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CLIMATOLOGICAL SERVICES: CLIMATOLOGICAL MEMORANDUM No.6

Extreme Wind Speeds over Great Britain and N. Ireland

By H. C Shellard, B.Sc.

Introduction

Requests are frequently received from design or consulting engineers for information on the maximum wind velocities which are to be expected in various parts of the country. This information is needed in order to calculate the greatest wind pressures which may affect a given structure so that this structure, (which may be a tall building, a chimney stack, a tower, a bridge etc.), can be designed to withstand such pressures. Thus the engineer requires from the climatologist estimates of the probable maximum velocity for a specified interval and the probable maximum gust at a given place and height above the ground.

The climatologist has at his disposal the anemograph records* from a network of stations which may cover the country more or less adequately, although there may be important gaps. In the past the usual procedure has been to examine the wind records from the station, or stations, nearest to the site and to take out the highest speeds so far recorded. These have then been adjusted, using the appropriate velocity/height relations, [1,2] so as to be representative of the desired height above the ground (which may be several hundreds of feet), and an approximate allowance made for difference in exposure. The anemograph will normally be on a fairly open and level site while the proposed structure may be sheltered by other buildings etc. or may be on a hill-top.

Objections to the procedure outlined above are, first, that the absolute extreme value tends to increase as the length of record increases, whereas the periods over which wind records in this country are available vary from less than 10 years to a little over 40 years; and second, that it is statistically unsound to try to estimate the largest possible value without regard to the frequency with which very high values are likely to occur. What is really required is an estimate of the probability of occurrence of extreme values based not on one extreme alone but on all the values available. This should enable the engineer to design his structure economically on the basis of a calculated risk i.e. that it would fail within a specified time interval, say 100 years. The requirement can be met by applying to the data the statistical theory of extreme values, as developed by Gumbel[3] and others.

Application of extreme probability theory to annual extreme wind speeds

Table I lists the highest gust speeds in m.p.h. recorded at Cardington in the years 1932-1954 inclusive, arranged in order of size from the smallest to the largest. The fourth column gives the corresponding values of $\frac{m}{n+1}$ where m is the rank and n the number of observations, in this case 23; they provide plotting positions for use on extreme probability graph paper and may be regarded as representing the frequencies with which the corresponding values of x (highest gust) are not exceeded. Extreme value probability graph paper has a uniform scale along one axis, usually the vertical. This is used for the observed values. The horizontal axis is the probability scale and it is marked according to the formula $y = -\log_e(-\log_e p)$. On this scale the limiting values $p = 0$ and $p = 1$ are never reached but if $p = .01$ were taken as $y = 0$ then $p = .50$ would be 2.034 units, $p = .90$ would

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* All the records used in this paper are those of pressure tube anemographs.

be 6.963 units and p = .9999 would be 10.877 units to the right of the origin. If a set of extreme values conforms to Gumbel's theory, then when those values are plotted against $p = \frac{m}{n-1}$ on extreme value probability paper the points obtained will lie along a straight line. If extreme value probability paper is not available then values of $y = -\log_e(\log_e p)$ can either be computed or taken from published tables [4]. The extremes can then be plotted against y on ordinary graph paper. Values of y for the set of highest gust data from Cardington are given in the last column of Table I and Fig.1 shows the plotted data for both the highest gusts and the highest mean hourly speeds recorded at that station during the years 1932-1954 inclusive. Both the p and y scales are shown and also that of T, the return period in years, which is equal to $\frac{1}{1-p}$. This is the average time interval between recurrences of an event and is useful because it allows the annual maximum value which may be expected to be exceeded on the average only once in any desired number of years to be read off directly from the graph.

It can be seen from Fig.1 that the Cardington wind data fit the theory quite well and the fitted straight lines have been computed and drawn in. The lines on either side are called control curves and they indicate the limits between which each extreme value should lie with a probability of .68, the theory being accepted if all the observations lie between them. By extrapolating the fitted straight line it is possible to predict the return period corresponding to any desired speed or the speed which has any desired return period. With only 20 to 30 years of record available it would probably be unwise to carry the extrapolation very far, certainly not beyond 100 years. Thus from Fig.1 it may be inferred that the speeds which are likely to be exceeded only once in 50 years are 103 m.p.h. in a gust and 66 m.p.h. averaged over one hour. These speeds relate to the effective height of the Cardington anemograph, i.e. 135 feet above the ground.

