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WIND TUNNEL INVESTIGATION OF AN OFFICE BUILDING

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SUMMARY

A large office building, consisting of several octogonal towers and other blocks was tested in the boundary layer wind tunnel of Bundesversuchs- und Forschungsanstalt Arsenal, Vienna. The purpose of this investigation was threefold. First, to determine the highest suction pressures which are relevant for the fixing of the cladding. Secondly, due to the arrangement of the inlets and outlets of the ventilation system (in some cases on the same tower) and due to the arrangement of the octogonal towers of different heights, some recirculation problems could be expected. A tracer gas method was applied to remedy this second problem. Thirdly, as the flat roof of some towers were intended to be used as recreational areas, wind velocities in these areas were studied by means of an erosion technique using flour; the accuracy of this method was checked by hot wire measurements in a third test.

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1. INTRODUCTION

A large office building was planned in the centre of Vienna on the bank of the river Danube. The building complex covers an area of about 80.000 m^2. The main parts of it are towers with octogonal cross-sections and various heights. Since these towers are significantly higher than the surrounding buildings, severe strong wind effects were to be expected. Therefore a wind tunnel investigation was recommended to study the following wind effects.

1) High suction pressures at the corners of the octogonal towers. The forces caused by these pressures are of main interest for the fixing of the cladding elements.

2) The air intakes and outlets of the ventilation system and the stacks air situated on the tops of the towers. At certain wind directions the danger of recirculation between in- and outlets was expected, especially an influence of the lower tower on the higher ones. In the wind tunnel investigation the recirculation rates were measured.

3) As some of the flat roofs of the towers were intended to be recreational areas, it therefore became necessary to measure the wind velocities and gustiness in a height of about 1 m above these flat roofs.

2) EXPERIMENTAL TECHNIQUE - WIND TUNNEL

The investigations were carried out in the wind tunnel of the Maschinenbautechnische Versuchsanstalt Arsenal, Vienna. This open circuit tunnel has been designed specifically for the study of the aerodynamics of buildings. The test section is approximately 3 m long and the dimensions of the cross section are 1.7 x 1.2 m (Fig.1). The boundary layer develops in a fetch which is about 8 m long. The floor of this section can be fitted with different roughness elements. The air is sucked in from the laboratory hall which has a volume of approximately 9ooo m^3, which is of some significance for the concentration tests. A coarse grid consisting of boards .1 m thick helps to increase the turbulence level. A tripping fence with a height of .2 m starts the development of the boundary layer. This configuration of the roughness elements was chosen to give an exponent α = o.2 for the power law. According to the mean height of the surrounding buildings a displacement of the zero-velocity plane of about 2o m is to be expected in the full scale velocity field.

The mean velocity and the rms-turbulence level are plotted versus the height above the ground in fig. 2. The correct modelling of the atmospheric turbulence is of special importance in investigations of the dispersion of effluents.

3. PRESSURE MEASUREMENTS

Since the office building consists of many octogonal towers and other blocks it would have been very laborious to measure pressures at all points of interest on such a complex model. For that reason the investigation was divided into two parts. In the first, pressure measurements were carried out on the surface of a single octogonal tower on the scale of 1 : 2oo (Fig.3) to detect regions where the highest suctions occur. The model was equipped with an interchangeable section, with 9o pressure taps located on the perimeter. A scanivalve pressure measurement system with 96 ports was used to measure the pressure transients. The tubelength between the face of tapping on the model to the face of the Scanivalve connector was approximately .3 m with a diameter of .6 mm, so rather a flat frequency response was achieved up to 1oo cycles per second (Cook, 1975).

There was no restrictor for minimizing distortion effects. The pressure switches were fitted with DISA 51F32 low pressure transducers. The reference side of the pressure transducer was connected with the static side of a Prandtl tube placed in the flow upstreams of the building. The reference dynamic pressure was also measured with the tube.

Each pressure port was sampled at 1ooo measurements/sec for a total of 13 92o values. First the computer processing converted all data to the usual pressure coefficients and then the mean value and the probability density distribution of these coefficients were calculated.

The highest suction coefficients occurred for a flow angle of about 11° to one surface plane. The results for two cross sections in different heights are plotted in fig. 4. The lowest mean value is about C_p = -1.6 referred to the mean value of the dynamic pressure at the height of the roof. This value was measured at a point near the corner just below the roof. For lower levels of the measuring plane the minimum values are less. The extreme minimum value of the pressure fluctuations, which means one value out of a set of 13 92o, was as low as C_p = -5.6 and occurred at point no.19. The probability density distribution of the pressures at this point is plotted in fig. 5.

