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# NIST/TTU Cooperative Agreement – Windstorm Mitigation Initiative: Wind Tunnel Experiments on Generic Low Buildings

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# 1 INTRODUCTION

This study is part of the NIST/TTU Cooperative Agreement – Windstorm Mitigation Initiative, jointly sponsored by the National Bureau of Standards and Technology and Texas Tech University. It forms part of a larger scope of generic low building testing and analysis. The objective of the initiative is “to conduct research to mitigate detrimental effects of wind stroms on low buildings and structures and on human activities”. This portion of the study is part of reseach thrust 4: Integrated testing for wind effects.

As part of the Windstorm Mitigation Initiative, a testing program was initiated to create a low building database for the purpose of providing time series of wind load data for public access. The data may be used in the dynamic design of low buildings.

This phase of the experimental program consists of two different sets of tests. The first set of tests was on generic low building models with the aim to provide a low-rise building database via electronic means. The second set of tests was on the models of the TTU full scale house with the aim to carry out comparison of the results from full- and model-scale experiments and comparison of the results from model-scale experiments in different laboratories.

The current testing program has a total of 5 different generic building model variations:

**Generic Model Tests**

Test 1. 125’x80’, 4 heights, 1:12 roof slope, 2 exposures, 1:100 scale
Test 2. 125’x80’, 4 heights, 3:12 roof slope, 2 exposures, 1:100 scale
Test 3. 125’x80’, 4 heights, ¼:12 roof slope, 2 exposures, 1:100 scale
Test 4. 62.5’x40’, 4 heights, 1:12 roof slope, 2 exposures, 1:100 scale
Test 5. 250’x160’, 4 heights, 1:12 roof slope, 2 exposures, 1:100 scale

and three different models of the full scale building at the Texas Tech Wind Engineering Research Field Laboratory (WERFL):

**WERFL Building Tests**

Test 6. 45’x30’x13’, 1:48 roof slope, 2 exposures, 1:50 scale (UWO model)
Test 7. 45’x30’x13’, 1:48 roof slope, 2 exposures, 1:100 scale (UWO model)
Test 8. 45’x30’x13’, 1:48 roof slope, 2 exposures, 1:100 scale (CSU model)

The two UWO models of the WERFL building constructed at the University of Western Ontario (UWO) included a 1:50 scale model primarily for local point pressure measurements, and a 1:100 scale model primarily for structural load evaluation. The model provided by Colorado State University (CSU) included the pressure taps for local point pressure measurements.

Details of the model variations are described in Section 2.2.

This report provides basic information on the test parameters used in these wind tunnel tests and describes the data quality control checks undertaken.

The data from all of the tests described above will form part of the overall generic low building database. Detailed time series of all the pressure data are available through the standard archival system described in this report.

Other tests on generic models with additional variation in building size and roof slope (187.5’x120’, 1:12 roof slope and 125’x80’, 6:12 roof slope) are reported elsewhere [1]. Additional wind tunnel tests on a different set of generic models (200’x100’ at 1:200 length scale) including investigation of the effects of length scale, building length and parapet are also reported in [1].

# 2 MODEL TESTS

## 2.1 The modelling of the wind

### 2.1.1 Terrain modelling

The basic tool used is the Laboratory's boundary layer wind tunnel. The tunnel is designed with a long test section, which allows extended models of upwind terrain to be placed in front of the model of the building under test. The wind flow then develops characteristics which are similar to the wind over the different terrain conditions.

For the generic model tests (Tests 1 to 5), two typical terrain cases were used; namely, the open and suburban exposures, defined as having roughness length, $z_o$, of 0.03 m and 0.3 m respectively. Simulated winds at 1:100 scale were used in the generic model experiments. Figure 1 shows an example of the generic model in the wind tunnel with the two upstream terrain simulations.

For the WERFL building model tests (Tests 6 to 8), two definitions of nominally open exposure conditions were used. These are based on the range of full scale conditions measured at the WERFL site. For the purpose of comparison with the full scale pressure data, the wind tunnel test data were obtained with simulated winds near two ends of the range of the full scale site condition; namely, at the 10th and 90th percentile of the site condition measurements; primarily focussing on the turbulence intensities from the site measurements. A cross-check with the power law exponents derived also from the site measurements confirms that the 10th and 90th percentile of these measurements are consistent with generally accepted values.

The two terrain cases can be broadly defined as open exposure; with turbulence intensities matching those obtained using ESDU formulation [2,3] for roughness lengths, $z_o$, of 0.01 m and 0.087 m respectively. Wind characteristics for 1:50 and 1:100 length scales were developed for the three models tested. Figures 2 and 3 show the UWO and CSU models in the wind tunnel.

For all tests, three 5-foot high spires were placed at the entrance of the wind tunnel as well as a 1.25 feet high barrier across the wind tunnel immediately downstream of the spires. These two devices produce the large scale wind gusts in the wind tunnel. Various heights of roughness elements were used along the 100-foot wind tunnel section to provide mixing of the wind gusts and generate the boundary layer characteristics. Note that the required roughness elements tend to be relatively higher for the model case than in full scale. For this reason, it is unrealistic to continue these roughness elements right up to the model. In practice, smaller roughness elements are used very close to the model and some distortion of flow turbulence modelling at low heights is accepted in order to maintain better overall flow homogeneity over the model.

### 2.1.2 Characteristics of the modelled wind

The simulation of the wind speed and turbulence intensity profiles for all tests described here was based on the wind characteristics described by ESDU 82026 [2], 83045 [3] and 74031[4] for mean wind speed profile, turbulence intensity and wind spectrum respectively. Figures 4 and 5 show the 1:100 scale wind speed and turbulence intensity profiles for open and suburban simulation respectively for the generic model tests. Figures 6 to 9 show the lower ($z_o$ = 0.01 m) and upper ($z_o$ =0.087 m) bounds of the open exposure simulation used in the WERFL building tests. The profiles were measured without any building model present at a location 18” (model scale) upstream of the center of the turntable; approximately at the leading edges of the models. The matching characteristics determined using ESDU are superimposed. Based on the comparison of turbulence intensities, the simulated exposures match the roughness lengths of $z_o$ = 0.01 m and $z_o$ =0.087 m satisfactorily over the heights of the building models.

Figures 10 to 12 show the normalized longitudinal, lateral and vertical wind spectra respectively, measured in open exposure at 32' (full scale) above ground. They are shown to match the ESDU spectra reasonably well. At this height, $\sigma_v / \sigma_u = 0.68$ and $\sigma_w / \sigma_u = 0.4$ where $u$, $v$ and $w$ denote the longitudinal, lateral and vertical directions respectively.

The longitudinal turbulence scale is shown to have a mismatch by about a factor of two based on the shift in the high frequency end of the spectra. This level of mismatch is likely to be inconsequential for local pressures. The scale mismatch would be expected to have more importance for area or frame loads where the spatial correlation of the loads are important; however, even here a factor of two in scale is moderated dramatically when translated into an area integral (see Surry [5] for example). Typically, the order of error associated with a scale mismatch of a factor of two should be in the 5 to 10% range.

## 2.2 The Measurements of Local Pressures

### 2.2.1 Model instrumentation

A total of 8 different model variations have been tested. Parametrically, the generic model tests include 125'x80' models with various heights and three different roof slopes; ¼:12, 1:12 and 3:12. They also include 1:12 roof slope buildings with three different plan sizes; 62.5'x40', 125'x80 and 250'x160'. Note that all the generic model tests (Tests 1 to 5) were carried out based on 1:100 scale wind simulation.

For the WERFL building test, models built at two different testing facilities, UWO and CSU, were tested. The UWO models were tested at two different scales; 1:50 and 1:100. Tables 1 and 2 summarize the model and test parameters for the generic model tests and the WERFL building tests respectively.

Figure 13 shows the basic tap arrangement for the 1:12 roof slope buildings. The roof tap arrangement is essentially the same for generic model tests of all three roof slopes. Figure 14 shows the tap layout of the gable end walls for the 3:12 and ¼:12 roof slope buildings and Figure 15 shows the tap layout of the side walls for the 3:12 and ¼:12 roof slope buildings.

Except for the 250'x160' model (Test 4), all the generic model tests included internal pressure measurements due to distributed leakage. The distributed leakage on the models was represented by 80 - 1/16" (model scale) diameter holes distributed over the wall areas. For the 125'x80' buildings, the distributed leakage area is about 0.1% of the total wall areas corresponding to the largest building height of 40'. As the building height is reduced, the leakage openings are also reduced, maintaining the approximate leakage ratio. For the 62.5'x40' building, the distributed leakage area is about 0.2% of the total wall areas.

The 125'x80', 1:12 roof slope building test (Test 1) also included internal pressure measurements due to dominant openings. Additional small and large openings representing 0.1% and 1% of the total wall areas were modelled. Pictures showing these openings on the model are shown in Figure 16. During testing, internal pressures due to the openings were measured also with the distributed leakage in the model. In order to be able to measure the dynamic internal pressures, the interior volume of the model is exaggerated approximately based on the following volumetric scaling.

$$\lambda_{vol} = \frac{\lambda_L^3}{\lambda_{vel}^2} \approx \frac{(1/100)^3}{(1/4)^2} = \frac{1}{62500}$$

The actual model internal volume, including the volume of the model and a sealed chamber extending below the turntable, was 6.27 $ft^3$. The actual volumetric scale based on the 40' building was

$$\lambda_{vol} = \frac{6.27\,ft^3}{416666\,ft^3} = \frac{1}{66422}$$

For the 16' building, a portion of the volume in the chamber was filled with Styrofoam in order to maintain the volume similitude. Close-up views of the modelled internal volume are shown in Figure 17. The sealed chamber was also used for all other tests with internal pressure measurements but the volumetric scaling was not critical since dynamic internal pressures are not expected to be significant for buildings with distributed leakage only.

Figures 18 and 19 show the tap layout of the UWO model of the WERFL building. Figure 20 shows the tap layout of the CSU model of the WERFL building. The pressure tap numbering systems for all model tests are included in Appendix A. Views of the models are shown in Figures 21 to 28.

### 2.2.2 Model tubing system

A 30-inch long tubing system was used to connect the pressure taps to solid state high speed pressure scanners. This tubing consists of a 12-inch long PVC tube with internal diameter of 0.053 in connected to the model which is connected by a pass-through plate with a 1.25-inch long brass tubing going into the sealed chamber, two restrictors and a 13-inch long PVC tube with internal diameter of 0.035 in connecting to the pressure scanner. The frequency response of this tubing system was tested in a separate testing chamber by measuring the transfer function of an input white noise signal and the signal after passing through the tubing system. Figure 29 shows the tubing response with an illustrative diagram of the tubing arrangement used.

### 2.2.3 Wind tunnel measurements

A high speed solid state pressure scanning system was used to take the pressure measurements. For the generic model tests, measurements were taken at 37 wind angles over the range between $180^0$ and $360^0$ at $5^0$ increments. The definition of wind direction can be found in Figure 13. The wind directions tested are summarized in Table 1 and Appendix B. For the WERFL building tests, tests were carried out for winds approaching the quadrant with the high concentration of pressure taps. The wind directions tested are summarized in Table 2 and Appendix B..

For the generic model tests, pressure measurements were sampled at 500 samples per second for 100 seconds. Based on a nominal full scale roof height wind speed of 84 mph (approximated Hurricane Andrew condition), the sampled data are equivalent to about 22 samples per second for 0.64 hours in full scale for the open exposure tests and equivalent to about 29 samples per second for 0.48 hours in full scale for the suburban exposure tests. All of the samples were stored. Summary data sheets for the generic model tests are included in Appendix B.

For the WERFL building 1:50 scale tests, pressure data were sampled at 250 samples per second for 180 seconds. Based on the same nominal full scale roof height wind speed of 84 mph as above, the sampled data are equivalent to about 22 to 26 samples per second for 0.58 to 0.49 hours in full scale for the two exposures. For the 1:100 scale tests, pressure data were sampled at 500 samples per second for 100 seconds. The sampled data are equivalent to about 22 to 29 samples per second for 0.64 to 0.48 hours in full scale for the two exposures.

In addition, the WERFL building 1:50 scale model test at the wind angle of $45^0$ and exposure 1 ($z_o$=0.01 m) has been repeated 20 times in order to examine the variability of the aerodynamic data excluding the non-aerodynamic effects such as model, set-up and instrumentation. Similar repeats have also been carried out for the 1:100 scale model tests. Summary data sheets for the WERFL building tests are included in Appendix B.

All instrumented taps were measured essentially instantaneously. The measurements taken within the sampling cycle have a maximum time lag of about 15/16 of the sampling rate. For example, the generic model tests have a maximum time lag of approximately 15/16x0.002 seconds = 1.875 milliseconds. This time lag is corrected by linear interpolation of the data within the same sample cycle.

In addition to storing all time histories of the pressure measurements, the maximum, minimum, mean and rms pressure from these time histories were calculated and reviewed as a data quality check.

### 2.2.4 Aerodynamic data

All the time series files were stored in an archive to be accessible by electronic means. The raw data have been referenced to the dynamic pressure taken at an upper reference level in the wind tunnel.

For general use, the roof height referenced pressure coefficients are needed and are defined using the following expression:

$$C_{p_H} = C_{p_{\mathrm{ref}}} \left( \frac{V_{\mathrm{ref}}}{V_H} \right)^2$$

where $\left( \frac{V_{\mathrm{ref}}}{V_H} \right)^2$ is a conversion factor obtained from the wind tunnel experiments and is the ratio of the dynamic pressure at the reference height in the wind tunnel where upper level wind speed is taken (subscript ref ) and the dynamic pressure at roof (eave) height (subscript $H$ ). Because of high turbulence near roof height, the measurements taken at this level have large variability. The uncertainties of this factor and wind tunnel testing on low buildings are further discussed in the following section. General discussion on the variability of wind tunnel testing on low buildings can be found in Kopp, et al. [6].

Table 3 summarizes the factors used for re-referencing the pressure coefficients to roof height dynamic pressures.

The maximum and minimum pressure coefficients included in this report have been Lieblein-fitted and are more statistically stable quantities than the measured peaks. This involves dividing the record into 10 parts, using the Lieblein BLUE formulation [7] with the 10 individual peaks to estimate the mode and dispersion of the Type I extreme value distribution, and using these to obtain the “best” expected peak for the entire record.

# 3 VARIABILITY OF ROOF HEIGHT DYNAMIC PRESSURES

## 3.1 Background

It is widely accepted that aerodynamic data referenced to roof height dynamic pressure produces the least variability. All low building pressure data sets follow this convention, including those in building codes. It is also intended in this study that all acquired data will be presented and compared based on such a definition.

Because of the high turbulence at the heights of low buildings, it is generally not practical to use the roof height wind speed as a close loop control of the wind tunnel test wind speed. A pitot-static tube at upper level, outside of the boundary layer of the wind tunnel roof is generally used as the reference wind speed for test purposes. All raw pressure data are initially referenced to this upper level wind speed. By knowing the ratio of the roof height and upper level reference wind speed, conversion can be carried out to obtain pressure coefficients referenced to roof height dynamic pressure.

It is common practice to carry out wind profile measurements for the simulated wind for any wind tunnel test. The wind speed profile can then be used to obtain this roof-to-reference-height speed ratio. In the experiments described in this report, wind speed profile measurements have been taken for each of the wind tunnel simulations mentioned in the previous sections. The measurements include hot-wire anemometer and pitot static tubes at various heights in the wind tunnel. Two hot-wire anemometers were used, each travelling approximately half the height of the wind tunnel. Two pitot-static tubes were mounted beside the hot-wire anemometers. While the hot-wire anemometers are capable of measuring mean wind speeds and turbulence intensities, the mean speeds are sensitive to small temperature fluctuations. The pitot-static tubes do not have the frequency response to give correct turbulence intensities but are insensitive to temperature and are used as a cross-check of the mean wind speed.

Because of the low height of the low buildings, the wind speed ratios at roof and reference height can be as small as 0.5. When converted to dynamic pressures, the ratio becomes 0.25 and the conversion factor can be in the order of 4. A small error in the wind speed ratio can affect significantly the pressure coefficients referenced to roof height.

## 3.2 UWO Wind Speed Profiles and Conversion Factors

The mean wind profiles between the hot-wire and pitot-static measurements are shown to be comparable. It is recognized that the roof height dynamic pressure may be best measured using a pitot-static tube at roof height. This has been done for all tests. However, for low roof height cases in rougher terrain, the roof height pitot-static tube located off the turntable can be affected significantly by the roughness elements. It was decided that additional pitot-static tubes at an intermediate height upstream of the turnatable at about ¼ point of the width of the wind tunnel and at the centerline of the wind tunnel should be installed and sampled in every test. The intermediate heights used in these tests were 70 feet (equivalent full scale) for the 1:50 scale tests and 160 feet (equivalent full scale) for the 1:100 scale tests. These data are used based on the premise that the intermediate height measurements will give a reference related to upper level wind speed measurements during the time of the tests and that the lower part of the wind profile will have little variation between the intermediate measuring location and the roof height.

In addition to the measurements taken during the tests, three subsequent sets of reference pressure measurements were taken separated by 3 months. Although the data show some variation, they are consistent. They did not match the roof height measurements taken during the 125’x80’, 1:12 roof slope building model tests (the first attempt of Test 1). It was subsequently discovered that the first attempt of Test 1 suffered from a static pressure problem. While the pressure data for Test 1 have been re-tested, the dynamic pressure ratios from the original data for Test 1 were found to be consistent when approximate corrections for the static pressure problem were applied.

Table 4 summarizes the measurements of the roof height and intermediate height wind speed ratios and the variability of the measurements. With no obvious difference among the tests, overall averages of the ratios taken in different measurements were taken as best estimates. The range of the roof-height-to-intermediate-height speed ratios is -4% to +3% of the average values while the range of the intermediate-height-to-reference-height speed ratios is -2% to +1% of the average.

# 4 DATA QUALITY CHECKS

## 4.1 General

General checks have been carried out to ensure consistency of the current data with other data sets. In some cases, data from similar tests were used for comparison. All wind tunnel experiments are expected to have inherent uncertainties; further discussion on the topic of experimental uncertainties can be found in Kopp, et al. [6].

## 4.2 Overall data checks

For an isolated low building, the pressure variations on the building are directly related to the energy in the incident wind. The total fluctuating energy measured on the building will vary with wind direction because of the detailed aerodynamics but Holmes [8] has suggested that the variation can be expected to be slow. Thus, the calculation of the overall sum of variances at all point measurements and its variation with wind direction offers a simple way of checking the overall data consistency.

$$E_{\text{var}}(\alpha) = \sum_{\text{all taps}} \sigma^2_{C_p}(\alpha)$$

An alternative measure is the sum of mean square values about zero over all pressure taps. This is related to the total energy rather than just the fluctuating energy inherent in the above expression.

$$E_{\text{mean square}}(\alpha) = \sum_{\text{all taps}} \left[\overline{C_p^2(\alpha,t)}\right] = \sum_{\text{all taps}} \left[\sigma^2_{C_p}(\alpha) + \overline{C}_p^2(\alpha)\right]$$

The sum of variances and the sum of mean square values were calculated for all data sets and their variations with wind direction are shown in Appendix C.

The sum of mean square values are seen to be slightly less variable than the sum of variances. As far as the variation with wind direction is concerned, it was found that most of the data sets appear to be well behaved. In a few occasions, the sum of variances indicates large variation with wind direction whereas the sum of mean squares shows a much smoother behaviour. Nevertheless, data sets showing a large change in the variance summation have been examined; however, no clear reason for the deviation is obvious. Since equal weighting is given to each tap, some of the variability may be due to the non-uniform tap resolution. The figures in Appendix C can be used as a guide for a general level of reliability of the data within the data sets.

For example, in the case of Test 4. 12-ft building in suburban terrain, data at 0° have been identified as unreliable because of a reference pressure problem. The error is relatively small and it affects the smaller readings more significantly. The sum of variances is shown to be very different when compared with the adjacent wind angles but the sum of mean squares are similar, suggesting that the error does not affect the large peak pressures significantly.

## 4.3 Comparison of data within the database

The following comparisons provide an initial summary of the low building database by examining the spatial variation of the mean and rms pressure coefficients. The analysis makes use of the building configurations tested at UWO to separately examine the effects of roof slope, building height and building plan dimension on local pressure coefficients. This was repeated along two lines of pressure taps, firstly along a line in the middle of the building (mid-span) for a wind direction of 270$^o$ and secondly at a short distance from the building edge for a wind direction of 325$^o$. Only the results from the open country terrain are included in this report.

### 4.3.1 Effect of building height

Comparisons were made to determine the effect of building height on wind loads. Only the results from the 1:12 building are presented in this report. It is the current understanding for building roofs large enough for flow reattachment to take place that local pressure coefficients on the building roof, when referenced to the eaves height mean dynamic pressure, $q_H$, are dependent on the ratio of $\frac{(x,y)}{H}$, or, $\frac{\text{distance from leading edge}}{\text{building height}}$. Figure 13 shows the coordinate system used for the roof area. The origin is at the building corner with the high tap density, with the x axis in the direction of the gable end wall and the y axis along the long side wall of the building. In particular, it is believed that once the flow has separated from the leading edge (or corner) of the building, the distance until the flow reattaches is proportional to the height of the building. This is shown in Figure 30, which presents the spatial variation of the mean and rms pressure coefficients along the line of taps at mid-span, for a wind direction of 270°. Note that the distance of the tap from the leading edge of the building, $x$, is normalized by the eave height of the building, $H$. The figures show the pressure coefficients at the leading edge collapse reasonably well within the separated and reattached flow region for all buildings for $x/H < \sim 1.0$. Deviations in the mean pressure coefficients begin to occur as $x/H$ approaches the building ridge, with secondary separation of the flow at the ridge for all four building heights. It can be seen in Figure 30 that the pressure levels off on the 16 ft building prior to the ridge for $x/H > \sim 1.4$, indicating fully reattached flow. This is similar on the 24 ft building. There is clear evidence of increases in mean and rms pressure coefficients at the ridge for the 16 ft and 24 ft buildings. Slight increases in mean pressure coefficients can also be seen at the ridge on the 32 ft and 40 ft buildings, indicating the flow is not fully reattached before reaching the ridge, at $x/H$ of 1.25 and 1.0 respectively. It is not clear what kind of normalization could collapse the data in the lee of the ridge. Since the flow adjusts to the presence of the ridge upstream of the ridge, normalization based on the distance from the ridge, for locations in its lee may not be entirely appropriate. It should be noted that, over the complete roof, the neural network approach of Chen et al. [9] captures the variations of the mean and rms pressure coefficients more accurately than this simple relationship with roof height.

Similar comparisons were performed for a line of taps located a distance approximately $y/H = 0.41$ from the building edge and for a wind direction of 325° in Figure 31. In this case, the line of pressure taps is chosen such that it crosses the path of both corner vortices. Different rows of pressure taps were used for different building heights in order to maintain similar ratios of $y/H$ for comparison. As such, no pressure taps are available for comparison in the lee of the ridge for the 24 ft and 40 ft buildings. The distribution of the mean and rms coefficients clearly show the presence of the two corner vortices by the large rms values at the leading edge and again at $x/H \approx 1.2$. The figures indicate that $\frac{(x,y)}{H}$ is a reasonable normalizing parameter for the pressure distribution up until the center of the second vortex. For this line of taps, both the mean and rms coefficients are strongly affected by the ridge where the pressure gradient is very high, just ahead of flow separation at the ridge.

### 4.3.2 Effect of roof pitch

Three different roof slopes have been tested (¼:12 , 1:12, and 3:12) in this phase of the testing program for buildings with the same plan dimensions of 125 ft x 80 ft. Comparisons of the effect of roof pitch on local pressure coefficients are limited to the building height of 24 ft.

Figure 32 presents the effect of roof slope on the mean and rms pressure coefficients measured at mid-span, for a wind direction of 270°. The figures indicate that the pressure distributions on the ¼:12 and 1:12 roof sloped buildings are relatively similar for this wind direction, consistent with the assumption that roof slopes less than 10° have similar aerodynamic behaviour. Mean pressure coefficients for the 1:12 roof slope building are higher by less than 12% at the leading edge and 30% behind the ridge. In absolute values, this equates to a difference in pressure coefficient of less than 0.15 in both instances. The results from the 3:12 roof slope show the greatest variation with roof slope. As expected, the steeper roof slope has a significant reduction in suction pressures at the leading edge of the building because of the earlier reattachment; however, there is an increase in the suction pressures behind the ridge.

Similar trends were observed near the roof edge for winds approaching from 325$^o$, as shown in Figure 33. In this case, the third row of pressure taps was used for the comparisons ( $y/H = 0.28$ ). Again, the ¼:12 and 1:12 buildings show similar pressure distributions until just before the ridge. Beyond the ridge, the mean and rms coefficients increase with roof slope.

### 4.3.3 Effect of building plan dimensions

All buildings tested in the current testing program have the same length to width ratio. For the 1:12 roof slope, three different building plan dimensions, 62.5 ft x 40 ft, 125 ft x 80 ft, and 250 ft x 160 ft, were tested in this phase of the program. Among three of the buildings tested, appropriate roof heights are selected, i.e., 62.5 ft x 40ft x 12 ft, 125 ft x 80 ft x 24 ft and 250 ft x 160 ft x 40 ft, for comparison among geometrically similar buildings with variation only in size, although the largest model is relatively shorter by proportion. Figure 34 presents the spatial variation of the mean and rms pressure coefficients recorded along the row of taps at mid-span for a wind direction of 270$^o$, for each of the above buildings. Comparisons of the mean pressure distribution show good agreement at the leading edge and behind the ridge of the buildings. The largest building size gives slightly higher mean pressures at the leading edge but otherwise all three buildings agree quite well. For rms pressures, Figure 34 show good agreement among all three buildings except higher values for the smallest building at the leading edge.

### 4.3.4 Comparison with Full Scale TTU Data

The previous comparisons show that normalized distance from the building edge, $(x,y)/H$ , provides a reasonably good collapse of the aerodynamic data among wind tunnel tests. Comparison with the TTU field experiment data [10] will now be made to assess similar relationships with the full-scale data. It should be noted that the standard open exposure ( $z_o$ = 0.03 m) used in the wind tunnel tests falls within the range of full scale terrain condition based on the reported turbulence intensities taken at TTU and the data are therefore generally comparable.

Figure 35 shows the mean, rms and peak pressure coefficients along the first row of pressure taps on the TTU building; i.e. taps 50101, 50501 and 50901. The TTU building has dimensions of 45 ft x 30 ft x 13 ft with a ¼:12 roof slope. These are compared with the second row of taps on the ¼ :12 roof slope, 125 ft x 80 ft x 40 ft, building tests, the equivalent $y/H$ value is approximately 0.09. Data are available for the windward half of the roof up to $x/H = 1.0$. The comparison is for a cornering wind 35$^o$ from the long building axis (equivalent to 325$^o$ in the generic model test wind angle definition). These included all data from the TTU experiments with wind directions within 2.5$^o$ of 325$^o$. They are compared to wind tunnel results at 325$^o$ (note that definition of wind angle is based on the convention of the current NIST data). The top portion of Figure 35 shows that the mean pressures compare well. The rms pressure coefficients in the bottom half of Figure 35 show significant differences although the trend is captured, with the wind tunnel data being lower. This is in line with previous model scale / full scale comparisons of the TTU Building [11,12]. Similar differences are observed in the peak pressure coefficients shown in Figure 35 where the negative peaks under the vortex at Tap 50501 are not reproduced in the wind tunnel tests. Near the edge of the building, the wind tunnel results show a large negative peak pressure coefficient of $-10.7$ . The full scale data set does not have any pressure tap at this distance from the building edge. It is also interesting to observe that the wind tunnel data tends to envelope the lower range of the full-scale values.

Figure 36 shows the comparison of mean, rms and peak pressure coefficients between tap 50501 from the TTU full scale experiments and a comparable tap from the current NIST tests on the ¼ :12 roof slope, 125 ft x 80 ft x 40 ft building, based on normalized distance from the leading edge with $x/H = 0.36$ and $y/H = 0.09$. The comparison is limited to the cornering wind directions, equivalent to the NIST test angle range of 270$^o$ to 360$^o$.

Comparison of the mean pressure coefficients in Figure 36 shows good agreement, given the large variability of the full scale data. The rms pressure coefficients shown in Figure 36 from the current NIST data and the TTU do not match as well, although the wind tunnel data again envelope the lower range of the full-scale data. This is similar to previous comparisons carried out between the model tests of the TTU model and full-scale results [11,12,13,14]. Similar observations can be made for peak pressure coefficients from the current generic model tests and the TTU full-scale data. It can be concluded that the wind tunnel technique used cannot reproduce the highest peaks obtained near the edges of the roof, but does seem to match the lower end of the full-scale data.

### 4.3.5 Comparison with ASCE 7-02 Recommended Loads

The experimental results are compared for a limited number of cases with the existing American Society of Civil Engineers (ASCE 7-02) Standard [15], by comparing a number of area-averaged loading coefficients. St. Peirre et al. [16] presented a detailed comparison with wind load provisions for structural loads and also with Stathopoulos' data [17]. In addition to examining point pressure coefficients (single pressure taps), five area-averaged loading coefficients were developed at the leading corner of the building by simultaneously combining pressures recorded on a number of taps covering the area considered. The tap combinations used in the analysis are presented in Figure 37, where the corner of each loading area corresponds to the corner point of the building. Note that these may not be the worst locations for each of these areas, especially the smaller ones.

Figure 37 presents the minimum pressure coefficients versus loading area for a number of the current generic model data sets with constant plan dimensions of 125 ft x 80 ft. The pressure coefficients presented in the figure represent the worst pressure coefficients recorded over all wind directions. Also included in the figure are the ASCE 7-02 recommended loading coefficients obtained for the corresponding loading areas, <u>with all relevant reduction factors ignored in the analysis</u>. All coefficients presented in the figure are normalized by the 10-m height, 3-second gust wind speed, as recommended by the ASCE 7-02 standard.

The figure indicates that the area-averaged coefficients tend to increase with building height, with the worst coefficients occurring on the lesser sloped buildings. The worst point pressure coefficient of –5.2 was recorded on the 40 ft tall building with a 1:12 gable roof slope. In most cases the ASCE 7-02 derived loads were below the measured coefficients, in particular for the point pressures, where the H = 40 ft, 1:12 slope building configuration recorded a worst coefficient almost twice as large as the ASCE 7-02 derived load. However, the comparisons do improve for the larger areas, with the ASCE provisions underestimating the maximum experimental load by 30% for area 'A2' and by 20% for area 'A3'. Some of these differences would be reduced through the use of wind directionality factors, etc.

# 5 DATA ARCHIVAL SYSTEM

## 5.1 Background

The NIST aerodynamic database will be used by a large group of researchers for an extended period of time. All pressure readings taken in experiments carried out at UWO are routinely saved for later “off-line” analysis. These files are written in binary format and consist of a descriptive header followed by several thousand scans of “raw” integer counts from the Analog-to-Digital (A/D) converter. This technique generates a large quantity of data. For example, a 650-tap building yields a 40 MB file when sampled at 500 Hz for 60 seconds or over 1.3 GB for a typical test with 36 wind directions.

In the past, data files consisting of raw time series from UWO have been sent to other researchers written in a hexadecimal format for compactness and cross platform readability. Although it provided a usable way of conveying the data, details about test parameters, model and wind tunnel configuration, etc. were stored separately from the data. It became clear that as the number of data sets and configurations increases, the possibility of introducing errors due to miscommunication of experimental parameters becomes large.

The overall objective of the current archiving system is to provide the user with all the information needed to define the experiment within which the data were taken, and to allow the user to extract the data needed for further analysis. The information provided for the user includes pictures of the model and set-up, and whatever ancillary supporting information is deemed necessary to define the tests.

## 5.2 Selection of Data Format

Among several ‘standard’ data formats used within the scientific community, the NCSA (National Center For Supercomputing Applications) HDF (Hierarchical Data Format) was selected for the archive. This format was chosen for several reasons:

1. A large existing base (several platforms and languages) of public domain software libraries to access and manipulate HDF files;

2. The ability to manipulate large arrays and individual data items within a single container file; and

3. Continually improving support for HDF files in MATLAB which was the language chosen to develop the UWO supplied software.

More details regarding the HDF format are available on the following website: http://hdf.ncsa.uiuc.edu.

The key features of the implemented format are described below:

### 5.2.1 Self documentation

In order for the files to be self-documenting, a file-naming scheme which conveys information about the major test parameters by encoding them into specific fields of the filename has been adopted.

For example, a typical file name provides information on the originating facility, the roof slope, the exposure, the model scale, the leakage case for internal pressures, the building eave height and the wind angle:

Filename: ADW100o100S048a3250.HDF

pos 1-3 identifies the originating facility (ADW = Alan G. Davenport Wind Engineering Group)
pos 4-6 identifies the roof slope in 12ths multiplied by 100 (100 = 1:12 roof slope)

| | |
|---|---|
| pos 7 | identifies the exposure (o = open exposure) |
| pos 8-10 | identifies the model scale to 3 digits (100 = 1:100 length scale) |
| pos 11 | identifies the leakage case (S = small opening case) |
| pos 12-14 | is the building eave height in full scale feet to 3 digits (048 = 48 feet building height) |
| pos 15 | is the index for different cases with otherwise the same filename (a = case a) |
| pos 16-19 | is the wind angle in degrees to be read as xxx.x (3250 = 325.0 degree wind direction) |
| .HDF | identifies the data format as a Hierarchical Data File which is the standard file format chosen for the exchange of the data. |

The file includes a header that contains all possible details for interpreting the data. Due to the size of data sets within the file, the headers can be relatively large and still make up only a small percentage of the file. Some items within the comprehensive file header are:

- time stamp, experiment title, and originating organization
- azimuth, wind speed (roof height and reference height)
- file size: number of records times the size of records
- wind profile information
- mean wind speed
- turbulence intensity
- spectral density function
- tap locations/ tap mapping within the file
- details of model geometry

The last three points are achieved by referencing external profile and drawing files.

### 5.2.2 Building geometry and tap locations

The HDF files contain data items with supporting information for the data set. For example, information on the order of the data, the tap number and the building face number on which the tap is located are provided. To complement the tap coordinate information, data items of the building geometry and the tap locations in 3D coordinates as well as in 2D coordinates of a flattened coordinate system are available to draw a wire frame outline of the building and the tap locations for illustration.

### 5.2.3 Data handling

The data handling routines supplied by the NCSA as part of the HDF standard have the ability to extract any slice of any data item within an HDF file. These routines have been incorporated into the MATLAB HDF support facility. Specific functions have been developed to load and read the data set. Subroutines could be written to provide the casual user with data on a scan-by-scan basis thereby isolating the user from learning the mechanics of file buffers, etc.

## 5.3 Data generated at other facilities

For the archiving of data generated at other testing facilities, the MATLAB source code used for creating the UWO archives is available. This may be adapted by individual facilities to fit their raw data file format for conversion to the HDF file format. This program requires several basic input items to complete the documentation of the data set. The names of the required input files are assembled based on rules and information contained in control files which act as lookup tables.

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[16] L. St. Pierre, G.A. Kopp, D. Surry and T.C.E. Ho. The NIST aerodynamic database for wind loads on low buildings: Part 3. Structural loads. Submitted to the Journal of Wind Engineering and Industrial Aerodynamics. 2003.

[17] T. Stathopolous. *Turbulent Wind Action On Low-rise Buildings*. Ph.D Thesis, University of Western Ontario, 1979.

# TABLES

**TABLE 1 TEST CONFIGURATIONS FOR THE GENERIC MODEL TESTS (TESTS 1 TO 5)**

| Test | Plan Dimensions | Heights | Roof Slope | Length Scale | Internal Pressure Measurements |
|---|---|---|---|---|---|
| **1** | 125'x80' | 16', 24', 32', 40' | 1:12 | 1:100 | Due to distributed leakage for all cases; due to dominant openings for 16' and 40' buildings. |
| **2** | 125'x80' | 16', 24', 32', 40' | 3:12 | 1:00 | Due to distributed leakage for all cases. |
| **3** | 125'x80' | 12', 18', 24', 32', 40' | 1/4:12 | 1:100 | Due to distributed leakage for all cases. |
| **4** | 62.5'x40' | 12', 18', 24', 40' | 1:12 | 1:100 | Due to distributed leakage for all cases. |
| **5** | 250'x160' | 12', 18', 24', 40' | 1:12 | 1:100 | No internal pressure measurements. |

**TABLE 2 TEST CONFIGURATIONS FOR THE WERFL BUILDING MODEL TESTS (TESTS 6 TO 8)**

| Test | Model | Plan Dimensions | Heights | Roof Slope | Length Scale | Remarks |
|---|---|---|---|---|---|---|
| **6** | UWO | 45'x30' | 13' | 1:48 | 1:50 | Tap layout primarily for local pressure measurements. |
| **7** | UWO | 45'x30' | 13' | 1:48 | 1:100 | Tap layout primarily for structural load calculations using local pressure measurements. |
| **8** | CSU | 45'x30' | 13' | 1:48 | 1:100 | |

Note: The pressure tap layout for these models follows the pressure measurement locations instrumented on the WERFL full scale building.