Results. The wind data from 48 anemograph stations have been analysed in this way and the results are set out in Table II, which refers to mean hourly speeds and Table III, which refers to gust speeds. In every case the values refer to a height of 10 metres (33 feet) above the ground and have been reduced to that level using the formulae $v_{10} = v_h \cdot \left[\frac{10}{h}\right]^{0.17}$ for mean speeds[5] and $v_{10} = v_h \cdot \left[\frac{10}{h}\right]^{0.085}$ for gusts,[6] where h is the effective height of the anemograph. The highest speeds on record, up to December 1954, the mean annual maxima and the number of years of the record are also given.

The highest mean hourly speeds at 10 metres (33 ft.) likely to be exceeded only once in 50 years are plotted in Fig.2 on a map of the British Isles on which tentative isopleths at intervals of 10 m.p.h. have been drawn in to show the general distribution. Fig. 3 has been drawn similarly to show the general distribution of gust speeds likely to be exceeded only once in 50 years. It must be emphasised that extreme wind speeds are greatly dependent on local topography and that these maps only represent a broad picture based on wind observations which, generally speaking, relate to open and level sites. Such maps must therefore be used with great caution, as values interpolated from them may need considerable adjustment in the light of a study of the actual exposure of any specified location. Nevertheless it is considered that Fig.3 is more satisfactory than a map which is simply based on the highest recorded gusts such as the one in Reference 7.

It should be pointed out that the current Code of Practice concerned with the calculation of wind pressures on buildings requires the use of the highest expected mean wind speed over one minute. The records from standard anemographs have too close a time scale for means to be measured over such a short period, however, and the available statistics are limited to means over one hour, together with details of the highest gusts. The highest mean over one minute will clearly lie somewhere between the highest hourly mean wind and the highest gust - the duration of a gust being of the order of a second. An examination by G.A. Bull (unpublished) of special anemograph records (obtained at Cardington), which had a much more open time scale, has shown that the highest one minute mean lies much nearer to the highest hourly mean than it does to the highest gust and that it can be taken approximately as the highest hourly mean plus 10 m.p.h.

NOTE on Tables II and III

The columns "Highest on record" refer to the period up to December, 1954.

References

1. London, Meteorological Office. Observer's Handbook, M.O.554, 1952, p.72.

2. Bilham; E.G.; Notes on extreme gusts recorded in the British Isles. Unpublished 1938.

3. Gumbel, E.J.; Statistical theory of extreme values and some practical applications. Appl. Math. Ser. U.S. Bur. Stand., Washington D.C. No.33, 1954.

4. U.S. Bur. Stand. Washington D.C. Probability Tables for the analysis of extreme value data. Appl. Math. Ser. No.22, 1953.

5. Carruthers, N.; Variations in wind velocity near the ground. Q.J.R. Met. Soc.69, 1943, p.293.

6. Deacon, E.L.; Gust variation with height up to 150m. Q.J.R. Met. Soc.81, 1955, p.562.

7. London, Meteorological Office. Climatological Atlas of the British Isles, M.O.488, 1952, p.20.

8. British Standard Code of Practice C.P. 3 Chapter V (1952), Code of functional requirements of buildings. Chapter 5, Loading, p.22.

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Table I

ANNUAL MAXIMUM WIND SPEEDS (GUSTS) AT CARDINGTON, 1932–54				
RANK m	HIGHEST GUST x m.p.h.	YEAR	PLOTTING POSITION $p = \frac{m}{N+1}$	REDUCED VARIATE $y = -\log_e(-\log_e p)$
1	55	1953	0·042	−1·16
2	59	1950	0·083	−0·91
3	60	1941	0·125	−0·73
4	61	1951	0·167	−0·58
5	62	1952	0·208	−0·45
6	63	1937	0·250	−0·33
7	63	1939	0·292	−0·21
8	64	1942	0·333	−0·09
9	65	1933	0·375	0·02
10	67	1949	0·417	0·13
11	68	1948	0·458	0·25
12	69	1945	0·500	0·37
13	71	1940	0·542	0·49
14	72	1934	0·583	0·62
15	72	1944	0·625	0·75
16	76	1954	0·667	0·90
17	78	1943	0·708	1·06
18	78	1946	0·750	1·25
19	81	1932	0·792	1·46
20	82	1936	0·833	1·70
21	86	1938	0·875	2·01
22	88	1935	0·917	2·44
23	93	1947	0·958	3·15

