NOAA Technical Memorandum ERL ARL-105

A COMPARISON OF MEASURED VERSUS MODEL-PREDICTED EFFLUENT DIFFUSION FOR GROUND RELEASES

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Abstract. A straight-line, Gaussian diffusion model utilizing the $\Delta T/\Delta Z$ diffusion classification scheme is used to compare model predicted versus measured effluent diffusion parameters for ground releases. The measured data came from 8 tracer gas field experiments, 3 of which were conducted with the tracer release being from an actual nuclear reactor facility. Ratios of predicted versus measured χ/Q values were computed as well as ratios of measured versus predicted σ_y and σ_z values. The data were separated according to 1) building and non-building wake experiments, 2) wind speeds equal to or less than 2 m/s and greater than 2 m/s, and 3) stability classes A, D, E-F, and G. All ratios were plotted as a function of stability and the geometric mean and the median for each set was computed.

1. INTRODUCTION

Concern about the validation of atmospheric dispersion models, especially with regard to inadvertent radioactive releases from nuclear reactors, has been heightened as a result of the Three Mile Island Reactor incident. Recent studies by Horst et al. (1979) and Van der Hoven (1976) have attempted to analyze atmospheric tracer concentration data as related to the measured meteorological data which in turn is used as input to the particular diffusion model being tested.

The problem of comparing measured versus predicted effluent diffusion is two-fold. First, an appropriate model which is a mathematical expression of the diffusion process must be selected. Secondly, quantitative values for the variables in the model must be selected by direct measurement or by other appropriate meteorological or physical criteria. The Nuclear Regulatory Commission (1979) in its Regulatory Guide 1.145 (draft) gives guidance as to the model and the selection of input parameters that might be used in making evaluations of postulated hypothetical accidental releases. This guidance could also be used to determine real-time estimates of downwind concentrations in the event of an accidental radioactive release from a reactor. Specifically, the widely-used Gaussian diffusion equation is suggested such that for a ground source and plume centerline determination the expression is:

$$\chi/Q = (\pi\sigma_y\sigma_z u)^{-1}, \qquad (1)$$

where χ is the downwind concentration, Q is the effluent emission rate, u is the wind speed and σ_y and σ_z, as functions of downwind distance, are the crosswind and vertical standard deviation of the concentration distribution. Based on empirical data, Pasquill (1961) categorized the horizontal and vertical spread into six classes ranging from extremely unstable to moderately stable and labeled the classes A through F. Gifford (1968) shows this relationship as a set of σ_y and σ_z curves measured in meters as a function of downwind distance. More recently a curve labeled G representing the very stable case has been added and has been assigned a value of σ_y (G) = 2/3 σ_y (F) and σ_z (G) = 3/5 (F) in Regulatory Guide 1.145.

The Nuclear Regulatory Commission (1972) in Regulatory Guide 1.23 suggests diffusion classification schemes based on temperature gradient in the vertical ($\Delta T/\Delta Z$) or the standard deviation of the horizontal wind direction (σ_θ). The $\Delta T/\Delta Z$ method is the one most widely used partly because of its ease of measurement. A difficulty encountered with the σ_θ method of classification is that most wind measuring equipment at reactor sites do not respond to winds below about 1 mile per hour. Another difficulty in using σ_θ to quantify both σ_y and σ_z under low wind, inversion conditions is that σ_θ may often be large, indicating large horizontal spread, but also then implying greater vertical diffusion than is actually the case. It is realized that using the $\Delta T/\Delta Z$ scheme to quantify both the diffusion in the horizontal and in the vertical also has its difficulties, not the least of which is the assumption that limited vertical diffusion, which one expects under stable, light wind situations, will also hold true in the horizontal diffusion. As a means towards rectifying this apparent underprediction of horizontal diffusion under stable conditions using the $\Delta T/\Delta Z$ classification scheme, Regulatory Guide 1.145 suggests a correction factor to increase σ_y for neutral and stable conditions for winds less than 6 m/s. Since the straight-line, Gaussian diffusion model utilizing the $\Delta T/\Delta Z$ diffusion classification scheme is the method most widely used in reactor safety assessment reports, the analysis which is to follow uses the same method to compare model-predicted versus measured concentrations and diffusion parameters, but without the "meander" correction factor mentioned above.

2. FIELD DATA

The measured data comes from a number of tracer field experiments conducted during the last two decades and listed in Table 1. In addition to separating the data by $\Delta T/\Delta Z$ stability classes, a further distinction was made between wind speeds equal to or less than 2 m/s and those greater than 2 m/s. Furthermore, the field experiments conducted around an actual nuclear reactor facility and thus involving a building wake effect were separated from the open field experiments. The dark triangle, square and circle listed in Table 1 are, respectively, the San Onofre, Rancho Seco, and EOCR reactor facilities from which tracer diffusion experiments were conducted. The open symbols are open field tests of varying terrain described by Van der Hoven (1976).

3. DATA ANALYSIS

From the experimental data found in the references listed in Table 1, the measured peak χ/Q and the σ_y values along given arcs were extracted. Using these values in addition to the wind speed, a σ_z value could be calculated from Equation 1. The following ratios were then computed:

(1) Predicted versus Measured χ/Q

(2) Measured versus Predicted σ_y

(3) Measured versus Predicted σ_z

Table I

Symbol	Location	Reference
○	Idaho	Izlitzer et al (1963) and Sagendorf et al (1974)
+	Washington	Nickola (1977)
◊	Pennsylvania	Metropolitan Edison Co. (1972)
*	Louisiana	Gulf States Utilities (1974)
□	Tennessee	Wilson et al (1976)
▲	California	Septoff et al (1977)
■	California	Start et al (1977)
●	Idaho	Start et al (1980)

In each case a ratio value greater than 1.0 would indicate an overprediction of effluent concentration. Figures 1 through 6 are plots of the geometric mean and median of these ratios as a function of stability, wind speed (equal to or less than 2 m/s and greater than 2 m/s), and building or non-building wake. The ratio plots for all distances combined show several general features, namely:

1. A decrease in ratio from stable to unstable cases.
2. Lower ratios for wind speeds above 2 m/s.
3. Ratios at 1.0 or below for the unstable (Type A) cases.
4. Very little difference between the geometric mean and the median.
5. Generally higher ratios for the building wake cases versus the non-building cases.
6. A decrease in χ/Q ratio from the E-F stability to the G stability for speeds equal to or less than 2 m/s, with the reverse being true for speeds above 2 m/s.
7. A consistent decrease in σ_y ratios from the very stable G type to the very unstable A type.

Figures 7 through 26 are the plots of the χ/Q, σ_y, and σ_z ratios as a function of downwind distance. The data are separated by diffusion type (A, D, E-F and G) and wind speed as before. The solid symbols are the building wake experiments while the open symbols represent open terrain tracer releases as identified in Table 1.

In general, there does not seem to be any recognizable relationship between the various χ/Q ratios (Figs. 7-14) and downwind distance. For example, for Type E-F, Fig. 9 shows a wide spread of χ/Q ratios over almost 4 orders of magnitude between downwind distances of 100 to 2000 m and a wind speed equal to or less than 2 m/s. The geometric mean in this case was a ratio of 148 (Fig. 1) for the building wake cases and 44 (Fig. 2) for the non-building wake experiments. No χ/Q ratio in Fig. 9 went below 2.0. Combining the neutral and stable cases (D, E-F, and G) for all tests regardless of speed and emission configuration for a total of 423 χ/Q ratios, only 3 were below 1.0. These 3 cases (Figs. 12 and 13) were non-building wake experiments at Hanford, Washington with speeds of 2.9, 4.8 and 7.4 m/s at a height of 10 m.

The σ_y ratios, similarly, do not show any recognizable trend with downwind distance as illustrated in Figs. 15 through 18. However, the spread of σ_y ratio values is only about one order of magnitude (factor of 10) whereas χ/Q ratios showed a range of 10^4.

As noted earlier in section 3, the "measured" σ_z is actually not a measured value from a distribution of concentration in the vertical, but is calculated such that, in reality, the χ/Q ratio equals the σ_y ratio multiplied by the σ_z ratio. This, in effect, makes the σ_z ratio a residual factor after the σ_y ratio has been calculated from measurements. It is not surprising then, to note that since the σ_y ratios vary by only a factor of 10 (Figs. 15 through 18), the σ_z ratios (Figs. 19-26) are similar to the χ/Q ratios which vary over a range of 10^3 to 10^4 (Figs. 7-14).

4. DISCUSSION

Since the practical concern in this instance is the accidental release of radioactive effluents from nuclear reactors assuming a ground release, the results from the building wake experiments would be directly applicable. The predicted versus measured concentration ratios of a surface release from a building (Fig. 1) shows that on the average (geometric mean), there is an overprediction for the very stable, type G cases with speeds equal to or less than 2 m/s by a factor of 100. The contribution to this overprediction by horizontal diffusion as indicated by the σ_y ratio (Fig. 3) is about 8 and for the vertical diffusion as indicated by the σ_z ratios (Fig. 5) is about 10. There seems to be very little difference between the with or without building wake configuration for the average σ_y ratio for wind speeds equal to or less than 2 m/s (Figs. 3 and 4). For the slightly to moderately stable conditions (type E-F) and low wind speeds, the concentration ratio (χ/Q) is also a factor of about 100 (Fig. 1), and drops down to 20 for neutral (type D) conditions and 2 for very unstable conditions.

The preceding discussion would indicate that, because of the larger overprediction of downwind concentrations using the Gaussian model and the temperature gradient in the vertical as a stability criteria, either a new model needs to be used or the criteria used to quantify the diffusion parameters needs to be changed or adjusted. One approach might be the adjustment (increase) in the σ_y values under low wind speed, inversion conditions in order to account for the meander effect. The Regulatory Guide 1.145 presents such a scheme allowing a factor of 6 increase in σ_y for very stable conditions and wind speeds less than 2 m/s. A second approach might be to use the relationship between σ_θ and σ_y as shown in Regulatory Guide 1.23, or as recommended by Draxler (1976). This does, however, present a problem for wind speeds below the starting speed of the anemometer when, essentially, the instrument is not activated. At present, in Regulatory Guide 1.145, no adjustment is made to σ_z, the vertical diffusion parameter. One might consider using a building wake adjustment to σ_z to account for increased vertical diffusion behind the reactor building complex. However, the present building wake model in Regulatory Guide 1.145 is hardly sufficient to allow for the factor of 10 or more shown for the σ_z ratio (Fig. 5) for neutral and stable conditions with winds equal to or less than 2 m/s.

The use of an entirely different model such as the particle-in-cell approach still requires a criteria to parameterize the diffusion rates. Similarly, the use of K-theory models requires the selection of diffusivity rates. Still another approach is a segmented Gaussian plume model (Sagendorf, 1974), but this too requires diffusion rate parameterization in addition to computations every few minutes with a measured wind speed and direction for each segment.

5. CONCLUSION

For the realistic situation of an inadvertent ground level release of radioactive effluents from a nuclear reactor complex under neutral and stable temperature lapse rates, measured concentrations are shown to be considerably lower than Gaussian-predicted concentrations when the temperature gradient with height is used as a criteria for selecting the vertical as well as the horizontal diffusion rates. The suggested meander adjustment to σ_y as stated in the proposed Regulatory Guide 1.145 is very similar to the average σ_y values shown in Fig. 3 of this study. It would also appear from an inspection and comparison of Figs. 5 (building wake) and 6 (non-building wake) that a similar or somewhat greater factor would be appropriate for σ_z due to what might be called a building wake effect.

6. ACKNOWLEDGMENT

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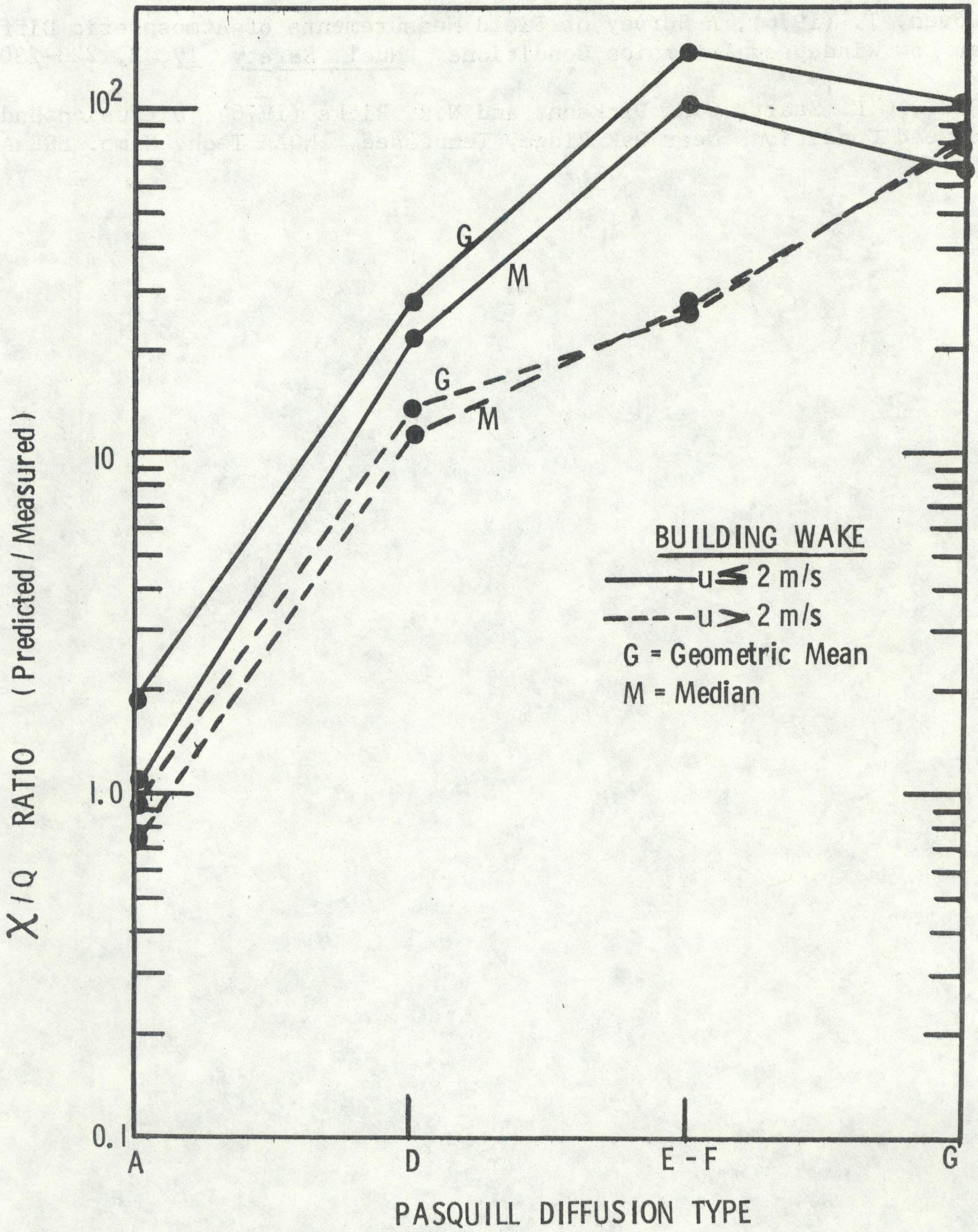


Fig. 1. Average χ/Q Ratio versus Diffusion Type for Building Wake Experiments.

