Limit state winds for a Wellington site calculated from pressure gradient data

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Summary

Unlike conditions in the open seas where wind speed is approximately proportional to the pressure gradient, in Cook Strait wind speed has a markedly non-linear relationship with the pressure gradient. This has the effect that wind speeds tend to be high in Cook Strait under moderate pressure gradients but with extreme gradients the wind speeds may be less than values on open coasts. Pressure data offers an independent source for calculating speed values at a range of return periods. These are in approximate agreement with values in NZS 4203 but the agreement is affected by the non-linearity of the relation.

Introduction

Cook Strait is noted for its high frequency of strong winds. The strongest wind speeds recorded by anemometers close to the strait have been from a southerly direction during the Wahine storm (10/4/68). The wind speeds which may realistically be expected in future extreme storms in Cook Strait are important for many purposes. This paper presents a method for combining wind and pressure data from meteorological stations to infer extreme winds about Cook Strait. Because of the importance of winds at long return periods for design and risk studies, the results have been compared with the data previously inferred from station data and published in NZS 4203 (1992).

Wind data

Wind data, in the Cook Strait area, are available from the land stations shown in Fig. 1. These data, at coastal and island sites, have the advantage over ship reports of being made using instruments which can be kept in the same place on a stable structure for a prolonged period. However, sea cliffs can have major effects on the wind speeds not only when the measurement site is on top of the cliff but also when the cliff is alongside or even behind the instrument. Also, few of the stations in Fig.1 have data which are available over a long time or do not have substantial gaps. Additionally, mean speed data, even when complete, consists of averages over 10 minutes at hourly intervals so the sampling is only over part of the time. Wellington Airport or Kaukau have the longest and most useful data sets.

Pressure gradients and surface winds

A previous analysis to determine extreme wind speeds on the New Zealand coast (Reid, 1981) used analyses of maximum pressure differences between coastal stations. The pressure differences could be used to obtain the onshore wind speed by means of the geostrophic relation. In this way, problems of obtaining suitable coastal wind measurements and difficulties in maintaining wind observations in extreme conditions could be overcome through the use of pressure data . The winds which were determined were directed onshore and were regarded as applicable to points between the pressure-measuring stations. The pressure difference between Wellington and Christchurch was used and was compared with winds at Kaikoura. In this case, high pressure gradient occurrences did not bear a strong relationship to the associated wind speeds at Kaikoura. A somewhat surprising finding of the 1981 study was that, based on the data available at that time (17-year periods up to 1978 were used), intense onshore pressure gradients were less frequent on this section of coast than on to the northern and southern extremities of the country. The Wahine storm produced very large gradients but there were comparatively few other occurrences above the threshold used.

Unlike the situation over the open seas where winds tend to be parallel to the isobars (lines of constant pressure), the flow into Cook Strait is mainly across the isobars. This is because the speed and direction of the wind has to change a lot near Cook Strait due to obstructing mountain ranges. The required accelerations are obtained from the flow accelerating down the pressure gradient. In Cook Strait, the method of using the onshore pressure gradient will not give correct predictions of wind speeds because accelerations of the flow produce conditions which are far from geostrophic. However, if the equations which include acceleration can be applied, the method of using the pressure differences can be made applicable.

Analyses of Cook Strait pressure data (Reid, 1996) showed that the major contributions to the pressure gradients are generally from the differences between stations in the north/south direction or across the ranges. The east/west pressure differences had a smaller influence on the magnitudes of the gradients but had a strong effect on the directions of the gradients. In the narrows of the strait, analysis of the cross-wind balance of forces showed that there was a forcing acting towards the South Island in both northerlies and southerlies. This seemed to correspond to a curvature of the flow around the northeast corner of the South Island. Pressure gradients in the area between Cape Campbell and Wellington were found to be unusual in that there was little consistency in their directions, possibly because they have a role in reorienting wind directions through Cook Strait. An important feature of the balance of forces in the along-wind direction was that the same pressure gradient was associated with a higher wind speed in southerlies than in northerlies, suggesting lower accelerations with the southerly i.e. the speed has reached its highest point before it enters the Strait. It has been found that the pressure drop along the Kaikoura coast applied in Bernoulli's equation is quite a good predictor of wind speed.

In Fig. 2, pressure difference data between the station pair Kaikoura/Wellington has been used as a predictor and plotted against the simultaneous wind speeds at Kaukau for southerly winds. Unfortunately, data from Cape Campbell (which has a better proximity to the Kaikoura coast and would have been a better station to use) is not as complete as that from Kaikoura, Wellington and Christchurch and has not been used. The pressure difference can be negative or positive but for southerly wind directions is mostly positive. The data not only consists of values from the one year period (1 April 1993 - 31 March 1994) used by Reid (1996) but has been supplemented with additional data to better define the high wind speed end of the relationship. Data from the years 1980 - 1986 have been used to define the variation at about 20 m/s and data from the period 1970 - 1980 have been used to improve the definition at speeds in the range 25 to 30 m/s. Whereas the low speed data are not inconsistent with a linear relation between the speed and the pressure difference, there is considerable curvature suggested by the high speed data and the data have been found to be well fitted by a quadratic function.

