$

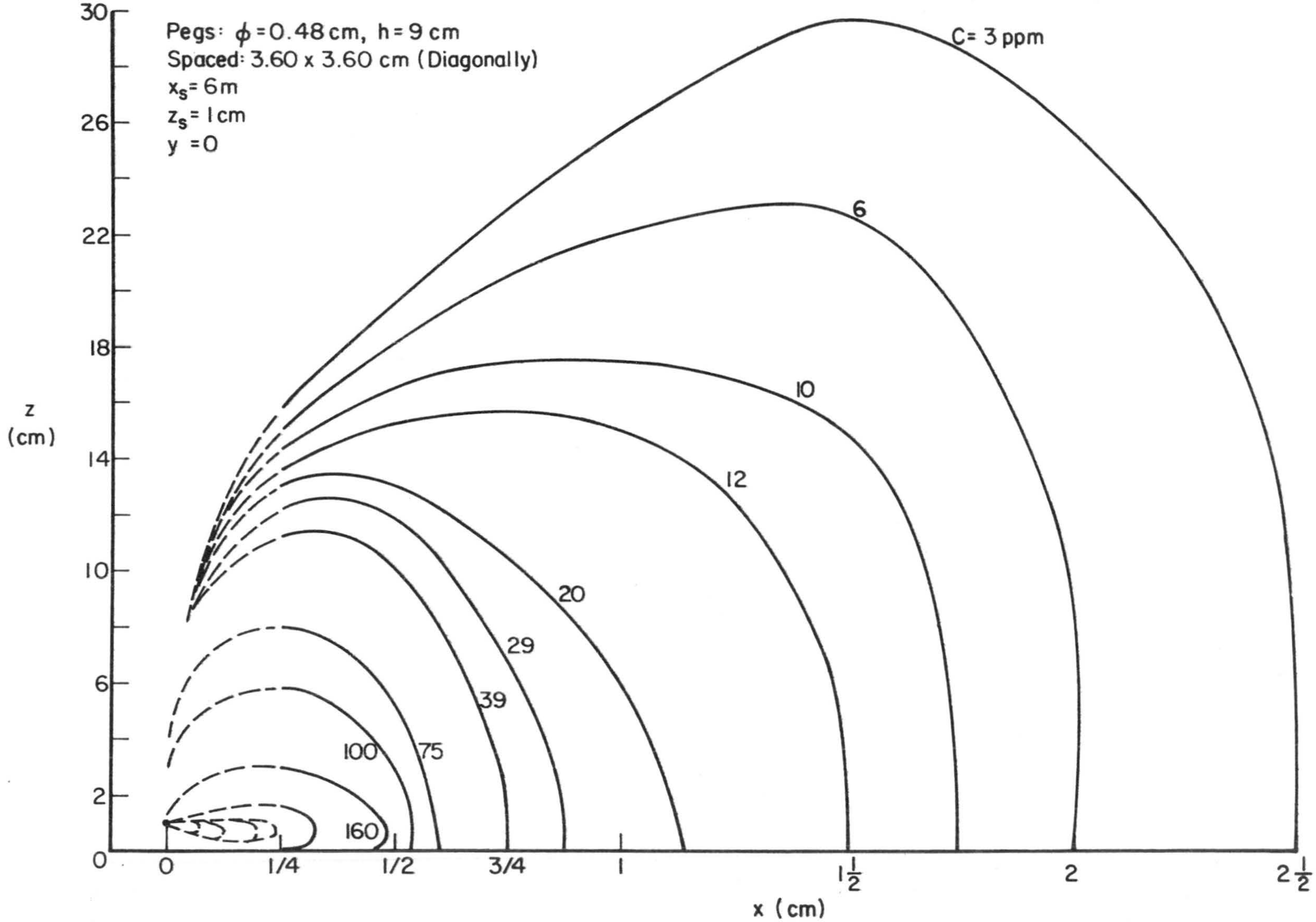


Fig. 33. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal). x_s = 6, z_s = 1 cm

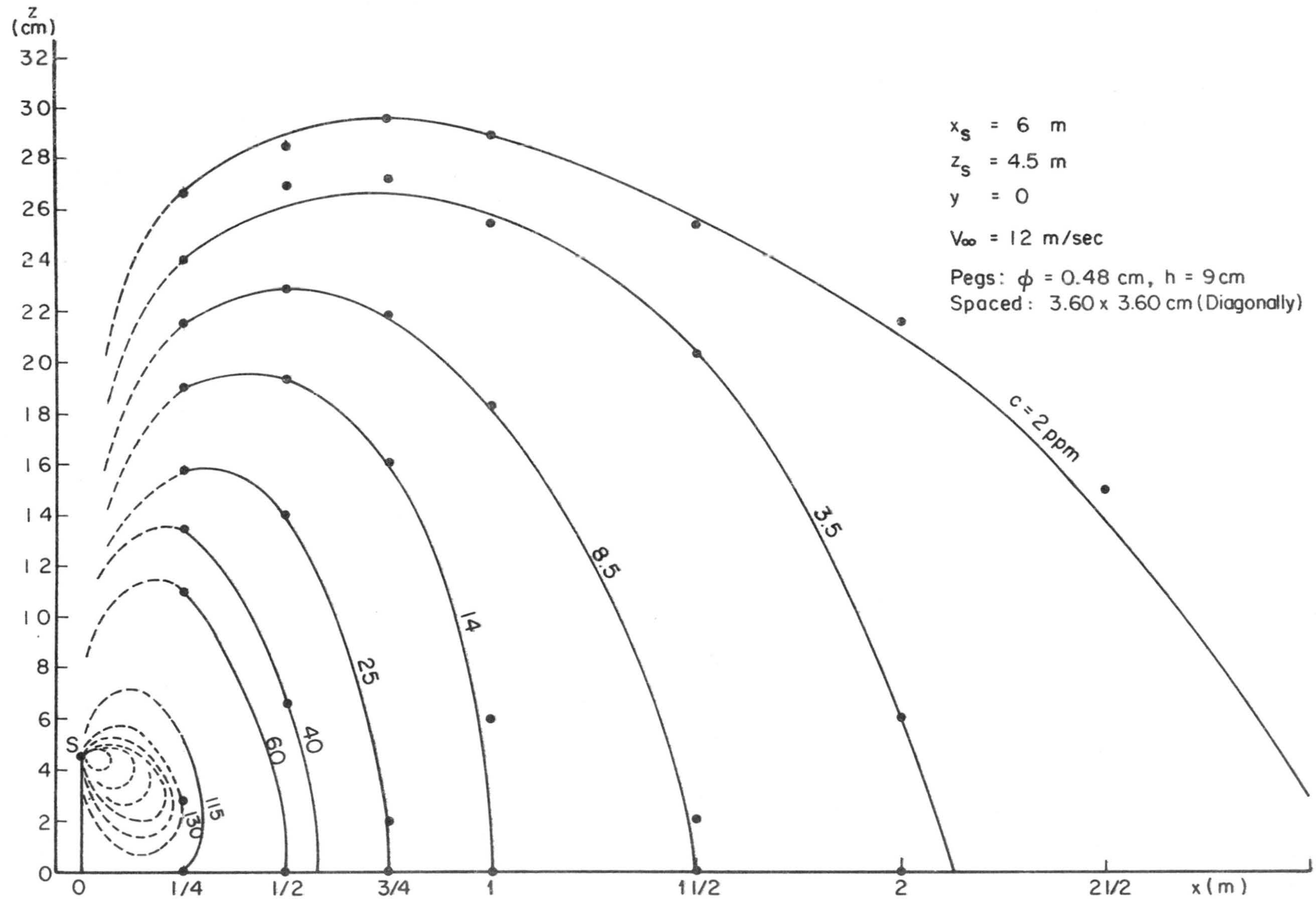


Fig. 34. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal).
$x_s = 6$, $z_s = 0.5$ h

