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WIND LOADING ON A RECTANGULAR BLOCK

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SUMMARY

Measurements of the mean pressure distribution on a rectangular block in uniform flows and in a simulated atmospheric wind have been made. The mean pressure coefficient distributions in these two types of flow are remarkably similar, provided the pressure coefficients are based on the wind speed at roof level. Plain parapets were found to reduce the suctions on the roof but, for large buildings, the parapets would have to be very high to be of significant benefit.

A few measurements of fluctuating pressures were made; it is concluded that in some flow situations the instantaneous pressure distribution is significantly different from the mean pressure distribution.

1. INTRODUCTION

Several wind tunnel tests on specific power station buildings have been carried out at C.E.R.L. In all of these tests it was necessary to carry out the tests in a uniform incident flow and to make various assumptions to relate the measured mean pressure distributions to the extreme pressure distribution that would be obtained in the atmospheric wind. The current Code of Practice (1970) embodies most of these assumptions.

It is becoming evident that shear and turbulence can cause significant changes in the pressure distribution on a model building; the measured effects probably depend on the shape of the building being tested. However, most of this experimental work has been carried out on models of tall buildings. The aim of the work presented in this Note is to compare the results of tests in a uniform incident flow with those of tests in a simulated atmospheric wind for a building that represents approximately a power station boiler house. The comparison is mainly concerned with mean pressure distributions; the important question of the relationship between the extreme loadings and the mean loadings will be studied at later stage.

2. WIND TUNNEL MODEL

The model used in this investigation was a floor mounted rectangular block 763 mm by 152 mm in plan and 305 mm high. Pressure tappings were fitted in the roof and on two of the walls. It can be regarded as an idealized model of a power station boiler house without the turbine house.

3. MEASUREMENT OF MEAN PRESSURES

The model was mounted in the centre of the turntable of the C.E.R.L. Low-Speed Wind Tunnel. The tests were carried out in a uniform incident flow and also in a turbulent shear flow representing the atmospheric wind over open country. The method of producing the latter flow is described by Counihan (1968) where full details of the structure of the flow are given. A simulated atmospheric boundary layer with a thickness of 1.22 m was used and the mean velocity profile was, to a satisfactory approximation, given by a 1/7th power law.

Pressures were measured relative to the free-stream static pressure upstream of the model. The total pressure was measured at roof level at a position well upstream of the model; in the uniform flow, the position of the total pressure measurement is arbitrary. Pressure coefficients are therefore based on the wind speed at roof level.

A multi-tube manometer was used for the pressure measurements; by adjustment of the tilt and reservoir level of the manometer it was possible to read pressure coefficients directly from the manometer without any subsequent calculations.

As the model was rectangular in all views, it was convenient to connect the tappings over half of a wall or a quarter of the roof and make measurements for wind directions from 0 to 360^o in 15^o increments. The symmetry of the model was used to deduce the complete pressure distributions for wind directions from 0 to 90^o.

A wind direction of 0^o is normal to the wider face of the model and 90^o is normal to the narrower face.

4. MEASUREMENT OF FLUCTUATING PRESSURES

Fluctuating pressures were measured in the manner described by Tunstall (1970). Only a few measurements could be obtained because of the limited equipment available at the time of the tests.

Fluctuating pressures were measured only for the uniform flow. In view of the complexity of these results, it was decided to proceed with tests on simple two-dimensional prisms before continuing with detailed work on finite models.

5. DISCUSSION OF RESULTS

5.1 Mean Pressures

The mean pressures are presented as isobars plotted on an exploded (3rd angle) view of the surfaces of the model. The pressure coefficients are based on the dynamic head at roof level. The mean pressure distributions for wind directions of 90° (Fig. 1), 0° (Fig. 2) and 60° (Fig. 3, 4) have been selected to show the main features of the results; for wind directions of 0° and 90° the distributions are symmetrical, so the results for turbulent shear flow and for uniform flow have been presented on the same Figure.

The results for uniform flow in Fig. 1 and 3 are typical of the available published results for uniform incident flow conditions, for example ESDU (1971). The mean pressure distribution of Fig. 2 for uniform flow is unusual but similar distributions have been obtained previously by Chien, Feng, Wang and Siao (1951). It appears that this distribution occurs when the building has an elongated planform but it does not occur for flat plates normal to the flow.