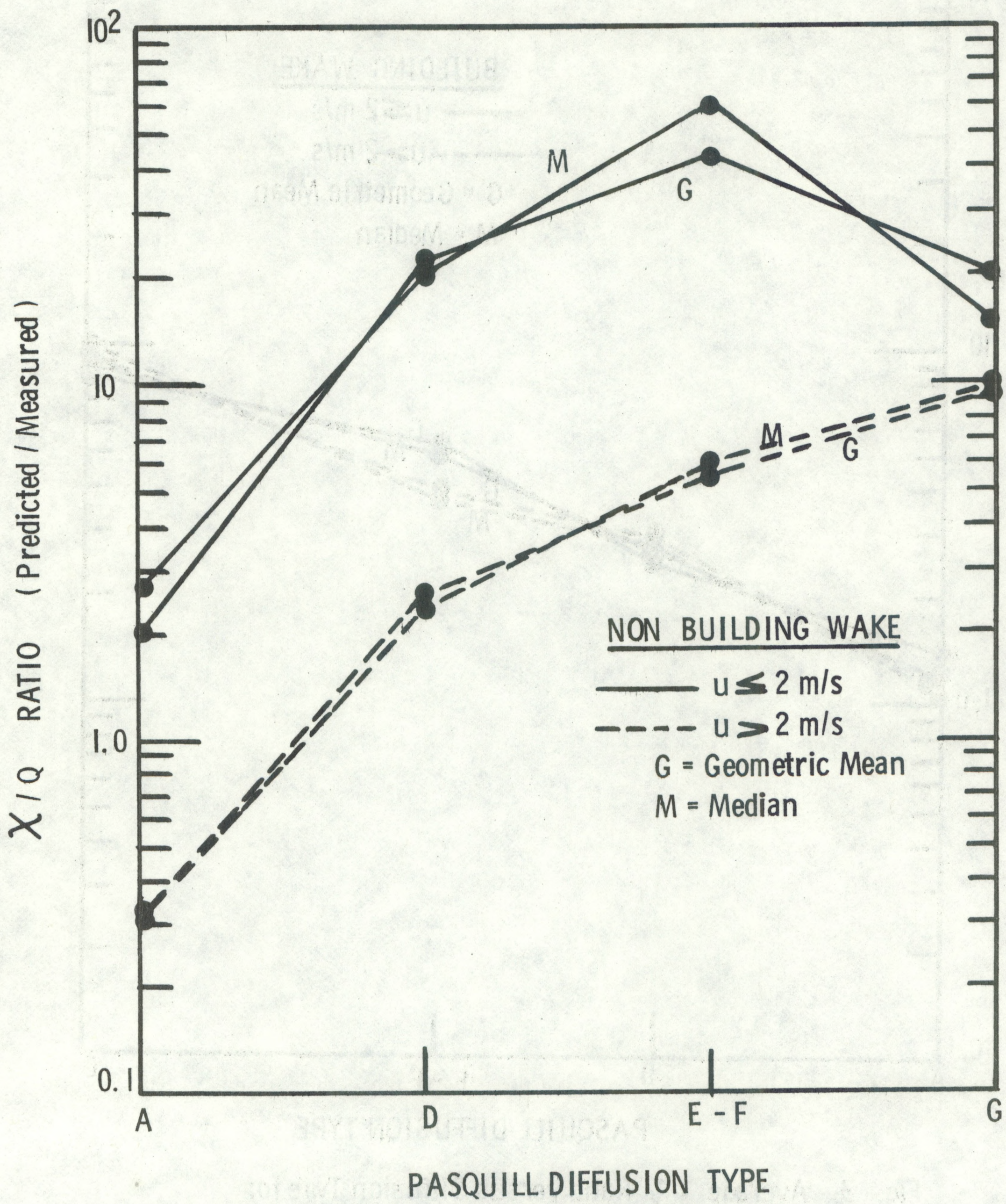


Fig. 2. Average χ/ Q Ratio versus Diffusion Type for Non-Building Wake Experiments.

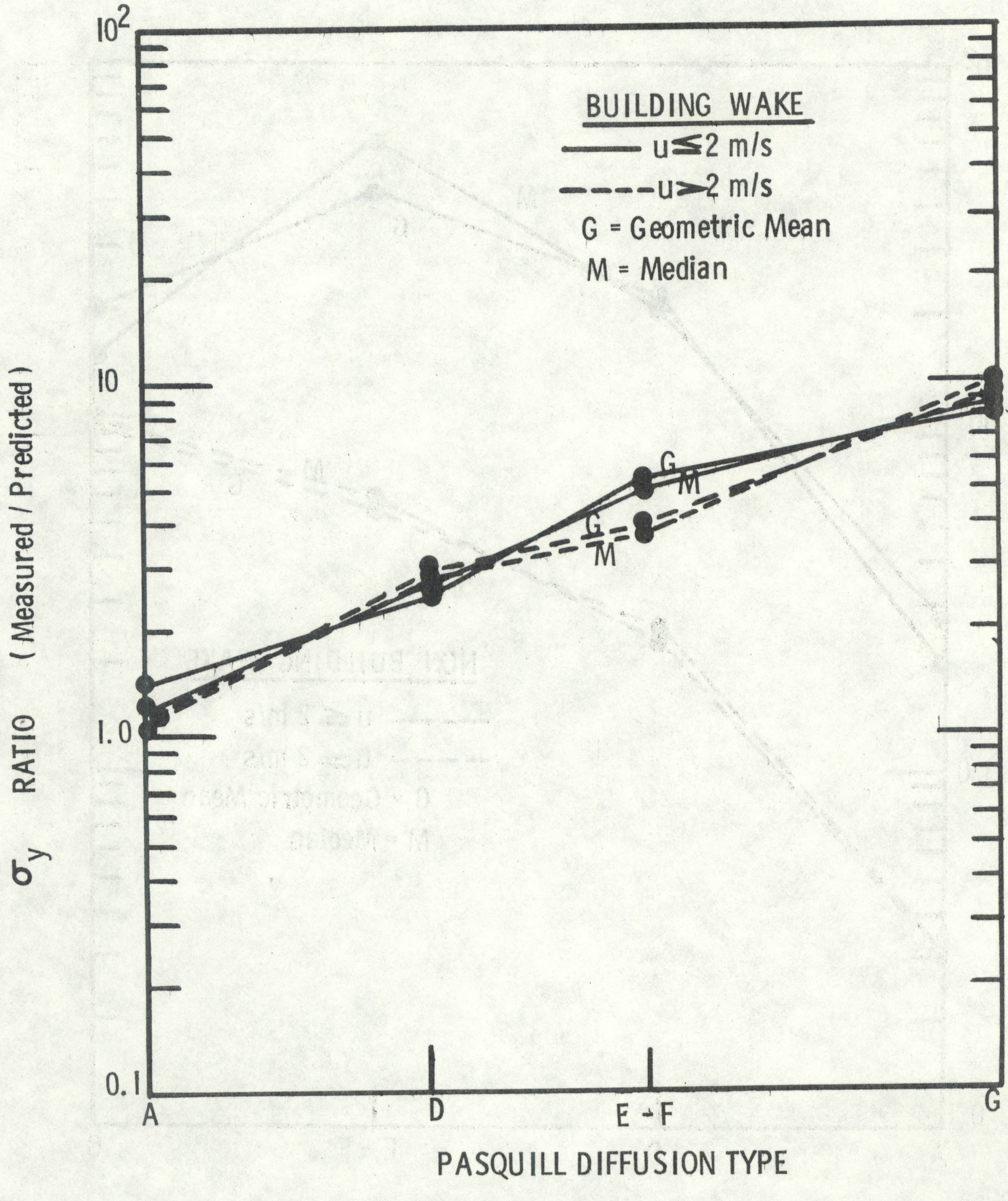


Fig. 3. Average σ_y Ratio versus Diffusion Type for Building Wake Experiments.

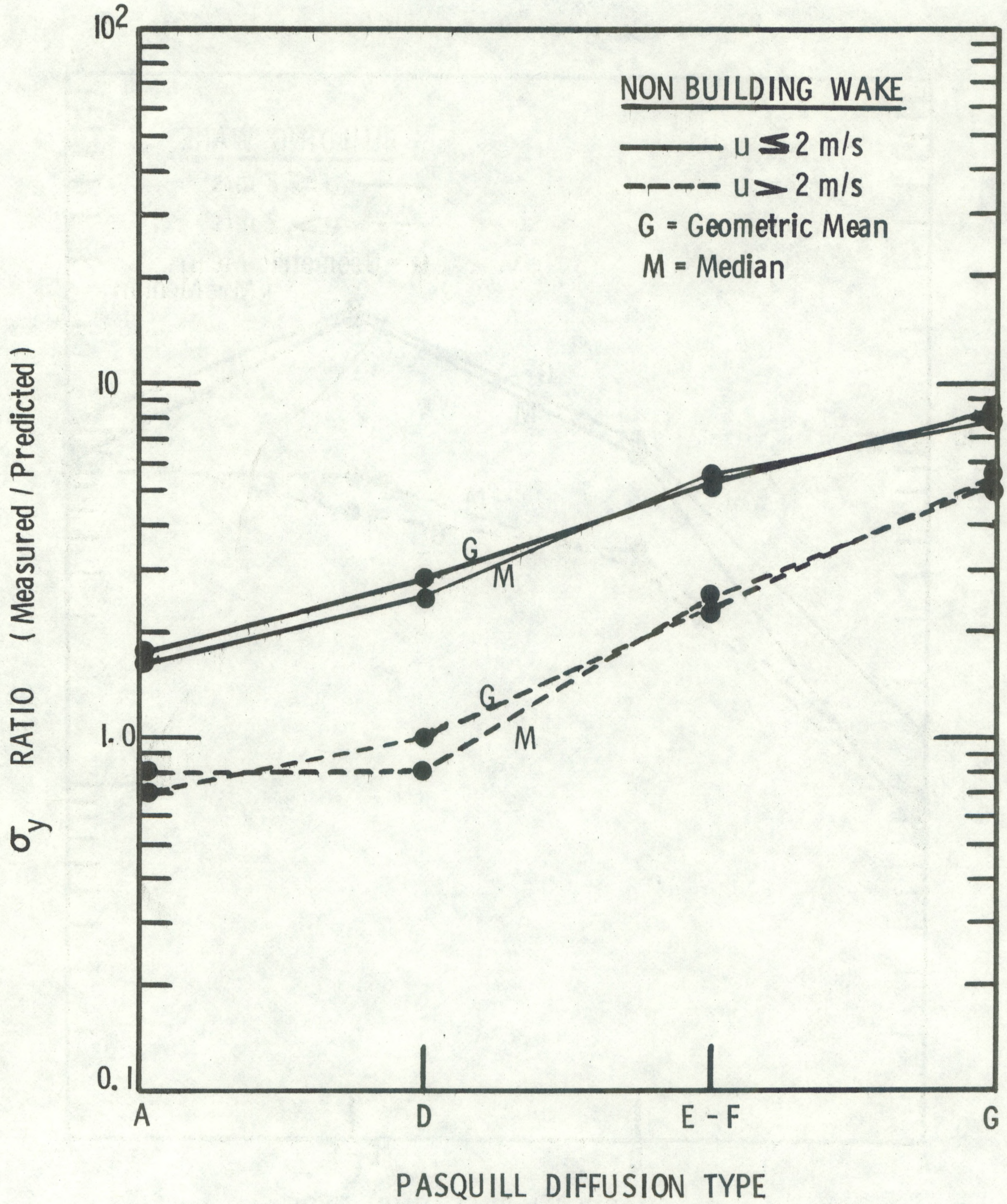


Fig. 4. Average σ_y Ratio versus Diffusion Type for Non-Building Wake Experiments.

