FULL SCALE MEASUREMENTS OF WIND-VELOCITY AT THE NEW COMMERZBANK-BUILDING IN FRANKFURT/MAIN

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SUMMARY

This paper describes the first results obtained from measuring of the wind velocity with propeller-anemometers at different heights during the construction period of the new Commerzbank building in Frankfurt/Main. The anemometers were located on two cranes more than 10 m above the actual height of the building and rose in height with the cranes. Another anemometer was located approx. 10 m above the top of a nearby high-rise building to correlate the measurements taken at different times and heights. This enabled us to calculate a typical profile of mean wind velocity for such an inner-city region and to obtain some information about the statistical and dynamic properties of the wind. The data used for this paper were collected from February 1996 to October 1996, but the measurements will continue.

1 INTRODUCTION

The city of Frankfurt includes a unique constellation of high-rise buildings not found in any other town in Germany (see Fig. 1). The calculation of the windloads in such a region depends on a number of simplifications. For tall buildings the vertical profile of wind velocity has a significant influence on the

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windload. It is therefore very important to find out as much as possible about the vertical profile and other characteristics of the wind velocity.

The profile of the wind velocity depends on the roughness of the surrounding area. In urban areas this is very high but also very inhomogenous and we know only a little about it. In the old German code [1] the interdependence of wind loads and the roughness of the surrounding area is not taken into account. The windmap show only four zones with different mean wind velocities. Because of this simplification the windloads in urban areas will always appear higher than they are in reality. The new Eurocode 1 [2] includes four terrain categories with different roughness-parameters and in addition to that there are special windmaps based on different mean wind velocities for different locations.

![Fig. 1: View from the new Commerzbank-Building to the West](image-url)
The Commerzbank AG is now erecting a new high-rise building in the city of Frankfurt. This has given us the opportunity to take measurements in order to analyse the windloads in inner-city regions. It has been possible to measure wind velocity at different heights while the building was under construction because we were able to install the anemometers on cranes more than 10m above the actual height of the building and rising with the cranes as the building grew in height. In combination with another measuring instrument permanently installed at the top of a nearby high-rise building we calculated a relative wind-profile unaffected by the building itself.

These measurements can therefore give us a lot of information about the wind loads on tall buildings in urban areas such as Frankfurt which include many high-rise buildings.

Future plans include carrying out a wind-tunnel test to verify and generalise these results.
2 DESCRIPTION OF THE NEW COMMERZBANK-BUILDING

It is a 63-storey-building which reaches a height of approx. 300 m including a 40 m high mast at the top. It is located next to the old Commerzbank-building (110 m). The building is triangular in plan with slightly curved sides. Each side has a length of approximately 60 m. The sides are arranged around a large atrium. On every floor two of the sides comprise offices etc. and the third side comprises a garden or the space above a garden. The gardens are located on varying sides of the building. The height of comprises is four floors. Each side and core of the building reaches a different height. The highest core (the western elevation) reaches a height of 259 m and there is located a 40 m mast on the top (see Fig. 3).

Fig. 3: Eastern Elevation of the Commerzbank-Building
Wind resistance is given by the three cores, which will be found in the corners of the building. The main construction elements are six mega-columns (7.77 m x 1.20 m) located in these cores. The two mega-columns in each corner are coupled by steel-framework. The cores are coupled along each elevation with steel-frames which are eight floors high, followed by four floors (the floors with the garden/enclosing a garden) without any connection. The columns themselves are of mixed construction consisting of a steel framework and reinforced concrete.

The floors are also of mixed construction combining steel beams and concrete slabs on metal panels. The structure spans from the steel frames in each elevation to the steel-beams in the atrium, which rest on three steel columns in the corners of the atrium (see Fig. 4 and Fig. 5).

The building has a pile foundation structure. The piles are approx. 45 m long reaching through the clay below the building into the limestone underneath. Many piles hold measurement instruments providing data which is analysed by the „Institut für Geotechnik“ at the TH Darmstadt.
3 DESCRIPTION OF THE EQUIPMENT

3.1 Measurements of the wind velocity

The wind-velocity is measured with propeller-anemometer. The specifications are shown in Table 1.