The effect of turbulence and shear on the flow depends on the wind direction. When the flow is normal to the narrow face, Fig. 1, there is very little change on the upstream and downstream faces but on the roof and side walls there is a slight increase in the suctions near the upstream edge in the case of the turbulent shear flow. However, the recovery of pressure to a value near to the free-stream static pressure occurs more quickly in turbulent shear flow.

For the flow normal to the wide face, Fig. 2, there are slightly higher suctions on the roof and side wall in the turbulent shear flow.

For a very long or a very short building, it can be seen from Fig. 1 and 2 that the general pattern of the flow does not drastically change. However, the flow reattachment, which is responsible for the pressure recovery shown in Fig. 1, occurs nearer the upstream edges of the side walls and roof inturbulent shear flow. For a building with a streamwise length such that the downstream face is in the zone of pressure recovery one might expect a greater effect of turbulence on the flow. McLaren (1970) has published some results on the effect of turbulent shear flow on a cube and finds significant changes. It seems probable that the major effects of turbulence on the flow pattern as a whole occur for planforms with side ratios between 2:1 and 1:2; measurements on two-dimensional prisms with these side ratios are in progress at C.E.R.L.

The intermediate flow directions are less affected by turbulent shear flow as opposed to a uniform incident flow; a typical comparison is given in Fig. 3 and 4. The general patterns of the pressure distributions are the same in both flows. The isobars are characteristic of those obtained when a pair of strong vortices originate at the windward corner of the roof. On the whole, taking the results for all wind directions, the vortex pattern is clearer in the turbulent shear flow. It is known that one of the effects of shear is to induce a flow down the faces of the building; it may be that this causes the roof vortices to be brought nearer to the roof and so give rise to slightly higher suctions.

5.2 Fluctuating Pressures

The measured values of the r.m.s. pressure coefficient are not sufficient to determine the nature of the flow in any detail. Tests were carried out only in uniform flow. Table 1 shows typical results obtained.

Table 1

Wind direction	Typical r.m.s. Cp	Largest r.m.s. Cp	Location of Large fluctuations
0°	0.20	0.25	Everywhere
60°	0.05	0.20	Very local at roof windward apex
90°	0.05	0.15	Only in reattachment zone.

The wind direction of 0° is the most interesting of these cases. There is apparently no stagnation point in the mean pressure distribution (Fig. 2 refers) and there are high pressure fluctuations on all faces. The mean pressure distribution is very similar to the average of the mean pressure distributions for +15° and -15° and it was found that the stagnation point moves a long way across the face for a small change in wind direction. It seems probable, therefore, that there is an instability in the wake which causes the instantaneous stagnation point to move across the face. It is equally probable that the instantaneous stagnation point would be on either side of the centreline. The very high pressure fluctuations would then be explicable. The implication is that it is not realistic to allow for the pressure fluctuations by means of a factor applied uniformly to the mean loading as is effectively assumed in the Code of Practice.

The main point to be made about the measured pressure fluctuations is that significant fluctuations arise from processes which occur in uniform incident flows. Consequently, it cannot be assumed that a gust factor can be applied directly to measured mean pressures to allow for incident dynamic head fluctuations.

6. EFFECT OF PARAPETS

The effect of plain parapets of various heights on the time averaged roof pressures is shown in Fig. 5 for a wind direction of 60°. All of these results were obtained in turbulent shear flow. Similar effects were found at all wind directions from 30° to 75° and the effects were small for wind directions of 0° and 90°. There is a general reduction of the extreme suctions as the parapet height is increased but very high parapets are needed to produce any worthwhile benefit. Scruton (1963) has indicated that there are cases in which parapets are of great benefit in reducing extreme suctions. It is not clear whether the presence of shear flow or the particular shape of the building prevents these benefits being obtained in the present case.

7. IMPLICATIONS WITH REGARD TO PREVIOUS WORK

Previous ad hoc tests carried out by Counihan (1966) Hopley (1966) and Armitt (1971) for various power station models used a uniform incident flow although Counihan investigated briefly the effects of turbulent shear flow using a less satisfactory simulation method than is now available. The conclusion to be drawn from the present results is that, so long as attention is confined to the mean pressure distribution, the previous results are generally valid but there may be detailed local changes such as the exact position of flow reattachment on the roof. For technical reasons, the measurement of fluctuating pressures was not attempted in these earlier tests; evidently some margin is needed to cover their effects. A brief discussion of this matter is given by Armitt (1971).