Table II - Maximum mean hourly wind speeds in m.p.h. at 33 feet above the ground

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years 10	20	50	100	Highest on record	Mean Annual Maximum
Lerwick	24	1931-54	67	70	75	79	73	57.7
Kirkwall	14	1930-43	58	61	65	69	59	50.1
Stornoway	18	1937-54	67	71	77	81	73	56.5
Aberdeen	15	1933-47	44	47	52	55	44	35.5
Balmakewan	21	1915-35	45	48	53	56	51	36.8
Bell Rock	25	1930-54	57	60	63	66	59	49.3
Edinburgh	38	(1915-33 (1936-54	56	59	63	65	59	49.5
Tiree	28	1927-54	62	67	73	77	64	51.5
Paisley	41	1914-54	41	43	46	48	43	36.2
Prestwick	11	1944-54	52	55	58	61	48	45.2
Eskdalemuir	32	1914-45	54	57	60	63	56	47.1
Point of Ayre	19	1936-54	59	63	67	71	63	49.9
Durham	17	1938-54	48	51	55	57	50	41.2
South Shields	21	1934-54	56	60	66	71	61	44.7
Catterick	10	1933-42	51	56	62	67	49	38.8
Spurn Head	29	(1922-46 (1948-50,54	56	59	62	65	59	50.1
Cranwell	23	(1928-42,44 (1947-48,50-54	47	50	54	57	49	38.7
Gorleston	36	(1913-31,34-39 (1941-46,48,51-54	50	53	57	59	55	43.8
Felixstowe	17	(1931-35,37-38 (1944-52,54	45	48	51	54	45	39.1
Mildenhall	17	1938-54	48	52	57	61	56	37.7
Cardington	23	1932-54	44	48	52	56	49	36.2
Shoeburyness	29	1926-54	46	49	52	55	43	39.7
Leicester	10	(1938-40,43-45 (1947-50	45	50	56	61	42	33.0
Birmingham	31	1924-54	38	40	43	46	38	31.7
London (Kingsway)	11	1944-54	37	40	43	46	34	29.7
Croydon	23	(1928-39 (1944-54	41	44	47	50	45	34.8
Kew Observatory	24	1931-54	33	34	36	38	34	28.9
Dover	21	(1924-39 (1948-50,53-54	44	45	48	50	46	39.1
Lympne	27	(1923-29,31-43 (1945-51	48	50	54	56	52	42.0
Manston	12	1943-54	46	48	51	54	45	39.6
Thorney Island	12	1943-54	43	46	50	53	45	36.2
Calshot	24	(1920,22-41 (1950-52	51	54	58	61	50	43.0
S. Farnborough	10	1945-54	50	55	62	68	49	36.8
Boscombe Down	22	1933-54	48	51	54	57	49	41.4
Larkhill	24	1931-54	46	48	51	53	46	40.6

Table II - Maximum mean hourly wind speeds in m.p.h. at 33 feet above the ground (Cont.)

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years 10	20	50	100	Highest on record	Mean Annual Maximum
Fleetwood	29	(1924-43 (1946-54	61	65	70	73	62	52.5
Manchester Airport	13	(1942-50 (1954	54	58	63	67	54	44.3
Southport	42	1913-54	60	63	68	71	65	51.0
Bidston	25	(1929-44 (1946-54	57	60	65	68	62	48.3
Sealand	19	(1928-41 (1943-47	49	52	56	59	53	41.4
Holyhead	19	1933-51	61	64	69	73	64	51.7
Aberporth	10	1945-54	56	60	66	70	56	45.4
St. Ann's Head	14	(1935-46 (1948-49	69	75	83	89	78	54.9
Plymouth	30	(1921-43 (1947-48,50-54	53	57	61	64	58	45.4
The Lizard	17	(1935-42,45-47 (1949-54	63	66	70	74	67	54.8
Pendennis Castle	20	(1929-38 (1941-50	65	68	72	75	67	58.2
Scilly	28	1927-54	62	66	71	75	67	53.1
Aldergrove	25	(1928-46 (1949-54	45	48	51	54	48	38.9