**TABLE 3 FACTORS FOR RE-REFERENCING PRESSURE COEFFICIENTS TO ROOF HEIGHT DYNAMIC PRESSURES**

**Generic Model Tests**

| Test | Building Height (ft) | Exposure 1 | Exposure 2 |
|---|---|---|---|
| | | Open | Suburban |
| 1 to 5 | 12 | 3.18 | 5.00 |
| | 16 | 2.96 | 4.59 |
| | 18 | 2.90 | 4.57 |
| | 24 | 2.60 | 4.21 |
| | 32 | 2.43 | 3.82 |
| | 40 | 2.32 | 3.51 |

**WERFL Building Model Tests**

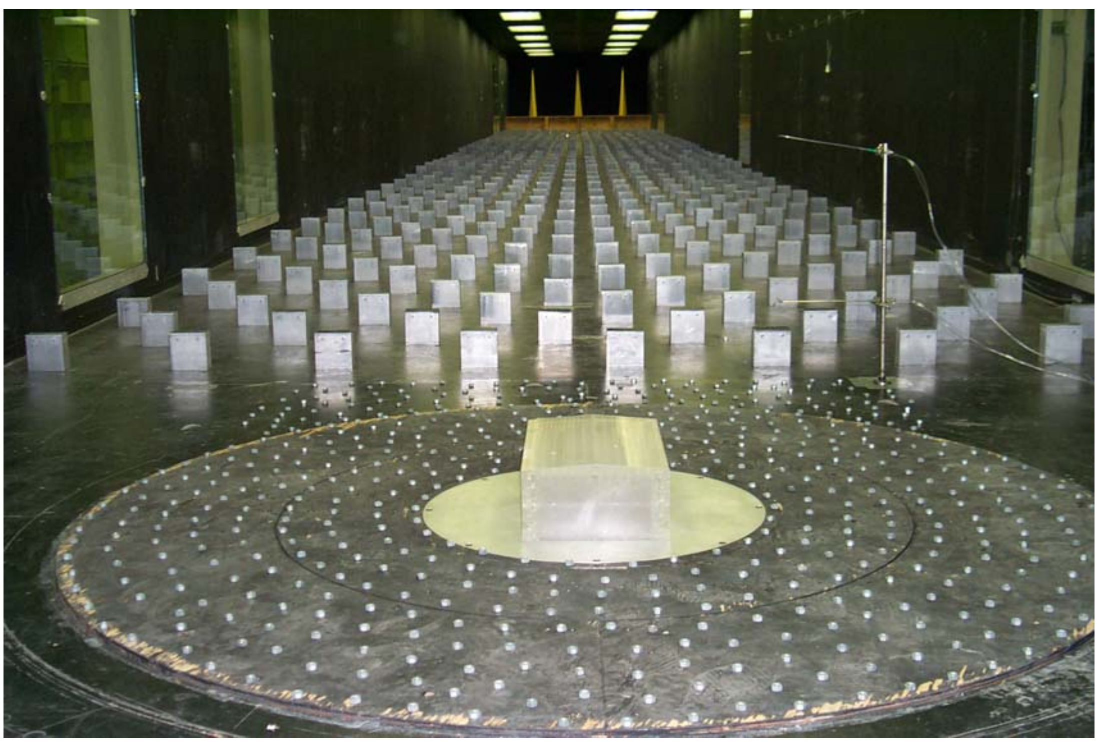
| Test | Building Height (ft) | Exposure 1 | Exposure 2 |
|---|---|---|---|
| | | 10th percentile (see Figures 6 and 8) | 90th percentile (see Figures 7 and 9) |
| **6** | 13 | 2.39 | 3.44 |
| **7** | 13 | 2.31 | 4.00 |
| **8** | 13 | 2.31 | 4.00 |

**TABLE 4 REFERENCE WIND SPEED / PRESSURE MEAUSREMENTS**

| Exposure | Eave Height | VH/Vint | | | | Vint/Vref | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Profile (pitot) | Pressure meas. 1 | Pressure meas. 2 | Average | Profile (pitot) | Pressure meas. 1 | Pressure meas. 2 | Pressure meas. during tests (1:12) | Pressure meas. during test (3:12) | Average |
| Open | 16 ft | 0.713 | 0.747 | 0.766 | 0.742 | 0.79 | 0.791 | 0.772 | 0.784 | 0.777 | 0.783 |
| | 24 ft | 0.782 | 0.787 | 0.814 | 0.794 | 0.79 | 0.779 | 0.779 | 0.784 | 0.775 | 0.781 |
| | 32 ft | 0.815 | 0.824 | 0.831 | 0.823 | 0.79 | 0.778 | 0.77 | 0.784 | 0.772 | 0.779 |
| | 40 ft | 0.828 | 0.841 | 0.86 | 0.843 | 0.79 | 0.775 | 0.773 | 0.784 | 0.771 | 0.779 |
| | 60 ft | | 0.893 | 0.896 | 0.895 | 0.79 | 0.791 | 0.771 | | | 0.784 |
| Suburban | 16 ft | 0.666 | | 0.66 | 0.663 | 0.711 | | 0.695 | 0.704 | 0.705 | 0.704 |
| | 24 ft | 0.685 | | 0.695 | 0.69 | 0.711 | | 0.699 | 0.704 | 0.711 | 0.706 |
| | 32 ft | 0.729 | | 0.731 | 0.73 | 0.711 | | 0.687 | 0.704 | 0.704 | 0.701 |
| | 40 ft | 0.766 | | 0.748 | 0.757 | 0.711 | | 0.701 | 0.704 | 0.704 | 0.705 |
| | 60 ft | | | 0.789 | 0.789 | 0.711 | | 0.692 | | | 0.702 |

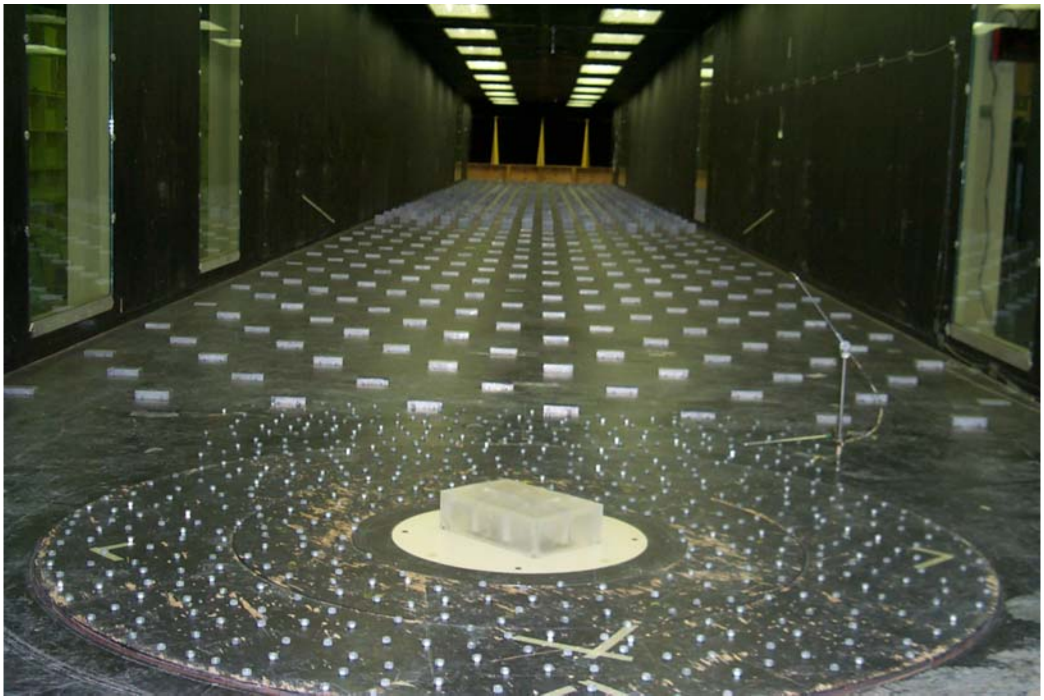
# FIGURES

**EXPOSURE 1 (OPEN)**

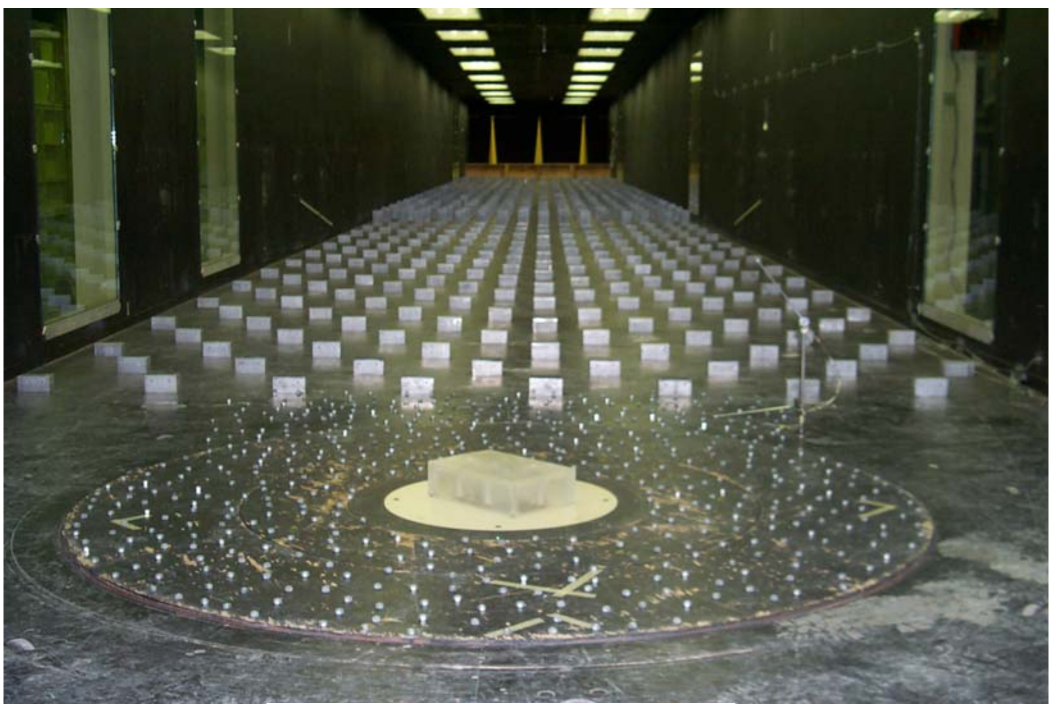


**EXPOSURE 2 (SUBURBAN)**

**FIGURE 1 VIEWS OF A GENERIC BUILDING MODEL IN THE WIND TUNNEL**



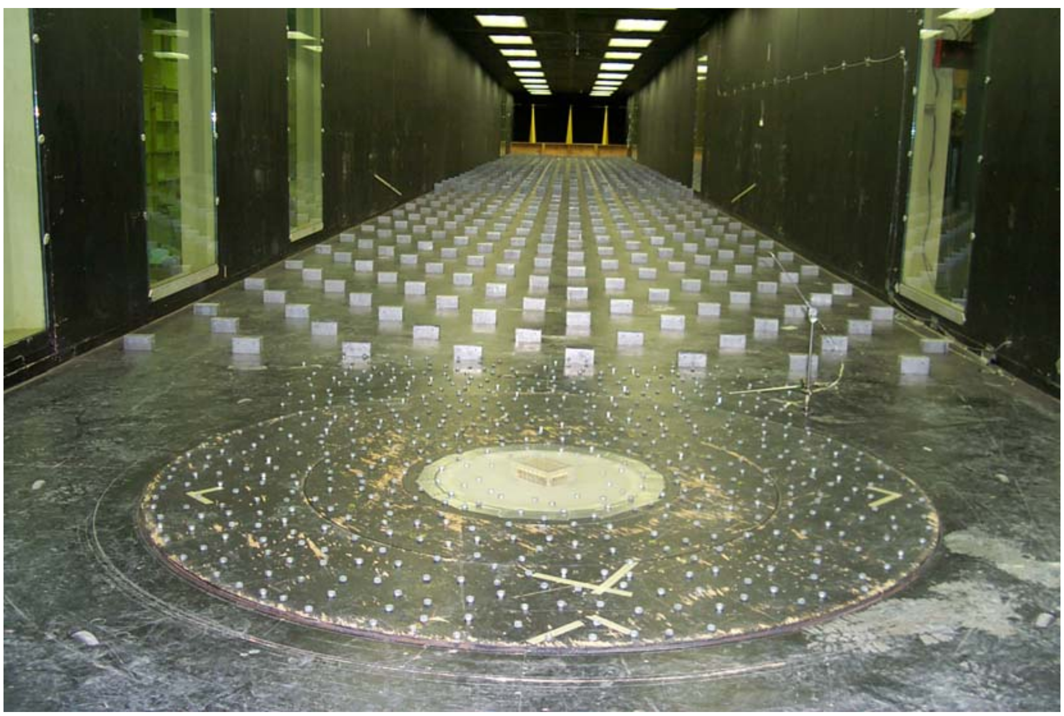
**EXPOSURE 1 (zo = 0.01 m)**



**EXPOSURE 2 (zo = 0.087 m)**

**FIGURE 2 VIEWS OF THE 1:50 WERFL BUILDING MODEL IN THE WIND TUNNEL**

**EXPOSURE 1 (zo = 0.01 m)**



**EXPOSURE 2 (zo = 0.087 m)**

**FIGURE 3 VIEWS OF THE 1:100 WERFL BUILDING MODEL IN THE WIND TUNNEL**

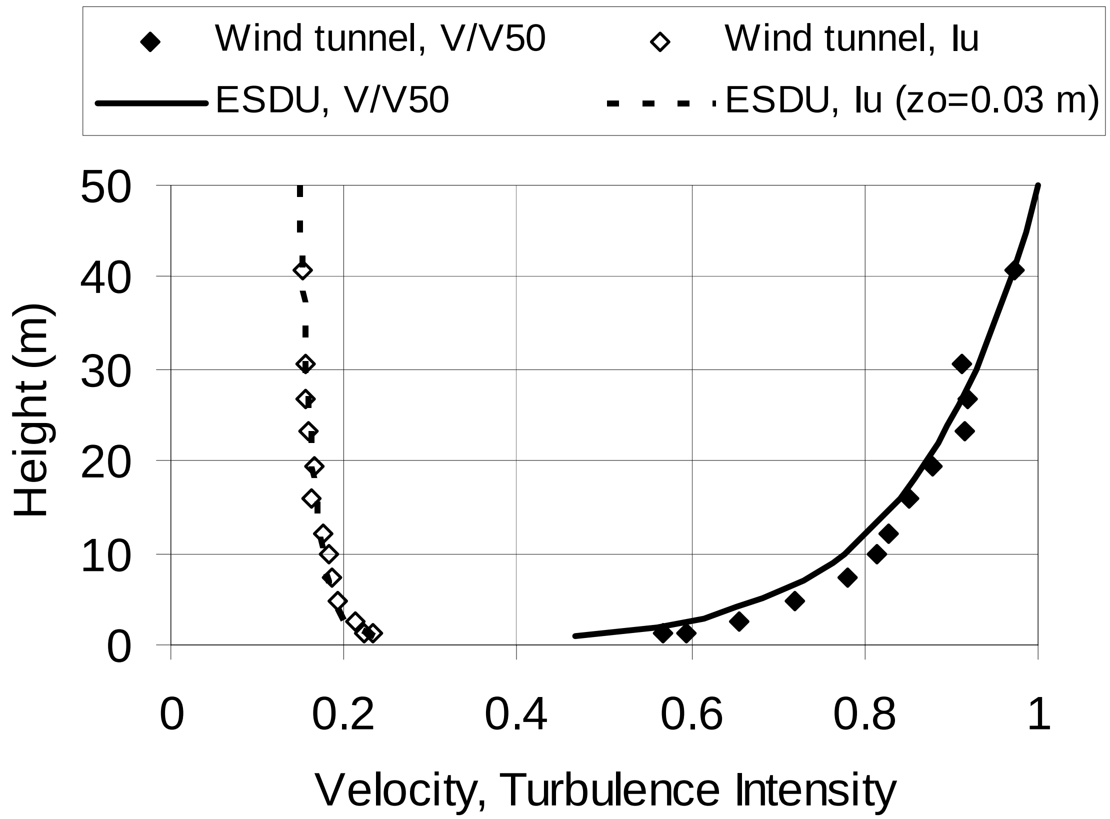



**FIGURE 4** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:100 SCALE WIND SIMULATION - OPEN EXPOSURE**

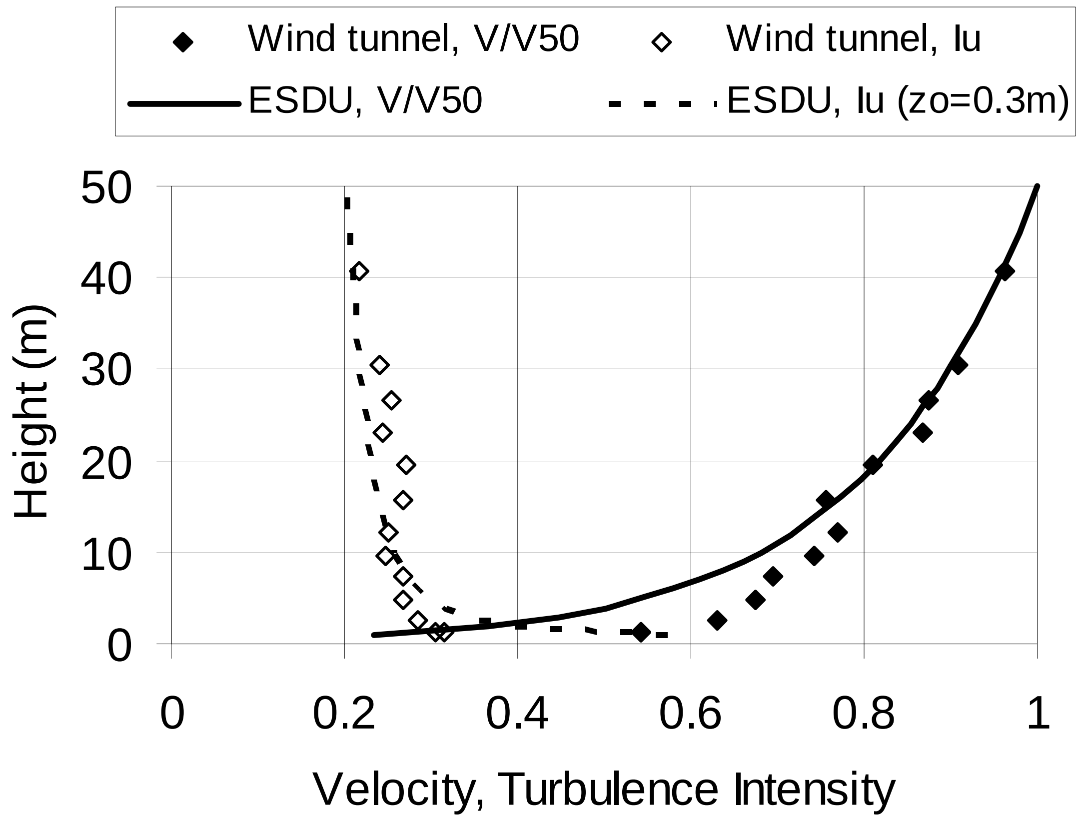



**FIGURE 5** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:100 SCALE WIND SIMULATION - SUBURBAN EXPOSURE**

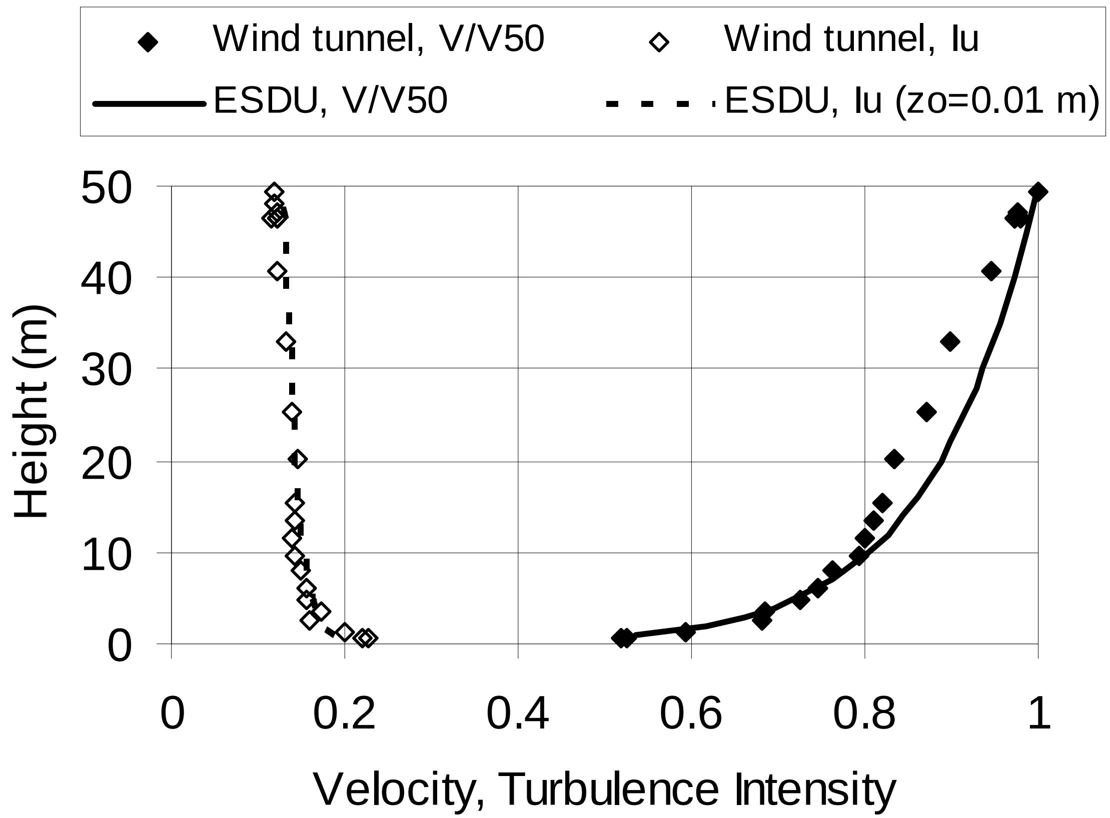



**FIGURE 6** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:50 SCALE WIND SIMULATION FOR THE WERFL BUILDING MODEL TEST – EXPOSURE 1 ($10^{TH}$ PERCENTILE)**

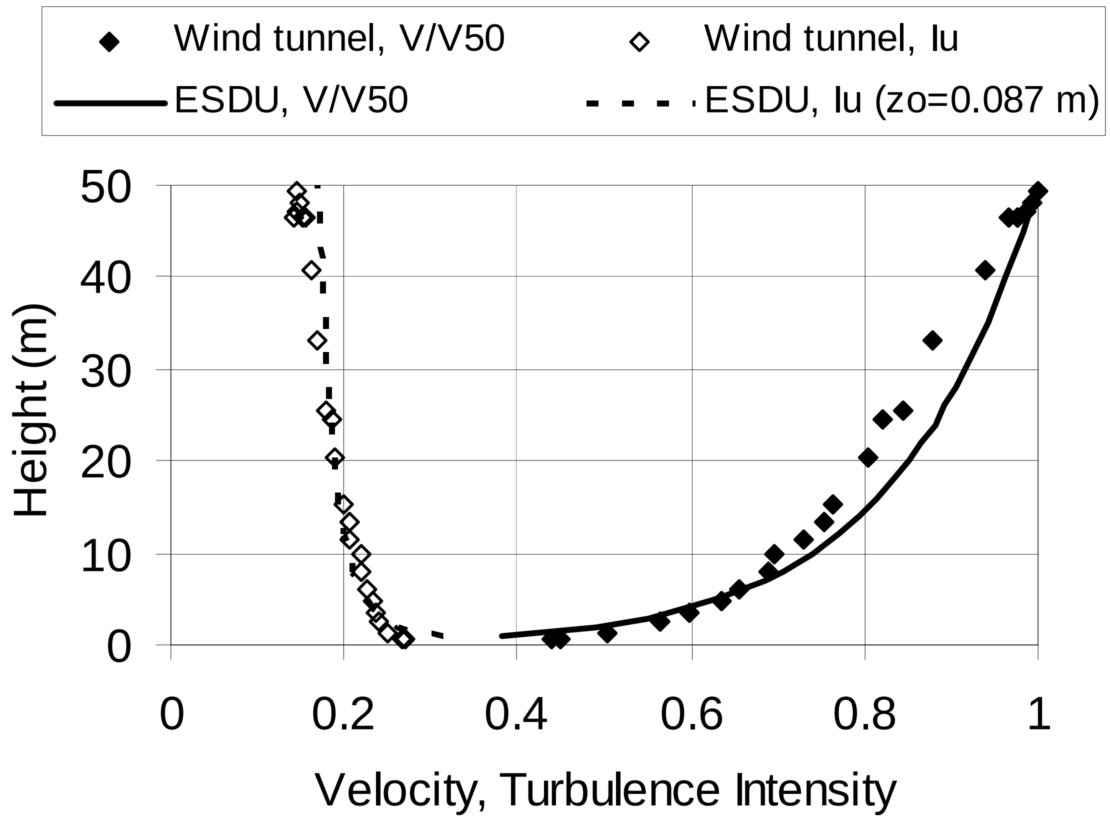



**FIGURE 7** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:50 SCALE WIND SIMULATION FOR THE WERFL BUILDING MODEL TEST – EXPOSURE 2 ($90^{TH}$ PERCENTILE)**

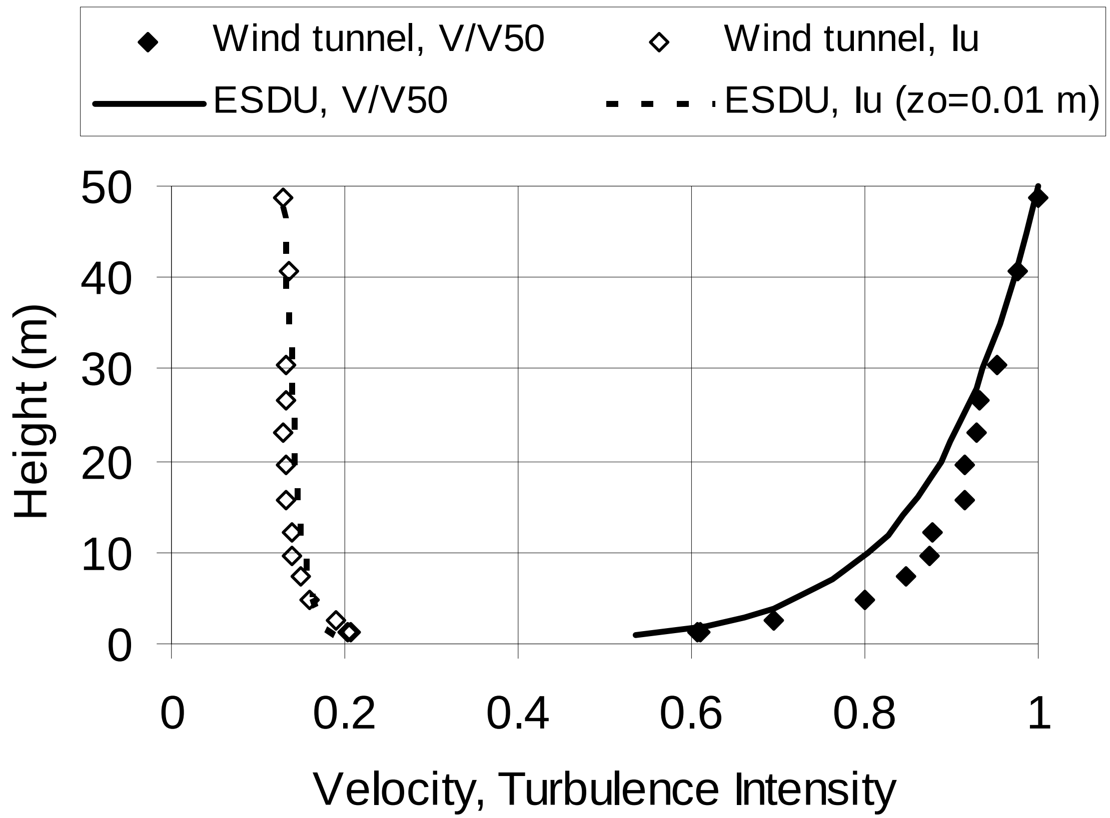



**FIGURE 8** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:100 SCALE WIND SIMULATION FOR THE WERFL BUILDING MODEL TEST – EXPOSURE 1 (10TH PERCENTILE)**

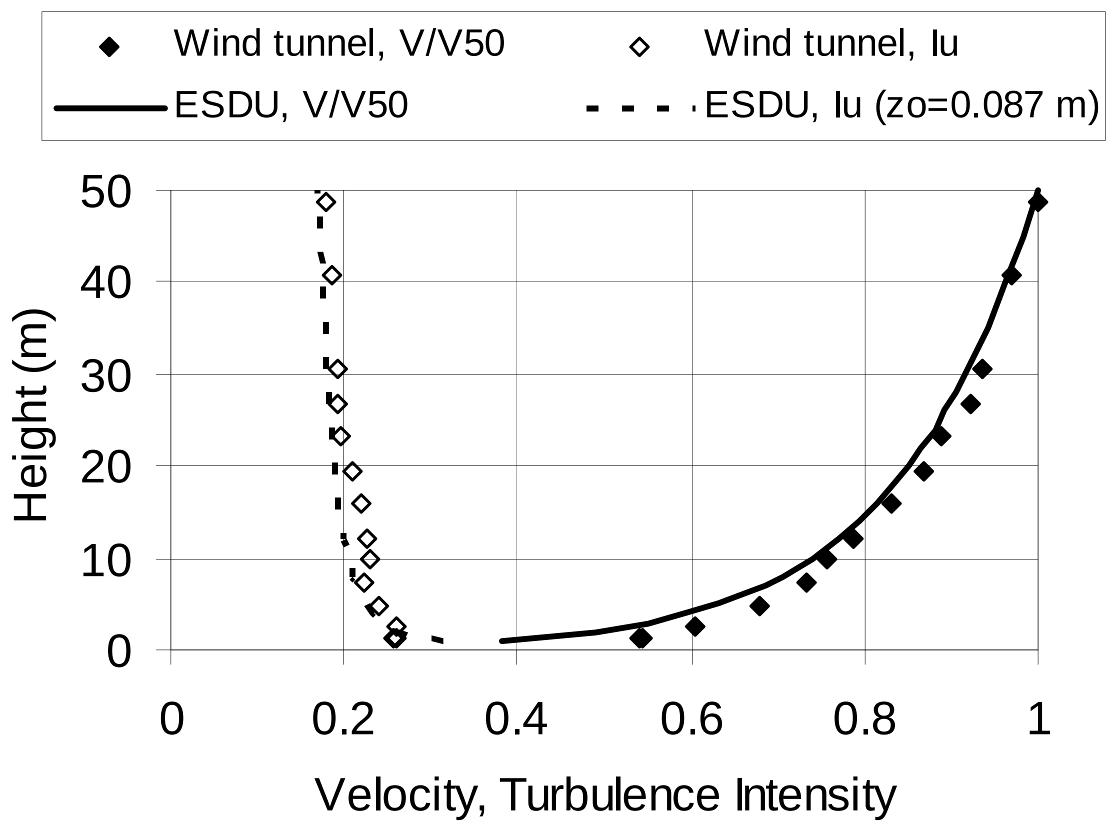



**FIGURE 9** **WIND SPEED AND TURBULENCE INTENSITY PROFILE. 1:100 SCALE WIND SIMULATION FOR THE WERFL BUILDING MODEL TEST – EXPOSURE 2 (90$^{TH}$ PERCENTILE)**

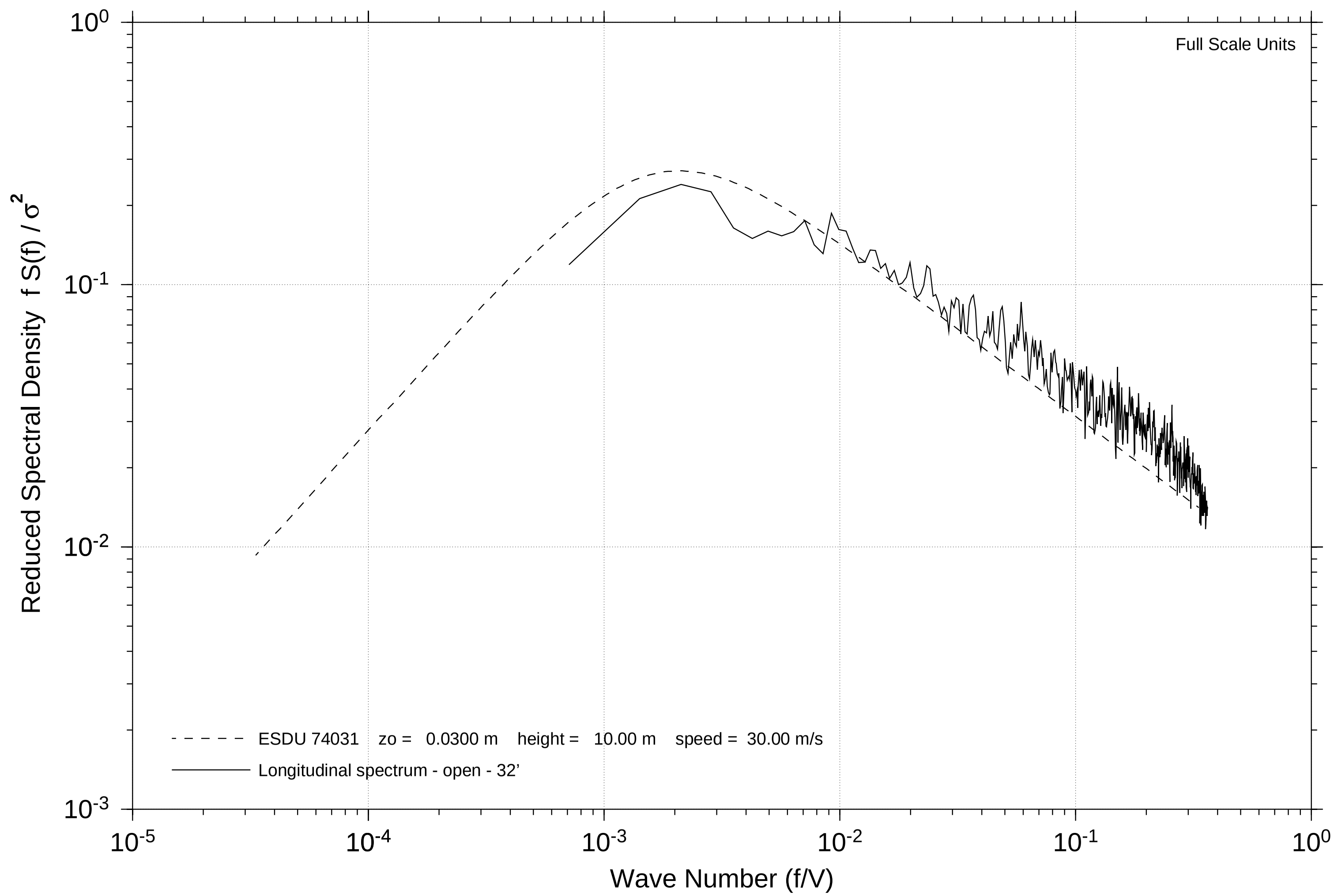



**FIGURE 10 LONGITUDINAL WIND SPECTRA**

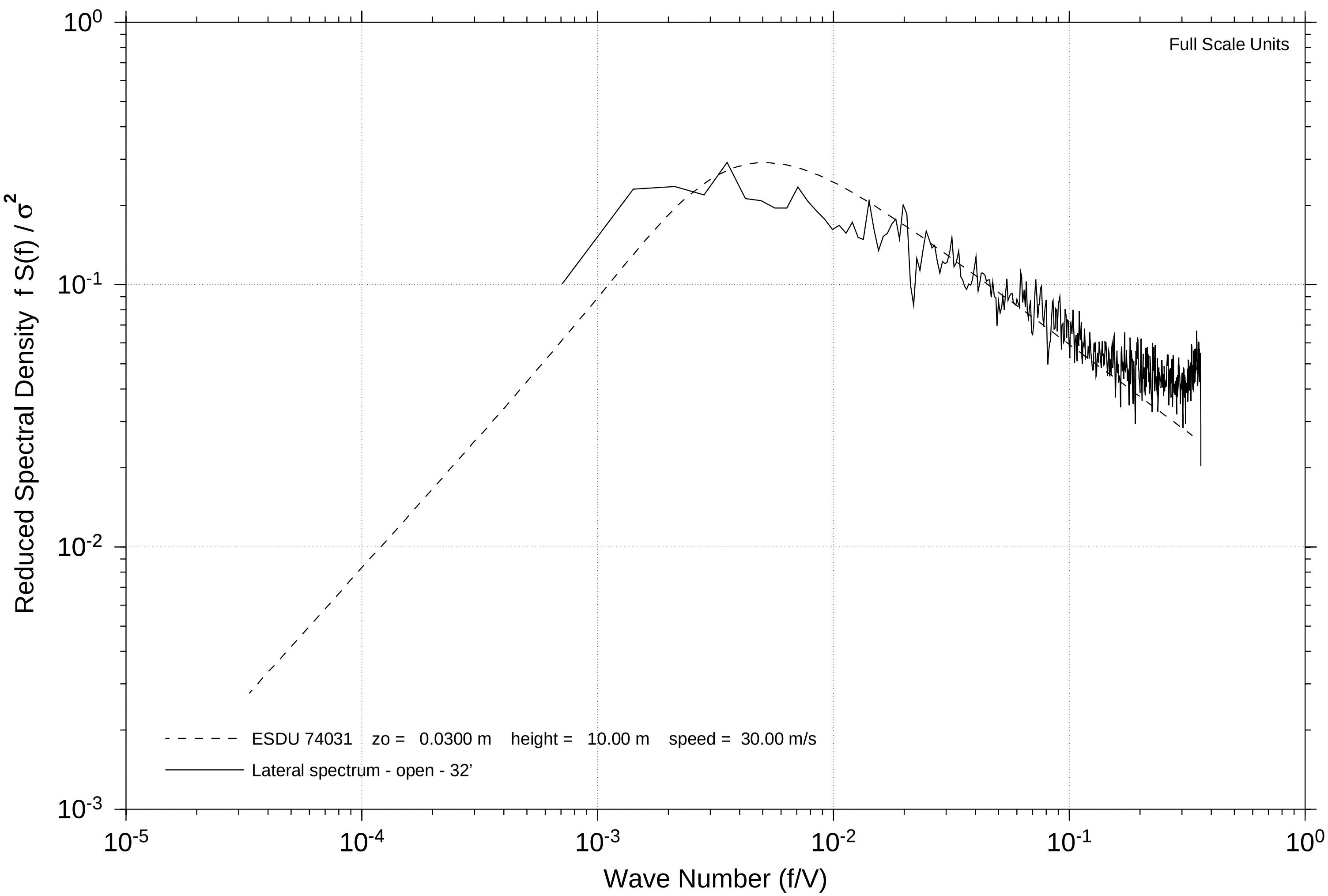



**FIGURE 11 LATERAL WIND SPECTRA**

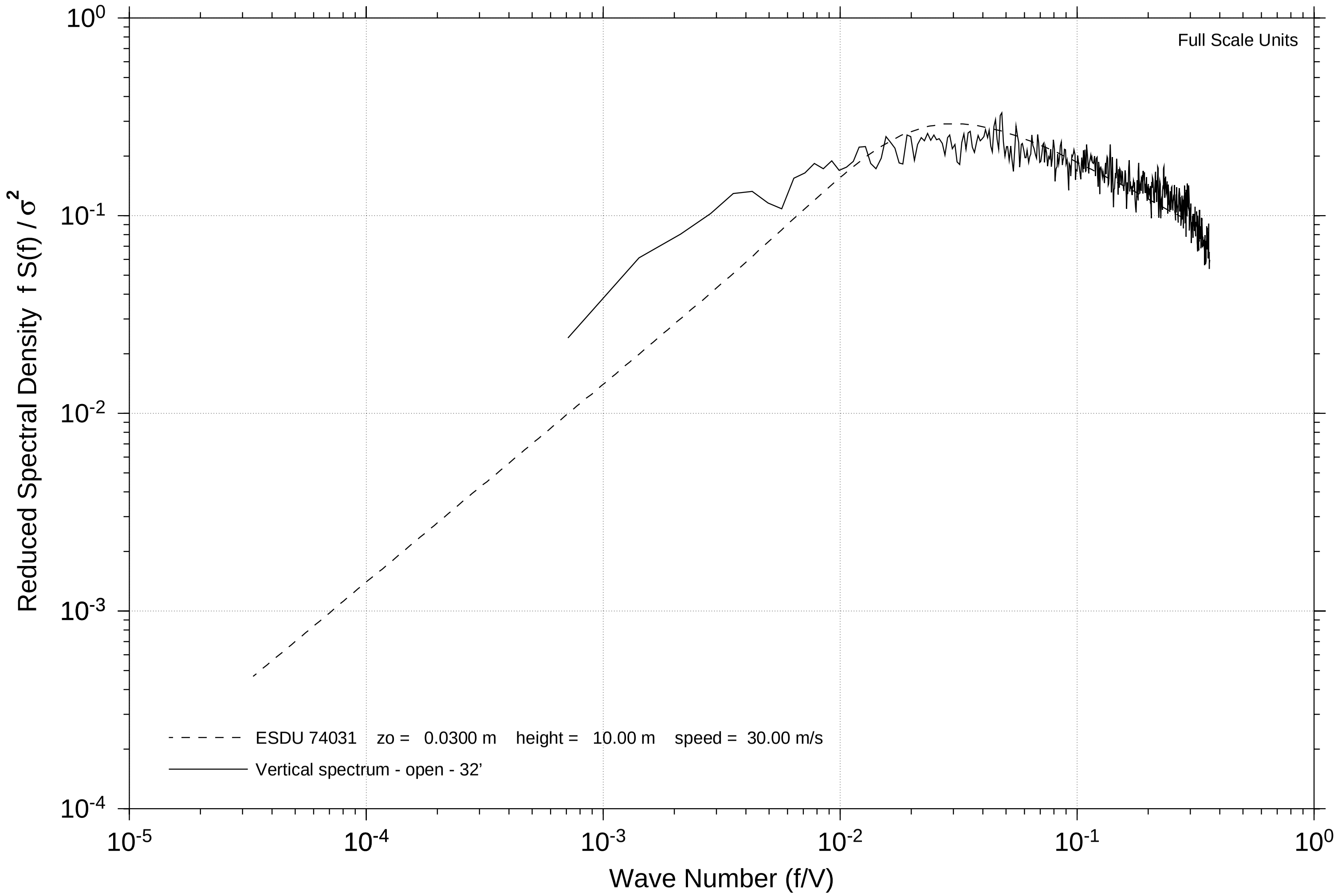



**FIGURE 12 VERTICAL WIND SPECTRA**

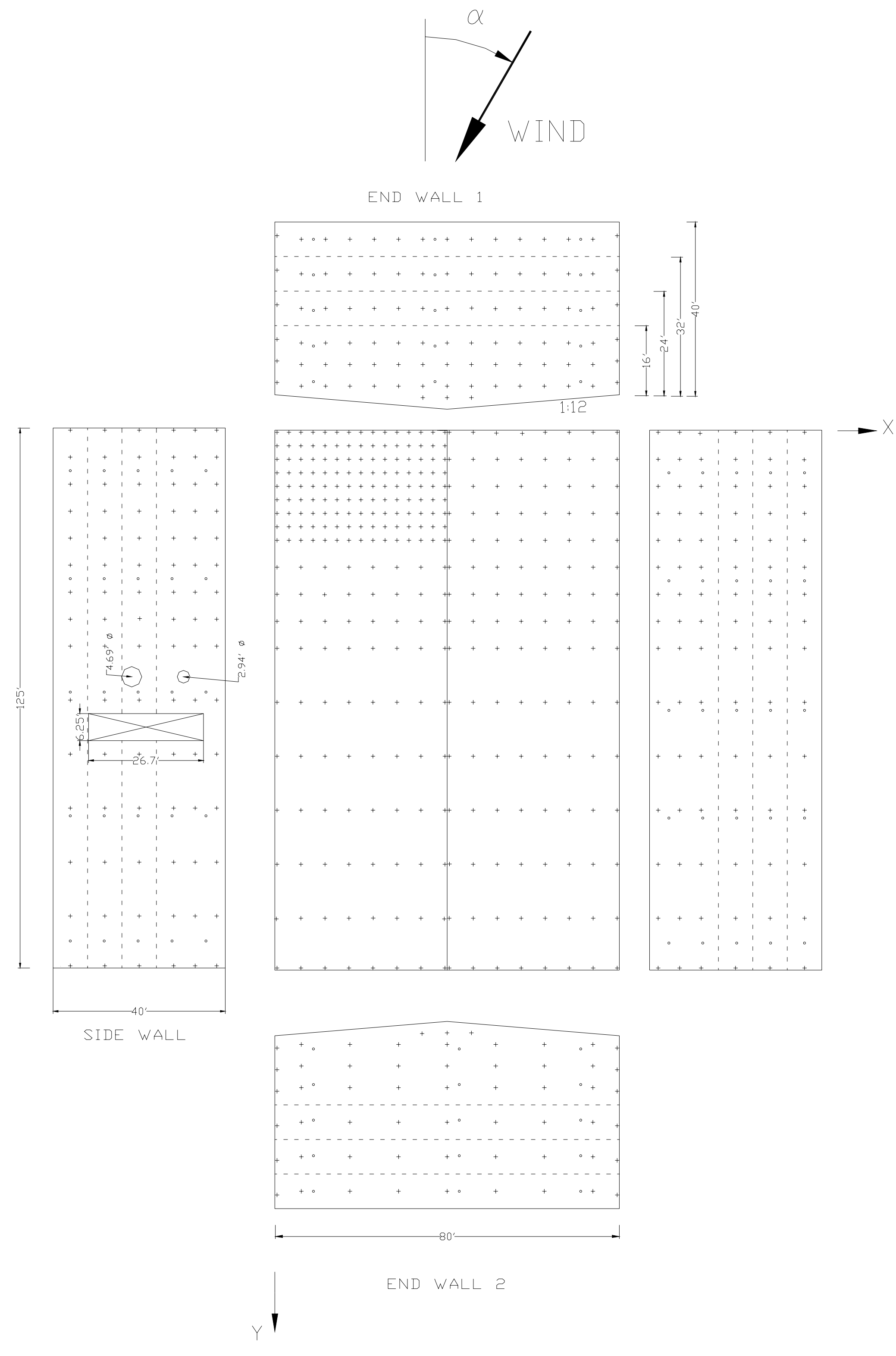



**FIGURE 13 EXPLODED VIEW OF THE 1:12 ROOF LOPE BUILDING – GENERIC BUILDING MODELS**

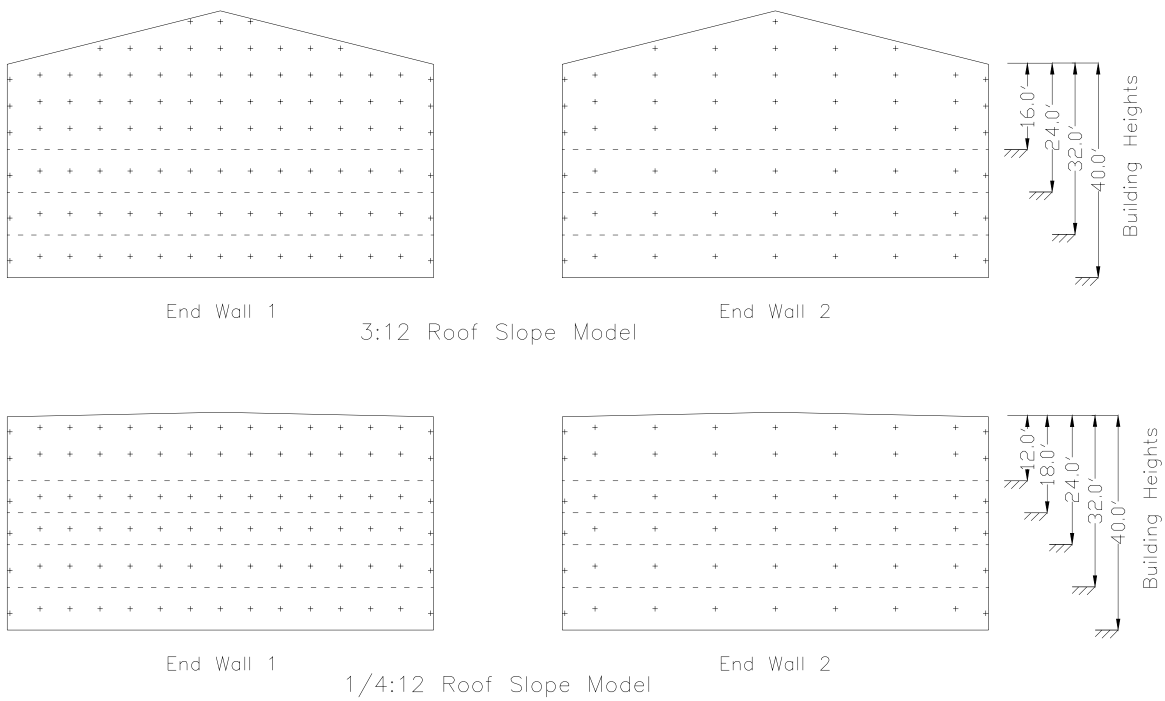
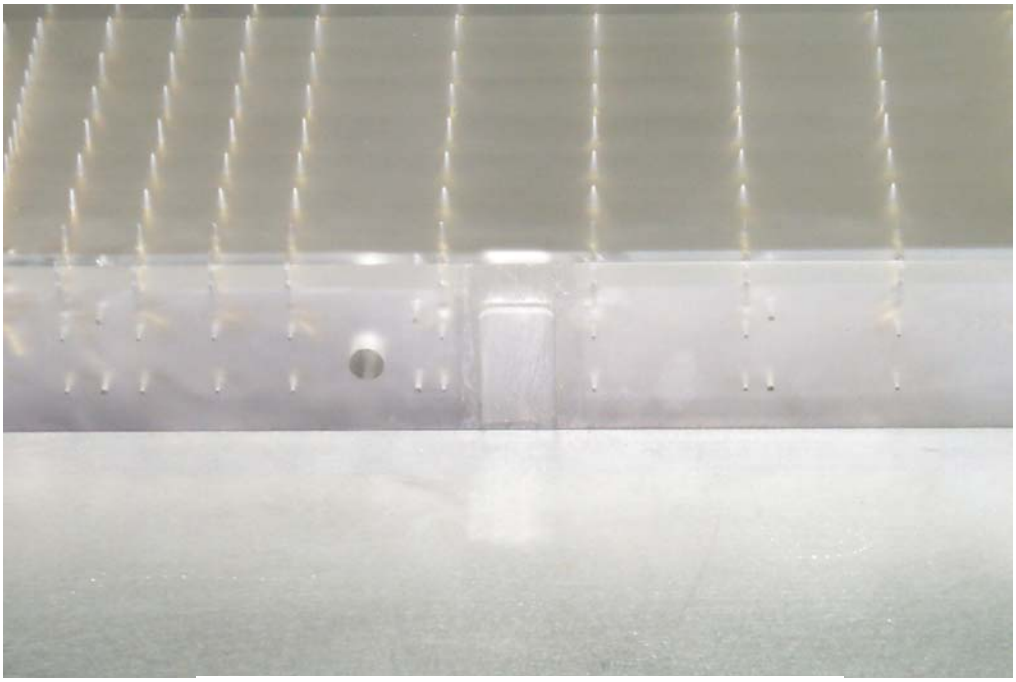



