Paper 15

THE NATURE OF GUST LOADING ON TALL BUILDINGS

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Abstract

An account is given of the measurement of wind loads on a tall building in Central London. It is reported that local suction loads on cladding are more severe than had been indicated by wind tunnel tests in smooth flow. Face-on winds produce the maximum structural loading. Under these winds it is found that the whole load is carried by the windward face of the building, the load on the leeward face being negligible. The short duration structural loads are about 60% greater than the 1 minute averages that have been the basis of many codes of practice, but the overall drag coefficient in the natural wind appears to decrease as wind- and load-averaging times are decreased, and it is in consequence less for gust loading conditions than that usually assumed in wind load calculations based on model tests. These two effects largely balance each other.

In consequence the maximum overall loads on the structure are likely to be similar to those indicated by the British Code of Practice, but the cladding loads may be approximately twice as great as those given by the Code.

Résumé

Les auteurs rendent compte de la mesure des surcharges éoliennes contre des bâtiments élevés situés au centre de Londres. Ils exposent que les forces d'aspiration locales sur les revêtements sont bien plus grandes que ne l'avaient indiqué les essais en soufflerie à écoulement régulier. Ce sont les vents de front qui produisent sur les constructions la surcharge éolienne la plus forte. On a trouvé qu'en présence de ces vents la surcharge totale est supportée par la façade au vent, celle de la face sous le vent étant négligeable. Les surcharges éoliennes brèves contre la construction sont d'environ 60 pour cent plus fortes que la moyenne à la minute qui a servi de base à de nombreux Codes de construction; cependant le coefficient total de trainée sous le vent parait décroître en même temps que diminue la durée qui sert à l'établissement des moyennes de surcharges éoliennes et de vitesse de vent. Le coefficient total de trainée est par conséquent moindre dans le cas de rafales qu'il n'avait d'abord été estimé par des essais sur maquettes. Ces deux effets se contrebalancent.

Conséquemment la surcharge totale maximale de vent sur les constructions est vraisemblablement semblable à celle indiquée par le Code britannique de construction; par contre la surcharge sur les parements peut être approximativement double de celle indiquée par le Code.

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1. INTRODUCTION

The research reported in this paper stems from an investigation by the Building Research Station into the general problems of wind load on buildings. A survey in 1957 had revealed several serious gaps in the data available for the determination of wind loads in structural design. One of these related to tall buildings which, at that time, were beginning to be erected in the United Kingdom in considerable numbers.

The tall shape of these buildings, and the fact that they stood prominently above their neighbours into the wind stream, made the wind load of particular significance in the design; and the newer forms of lightweight construction then coming into fashion appeared to make these buildings especially susceptible to the effects of the wind.

It was therefore decided to concentrate a major part of the Station's work on wind loading on to the problem of tall buildings; and because relatively little was known of the effects of gustiness and turbulance in the natural wind, it was decided to carry out the work at full scale. It was further decided to make a direct comparison between the results of the full scale test and those from a wind tunnel test on a model of the actual building.

2. THE TEST BUILDING

After some enquiry among architects and building contractors a building project was discovered which appeared to be suitable, both as regards design and siting, for the measurement of wind pressures. At that time, in late

1960, the project was still on the drawing board, a prerequisite in an experiment such as this where considerable instrumentation has to be incorporated in the structure.

The building was to be an 18-storey office block having a rectangular plan with sides of 142 ft (42 m) and 58 ft (18 m) and with relatively smooth façades. The construction was to be in reinforced concrete with a curtain wall cladding, the wind load being taken by internal spines housing the lifts and stairways. The site was in the Barbican development in the City of London and had the experimental advantage of a relatively unobstructed wind from the west; while to the east and north-east several other buildings of similar height could be expected to make the wind from that quarter more turbulent and so provide a contrasting condition.

By courtesy of the architects, Messrs R. Seifert and Partners, and with their assistance, plans were made to install wind-pressure transducers in the cladding of the building, and to insert pressure tubes and cables through the mullions and ceiling spaces in phase with the construction of the building. The building was completed in 1963 and was occupied by the Royal Exchange Assurance who have kindly co-operated in the provision of facilities for the measurement of wind pressure. The building, now known as Royex House, is shown in Figure 1. The site plan showing the position of neighbouring tall buildings is Figure 2.

3. INSTRUMENTATION

The wind pressure transducers had been developed at the Building Research Station for this programme and were basically similar to those used in a pilot experiment and described in an earlier paper[1]. They had a natural frequency of about 70 c/sec and so were capable of recording the shortest transient loads thought to be of significance in this investigation.

Forty eight transducers were used. They were arranged in a similar assymetric pattern on each of the four faces of the building as shown in Figure 3, this pattern being adopted in the expectation that it would effectively increase the number of measuring positions on each face by the combination of results obtained when the wind was equally inclined on either side of the normal to the face. (In practice this did not work out well as very few suitable pairs of winds of comparable strength occurred during the recording periods.)

Each gauge (transducer) recorded the pressure difference between the face of the gauge (the outside of the cladding) and the pressure inside the gauge body. The gauge bodies were therefore connected by pressure tubes to a common reservoir, one reservoir for the 16 gauges at each floor level, to ensure that all those gauge readings were relative to a common back pressure. The reservoirs were open to atmosphere and located in the ceiling spaces near the centre of the building so as to be representative of the mean internal pressure in the building.

All the gauges were connected by cable to a central recording room where two 24-channel U.V. galvanometer recorders were housed. The two recorders were operated in synchronism and could be switched on under the control of a wind-operated switch at any pre-set level of wind speed. A clock-operated printer identified the time on the recorder charts so that wind-pressure records could be matched in time with the records of wind speed and direction obtained from the London Weather Centre which was about 1 mile to the west of the test building. The anemometer there was at about the same height as the top of Royex House. The instrumentation was completed during 1964.

4. WIND-PRESSURE RECORDINGS

Recordings of wind-pressure on the test building were made during the period 1964 to 1966, the recorder generally being set to switch on when wind speeds

exceeded 30 knots (15 m/sec). A polar diagram showing a representative selection of the winds for which pressure records were obtained is reproduced in Figure 4. It will be noted that the winds are predominantly from between west and south and between east and north. Hence the sparseness of pairs of comparable winds symmetrically inclined to the normals to the building faces, referred to in section 3.

The recorders were generally run at a paper speed of 1 mm/sec and recordings vary in length up to about half an hour. Only the more interesting portions have been measured however, and representative lengths analysed cover between ten and twenty minutes each. Short extracts from recordings showing the characteristics of the loading under winds (a) at a glancing angle and (b) direct on to a major face are shown in Figures 5a and 5b respectively.

A few records were run at a paper speed of 10 mm/sec in order to reveal in more detail the fine structure of the pressure variations.

Since the wind-pressure records were made relative to the pressure within the building, it was necessary for this to be assessed. This was done on several occasions and under various conditions of wind and temperature by means of an aneroid barometer capable of discrimination to 0.1mb. Comparison of the barometer reading at various floor levels with the reading taken on the ground outside, at a position well away from the effects of surrounding buildings, and after making the necessary height and temperature corrections, showed no measurable departure from atmospheric pressure under calm conditions; and only about 0.1 mb (about 0.2 lb/ft^2) positive on a very windy day. In view of the difficulty in obtaining an accurate barometric reading in a wind, this small positive indication is within the probable experimental error, and it was assumed that the pressure within the building was at all times atmospheric.

