Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 79 (1998)

Artikel: Wind velocity and building reactions of high-rise structures
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DOI: https://doi.org/10.5169/seals-59942

Wind Velocity and Building Reactions of High-Rise Structures

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Summary

This paper describes the results obtained from wind velocity measurements at different heights in combination with longitudinal extensions in the main construction elements during the construction period of the new Commerzbank building in Frankfurt/Main. Additionally, a wind-tunnel test was carried out for comparison. A typical profile and other characteristics of the wind velocity plus resulting reactions of the building in an inner-city region were measured and compared with theoretical calculations and the coming European standard Eurocode 1 Part 2.4 "wind loads". The main result showed, that wind loads on high-rise buildings in inner-city regions are assumed much too high in the German and European standard, and, as such, may be reduced.

1 Introduction

From 1995 to 1997 a new high-rise building for the Commerzbank AG was erected in the city of Frankfurt (see [4], [6] and [10]). It is a 63-story building, which reaches to a height of approx. 300 m, including a 40 m high mast - making it the tallest building in Europe (see Fig. 1). It is located in an area with many other high-rise buildings.

This provided the opportunity to measure and analyze the wind velocity and resulting wind loads on a high-rise building in such an inner-city region. For tall buildings the vertical profile of wind velocity has a significant influence on the wind loads.

The wind velocities were measured on cranes at heights of 261 m, 219 m, and 216 m at the building site, at 153 m on top of a nearby high-rise building, and at 60 m in a region with only lower buildings. The measuring instruments for the longitudinal extensions were located inside 6 mega-columns on the 1st floor to get the reactions at the baseline of the building.

Thus, it was possible to measure the wind velocity at definite heights and the resulting base moment of the building from the wind loads simultaneously. Additionally, a wind-tunnel test was carried out to generalize the results.

Fig. 1: Eastern elevation of the new Commerzbank-Building

2 Description of the equipment

2.1 Measurements of the wind velocity

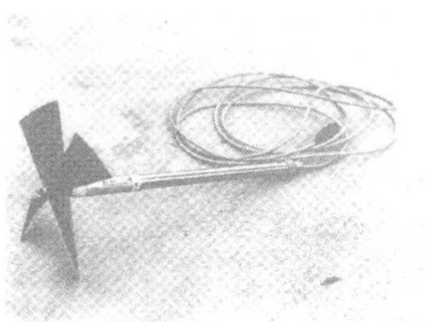
During the construction period three measuring points were installed: two on top of the cranes, which were raised consecutively with each constructional phase, and one on a 6 m high mast on top of the nearby Eurotower (147 m) (see Fig. 3 and Fig. 4). At each point of installation three anemometers measuring the wind velocity in three directions were implemented to determine the absolute velocity and direction. Most of the time, mainly at the end of the construction period, two installations were available, one on a crane at a height of 261 m and one on the Eurotower. The specifications of the used anemometers (see Fig. 2) are shown in Table 1. In addition to these measurements, the mean wind velocity at a height of 60 m was obtained from a weather station located 2 km from the Commerzbank tower in an area with only lower buildings.

The data were transmitted via radio signal to a PC located in a room in the second basement, and the data from all anemometers were saved simultaneously every two seconds (for detailed information see [5]).

Table 1: Specifications of the propeller anemometers

Description	Propeller Anemometer
Measuring mode	Digital (Impulses)
Range	±0.15 ~ ± 60 m / sec
Accuracy	< 1.0 % of value measured
Resolution	< 0.13 cm / sec
Length of inertia	2.0 m ± 0.1 m
Measurement cycle	Once every two seconds

Fig. 2: propeller-anemometer



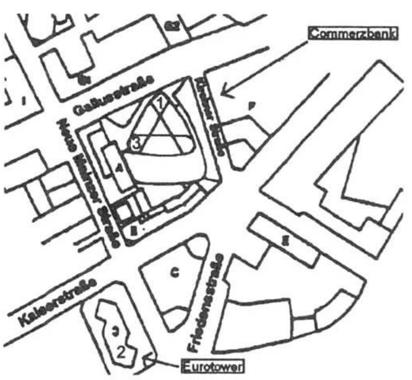


Fig. 3: Location of the measurement instrumentation (1, 2, 3)

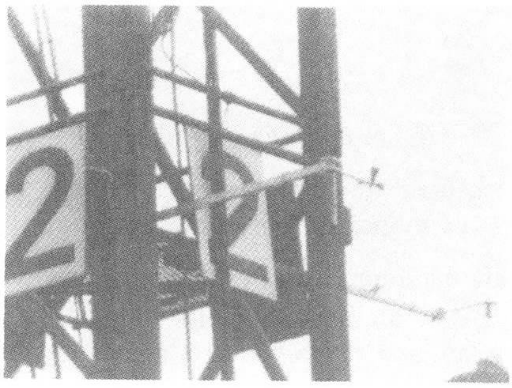


Fig. 4: Propeller-anemometer at crane 2 (Installation Number 1)

2.2 Measurements of the longitudinal extensions

The total resistance of the building against wind is provided by the six mega-columns coupled with steel frameworks. Thus, it was possible to calculate the whole reaction of the building against wind only from the measured extensions, using the modulus of elasticity and section modulus.