**FIGURE 14 PRESSURE TAP LAYOUT ON THE GABLE END WALLS OF THE 3:12 AND ¼:12 ROOF SLOPE BUILDING MODELS**


**FIGURE 15 PRESSURE TAP LAYOUT ON THE SIDE WALLS OF THE 3:12 AND ¼:12 ROOF SLOPE BUILDING MODELS**



OPENINGS ON THE 16' BUILDING MODEL

OPENINGS ON THE 40' BUILDING MODEL

**FIGURE 16 VIEWS OF THE DOMINANT OPENINGS ON THE 125'X80', 1:12 ROOF SLOPE BUILDING**

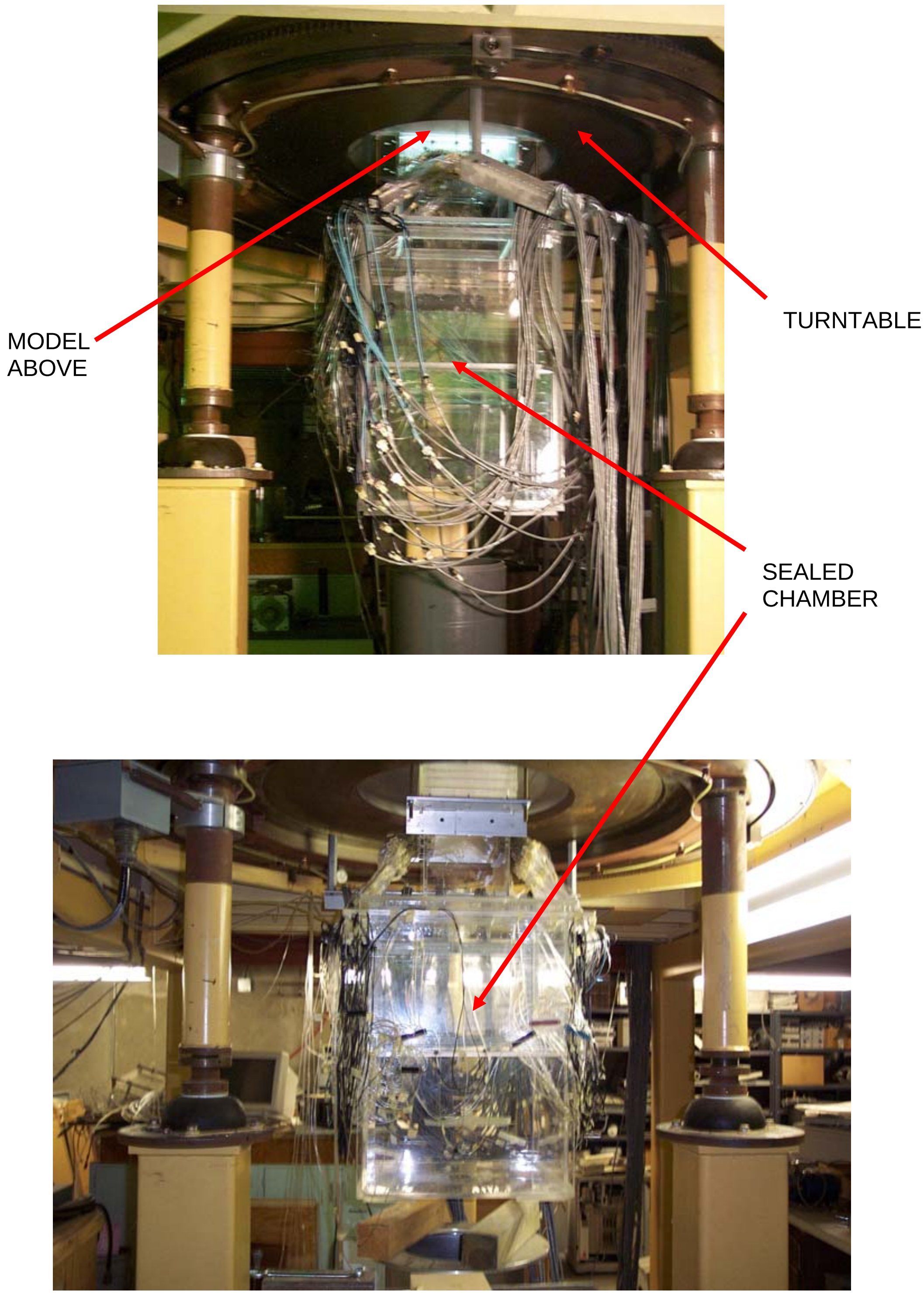



**FIGURE 17 VIEWS OF SEALED CHAMBER UNDERNEATH THE TURNTABLE FOR VOLUMETRIC SCALING**

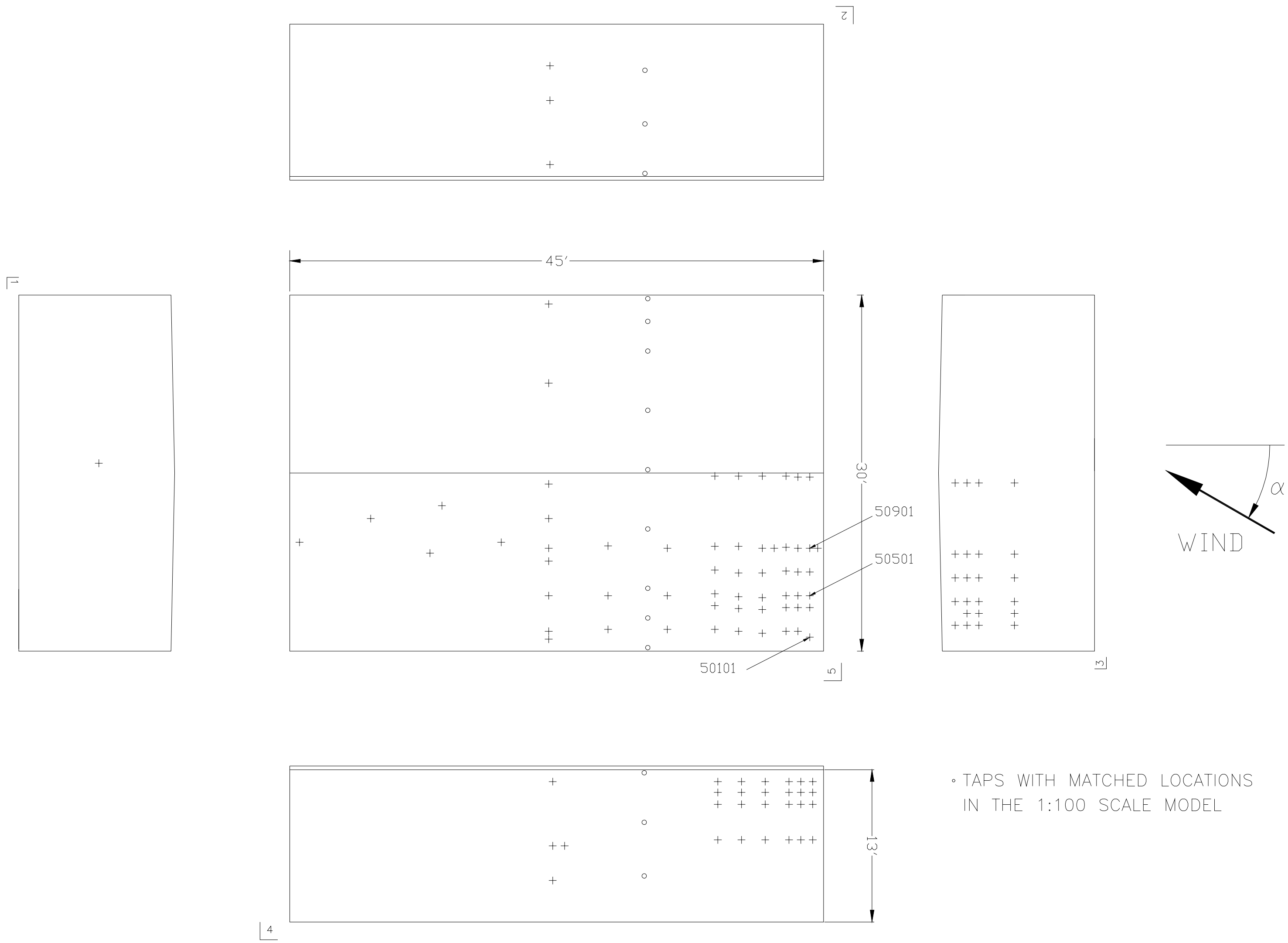



**FIGURE 18 PRESSURE TAP LAYOUT OF THE 1:50 SCALE UWO MODEL OF THE WERFL BUILDING**

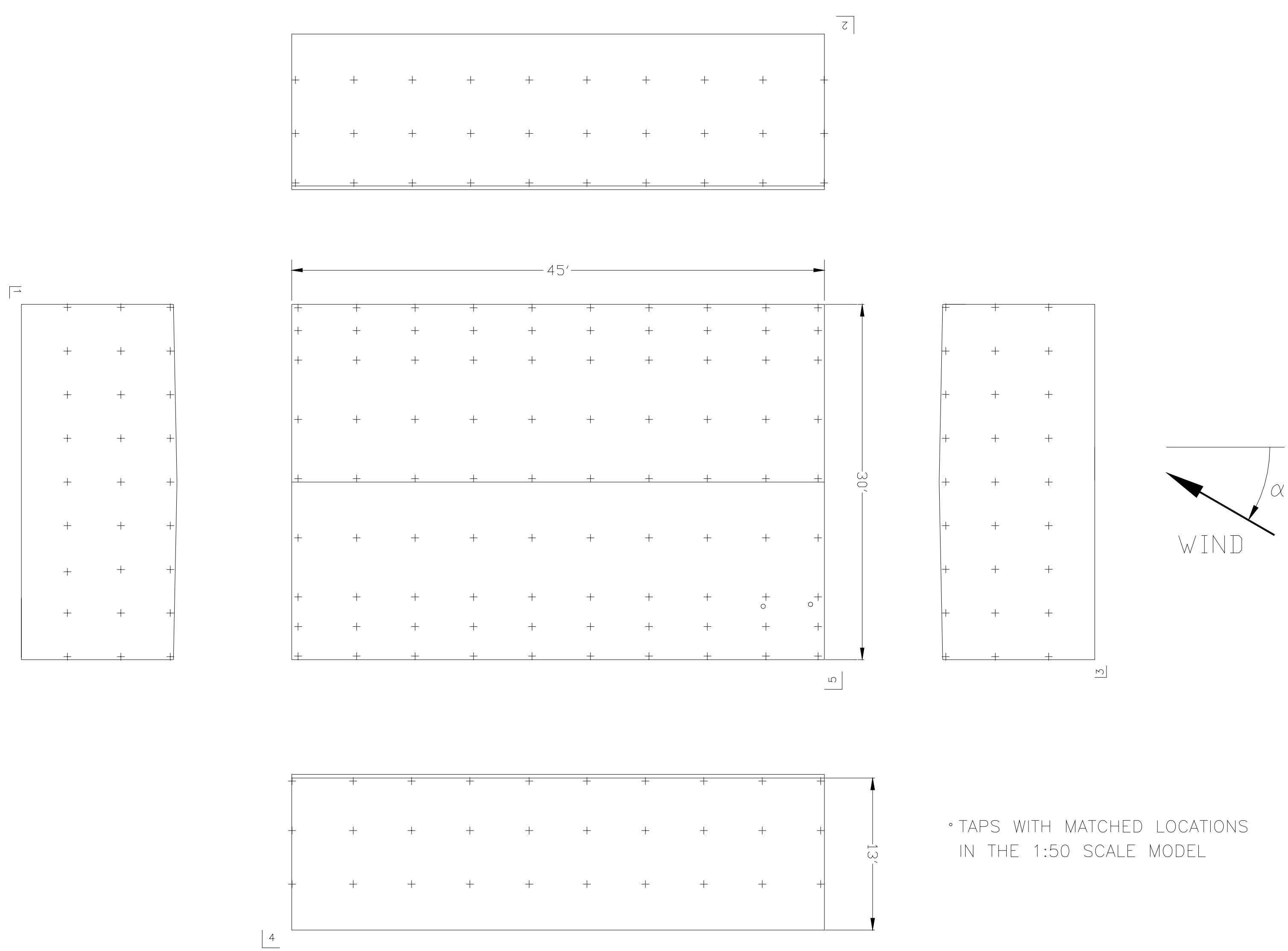



**FIGURE 19 PRESSURE TAP LAYOUT OF THE 1:100 SCALE UWO MODEL OF THE WERFL BUILDING**

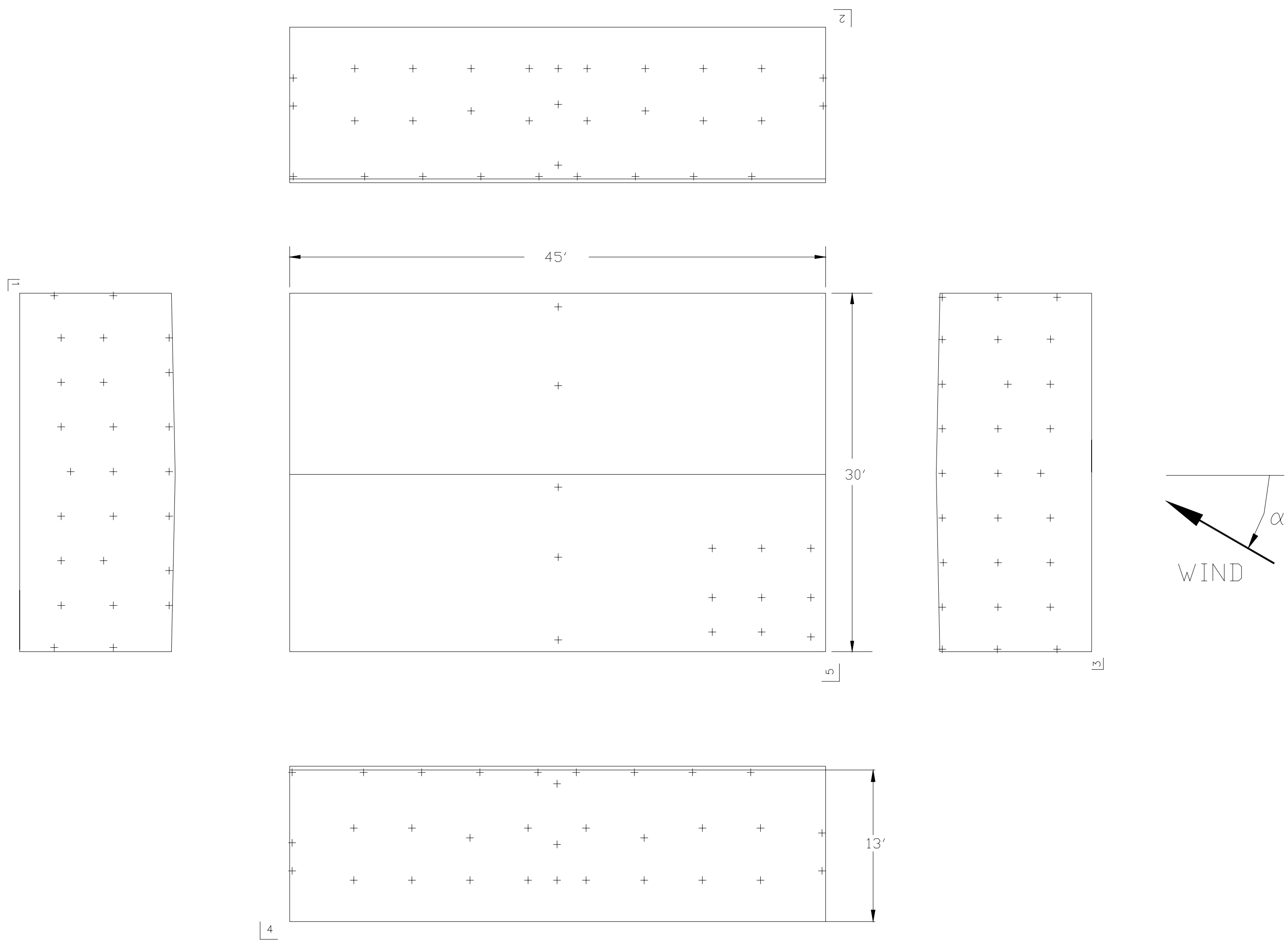



**FIGURE 20 PRESSURE TAP LAYOUT OF THE 1:100 SCALE CSU MODEL OF THE WERFL BUILDING**

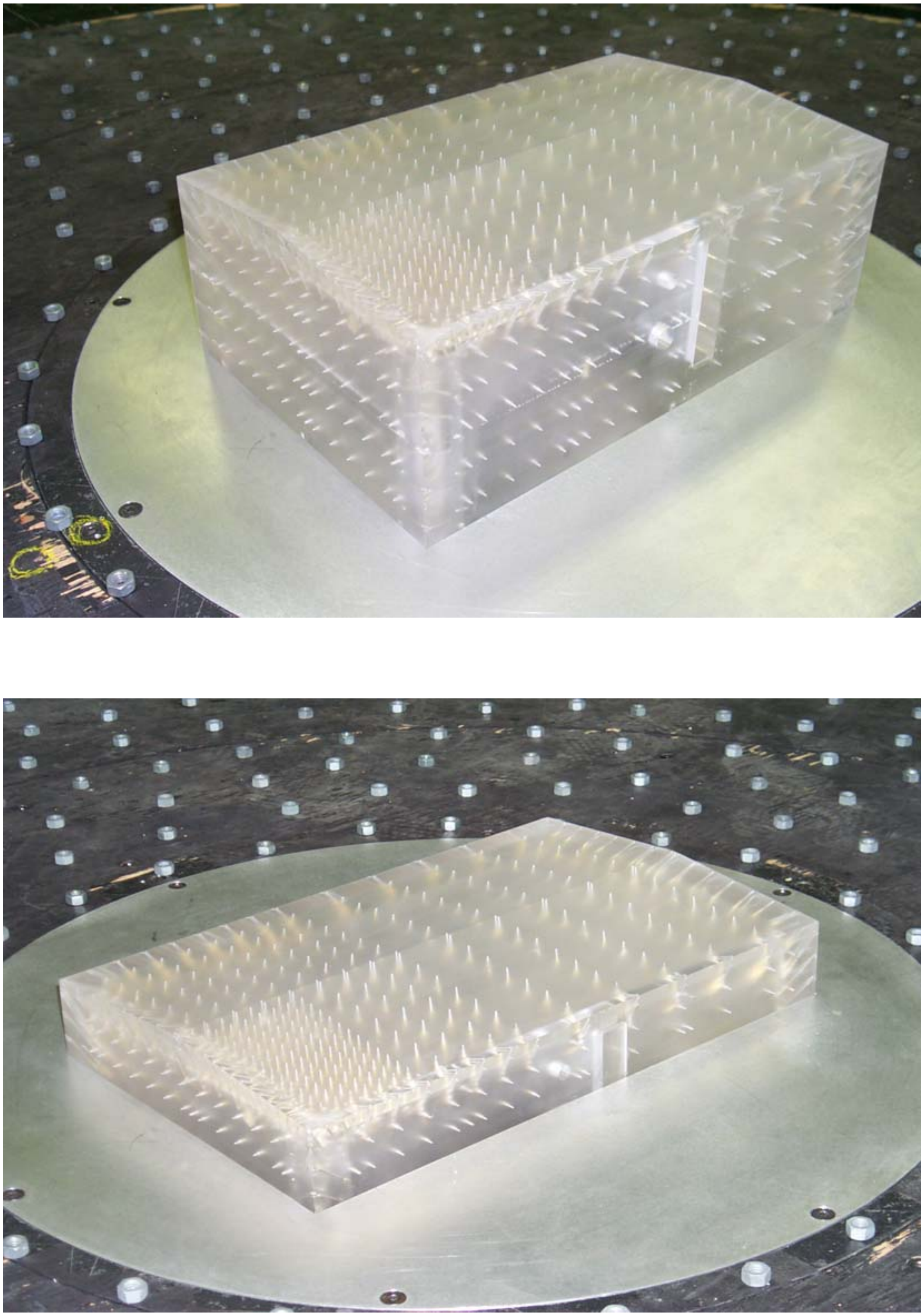
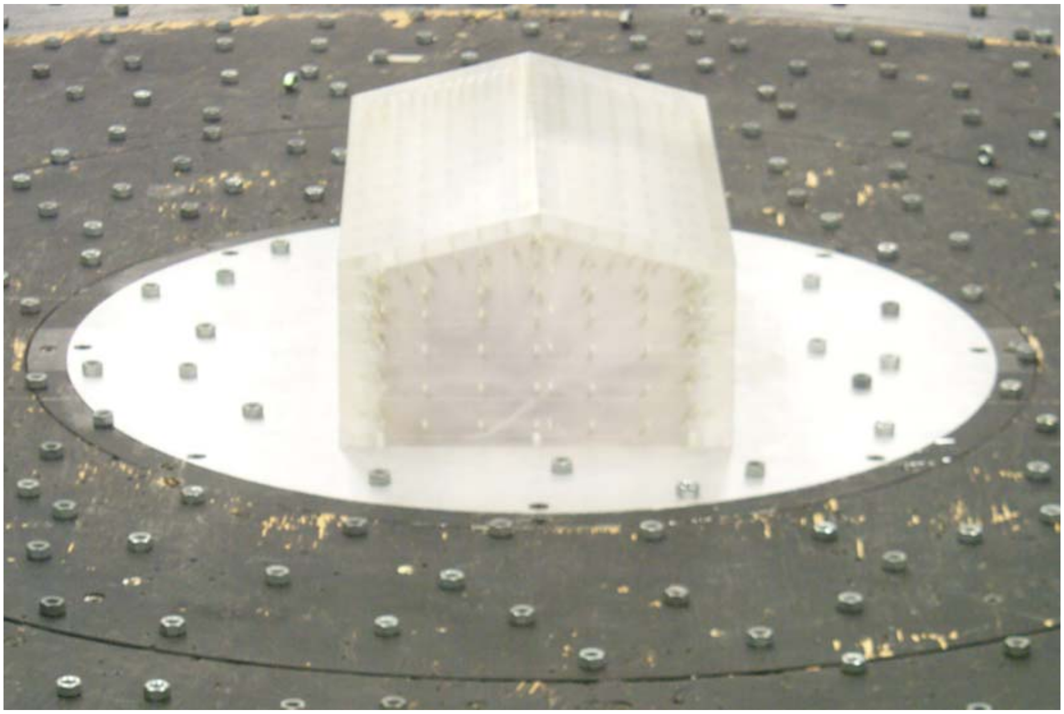