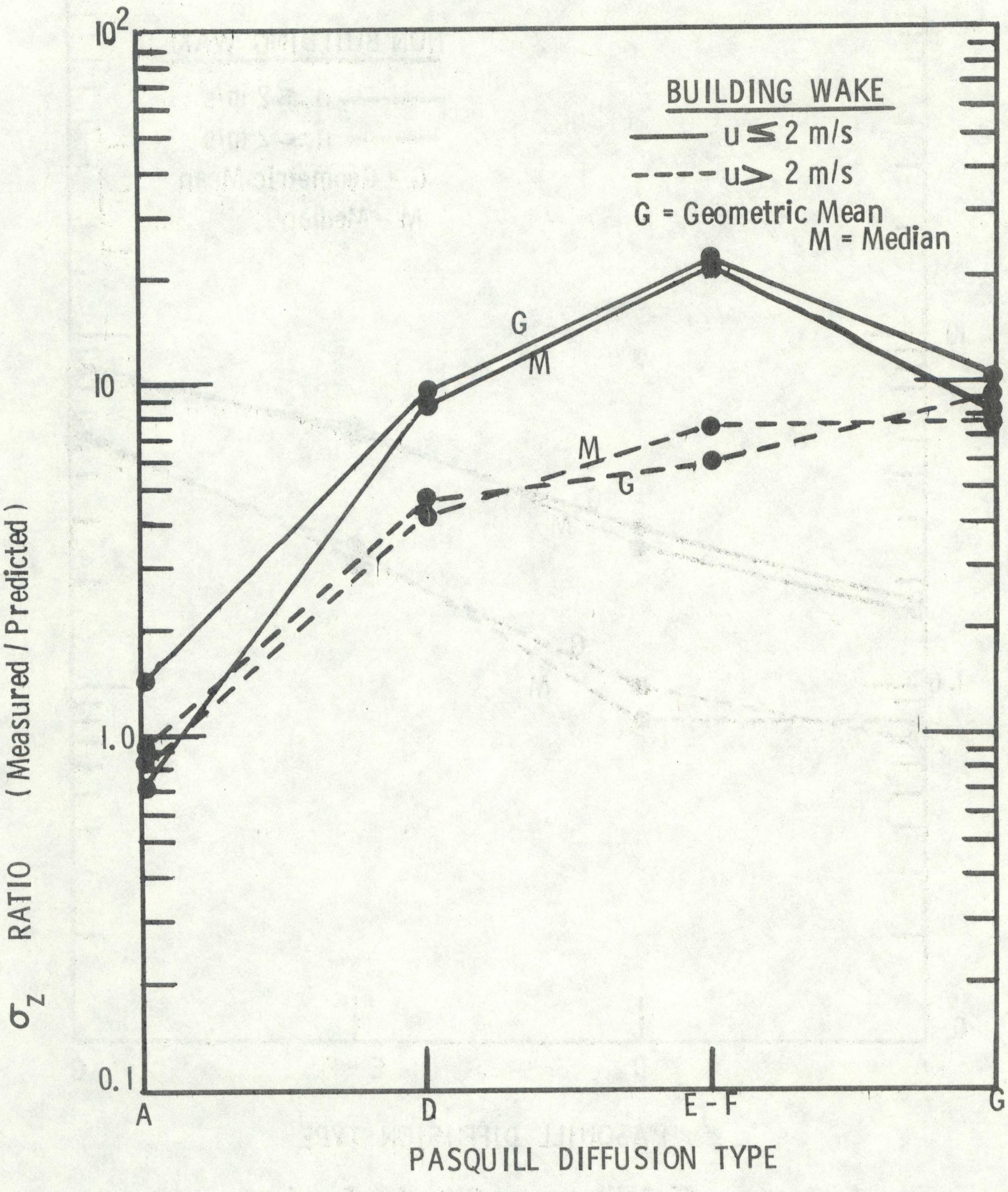


Fig. 5. Average σ_Z Ratio versus Diffusion Type For Building Wake Experiments.

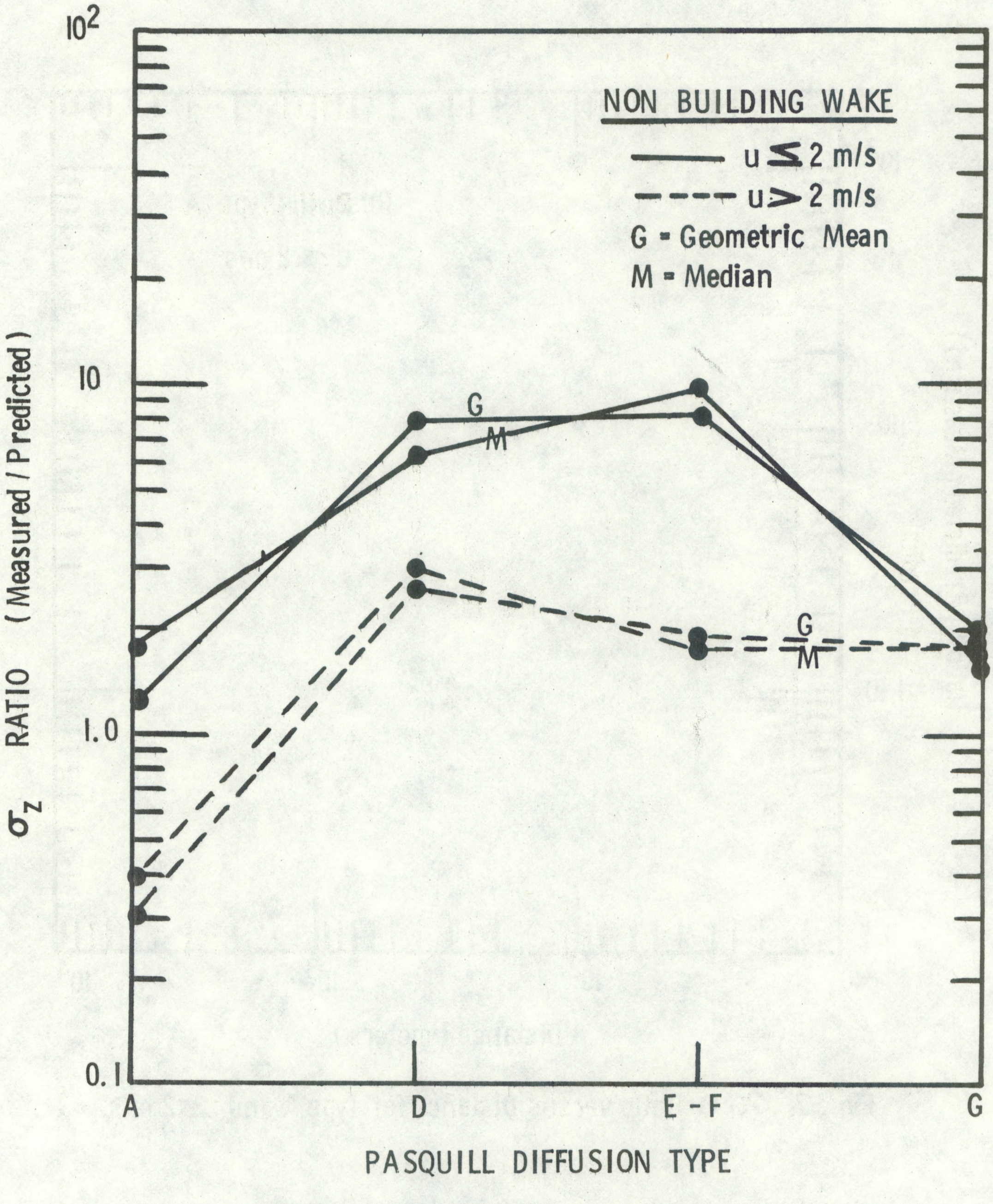


Fig. 6. Average σ_Z Ratio versus Diffusion Type for Non-Building Wake Experiments.

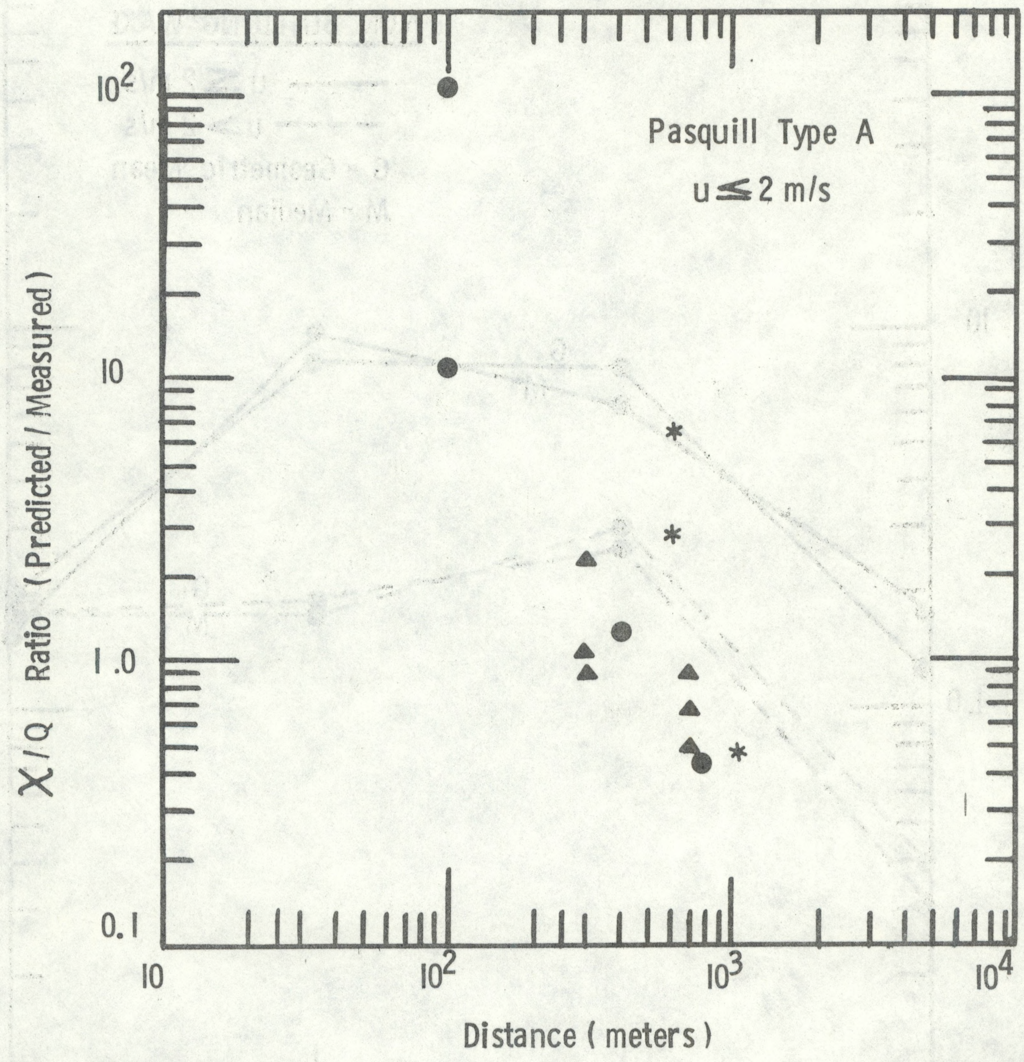


Fig. 7. χ/Q Ratio versus Distance for Type A and $u \leq 2$ m/s.

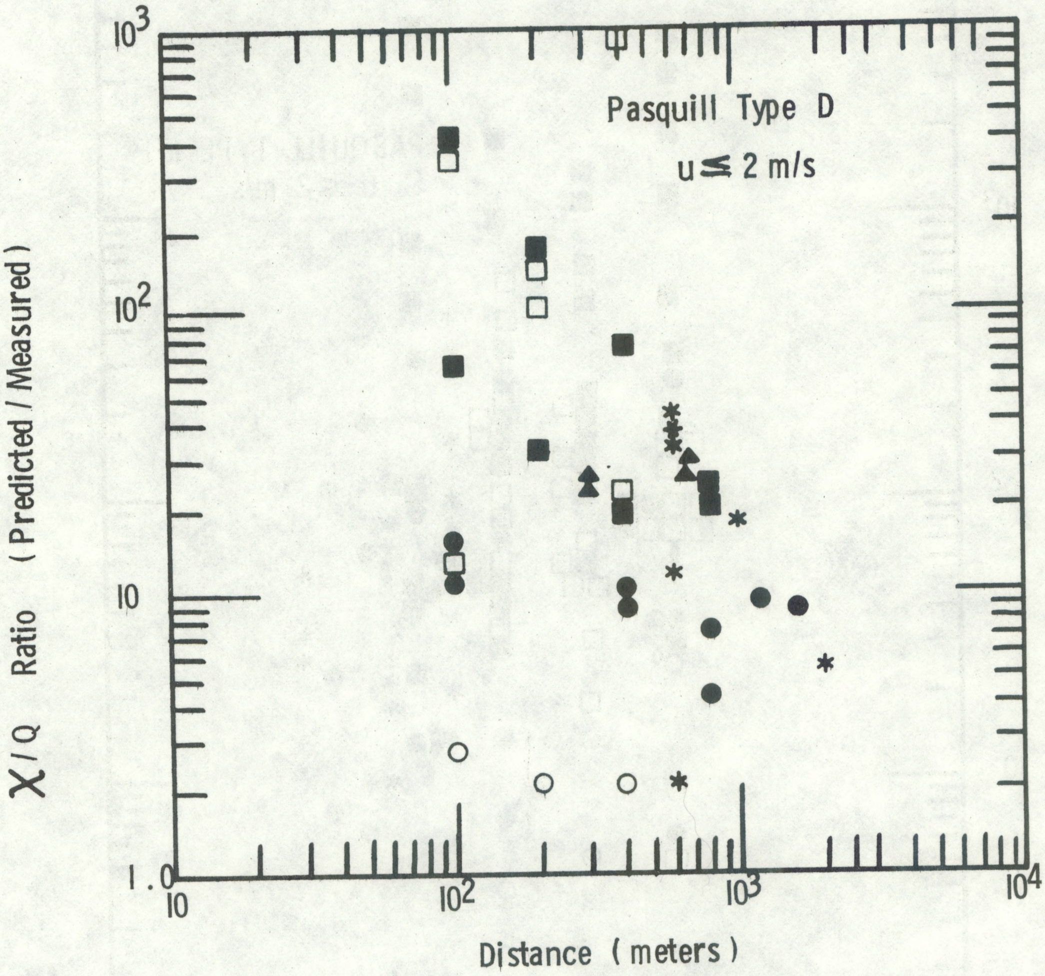


Fig. 8. χ/ Q Ratio versus Distance for Type D and u≤2 m/s.

