Measurement of wind-driven rain

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Introduction

It was established in a recent survey, carried out by the Centre for Window and Cladding Technology, Bath, U.K., that weathertightness was recognized as the problem of first priority by the industry. Weathertightness of building envelopes is affected by many factors, for example its design, joint detailing and workmanship. However it is also important to know the 'loading environment', i.e. the wind and the rain, for weathertightness design.
Wind and rain have been measured for centuries all around the world. Unfortunately their measurements and analysis were usually done separately and the resulting statistics and charts are un-related to one another. This paper describes a facility where wind, rain and wind-driven rain are monitored simultaneously. Some preliminary results on the characteristics of wind-driven rain are also presented.

Wind and wind-driven rain measurement in Singapore

A wind-driven rain measuring station has been set-up inside the campus of the University. The site is about 40m square and located on a small piece of flat land. Monitoring devices are set-up to record wind speed, wind direction, rainfall intensity and wind-driven rain intensities.

Wind measurements :- A 20 metre tall mast is installed at the centre of the site with five levels of anemometers mounted on the mast for wind speed measurements. Wind direction sensors are also installed at three levels. The cup type anemometer is used in the present study.

Rain and wind-driven rain measurements :- For the measurement of wind-driven rain, a special wind-driven rain measuring device has to be constructed. The function of the device is to capture and monitor the amount of rain (driven by wind) impinging onto vertical surfaces. The tricky part of the design is that, on the one hand the device is needed to capture the wind-driven rain but on the other hand the device is not to obstruct the wind. A wind-driven rain tower was designed by the author and was first constructed and installed in CSIRO, Sydney. A modified version of the design is used in the present study. The wind-driven rain tower is a square column of about 3m in height. At the top portion of the tower are five openings; one horizontal to capture the rain falling on the horizontal surface (the normal rainfall), and four vertical openings facing north, east, south and west respectively to capture the wind-driven rain falling on the vertical planes. There are flow paths inter-connecting the openings such that the wind can blow through the tower.

Although the immediate surrounding of the site is quite open (with the exception of some trees towards the north-east), further away there are low-rise and high-rise buildings. The following gives a brief description of the site environment. Towards its west and north is the open space of the sports field. Towards its south, it is also quite open with the land gently sloping downwards and with the general terrain slightly below the site. In all these directions, there are isolated low-rise buildings beyond the open space. Towards its east, immediately it is quite open but further upstream there are groups of 12-storey high residential buildings.

All the wind and rain data are being monitored continuously and recorded by a data-logger. Normally when it is not raining, data are monitored at one second intervals and the statistics of the data (mean, standard deviations, maximum and minimum wind speeds) are recorded at one hour intervals. When it is raining data statistics of the wind and data of the normal and wind-driven rain intensities are recorded at one minute intervals. In the event of strong gusts (instantaneous wind speed more than 10m/s), data are monitored at 0.25 second intervals and data statistics are recorded at 30-second intervals.

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Observations

Analysis is carried out on a data-base which contains the simultaneous recordings of wind (speeds and directions), rain and wind-driven rain. Some preliminary observations are described as follows.

Figure 1 shows the result of a typical rain storm with higher rainfall intensities. The normal (rain fall onto a horizontal surface) rainfall, and the wind-driven rain (w.d.r.) intensities captured by the four wind-driven rain gauges for the sixty-minute duration are plotted. The rain and w.d.r. for each and every minute are expressed as the equivalent mean hourly intensity. It can be seen that there are two bulks of rain, the first 15 minutes and from 20-50 minutes. The highest rainfall is at about the thirty third minute with an equivalent intensity of more than 100mm/hr. Looking at the w.d.r., during the first bulk of rainfall, the north facing and the west facing gauges are observed to capture the most w.d.r. with the west slightly larger. During the second bulk of rainfall, the north facing gauge captured by far the largest amount of w.d.r. Those captured by the west facing gauge is much smaller. The other two gauges, the south facing and the east facing ones captured very little w.d.r. What small amounts being recorded were the result of the high level of turbulence during the rain storm.