FIGURE 21 CLOSE-UP VIEWS OF THE GENERIC BUILDING MODEL - TEST 1



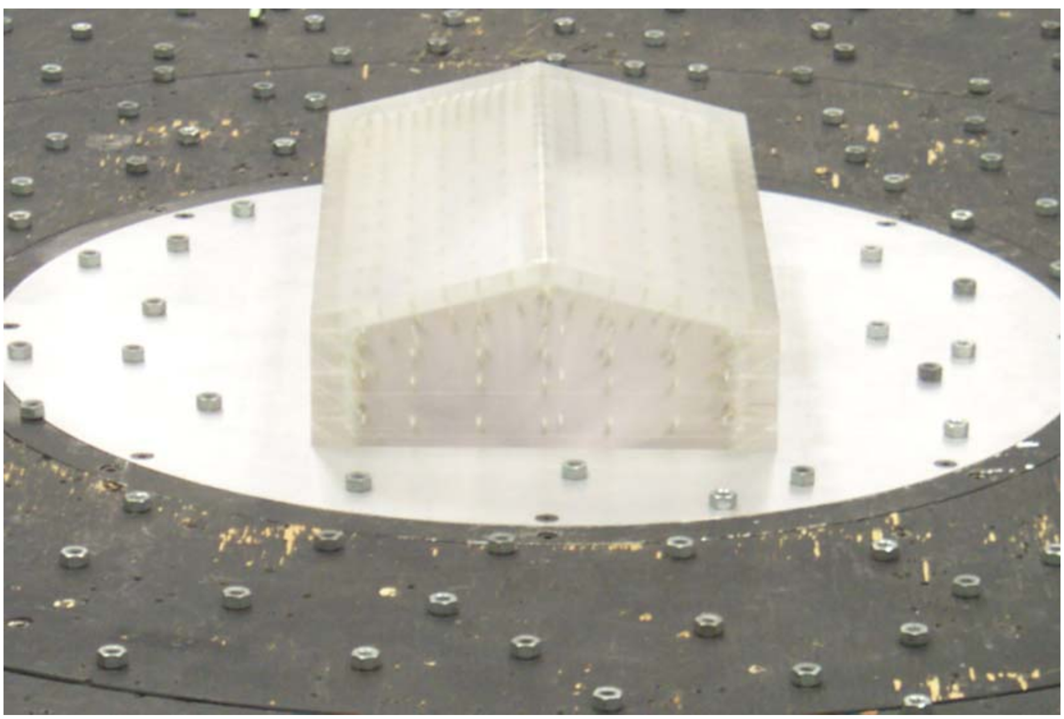


**FIGURE 22 CLOSE-UP VIEWS OF THE GENERIC BUILDING MODEL - TEST 2**

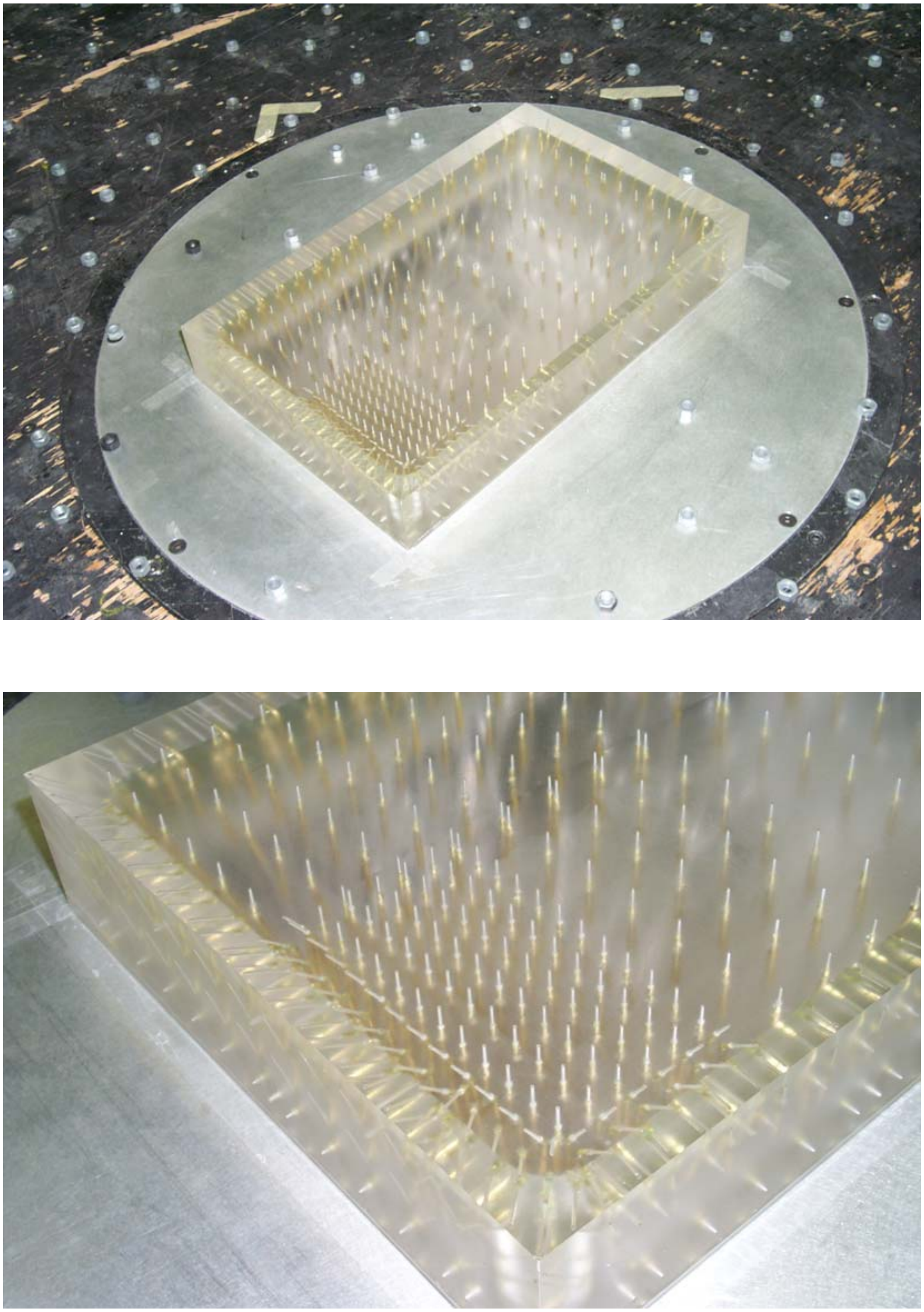


**FIGURE 23 CLOSE-UP VIEWS OF THE GENERIC BUILDING MODEL - TEST 3**

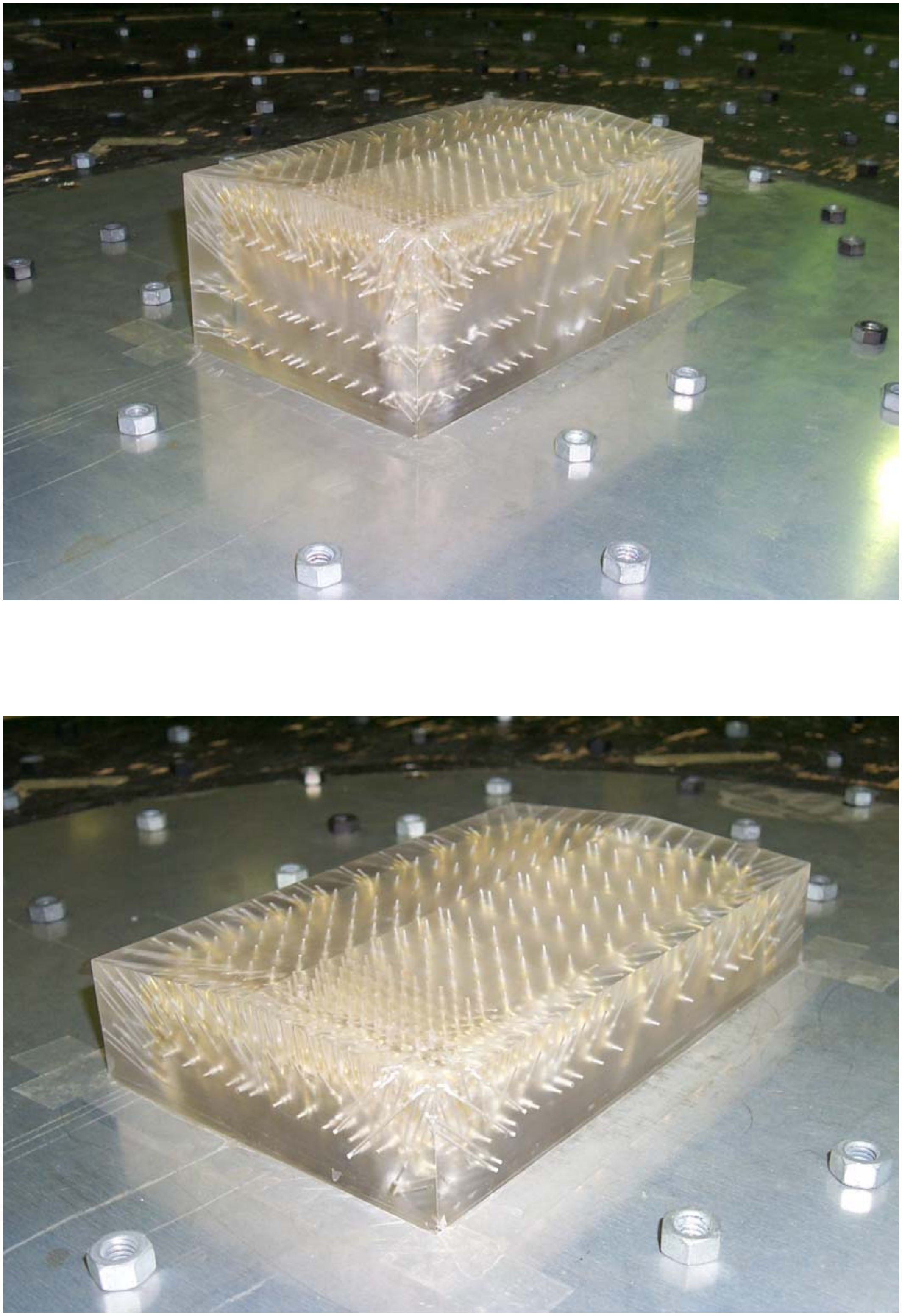


**FIGURE 24 CLOSE-UP VIEWS OF THE GENERIC BUILDING MODEL - TEST 4**

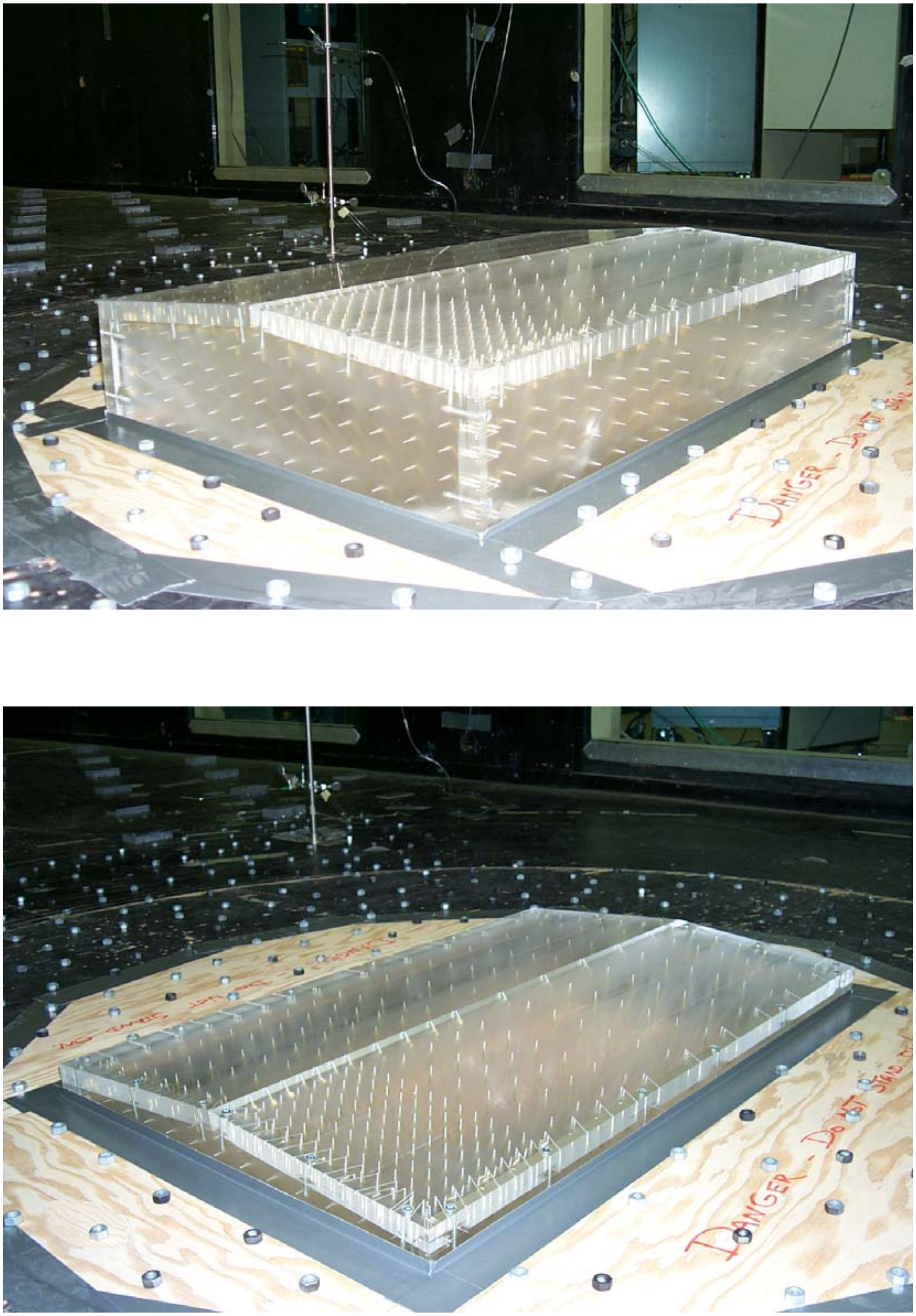



**FIGURE 25 CLOSE-UP VIEWS OF THE GENERIC BUILDING MODEL - TEST 5**

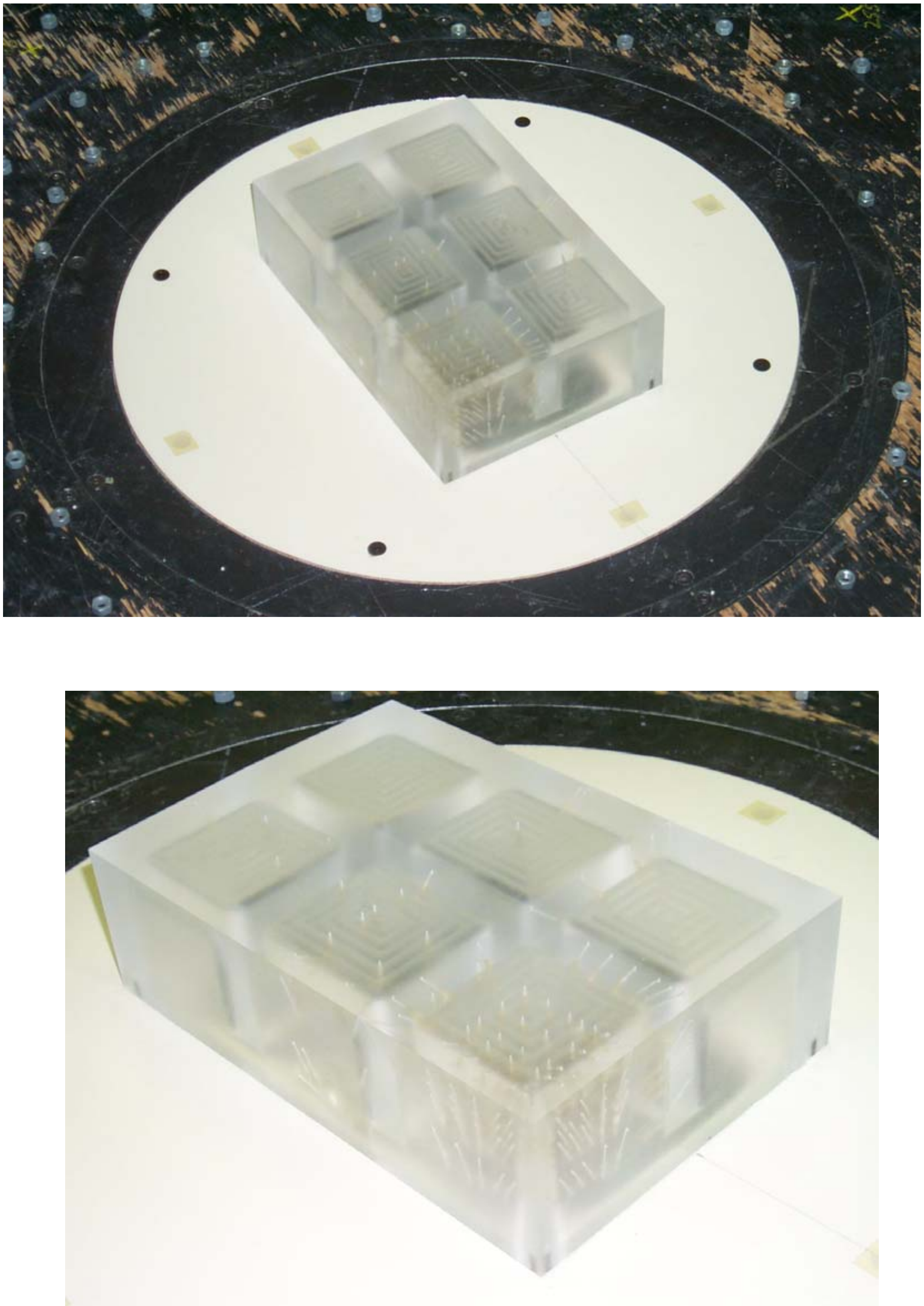


**FIGURE 26 CLOSE-UP VIEWS OF THE 1:50 SCALE UWO MODEL OF THE WERFL BUILDING - TEST 6**

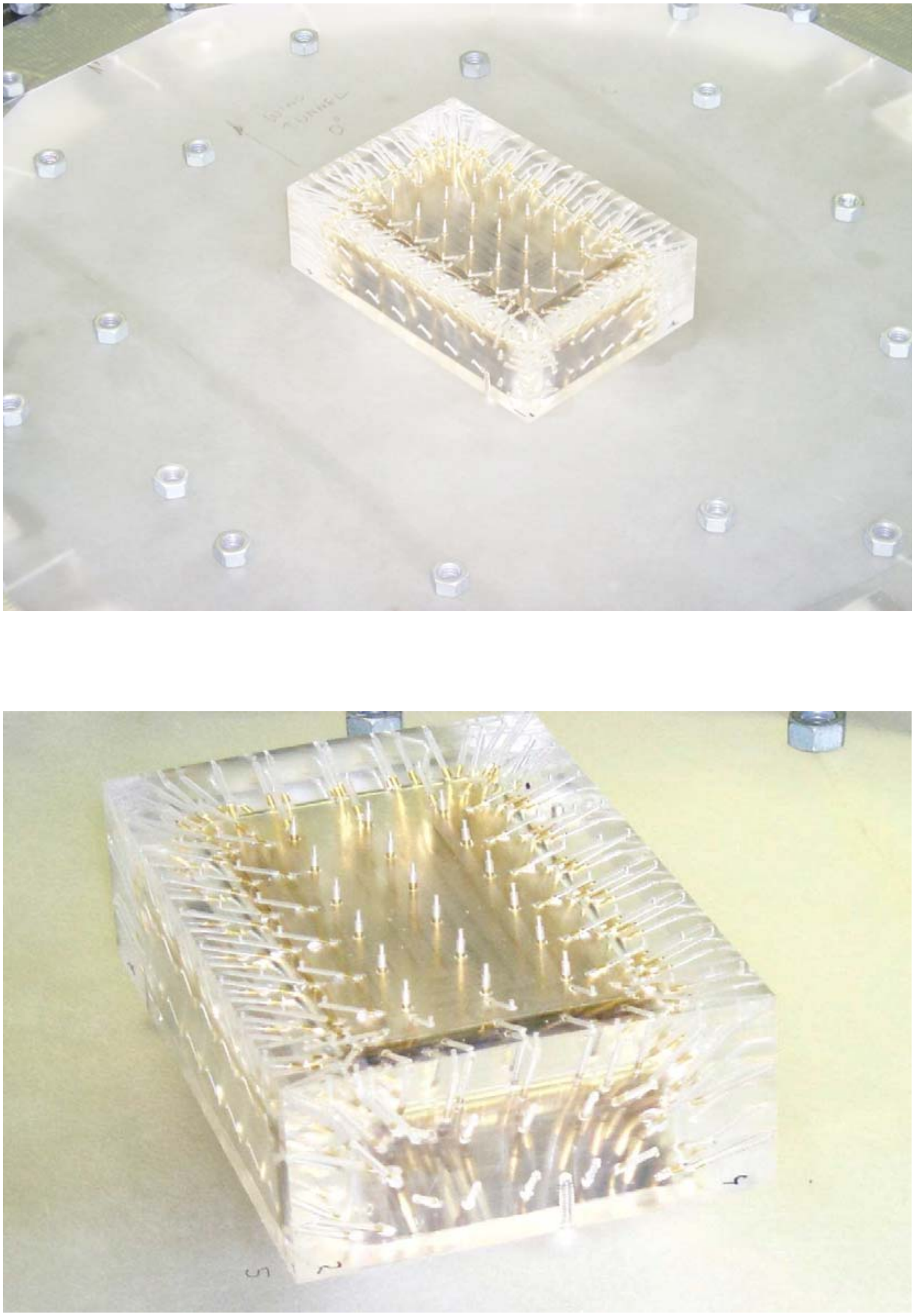


**FIGURE 27 CLOSE-UP VIEWS OF THE 1:100 SCALE UWO MODEL OF THE WERFL BUILDING - TEST 7**

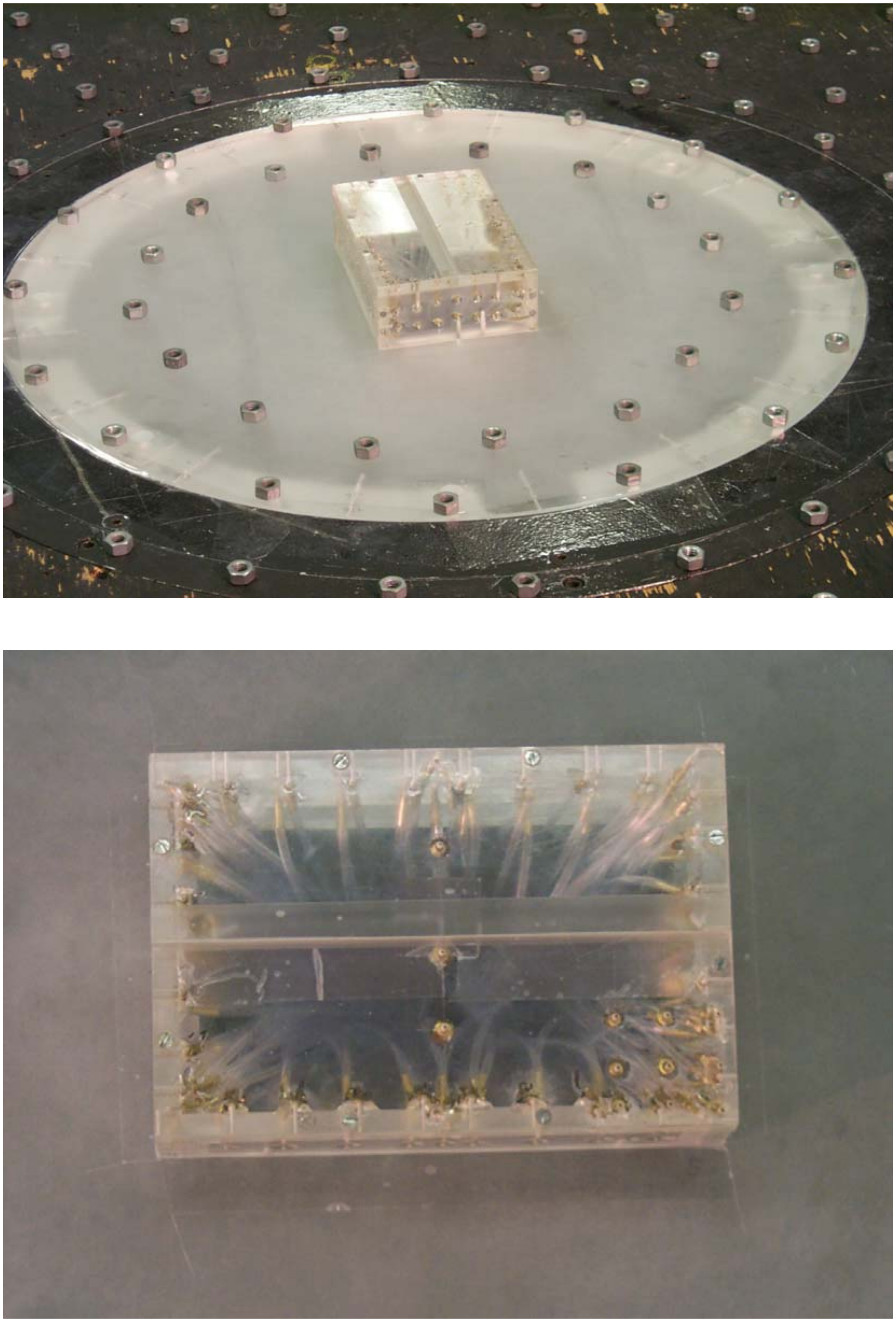


**FIGURE 28 CLOSE-UP VIEWS OF THE 1:100 SCALE CSU MODEL OF THE WERFL BUILDING - TEST 8**

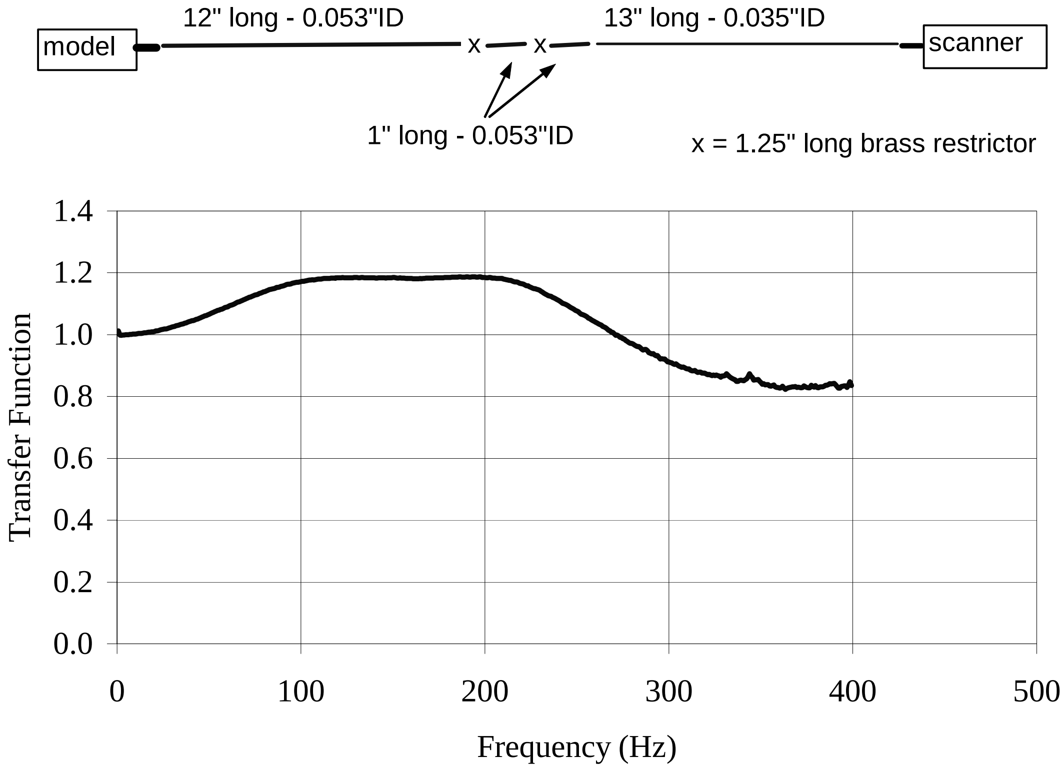
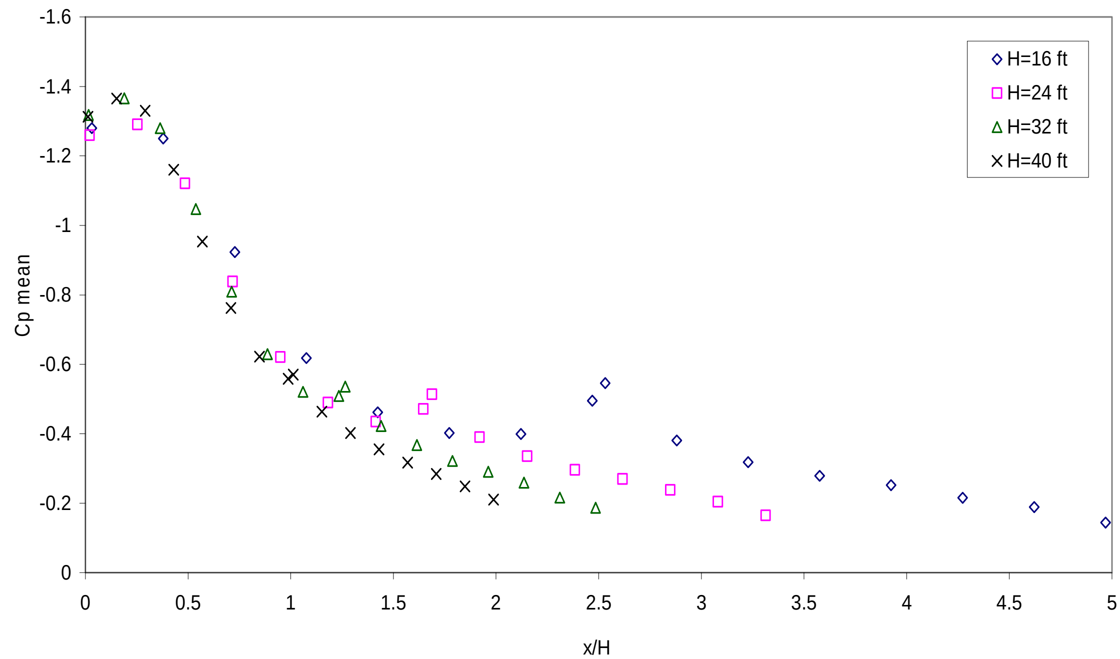



**FIGURE 29 FREQUENCY RESPONSE CHARACTERISTICS OF THE PRESSURE TUBIING SYSTEM USED**



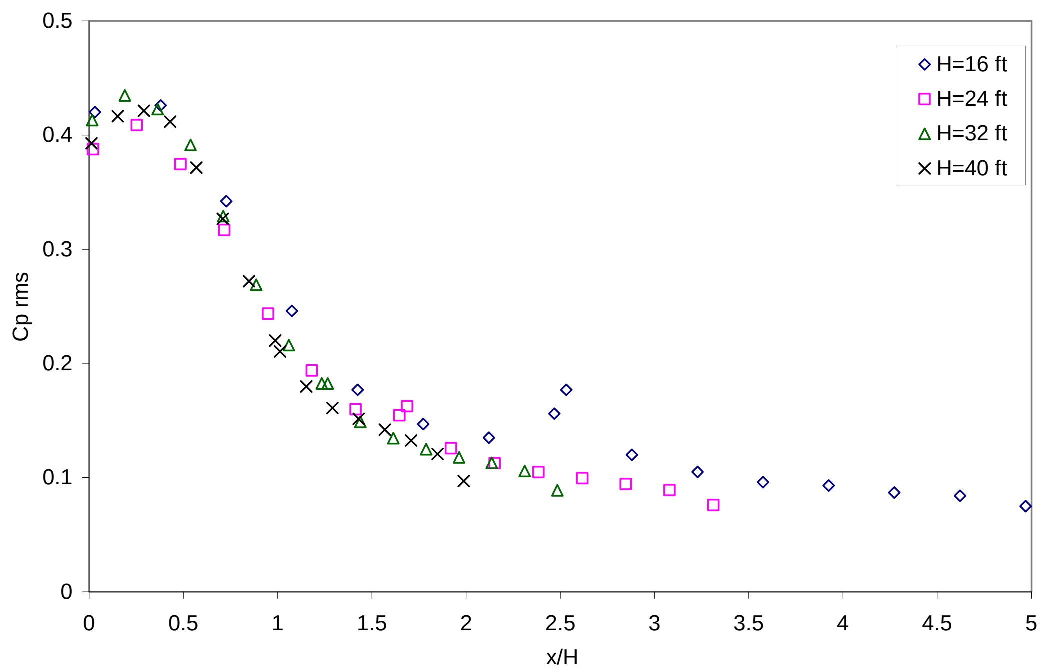
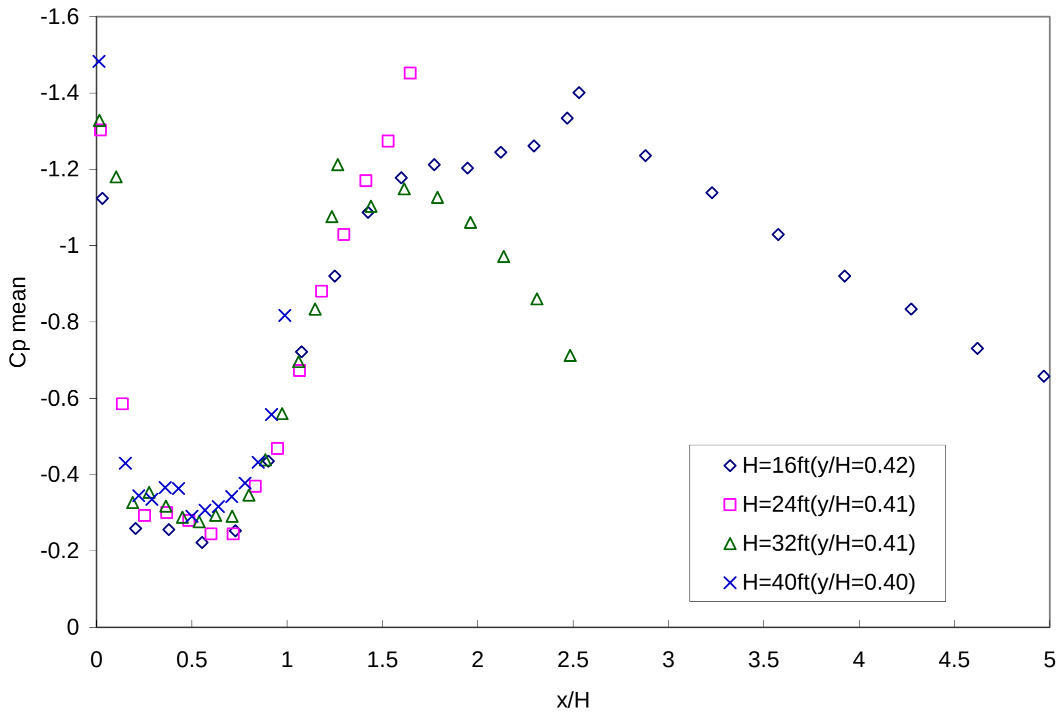




**FIGURE 30 VARIATION OF PRESSURE COEFFICIENTS ALONG A LINE OF TAPS AT MID-SPAN WITH DIFFERENT ROOF HEIGHTS (1:12 ROOF SLOPE; WIND ANGLE 270$^{O}$)**



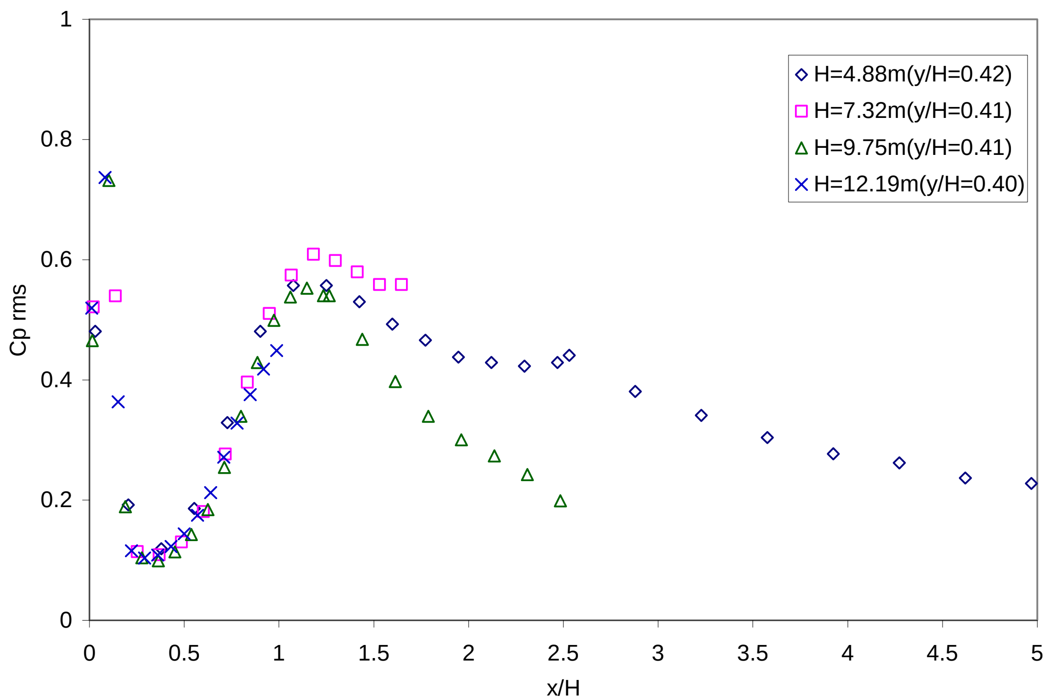




**FIGURE 31 VARIATION OF PRESSURE COEFFICIENTS ALONG A LINE OF TAPS NEAR THE EDGE OF THE BUILDINGS WITH DIFFERENT ROOF HEIGHTS (1:12 ROOF SLOPE; WIND ANGLE 325$^{O}$)**

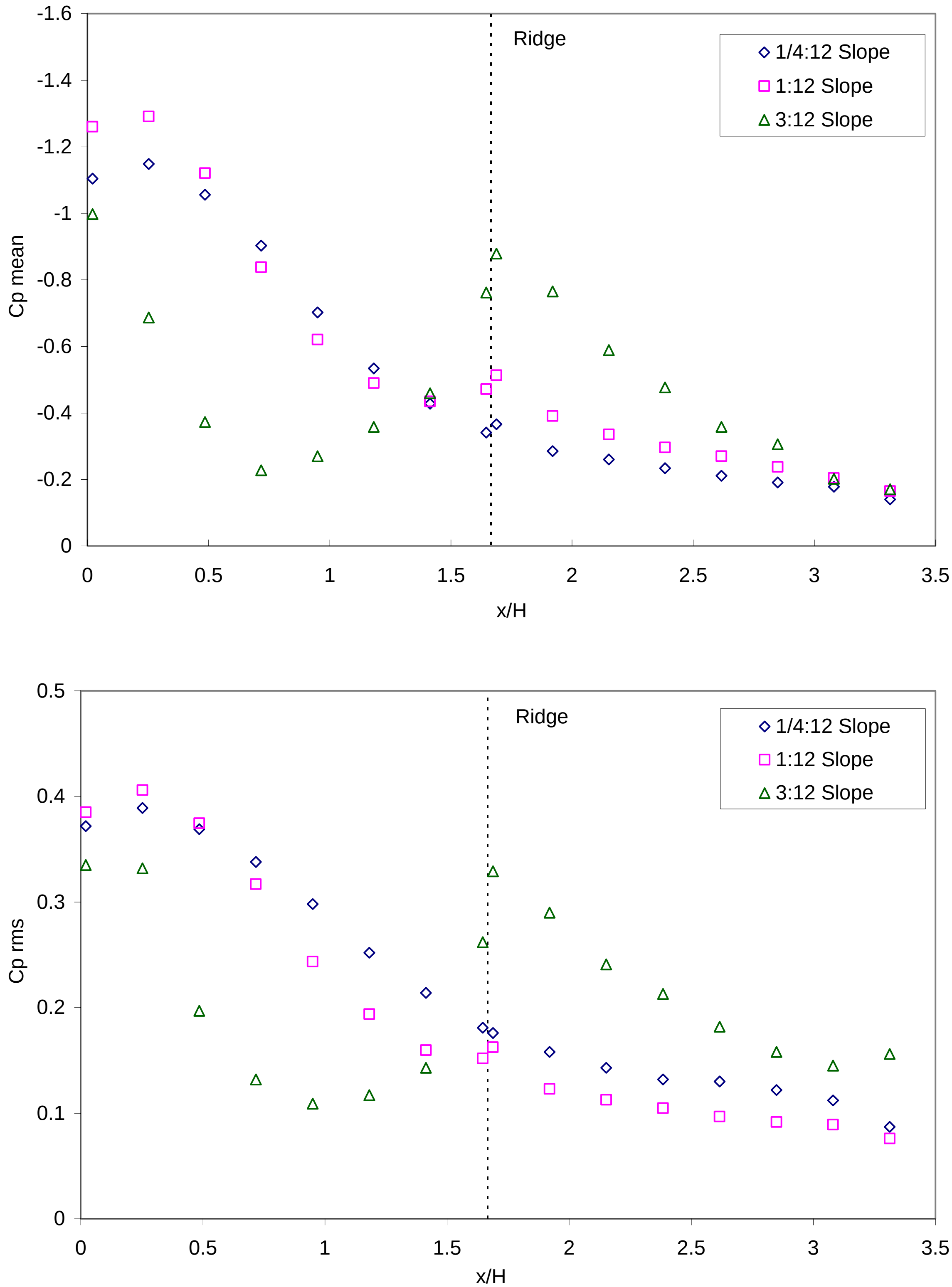
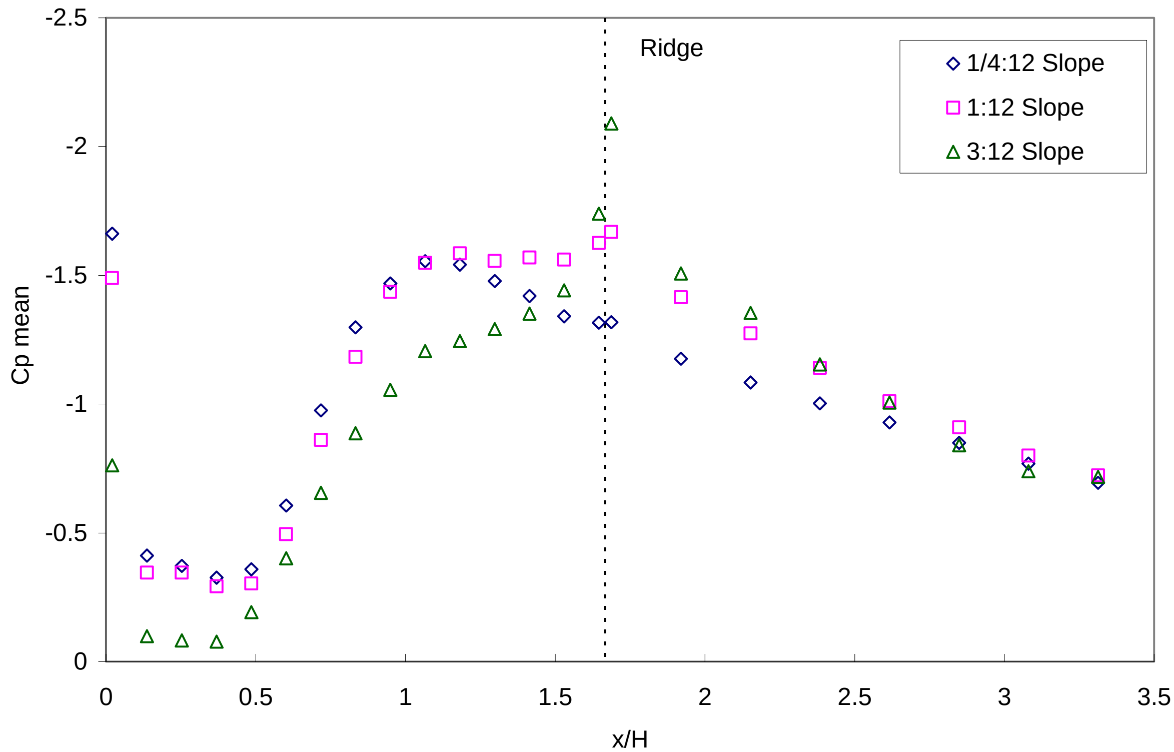



**FIGURE 32 VARIATION OF PRESSURE COEFFICIENTS ALONG A LINE OF TAPS AT MID-SPAN WITH DIFFERENT ROOF SLOPES (24 FT BUILDING HEIGHT; WIND ANGLE 270$^{O}$)**



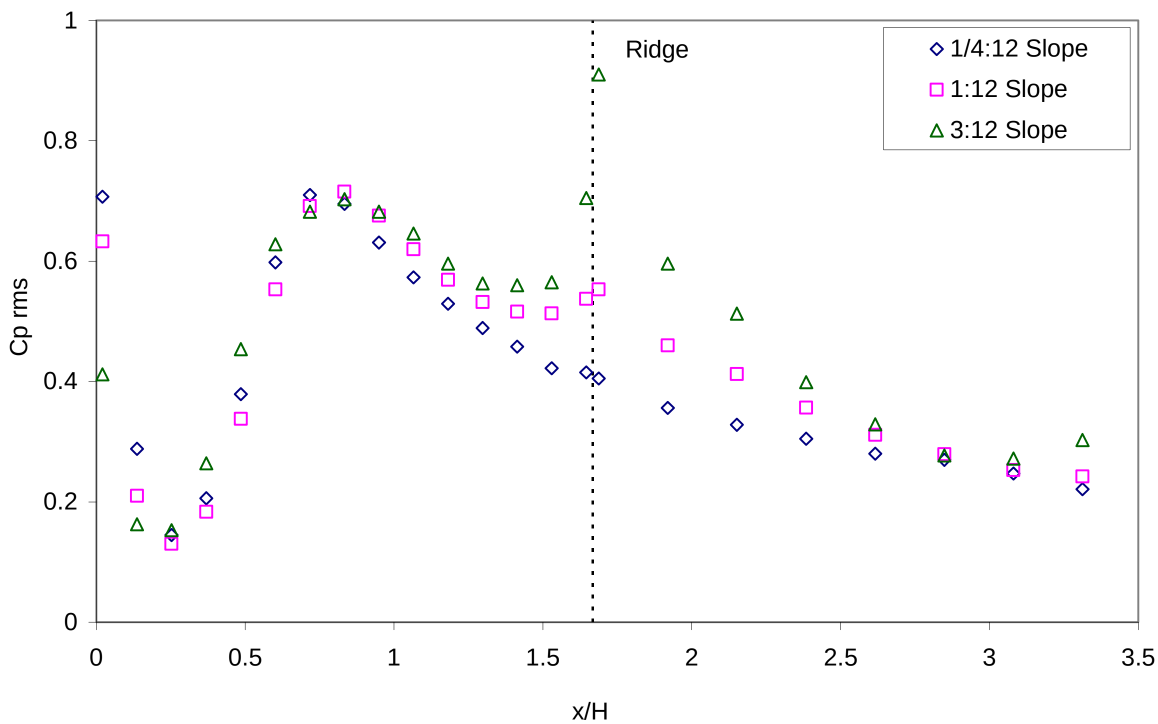
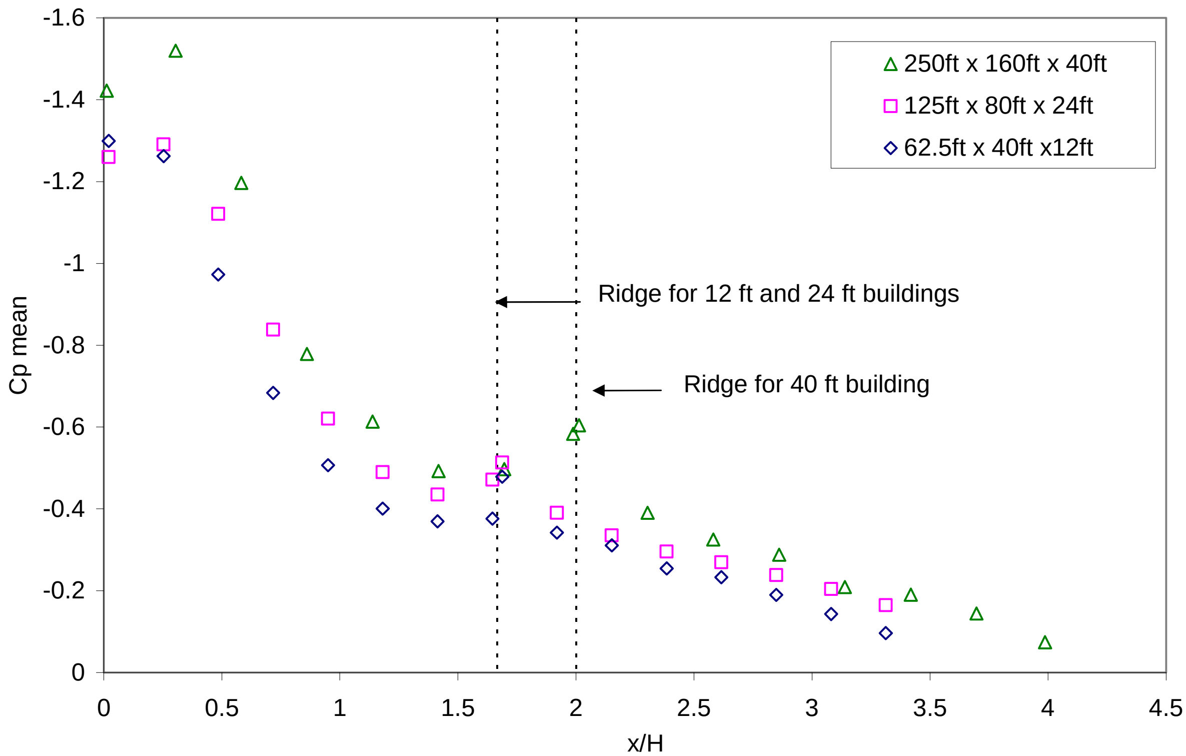




**FIGURE 33 VARIATION OF PRESSURE COEFFICIENTS ALONG A LINE OF TAPS NEAR THE EDGE OF THE BUILDINGS WITH DIFFERENT ROOF SLOPES (24 FT BUILDING HEIGHT; WIND ANGLE 325$^{O}$)**



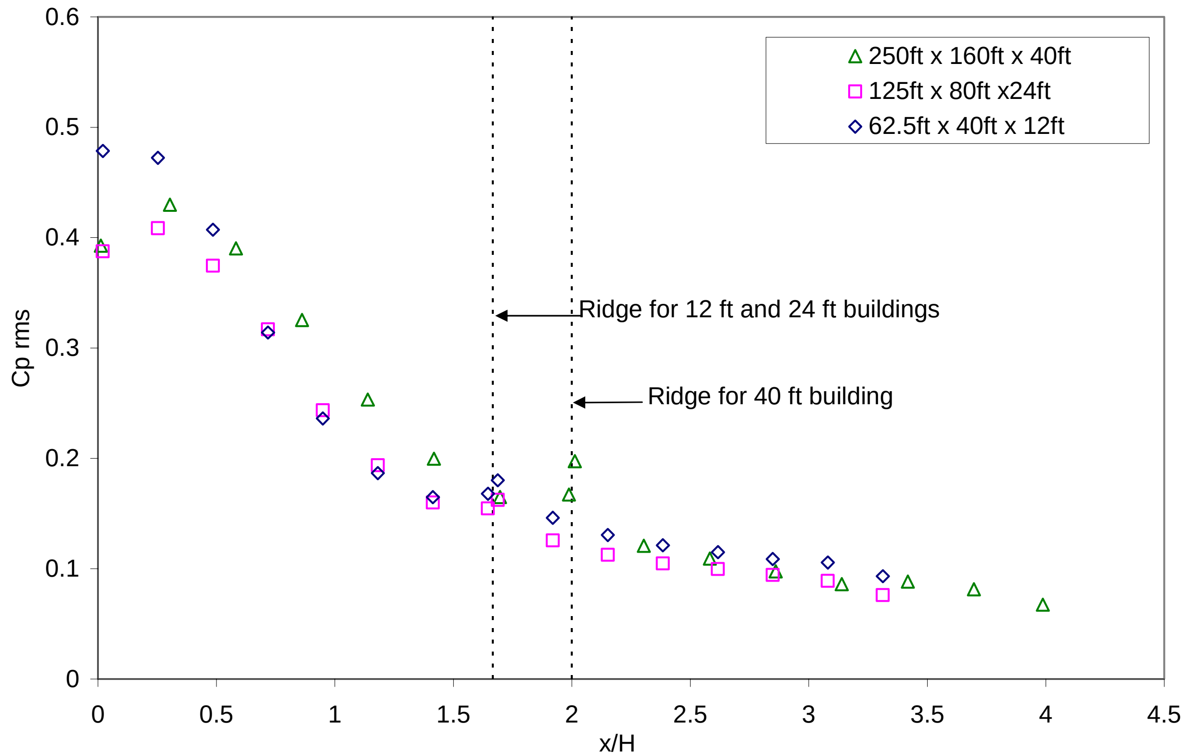
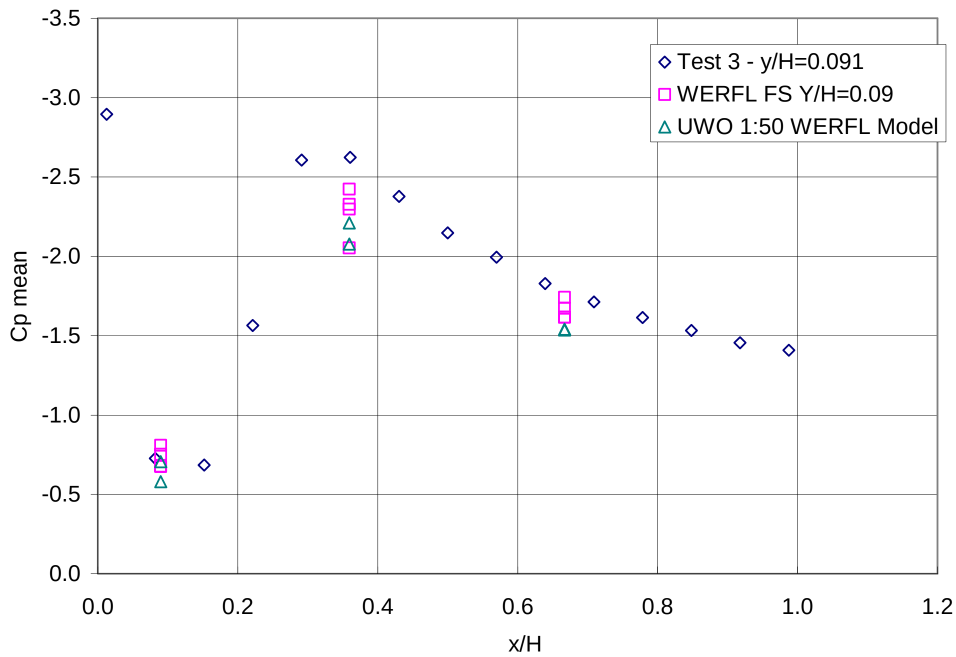




**FIGURE 34 VARIATION OF PRESSURE COEFFICIENTS ALONG A LINE OF TAPS AT MID-SPAN WITH DIFFERENT PLAN DIMENSIONS (WIND ANGLE 270°)**



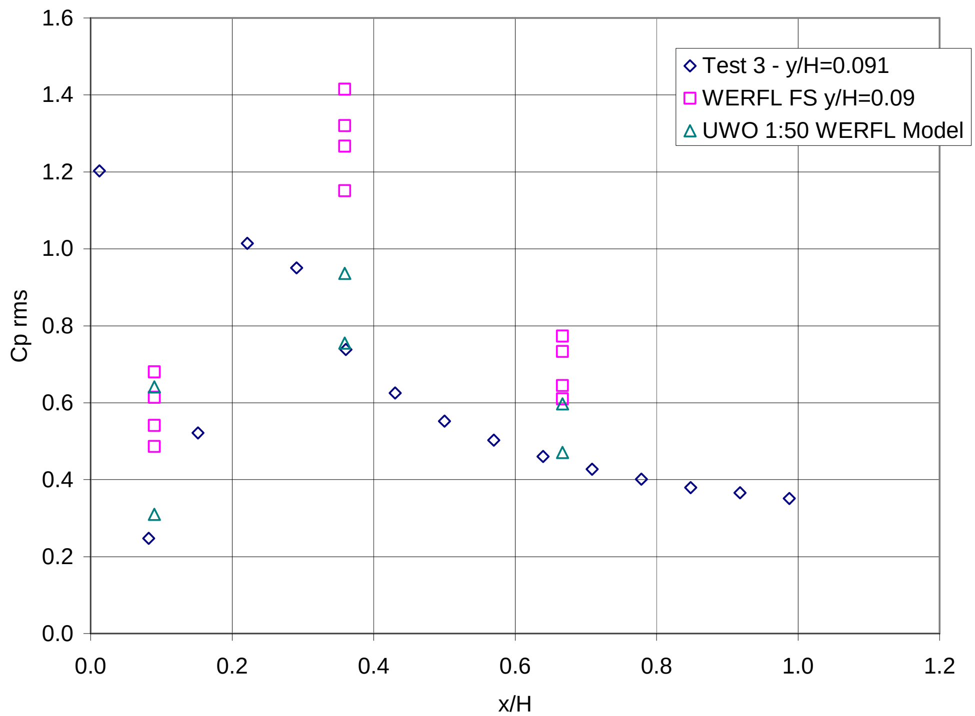




**FIGURE 35 COMPARISON OF THE PRESSURE COEFFICIENTS AMONG THE GENERIC MODEL TEST 3, WERFL BUILDING MODEL TEST 6 AND FULL SCALE WERFL BUILDING RESULTS (WIND ANGLE 325$^{O}$)**

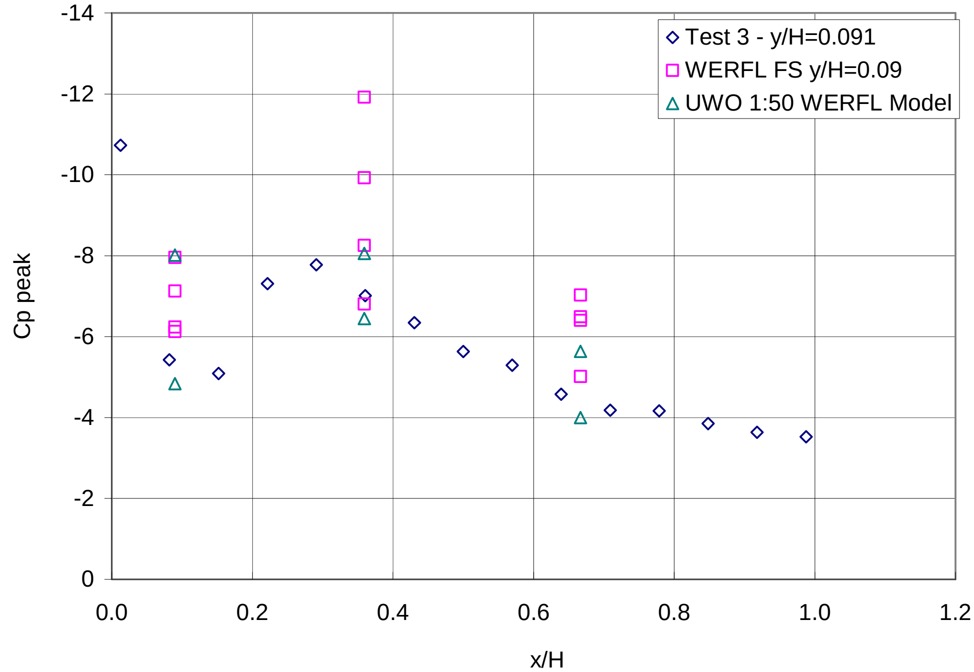
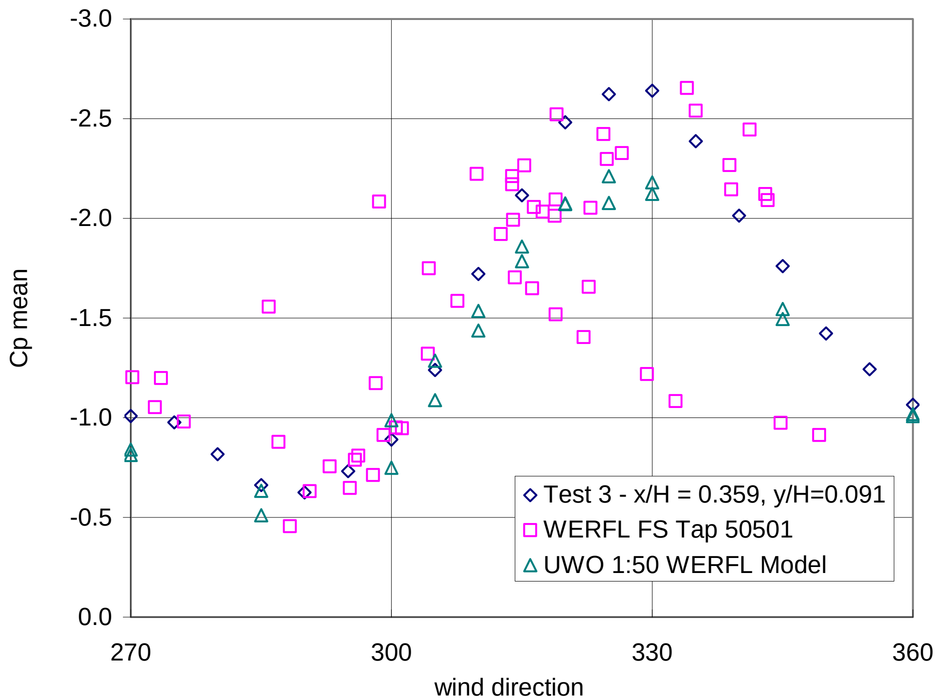