8. FURTHER WORK

Several problem areas have been identified in these tests. Work is in progress to investigate these in detail. The effect of turbulence on the flow around two-dimensional prisms with various cross sections is being investigated to determine the building shapes that are likely to be significantly affected. There is a need to study instabilities of the kind which give rise to large fluctuating pressures such as were obtained for the flow normal to the wider face of the model. There is also a need to study the process of the flow reattachment as this gives rise to appreciable pressure fluctuations and appears to be significantly affected by turbulence.

9. CONCLUSIONS

For a typical boiler house, the mean pressure distribution is only slightly affected by the turbulence and shear in the atmospheric wind. This may not be true for buildings which are more nearly cube shaped. In a turbulent shear flow, the wind speed at roof level determines the magnitude of the mean wind loading.

Substantial fluctuating pressures were measured in some cases. More work is needed before the significance of these fluctuations on the design loadings can be determined.

The effect of parapets on the mean loadings on the roof of a boiler house is small for parapets of reasonable height.

10. REFERENCES

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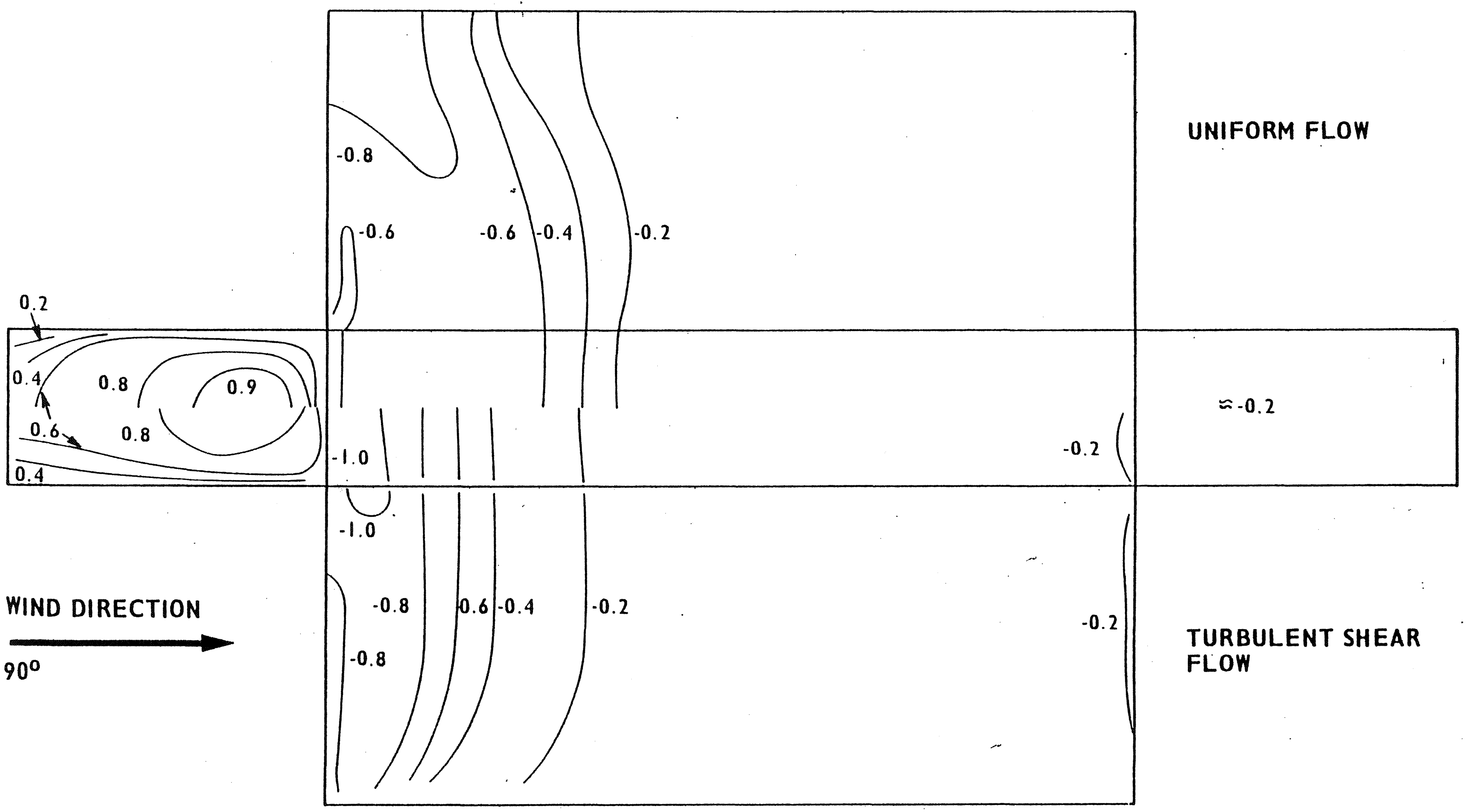