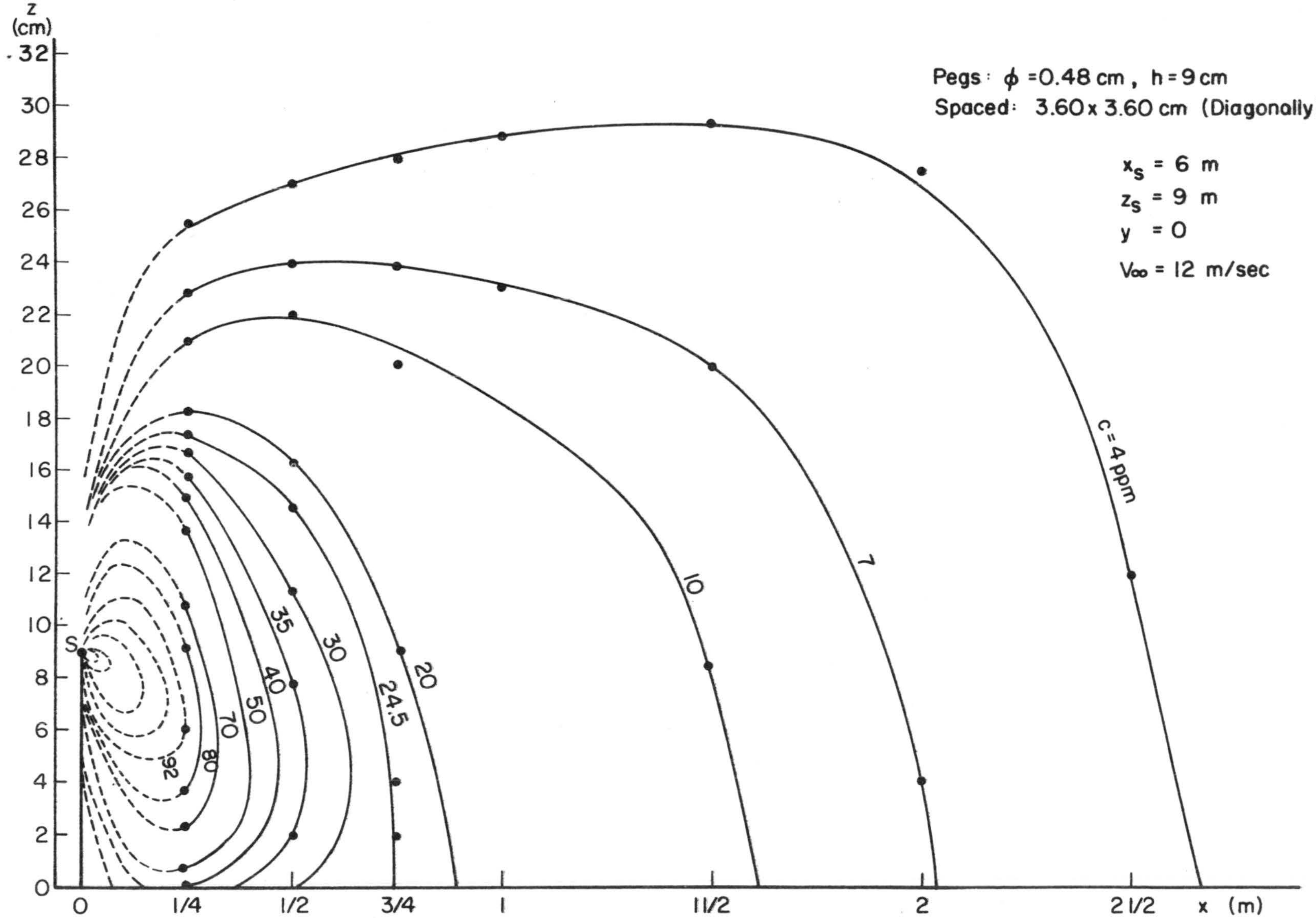


Fig. 35. Diffusion in the canopy-isoconcentration lines (2. 54 x 2. 54 diagonal).
x_s = 6, z_s = h