**FIGURE 34 (CONTINUED)**



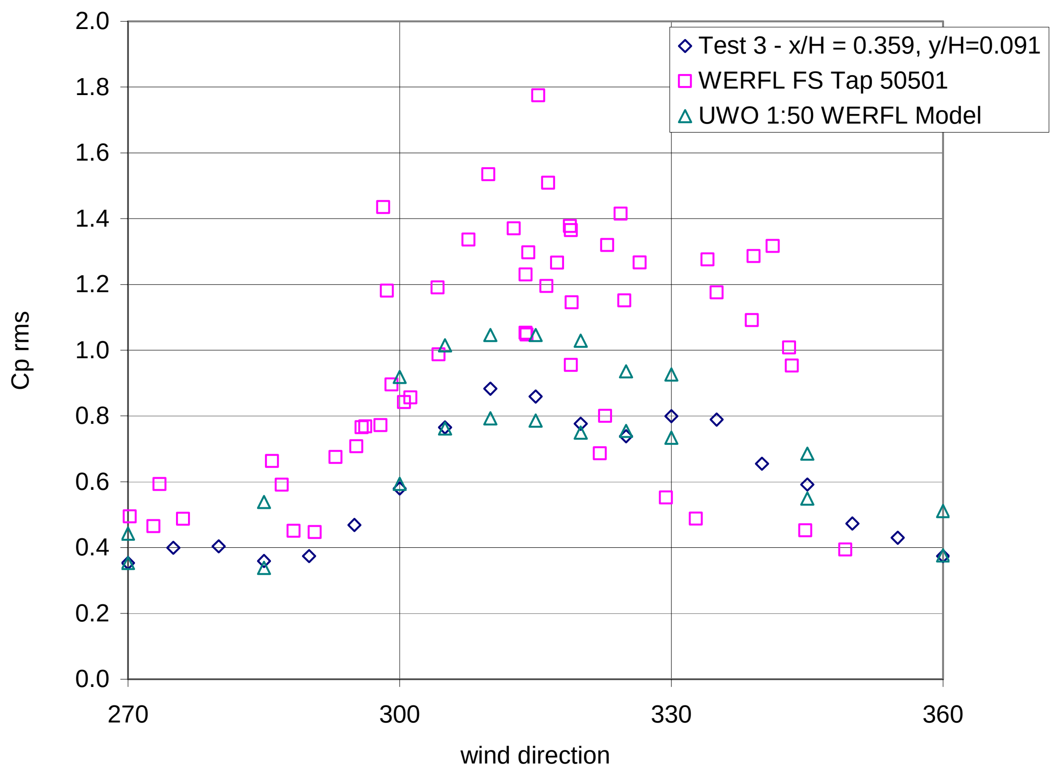




**FIGURE 36 COMPARISON OF THE PRESSURE COEFFICIENTS FOR TAP 50501 AMONG THE GENERIC MODEL TEST 3, WERFL BUILDING MODEL TEST 6 AND FULL SCALE WERFL BUILDING RESULTS (WIND ANGLE 325$^{O}$)**

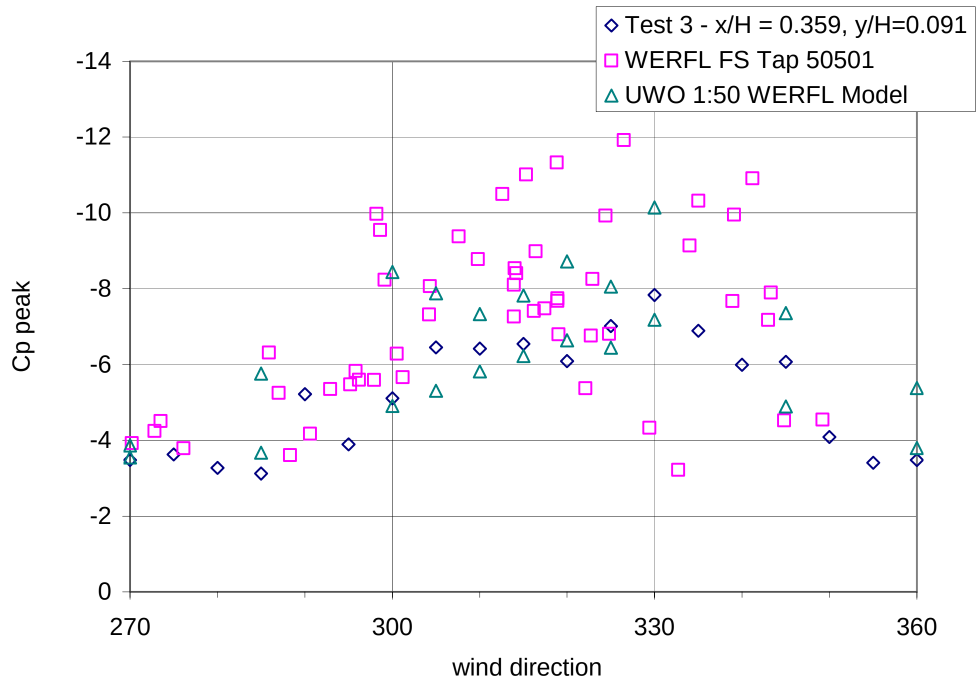
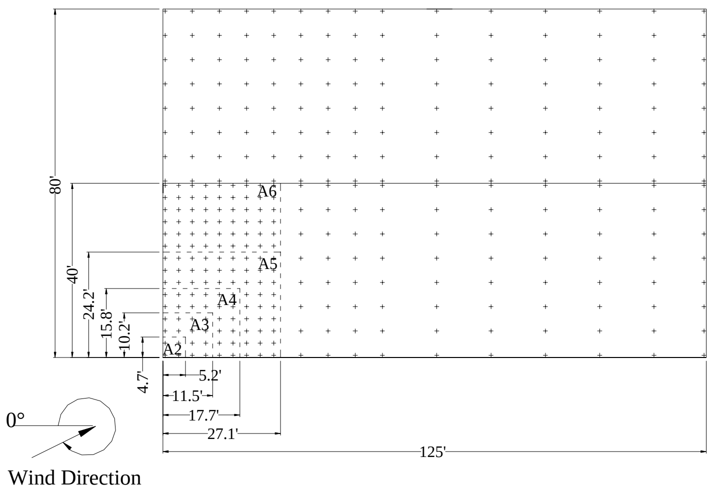



**FIGURE 35 (CONTINUED)**



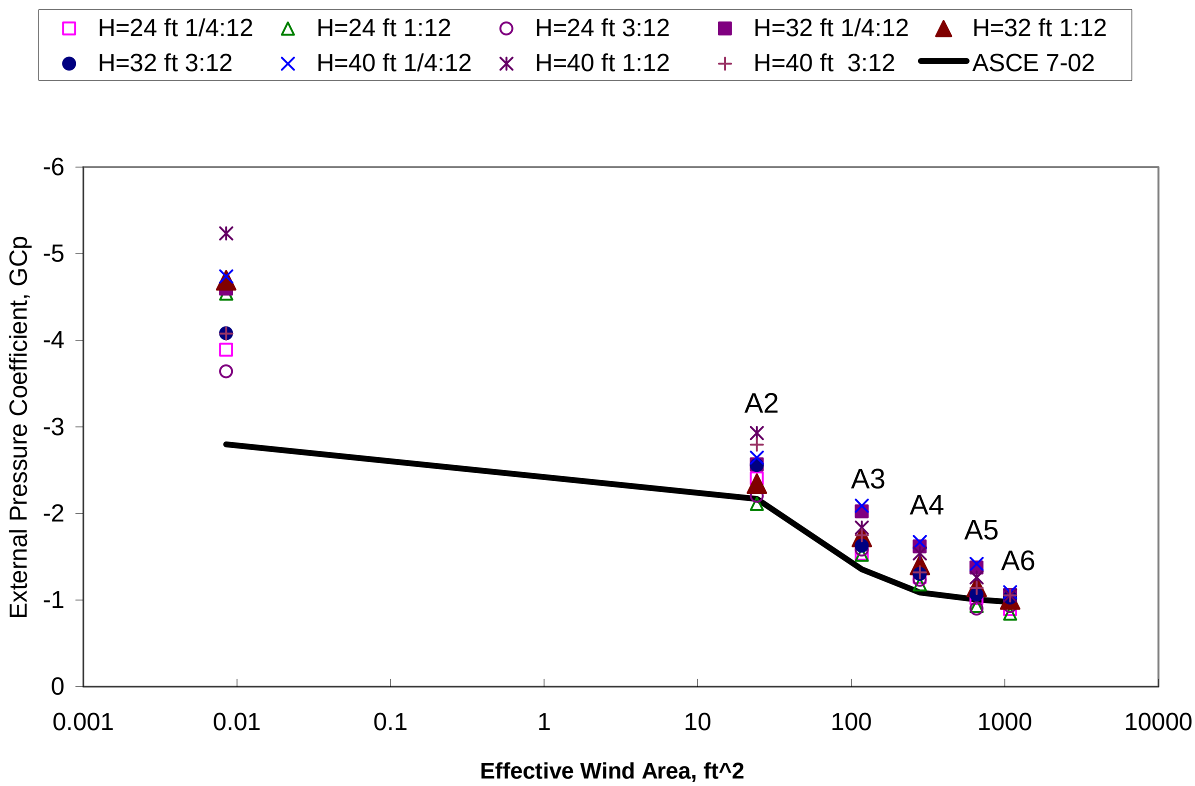
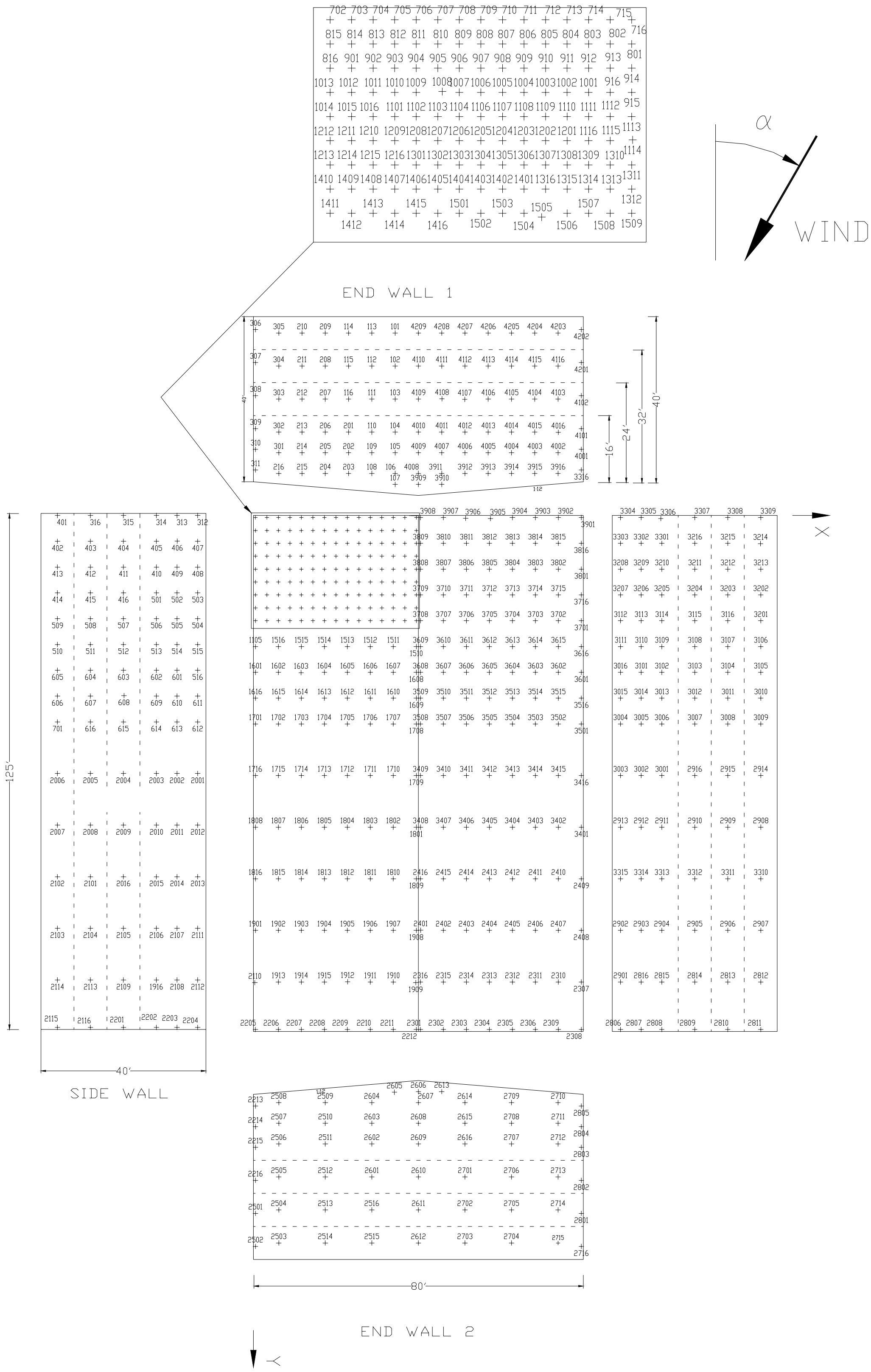




**FIGURE 37 COMPARISON OF AERA-AVERAGED PRESSURE COEFFICIENTS WITH ASCE 7-02 RECOMMENDED LOADS**

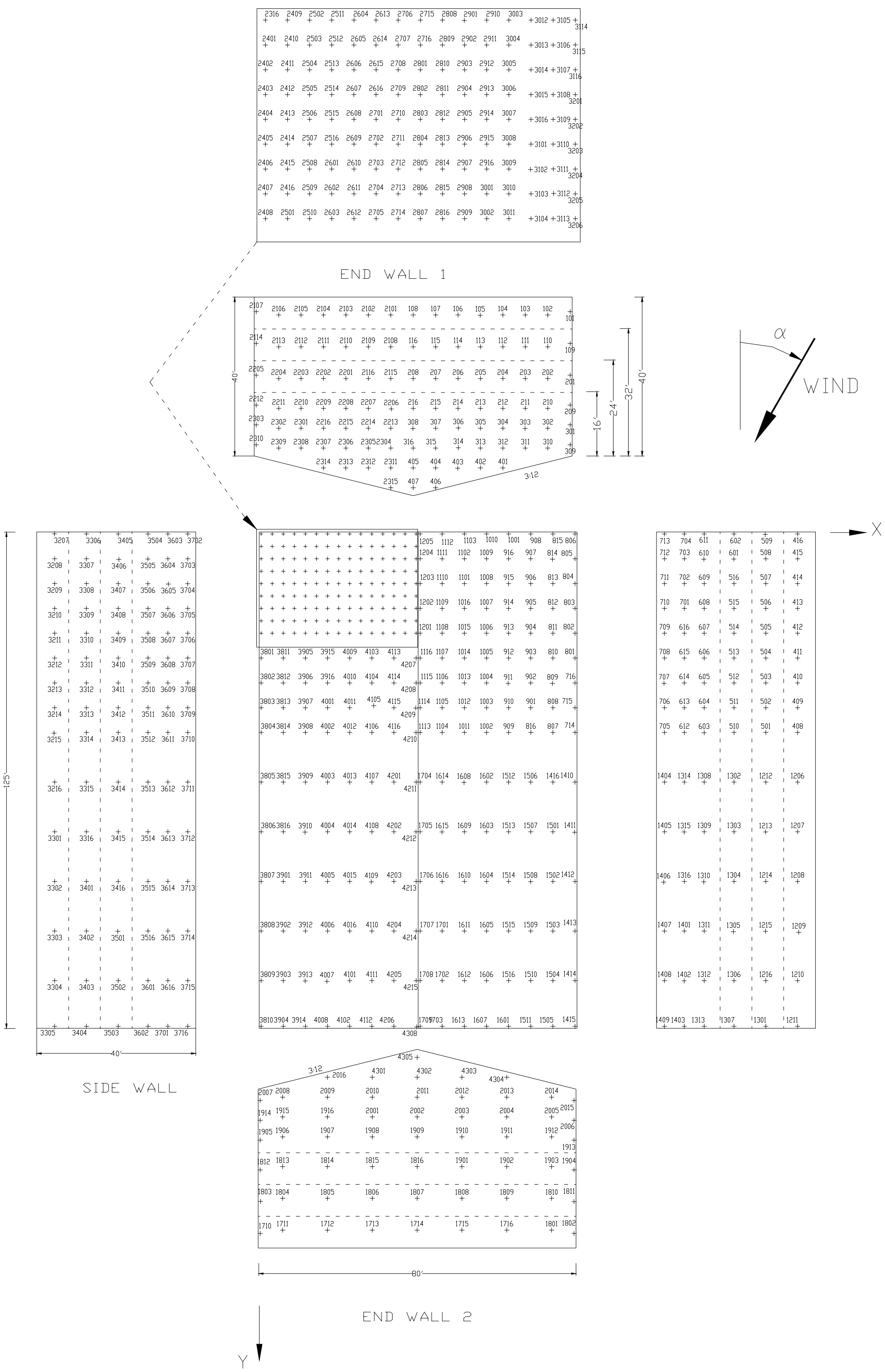
# APPENDIX A

## PRESSURE TAP LAYOUT AND NOMENCLATURE

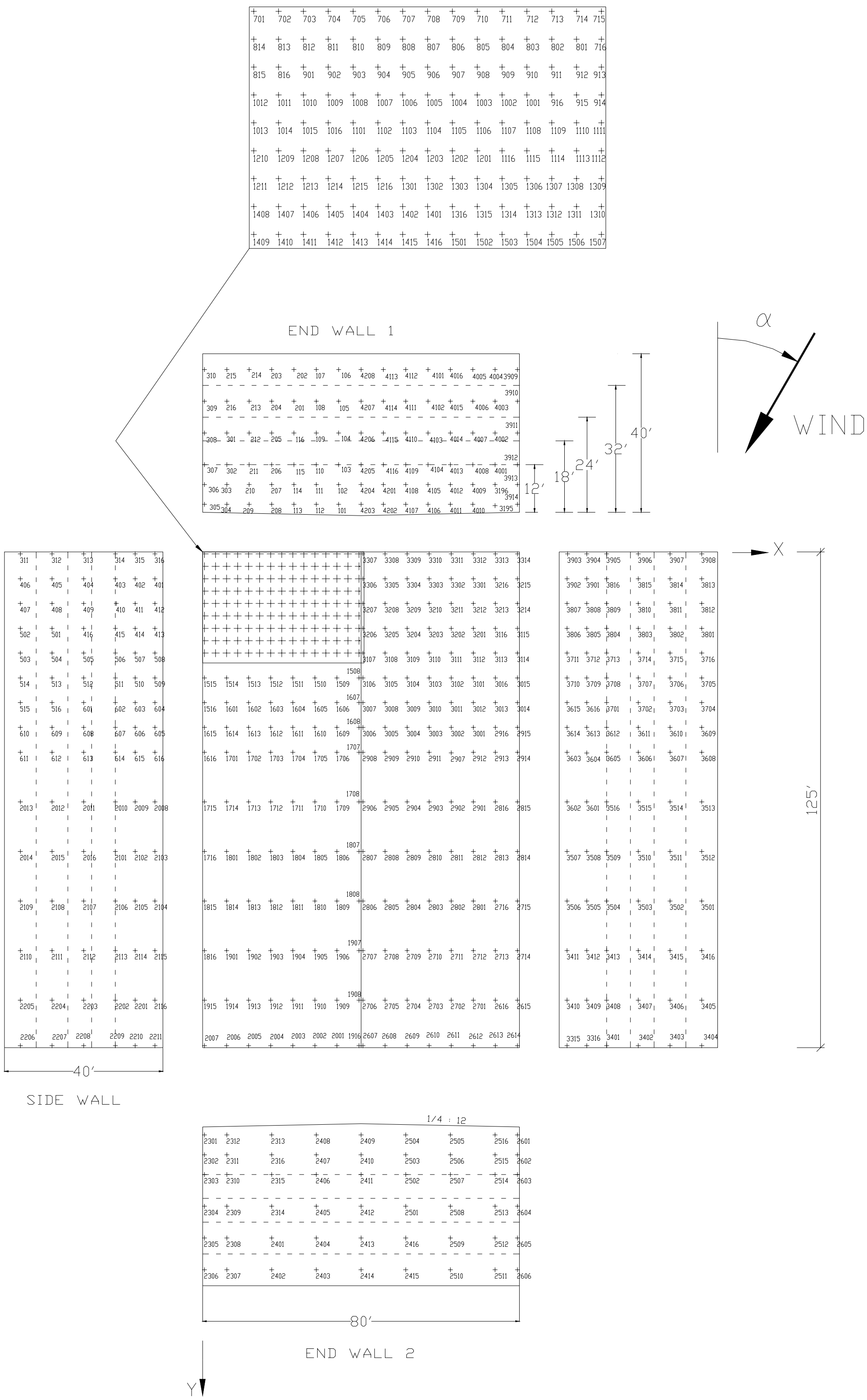
# Test 1



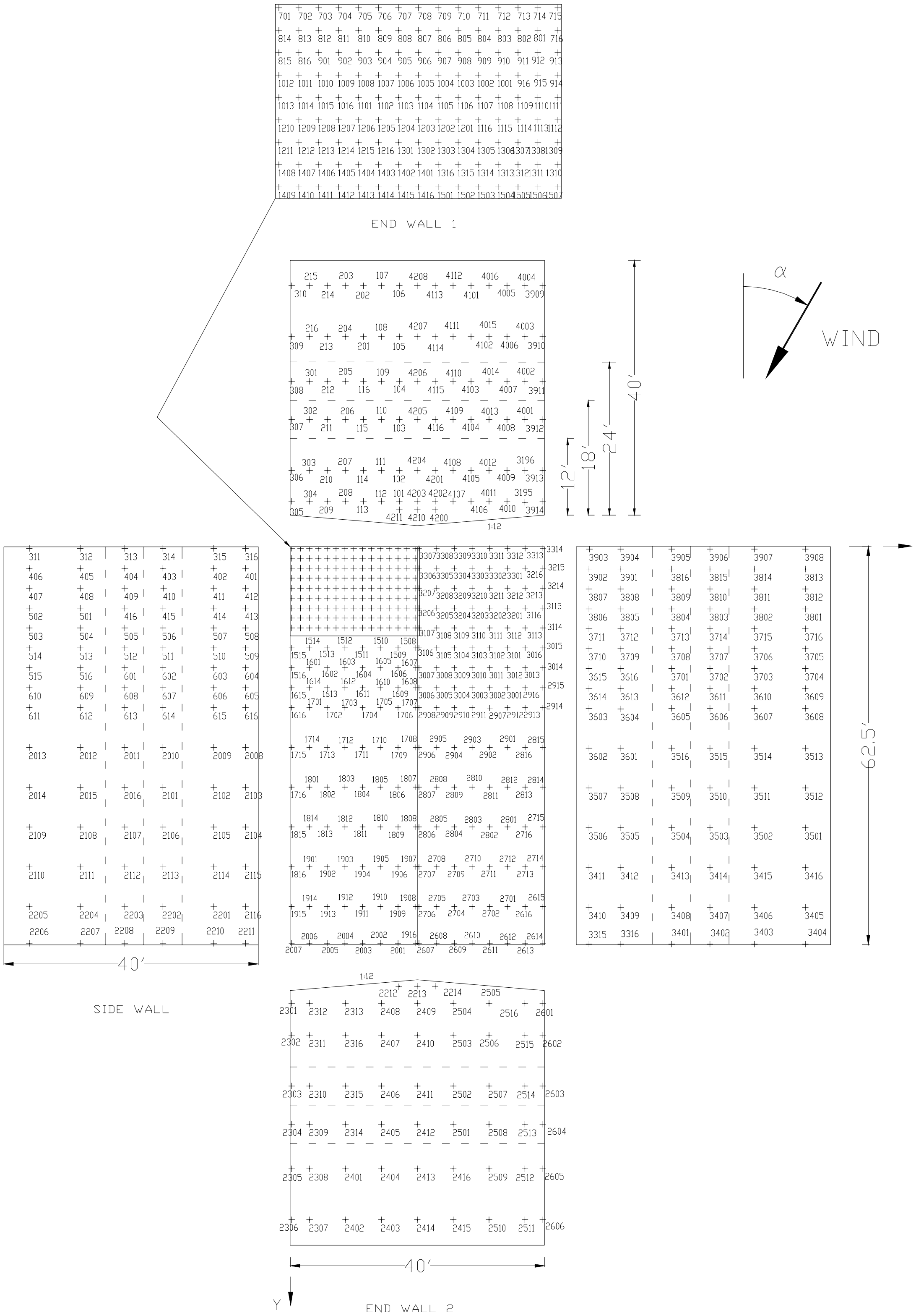
# Test 2



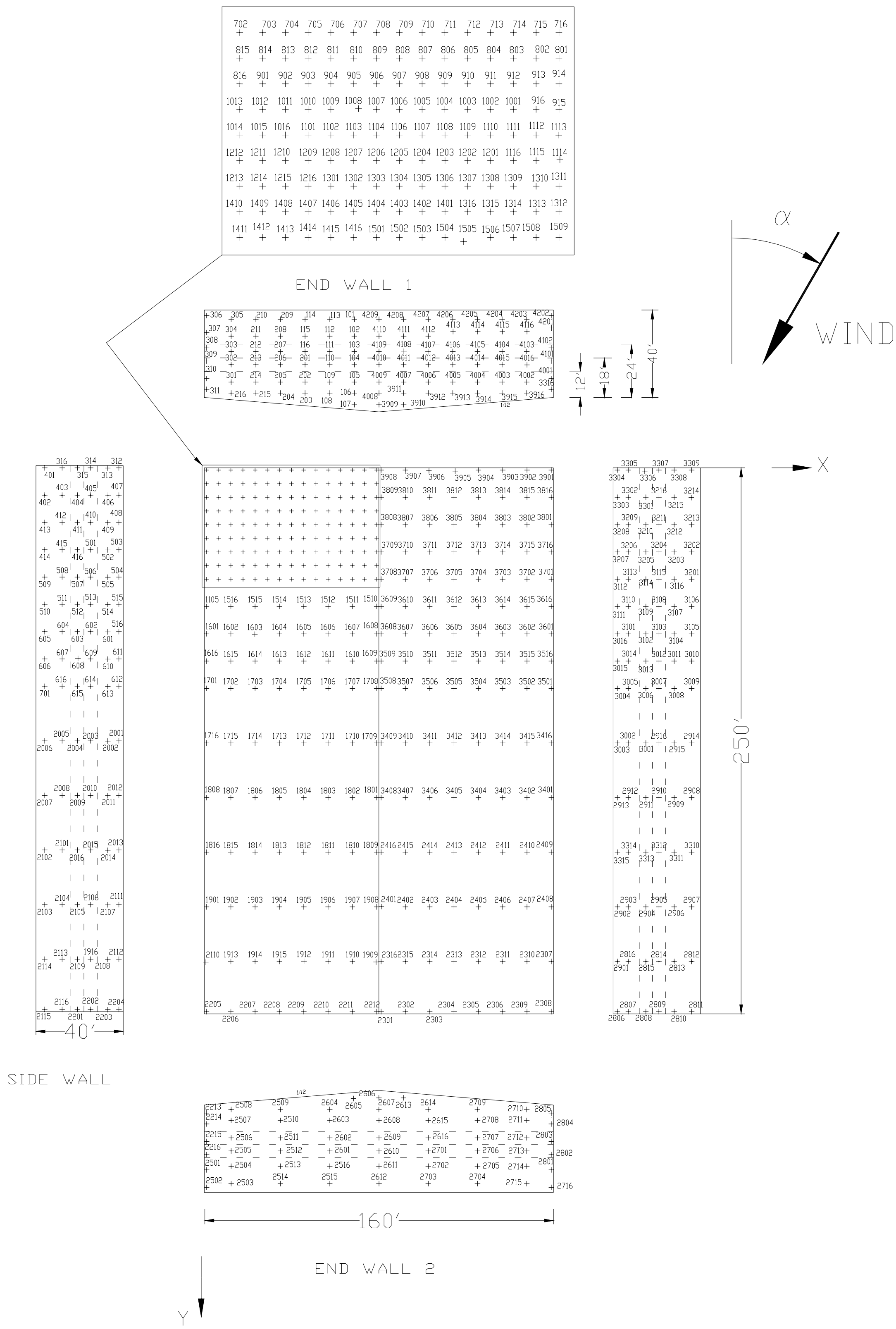
# Test 3


END WALL 1
α
WIND
40′
32′
24′
18′
12′
X
125′
40′
SIDE WALL
1/4 : 12
80′
END WALL 2
Y

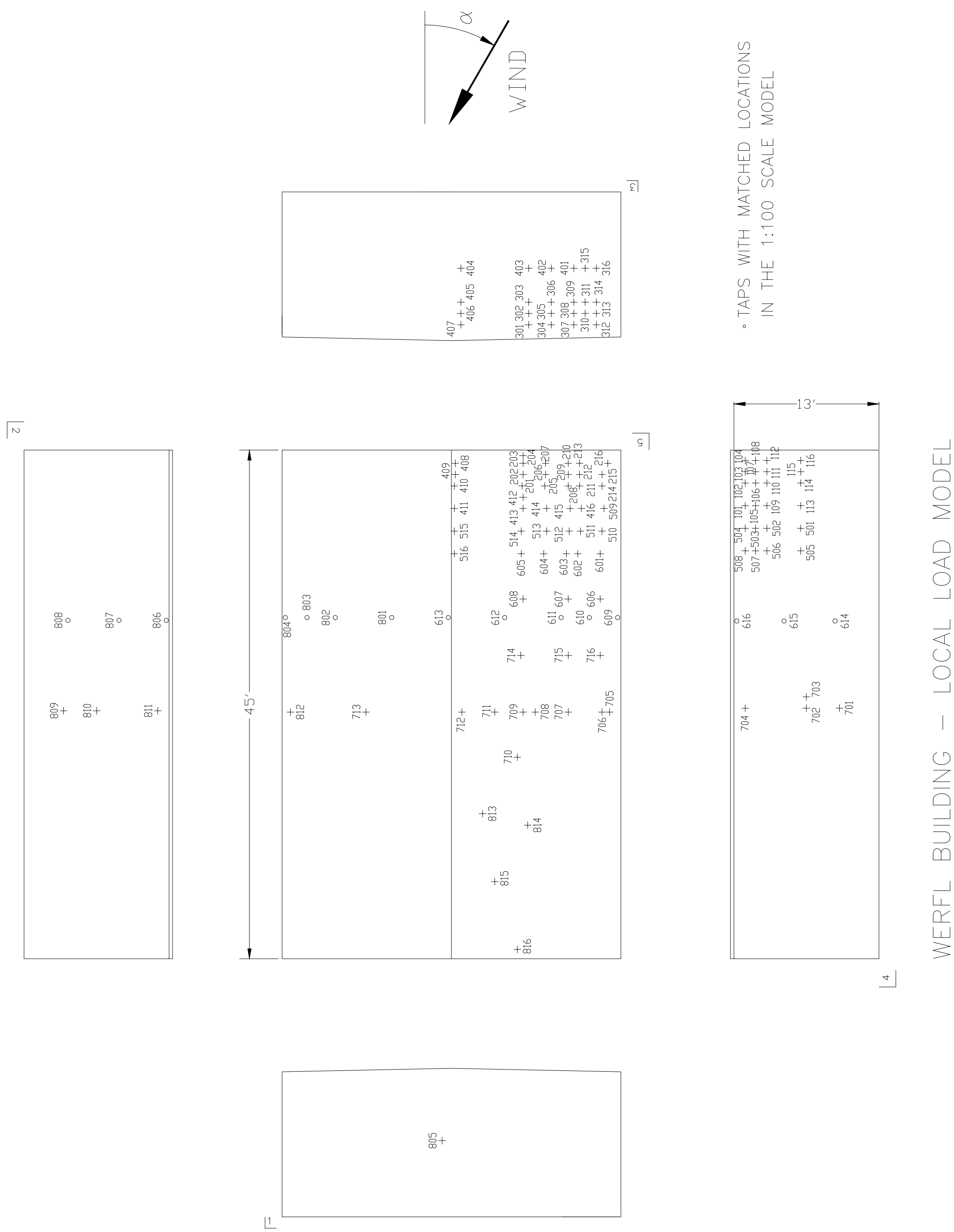
# Test 4



# Test 5

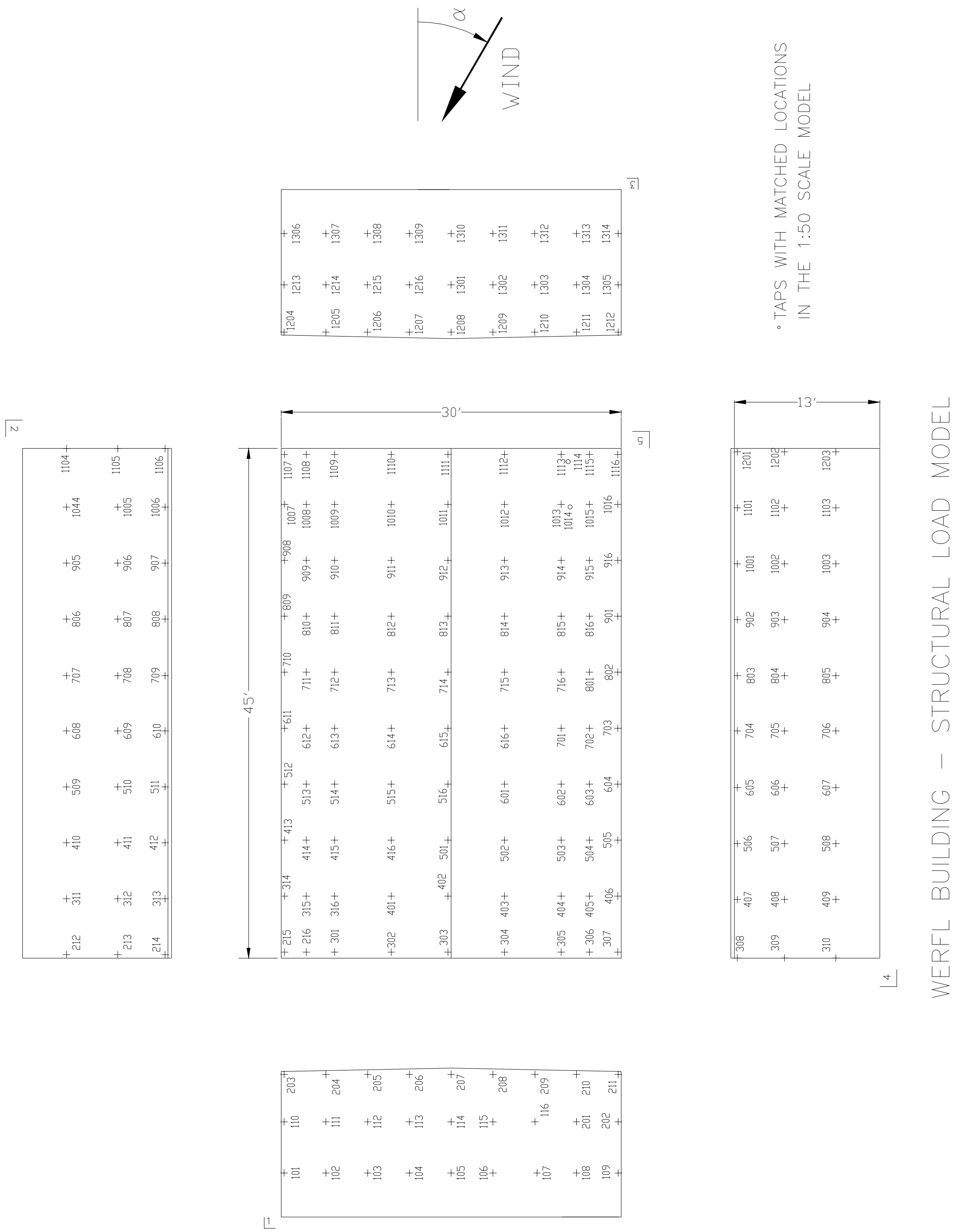


# Test 6

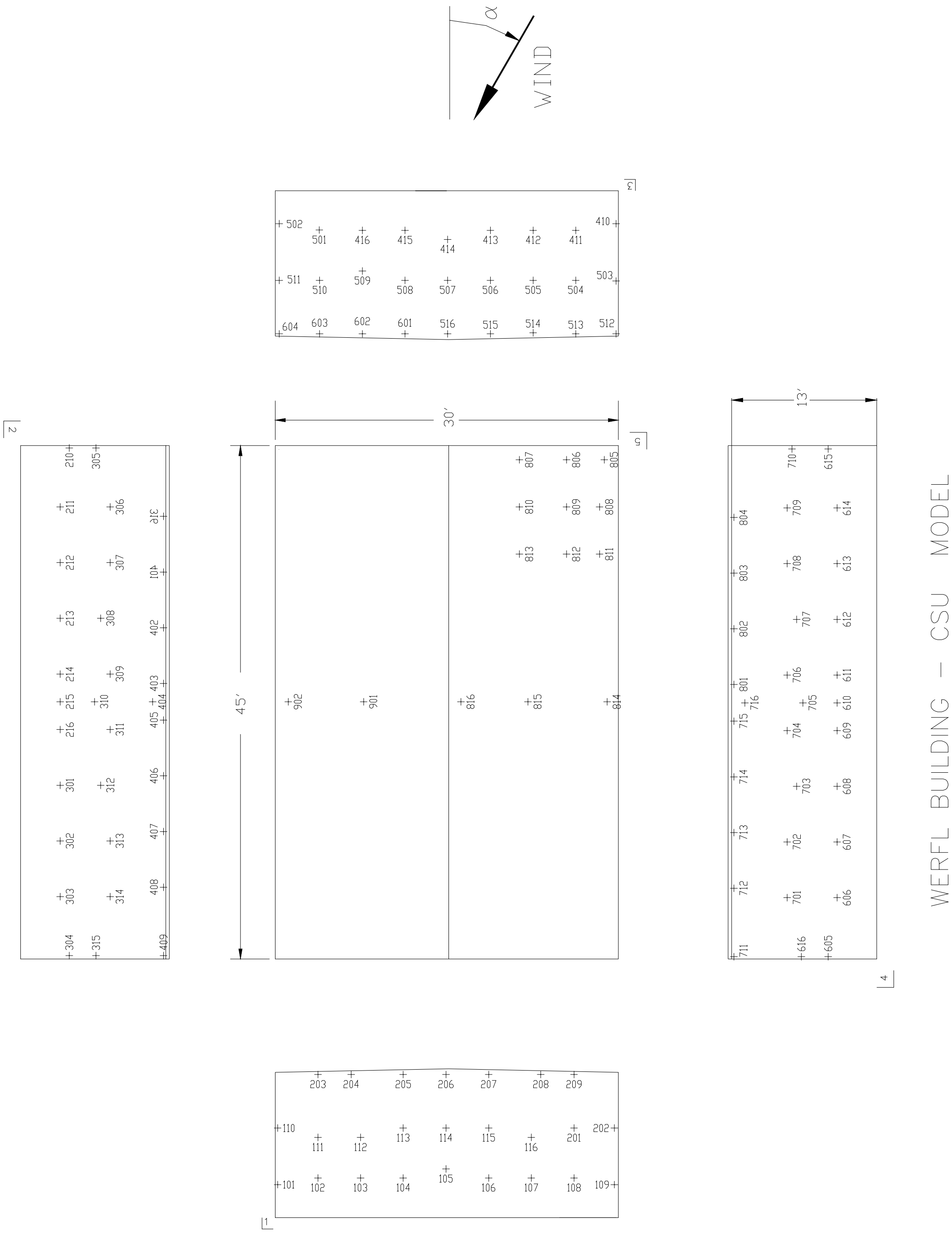


WIND
TAPS WITH MATCHED LOCATIONS IN THE 1:100 SCALE MODEL
13'
45'
WERFL BUILDING – LOCAL LOAD MODEL

# Test 7


α
WIND
30'
45'
13'
◦ TAPS WITH MATCHED LOCATIONS
IN THE 1:50 SCALE MODEL
WERFL BUILDING – STRUCTURAL LOAD MODEL

# Test 8



# APPENDIX B

## SUMMARY DATA SHEETS

**SUMMARY DATA SHEET**

**TEST 1 – GENERIC MODEL (125'x80', 1:12 ROOF SLOPE)**

<table>
<tr><td colspan="2">Building dimensions</td><td colspan="2">125' x 80' x four different eave heights; 1:12 roof slope gable roof</td></tr>
<tr><td colspan="2">Model scale</td><td colspan="2">1:100</td></tr>
<tr><td colspan="2">Number of pressure taps</td><td colspan="2">665 external taps + 2 internal taps</td></tr>
<tr><td colspan="2">Sampling frequency</td><td colspan="2">500 Hz</td></tr>
<tr><td colspan="2">Sampling period</td><td colspan="2">100 seconds</td></tr>
<tr><td colspan="2">Reference wind tunnel speed</td><td colspan="2">45 fps, nominal (see note 1)</td></tr>
<tr><td colspan="2">Test angles</td><td colspan="2">Every 5$^{o}$ between 180$^{o}$ and 360$^{o}$ (inclusive)</td></tr>
<tr><td colspan="2">Upstream exposure</td><td>1</td><td>2</td></tr>
<tr><td colspan="2">Exposure description</td><td>Open country</td><td>Suburban</td></tr>
<tr><td rowspan="4">Ratio of roof to reference wind speed (see note 2)</td><td>H=16'</td><td>0.581</td><td>0.467</td></tr>
<tr><td>H=24'</td><td>0.620</td><td>0.487</td></tr>
<tr><td>H=32'</td><td>0.642</td><td>0.512</td></tr>
<tr><td>H=40'</td><td>0.657</td><td>0.534</td></tr>
<tr><td rowspan="4">Nominal roof height wind speed, $V_{Hm}$, in fps (see notes 1 and 2)</td><td>H=16'</td><td>26</td><td>21</td></tr>
<tr><td>H=24'</td><td>28</td><td>22</td></tr>
<tr><td>H=32'</td><td>29</td><td>23</td></tr>
<tr><td>H=40'</td><td>30</td><td>24</td></tr>
<tr><td colspan="2">Full scale mean wind speed at roof height (fps)</td><td colspan="2">$V_H$</td></tr>
<tr><td colspan="2">Equivalent full scale sampling frequency</td><td colspan="2">$\frac{5\,V_H}{V_{Hm}}$</td></tr>
<tr><td colspan="2">Equivalent full scale sampling duration (seconds)</td><td colspan="2">$\frac{10000\,V_{Hm}}{V_H}$</td></tr>
<tr><td colspan="2">Test file identifications:</td><td colspan="2"></td></tr>
<tr><td>No leakage</td><td>H=32'</td><td>SG1___</td><td></td></tr>
<tr><td rowspan="4">Distributed leakage</td><td>H=16'</td><td>EE1___</td><td>EE2___</td></tr>
<tr><td>H=24'</td><td>EF1___</td><td>EF2___</td></tr>
<tr><td>H=32'</td><td>EG1___</td><td>EG2___</td></tr>
<tr><td>H=40'</td><td>EH1___</td><td>EH2___</td></tr>
<tr><td rowspan="2">Small opening</td><td>H-16'</td><td>FE1___</td><td>FE2___</td></tr>
<tr><td>H=40'</td><td>GH1___</td><td>GH2___</td></tr>
<tr><td rowspan="2">Large opening</td><td>H=16'</td><td>HE1___</td><td>HE2___</td></tr>
<tr><td>H=40'</td><td>HH1___</td><td>HH2___</td></tr>
</table>