5. ANALYSIS OF RECORDS

Direct inspection of the wind-pressure recordings has proved most valuable as a first stage in the analysis, and has justified the adoption of this recording technique in spite of the greater convenience of magnetic tape recording as a first stage in data processing. For example, reference to Figure 5a shows at once how, in a southerly wind (bearing 190°) the local loadings on the east and west faces consist of a rapid succession of relatively short pulses of suction. The most severe suctions occur at the position 13W1, near the southerly end of the west face. In the four minutes of the extract reproduced (the upper scale gives time in seconds) there are 6 severe suction loads in addition to a great many of less intensity. At the 13th floor level, and at the 7th, the local peak loads, on both east and west faces are a maximum at the windward ends of the faces and fall off towards the northern ends. At the 17th floor, near the roof, however, the fall-off of local suction along the faces from south to north is much less marked. This is seen particularly clearly on the east face (gauges 17E4 to 17E1). It can also be seen how the peak suctions occur progressively later at successive positions along the face; and how, owing to the brevity of the loadings, peak suctions do not occur simultaneously over more than two adjacent gauge positions.

It is of interest to compare the effects of the southerly (glancing) wind with those of a wind that was blowing almost directly against the west face. A similar length of recording is shown in Figure 5b. The positive pressures on the west face are generally slower to build up and of longer duration than the loads under the glancing wind, and all except the shortest transients affect the whole face simultaneously. A significant feature is the relative quiet that exists on the east face. The pressures generally are not far from zero and only small brief transients, presumably due to turbulence, are to be seen.

The wind-pressure records were generally measured at 1 mm intervals; that is, second by second for most records, and at $^1/_{10}$ second intervals for the more open ones. The measurement was carried out on a Benson Lehner trace reader, by means of which the pressure values were punched on to paper tape for computer analysis.

The analysis was planned to provide data on two distinct aspects of the wind-load problem : (a) the local wind loads on cladding, and (b) the overall wind load on the building having regard to the structural design. Time has not yet permitted the complete analysis to be carried out, so attention has been concentrated on the major faces of the building, that is, the west and east faces, since these provide the critical data for the maximum overall wind load.

For each pressure-measuring position on the west and east faces, mean pressures over various periods of time from 1 second to 10 minutes have been computed as running means throughout the lengths of the measured recordings. These show the relative significance of different wind-averaging periods for a range of conditions of wind incidence. The local loadings, which of course are significant for the design of cladding and its fixings, will be considered first.

5.1 Local loadings

As mentioned earlier, visual inspection of the wind-pressure recordings had made it apparent that the most severe loadings on cladding occurred under the incidence of glancing winds, and in consequence several of these were examined.

Characteristic plots showing the distribution of maximum 3-second-mean suction loads (not necessarily occurring simultaneously) on both west and east faces under a range of glancing winds from approximately north and south are shown in Figures 6 and 7. These portray clearly the features noted from the visual inspection of the recordings, namely that the highest local suctions occur at the leading edge of the face but well below the top of the building.

There is an interesting difference to be noted between effects of the northerly and southerly winds. The former are relatively unobstructed by tall buildings in their approach to Royex House whereas the latter are considerably modified by the large building just to the south (see Figure 2). This building, which was not shown in the site development plan, was erected after preparation for the wind-pressure measurements had begun. It has complicated the immediate environment, but some advantage can now be taken of its presence. It is found that the effect of the obstruction has been to reduce the suctions due to a 49 m.p.h. (22 m/sec) southerly wind to about the same level as those due to a 34 m.p.h. (15 m/sec) northerly wind. Moreover, in the lee of the obstruction, the suctions fall off considerably on the lower parts of the building as compared with those due to the northerly wind.

The extreme positive and negative pressures, averaged over 3 seconds and 60 seconds, measured on the east and west faces under a northerly (25°) wind are shown in more conventional form in Figure 8 for each of the three floor levels at which measurements were taken. Also included are curves corresponding to the pressure coefficients obtained on a model of Royex House tested at the National Physical Laboratory(2) in a wind tunnel having a vertical wind gradient simulating the natural wind, but without turbulence. The N.P.L. pressure coefficients have been converted to pressures on the basis of the 60 second mean speed of the natural wind. It can be seen that there is reasonable agreement between the model results and the full scale on the basis of the 60 second mean wind, but that the short gusts in the natural wind have produced a distribution of local suction under the glancing wind that is not at all indicated in the model tests. Peak suctions (3-second mean) having coefficients of -1.5 and -1.6 are indicated.

The effect of averaging time on the local loadings is shown in Figure 9 for a wind gusting to 46 m.p.h. (21 m/sec) from 190°. The diagram is for gauge position 13W1 but is typical for cladding near the leading edge of a face under a glancing wind. The important feature is the large increase in the suction loading as the averaging time is decreased. Compared with the 1 minute loading, the suction averaged over 15 seconds is 1.6 times as great; the 3 second suction is up by a factor of 3.2; and the 1 second suction by a factor of 5.7. Based on the 3 second gust speed, the effective pressure coefficient for the 3 second loading is -1.25, but a pressure coefficient of -2.2 would be required to indicate the peak suction relative to the measured gust speed.

It is interesting to note that, owing to the turbulent character of the wind, there is in fact some occasional positive pressure at this position even when it is primarily subject to a glancing wind : but the positive pressures are small and brief and reduce to zero when averaged over 40 seconds. The fact that they occur at all emphasizes the surging character of the wind and the need for secure fastening of cladding, especially at these near-corner positions.

5.2 <u>Overall structural loadings</u>

The overall wind loading on the building and on various parts of it has been derived from the summation of the simultaneous local loadings on areas around each of the pressure measuring positions. Only winds approximately normal to the major faces have been used in this part of the study. The summation has been carried out in various stages to give (a) the loading on one-foot-high slices of each face at the 7th, 13th and 17th floor levels; (b) the total simultaneous load on the windward and leeward faces together at each of these floor levels; (c) the total load on each complete face; and (d) the total load measured simultaneously for the whole building. In cases (a) and (c) the loads have been computed second by second throughout the measured lengths of the recordings, and running means over various averaging periods have been obtained as for the individual pressure readings. Cases (b) and (d) have been computed from the above, covering periods of peak loading.

A summary of the results for two recordings, one from a westerly wind and the other from an easterly, is given in Tables I and II and curves showing the variation of peak load with time are given in Figures 10 and 11. There are some important features to be noted. The first is that practically the whole of the peak wind load is taken by the windward face of the building. The simultaneous load on the leeward face is quite negligible. It does in fact fluctuate between small positive and small negative pressures relative to the internal pressure in the building, with an overall bias to be positive, especially on the lower part of the building. This suggests that the internal pressure is slightly below atmospheric, the depression being too small however to have been detected by the aneroid barometer.

Tables I and II have been expressed as loads rather than as pressure coefficients because this seems more meaningful in the present context where loadings over different time periods are being considered. The maximum 3-second loading can however be referred to the maximum gust speed (assumed to be an average over 3 seconds) to give a pressure coefficient for comparison with other work and with wind tunnel test results. From Table I, dealing with the westerly (relatively unobstructed) wind, it is found that the coefficients for strips at the 7th, 13th and 17th floor levels on the windward face are 0.83, 0.92 and 0.87 respectively, and C_p for the windward face as a whole is 0.83. It will be noticed that the loads averaged over 3 seconds are, at all levels and for the face as a whole, about 60% greater than the corresponding loads averaged over 1 minute, which is the basic wind used in the current U.K. code of practice. The results for the building as a whole are illustrated graphically in Figure 12.