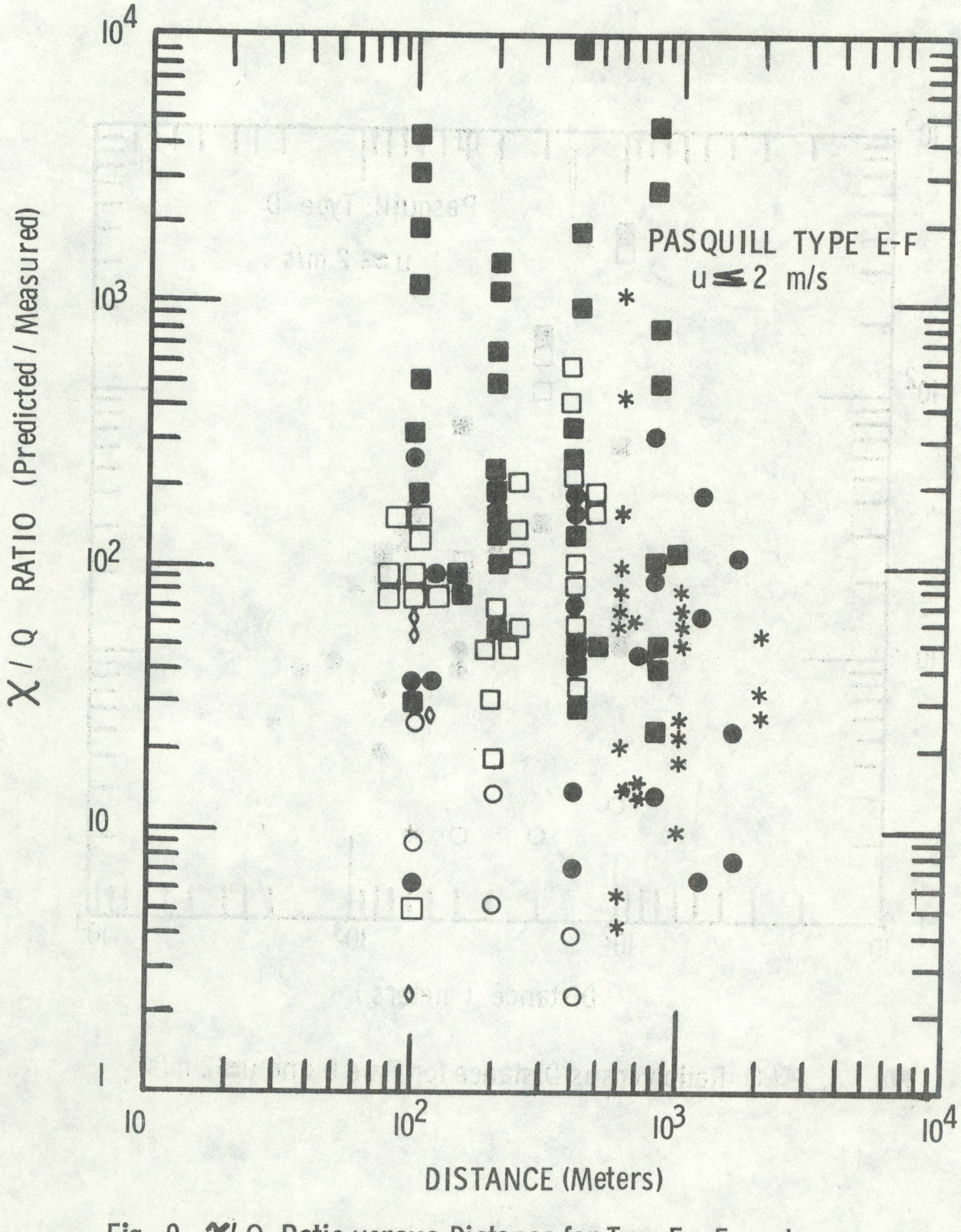


Fig. 9. X/Q Ratio versus Distance for Type E - F and u ≤ 2 m/s.

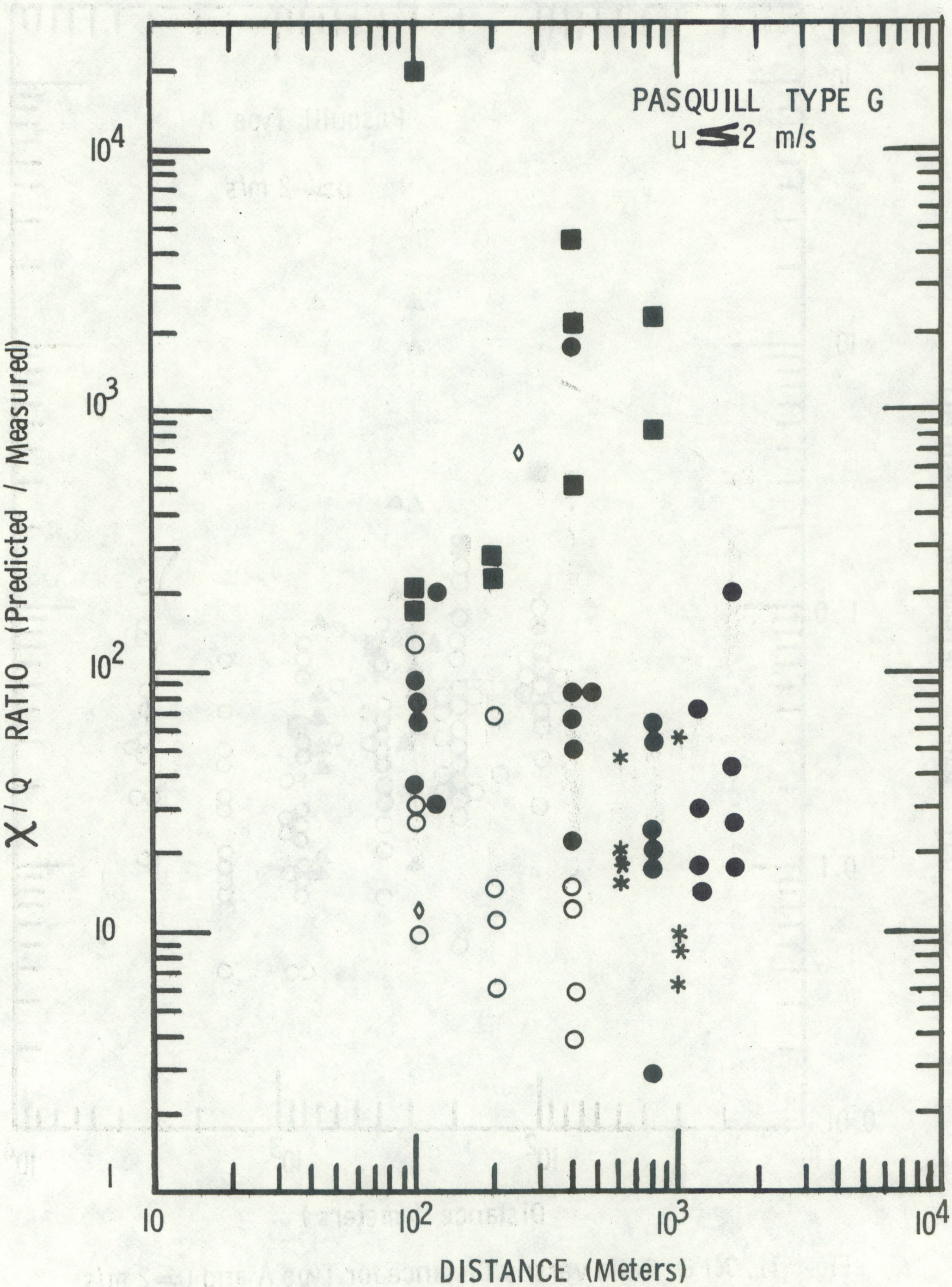


Fig. 10. χ/ Q Ratio versus Distance for Type G and u ≤ 2 m/s.

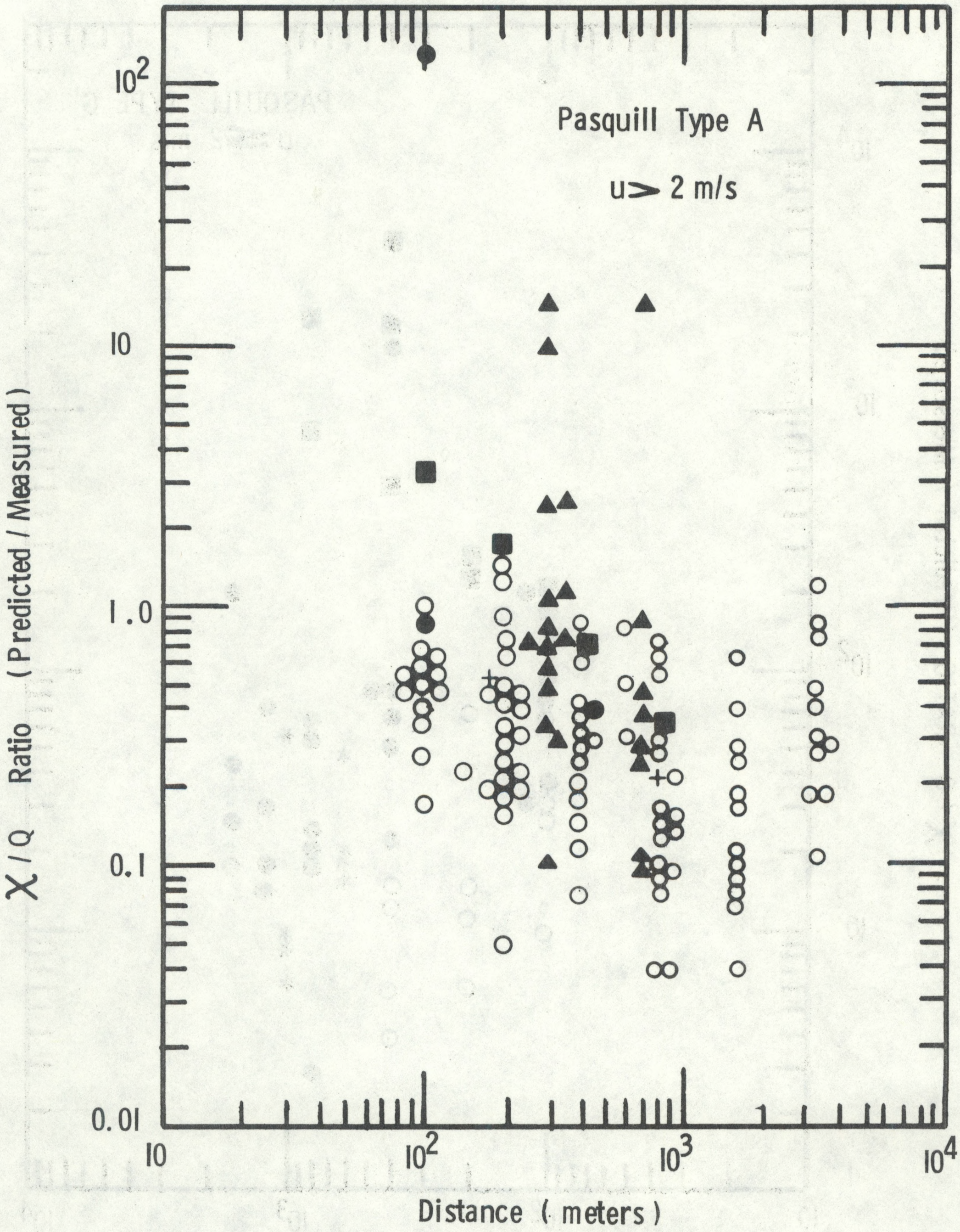


Fig. 11. X/Q Ratio versus Distance for Type A and u>2 m/s.

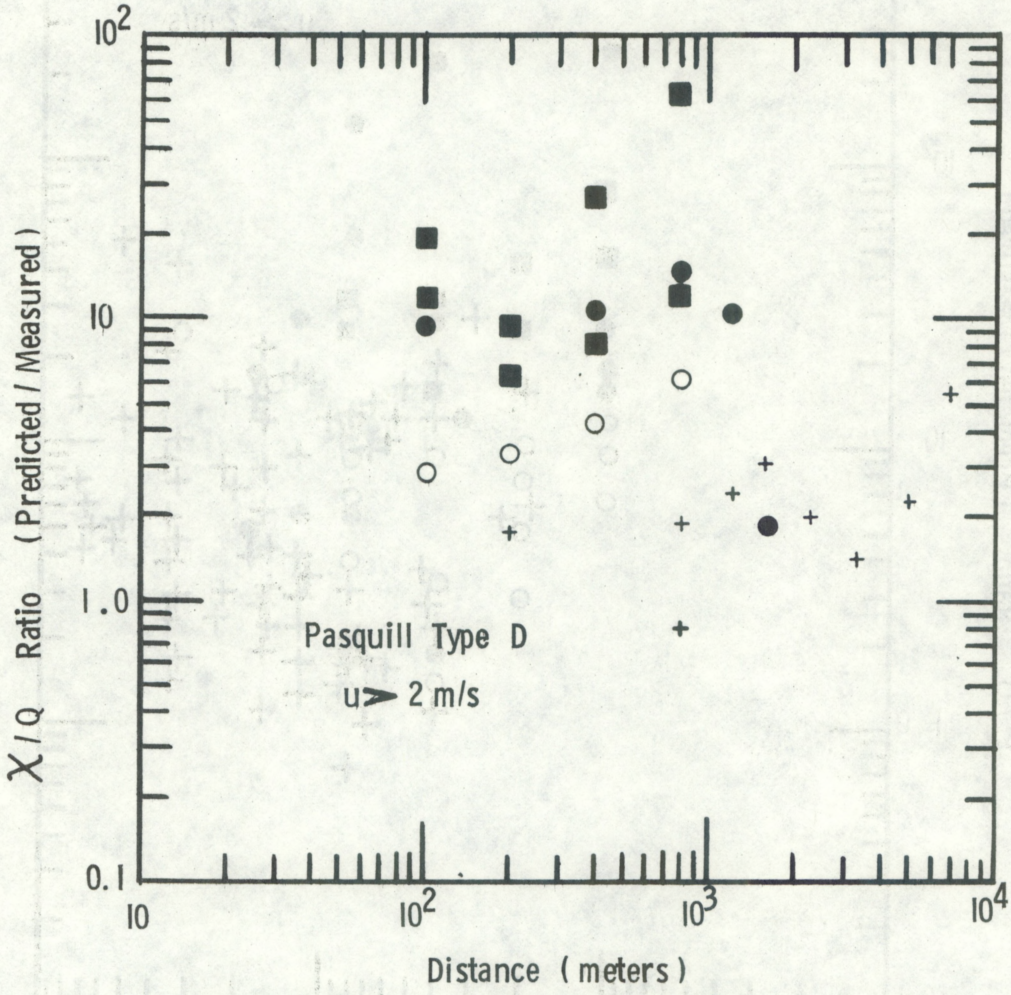


Fig. 12. χ/ Q Ratio versus Distance for Type D and u>2 m/s.