In the second part of the pressure investigation a full model on the scale 1 : 4oo was built, which is shown in fig.6. It was only equipped with pressure taps in those areas where high suction pressures were expected from the results of the previous test (fig.7). The same measuring equipment was used, and the probability density gave the extreme value for C_p = -5.8. (The mean value of C_p = -1.6 was also referred to the dynamic pressure at the height of the roof of the highest tower.) These values were in excellent agreement with the previous results from the single tower tests.

It is remarkable that these results are in excellent agreement with the values computed according to the new Austrian code of practice concerning wind loads. This code was renewed, like many other codes, and in some cases prescribed considerably higher loads than the old one. The probibility density distributions were slightly skewed in accordance with previous experimental results (Peterka and Cermak, 1975; Sockel, 1979).

4. CONCENTRATION MEASUREMENTS

The model on the scale 1 : 4oo was equiped with intake and exhaust openings (fig.9). The intakes at full scale are just under the flat roofs, the short stacks on the roofs are the outlets. So there is the possibility of recirculation at one tower or recirculation from the stacks of one tower to the intake of another tower. The discharge openings were connected with a fan which injected air which was mixed with propan of low concentration (about 5oo ppm). The intakes were connected with another fan and both volume streams were measured with Rotameters. The concentrations in both streams could be checked with a flame ionization detector with a high sensibility for hydrocarbon compounds and with a resolution better than 1 ppm. Fig. 8 shows a sketch of the test setup.

Since we have no meteorological wind tunnel, only a neutral atmosphere could be simulated. Moreover at the time of the experiments the temperature of the full scale effluents was not known exactly and therefore we neglected the effect of thermal buoyancy. Due to these simplifications, the similarity rules were restricted to the similarity properties of the flow field. This means a good simulation of the atmospheric boundary layer, especially of its turbulence characteristics. The arrangement in the wind tunnel for this purpose is discussed in section 2 of this paper. Since many recirculation problems are caused by an interference between the exhaust jet and the wake of a building, the wakes in model and prototype should be similar, which means the same Reynolds number. But this is not possible, as we all know, and for sharp edged bodies there is very little influence of the Re on the structure of the wake. Due to the geometric similarity of the exhaust openings and due to the full scale exhaust velocity we maintained, the ratio exhaust velocity to wind velocity had to be same for model and full scale. We changed the wind velocity in a range of 2 - 2o m/s. The very small diameter of the discharge tubes would have resulted in a laminar jet with quite different characteristics from a turbulent jet. This would be of little importance if the far flow field is considered because this field is dominated by the background turbulence (Meroney and Neff, 198o). But we were interested in the flow field near the source of the jet and therefore the openings were fitted with small disturbance generators. Fig. 9 shows the measured recirculation rates occuring at the prevailing wind directions, approximately NW and NE. The values are in the range of one percent. The highest recirculation rates occurs at NE wind direction in the wake of the building complex. About 2.4 % of the stackgases were sucked in by the intake of the same tower. The velocity of the stackgases is too small so they cannot leave the region of the separated flow behind the building.

In the NW direction the concentrations are in the same range. The concentration of the stackgases on the roofs of the buildings were measured at several wind directions and were also found to be in the range between 1 and 2 %.

It was decided that these values were not hazardous to health and therefore were acceptable. The results show a good reproducibility.

5. WIND VELOCITIES ON THE ROOF

From the top of the towers one has an excellent view across the river Danube to the new UNIDO Centre. Therefore it is understandable, that these areas were planned for sightseeing and recreation purposes. However, these areas could be very uncomfortable in the event of severe wind conditions caused by the different heights of the buildings and the separation zones of the flow.

A measurement with a hot wire probe would not always have been adequate due to the high turbulence level in the separation zones; moreover, this would have been a very timeconsuming task. Therefore an erosion technique proposed by Beranek and van Koten (1978) was applied, but with the modification that flour was uesed instead of sand. There were two further reasons for selecting this technique. One was that it can be carried out very quickly, and the other that the results can be easely interpreted. Both reasons are welcomed by architects.

For the purpose of calibration, the groundlevel of the measuring section (without a model) was sprinkled with flour. We made some tests with different wind tunnel speeds and turbulence intensities and found that the flour was blown away during the measuring time of 2 minutes when the sum of the mean velocity plus turbulence intensity $u + \sqrt{\overline{u'^2}}$ was about 7.5 m/s just above groundlevel. For the measurement of the velocity we used a hot wire anemometer. Therefore we assumed that in all our tests the flour would be blown away at $u + \sqrt{\overline{u'^2}} = 7.5$ m/s. This value was made non-dimensional using as reference the mean velocity at a height which corresponded to a full scale level of 12o m. The ratio of these two values may be defined to be a discomfort factor. One can find several definitions of such a factor in the literature. There are differences in the selection of the reference velocities, which are usually taken as the

mean velocities at the same height above the ground in the absence of the building. As to the characterisic velocity of the disturbed field we can find in some papers (Penwarden, 1974; Wiren, 1975; Wise, 197o) a mean value and in others a gust value $u + g\sqrt{\overline{u'^2}}$ (Isyumov and Davenport, 1975), where the gust factor g ranges over the interval $1 \leq g \leq 4$ (Lawson, 1975). This factor turned out to be 1, when the applied erosion method was used and agreed with the value proposed by Gandemer, 1976.