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 2 – GENERIC MODEL (125’x80’, 3:12 ROOF SLOPE)**

| | | | |
|---|---|---|---|
| Building dimensions | | 125’ x 80’ x four different eave heights; 3:12 roof slope gable roof | |
| Model scale | | 1:100 | |
| Number of pressure taps | | 677 external taps + 2 internal taps | |
| Sampling frequency | | 500 Hz | |
| Sampling period | | 100 seconds | |
| Reference wind tunnel speed | | 45 fps, nominal (see note 1) | |
| Test angles | | Every 5° between 180° and 360° (inclusive) | |
| Upstream exposure | | 1 | 2 |
| Exposure description | | Open country | Suburban |
| Ratio of roof to reference wind speed (see note 2) | H=16’ | 0.581 | 0.467 |
| | H=24’ | 0.620 | 0.487 |
| | H=32’ | 0.642 | 0.512 |
| | H=40’ | 0.657 | 0.534 |
| Nominal roof height wind speed, $V_{Hm}$, in fps (see notes 1 and 2) | H=16’ | 26 | 21 |
| | H=24’ | 28 | 22 |
| | H=32’ | 29 | 23 |
| | H=40’ | 30 | 24 |
| Full scale mean wind speed at roof height (fps) | | $V_H$ | |
| Equivalent full scale sampling frequency | | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | | |
| Distributed leakage | H=16’ | M11___ | M12___ |
| | H=24’ | M21___ | M22___ |
| | H=32’ | M31___ | M32___ |
| | H=40’ | M41___ | M42___ |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 3 – GENERIC MODEL (125’x80’, ¼:12 ROOF SLOPE)**

| | | | |
|---|---|---|---|
| Building dimensions | | 125’ x 80’ x five different eave heights; ¼:12 roof slope gable roof | |
| Model scale | | 1:100 | |
| Number of pressure taps | | 659 external taps + 3 internal taps | |
| Sampling frequency | | 500 Hz | |
| Sampling period | | 100 seconds | |
| Reference wind tunnel speed | | 45 fps, nominal (see note 1) | |
| Test angles | | Every $5^o$ from $270^o$ to $360^o$ and from $0^o$ to $90^o$ (inclusive) (except set II2, see note 3) | |
| Upstream exposure | | 1 | 2 |
| Exposure description | | Open country | Suburban |
| Ratio of roof to reference wind speed (see note 2) | H=12’ | 0.561 | 0.447 |
| | H=18’ | 0.587 | 0.468 |
| | H=24’ | 0.620 | 0.487 |
| | H=32’ | 0.642 | 0.512 |
| | H=40’ | 0.657 | 0.534 |
| Nominal roof height wind speed, $V_{Hm}$ , in fps (see notes 1 and 2) | H=12’ | 25 | 20 |
| | H=18’ | 26 | 21 |
| | H=24’ | 28 | 22 |
| | H=32’ | 29 | 23 |
| | H=40’ | 30 | 24 |
| Full scale mean wind speed at roof height (fps) | | $V_H$ | |
| Equivalent full scale sampling frequency | | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | | |
| Distributed leakage | H=12’ | II1___ | II2___ |
| | H=18’ | IJ1___ | IJ2___ |
| | H=24’ | IK1___ | IK2___ |
| | H=32’ | IL1___ | IL2___ |
| | H=40’ | IM1___ | IM2___ |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

3. Wind angles for set II2 are every $5^o$ from $90^o$, through $180^o$, to $270^o$.

**SUMMARY DATA SHEET**

**TEST 4 – GENERIC MODEL (62.5'x40', 1:12 ROOF SLOPE)**

| | | | |
|---|---|---|---|
| Building dimensions | | 62.5' x 40' x four different eave heights; 1:12 roof slope gable roof | |
| Model scale | | 1:100 | |
| Number of pressure taps | | 665 external taps + 3 internal taps | |
| Sampling frequency | | 500 Hz | |
| Sampling period | | 100 seconds | |
| Reference wind tunnel speed | | 45 fps, nominal (see note 1) | |
| Test angles | | Every 5$^o$ from 270$^o$ to 360$^o$ and from 0$^o$ to 90$^o$ (inclusive) | |
| Upstream exposure | | 1 | 2 |
| Exposure description | | Open country | Suburban |
| Ratio of roof to reference wind speed (see note 2) | H=12' | 0.561 | 0.447 |
| | H=18' | 0.587 | 0.468 |
| | H=24' | 0.620 | 0.487 |
| | H=40' | 0.657 | 0.534 |
| Nominal roof height wind speed, $V_{Hm}$ , in fps (see notes 1 and 2) | H=12' | 25 | 20 |
| | H=18' | 26 | 21 |
| | H=24' | 28 | 22 |
| | H=40' | 30 | 24 |
| Full scale mean wind speed at roof height (fps) | | $V_H$ | |
| Equivalent full scale sampling frequency | | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | | |
| Distributed leakage | H=12' | JN1___ | JN2___ |
| | H=18' | JM1___ | JM2___ |
| | H=24' | JO1___ | JO2___ |
| | H=40' | JP1___ | JP2___ |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 5 – GENERIC MODEL (250’x160’, 1:12 ROOF SLOPE)**

| | | | |
|---|---|---|---|
| Building dimensions | | 250’ x 160’ x four different eave heights; 1:12 roof slope gable roof | |
| Model scale | | 1:100 | |
| Number of pressure taps | | 665 external taps | |
| Sampling frequency | | 500 Hz | |
| Sampling period | | 100 seconds | |
| Reference wind tunnel speed | | 45 fps, nominal (see note 1) | |
| Test angles | | Every 5$^o$ from 270$^o$ to 360$^o$ and from 0$^o$ to 90$^o$ (inclusive) | |
| Upstream exposure | | 1 | 2 |
| Exposure description | | Open country | Suburban |
| Ratio of roof to reference wind speed (see note 2) | H=12’ | 0.561 | 0.447 |
| | H=18’ | 0.587 | 0.468 |
| | H=24’ | 0.620 | 0.487 |
| | H=40’ | 0.657 | 0.534 |
| Nominal roof height wind speed, $V_{Hm}$, in fps (see notes 1 and 2) | H=12’ | 25 | 20 |
| | H=18’ | 26 | 21 |
| | H=24’ | 28 | 22 |
| | H=40’ | 30 | 24 |
| Full scale mean wind speed at roof height (fps) | | $V_H$ | |
| Equivalent full scale sampling frequency | | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | | |
| No leakage or dominant openings | H=12’ | OU1___ | OU2___ |
| | H=18’ | OV1___ | OV2___ |
| | H=24’ | OW1___ | OW2___ |
| | H=40’ | OX1___ | OX2___ |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 6 – WERFL BUILDING – UWO 1:50 MODEL (45'x30'x13', ¼:12 ROOF SLOPE)**

| | | |
|---|---|---|
| Building dimensions | 45' x 30' x 13'; ¼:12 roof slope gable roof | |
| Model scale | 1:50 | |
| Number of pressure taps | 128 external taps | |
| Sampling frequency | 250 Hz | |
| Sampling period | 180 seconds | |
| Reference wind tunnel speed | 45 fps, nominal (see note 1) | |
| Test angles | 19 angles – 0°, 15°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 75°, 90°, 105°, 120°, 135°, 150°, 180°, 225°, 270°, 330° | |
| Upstream exposure | 1 | 2 |
| Exposure description | WERFL site condition (10th percentile) | WERFL site condition (90th percentile) |
| Roughness length (m) | 0.01 | 0.087 |
| Ratio of roof to reference wind speed (see note 2) | 0.647 | 0.539 |
| Nominal roof height wind speed, $V_{Hm}$ , in fps (see notes 1 and 2) | 29 | 24 |
| Full scale mean wind speed at roof height (fps) | $V_H$ | |
| Equivalent full scale sampling frequency | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | $\frac{9000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | |
| Basic tests | BT1___ | BT2___ |
| Additional tests: 20 repeat tests at 45° wind angle | BTR___ | |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.
2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 7 – WERFL BUILDING – UWO 1:100 MODEL (45’x30’x13’, ¼:12 ROOF SLOPE)**

| | | |
|---|---|---|
| Building dimensions | 45’ x 30’ x 13’; ¼:12 roof slope gable roof | |
| Model scale | 1:100 | |
| Number of pressure taps | 206 external taps | |
| Sampling frequency | 500 Hz | |
| Sampling period | 100 seconds | |
| Reference wind tunnel speed | 45 fps, nominal (see note 1) | |
| Test angles | 22 angles – 0°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 90°, 135°, 180°, 225°, 270°, 315° | |
| Upstream exposure | 1 | 2 |
| Exposure description | WERFL site condition (10th percentile) | WERFL site condition (90th percentile) |
| Roughness length (m) | 0.01 | 0.087 |
| Ratio of roof to reference wind speed (see note 2) | 0.658 | 0.500 |
| Nominal roof height wind speed, $V_{Hm}$, in fps (see notes 1 and 2) | 30 | 23 |
| Full scale mean wind speed at roof height (fps) | $V_H$ | |
| Equivalent full scale sampling frequency | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | |
| Basic tests | ST3___ | ST4___ |
| Additional tests: 20 repeat tests at 45° wind angle | STR___ | |

Notes:

1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

**SUMMARY DATA SHEET**

**TEST 8 – WERFL BUILDING – CSU 1:100 MODEL (45’x30’x13’, ¼:12 ROOF SLOPE)**

| | | |
|---|---|---|
| Building dimensions | 45’ x 30’ x 13’; ¼:12 roof slope gable roof | |
| Model scale | 1:100 | |
| Number of pressure taps | 130 external taps | |
| Sampling frequency | 500 Hz | |
| Sampling period | 100 seconds | |
| Reference wind tunnel speed | 45 fps, nominal (see note 1) | |
| Test angles | 22 angles – 0°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 90°, 135°, 180°, 225°, 270°, 315° | |
| Upstream exposure | 1 | 2 |
| Exposure description | WERFL site condition ($10^{th}$ percentile) | WERFL site condition ($90^{th}$ percentile) |
| Roughness length (m) | 0.01 | 0.087 |
| Ratio of roof to reference wind speed (see note 2) | 0.658 | 0.500 |
| Nominal roof height wind speed, $V_{Hm}$ , in fps (see notes 1 and 2) | 30 | 23 |
| Full scale mean wind speed at roof height (fps) | $V_H$ | |
| Equivalent full scale sampling frequency | $\frac{5\,V_H}{V_{Hm}}$ | |
| Equivalent full scale sampling duration (seconds) | $\frac{10000\,V_{Hm}}{V_H}$ | |
| **Test file identifications:** | | |
| Basic tests | TP3___, TR3___ | TP4___ |

Notes:

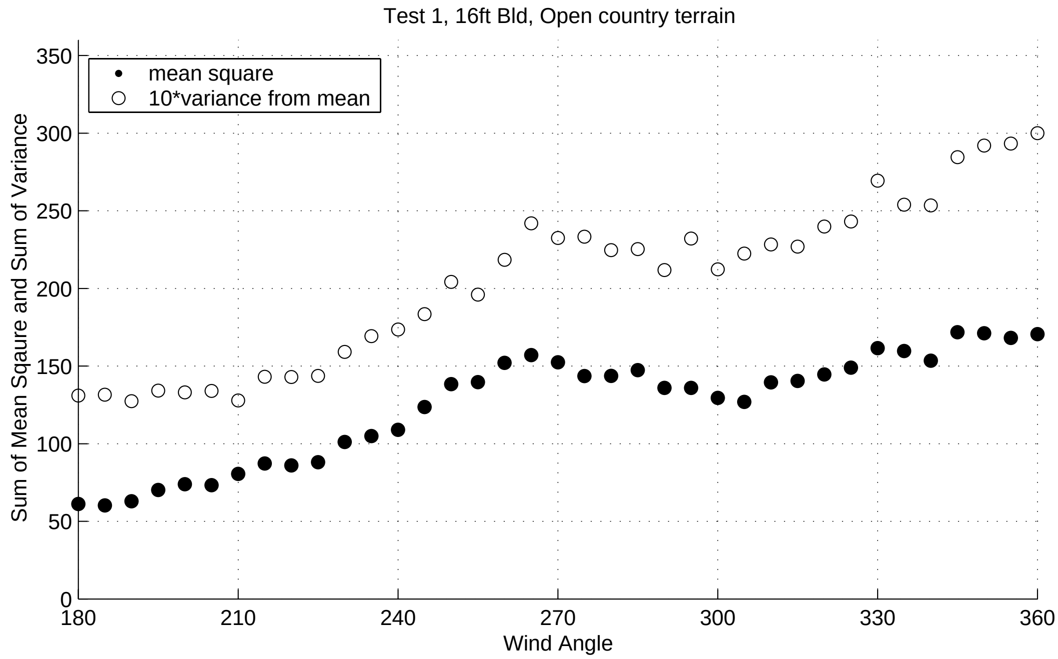
1. Actual wind speeds are within 5% of 45 fps at reference level. Pressure coefficients have been normalized based on actual wind tunnel speeds. For the determination of time scaling, nominal wind speed of 45 fps has been used.

2. Best estimates of ratios of roof height to reference wind speeds.

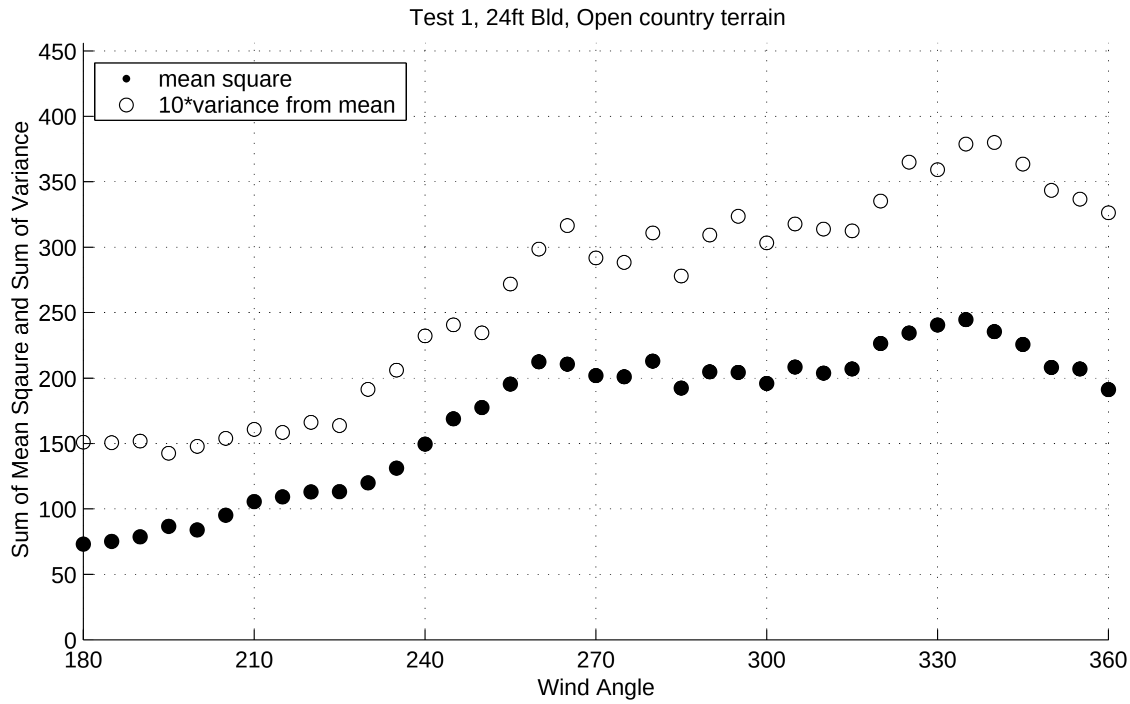
# APPENDIX C

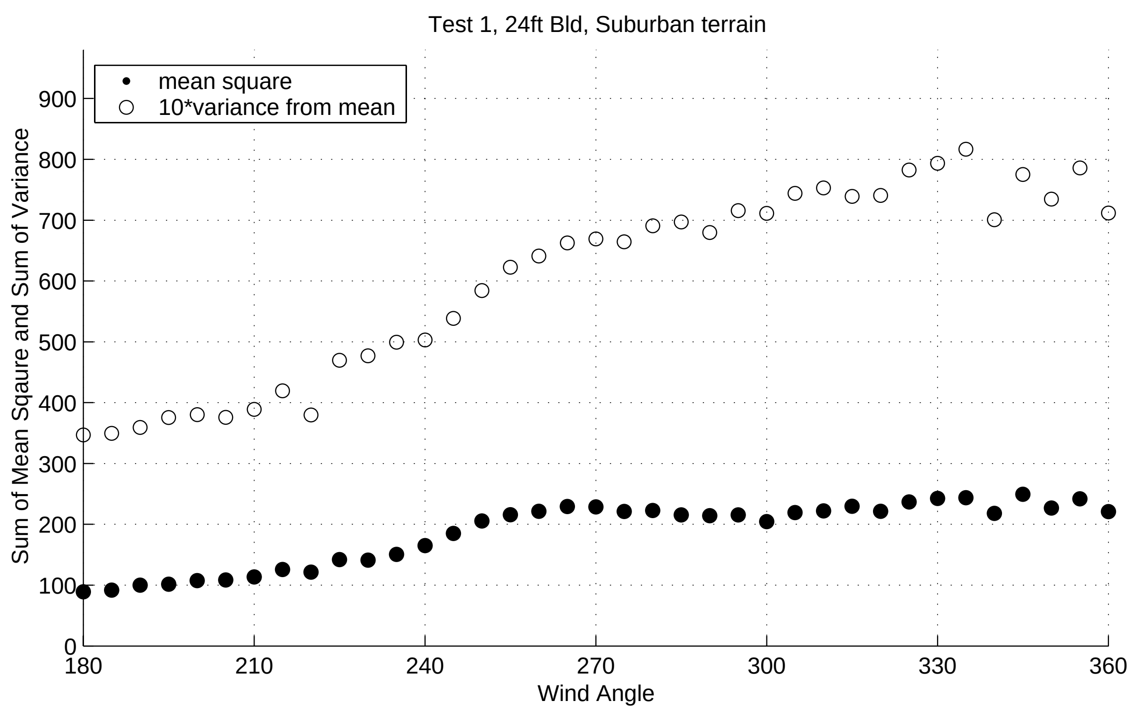
## SUM OF MEAN SQUARES AND SUM OF VARIANCES FOR ALL TESTS

- Note: Sums of mean squares and variances were calculated for Test 1 to Test 5 only.

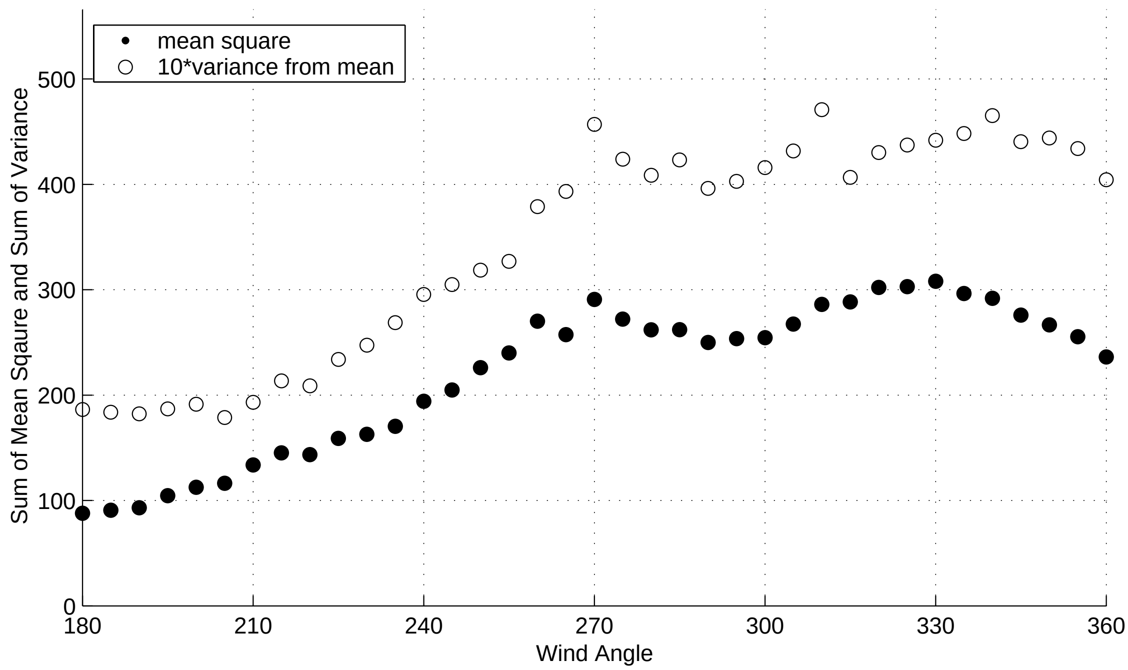

Test 1, 16ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
50
100
150
200
250
300
350
180
210
240
270
300
330
360
Wind Angle


Test 1, 16ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
100
200
300
400
500
600
700
180
210
240
270
300
330
360
Wind Angle

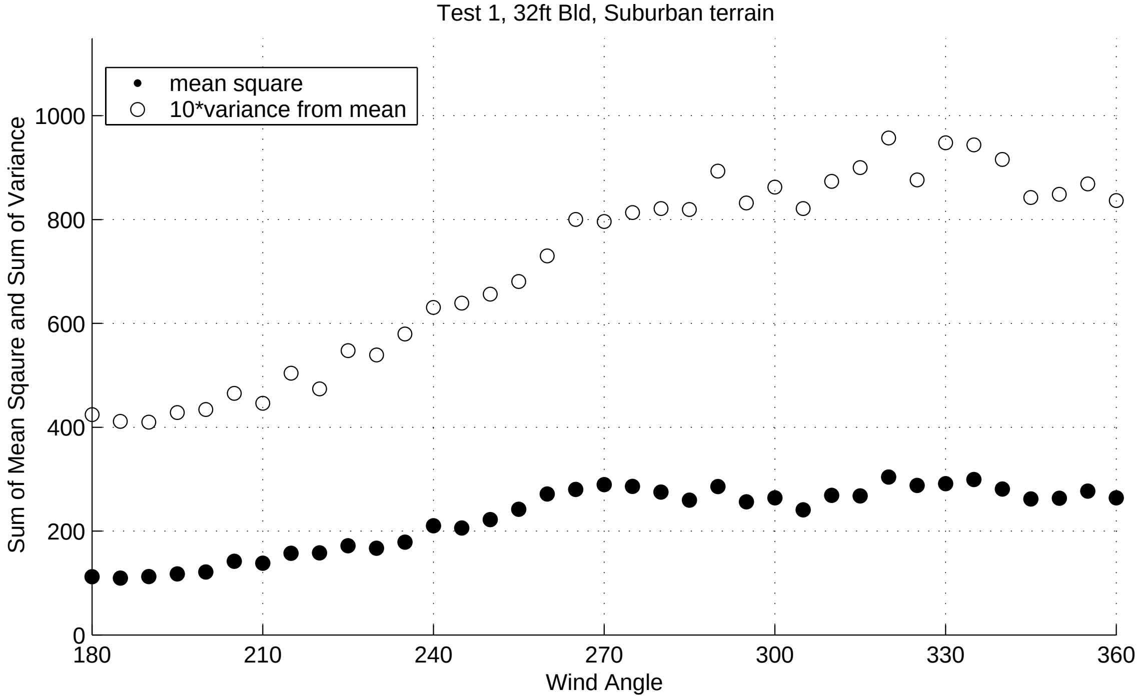

Test 1, 24ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
300
350
400
450
180
210
240
270
300
330
360


Test 1, 24ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
700
800
900
180
210
240
270
300
330
360

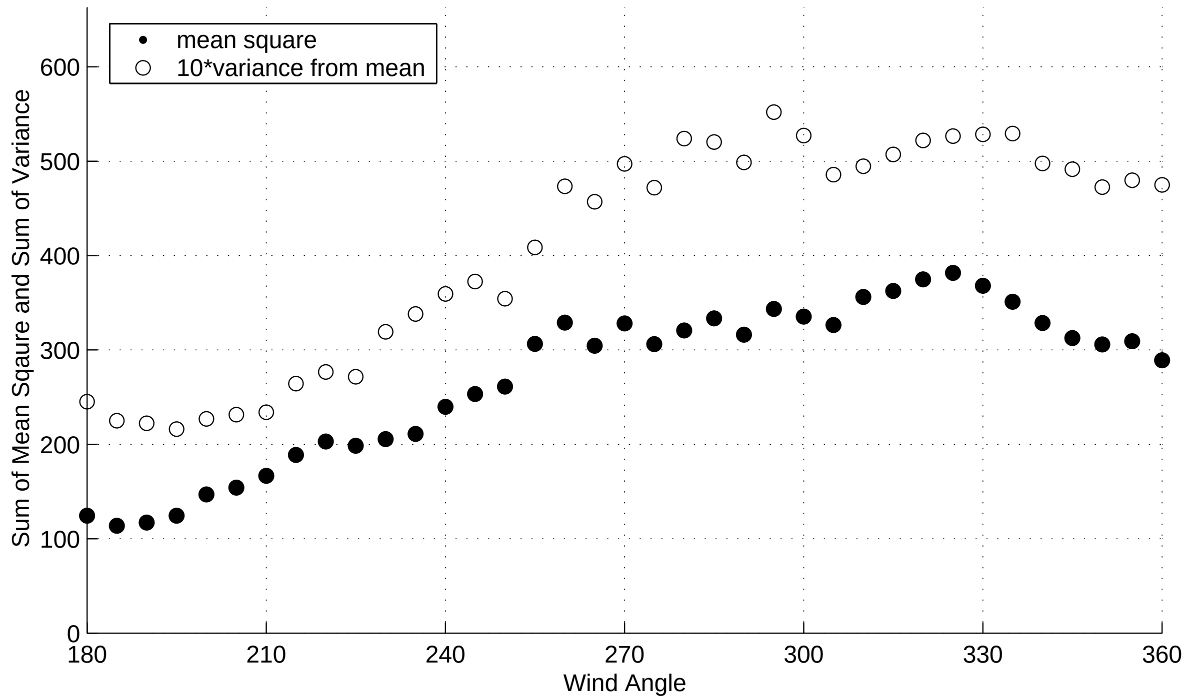
Test 1, 32ft Bld, Open country terrain



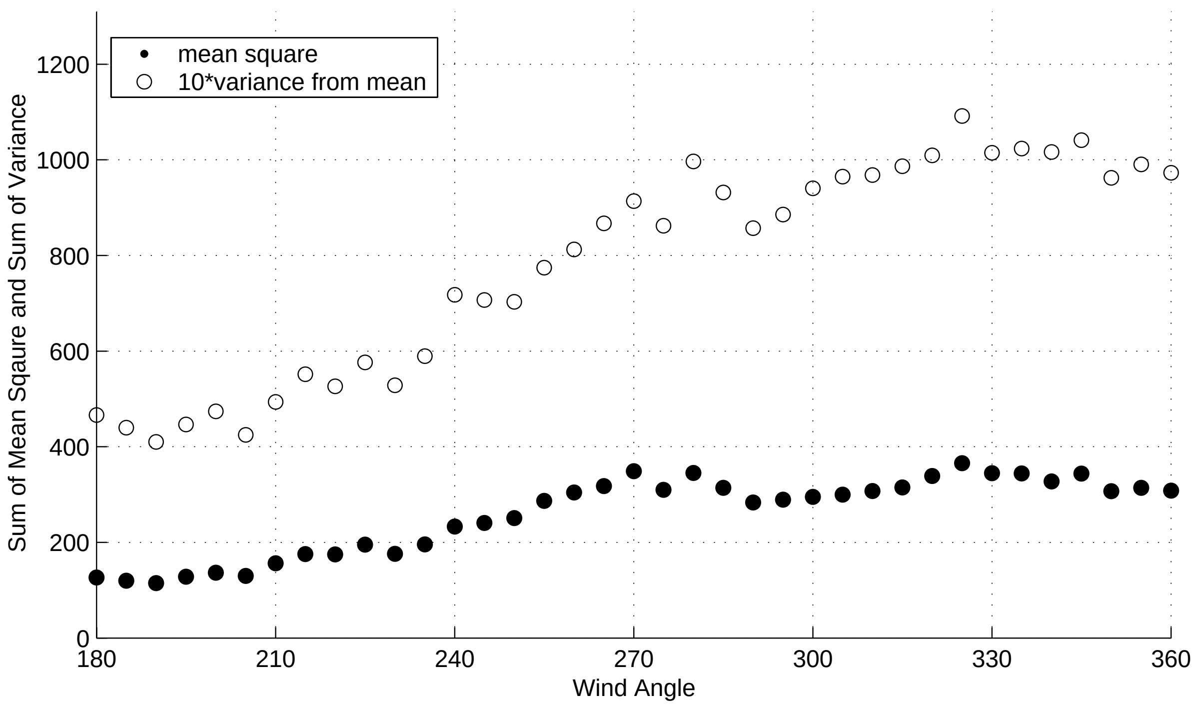

Test 1, 32ft Bld, Suburban terrain

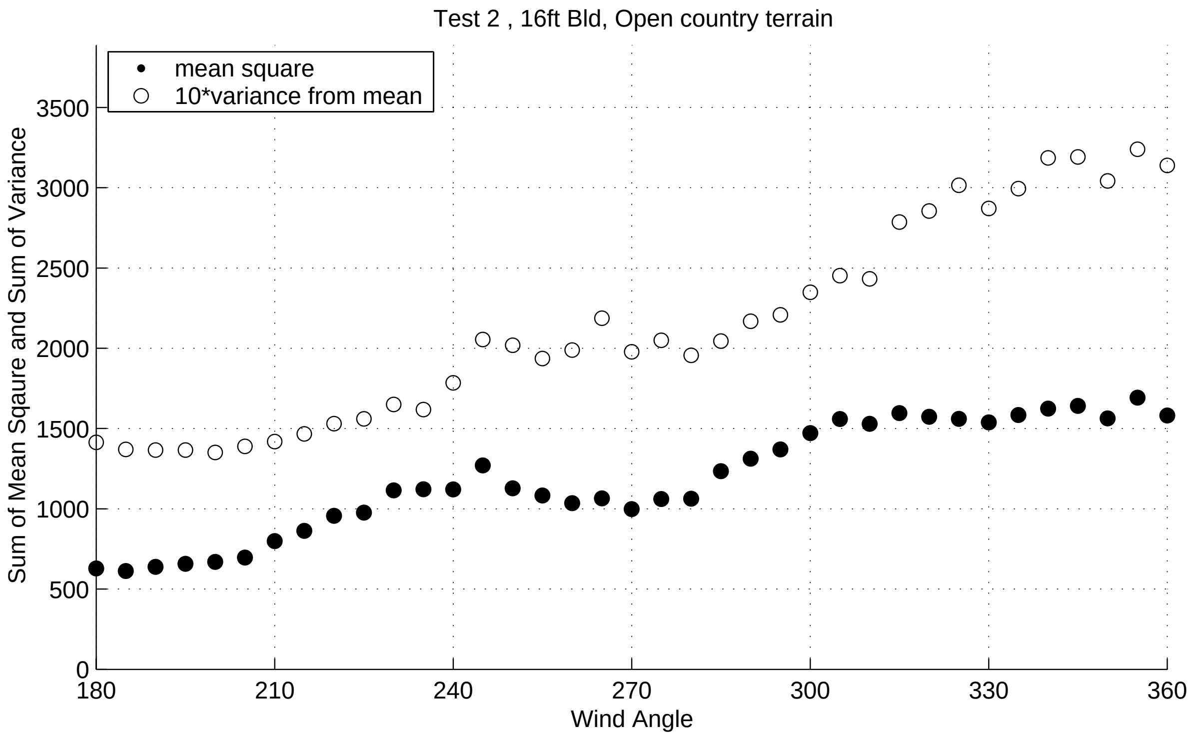


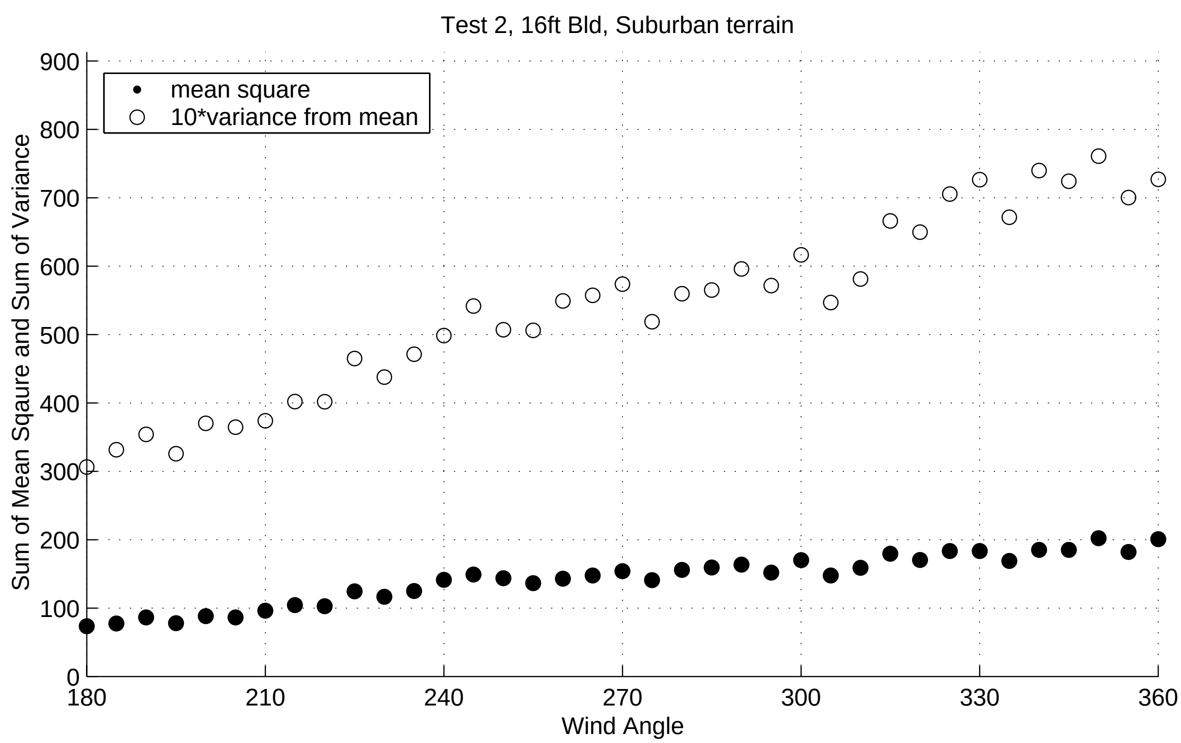
Test 1, 40ft Bld, Open country terrain

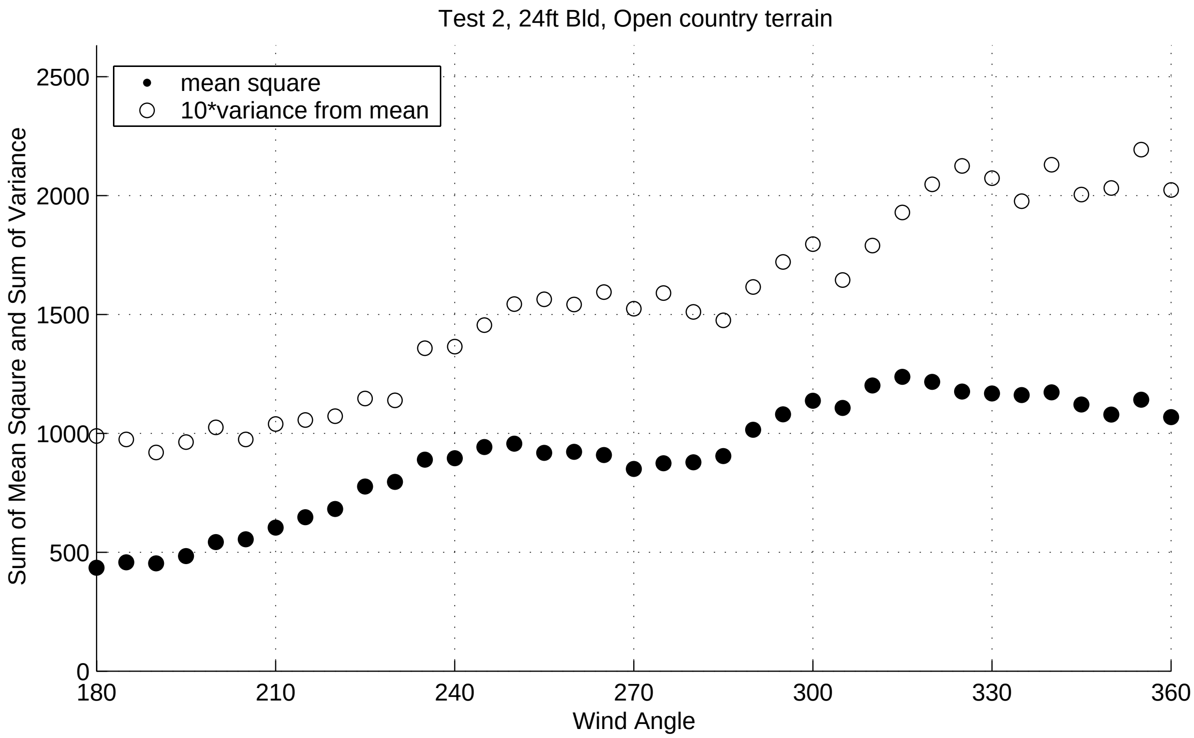


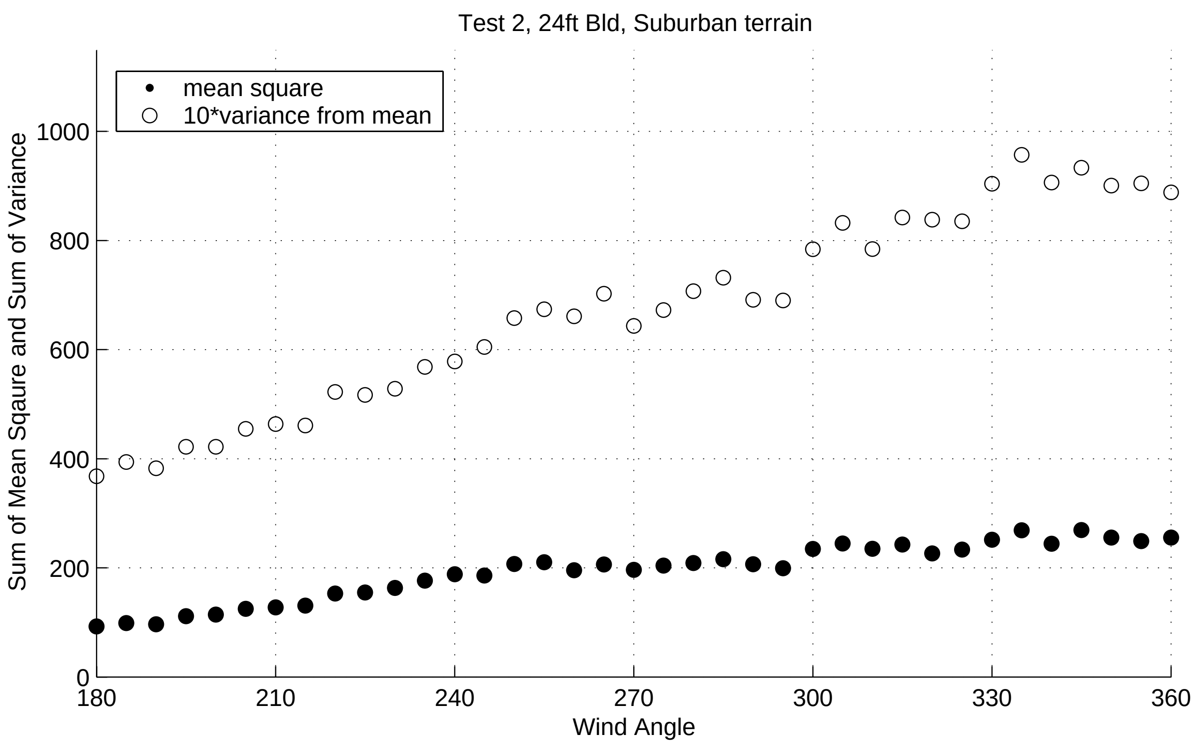

Test 1, 40ft Bld, Suburban terrain



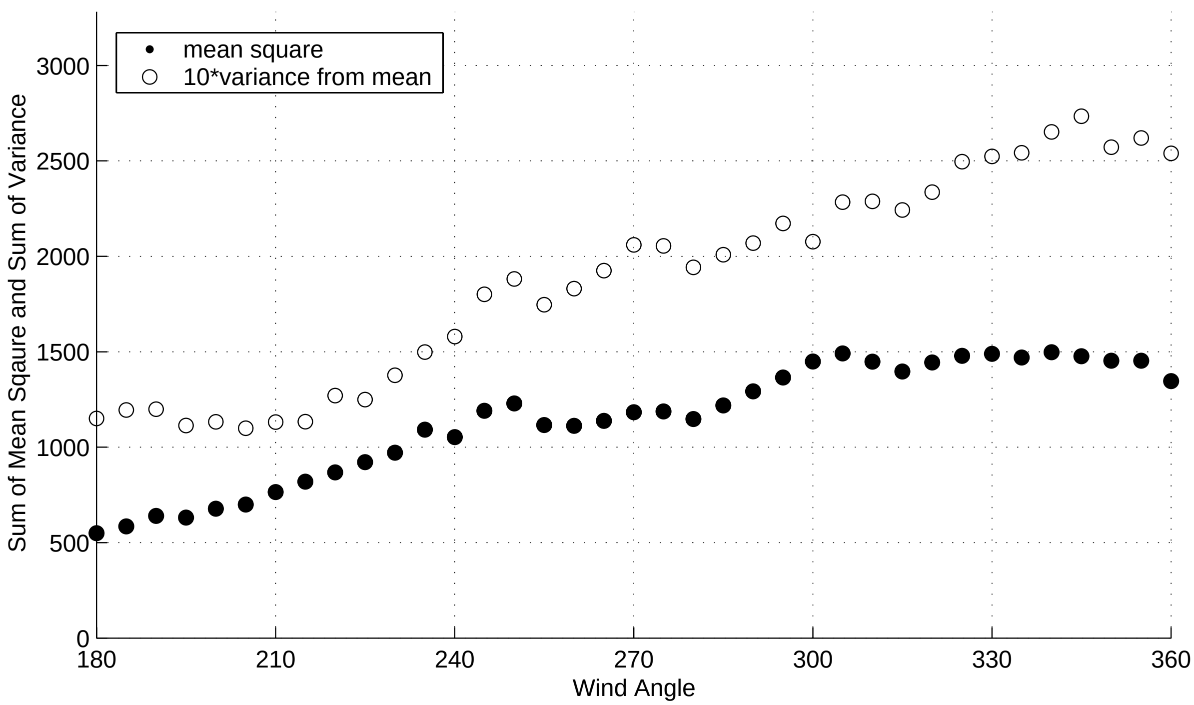

Test 2 , 16ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
500
1000
1500
2000
2500
3000
3500
180
210
240
270
300
330
360