At each point of installation we have three anemometer measuring the wind velocity in three dimensions in order to determine absolute velocity and direction. There are three points of measurement: two on the cranes above the new building and one on a 6 m high mast on top of the nearby Eurotower (147 m) (see Fig. 6).
The anemometers on the building site change their position with the cranes throughout the building period. They are more than 10 m above the actual height of the building for most of the time. Because of some problems while the experiments were carried out data is only available for heights of 216 m, 220 m and 261 m at the building site and 153 m at the nearby high-rise building.

Table 1: Specifications of the propeller anemometer

<table>
<thead>
<tr>
<th>Description</th>
<th>Propeller Anemometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring mode</td>
<td>Digital (Impulses)</td>
</tr>
<tr>
<td>Range</td>
<td>±0.15 ~ ± 60 m / sec</td>
</tr>
<tr>
<td>Accuracy</td>
<td>&lt; 1.0 % of value measured</td>
</tr>
<tr>
<td>Resolution</td>
<td>&lt; 0.13 cm / sec</td>
</tr>
<tr>
<td>Length of inertia</td>
<td>2.0 m ± 0.1 m</td>
</tr>
<tr>
<td>Measurement cycle</td>
<td>Once every two seconds</td>
</tr>
</tbody>
</table>
Fig. 6: Location of the three measurement instrumentation

The data is transmitted by radio to a Personal Computer located in a room in the second basement and the data from all anemometers is stored simultaneously every two seconds. The data which forms the basis of this paper was obtained from February to October 1996, and measurements are to continued. It is planned to install a set of anemometers on a mast at the top of the building at a height of approximately 275 m once the building is completed.

The data used here is derived from measurements taken over three periods at different heights. During the first period the measuring instruments were installed at heights of 216 m and 220 m at the building site and a height of 153 m at the nearby high-rise building. During the second period the instruments were located at heights of 261 m, 220 m and 153 m. During the final period, since May 1996, only two instruments were taking measurements at heights of 261 m and 153 m respectively. The most useful results for our analysis will came measurements taken during the second period.
3.2 Measurements of the longitudinal extensions

In addition to the instruments measuring wind velocity we have installed 29 instruments at first floor level in the six mega-columns in order to measure the longitudinal extensions. These measurements were transmitted to the PC every ten seconds simultaneously with the wind velocities measurements. This enabled us to calculate the Normalforces and the Moments at point of fixation of each of the mega-columns and the baseline of the building as it show us the reaction of the building to the wind loads. The results of these tests are not included in this paper.

4 RESULTS OF THE WIND MEASUREMENTS

4.1 Profile of the mean wind velocity

During periods of strong winds the ten-minute mean wind-velocity will form a typical profile, which can be described with the help of two models: the log-law model and the power-law model. The following sections give details of our analysis of the data obtained from the measurements compared to the profile provided by these models

4.1.1 Log-law model

The log-law model is based on a logarithmic profile and is defined as:

\[ V(z) = \frac{u^*}{\kappa \ln\left(\frac{z-d_0}{z_0}\right)} \]
with

\[ V(z) \text{ mean wind speed at height } z \]
\[ d_0 \text{ zero-plane displacement} \]
\[ u^* \text{ friction velocity } (= \sqrt{\frac{\tau_0}{\rho}}) \]
\[ \rho \text{ air density} \]
\[ \tau_0 \text{ shear stress at ground level} \]
\[ \kappa \text{ von Karmans’ constant } (\approx 0.4) \]
\[ z \text{ height above ground} \]
\[ z_0 \text{ aerodynamic roughness length of the surface} \]

Fig. 7 and Fig. 8 show the normalised ten-minute mean velocity \( V/V^* \) using typical parameters for inner-city regions with low-rise and high-rise buildings (see [4],[5]). The values used are \( d_0 = 15 \) m and \( z_0 = 3.0 \) m.