The loads from the easterly wind, given in Table II, are seen to be much lower than those of Table I even though the maximum gust speeds were nearly the same. The comparable C_p for the windward face is +0.24. This, it appears, must arise from the shielding effect of the buildings to windward (see Figure 2) even though these are neither very close nor densely packed. In spite of the more turbulent character of this wind, the main effects noticed in Table I can also be seen in Table II. As before, virtually the whole load is taken by the windward face of the building, and the leeward face is subject to small loads fluctuating from pressure to suction in relation to the internal pressure of the building. As before, there is a bias towards a positive (pressure) loading and it is most prominent on the lower part of the building.

A comparison of the overall loading under the westerly (unobstructed) wind with the wind tunnel test shows a generally similar distribution of load on the windward face. The mean pressure coefficient, based on maximum 3 second loadings and maximum gust speeds, is about +0.83 on the windward face as compared with a mean value of about +0.65 for the model, but is zero on the leeward face compared with -0.6 for the model. Thus the overall drag coefficient for the building in the natural wind, based on the 3 second loading, is 0.8 whereas that of the model is 1.25.

6. DISCUSSION OF RESULTS

Certain features of the wind loading emerge quite clearly. The actual local loadings in relation to the measured gust speeds are reasonably well correlated though a more precise knowledge of the gusts in the immediate vicinity of Royex House would have been preferable.

High suction loadings on the cladding under glancing winds are found in all the recordings. The values given may still not be absolute maxima since the gauge nearest the end of a major face was 11 ft from the corner of the building and higher suctions may occur in that region. The analysis of results from the north and south faces will throw further light on this, as on these minor faces the end gauges were only about 3 ft from the corner. Total outward loads will be estimated later when the results are available from the end faces.

A feature that requires further investigation is the difference in overall loading between westerly and easterly winds. The discrepancy is much larger than would have been expected from the apparent shielding effect of the neighbouring buildings and raises important problems as to the reductions in structural loading that might be appropriate in cases where a building is sited within a complex of equally tall structures.

The distribution of structural load between the major faces depends on the pressure level of the internal reservoirs to which the gauges were connected, and although the internal pressure in the building was carefully checked by aneroid barometer there must remain some doubt, in view of the unexpected results, as to whether conditions in the ceiling spaces were identical with the building as a whole. There can scarcely be more than a marginal difference, but this will be investigated.

The overall structural loads are not however dependent on the pressure levels of the internal reservoirs. Since both windward and leeward faces were connected to the same reference points the vector sum of their individual loads is a true total load for the building as a whole. The low drag coefficient under gust loading as compared with the results of model tests in smooth flow therefore needs some investigation.

To this end a comparison has been made between the maximum measured wind loads over a range of averaging times and the maximum speeds of the free wind over the same time intervals, the latter being taken from a Meteorological Office publication(3). This is shown in Figure 13 in which the gust speed

in the free wind in urban conditions for various gust durations is plotted as a ratio of the gust speed averaged over 1 minute. Curves are also plotted showing the variation with averaging period of the square roots of the measured maximum pressures, again as ratios in relation to the 1 minute averages. Separate curves are drawn for the local suctions under glancing winds and for the overall structural loading under face-on winds, and in each case a range of values is shown covering the various recordings that have been measured. It is seen that, as the averaging period is reduced, the suction loads on cladding can increase more rapidly than would be expected from the increase in the gust speed, but that the structural loads over short durations increase less rapidly than would have been expected. A possible explanation is that the suction loads produced by glancing winds can be magnified over the shorter time intervals by the varying angle of incidence of the turbulent wind. This possible effect was referred to by Scruton and Newberry(4) on the basis of tests by Davenport(5), Schwabe(6) and Keulegan and Carpenter(7). In the case of the structural loads due to the face-on wind it would appear that the building exerts a cushioning influence on the approaching gusts and that the shorter gusts are in consequence less severe than would be expected from the measurements of the free wind.

The effect of this on the structural loading has been investigated by analysis of the influence of averaging period on the drag coefficient. The results are plotted as a dashed line in Figure 13. It is seen that the drag coefficient, calculated on the basis of the free wind gust speed for each averaging period, decreases as the averaging time for both load and wind is decreased. This unexpected result necessitates a re-assessment of the technique by which wind loads are calculated. It can no longer be maintained that wind loads vary as the square of the wind speed without regard to the averaging period that is adopted.

6.1 Comparison between test results and C.P.3, Chap V loading

It is of interest to compare the measured loads on Royex House with values that could have been computed on the basis of the British Standard Code of Practice C.P.3, Chap.V. (1952)[8].

The maximum overall load in a 37 m.p.h. westerly wind was 78,800 lb. The expected maximum gust in a 50 year period is 87 m.p.h. at the height of 200 ft which corresponds approximately with the height of the building. This would produce an overall load of 437,000 lb. According to the code, the exposure B would be appropriate. This, for height 200 ft, gives a wind pressure $p = 17\ \text{lb/ft}^2$. This, acting on the area of 27,500 ft^2 of a major face, gives an overall load of 468,000 lb, which is in very good agreement with the peak load based on the actual measured pressures. It must not be overlooked, however, that the code loading has been derived from a wind speed averaged over 1 minute, and implies a load averaged over such a period, whereas, the actual load lasts only for a brief duration and is more realistically associated with the short gust.

The code recommendation that the overall load should be shared equally between the windward and leeward walls is at variance with the experimental results.

The use of the 1 minute mean wind speed in the code leads to cladding loads which are much below those expected on the basis of the measured pressures. For wall panels and sheeting the code gives pressures and suctions of 13.5 lb/ft^2 generally and suctions of 25 lb/ft^2 to be resisted by the fastenings of cladding near the corners of a building. The values appropriate to an 87 m.p.h. gust, on the basis of the measured loads, are in the range 20 to 25 lb/ft^2 for much of the cladding and up to 40 to 45 lb/ft^2 for cladding near the corners. Thus a considerable change in the code seems to be necessary.

7. APPLICATION TO DESIGN

It is apparent that short duration wind loads should be taken as the basis for both cladding and structural design, and it will now be considered how this can be most effectively achieved. The most reliable short duration wind speeds are those averaged over 3 seconds, described by the Meteorological Office as maximum gusts. These should therefore be adopted as basic wind speeds.

For most buildings the only available information on pressure and drag coefficients is that derived from wind tunnel tests. It is therefore necessary to formulate a relationship between the coefficients assumed from the results of model tests and the effective coefficients that need to be used on the full scale to adjust for the effects of short duration loadings. While it would not be wise to place too much confidence in the results from a single example, nor to generalize too far from the particular case, it can be stated that for Royex House, and presumably other buildings of generally similar size, shape and environment, it appears that the following applies:

For local loading on cladding, pressure coefficients generally between −1.0 and −1.5 should be used, with extreme values near ends of faces up to −2.5, based on the 3 second gust at the height of the building.

For structural loading against a major face of the building, the effective drag coefficient, related to the 3 second gust is 0.83. Compared with the coefficient of 1.25 found in the model test this is a reduction by a factor of 0.66. It therefore seems practicable to design the structure on the basis of the pressure head due to the gust speed at the height of the top of the building and the known drag coefficient or shape factor (derived from a model test in a wind gradient, but smooth flow) reduced by the factor of 0.66. The whole of the load should be assumed to act on the windward face. The vertical distribution is as indicated in Figure 12, the centre of pressure being at about 55% of the building height.

