

Modern design of television towers

F. LEONHARDT

Professor A. L. L. Baker, Imperial College of Science and Technology, London

Professor Leonhardt's elegant towers which are dotted all over Germany remind one of the more elegant chess pieces. I congratulate him on the way he has explained the problems of design and faced up to them with a great sense of responsibility.

90. In the UK we are finding, that in going higher, in many ways we are reaching a significant stage in design: we are going higher, we are meeting more wind pressure and we have lighter structures. We are therefore facing very indeterminate problems of much greater risks.

91. A draft wind loading code has been produced, and in recent discussions on wind my impression has been that in the new code, which is based mainly on experimental evidence in wind tunnels with some comparison with measurements in the field, the pressures are now a bit high, because if they occurred as predicted by the code, there would have been more damage in certain hurricanes and storms that we have had. I suspect that the discrepancy may be in extrapolating from the wind tunnel tests to the actual conditions in the field. Has Professor Leonhardt had similar experience?

92. Does he allow for tension in the concrete on these towers? I have always argued strongly against this. It may be that contractors in Germany are more reliable in making joints, but I would not allow for it in a case in which there could be uplift and in which lack of tension might lead to overturning of the top or some sort of failure.

93. We had an unfortunate experience with the cooling towers at Ferrybridge in which, had the concrete taken tension, the failure would not have occurred. As three towers collapsed and three stood up, the safety factor must have been about unity.

Mr M. Rees, Watermeyer, Legge, Piesold & Uhlmann

My first comment concerns the plate foundation versus the ring foundation. We have found on much lesser structures than these magnificent radio towers, namely for ordinary cylindrical chimneys up to some 80 m high, that the plate foundation provides a cheap method of improving the factor against overturning in conjunction with sand filling in the annular ring towards the bottom. I suppose it is the scale of the large radio tower that prevents one from doing this and so makes the plate foundation possible.

95. My second point concerns transverse and in-wind oscillations of the tower. Professor Leonhardt showed wind velocity plotted against transverse deflexion. Judging from the scale of deflexions at about 40 mm I would suggest that as one had dinner in the restaurant, oscillating presumably at about the natural frequency once every six seconds or so, the effect as the wind got up would perhaps become a little uncomfortable.

Mr H. L. Burrough and Dr M. J. Tunstall, Central Electricity Research Laboratories

High rise towers have certain structural features in common with the large chimney stacks which are being studied at CERL. Model and full-scale experiments are being conducted to determine the aerodynamic and structural parameters governing their wind excited oscillations.

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97. At sub-critical Reynolds number two-dimensional cylinders in uniform flow shed coherent vortices which may be represented by the well known von Kármán vortex sheet. The spectrum of velocity fluctuations in such a wake exhibits a narrow band peak at the vortex shedding frequency. In a wind tunnel a well defined critical speed is associated with the resonance between the coherent vortex shedding frequency and the model's natural frequency. These conditions may not exist for many full-scale structures where the coherency of the wake vortices can be influenced by a number of factors. These include the ratio of height to diameter, abrupt changes of diameter, taper angle, proximity to other buildings, turbulence and shear of the natural wind and efflux in the case of chimneys. Tests on aeroelastic finite models in non-uniform flows suggest that many of these factors tend to reduce the coherency of the vortices.

98. In a turbulent wind, if there were no wake excitation and assuming quasi-steady buffeting to apply, then the in-wind motion would be greater than the cross-wind motion. Dr Leonhardt's observations at Stuttgart agree with ours on full-scale stacks in that the cross-wind movement is the larger. The response of these chimneys to wind excitation plotted as amplitude against time appears as a modulated sine wave with a narrow band spectrum centred on the structural frequency. This compares closely to the response of a single degree of freedom, lightly damped oscillator responding to a broad band forcing function in the classical manner.

99. The broad band forcing function is a direct result of the vortices shed by these structures having their coherency reduced. Thus well defined critical wind speeds may not occur. There is no implication that the vortex shedding frequency is affected by the structural frequency. This type of interaction has been noted on models in uniform flow, but is limited to a narrow band about the critical wind speed where the frequency of the vortices is pulled to the structural frequency. It is unlikely that this phenomenon (vortex locking) is enhanced by the various factors mentioned.