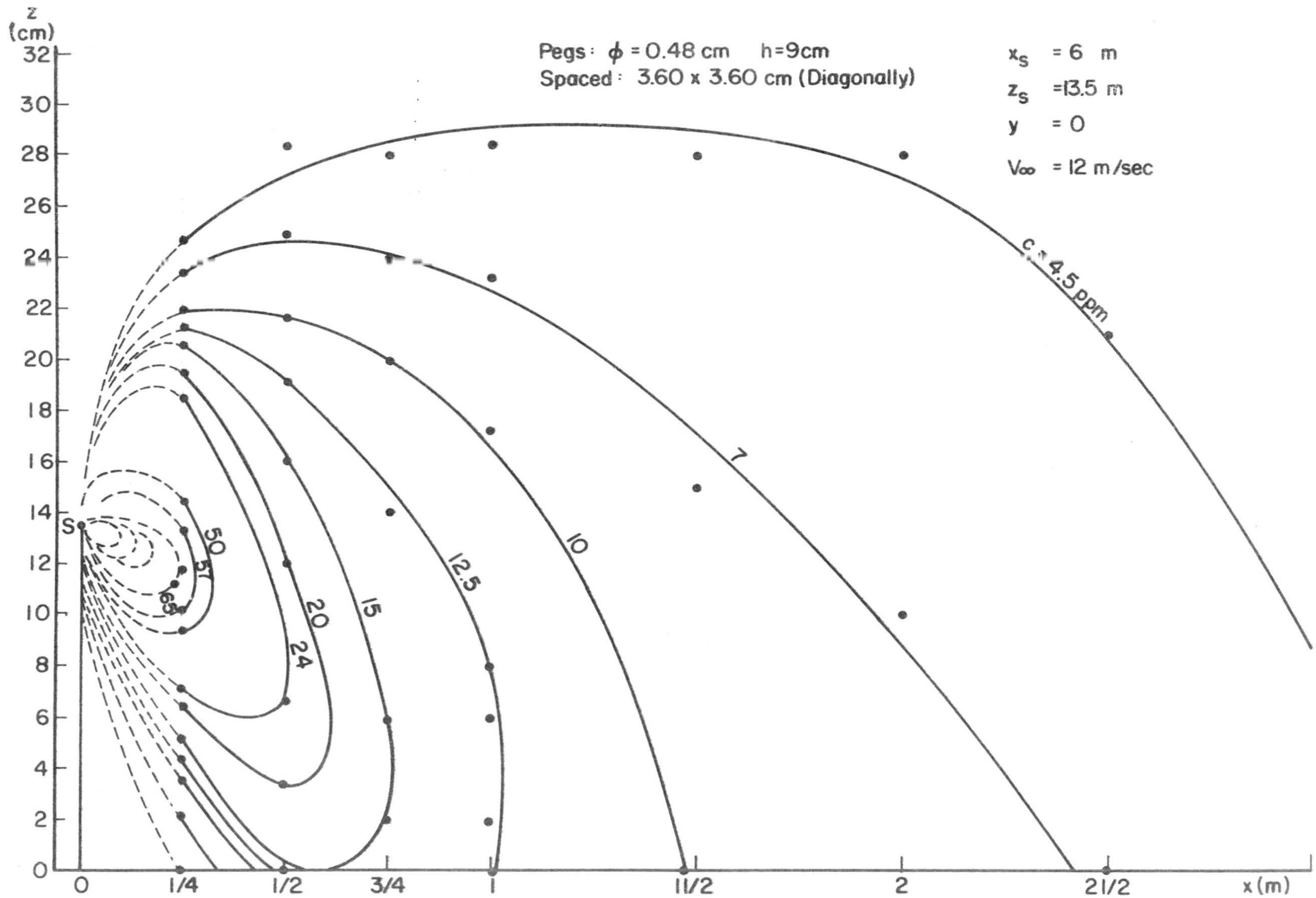


Fig. 36. Diffusion in the canopy-isoconcentration lines (2.54 x 2.54 diagonal).
x_S = 6, z_S = 1.5 h

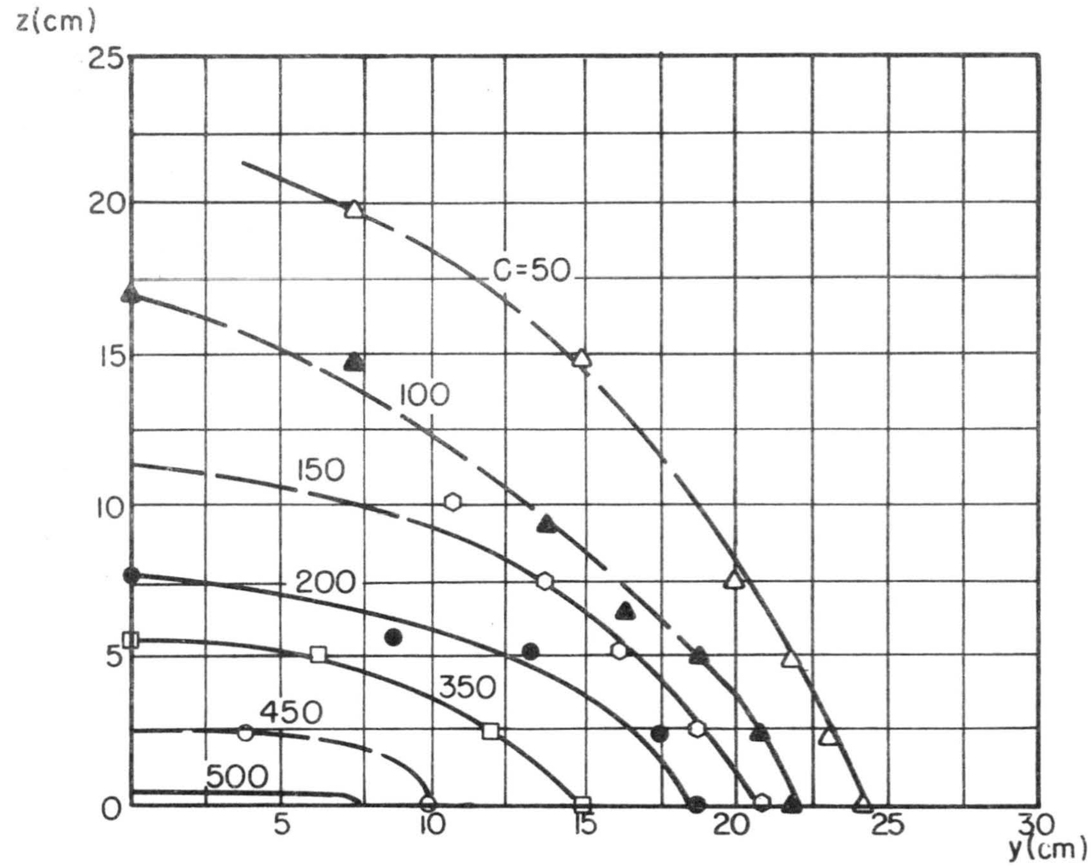


Fig. 37. Gaseous plume cross-section of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = 1 cm, x - 0.3 m

PEGS: ϕ = 0.48, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120,
SPACED: 2.54 x 2.54 cm

Z_s = 1 cm
X_s = 6 m
X = 0.30 m

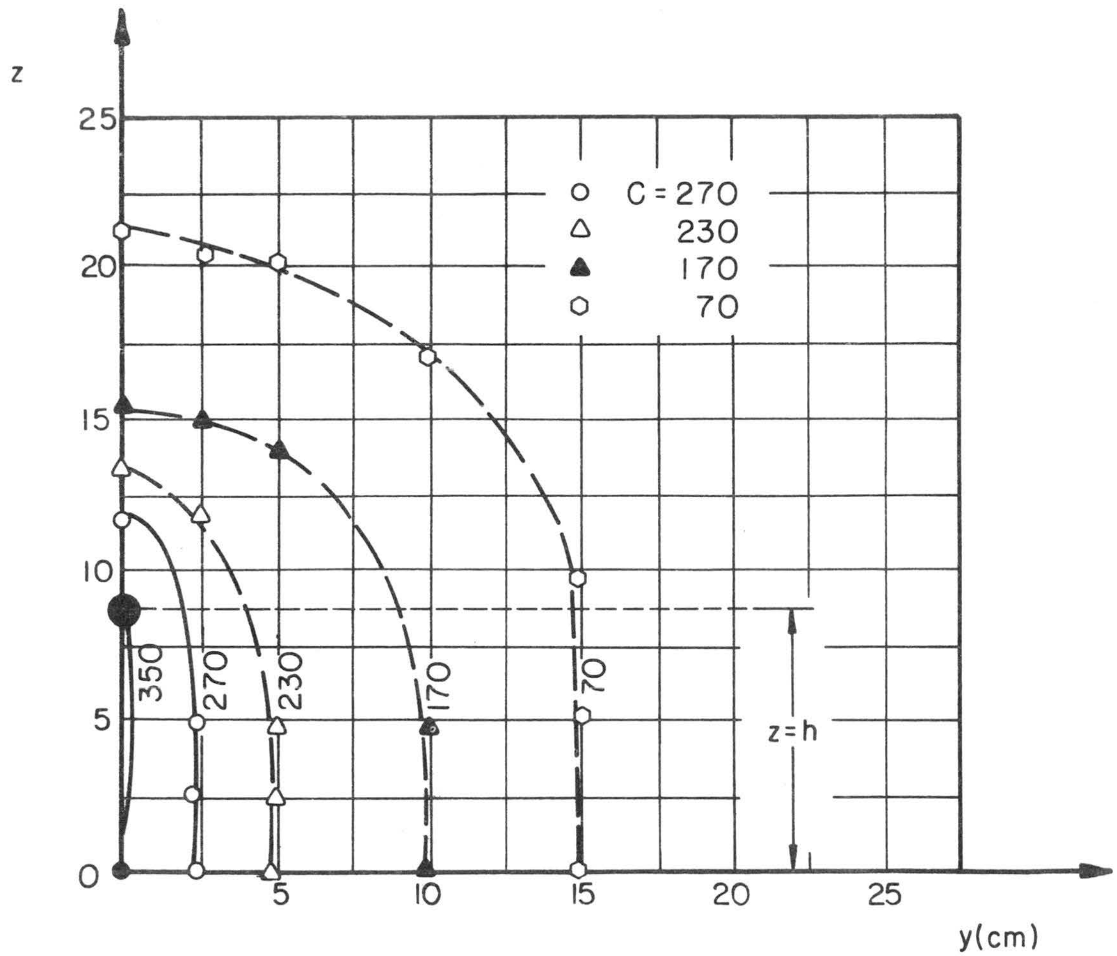


Fig. 38. Gaseous plume cross-section of a continuous point source in a model peg canopy (2.54 x 2.54 cm). x_s = 6 m, z_s = h, x = 0.3 m