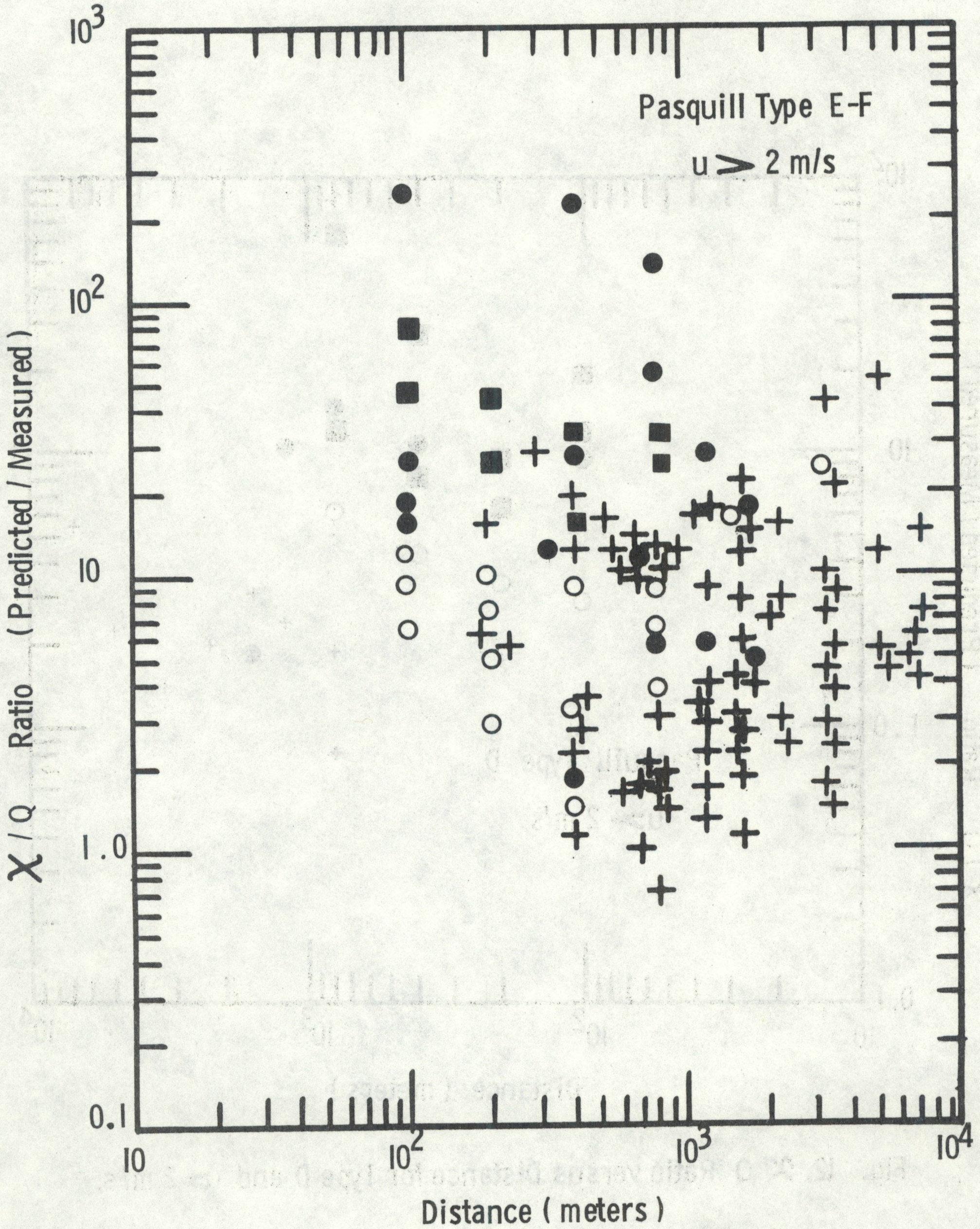


Fig. 13. χ/ Q Ratio versus Distance for Type E - F and u>2 m/s.

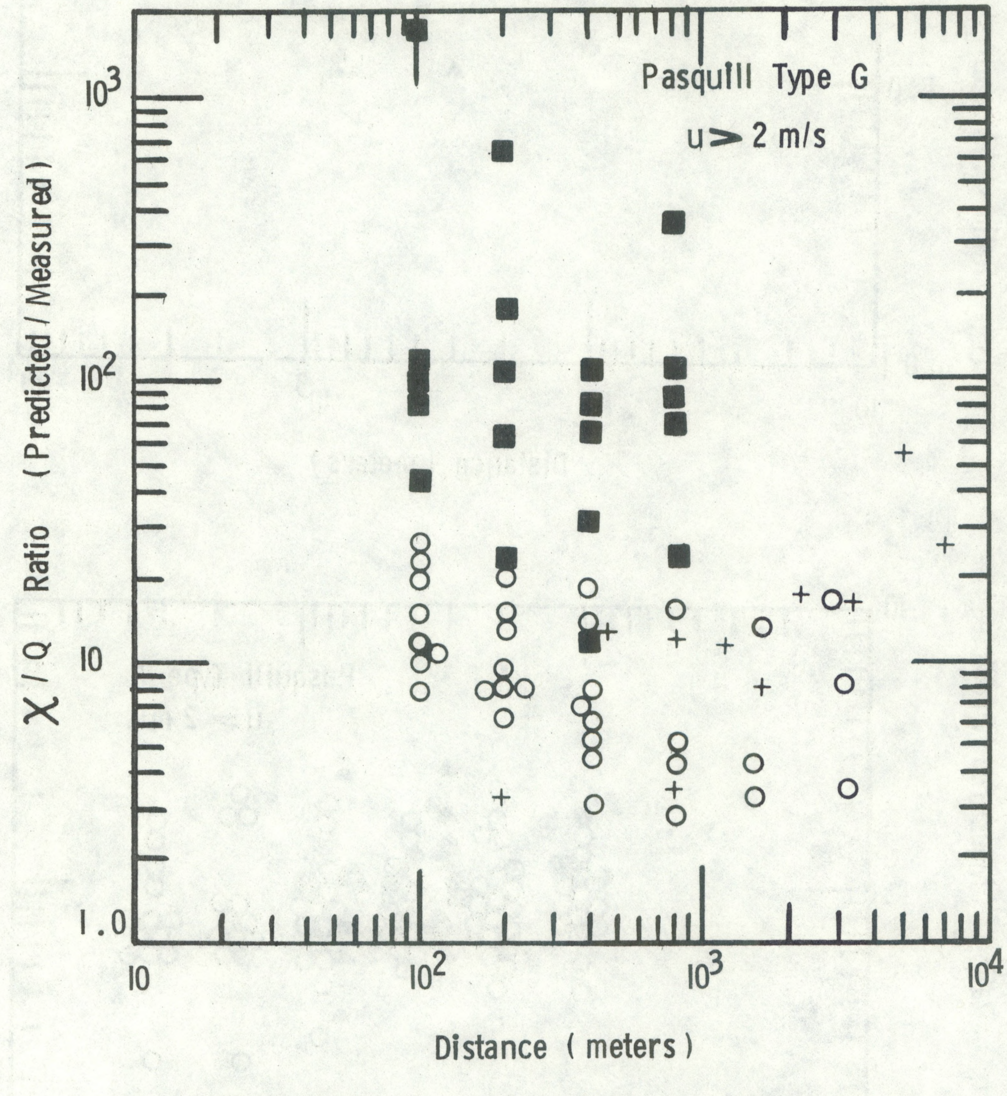


Fig. 14. X/ Q Ratio versus Distance for Type G and u > 2 m/s

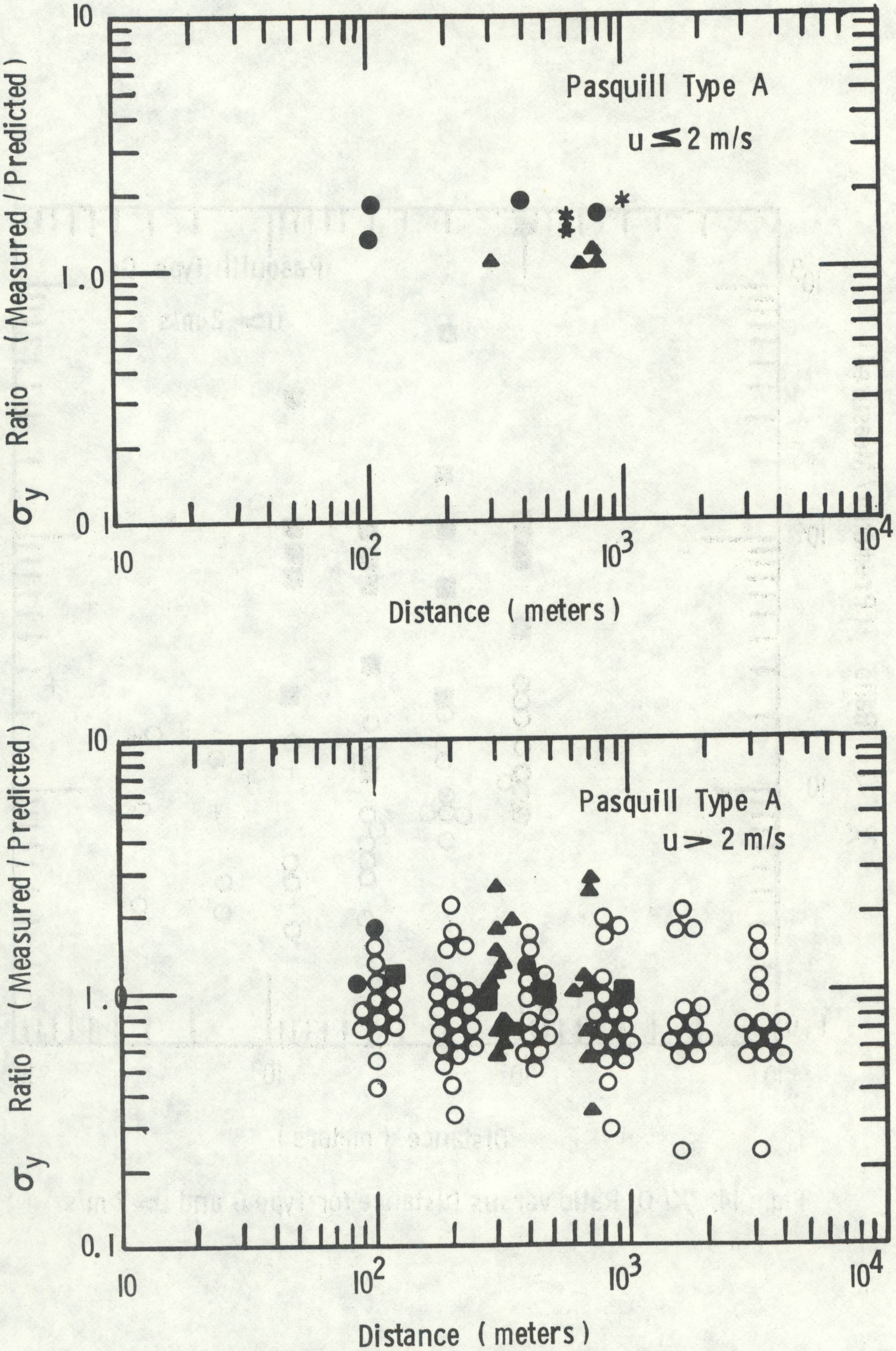
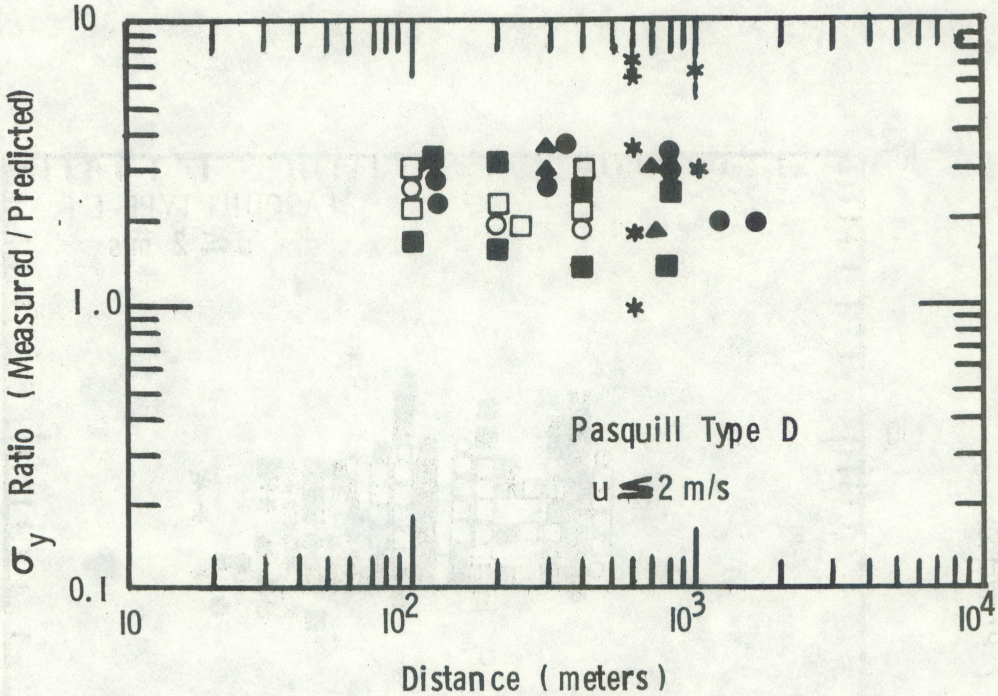


Fig. 15. σ_y Ratio versus Distance for Type A, u≤2 m/s and u>2 m/s.