Test 2, 16ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
700
800
900
180
210
240
270
300
330
360

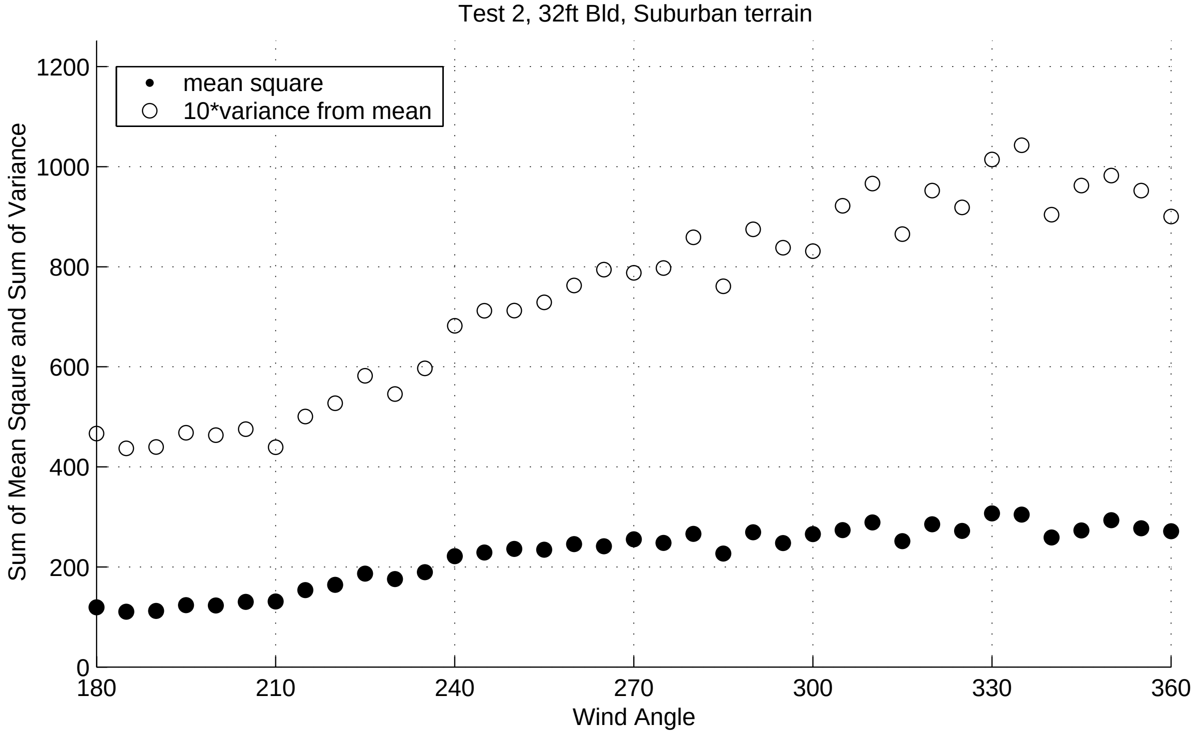

Test 2, 24ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
500
1000
1500
2000
2500
180
210
240
270
300
330
360

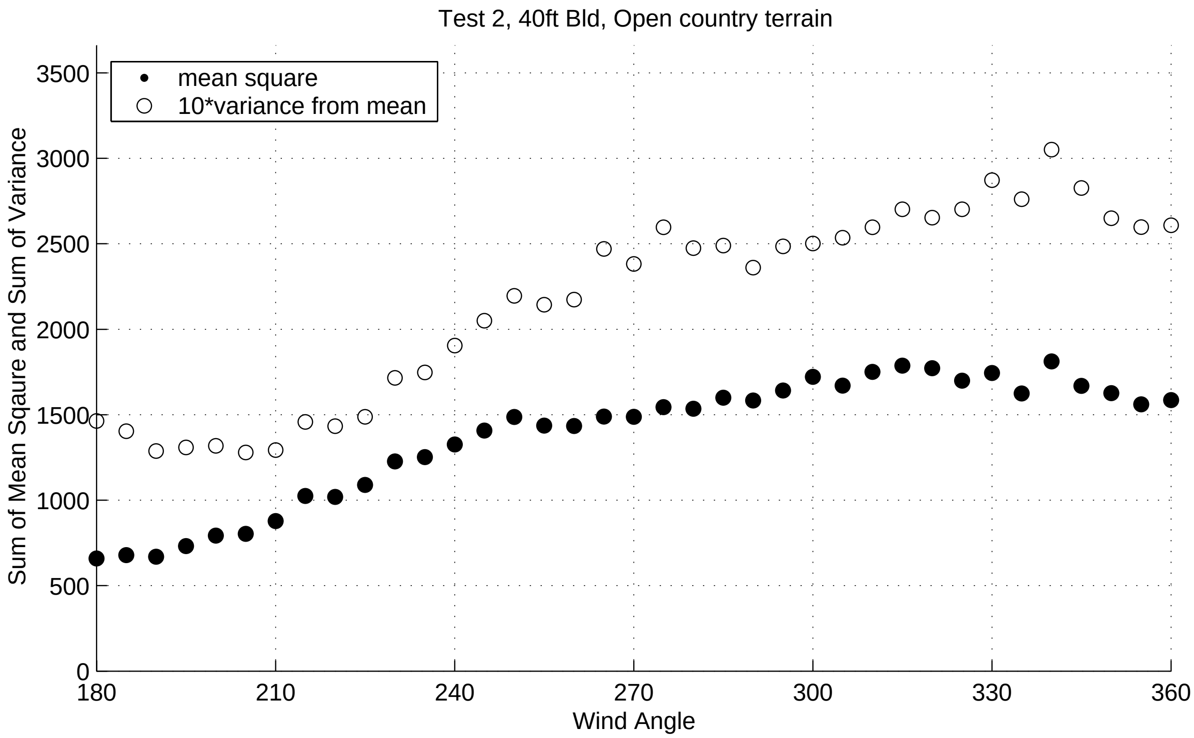

Test 2, 24ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
200
400
600
800
1000
180
210
240
270
300
330
360

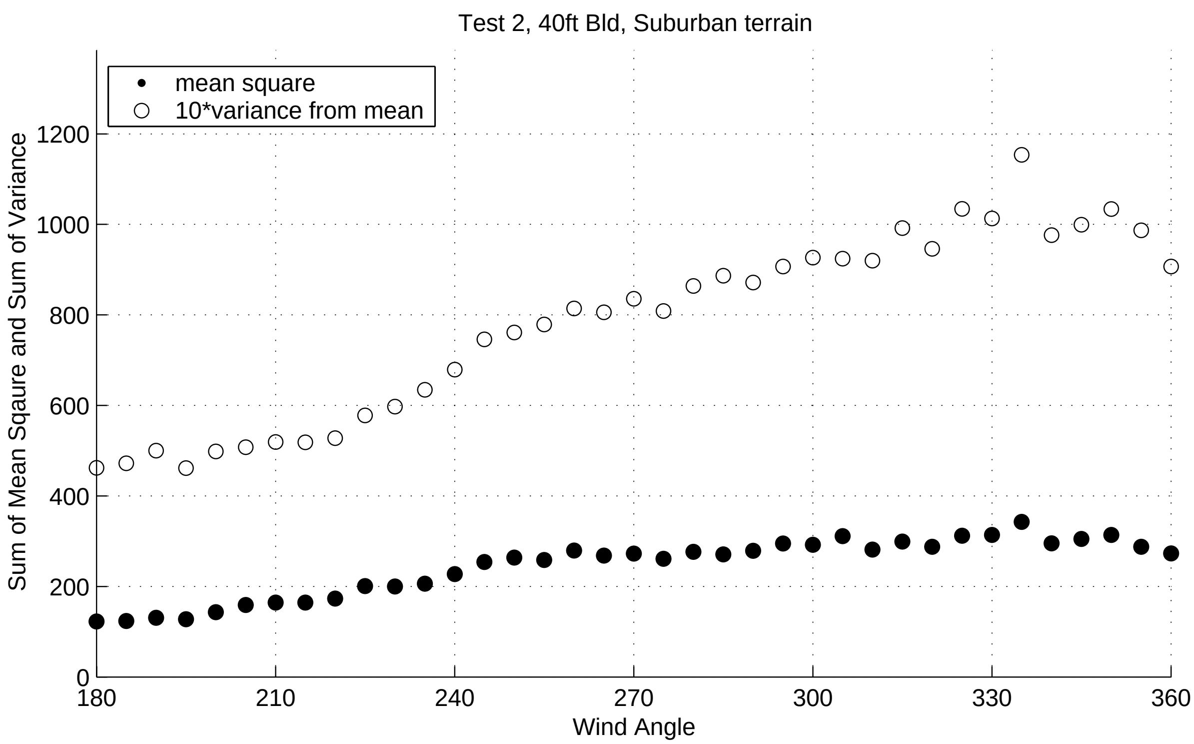
Test 2, 32ft Bld, Open country terrain

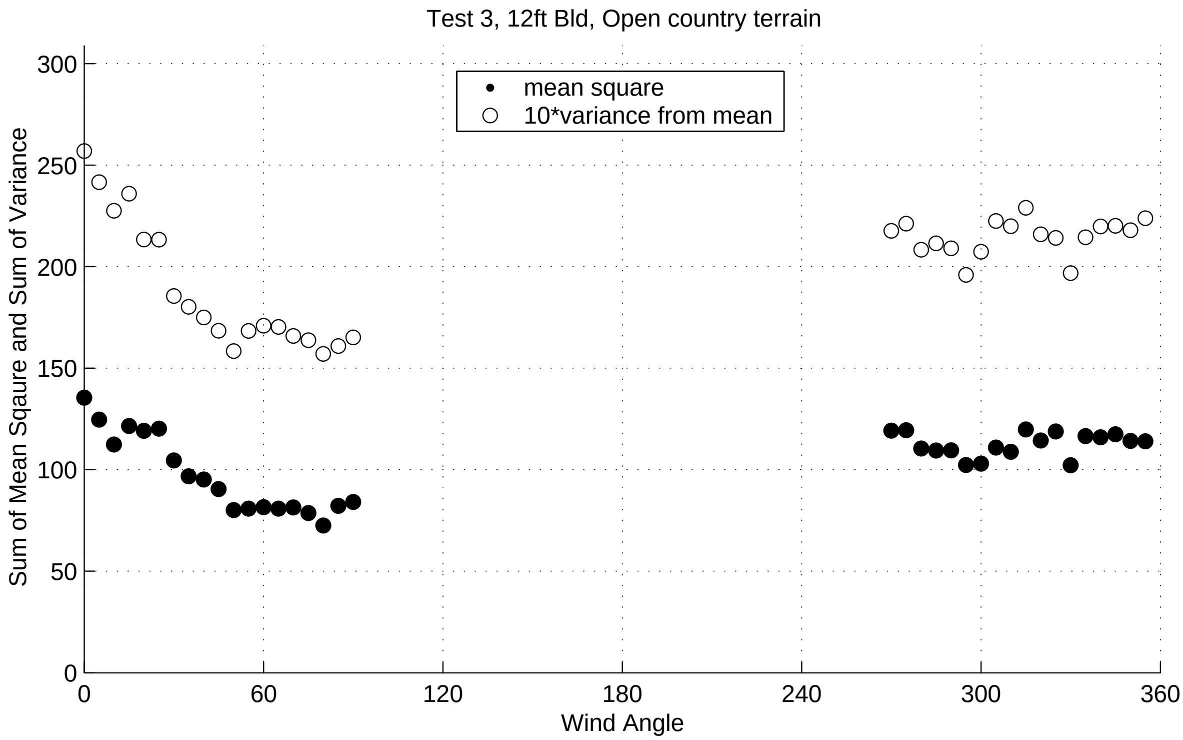


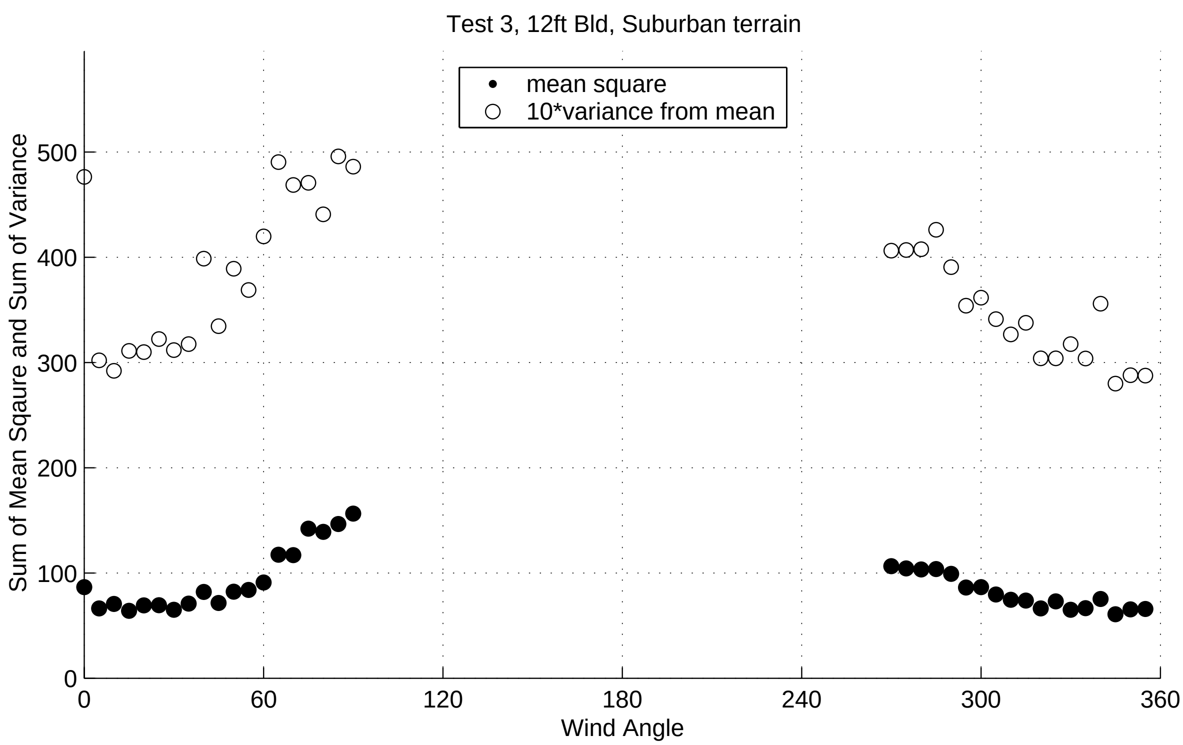

Test 2, 32ft Bld, Suburban terrain

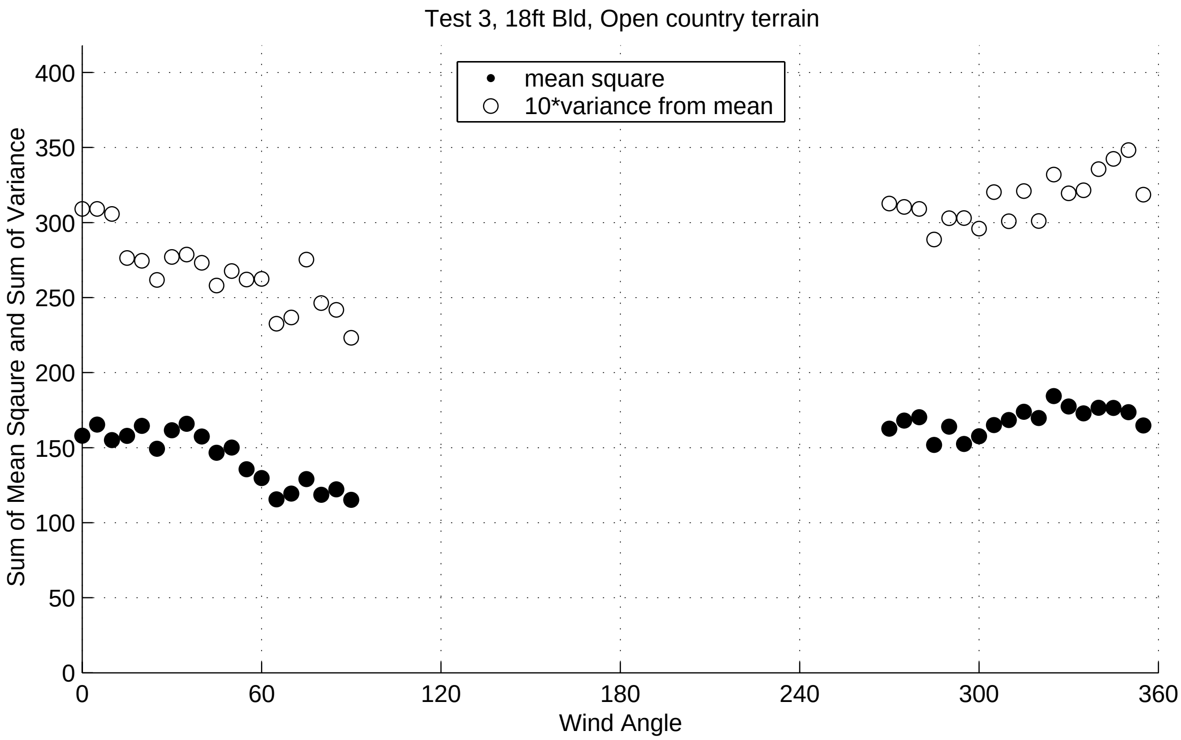


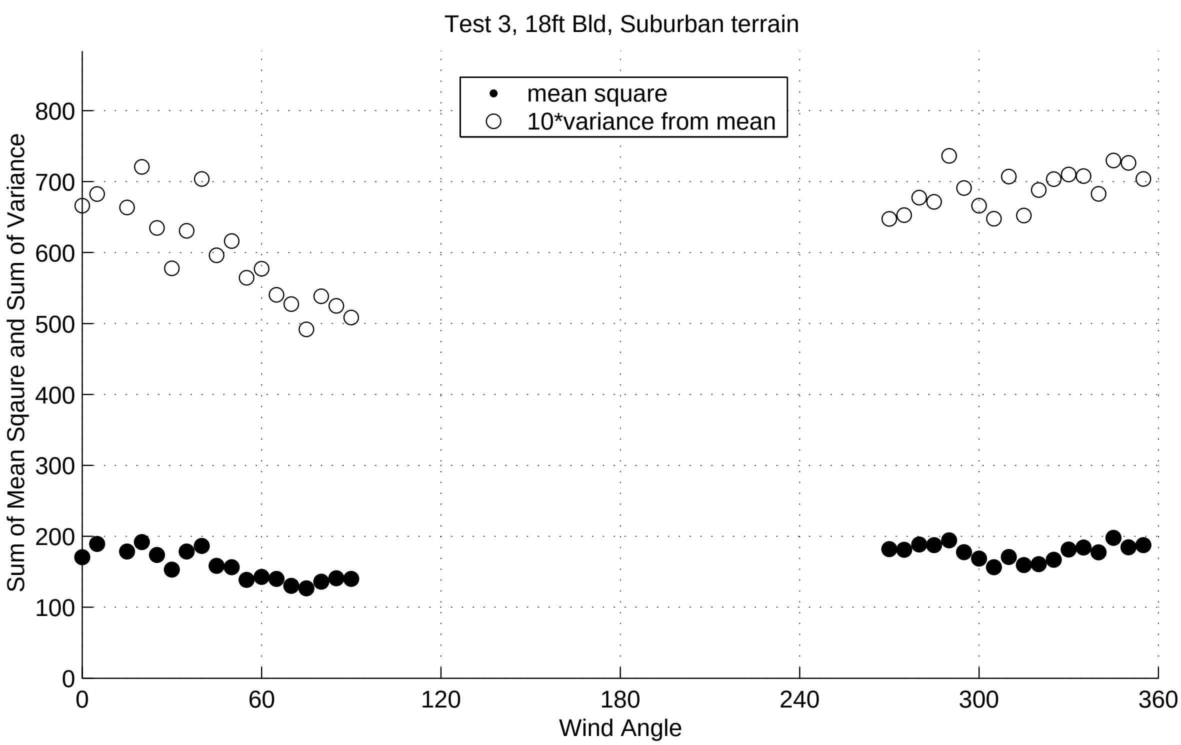

Test 2, 40ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
500
1000
1500
2000
2500
3000
3500
180
210
240
270
300
330
360

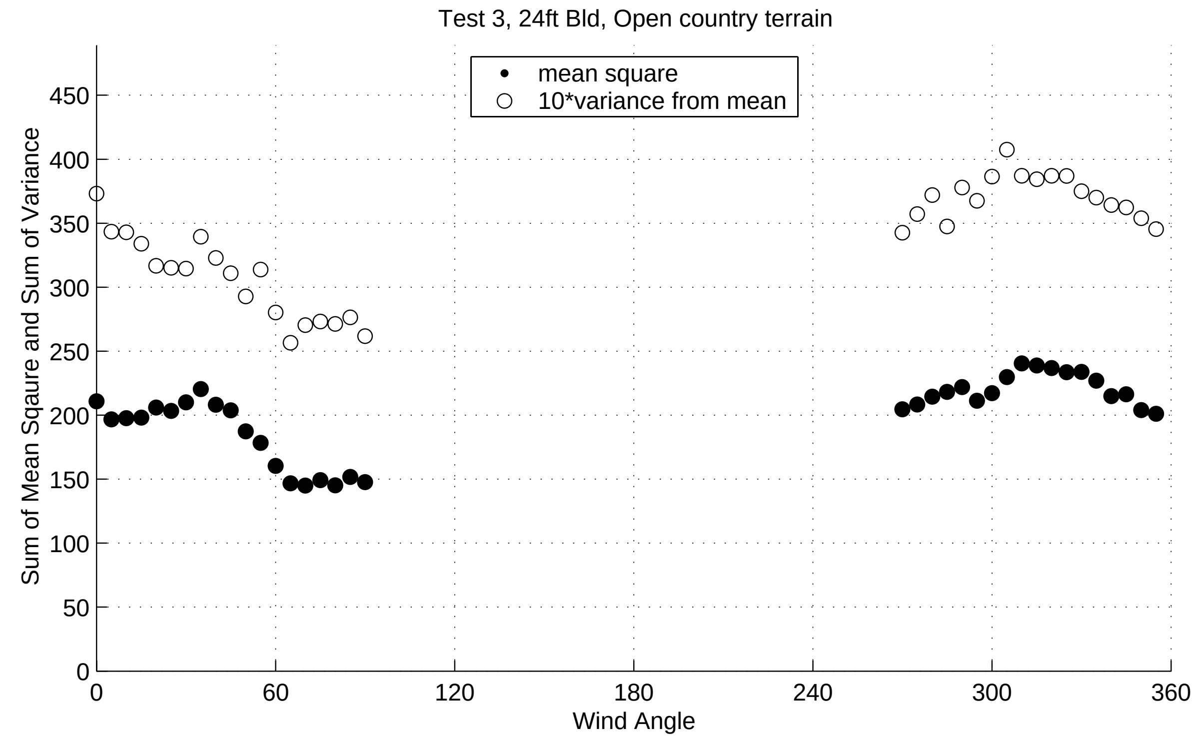

Test 2, 40ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
200
400
600
800
1000
1200
180
210
240
270
300
330
360

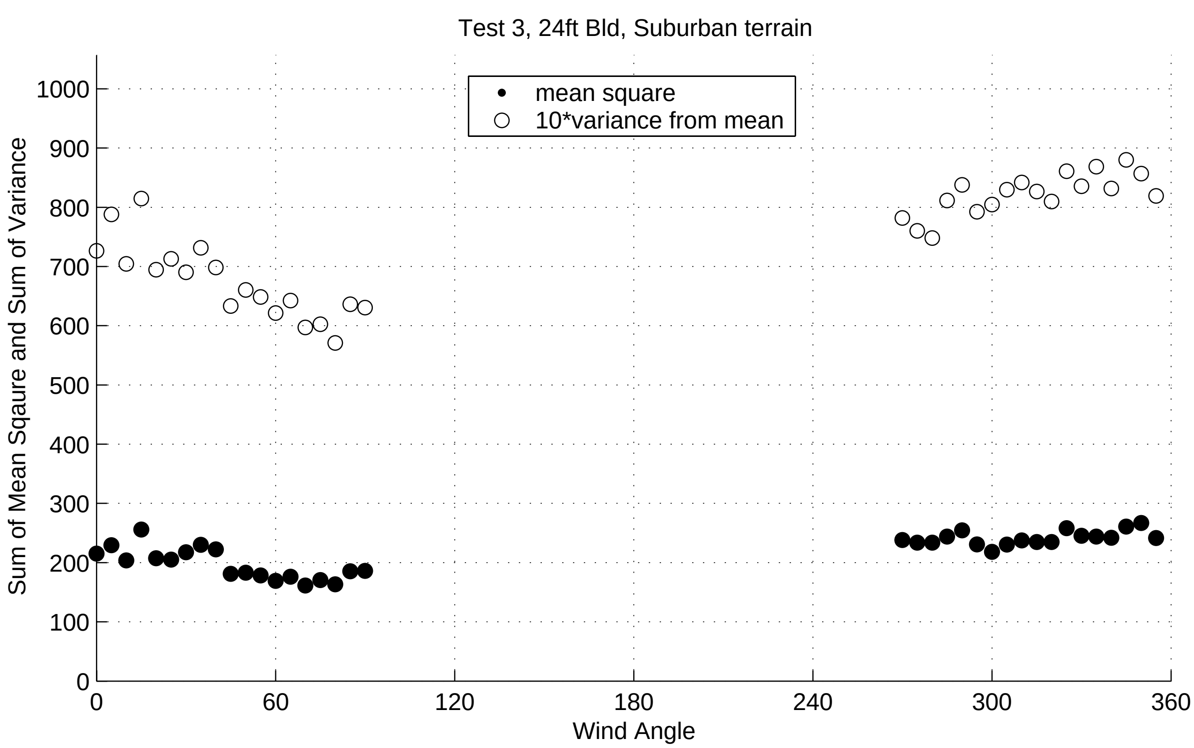

Test 3, 12ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
300
0
60
120
180
240
300
360

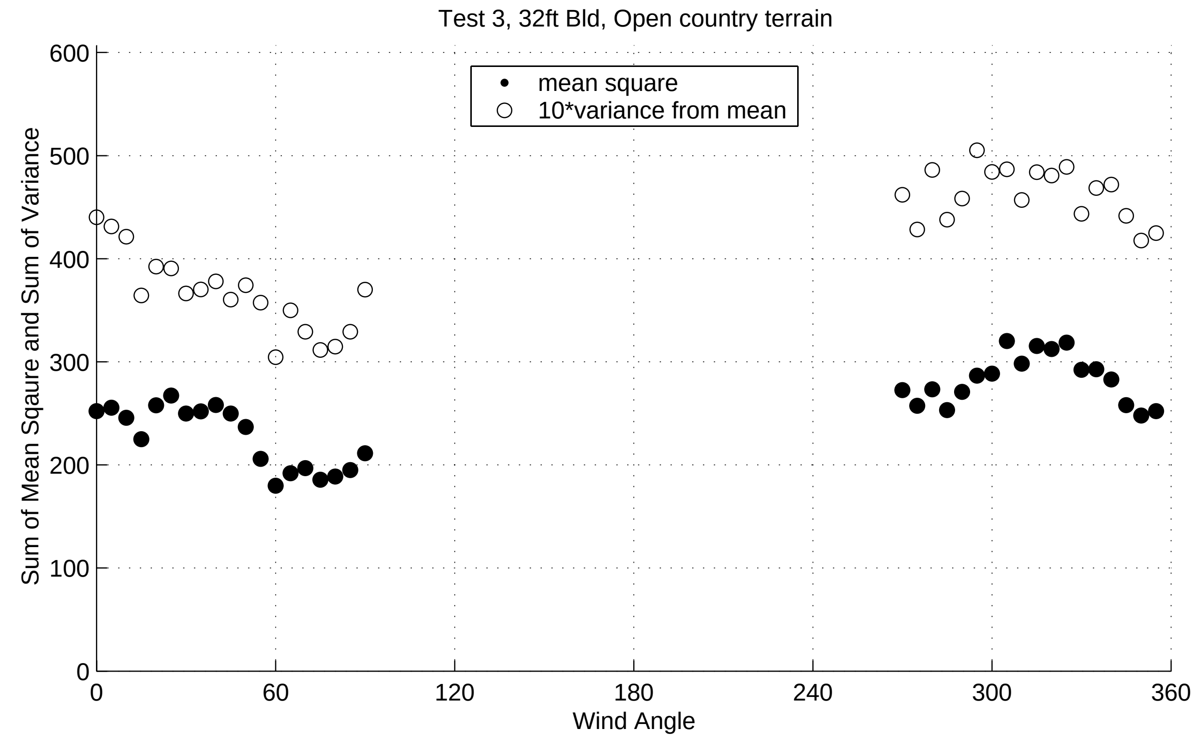

Test 3, 12ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
0
60
120
180
240
300
360


Test 3, 18ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
300
350
400
0
60
120
180
240
300
360

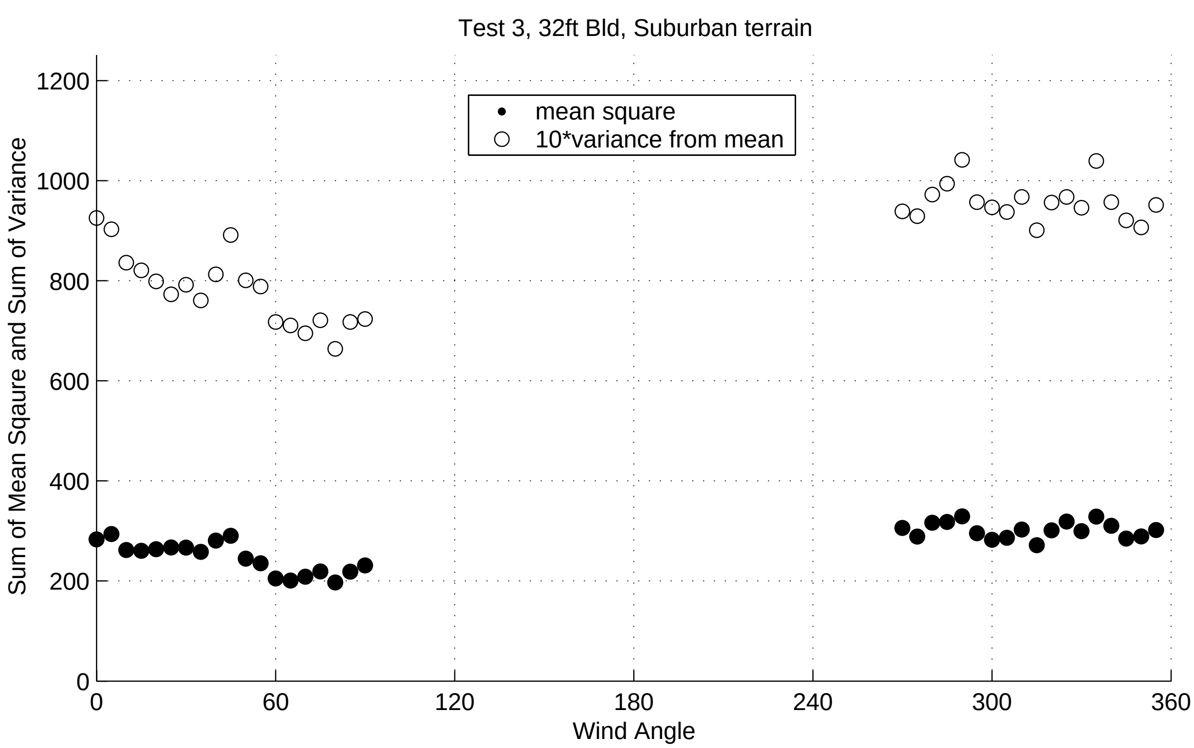

Test 3, 18ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
700
800
0
60
120
180
240
300
360


Test 3, 24ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
50
100
150
200
250
300
350
400
450
0
60
120
180
240
300
360
Wind Angle

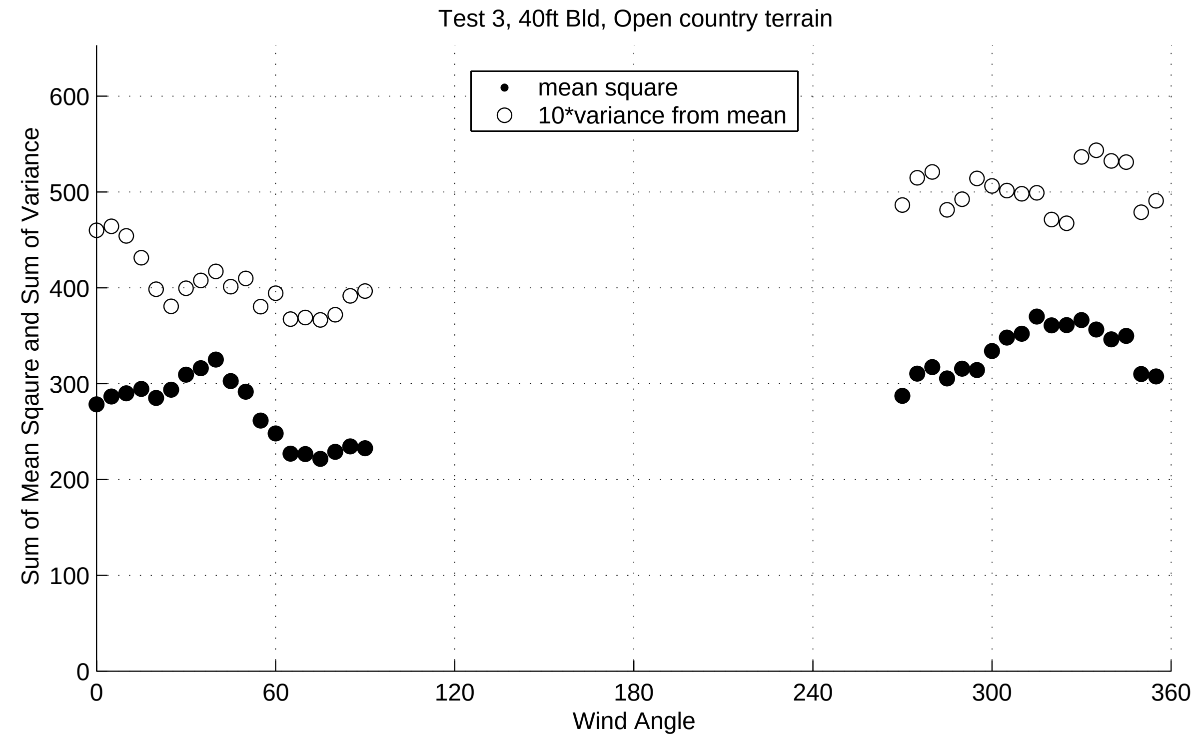

Test 3, 24ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
100
200
300
400
500
600
700
800
900
1000
0
60
120
180
240
300
360
Wind Angle



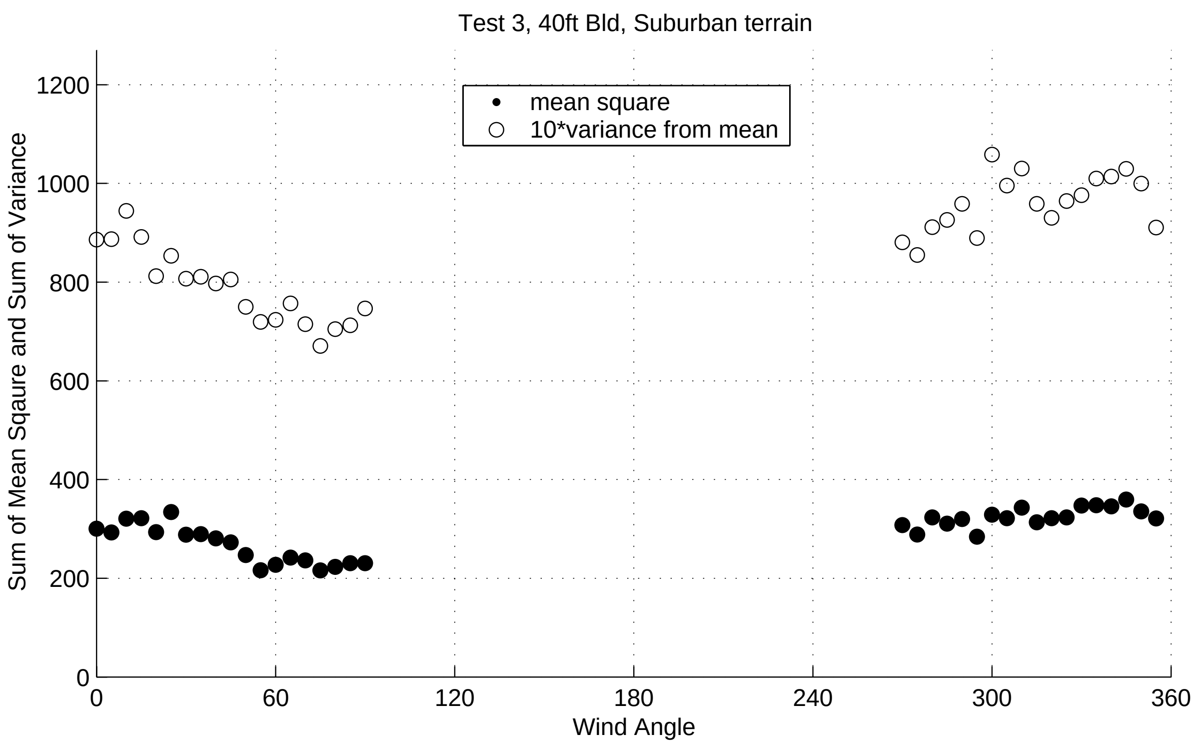
Test 3, 32ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
0
60
120
180
240
300
360

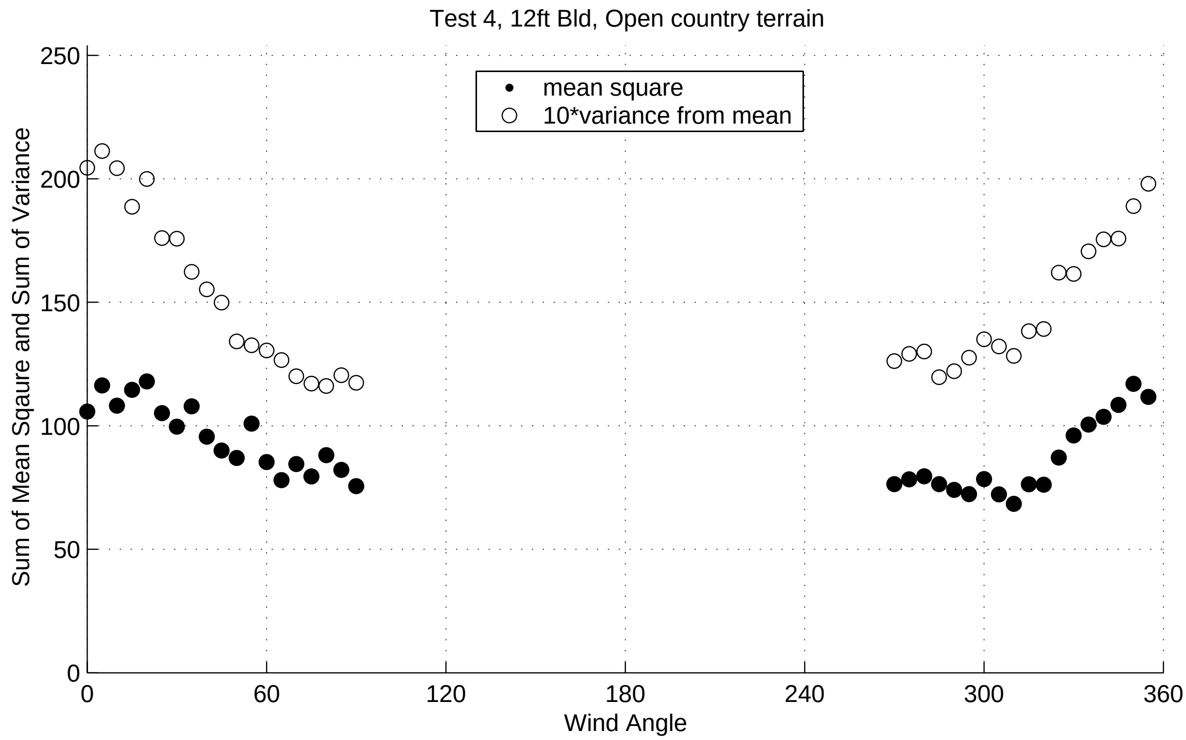
Test 3, 32ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
200
400
600
800
1000
1200
0
60
120
180
240
300
360