PEGS: ϕ = 0.48, h = 9 cm, L = 10.8 m, $\frac{L}{h}$ = 120,

Spaced: 2.54 x 2.54 cm

Z_s = h

X_s = 6m

X = 0.3 m

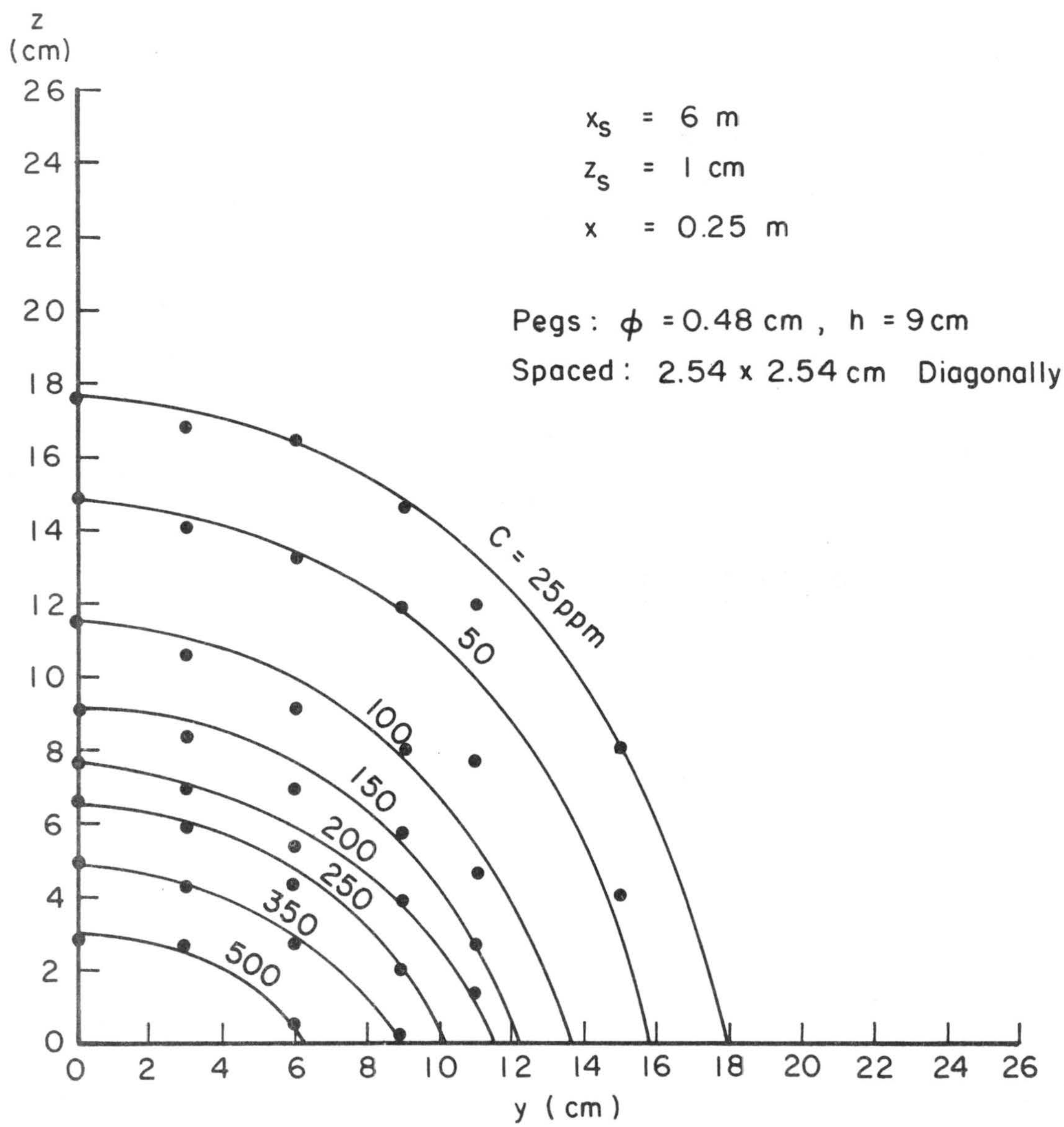


Fig. 39. Gaseous plume cross-section of a continuous point source in a model peg canopy (2.54 x 2.54 cm diagonal). x_s = 6 m, z_s = 1 cm, x = 0.25 m