It is interesting to note that this is effectively the same numerically as using the model test coefficient and reducing the pressure head of the 3-second gust by the factor of 0.66 : that is, reducing the wind speed by a factor of $\sqrt{0.66}$ i.e. 0.81. If this is applied to the free-wind curve of Figure 11, the 3 second value of 1.55 is reduced to 1.25 which, it will be noted, corresponds to a 12 second gust duration. For practical purposes in a similar urban environment it would thus be adequate to use the existing drag coefficient of the building derived from a model test and apply the pressure head corresponding to the 10 second gust, factors for which are available in reference (3). Further research is however necessary to determine what modifications to this recommendation are needed to make it applicable to other building shapes and sizes, and for environments having different turbulence characteristics.

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APPENDIX - The significance of the short duration gust

It may well be asked whether there is justification for considering short loading times for a building such as the one featured in this report. The question can be answered on several grounds.

First, the current tests have shown that the short duration wind loads on the whole building are in fact greater than the loads averaged over longer periods. Secondly, the natural period of sway of most buildings other than very tall towers and chimneys is less than 1 second and in consequence the short gust periods that are being considered are more than long enough for them to be fully effective dynamically. Thirdly, on the question of inertia, it is sometimes suggested that the inertia of most substantial buildings will render them proof against the influence of short gusts of wind. This is best answered by a simple example. The resistance due to the inertia of the building can be looked at independently of the resistance due to stress in the structure by considering the building to be isolated from its foundation and supported free of restraint. In the case of a building the size of Royex House, the 3 second gust load in a wind of 37 m.p.h. (16.5 m/sec) is about 40 tons (40600 kg) and for a peak gust of 75 m.p.h. (33.5 m/sec) would be about 160 tons (162,000 kg). If the total mass is, for example, 16,000 tons (16,200,000 kg), the acceleration produced by the wind would be $g/_{100}$, or about 0.3 ft/sec^2 (0.1 m/sec^2), which would lead to a displacement of about 1.5 ft (0.5 m) in the course of the gust action. Such a displacement would be quite unacceptable and the conclusion must be drawn that the inertia of the building plays only a small part in resisting the effect of gust loadings, at least down to the 3 second averaging period.

In respect of cladding the indications are that even shorter gusts are significant, but for the present the limits have not been explored.

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TABLE I - Loads on building face for various averaging times

West wind max. 37 m.p.h. (16.5 m/sec)

q (3 sec) = 3.4 lb/ft^2

Averaging period	Max. load on windward face (lb) (not necessarily simultaneous)				Simultaneous load on leeward face	Total load on building	Range of load on leeward face (lb)			
sec.	7th	13th	17th	Whole face			7th	13th	17th	Whole face
1	417	475	449	80100	+ 1300	78800	+ 106 + 8	+ 36 - 62	+ 43 - 84	+ 11100 - 1600
2	410	463	435	78500	+ 400	78100	+ 101 + 11	+ 33 - 58	+ 43 - 77	+ 10800 - 900
3	396	444	419	76000	+ 400	75600	+ 99 + 12	+ 31 - 51	+ 38 - 74	+ 10600 - 800
5	383	427	399	73800	+ 1400	72400	+ 96 + 14	+ 27 - 45	+ 33 - 62	+ 10400 - 500
10	341	366	368	68100	+ 3000	65100	+ 90 + 18	+ 23 - 39	+ 24 - 45	+ 9400 - 100
15	319	354	363	65600	+ 2600	63000	+ 90 + 23	+ 21 - 39	+ 21 - 42	+ 9300 + 500
30	281	317	303	56600	+ 3600	53000	+ 79 + 31	+ 16 - 27	+ 17 - 38	+ 8100 - 1800
60	251	285	262	50900	+ 4700	46200	+ 71 + 34	+ 13 - 19	+ 15 - 32	+ 6600 - 2000

Note : (1) Loads at 7th, 13th, 17th floors are for 1 ft high strip of face (area 142 ft^2)

(2) Area of whole face 27500 ft^2

(3) For 3 second loading - pressure coefficient = + 0.83 (windward face)

TABLE II - Loads on building face for various averaging times

East wind max. 39 m.p.h. (17.5 m/sec)

q (3 sec) = 3.9 lb/ft^2

Averaging period sec.	Max. load on windward face (lb) (not necessarily simultaneous) 7th	13th	17th	Whole face	Simultaneous load on leeward face	Total load on building	Range of load on leeward face (lb) 7th	13th	17th	Whole face
1	145	145	185	26700	- 400	27100	+ 41 - 5	+ 32 - 75	+ 22 - 23	+ 5600 - 1800
2	140	142	181	26100	+ 400	25700	+ 41 - 5	+ 25 - 38	+ 17 - 20	+ 5600 - 600
3	136	135	174	25200	+ 300	24900	+ 40 - 3	+ 23 - 25	+ 16' - 19	+ 5500 - 700
5	125	132	156	23800	+ 100	23700	+ 38 - 1	+ 22 - 14	+ 14 - 18	+ 5400 - 600
10	106	130	120	20800	+ 400	20400	+ 36 + 3	+ 19 - 8	+ 13 - 16	+ 4700 - 400
15	92	125	116	19400	+ 700	18700	+ 35 + 3	+ 19 - 6	+ 11 - 14	+ 4400 - 400
30	85	117	102	18700	+ 800	17900	+ 33 + 6	+ 17 - 3	+ 8 - 10	+ 4200 + 500
60	76	96	89	16300	+ 1200	15100	+ 32 + 9	+ 15 - 3	+ 5 - 8	+ 4100 + 600

Note : (1) Loads at 7th, 13th, 17th floors are for 1 ft high strip of face (area 142 ft^2)