![Graph showing normalised ten-minute mean velocity](image)

Fig. 7: Comparison of the measured 10-min. mean velocity in a period of approx. 30 min. with the log-law model. Date: 21.03.1996
Both Figures show that the measured wind velocity at the lowest height of 153 m is considerably below the ones calculated for the model. Trying to find parameters which can accurately describe the measured velocities will lead to unrealistic results. One influencing factor could be identified as the direction of the wind. The velocity at the height of 153 m is measured at the top of the nearby Eurotower. When the wind blows from north-north-east, the Eurotower is under the lee of the new building. The effect of this is shown in Fig. 9.

Fig. 8: Comparison of the measured 10-min. mean velocity in a period of approx. 60 min. with the log-law model. Date: 16.04.1996

Fig. 9: Comparison of two measurements: Eurotower under lee and not under lee.
### 4.1.2 Power-law model

The power-law model is represented by the following formula

\[ V(z) = V_{\text{ref}} \left[ \frac{z - d_0}{z_{\text{ref}}} \right]^\alpha \]

This model has no theoretical verification but is purely empirical. Typical values are for urban areas are \( d_0 \approx 15.0 \text{ m} \) and \( \alpha \approx 0.40 \) (see [3]). Fig. 10 shows the normalised ten-minutes mean velocities \( V/V_{\text{ref}} \) of a typical measurement. The velocities at the lowest height will again be considerably below the velocities predicted by the power-law. The result of this comparison is almost identical to the one shown for the log-law model above.

For \( \alpha = 0.69 \) the correspondence between the measurements and the predictions of the power-law model is found to be good. This very flat profile is shown in Fig. 11.

![Graph showing comparison of measured velocities with predicted ones](image)

**Fig. 10:** Comparison of the measured 10-min. mean velocity in a period of approx. 60 min. with the power-law model. Date: 16.04.1996
4.2 Turbulence structure

Through analysis of the data, turbulence intensity $I_U = \sigma_u / U_m$ and gust factor $G_U = U_{\max} / U_m$ were calculated. The values were calculated for an interval of 10 minutes. Fig. 12 shows the relationship between the mean wind velocity and the gust factor for heights of 153 m and 261 m. The data was obtained from the observation of the storm “Lilly” between 28th and 31st of October. It can be seen that the gust factor increases when height decreases and that the dispersion of the distribution of the gust factor decreases when the mean wind velocity increases.

Fig. 13 shows the relationship between turbulence intensity and mean wind velocity. Again it can be seen that turbulence intensity increases at the lower height and that the dispersion decreases with increases in the mean wind velocity. In addition to Chap. 0 the roughness lengths can be obtained from the gust factor using the relation

$$\sigma_{u(z)} / u_z = 1 / \ln(z / z_0)$$
Fig. 12: Relationship between mean wind velocity and gust factor

Fig. 14 shows the relationship between mean wind velocity and the roughness length calculated from the turbulence intensity. For \( H = 153 \) m the calculated roughness length for high mean wind velocity is approx. 7 m. This implies a high degree of influence from the rough urban area. At the height of 261 m the calculated roughness length for high wind velocities is approximately 0.1 m. At this height, the influence of the roughness of the ground is very small.

Fig. 13: Relationship between Mean Wind Velocity and Turbulence Intensity
CONCLUSIONS

The results presented above are only a small sample of results from the huge amount of data collected during the measuring period. The data shown are representative of the measurements as a whole. It is very significant that in city regions such as Frankfurt/Main the profile of the mean wind velocity decrease more slowly at lower heights than is predicted in the standard and works of reference. In [5] a city like Frankfurt with high-rise building is classified as „chaotic“. This means that no typical wind profile can be determined. However, our measurements show that the models used will always overestimate the velocities for heights lower than 250 m.

Our next step will be a wind-tunnel test to verify the measurements discussed above. In such a test we should be able to access the influence of nearby high-rise buildings and generalise the results for different conditions.
Literature


[2] Eurocode 1, Part 2.4 „Wind loads“