FIG. 1 RECTANGULAR BLOCK. PRESSURE DISTRIBUTION IN TURBULENT SHEAR FLOW AND UNIFORM FLOW

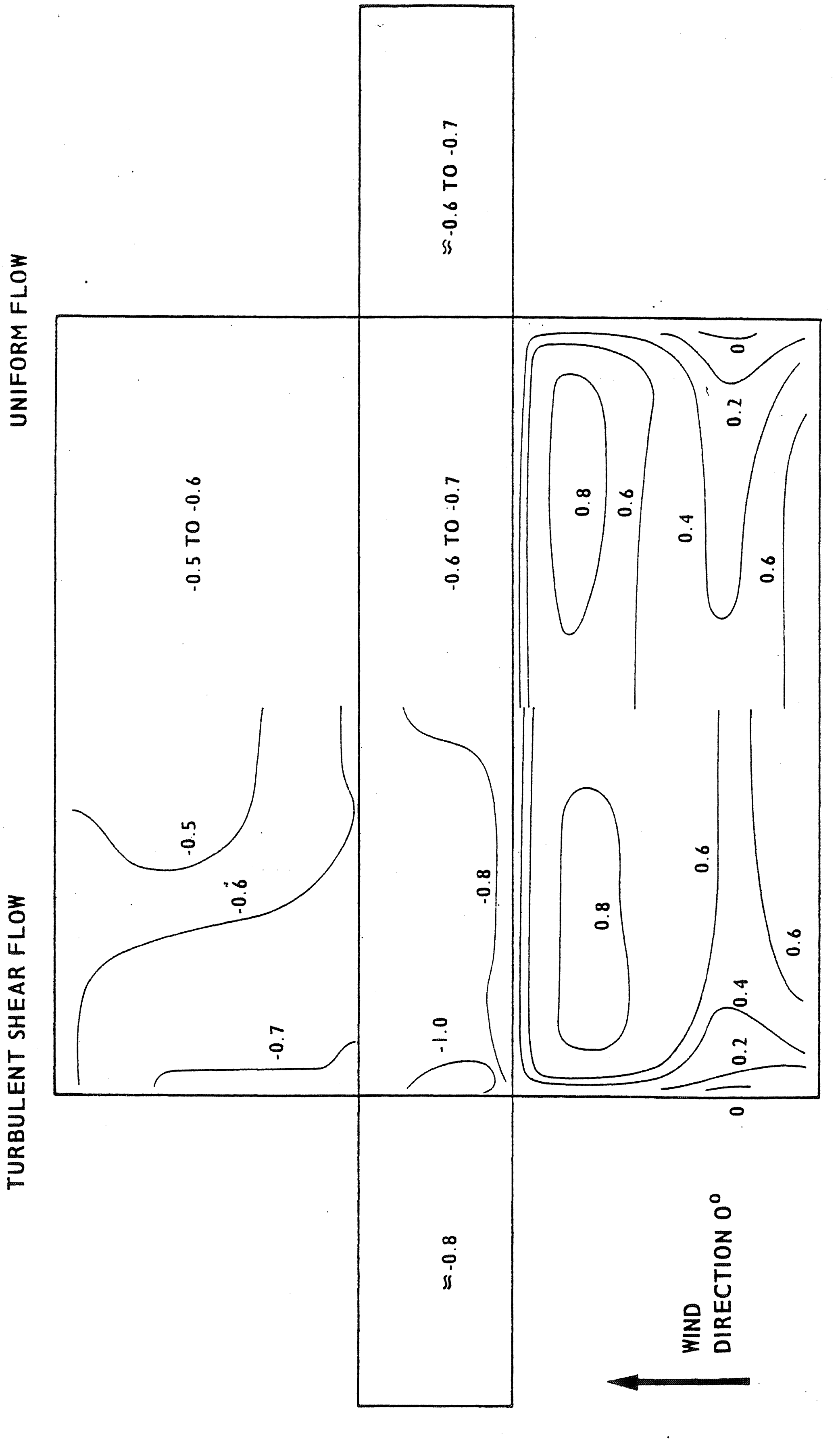

FIG. 2 RECTANGULAR BLOCK. MEAN PRESSURE DISTRIBUTION IN TURBULENT SHEAR FLOW AND UNIFORM FLOW