(2) Area of whole face 27500 ft^2

(3) For 3-second loading - pressure coefficient (windward face) = + 0.24

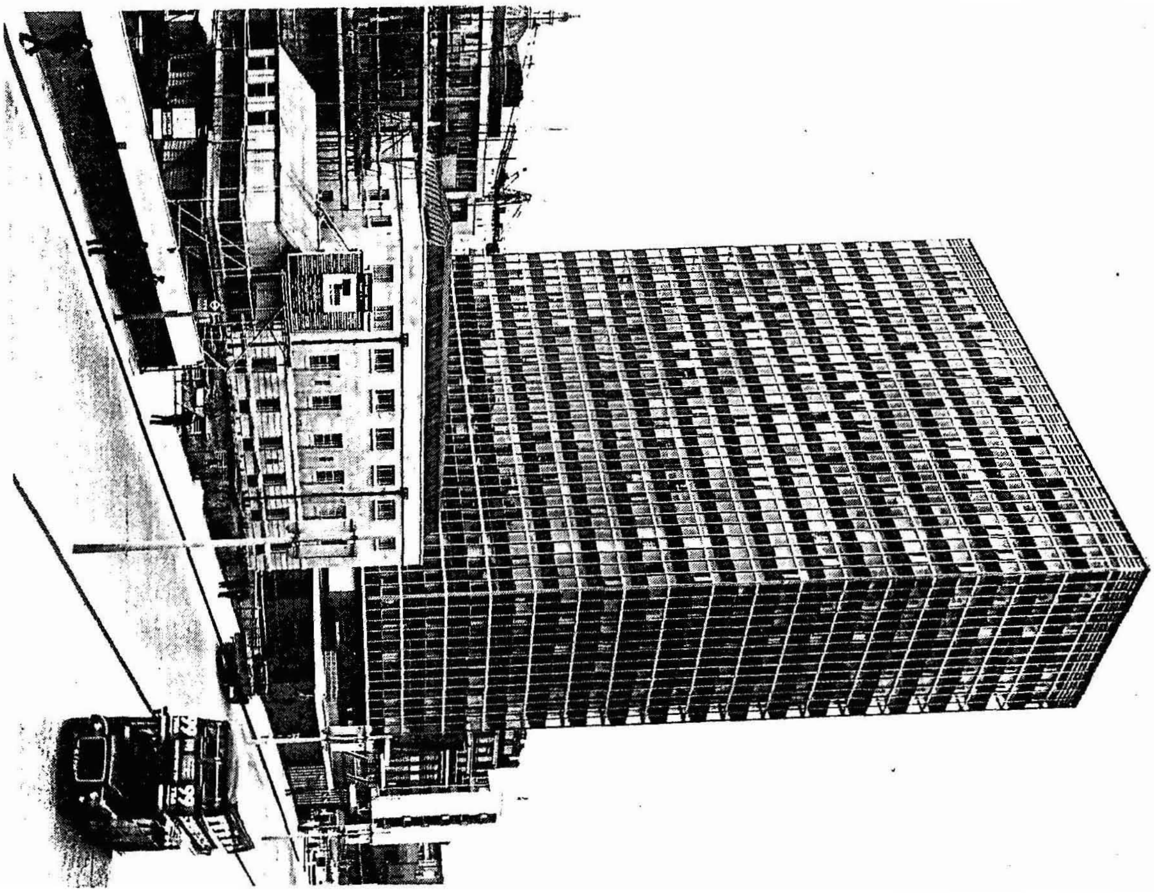


Figure 1: Royex House, Barbican, viewed from N.E.

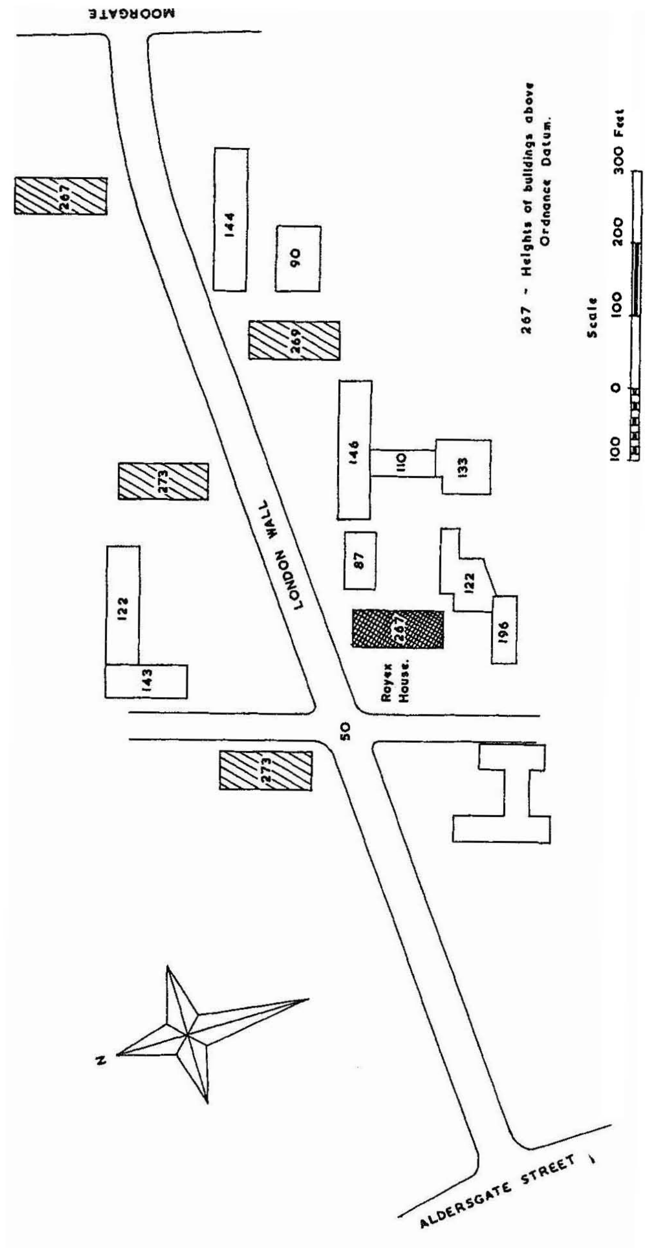


Figure 2 Site plan of area around Royex House.