Table III - Maximum gust speeds in m.p.h. at 33 feet above the ground

Lerwick	24	1931-54	98	102	108	112	101	87.0
Kirkwall	14	1930-43	92	97	102	106	100	82.3
Stornoway	18	1937-54	103	110	119	126	107	85.7
Aberdeen	15	1933-47	78	83	89	93	83	67.8
Balmakewan	21	1915-35	76	82	89	94	87	62.8
Bell Rock	25	1930-54	90	95	101	106	91	77.2
Edinburgh	38	(1915-33 (1936-54	86	90	96	99	87	76.7
Tiree	28	1927-54	96	102	111	118	106	79.7
Paisley	41	1914-54	87	93	99	105	104	74.7
Prestwick	11	1944-54	87	92	98	103	85	74.9
Eskdalemuir	32	1914-45	88	93	100	105	91	75.3
Point of Ayre	19	1936-54	88	93	99	104	90	75.9
Durham	17	1938-54	90	96	102	107	95	78.1
South Shields	21	1934-54	84	90	97	103	86	70.8
Catterick	10	1933-42	86	92	99	105	88	71.1
Spurn Head	29	(1922-46 (1948-50,54	85	90	96	101	91	73.7
Cranwell	24	(1928-44 (1947-48,50-54	88	96	106	113	108	68.7
Corleston	36	(1914-31,34-39 (1941-48,51-54	76	80	86	90	82	66.2
Felixstowe	17	(1931-35,37-38 (1944-52,54	81	87	95	101	85	66.3
Mildenhall	17	1938-54	88	94	103	110	94	71.3

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Table III - Maximum gust speeds in m.p.h. at 33 feet above the ground (Cont.)

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years				Highest on record	Mean Annual Maximum
			10	20	50	100		
Cardington	23	1932-54	78	84	91	97	83	63.1
Shoeburyness	29	1926-54	75	79	85	90	79	64.2
Leicester	10	(1938-40 (1943-45,47-50	83	91	101	108	84	65.2
Birmingham	31	1924-54	75	80	87	92	79	63.3
London (Kingsway)	11	1944-54	79	86	95	102	77	61.3
Croydon	23	(1928-39 (1944-54	76	80	86	90	77	64.8
Kew Observatory	24	1931-54	71	74	79	83	71	61.9
Dover	21	(1924-39 (1948-50,53-54	74	78	84	88	85	63.5
Lympne	27	(1923-29,31-43 (1945-51	80	84	89	93	84	69.8
Manston	12	1943-54	78	82	87	91	80	68.1
Thorney Island	12	1943-54	79	83	89	94	81	68.3
Calshot	24	(1920,22-41 (1950-52	80	85	92	98	86	67.2
S. Farnborough	10	1945-54	78	82	89	93	79	66.0
Boscombe Down	22	1933-54	79	84	89	94	86	68.7
Larkhill	24	1931-54	78	82	86	90	80	70.2
Fleetwood	29	(1924-43 (1946-54	88	93	100	106	91	75.4
Manchester Airport	10	(1942-50 (1954	91	97	105	111	90	75.7
Southport	42	1913-54	89	94	101	106	93	76.5
Bidston	25	(1929-44 (1946-54	95	100	107	112	100	82.3
Sealand	18	(1928-41 (1944-47	82	87	93	97	86	70.7
Holyhead	19	1933-51	94	100	107	113	107	79.1
Aberporth	10	1945-54	93	100	110	117	92	75.2
St. Ann's Head	13	(1935-45 (1948-49	105	112	122	128	>107	88.3
Plymouth	30	(1921-43 (1947-48,50-54	80	85	92	97	91	67.2
The Lizard	17	(1935-42 (1945-47,49-54	93	97	101	105	94	84.7
Pendennis Castle	20	(1929-38 (1941-50	100	106	114	120	102	85.2
Scilly	28	1927-54	98	104	111	116	107	84.8
Aldergrove	25	(1928-46 (1949-54	83	88	94	99	87	71.5