Strain transducers were installed at the first floor level within the six mega-columns (in addition to the instruments for the wind velocity) in order to measure the longitudinal extensions. Each column contains 5 steel bars with anchor plates at both ends (see Fig 5) and strain gauges used in a full-bridge configuration. The strain transducers were embedded in the reinforcement before casting (see Fig. 6).

The data was collected simultaneously with the wind velocities at ten-second intervals, rendering the analysis of the correlation between wind velocity and the reaction of the building possible.

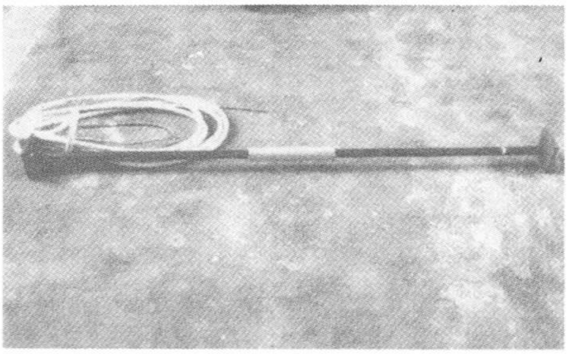


Fig. 5: Strain transducers

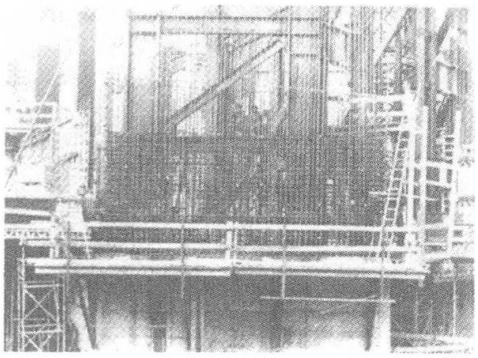


Fig. 6: Mega-column under construction

2.3 Wind-tunnel test

A wind-tunnel test was carried out to obtain additional information about the reaction of the Commerzbank-building against wind and generalize the full-scale measurements.

The pressure on the surface of the building was measured at 270 points for 12 different wind directions. Using these measurements, the base moment was calculated. The profile of the wind simulated in the test was a power-law profile with an exponent $\alpha = 0.25$. For detailed information see [7] and [9].

3 Results

3.1 Profile of the mean wind speed

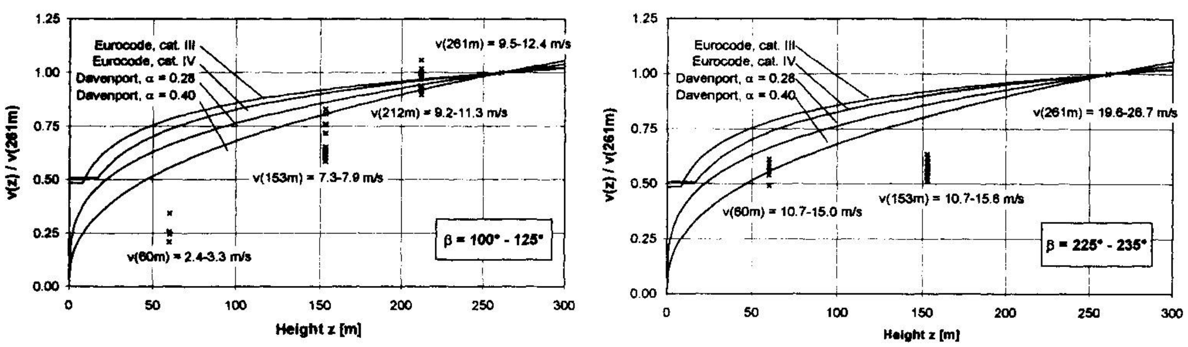
The measured wind velocity was compared with the power-law model from Davenport [3] and the log-law model used in Eurocode 1.

The left diagram in Fig. 7 shows mean wind velocities measured in ten-minute intervals at heights of 60 m, 153 m, 212 m, and 261 m. The measurements are compared with the results of the log-law and the power-law model for the terrain categories "suburban" ($\alpha = 0.28$, Kat. III) and "city-centers" ($\alpha = 0.40$, Kat. IV). These velocities are put into relation to the velocity at the height of 261 m.

The right diagram in Fig. 7 shows the measured mean wind velocities without the values at the height of 212 m. However, the wind velocities measured on this day were the highest ones of all measurements carried out.