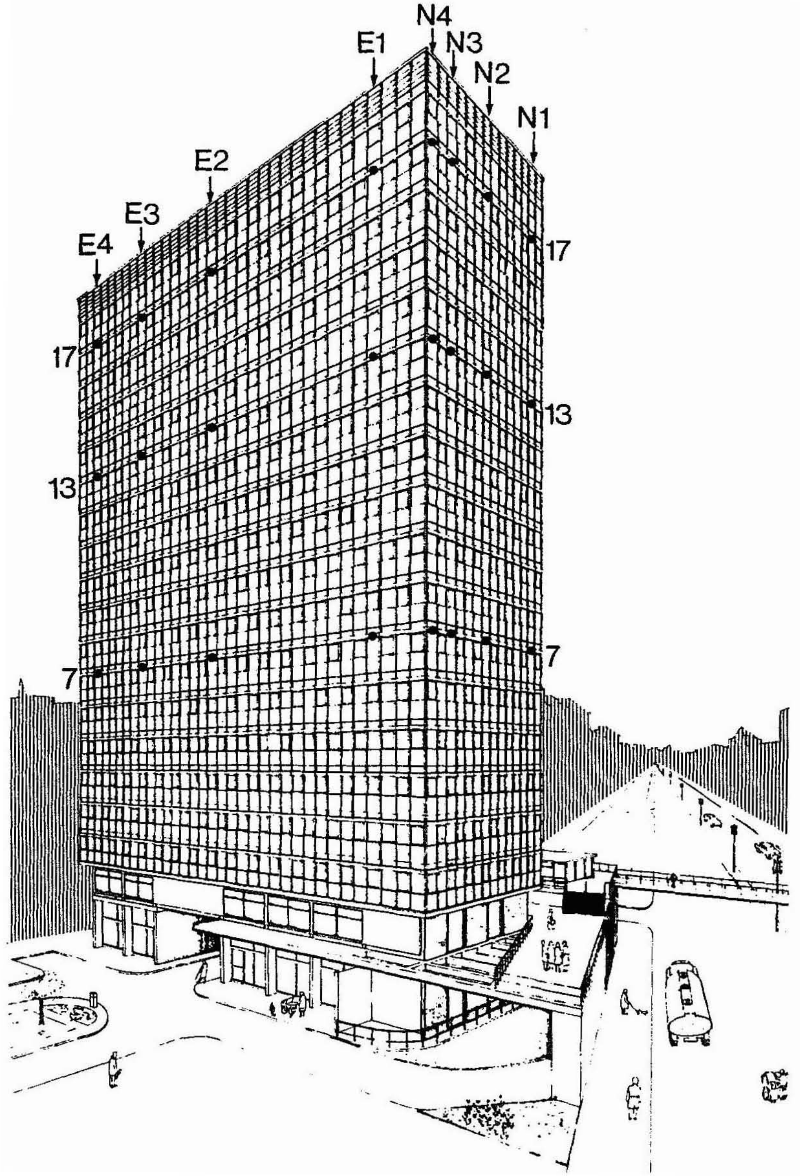


Figure 3 Arrangement of wind-pressure transducers on the face of Royex House

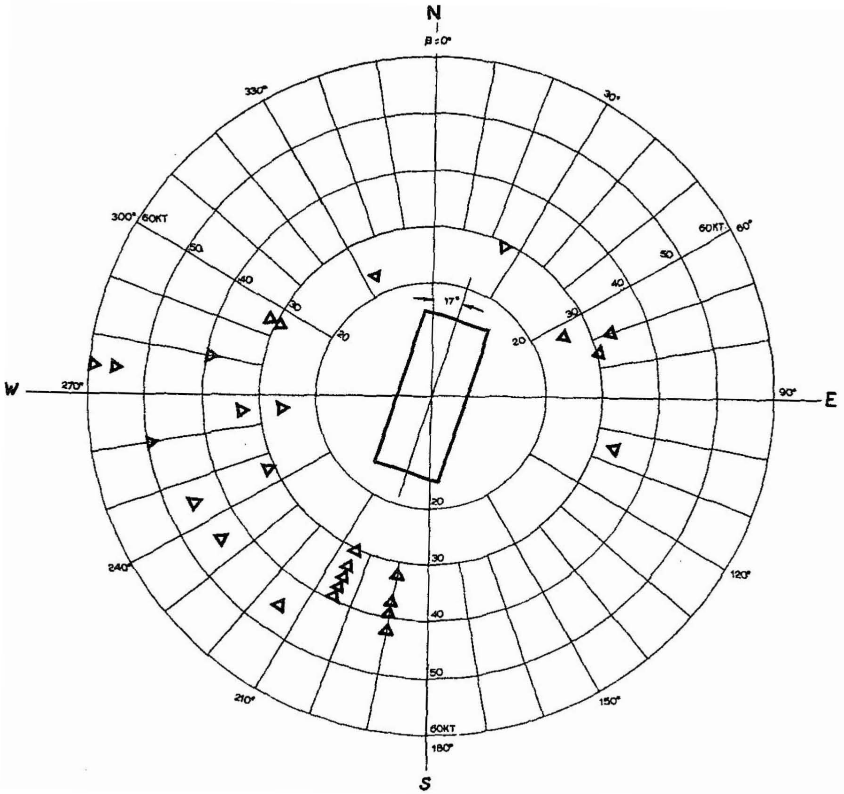


Figure 4 Polar diagram of winds from which recordings have been measured.

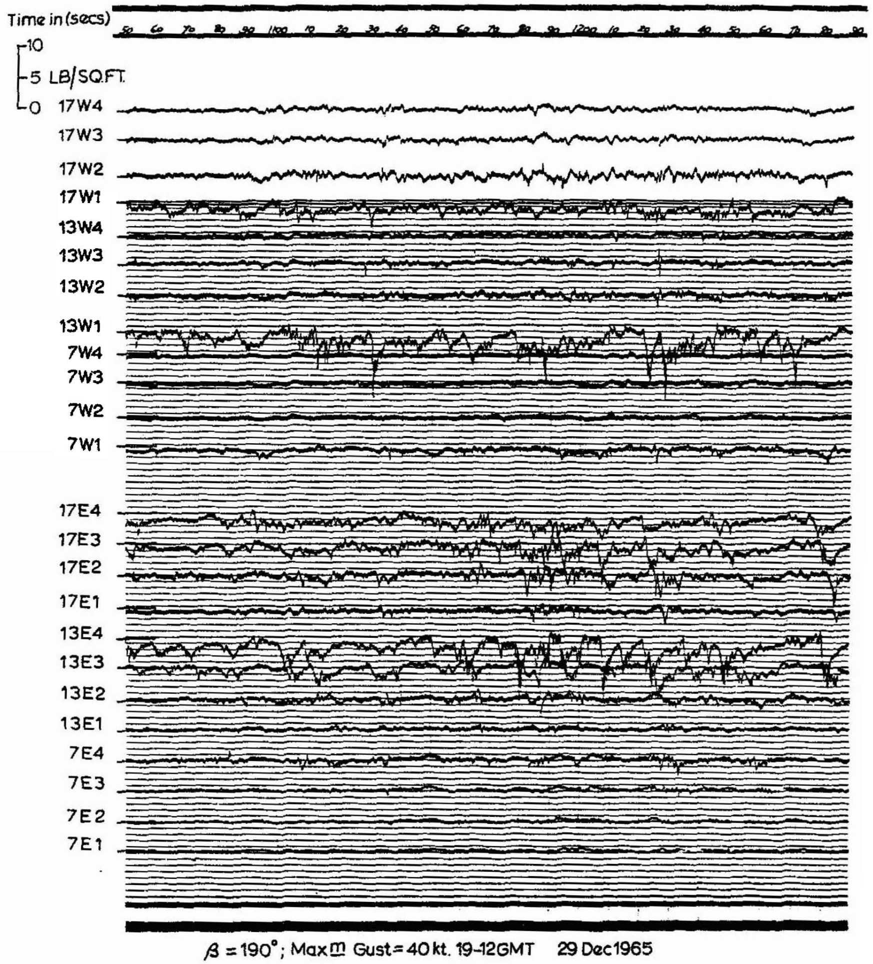


FIGURE 5(a)