For measuring purposes the model of the entire building site was placed in the tunnel and the flat roofs were sprinkled with flour. The mean wind speed was increased in 4 steps, each lasting two minutes, during which period the flour was blown away over still larger areas. Photographs were made after each step, the same negative being exposed several times. The areas where the flour remained are the brightest, those where the flour was blown off first, the darkest. Due to these 4 steps the photographs show four different zones of discomfort; zone 4 being the worst (fig.1o).

1 : White $(u + \sqrt{\overline{u'^2}})/u_{ref} \leq .75$

2 : $.75 < (u + \sqrt{\overline{u'^2}})/u_{ref} \leq 1.00$

3 : $1.00 < (u + \sqrt{\overline{u'^2}})/u_{ref} \leq 1.25$

4 : $1.25 < (u + \sqrt{\overline{u'^2}})/u_{ref}$

The reproducibility of the applied technique is excellent.

The main towers have been erected in 198o and the office building is now in the final stages of construction. It will soon be possible to check the accuracy of the wind tunnel results against full scale measurements and observations.

ACKNOWLEDGEMENTS

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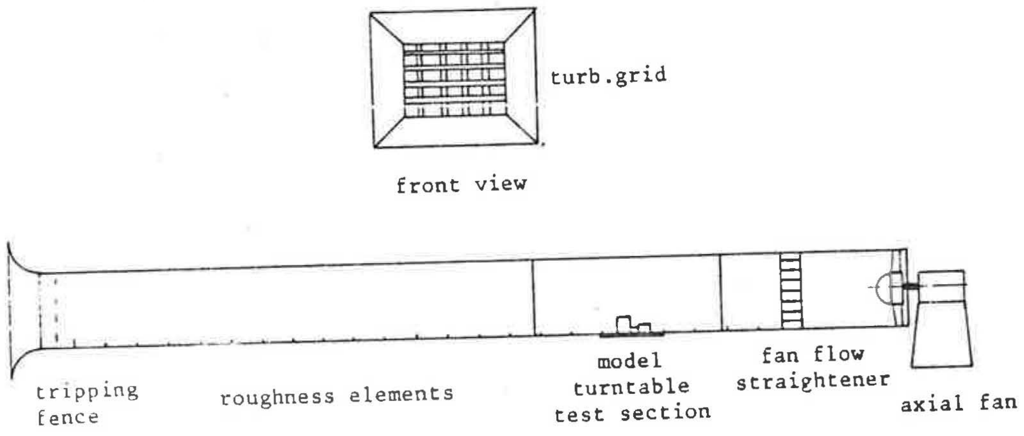