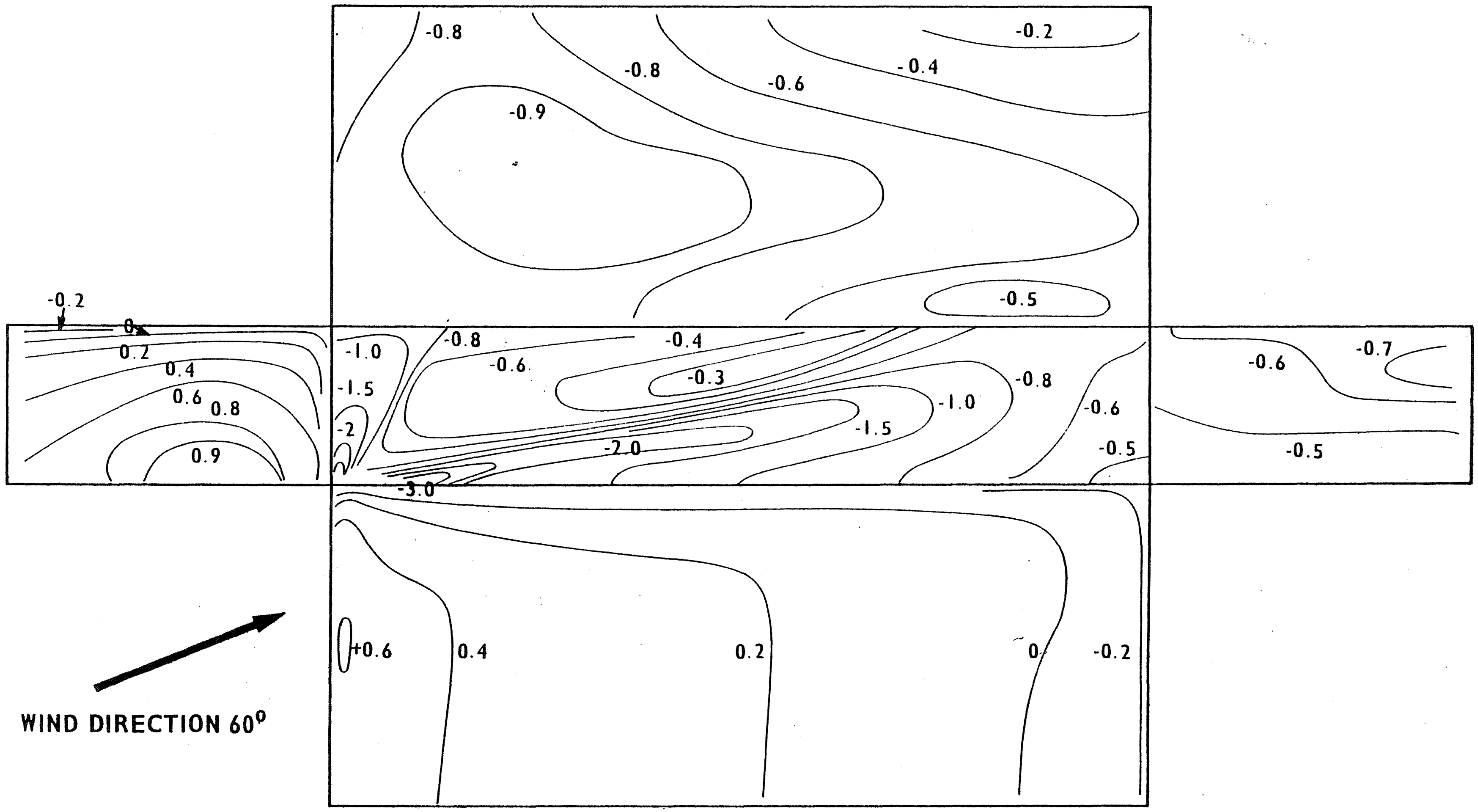

FIG. 3 RECTANGULAR BLOCK - MEAN PRESSURE DISTRIBUTION IN UNIFORM INCIDENT FLOW

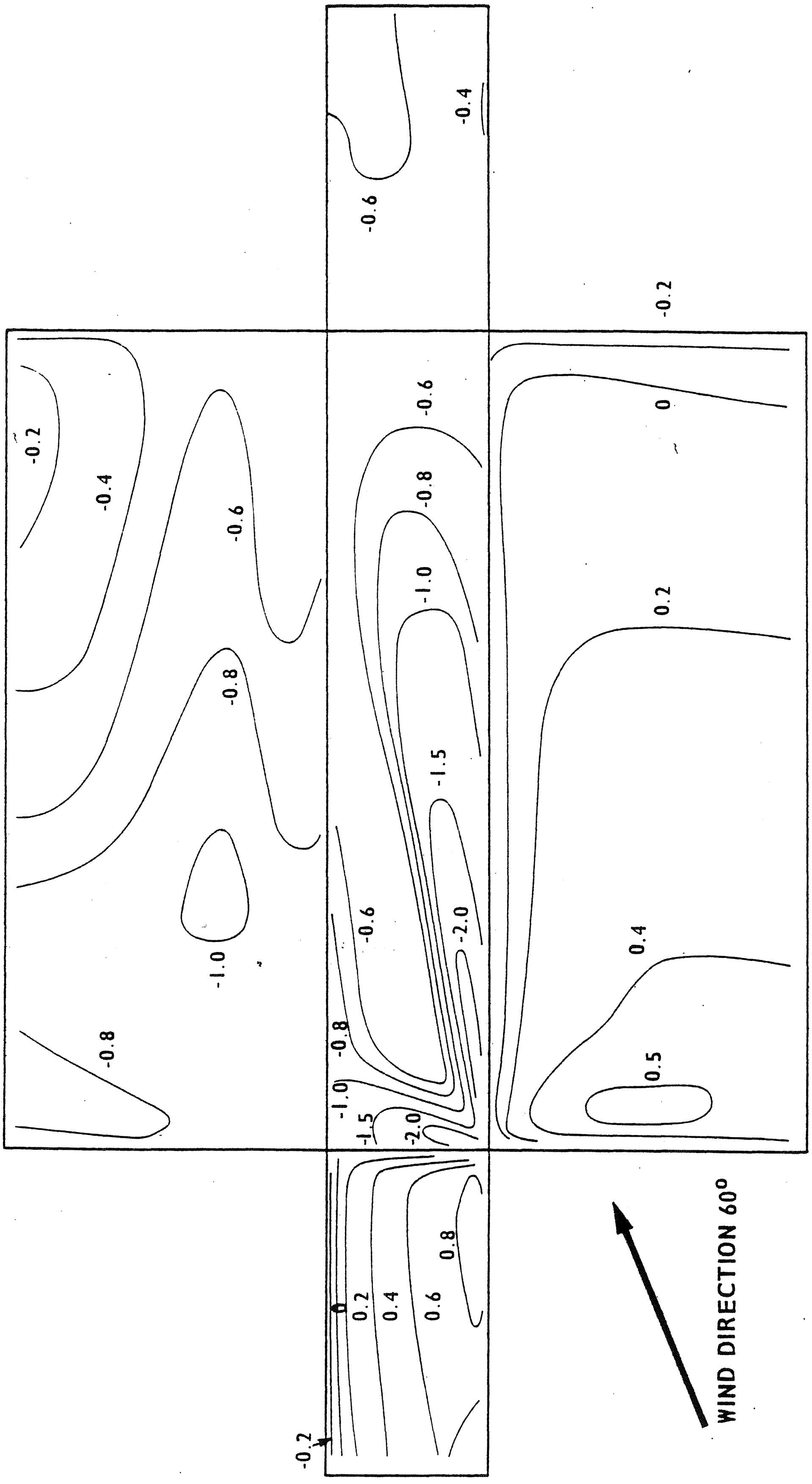

FIG. 4 RECTANGULAR BLOCK - MEAN PRESSURE DISTRIBUTION IN TURBULENT SHEAR FLOW

For the attention of:
The Civil Engineer, GDCD

CENTRAL ELECTRICITY RESEARCH LABORATORIES

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(Job No. VE 306)