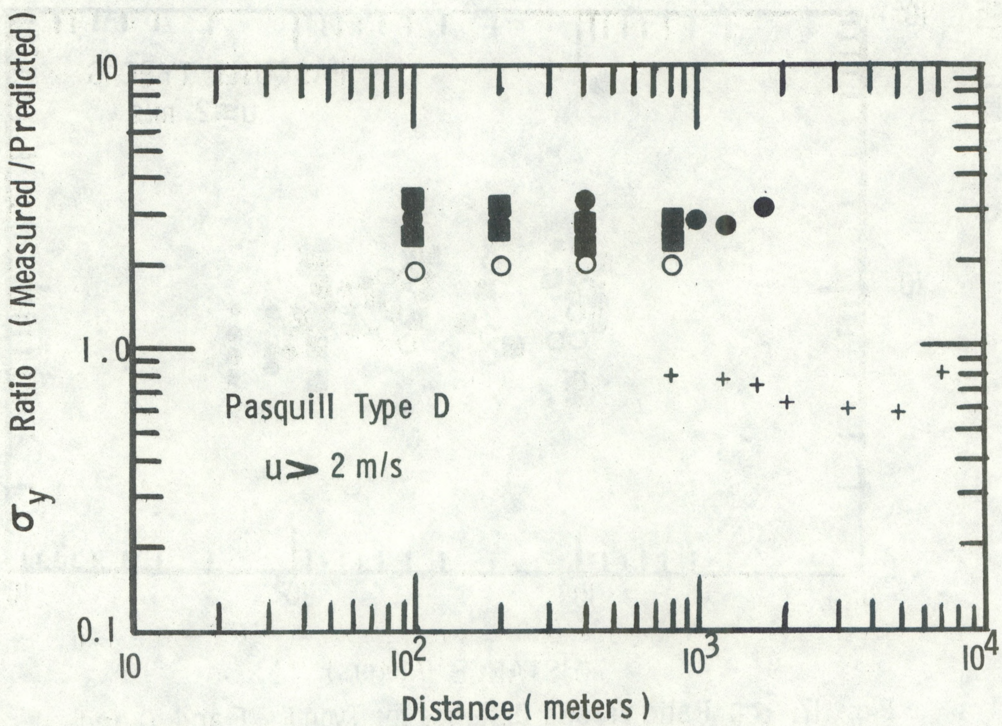


Fig. 16. σ_y Ratio versus Distance for Type D, u ≤ 2 m/s and u > 2 m/s.

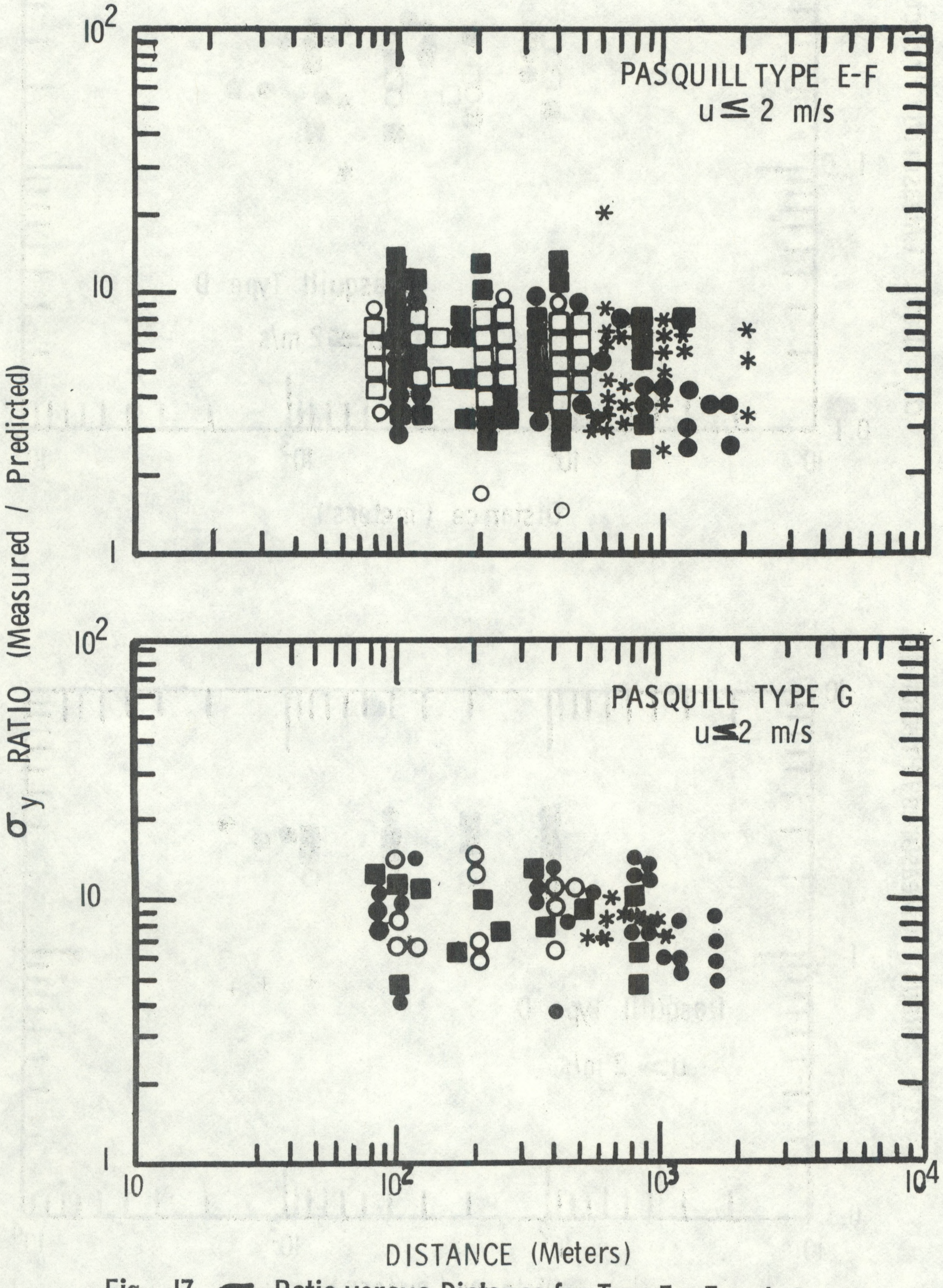
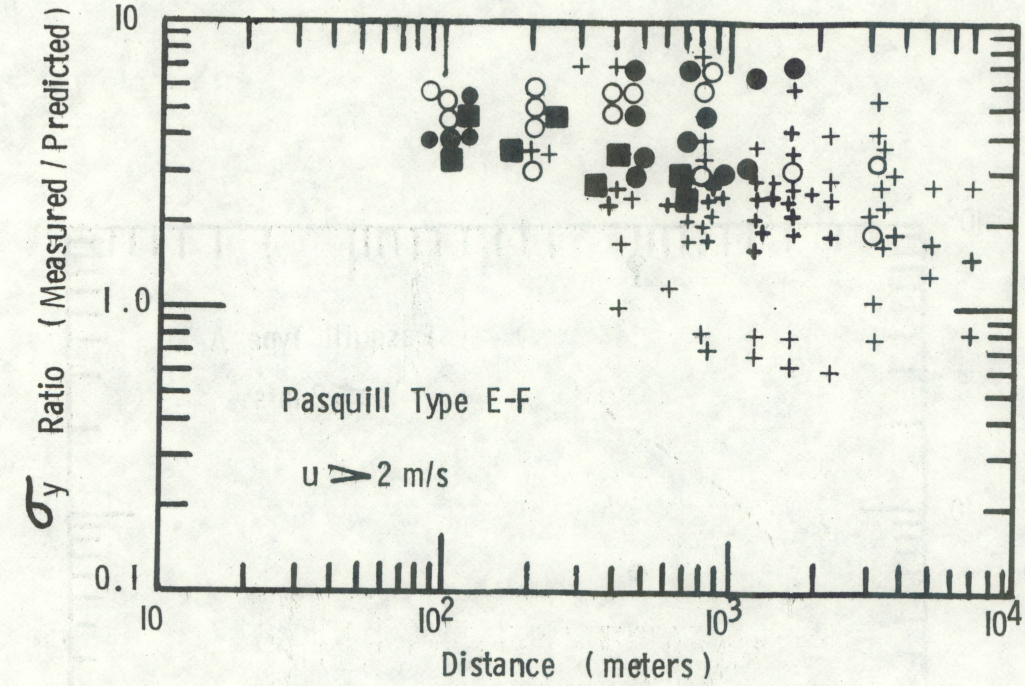


Fig. 17. σ_y Ratio versus Distance for Type E - F and G and $u \leq 2$ m/s



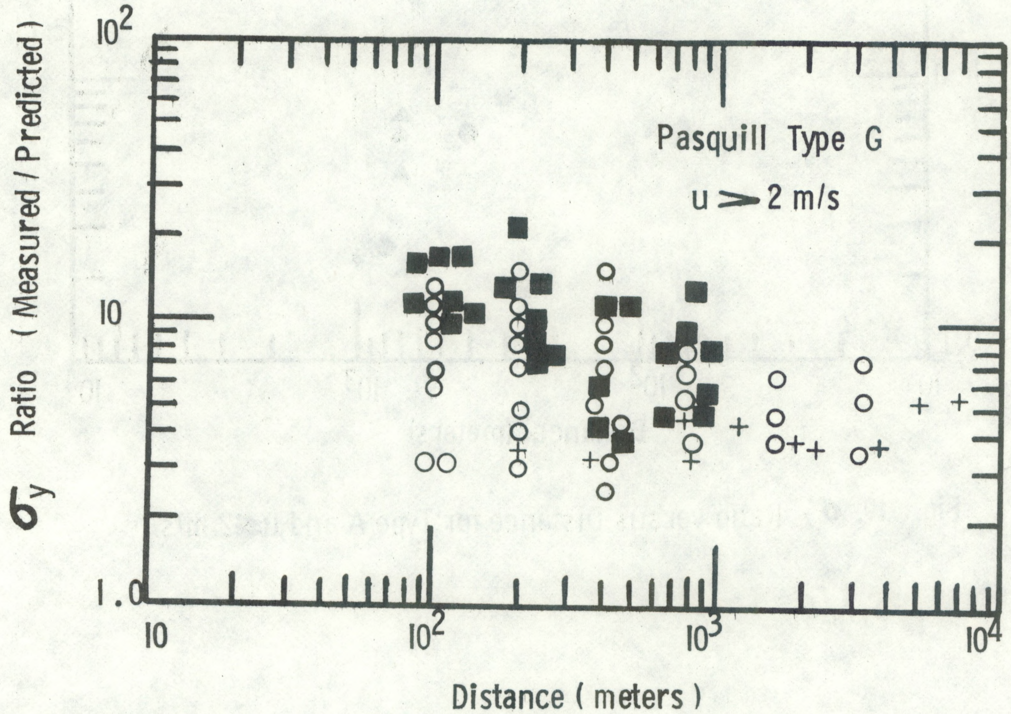


Fig. 18. σ_y Ratio versus Distance for Type E - F and G and $u \geq 2$ m/s.