Fig. 1: Boundary layer wind tunnel

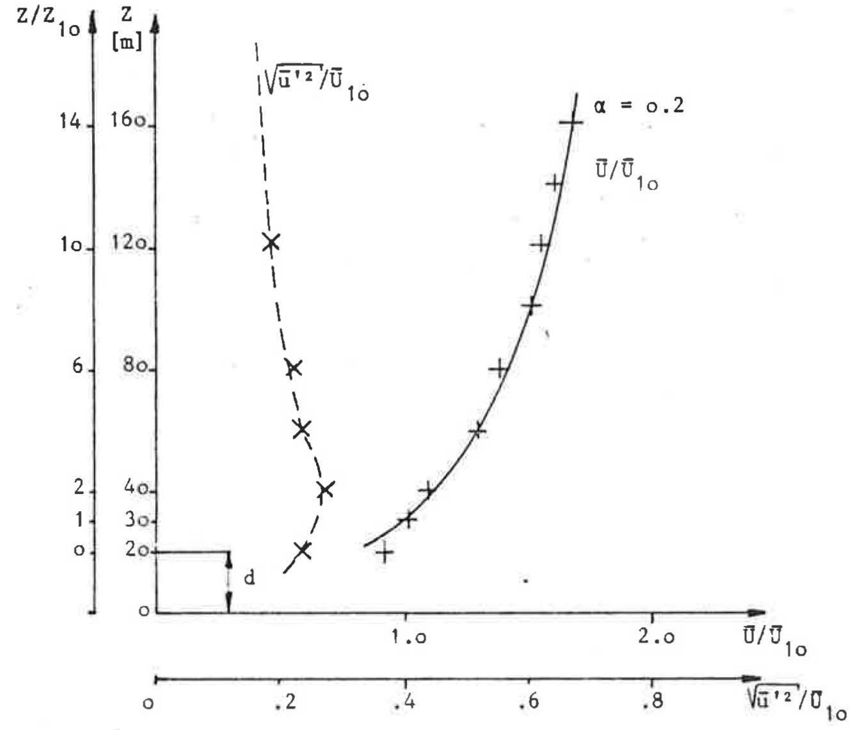


Fig. 2: Velocity profile and
longitudinal turbulence intensity

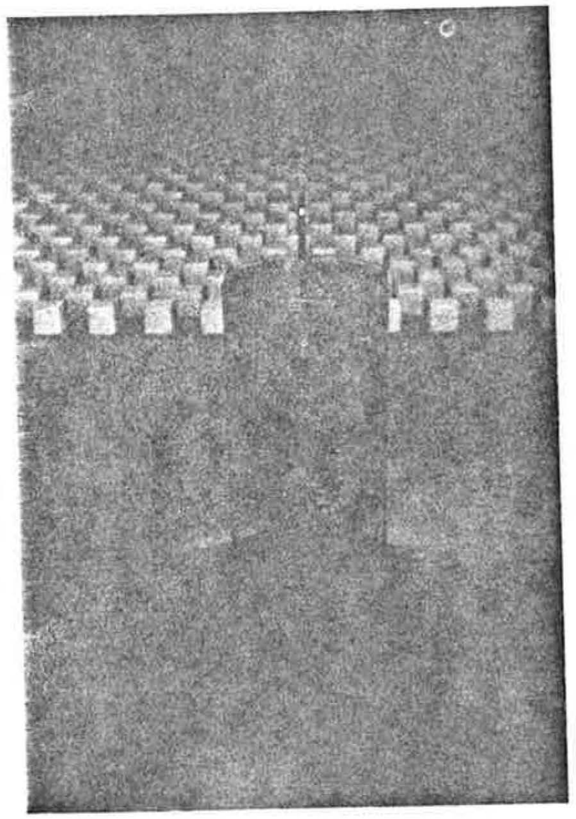


Fig. 3: Model of single octogonal tower on the scale 1: 2oo

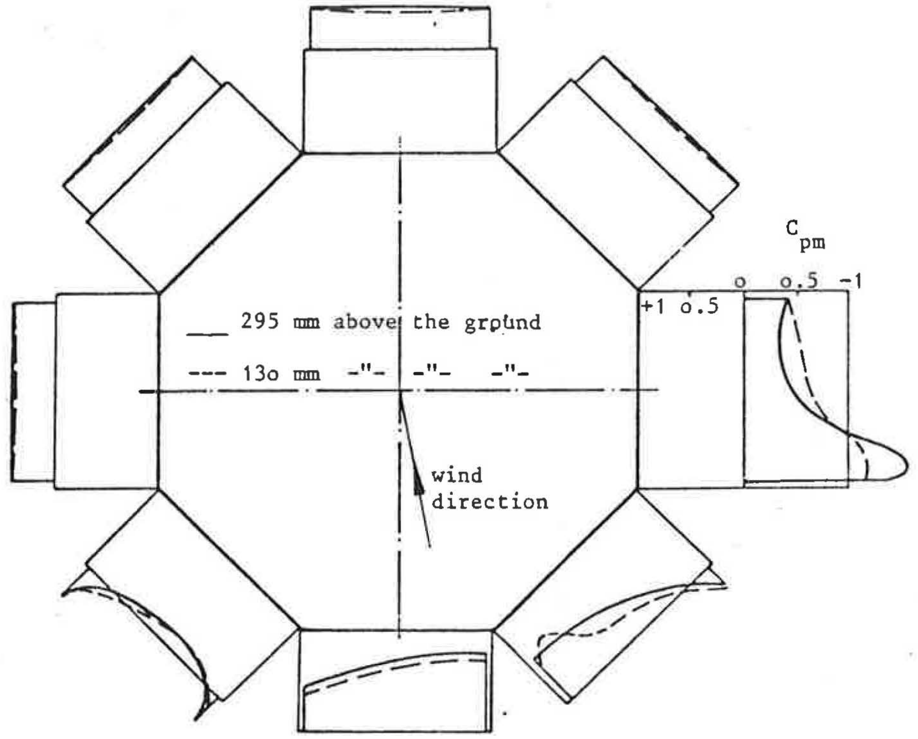


Fig. 4: Pressure coefficient C_{pm}
at different heights at the
perimeter of the octogon