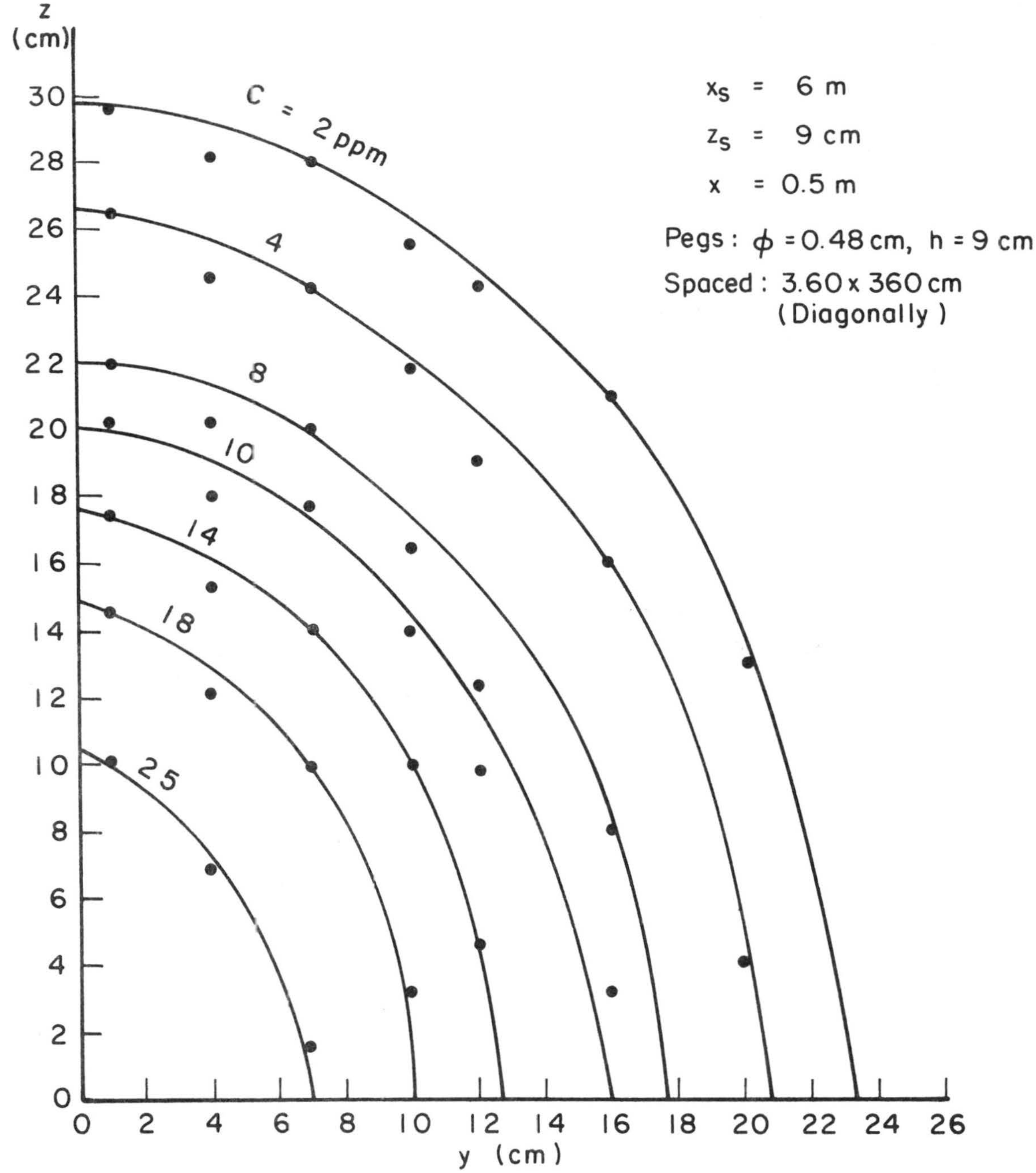


Fig. 40. Gaseous plume cross-section of a continuous point source in a model peg canopy (2.54 x 2.54 cm diagonal). x_s = 6 m, z_s = h, x = 0.5 m

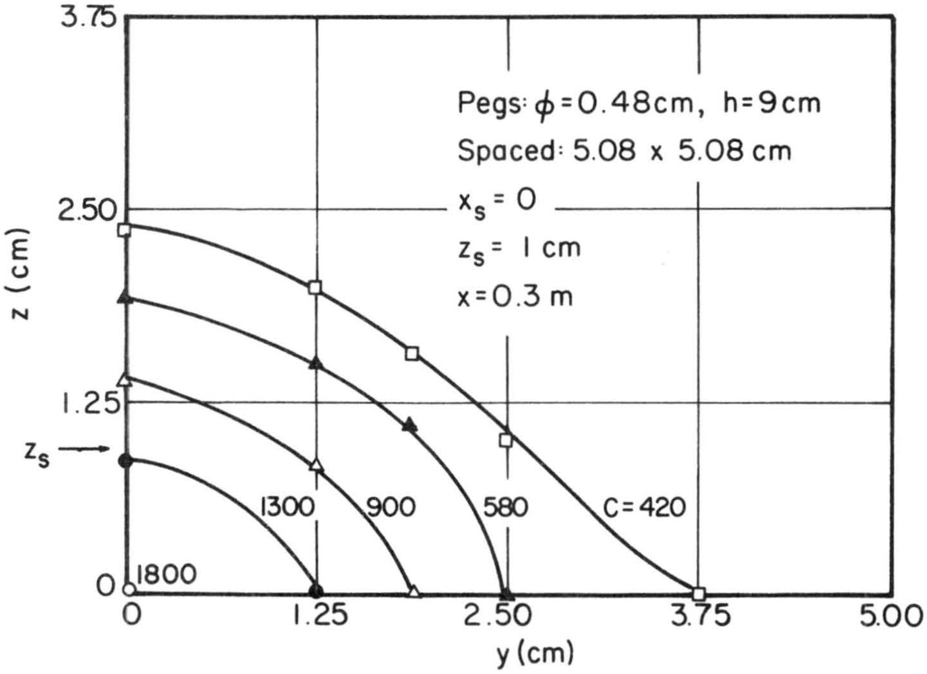


Fig. 41. Gaseous plume cross-section of a continuous point source in a model peg canopy (5.08 x 5.08 cm). x_s = 0 m, z_s = 1 cm, x = 0.3 m