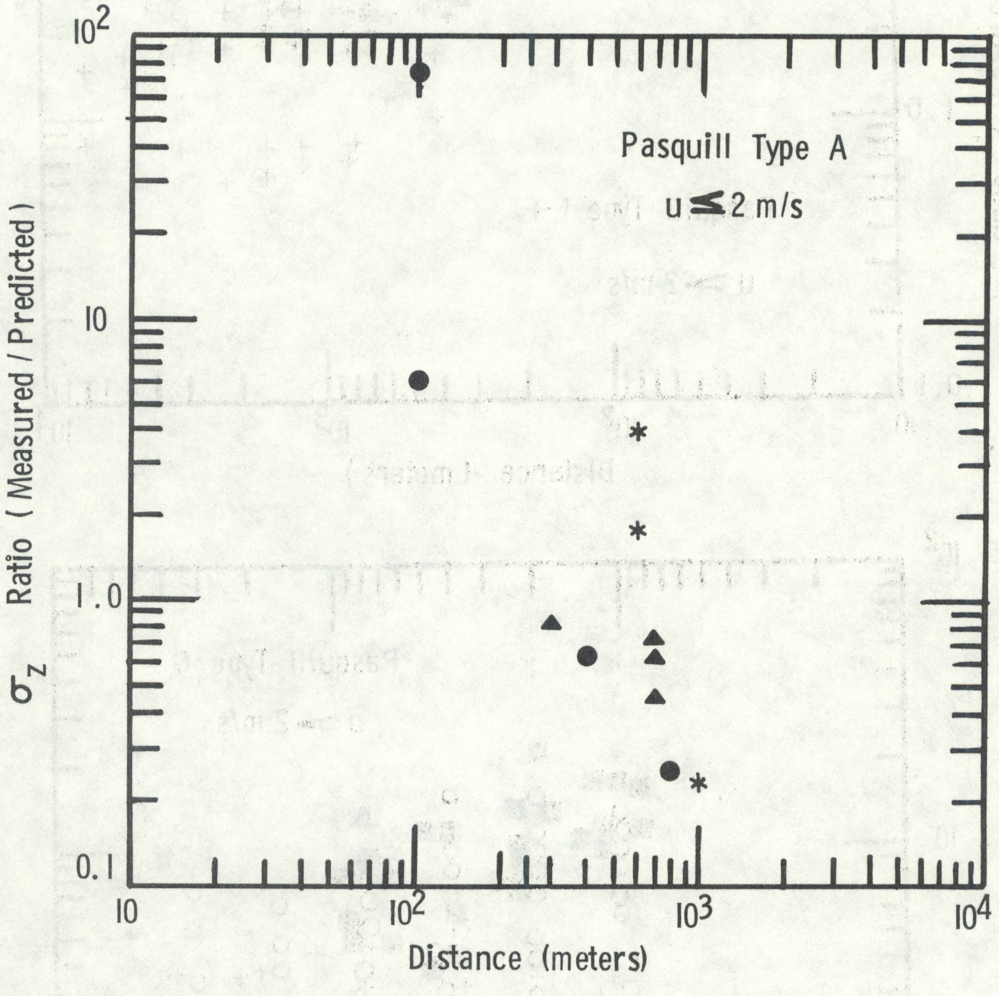


Fig. 19. σ_z Ratio versus Distance for Type A and u≤2 m/s.

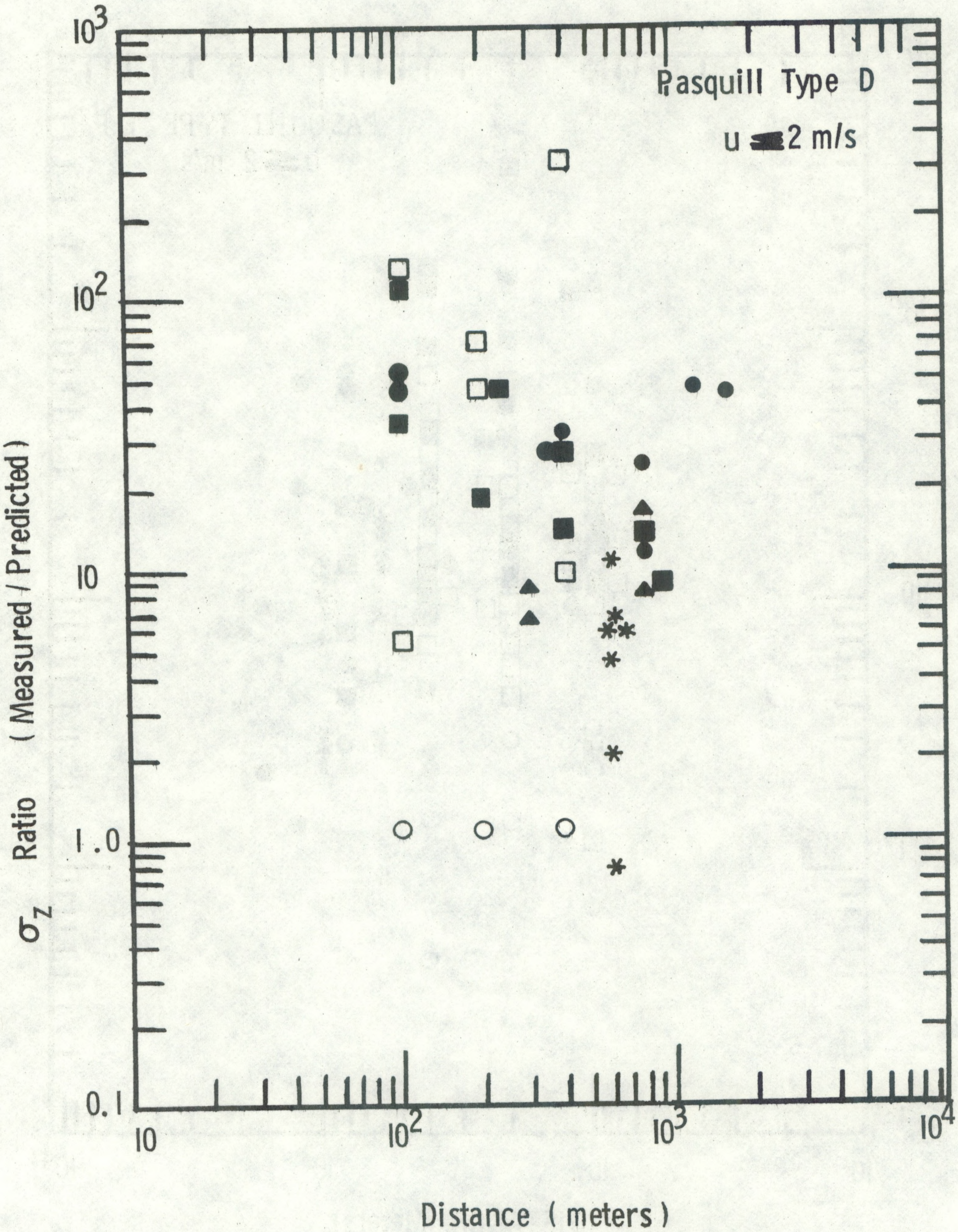


Fig. 20. σ_z Ratio versus Distance for Type D and u≤2 m/s.

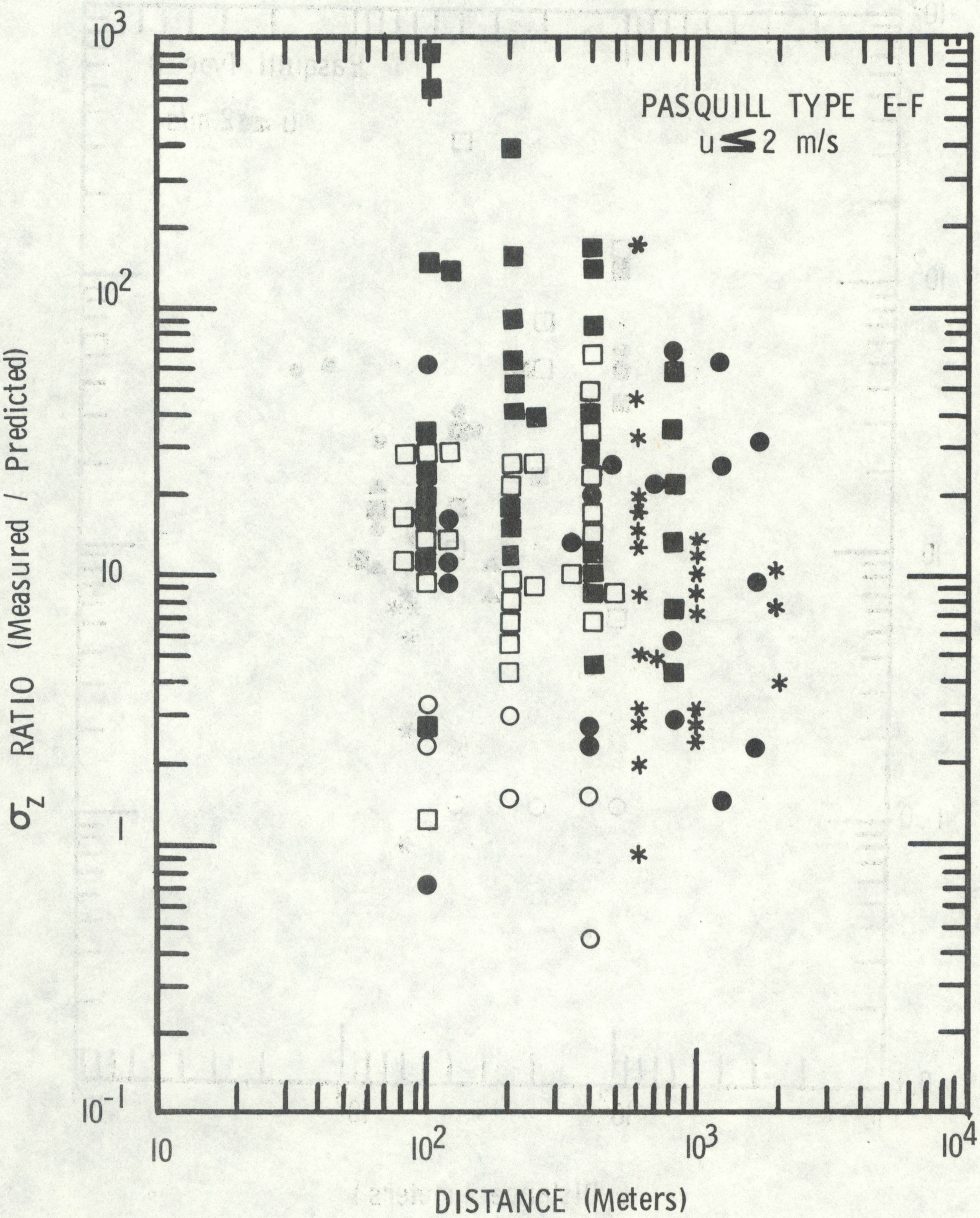


Fig. 21. σ_z Ratio versus Distance for Type E - F and u≤2 m/s.

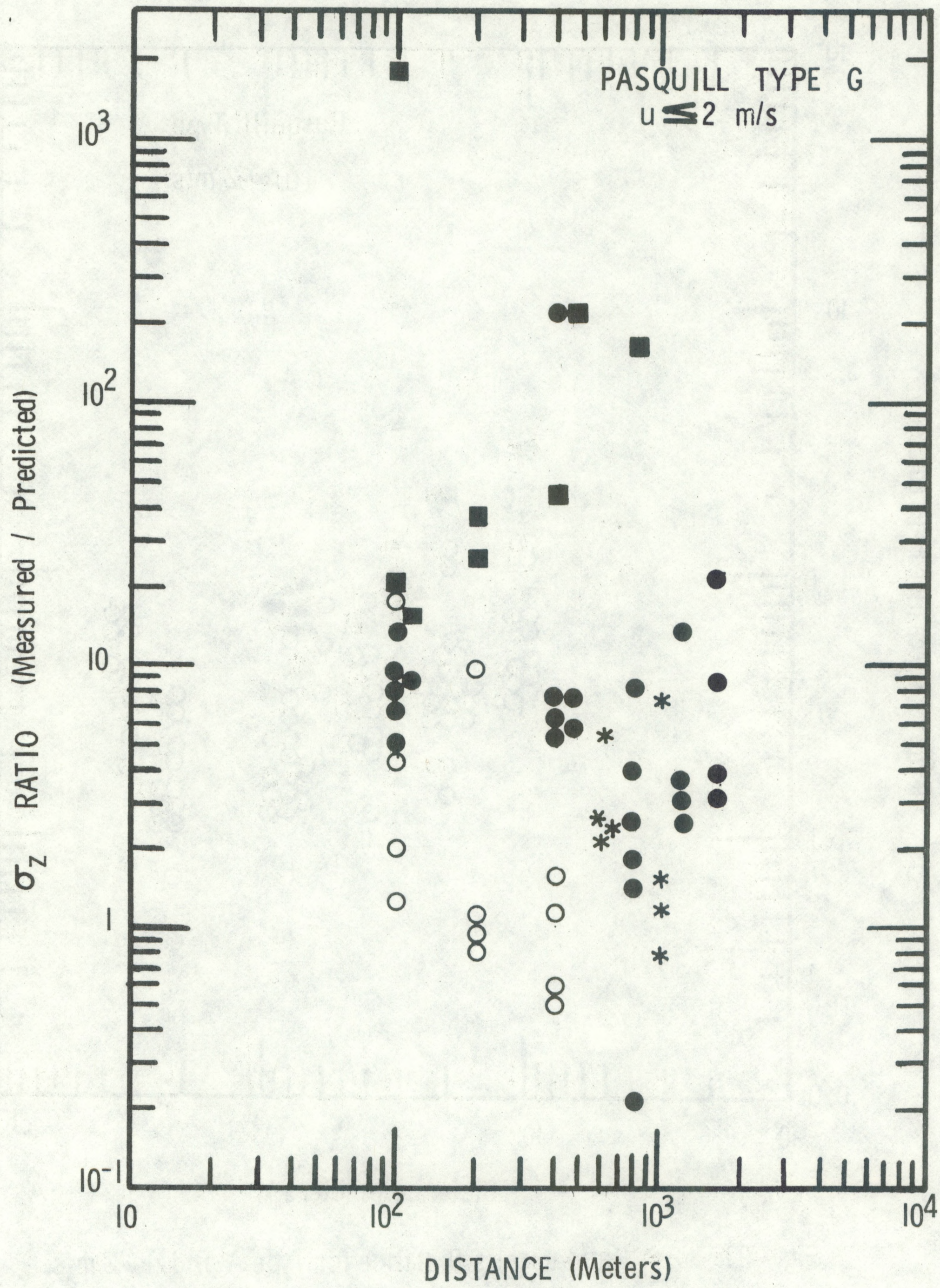


Fig. 22. σ_z Ratio versus Distance for Type G and u≤2 m/s.