EXTREME WINDS

Extreme value analyses made here have been based on the work of Gumbel (1958). The method depends on the largest events in the series being measured to a reasonable accuracy. An intermittent series of observations, or one in which the magnitude of the maxima is doubtful, is clearly not suitable. The longest available complete data series are the pressures at Christchurch and Wellington. The annual maximum pressure differences between Christchurch and

Wellington have been used to determine the extremes. The data are plotted as ranked values against the reduced variate y, where

$$y=-ln(-ln(1-1/T)) \qquad (1)$$

T is the return period of the speed value and is determined from Gringorten (1963)

$$T=(N+0.12)/(i-0.44) \qquad (2)$$

where N is the number of years of data and i is the rank of the speed value. The return periods of 5, 20, 50 and 350 years correspond approximately to reduced variates of 1.5, 3.0, 3.9, and 5.9, respectively. The plotted data and a best fit line are shown in Fig. 3.

Values of the pressure difference between Christchurch and Wellington have been evaluated from Fig. 3 at return periods of 5, 20, 50 and 350 years. These are return periods used in engineering design for a variety of types of structure and have corresponding pressure difference values which are equalled or exceeded at average intervals of the return period. These values are in the fourth column of Table 1. The pressure differences between Kaikoura and Wellington are closely related to the Christchurch to Wellington values and are in the third column of Table 1. The corresponding wind speeds from the fitted curve in Fig.2 multiplied by an appropriate gust factor (1.33) are in the left hand side of column five.

The wind speeds obtained in Table 1 may be compared with design code values given by NZS 4203 (1992) (henceforth called the code). The latter apply to all places in an area but the code is specific enough that the value for Kaukau may be compared directly with the code value multiplied by topography and height factors (both about 1.23). The resulting data are in the right hand side of column five. They are close to the observed values but are less than the observations at the low return periods.

CONCLUSIONS

Theory suggests and observations confirm a relation between wind and pressure gradients in Cook Strait fitted with a quadratic relation and this helps explain the unusual wind climate of Wellington, where quite high winds occur frequently. Gust wind speeds at a return period of 350 years, which are important for engineering design, are found to be 65 m/s at Kaukau. This is vclose to the value obtained from the code.

REFERENCES

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Gumbel, E.J. 1958: Statistics of extremes. New York, Columbia University Press.

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Reid, S.J., 1981: Extreme winds over the seas around New Zealand. *New Zealand Journal of Science,* **24**, 51-58.

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Table 1: Pressure differences at selected return periods and the corresponding speeds at Kaukau using best-fit curve.

Return period (years)	Reduced variate	Pressure difference P(KI)-P(WN) (hPa)	Pressure difference P(CH)-P(WN) (hPa)	Speed at Kaukau (m/s)	
				obs	code
5	1.50	10.3	14.0	50	47
20	2.97	13.0	17.6	56	53
50	3.90	14.7	19.8	60	58
350	5.86	18.1	24.4	65	66

FIGURES

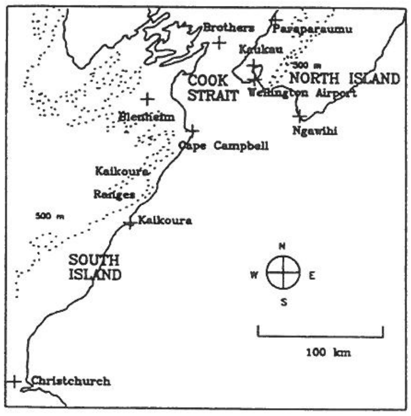

Fig. 1 : The positions of the meteorological stations in and around Cook Strait. The 500 m contour is shown.

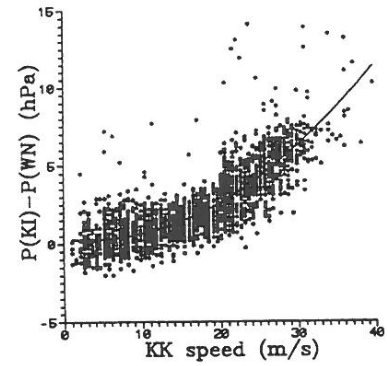

Fig. 2: Scatter plot of pressure differences between Kaikoura and Wellington versus Kaukau Second degree polynomial curves of best fit are drawn through the points. Data period 1970 - 1994 (see text).

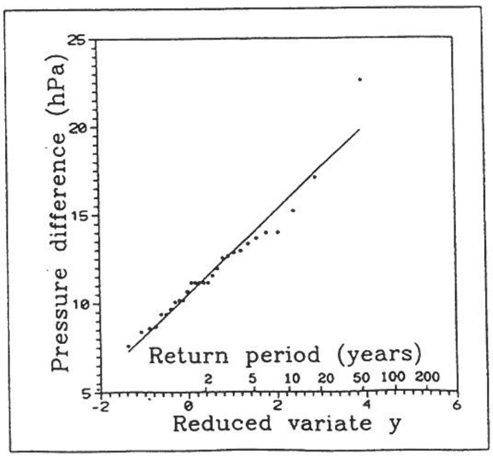

Fig. 3: Extreme value plot of annual maximum pressure differences Christchurch - Wellington. The data have been placed in order of magnitude and plotted against the reduced variate y (see text). Data period 1960 - 1994.