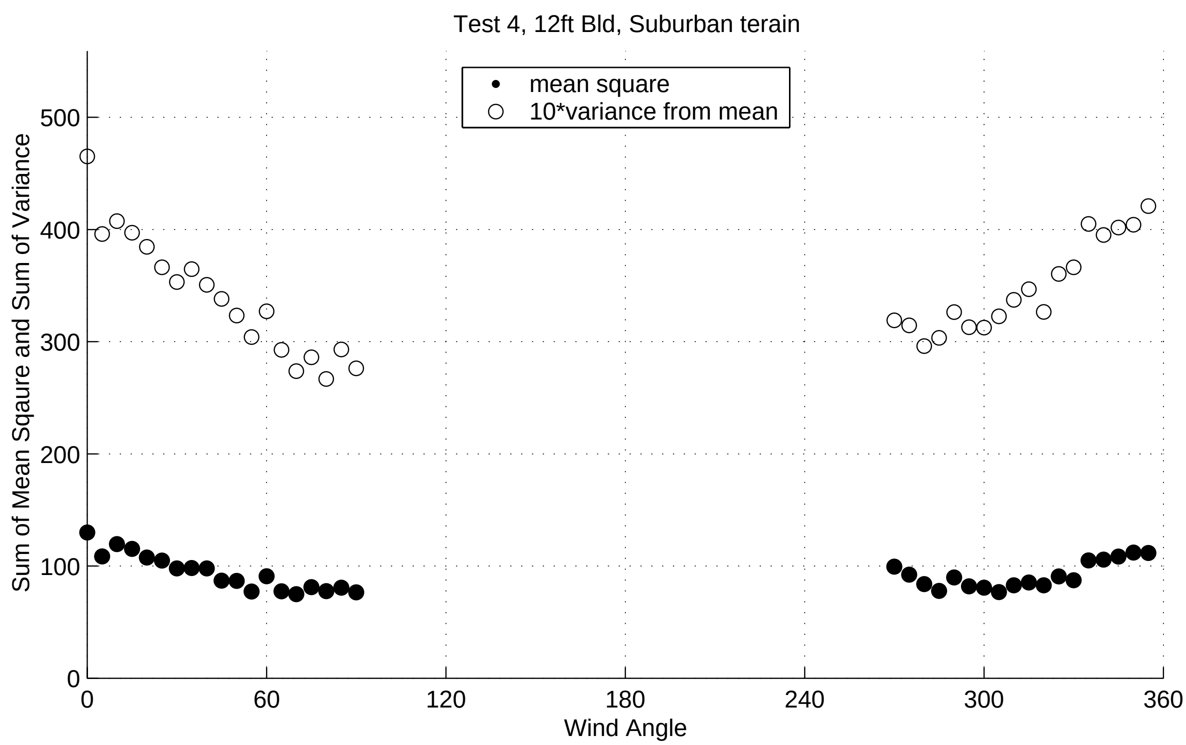


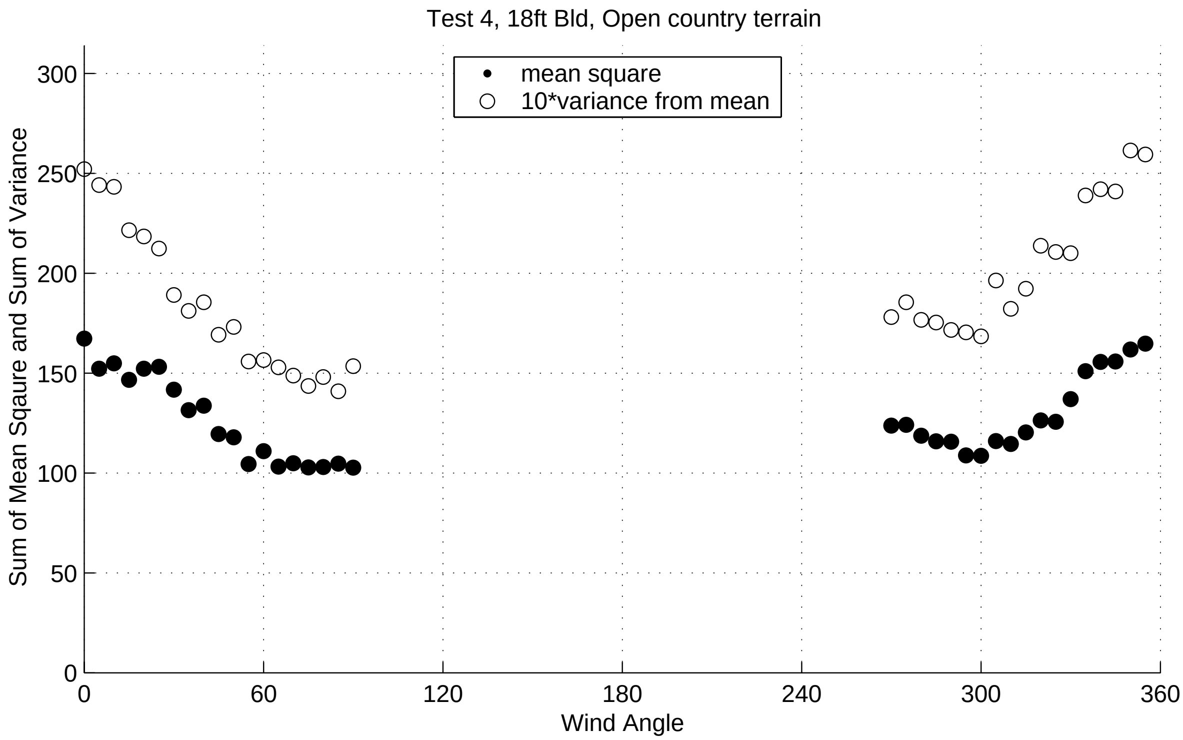
Test 3, 40ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle

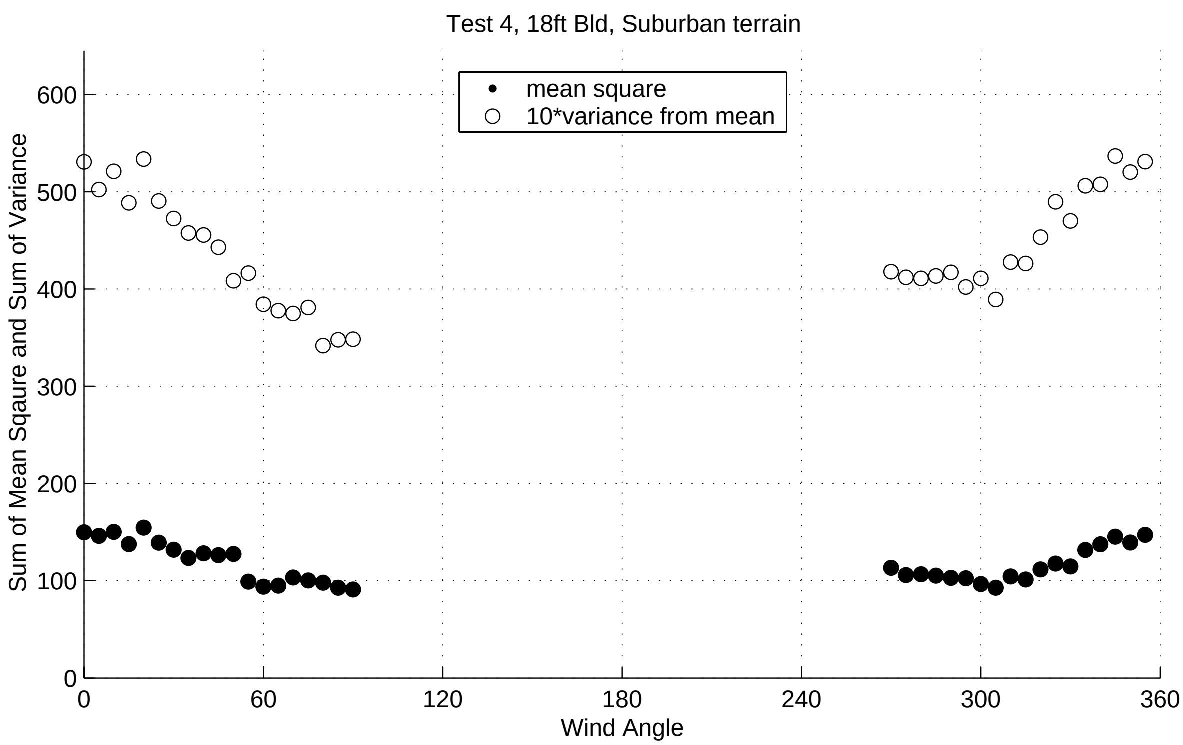



Test 3, 40ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle

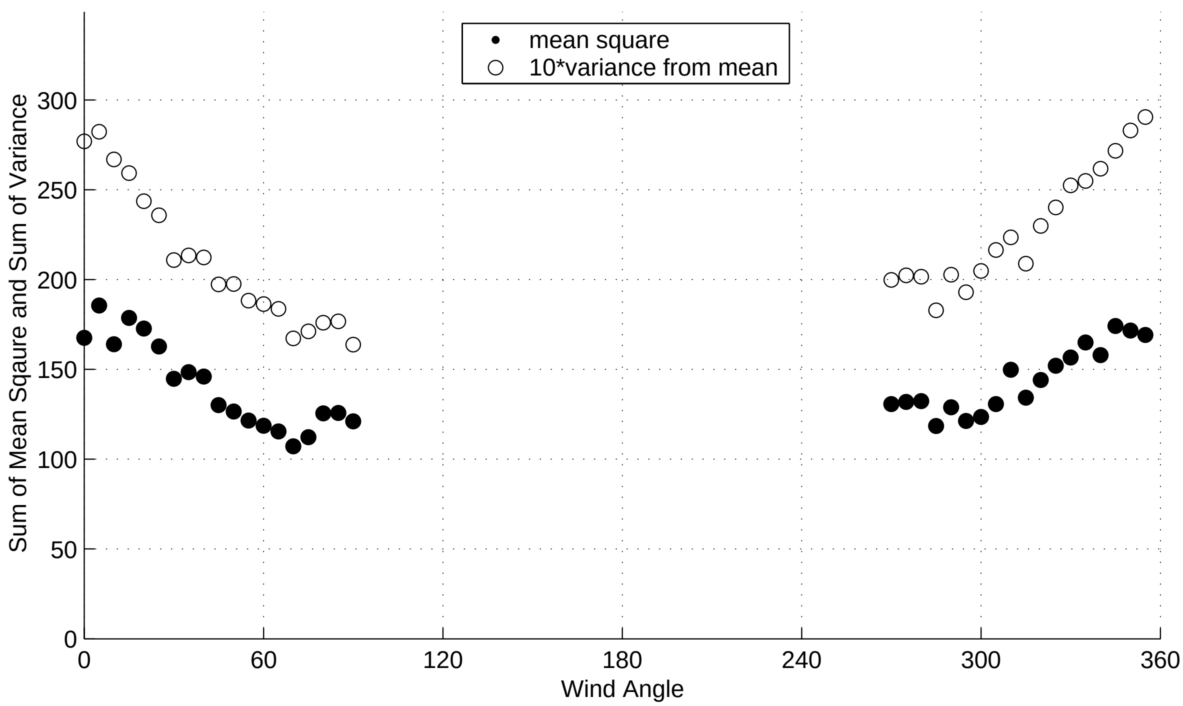

Test 4, 12ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
0
60
120
180
240
300
360


Test 4, 12ft Bld, Suburban terain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
0
60
120
180
240
300
360

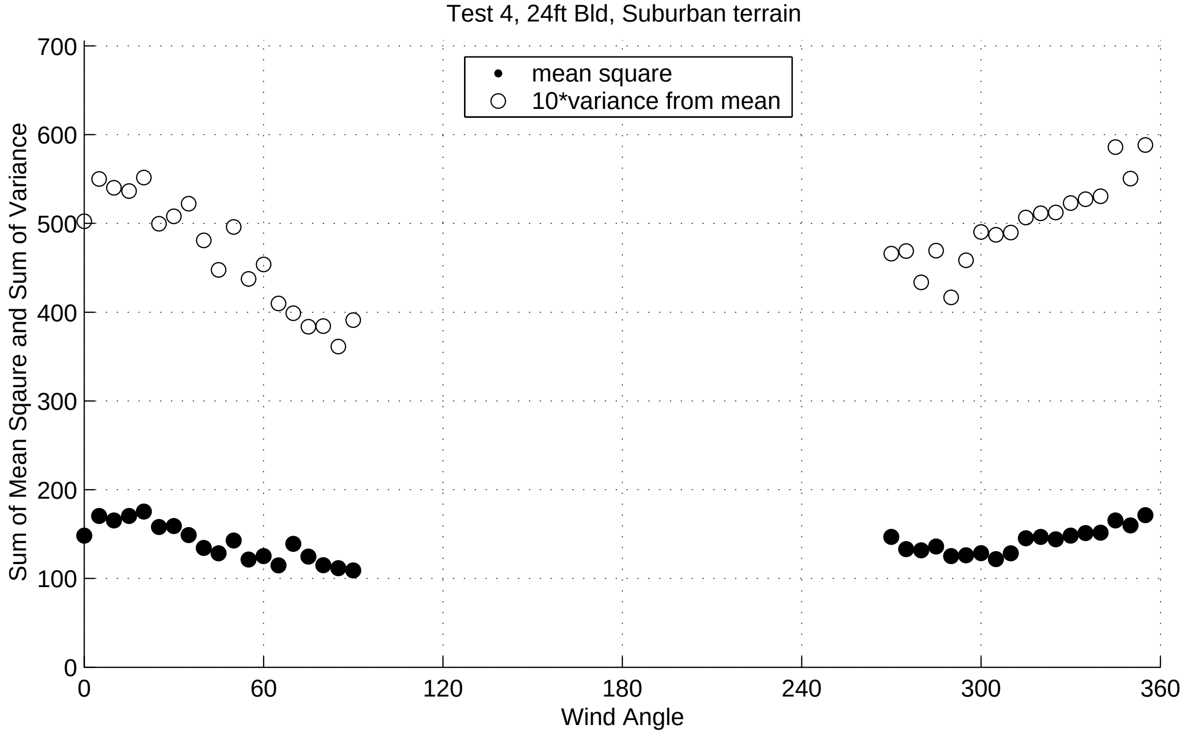

Test 4, 18ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
300
0
60
120
180
240
300
360


Test 4, 18ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
0
60
120
180
240
300
360

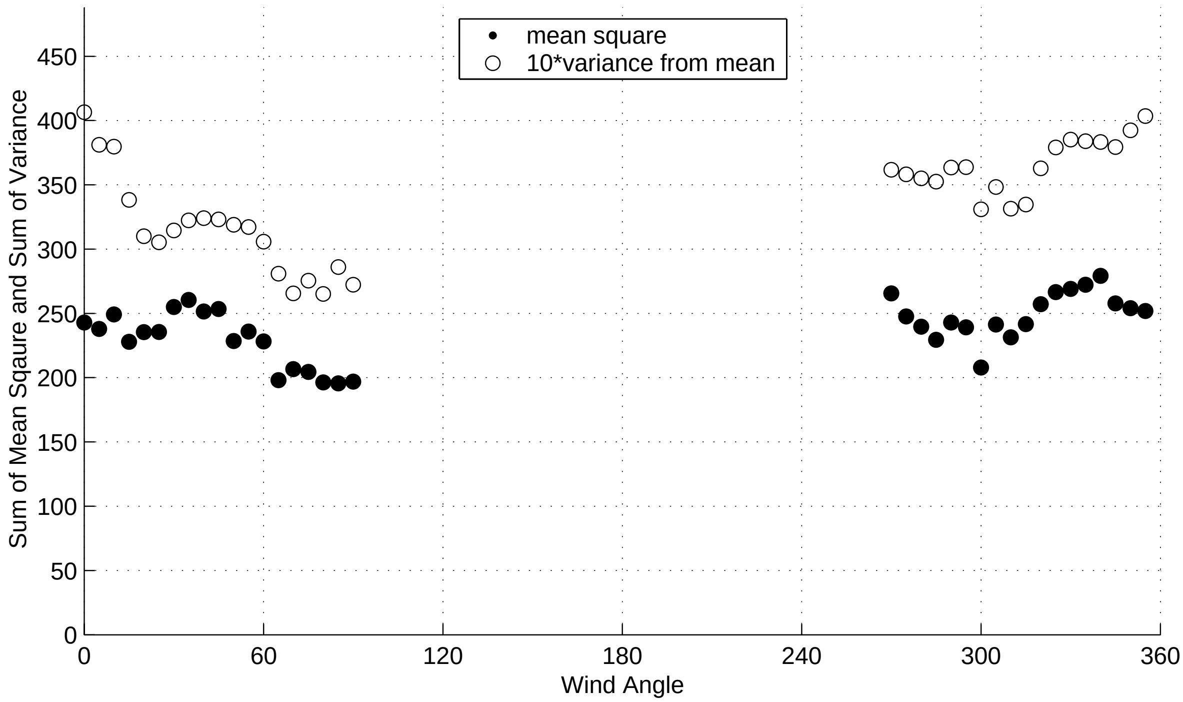
Test 4, 24ft Bld, Open country terrain



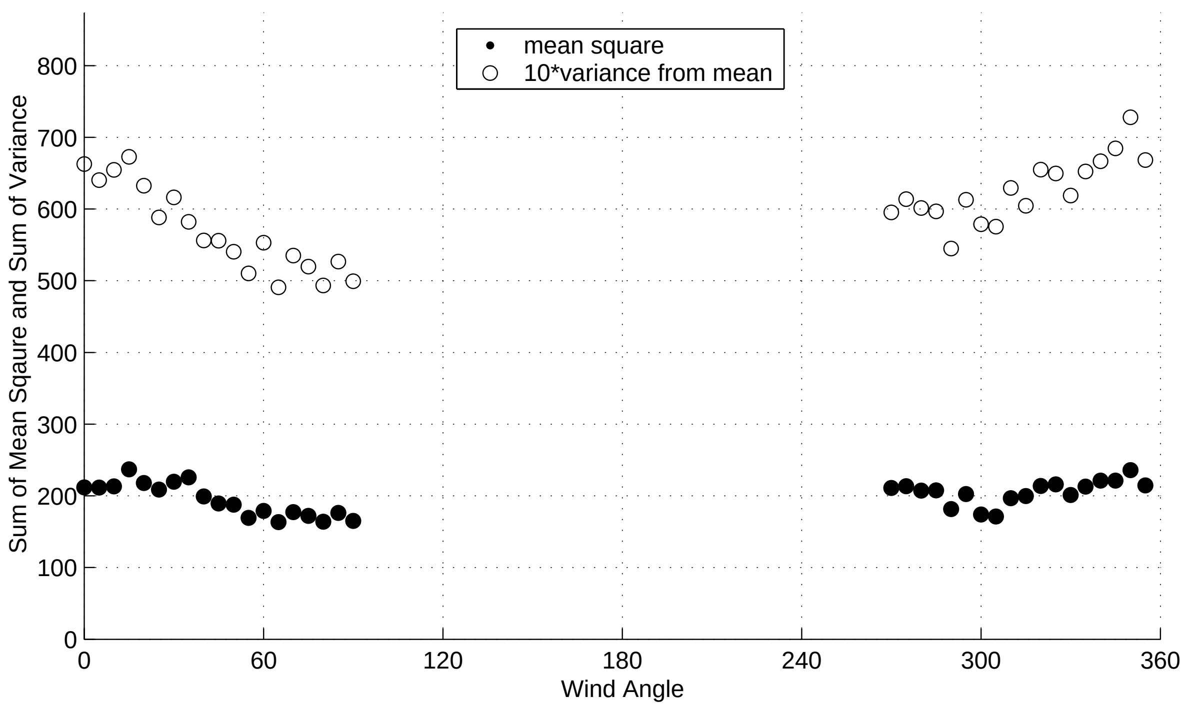

Test 4, 24ft Bld, Suburban terrain

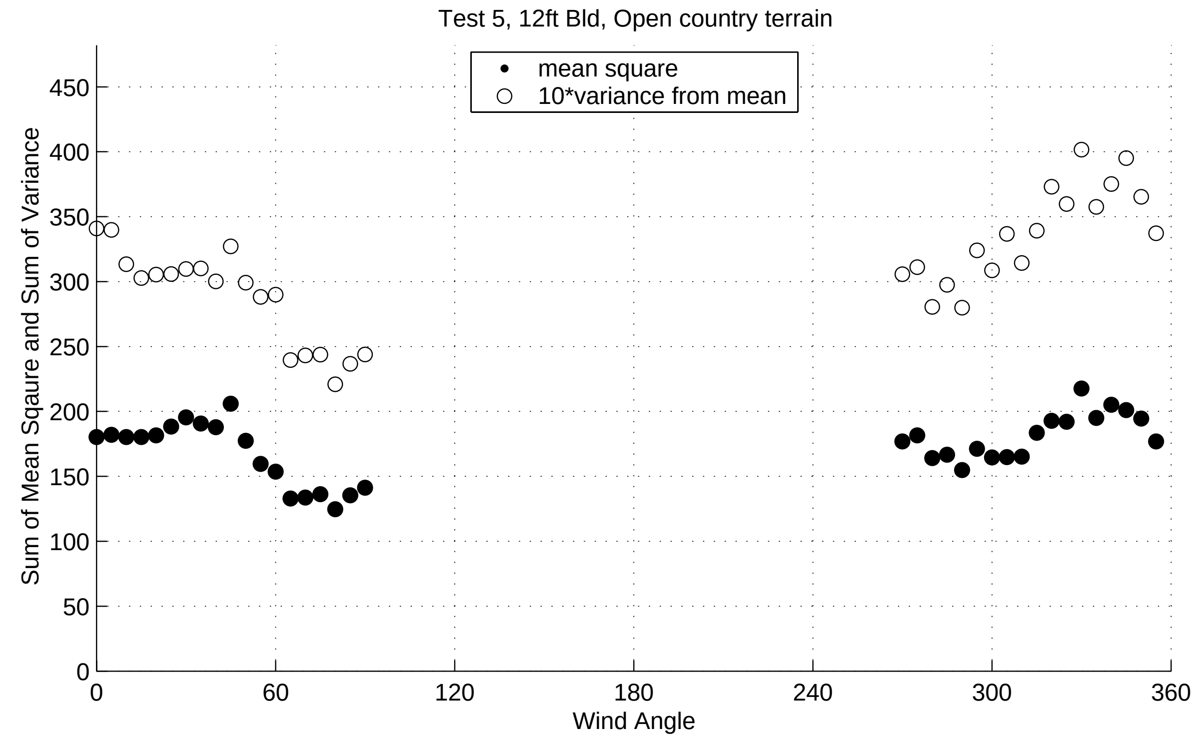


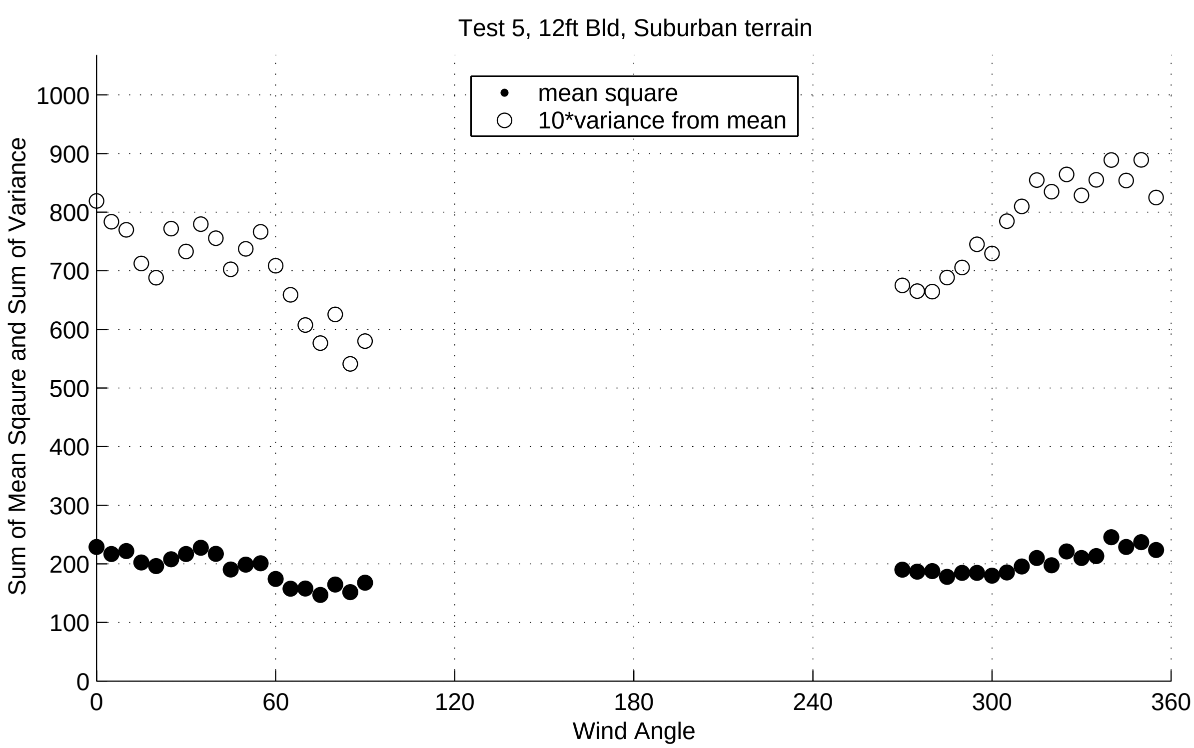
Test 4, 40ft Bld, Open country terrain

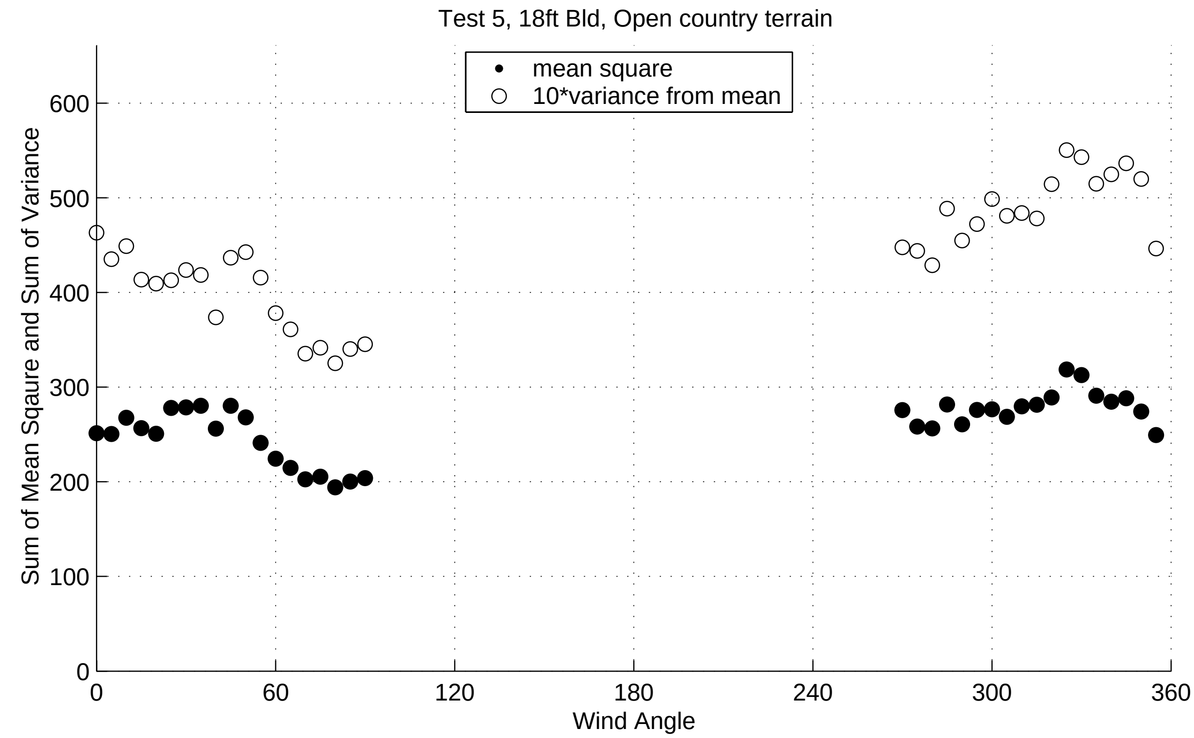


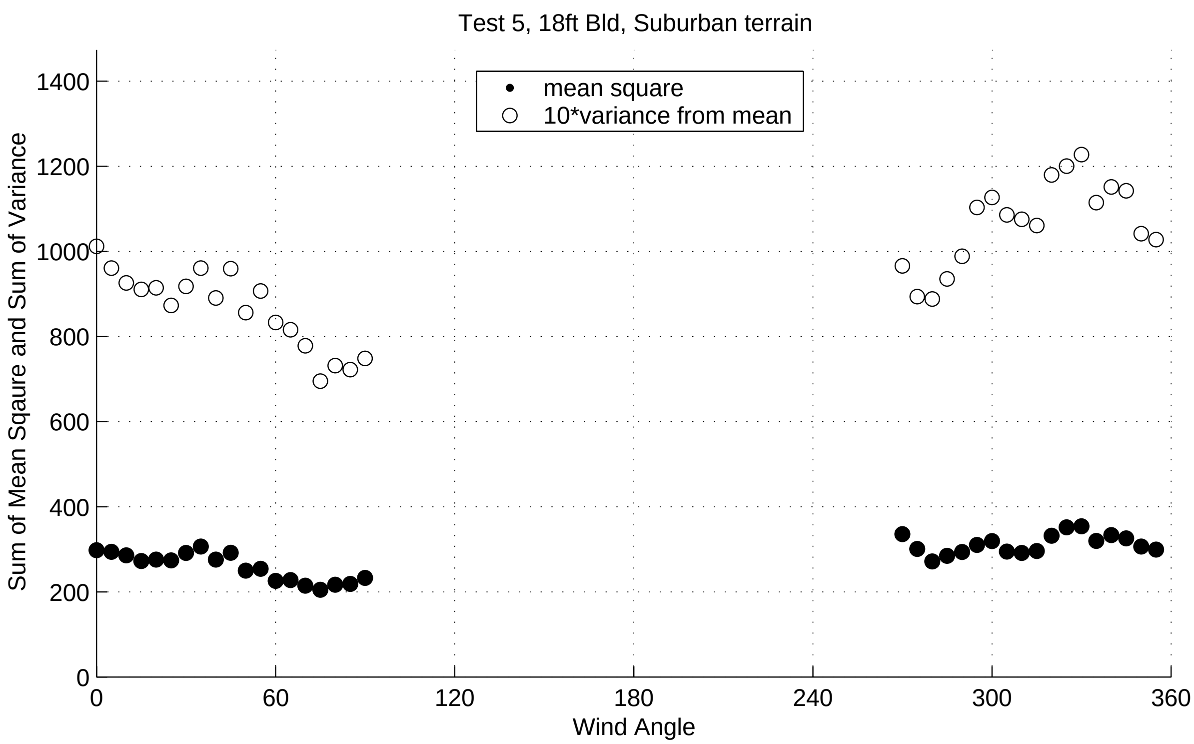

Test 4, 40ft Bld, Suburban terrain

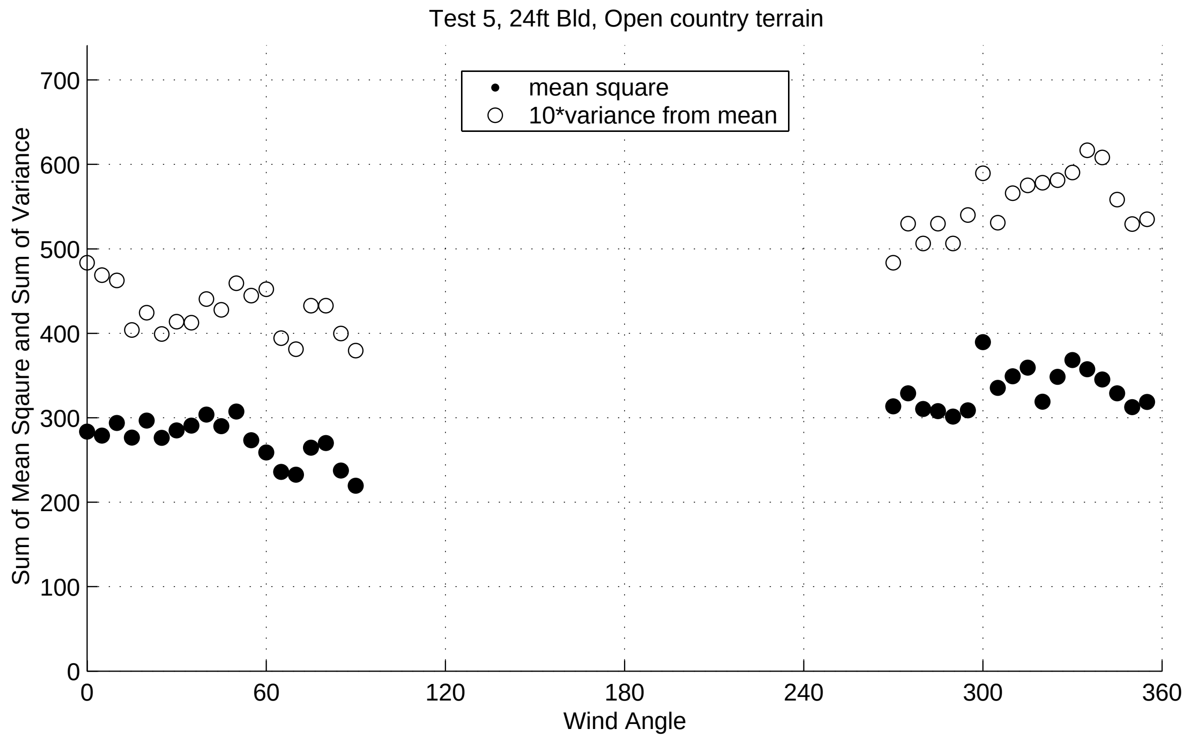


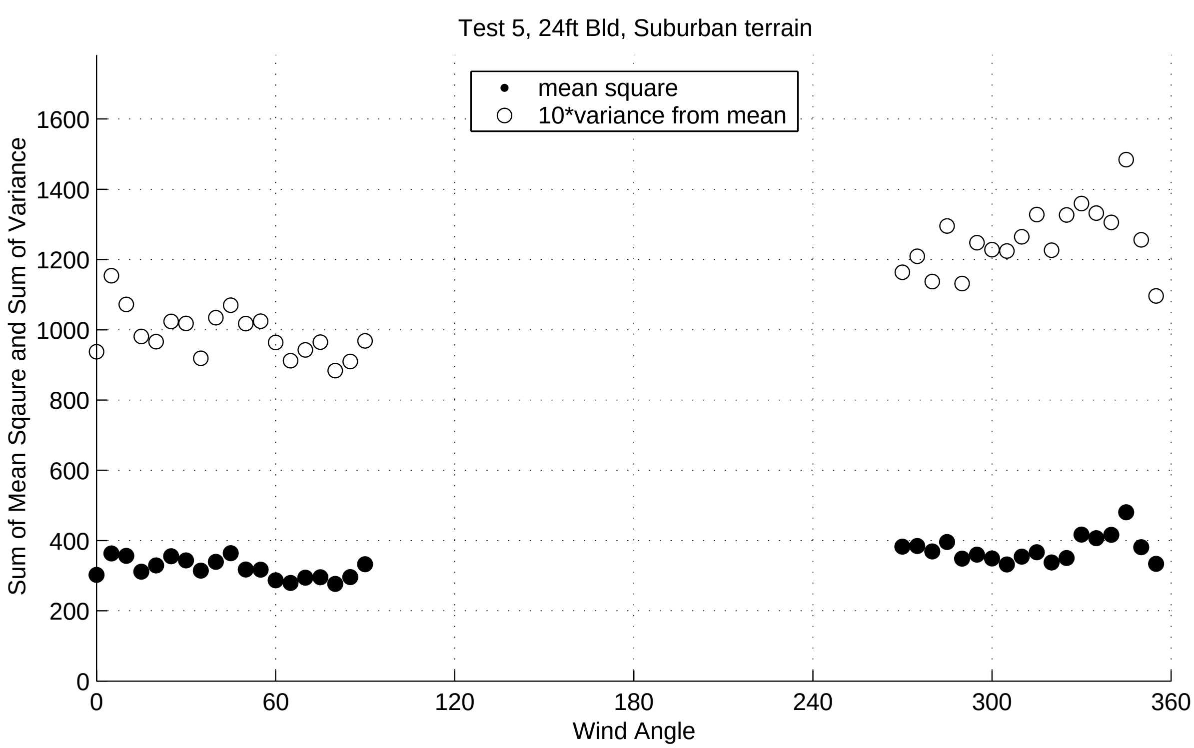

Test 5, 12ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
50
100
150
200
250
300
350
400
450
0
60
120
180
240
300
360

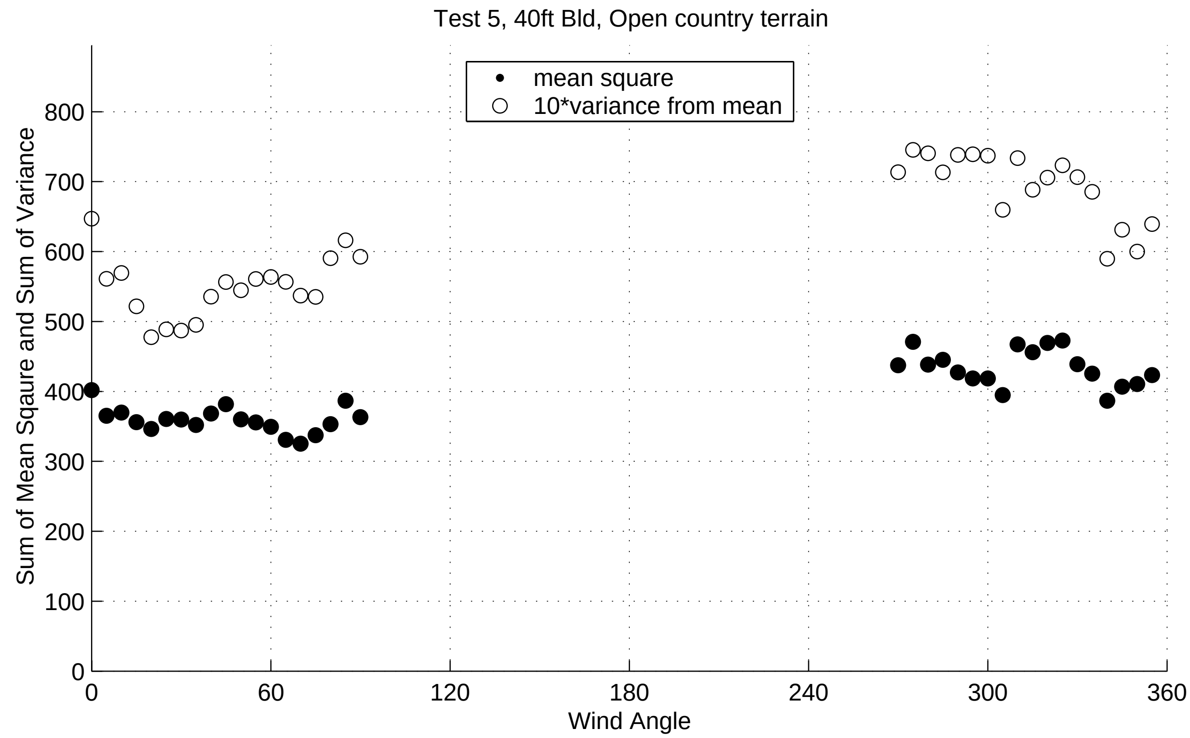

Test 5, 12ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
700
800
900
1000
0
60
120
180
240
300
360

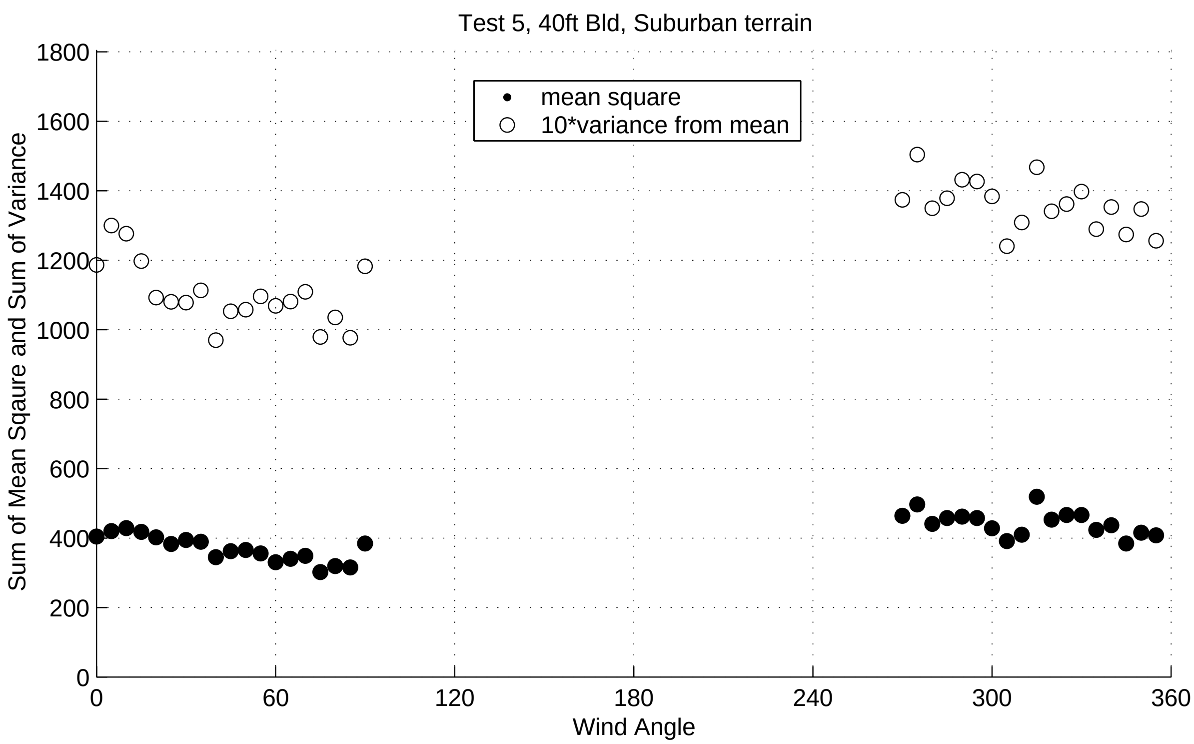

Test 5, 18ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
100
200
300
400
500
600
0
60
120
180
240
300
360
Wind Angle


Test 5, 18ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
0
200
400
600
800
1000
1200
1400
0
60
120
180
240
300
360
Wind Angle


Test 5, 24ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
700
600
500
400
300
200
100
0
0
60
120
180
240
300
360
Wind Angle


Test 5, 24ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
1600
1400
1200
1000
800
600
400
200
0
0
60
120
180
240
300
360
Wind Angle


Test 5, 40ft Bld, Open country terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
100
200
300
400
500
600
700
800
0
60
120
180
240
300
360


Test 5, 40ft Bld, Suburban terrain
mean square
10*variance from mean
Sum of Mean Sqaure and Sum of Variance
Wind Angle
0
200
400
600
800
1000
1200
1400
1600
1800
0
60
120
180
240
300
360