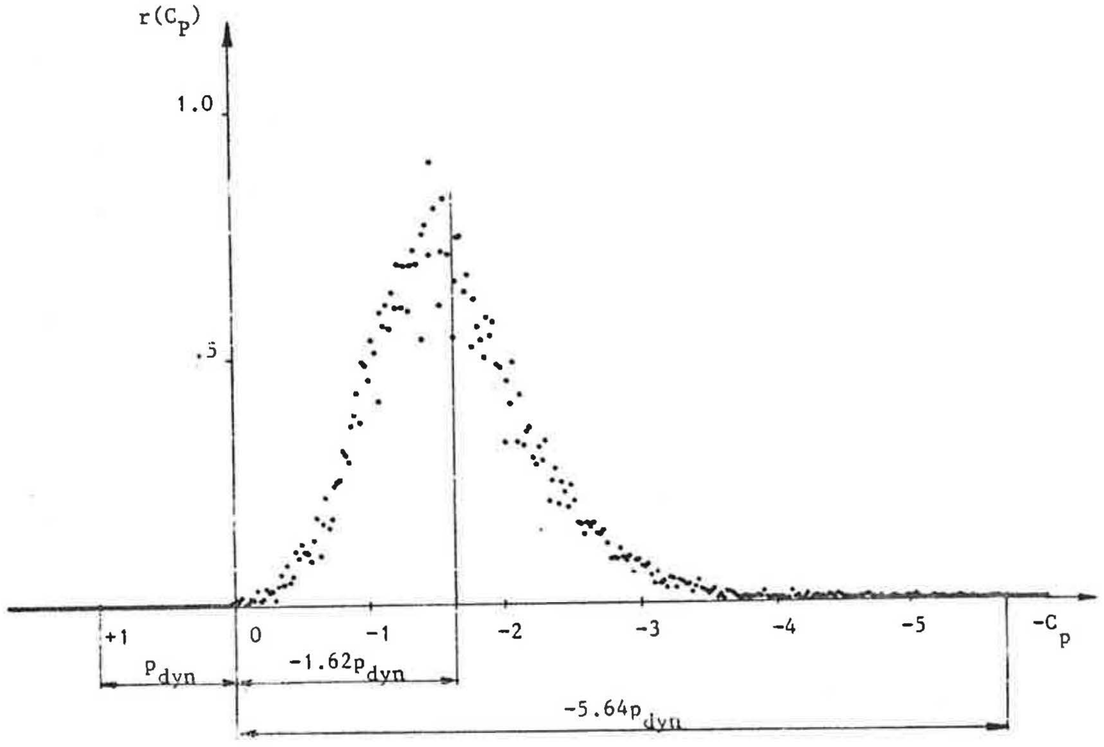


Fig. 5: Probability density distribution of pressure fluctuations

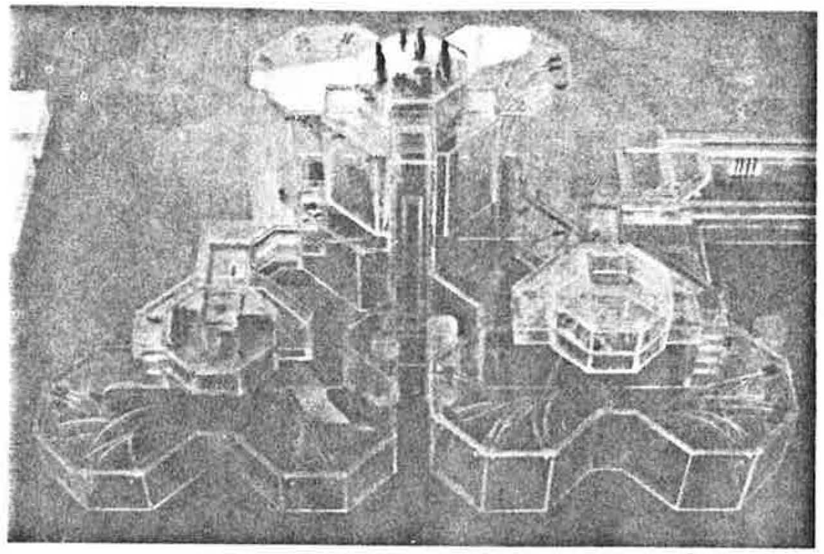


Fig. 6: Model of office building on the scale of 1 : 4oo

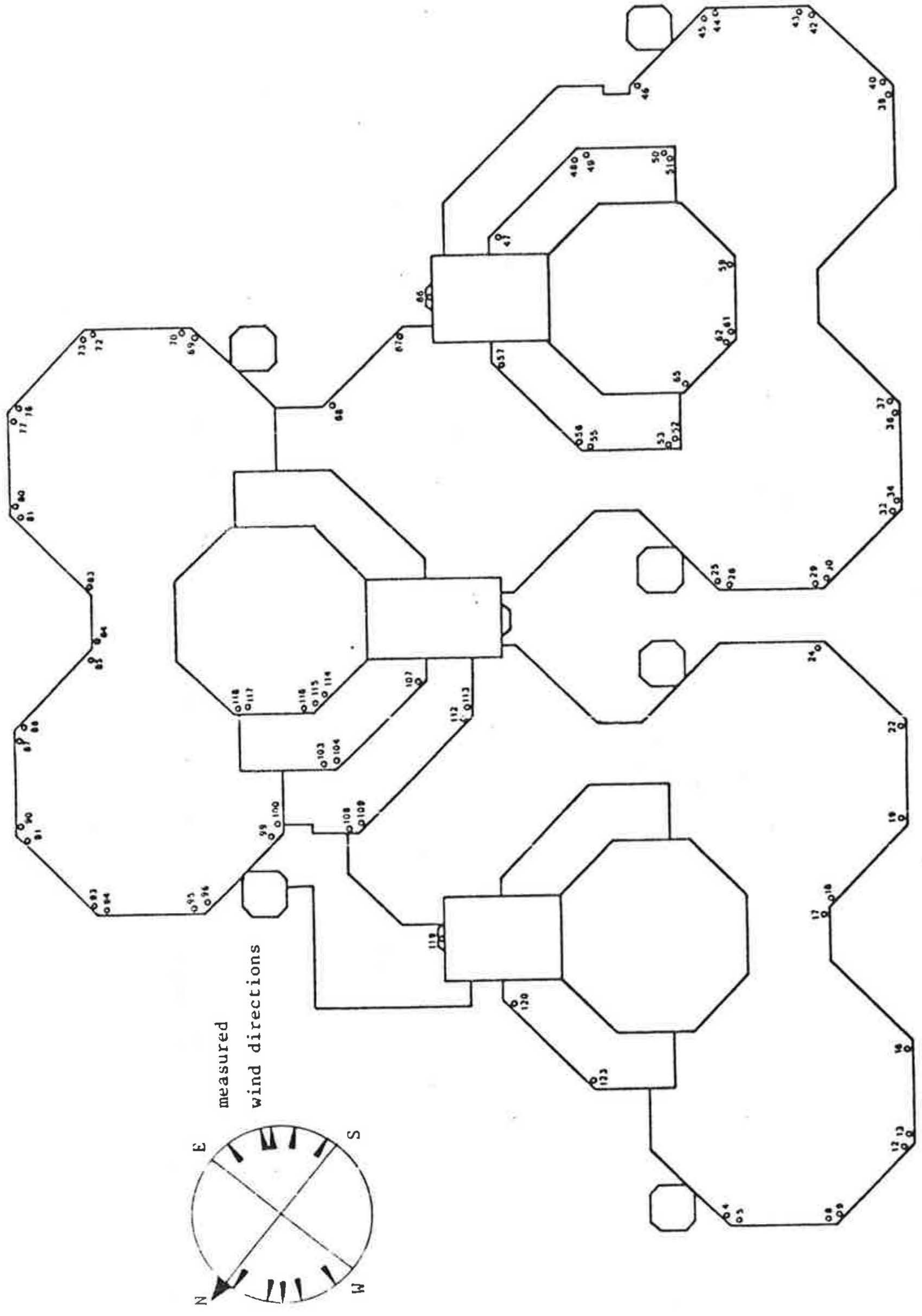


Fig.7: Setup of pressure taps on the model on the scale 1 : 4oo

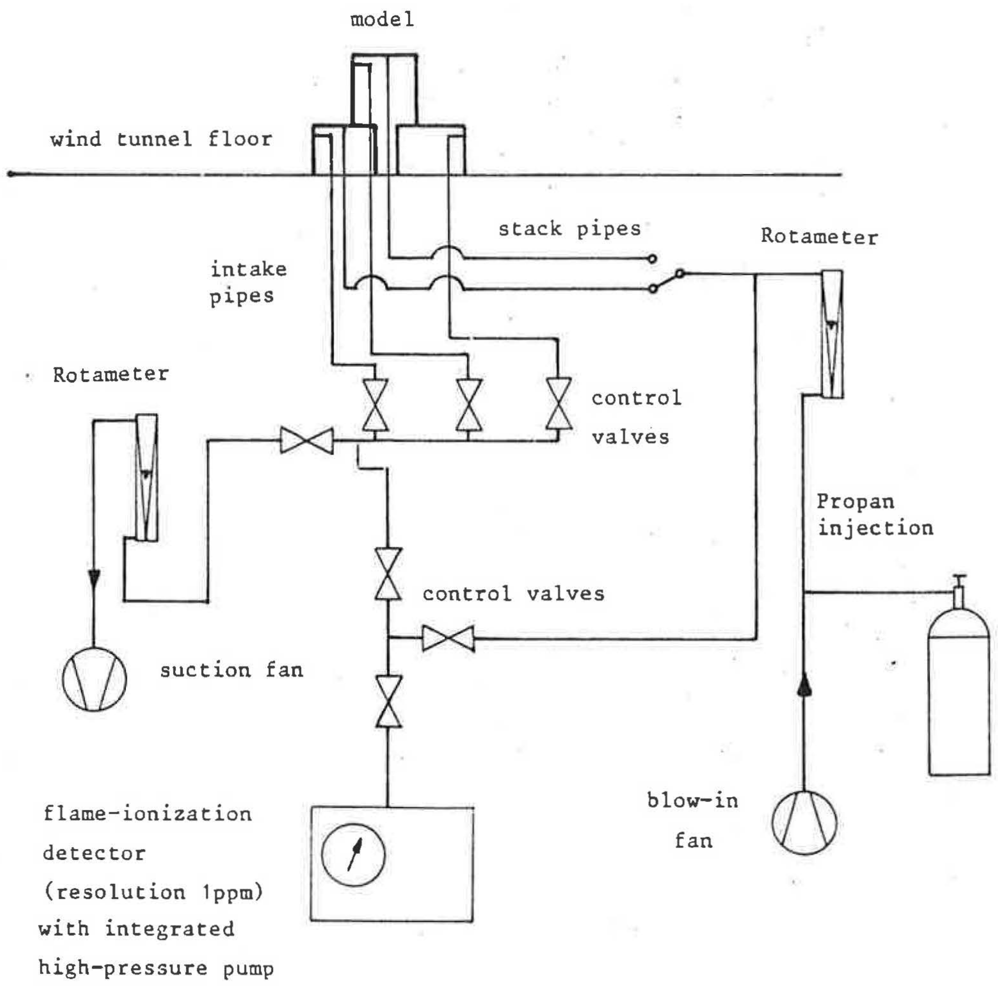


Fig. 8: Setup of the concentration measurement equipment

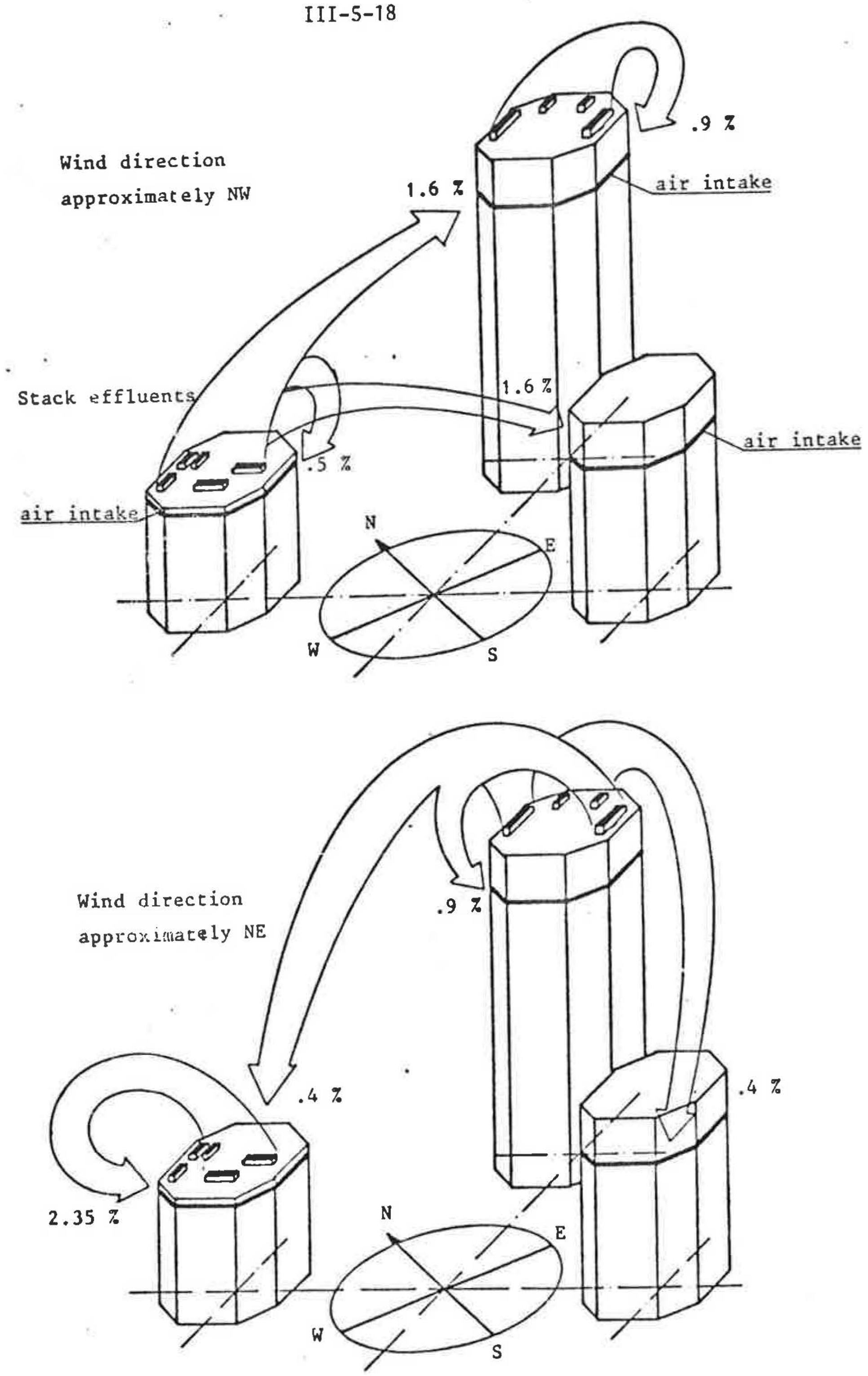
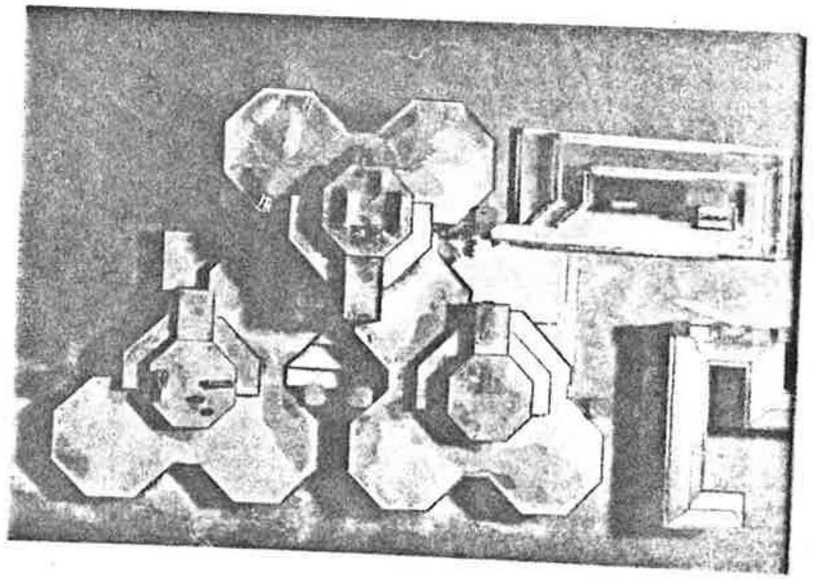