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Approved by: 2/apr. 74
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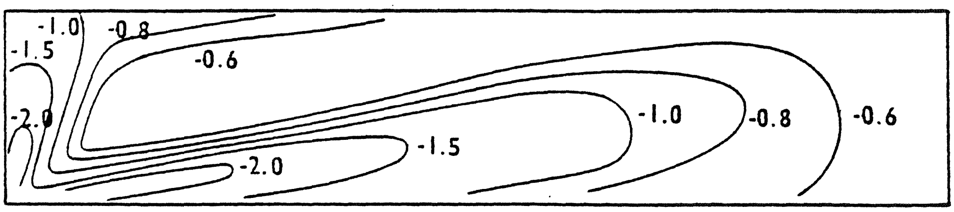
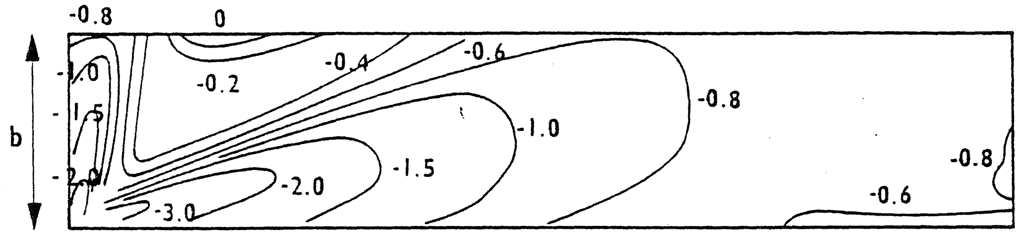
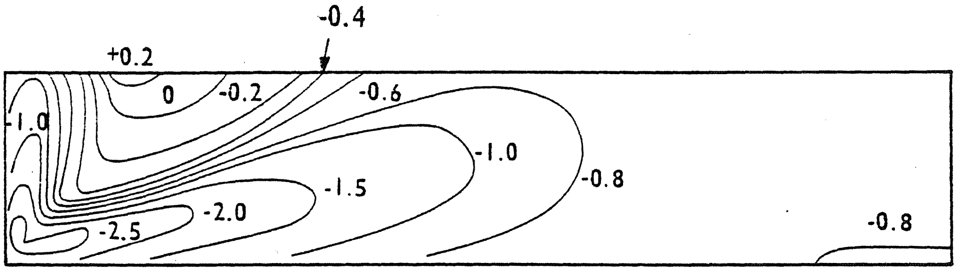
Date: 27 February 1974



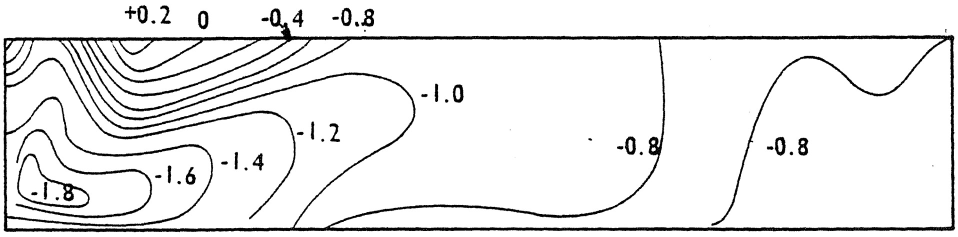
NO PARAPET



PARAPET HEIGHT = 0.025 b



PARAPET HEIGHT = 0.083 b



PARAPET HEIGHT = 0.166 b

FIG. 5 RECTANGULAR BLOCK - MEAN PRESSURE DISTRIBUTION ON ROOF IN TURBULENT SHEAR FLOW FOR VARIOUS PARAPET DIMENSIONS (WIND DIRECTION 60°)