100. From Fig. 44 it is not clear whether the ordinates are root mean square transverse amplitude and mean wind speed (and if so, what the averaging periods were) or instantaneous measurements of peak amplitude and wind speed. The data can be approximated by a power law of exponent two or slightly greater. This suggests that the spectrum of the forcing function in the region of the structural frequency was flat, implying either that the recorded wind speeds were far removed from the critical wind speed or that the forcing function was broad band. It would be interesting to know the cross-sectional dimensions and the natural frequency of the structure so that estimates of possible critical speeds could be made.

101. Measurements on a 198 m concrete stack with a mean diameter of 19 m have shown the logarithmic decrement of damping to be 0·03. This cannot be considered a high damping, even compared to steel stacks, particularly since for a broad band excitation the root mean square amplitude would be proportional to the inverse square root of the damping. However, the maximum observed amplitude of the concrete stack to date has been approximately 30 mm. We attribute this to two possible causes. First, a critical wind speed for the stack is likely to exceed 40 m/s, which is rarely approached. Second, measurements of the pressure exerted on the chimney surface at wind speeds up to 15 m/s indicate only broad band contributions from the vortex shedding.

102. It is essential that measurements are made on tall structures because of the difficulties in obtaining the very high Reynolds numbers relevant to full-scale structures in the available wind tunnels. While such results cannot replace wind tunnel testing, they will guide it and provide means of assessing its reliability.

Professor Leonhardt

In reply to **Professor Baker**, we also found that the measured deflexions of towers were considerably smaller than those which are calculated with quasistatic loads from the measured maximum speed of gusts with wind factors measured at models in wind

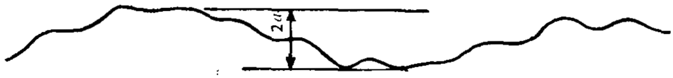

Fig. 45. Oscillation diagram

tunnels. This is probably due to the short duration of the gust peak and the inertia of big structures. Only further measurements on high rise structures can clarify the true behaviour.

104. We allow tension in the concrete of the tower shaft and are not afraid even of hair cracks under high wind loads. Of course, there must always be sufficient reinforcement, dimensioned for limit design so that there is the required or specified safety against overturning or other sorts of failure.

105. With reference to **Mr Rees's** comments, it is true that it is the large scale of the television towers which makes ring foundations superior to plate foundations, the latter being simple and economical for chimneys up to about 100 m high.

106. The wind oscillations with frequencies of $\frac{1}{5}$ s give such small accelerations that normal people do not feel them when sitting at a table in the restaurant. So far there have been no complaints of guests feeling uncomfortable. Due to the smooth façade there are also no disturbing wind noises in the restaurant during storms.

107. In reply to **Mr Burrough** and **Dr Tunstall**, the measurements of the wind-excited oscillations at the Stuttgart Tower were made between 1958 and 1959 with instruments and arrangements which were not fully suited for the purpose.[4] Since then better ways of measuring and recording such oscillations have been developed and will soon be used at different towers.

108. The wind velocity as plotted in Fig. 44 represents the average speeds of gusts measured by an anemometer of Fues fixed to the steel lattice mast on top of the tower, about 170 m above ground and about 4 m from this steel mast towards the main wind directions, thus getting the wind undisturbed by the tower itself. The maximum speed observed was 26 m/s. The oscillations were measured with two seismographs inside the concrete shaft at a height of about 160 m and during storms recorded on tape moving at 20 mm/s, giving records as shown on Fig. 45. The amplitude on Fig. 44 is half of the maximum value $2a$ of the oscillation's way transverse to the wind direction.

109. The natural frequency of the tower was measured to be 0·22 Hz for the first order and 1·3 Hz for the second order. The diameter d of the tower shaft is 10 m at the base and 5·0 m just below the four floor head at a height of about 136 m. Undoubtedly, further measurements at towers or tower-like high rise buildings will have to be made to be able to come to a better understanding of the real wind forces on tall structures with Reynolds numbers above 10^6.

Reference

4. LENK H. Über die Windschwingungen des Stuttgarter Fernsehturmes. *Die Bautechnik*, 1966, **5**, 7–8.