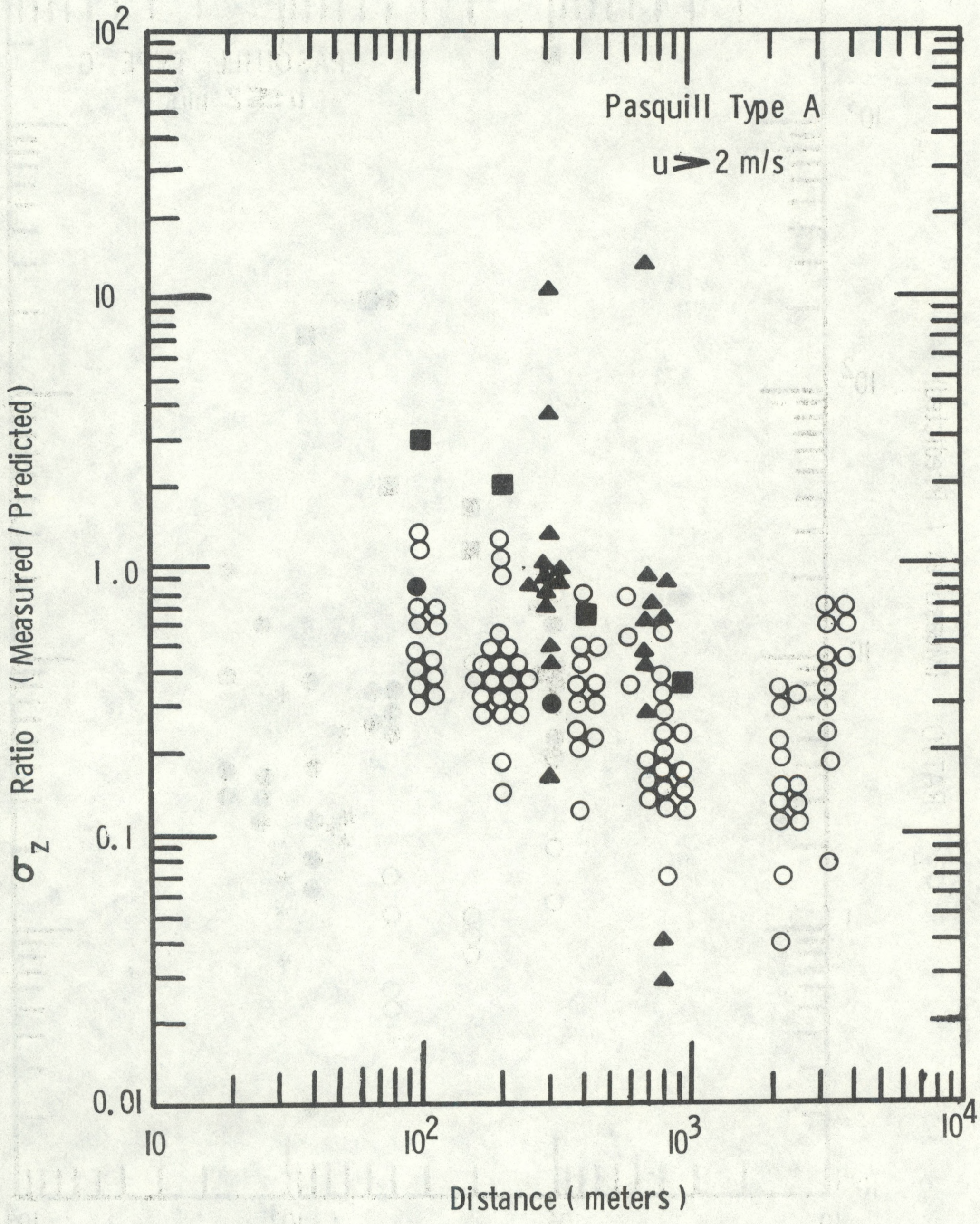


Fig. 23. σ_z Ratio versus Distance for Type A and u>2 m/s.

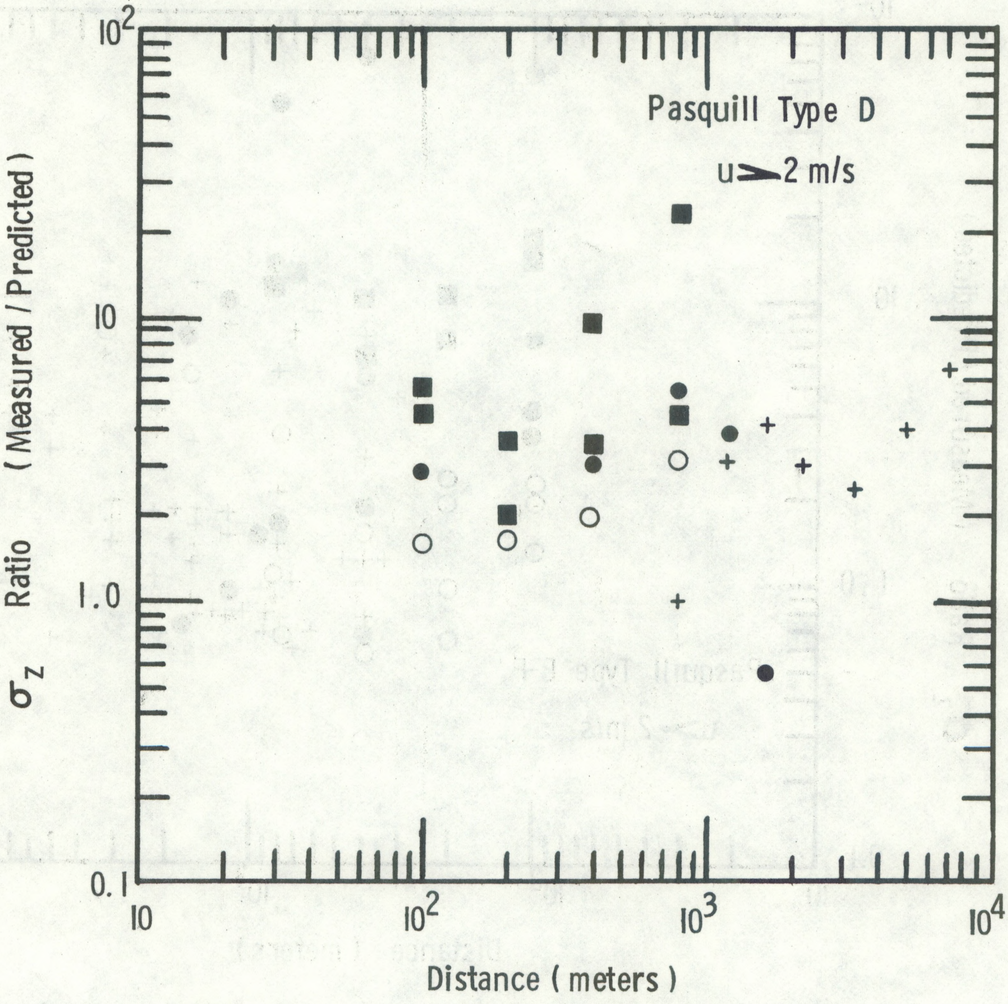


Fig. 24. σ_z Ratio versus Distance for Type D and u>2 m/s.

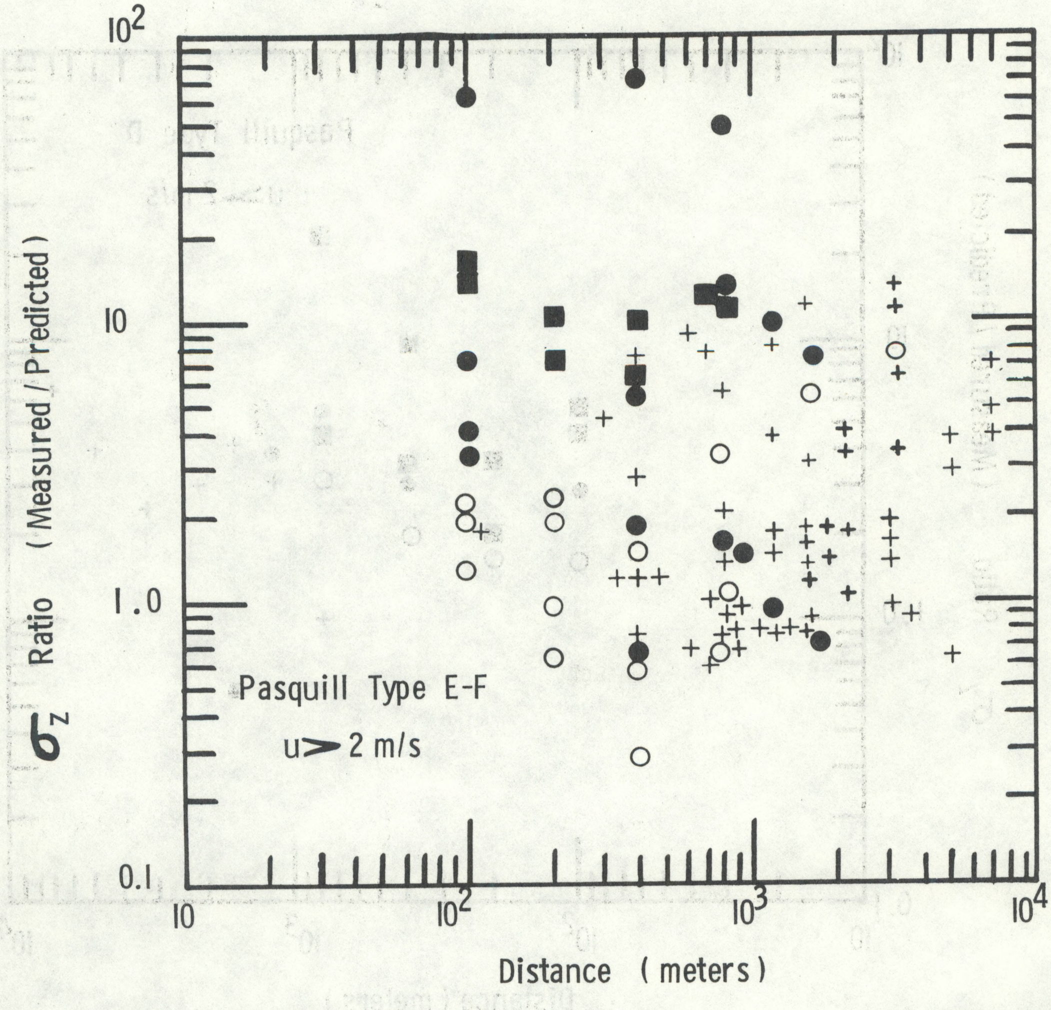


Fig. 25. σ_z Ratio versus Distance for Type E - F and u>2 m/s.

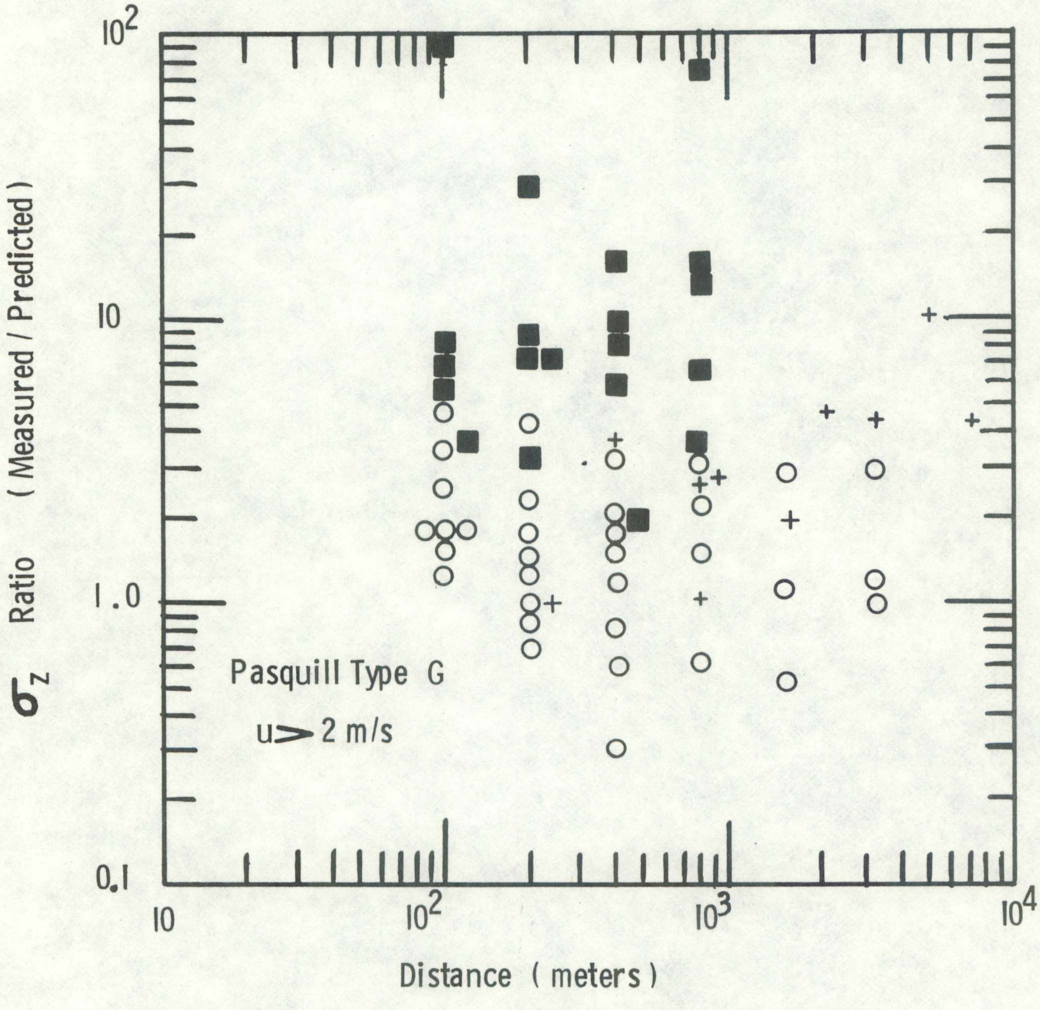


Fig. 26. σ_z Ratio versus Distance for Type G and u>2 m/s.