These figures show that the measured wind velocity is always lower than the velocities calculated with the log-law profile and also lower than calculated with the power-law profile for suburban areas. It can also be seen that the velocities calculated on the basis of Eurocode 1, categories III and IV, are greater than those calculated on the basis of the power-law model for the suburban areas ($\alpha = 0.28$) and city-centers ($\alpha = 0.40$). The profile of the log-law model is very flat, indicating that the velocities at the lower heights are too high.

The turbulence intensity and the spectral density of the measured wind velocities was also compared with the definitions by Davenport and Eurocode 1, but is not presented here. Detailed information is given in [1] and [2].



Date: 16.4.1996 Date: 29.10.1996 (storm "lilly")

Fig. 7: Comparison of the measured ten-min. mean velocity with those calculated with the power-law and the log-law model. At two different times.

3.2 Reaction of the building against wind

The dependence of the base moments on the wind direction is very strong. Therefore, the measured base moments were divided in a component around the east-west axis and the north-south axis.

Fig. 8 and Fig. 9 show the east-west and the north-south components of the base moment calculated on the basis of the wind-tunnel test and derived from the full-scale measurements. The moments are related to the wind pressure at 261 m.

The values obtained from the full-scale measurements are all similar to or lower than the wind-tunnel results. This means that the profile of the wind velocity has an higher exponent α than predicted by the wind-tunnel test. Only for the direction of 240° to 270° the wind-tunnel results and the full-scale measurements show nearly identical results due to a more precise modeling of the many high-rise buildings located in this direction and used in the wind-tunnel test.

In addition to the measurements, the reaction against wind was calculated with Eurocode 1 and Davenport. Table 2 shows the measured and calculated base moments for a similar situation. The actual reaction of the building is much lower than the calculated one according to Davenport or Eurocode 1.

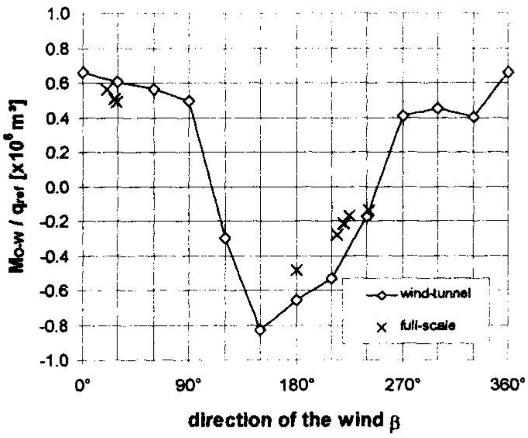


Fig. 8: Related base-moments around east-west axis

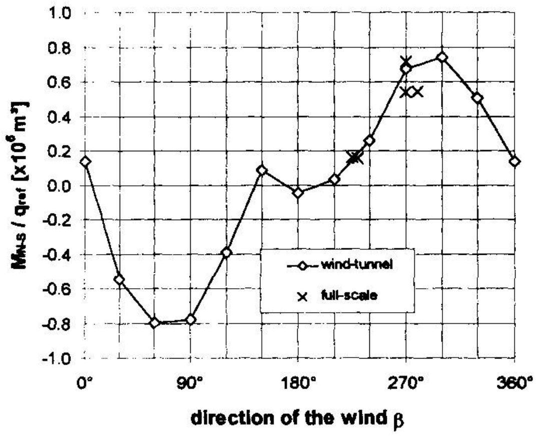


Fig. 9: Related base-moments around north-south axis

Table 2: Calculated and measured base-moments

Source	Base-Moment [MNm]
Full-scale measurements	686
Wind-tunnel test	825
Davenport, α=0.16 (=German standard)	1585
Davenport, α = 0.28	1120
Davenport, α = 0.40	727
Eurocode 1, Cat. III	1239
Eurocode 1, Cat. IV	956

4 Conclusion

The results of the measurements prove that in city regions - as, for instance, Frankfurt/Main - it seems to be permissible to use an exponential profile of the mean wind velocity with an exponent of $\alpha = 0.28$. Most measured data would also correlate to calculations with an exponent of 0.40. Also, the log-law model used in Eurocode 1 is very flat and does not correlate to the measurements. Therefore, it seems to be possible to reduce the wind loads given in Eurocode 1 for high-rise buildings.

The wind loads given in Eurocode 1 are restricted to buildings lower than 200 m. For high-rise buildings above 200 m, no standard will be given to calculate the wind loads. So it is necessary to establish another concept to describe these loads.

The measurements have proven, that a power-law model used to describe the profile of mean wind-velocity using parameters like ones described by Davenport will lead to realistic results. To generalize the results, however, measurements at other locations are necessary. Also, only little information was available regarding the dynamic characteristics of the wind velocity and the building. Further information in this field is needed.

In a next step, the "Institut für Massivbau" of the University of Technology in Darmstadt is carriging out new full-scale measurements at another new high-rise building in Frankfurt/Main, which is currently under construction.

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