FIGURE 5

EXTRACTS FROM WIND PRESSURE RECORDINGS:
(a) GLANCING WIND
(b) FACE-ON WIND

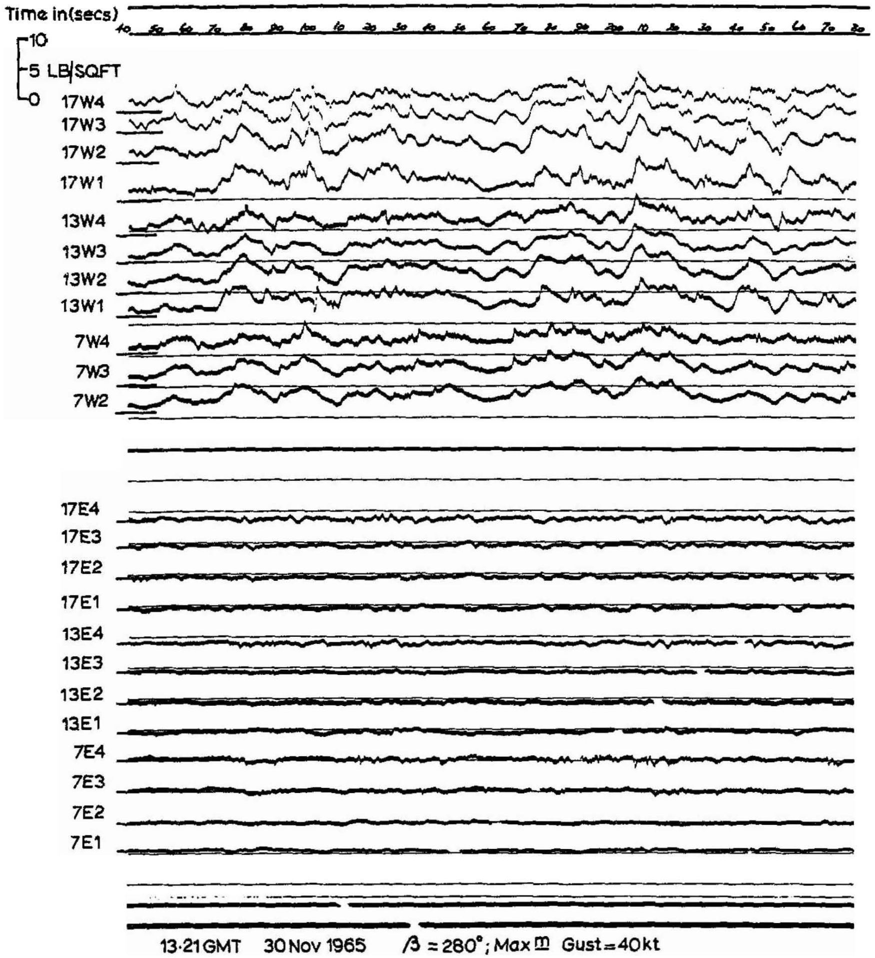
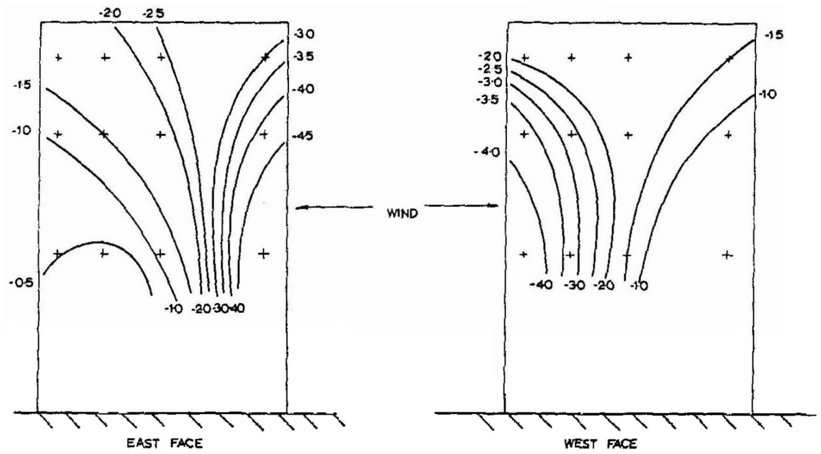


FIGURE 5(b)

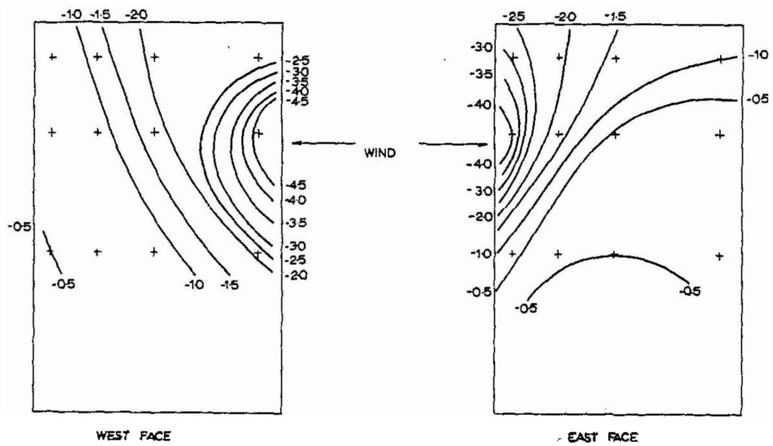
FIGURE 5

EXTRACTS FROM WIND PRESSURE RECORDINGS:
(a) GLANCING WIND
(b) FACE-ON WIND



WIND ANGLE β=25° GUST SPEED 34mph (15·5 M/SEC)
(a) PRESSURES IN LB/SQ.FT. GAUGE POSITIONS THUS: + (b)

FIGS. 6a & 6b. CONTOURS OF MAXIMUM SUCTION (3 SECOND MEANS) IN NORTHERLY WIND



WIND ANGLE β=190° GUST SPEED 49mph (22 M/SEC)
(a) PRESSURES IN LB/SQ FT. GAUGE POSITIONS THUS: + (b)

FIGS. 7a & 7b. CONTOURS OF MAXIMUM SUCTION (3 SECOND MEANS) IN SOUTHERLY WIND

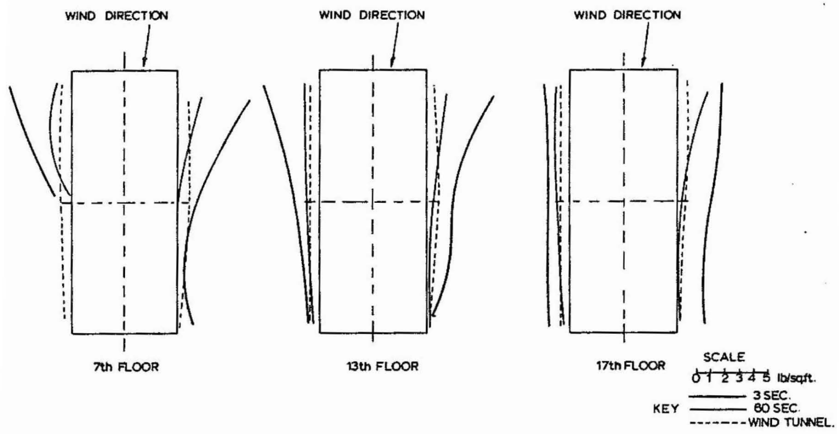


FIG. 8. LIMITS OF 3 AND 60 SECOND MEAN SUCTIONS UNDER A GLANCING WIND, COMPARED WITH WIND TUNNEL VALUES.