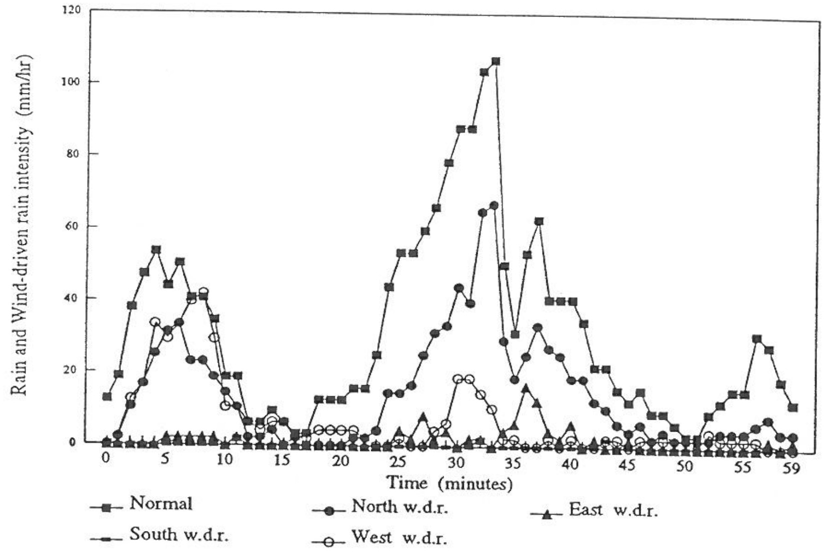

Figure 1 Rain and wind-driven rain intensities

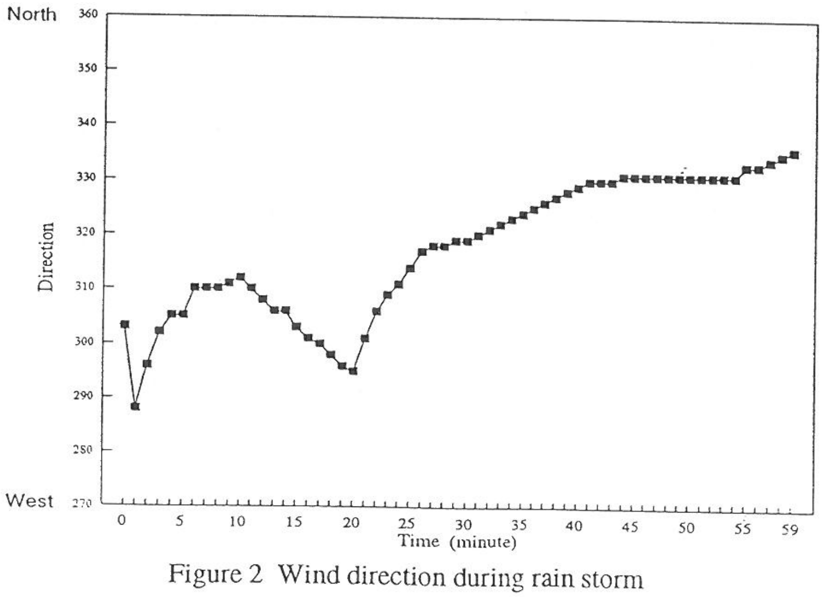

Figure 2 Wind direction during rain storm

The amount of w.d.r. captured by the various gauges is directly related to the direction of the wind which is shown in Figure 2. The wind direction was predominantly from the north-west. During the first 20 minutes, it was more west than north but became more north towards the later part of the hour. This explains the pattern of w.d.r. captured by the north and west facing gauges.

Another factor which affects the amount of w.d.r. is the wind speed. The higher the wind speed the more slanting is the raindrop trajectory and the higher will be the w.d.r. intensity. Figure 3 shows the wind speeds during the hour of rain storm. Plotted in the figure are the minute-mean (1 minute averaging period) wind speed at 10m height, minute-mean wind speed at w.d.r. gauge height and the maximum gust speed (during the minute) at w.d.r. gauge height. It can be seen that the 10m wind speed is larger than that of the gauge height (2.6m), but the gauge height gust speed is the larger of the three. Although their values are different, their variations are very similar, with perhaps more fluctuations of the gust speed. They all show increase in wind speed in the first 8 minutes and then the wind speeds dropped to almost zero at the twenty second minute. Then another increase and decrease in wind speeds in the next 30 minutes. It is interesting to note that the variations in wind speeds tie in with the variations in rainfall. This suggests a strong correlation in wind speed and rainfall intensity during the storm.