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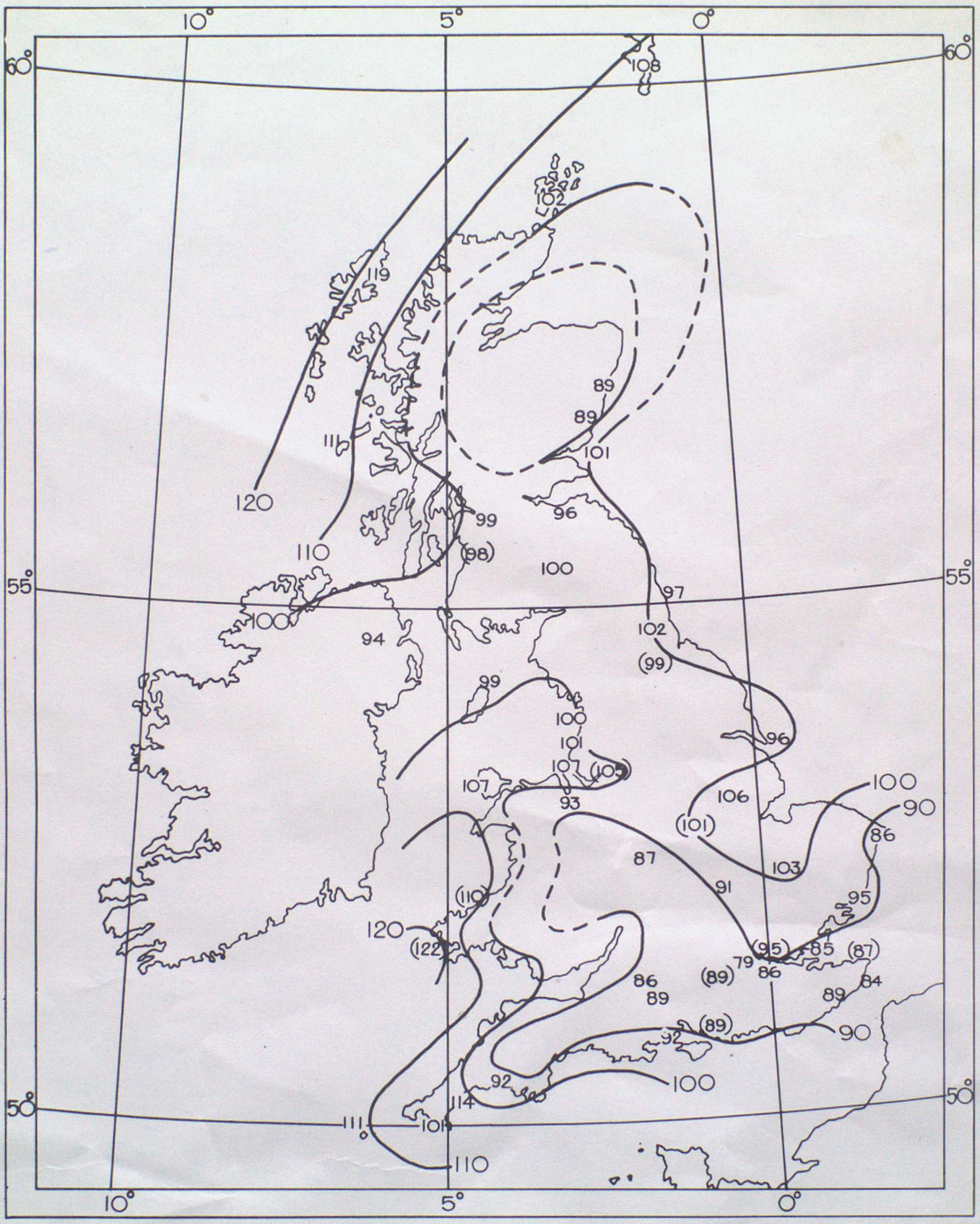


Fig.3 HIGHEST GUST SPEED AT 33 Ft. LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS M.P.H.
(VALUES BASED ON LESS THAN 15 YEARS OF RECORD BRACKETED)