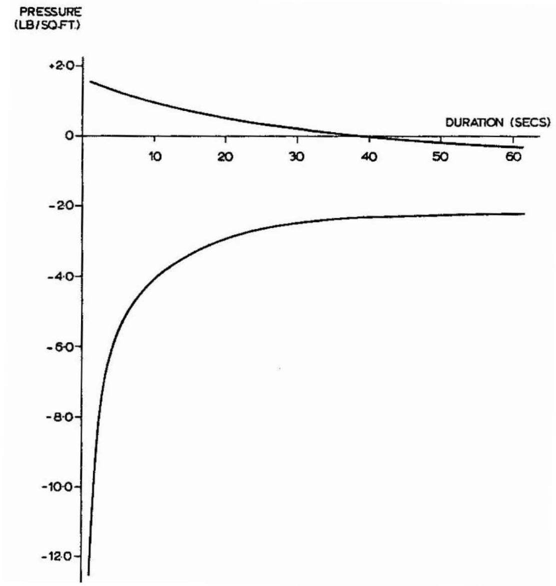


FIG. 9. EFFECT OF AVERAGING TIME ON LOCAL LOADS

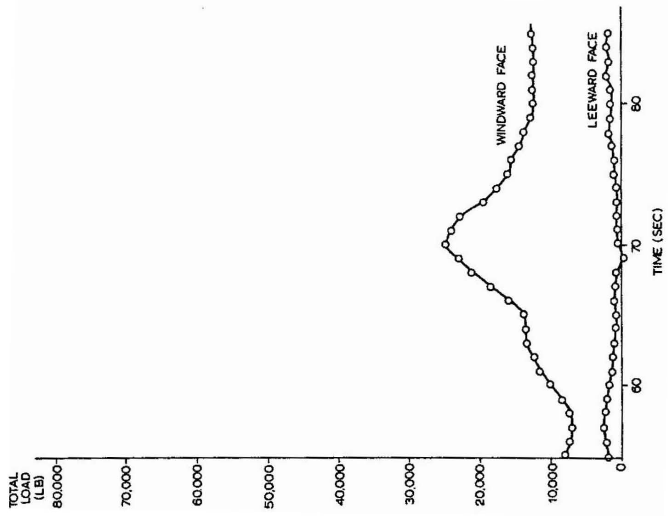


FIG. 11 EASTERLY WIND; MAX GUST 39 MPH

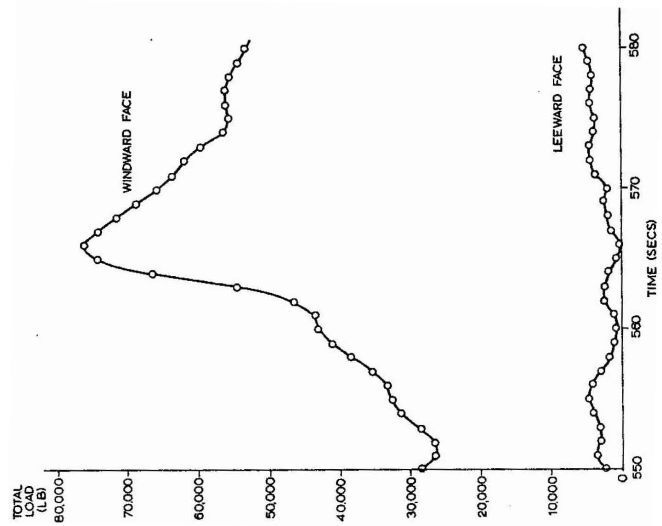


FIG. 10 WESTERLY WIND; MAX GUST 37 M.P.H.

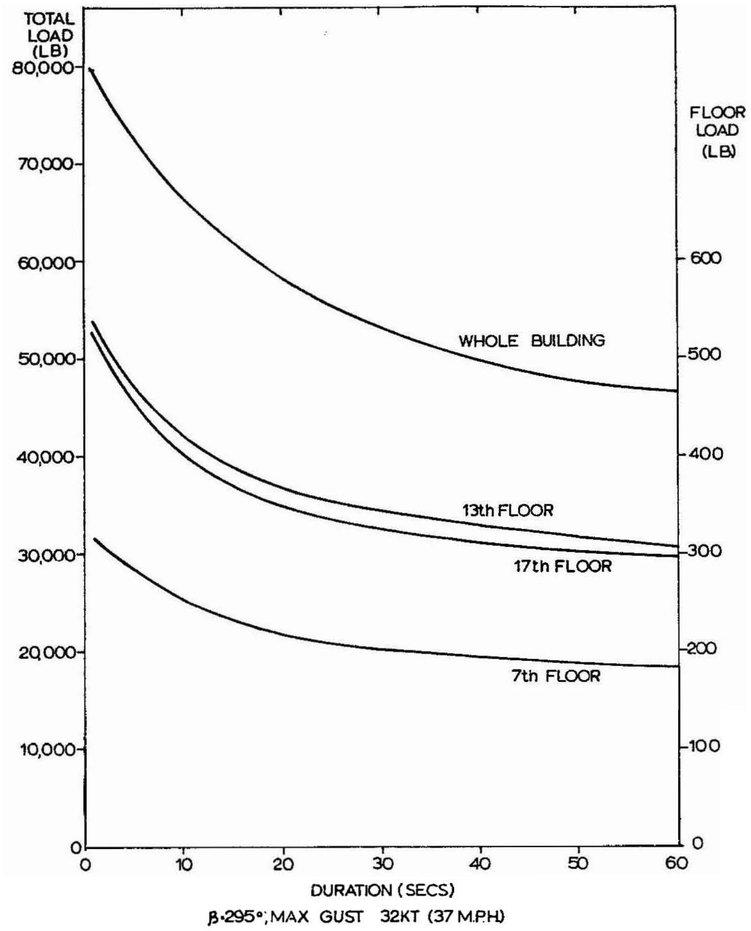


FIG.12 EFFECT OF AVERAGING TIME ON OVERALL FACE-ON LOADS (EAST AND WEST FACES TOGETHER)

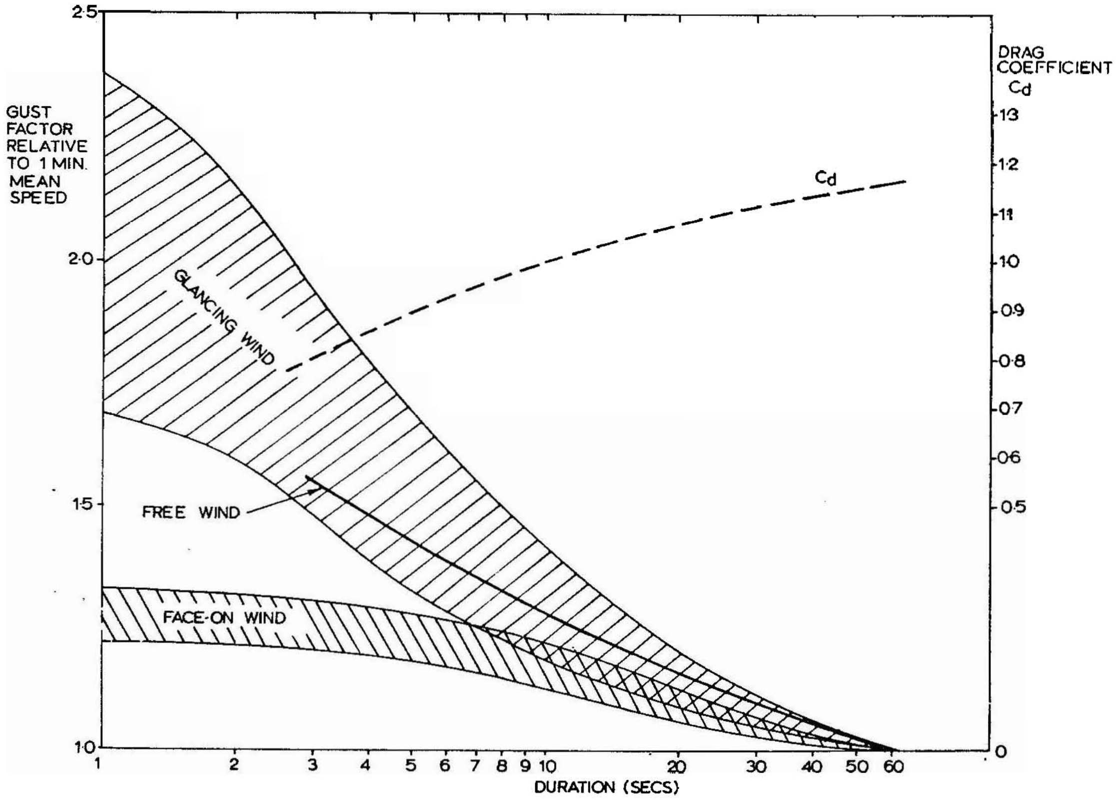


FIG 13 COMPARISON OF APPARENT GUST FACTORS ON BUILDING FOR FACE-ON AND GLANCING WINDS, WITH FREE WIND GUST FACTORS