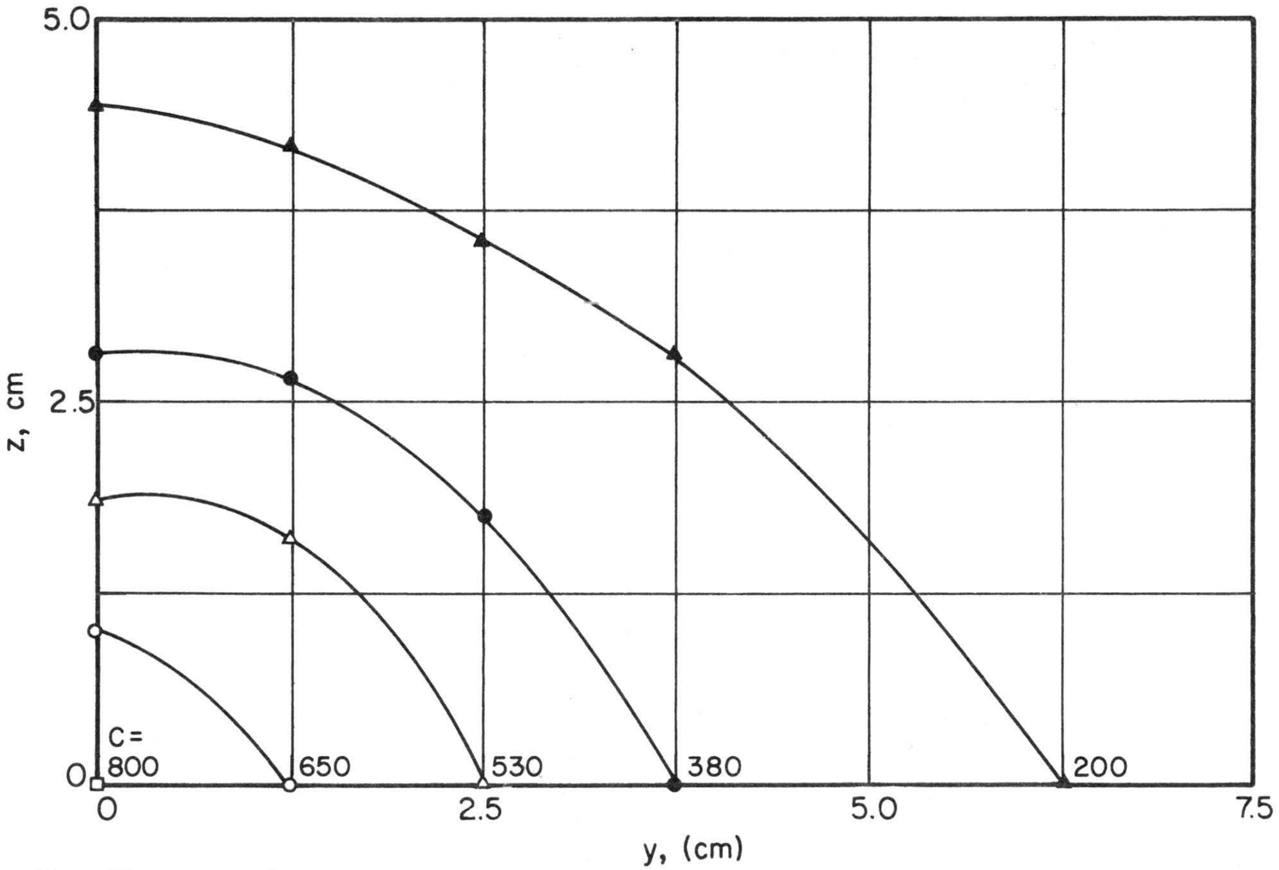


Fig. 42. Gaseous plume cross-section of a continuous point source in a model peg canopy (5.08 x 5.08 cm). x_s = 0 m, z_s = 1 cm, x = 0.6 m