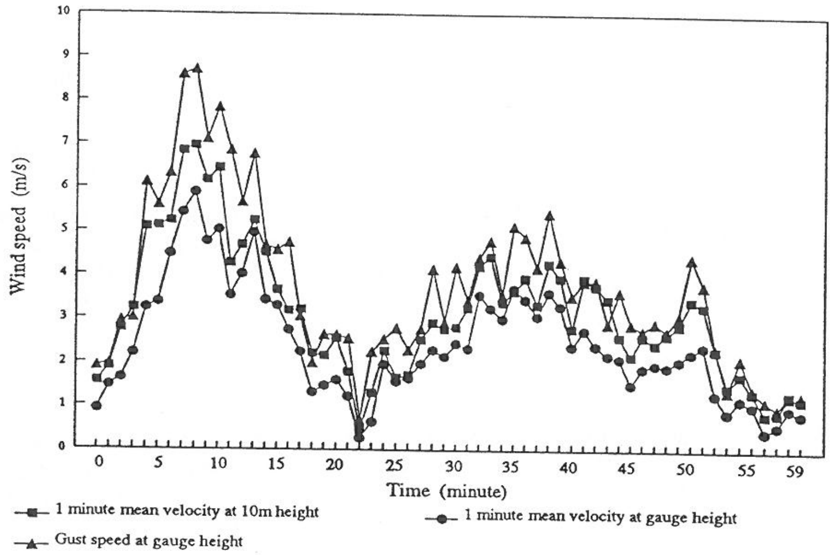

Figure 3 Wind speeds during rain storm

In studying rainfall, one of the important aspects is to study its intensity-duration relationship. Intensity-duration analysis was carried out on the rainfall record. The result for the storm is shown in Figure 4 where the maximum mean intensity of duration (T) is plotted against the duration T.

Using the usual logarithmic plot of the duration, the trend of increasing intensity with decrease of duration as expected, can be observed. Similar analysis was carried out on the record of the north facing w.d.r. gauge. As shown in Figure 4, it has a similar trend of variation.

At a given direction, the amount of w.d.r. is a function of the normal rainfall and the wind speed in that direction. Studies on the relationship of w.d.r. with wind and rain[1] indicated that w.d.r. can be expressed by the following equation

$$I_d = C_{dr} I_h U \quad (1)$$

where

I_d is the w.d.r. intensity, I_h is the intensity of the normal rainfall, U is the wind speed in the direction concern and C_{dr} is the driving-rain intensity coefficient.

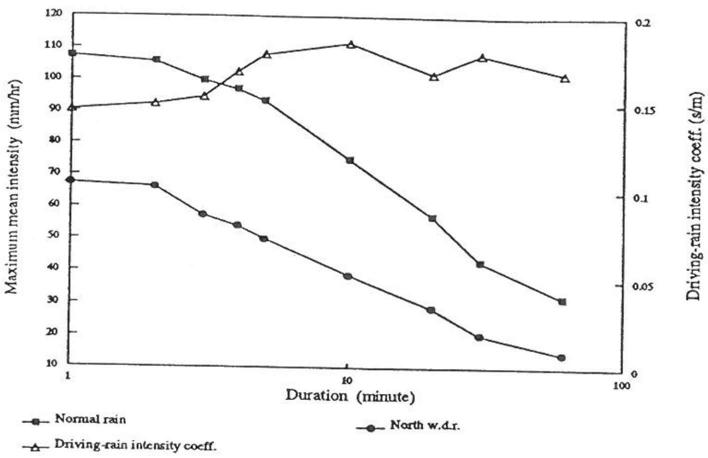

Figure 4 Rain and wind-driven rain intensity-duration relationship

It was reported that the driving-rain intensity coefficient is a function of drop size distribution of the rainfall which depends on the type and intensity of the rain storm. Using the drop size distribution model of Best, the value of C_{dr} was calculated to be around 0.15 to 0.21[1].

From Figure 4, at a given duration, the relationship between the intensity of the North w.d.r. and the product of the normal rainfall intensity and the north wind speed component at gauge height (mean of the duration) can be evaluated. The relational constant is the driving-rain coefficient. This coefficient for various durations are also plotted in Figure 4. Its value varies from 0.146 to 0.185 with a mean value of 0.166. These values confirm the finding of [1].

Conclusion

This paper describes the set-up of a wind-driven rain monitoring station. Preliminary results on wind-driven rain of a storm is also reported. It is observed that rain and wind are correlated during the storm. Wind-driven rain intensity is found to be directly proportional to the normal rainfall intensity and the wind velocity of the direction. The proportionality constant is calculated to be 0.166.

References

1 Choi, E. C. C. (1994), 'Characteristics of the co-occurrence of wind and rain and the driving-rain index', Journal of Wind Engineering and Industrial Aerodynamics, No.53, pp49-62.