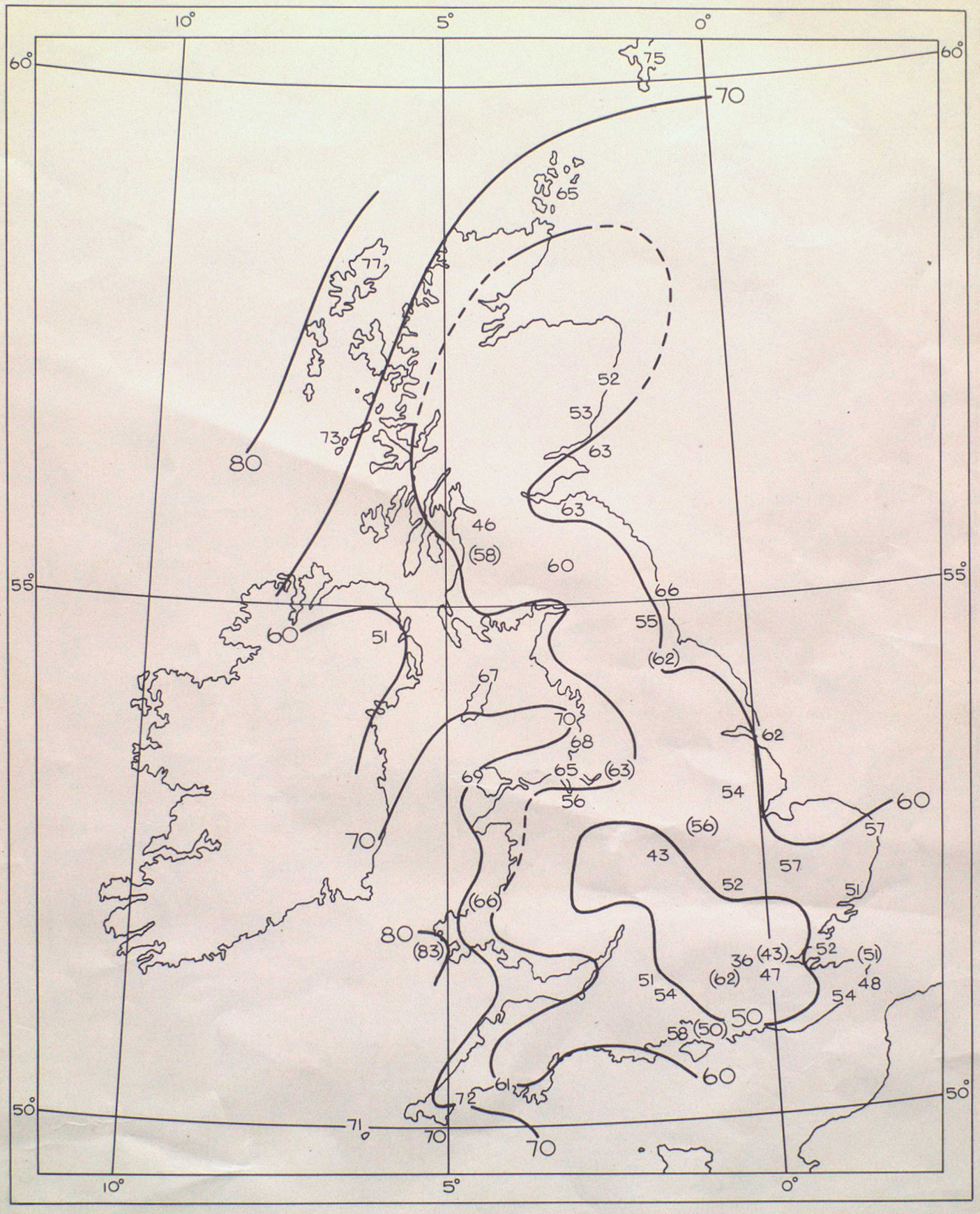
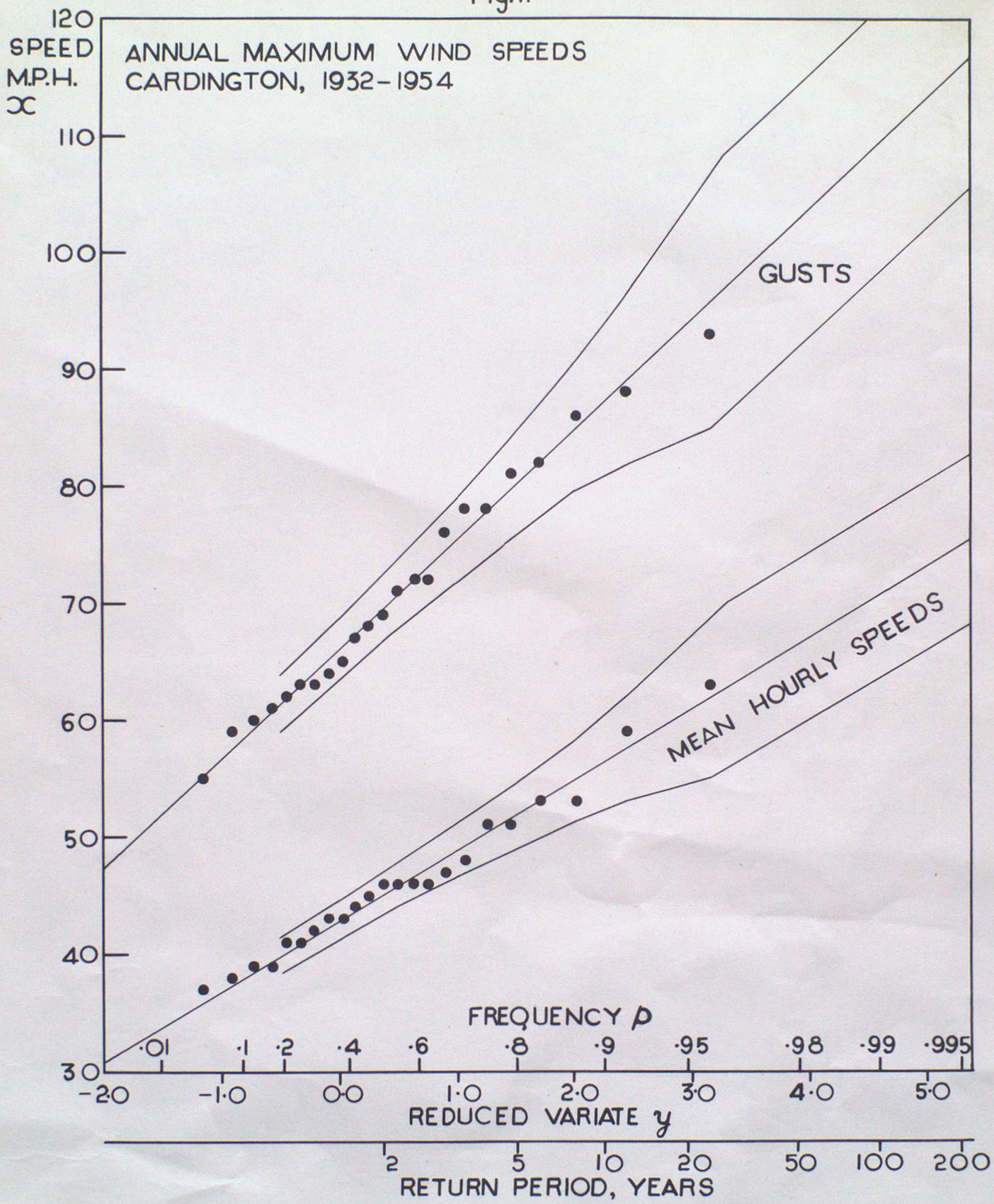


Fig. 2 HIGHEST MEAN HOURLY WIND SPEED AT 33 ft. LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS M.P.H.
(VALUES BASED ON LESS THAN 15 YEARS OF RECORD BRACKETED)

Fig.1.


ANNUAL MAXIMUM WIND SPEEDS
CARDINGTON, 1932-1954
SPEED M.P.H. x
120
110
100
90
80
70
60
50
40
30
GUSTS
MEAN HOURLY SPEEDS
FREQUENCY p
·01
·1
·2
·4
·6
·8
·9
·95
·98
·99
·995
-2·0
-1·0
0·0
1·0
2·0
3·0
4·0
5·0
REDUCED VARIATE y
2
5
10
20
50
100
200
RETURN PERIOD, YEARS