PEGS: ϕ = 0.48, h = 9cm, SPACED 5.08 x 5.08 cm

LINE OF CONSTANT CONCENTRATION

Z_S = 1cm

X_S = 0cm

X = 0.61 m

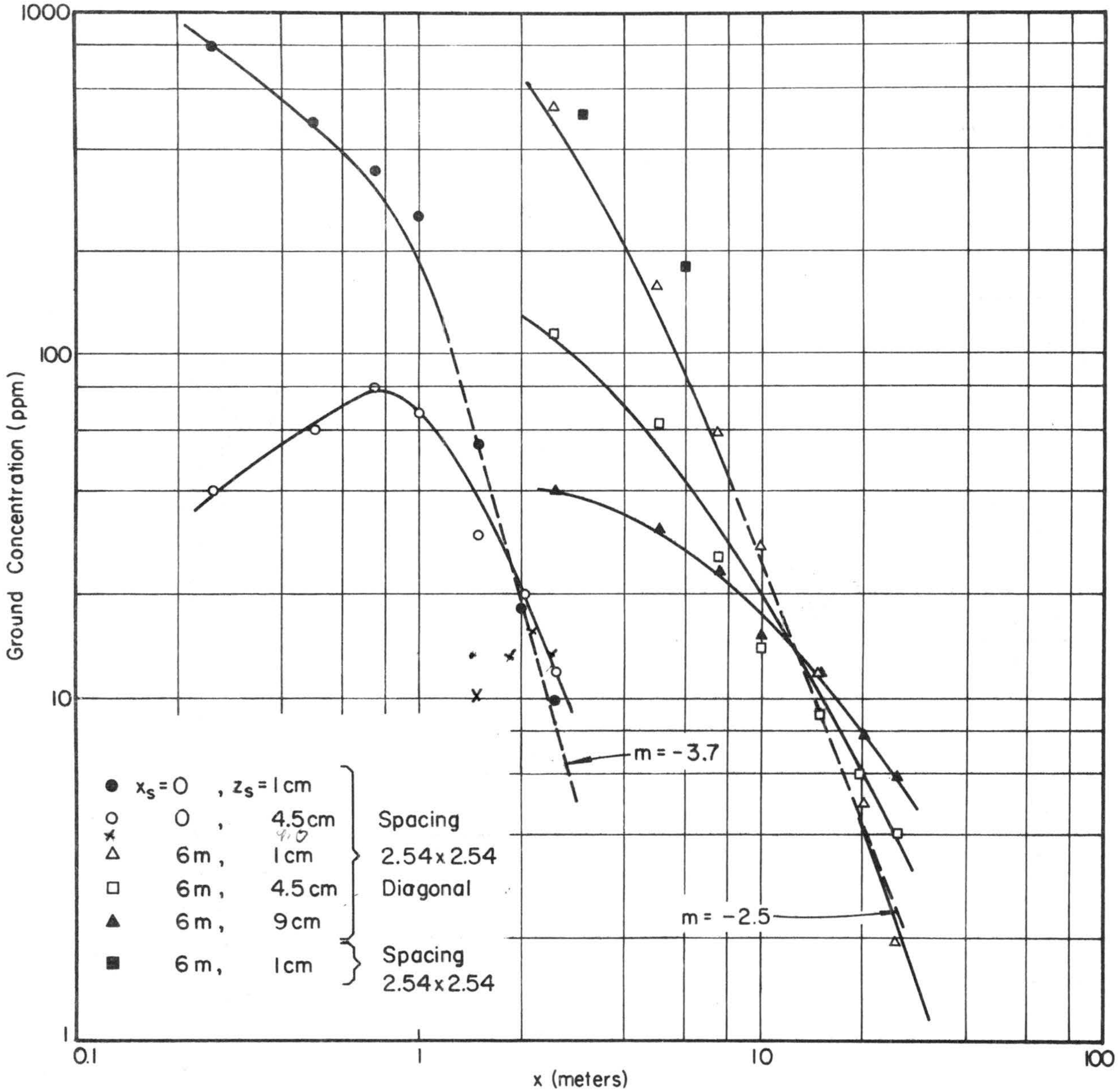


Fig. 43. Variation of ground level concentration with downstream distance

Pegs ϕ = 0.48 cm, h = 9 cm

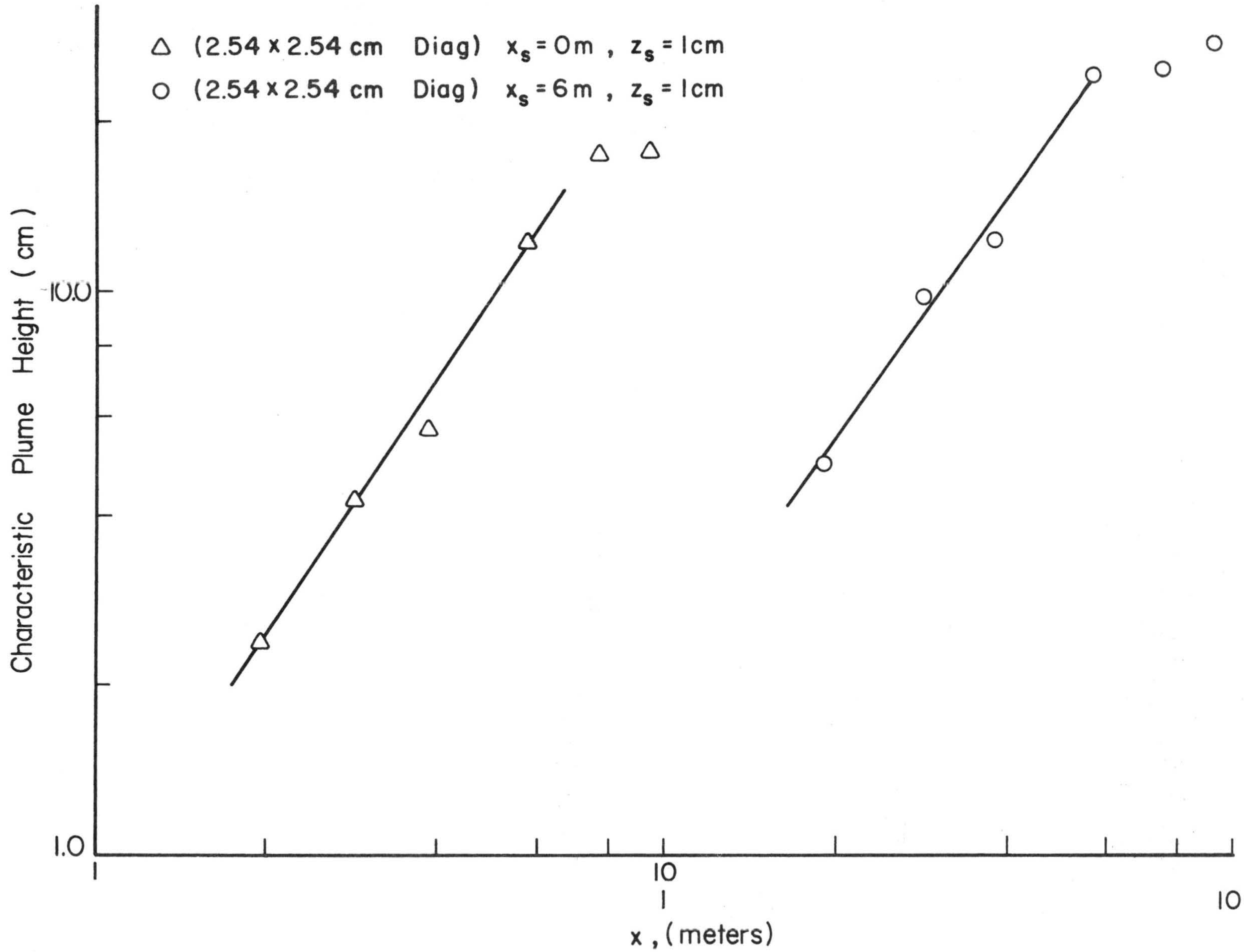


Fig. 44. Variation of characteristic plume height with downstream distance

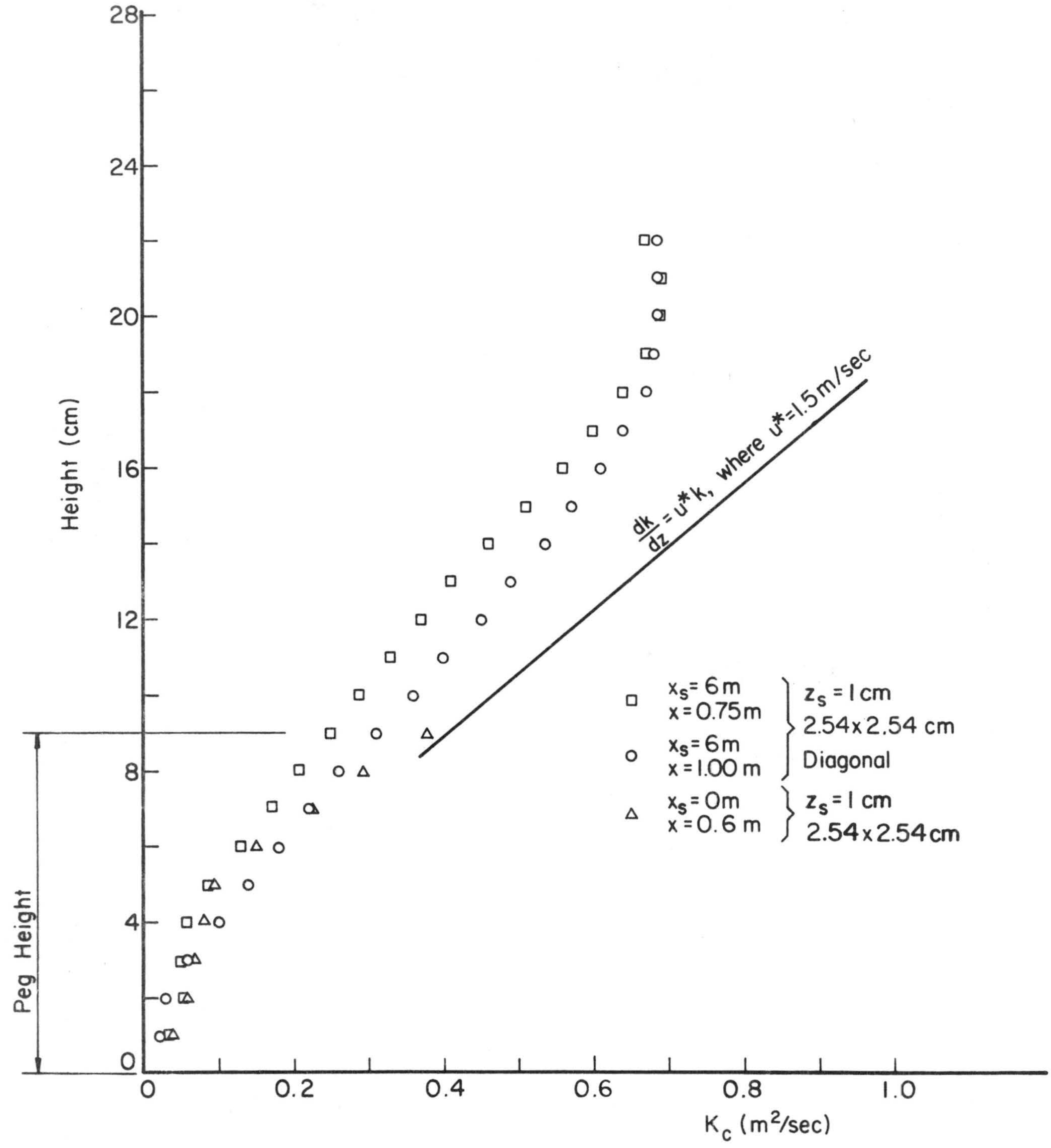


Fig. 45. Coefficient of turbulent diffusion

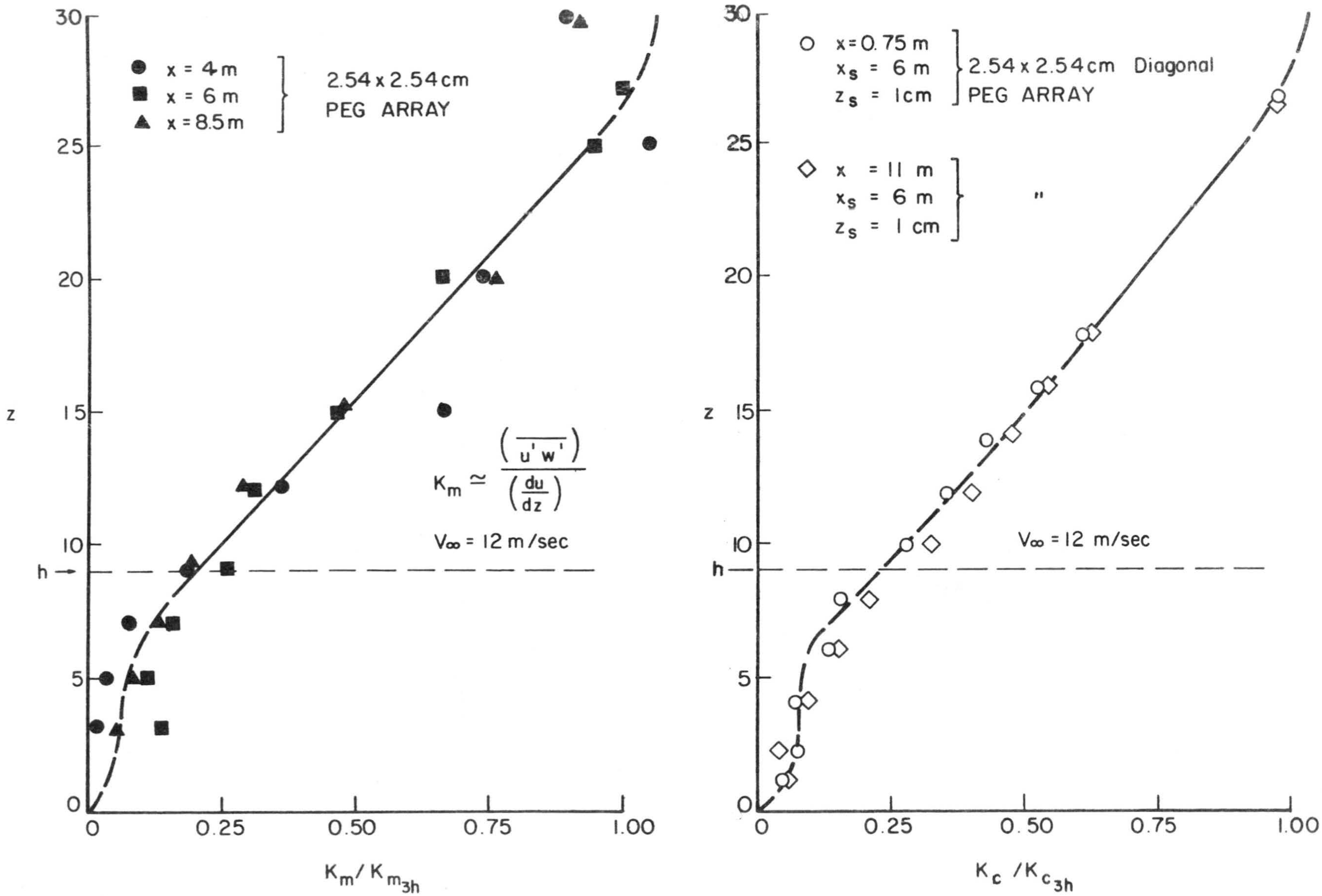


Fig. 46. Mass and momentum turbulent diffusion coefficients

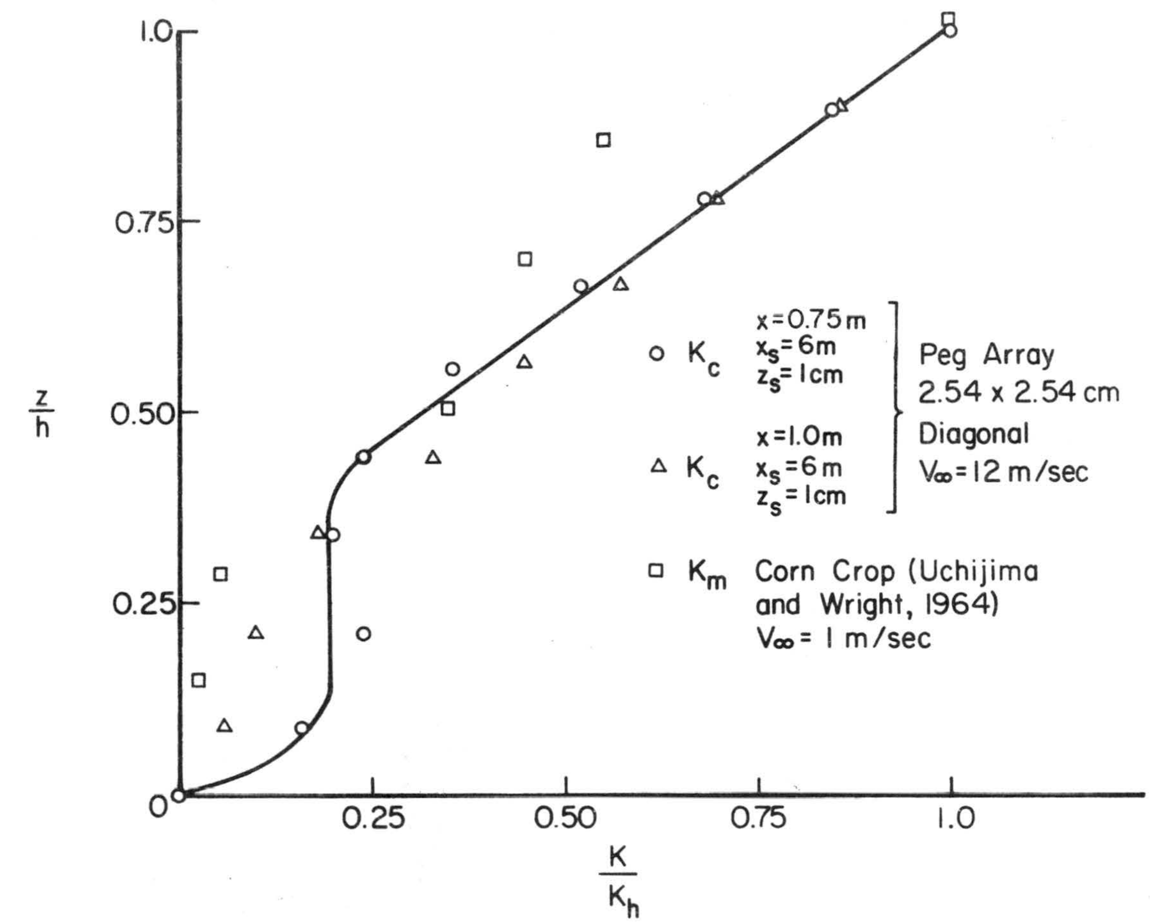


Fig. 47. Dimensionless eddy diffusion coefficient

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3. REPORT TITLE

"GASEOUS PLUME DIFFUSION CHARACTERISTICS WITHIN MODEL PEG CANOPIES"

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report

5. AUTHOR(S) *(Last name, first name, initial)*

Meroney, R. N.; Kesic, D.; and Yamada, T.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July, 1968	71	22

8a. CONTRACT OR GRANT NO. DAAB07-68-C-0423 b. PROJECT NO. 2275 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) CER68-69RNM-DK-TY-3 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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A point source of an air-helium mixture was released continuously at various positions within a simulated canopy composed of 9 cm high pegs, 0.48 cm diameter, spaced in several arrays (2.54 x 2.54, 3.55 x 3.55, and 5.08 x 5.08 cm). Variations of the vertical location of the source revealed the strongly nonisotropic character of diffusion within a canopy with respect to the relative diffusion rates in the lateral and vertical directions. When the source was placed at various downstream distances from the edge of the canopy, it displayed a tendency to exhale the plume near the front of the model canopy and to inhale the plume at distances further downstream. Calculations of the turbulent diffusion coefficient, K, within and above the canopy from the experimental data, reveal both a constant region and a region of linear increase with height increase as suggested by previous authors.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Simulation						
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