Fig. 9: Recirculation rate of effluents between the main towers at different wind directions



Wind direction NW

Fig. 1o: Velocity pattern on the roofs of the building

COLLOQUE "CONSTRUIRE AVEC LE VENT"
C.S.T.B. NANTES JUIN 1981

ETUDE DU TIRAGE DES CHEMINEES DU PROJET DE REACTEUR 1500 MWE A NEUTRONS RAPIDES

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RESUME :

Les réacteurs à neutrons rapides étant refroidis par du sodium à température élevée, il est particulièrement intéressant d'étudier pour les circuits ayant un rôle de sûreté des évacuations de puissance dans l'air par convection naturelle.

Le fonctionnement des circuits est lié au tirage des cheminées qui peut être lui-même influencé par divers paramètres tels que l'environnement du site, le plan masse de la centrale et les caractéristiques météorologiques locales en particulier la vitesse et direction du vent. Il est possible par un choix judicieux de l'emplacement des prises d'air et des aménagements d'ajutages de sortie de cheminées de rendre l'influence du vent toujours favorable.

Une étude a été confiée au CSTB NANTES au cours de laquelle ont été successivement abordées :

- l'étude du champ de pression induit par le vent sur les orifices d'aspiration d'air et d'extraction,
- l'étude de la géométrie des ajutages de sortie des cheminées.

Les conclusions de cette étude montrent que le bon fonctionnement des circuits est assuré pour l'ensemble des situations expérimentales envisagées.