

Preventing wind-induced oscillations of structures of circular section

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The problem of wind-induced oscillations of structures has been with us for some time now. There are several causes of aerodynamic instability and a large number of variables, both structural and aerodynamic, to be taken into account when considering the stability of a particular structure. Because of this, the scope of this Paper has been deliberately restricted to instability arising from vortex shedding from structures of circular section in order to provide as complete as possible coverage of at least one aspect. The intention is to give the engineer a comprehensive background in this particular field, to review the existing means of preventing instability, and to point out the uncertainties that still exist.

68. The Paper is concerned entirely with circular section structures for two reasons. First, the circle is a common form of structural shape and, second, most is known about the flow round these sections. We must emphasize, however, that we did not choose the circular section because it is the worst shape from stability considerations; there is every indication that many other sectional shapes are worse.

69. It seems likely that the problems of wind-induced oscillations will become more important with the advent of a new wind loading Code of Practice. This will probably reduce the time-averaged wind loading applicable to the circular section and will result in lighter and more flexible structures. These will be more prone to oscillate than structures designed to the old code.

Mr R. N. Sainsbury, John Mowlem & Co. Ltd

At one point in the Paper it is said that no instance has occurred of a full-scale concrete or brick stack oscillating. I wonder whether this is entirely in line with the Authors' expectations, or whether there are some concrete stacks which they would have expected to oscillate but did not and, if so, whether they feel there is a generally stated rule or expectation that concrete stacks will not oscillate and designers of concrete stacks can forget this hazard.

71. It was suggested that if mass is added to the top of a stack in an attempt to exclude oscillation in the first mode, the reduction of frequency of the second mode might bring that into the critical range. Because of the normally large difference between first and second natural frequencies this would seem improbable. I should be interested to know whether there have been cases of this actually happening, or whether this is a hypothetical situation which the Authors are considering.

72. I think the Paper becomes stimulating when, in § 21, the Authors introduce what they describe as a commonly held idea which they then say is fallacious. I refer to the suggestion that increasing the mass of a stack reduces its critical wind speed to a level at which there is not enough energy in the air flow to cause significant movement. I do not want to cross swords with the Authors on this point, but it seems possibly to be a matter of the way one looks at it. Having stopped the oscillation of a stack by adding mass, one engineer will say this is because the stack is now too heavy, another that since the frequency has been lowered the wind has not enough energy. The distinction is a fine one and I would appreciate a reference as to where it has

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been sorted out. The relevant factors, mass, critical velocity, damping, are likely to be closely interdependent and a high degree of control in the experiment to be necessary.

Dr T. A. Wyatt, Imperial College

I would like to say a little more on the fundamental level about structural damping, one of the major uncertainties in prediction, and it is worth relating this to what is in fact going on in the structure, and what can be done to improve it.

74. Structural damping is the physical dissipation of energy from the structure, and in virtually all civil engineering examples it does not matter how it is dissipated in detail: it is just the net amount that is significant. Generally speaking all elements of the structure dissipate some fraction of the energy that they store as oscillation progresses, but unfortunately most structural materials only dissipate a very small fraction. There is also energy dissipation by friction in connexions and seatings.

75. The Authors referred to an example of the deliberate addition of frictional damping in § 30. This was a temporary expedient. Although common structural materials are poor dampers, there are much better materials available. The fraction of the energy that is dissipated per cycle in cyclic loading of rubber, or better still, specially formulated synthetic polymer combined with a fibrous material, can be as high as unity or even greater. The problem is to ensure that a significant proportion of the energy of the oscillation enters as a strain energy in the damping material. It is hoped that potential manufacturers of such materials will pay more attention to the possibilities of such applications, and will develop materials to make this easier than it is at present.

76. The obvious first choice of method to use a rubber-based damper is to connect it in a link between a moving part of the structure and some fixed point, but this is clearly very difficult in the case of tall slender chimneys and towers.

77. This difficulty usually leads to placing rubber pads under the base of the structure, as illustrated by Mr Wootton. Unfortunately most of the available rubber-based materials have a much lower static stiffness than dynamic stiffness. Thus a pad designed to a dynamic stiffness, which will accept a reasonable amount of energy from the oscillation, will have a too low long term stiffness and the deformation of the structure under the hourly mean or long term wind load may be too large.

78. Progress is therefore called for to develop materials with a high energy dissipation ratio that nevertheless have less difference between the dynamic stiffness at frequencies around 1 Hz and the long term stiffness than the materials currently available. The material must also be able safely to dispose of the heat generated in doing its work.

79. In connexion with the amount of energy that has to dissipate it is important to look at the implications of § 11 of the Paper and to refer to one of Mr Wootton's previous papers.⁴ In the super-critical range of Reynolds number the amplitude of oscillation of something like 1% of the diameter of the stack is shown to be of paramount importance: so long as the amplitudes are kept within this limit, vortex shedding remains uncorrelated, and therefore relatively weak. If damping is not sufficient to keep the response to this excitation within about 1% of the diameter, the motion leads to synchronization of the vortices up the whole length of the stack. Excitation becomes an order of magnitude stronger, and the amplitudes would go up to values which for most large structures would be quite unacceptable.

80. Therefore damping has to be provided which keeps amplitudes down to 1%, which is useful because it means that the amounts of energy to be handled are relatively small. To provide from an added damper half of the total damping necessary for the 40 m stack discussed in Appendix 1 would mean less than 100 W being dissipated in the material at the times of critical wind speed. In referring to static drag values, the Authors provide information on long cylinders, and then put in

an alarming comment in § 63 to the effect that the drag values near the top of the stack are very much larger than the average. I wonder whether they can expand on the information which is already available,³⁷ as this may be of considerable significance in relation to the required bending strength of the stack.

Mr C. Scruton, National Physical Laboratory

One impression which I gained on reading this Paper was that, so far as wind-excited oscillations of circular section structures is concerned, prevention is far easier than prediction. The position has now been reached where devices can be recommended, especially aerodynamic devices, which will prevent any oscillations due to wind, but only rarely is the necessary information on aerodynamic excitation and structural damping available to enable a prediction to be made as to whether it is necessary to incorporate such devices. Further research on both of these aspects is required, but now at least there are remedial measures available if trouble occurs.

82. There are one or two points of detail which I would like to take up with my colleagues.

83. The first refers to the statement in § 21 which refutes what the Authors say is a commonly held belief that a low critical speed ensures stability because of the low energy associated with it. In the bald, unqualified terms of this statement I agree with the Authors that it is a fallacy. However, what I believe is commonly held by engineers and scientists is that for generally similar structures of about the same size, shape, etc. a reduction in the critical speed tends to reduce the amplitudes of oscillation, and in this qualified form the statement is not a fallacy. As is stated in the Paper, amplitudes build up until the aerodynamic excitation $-C_a$ equals the structural damping C_s , i.e. $C_a + C_s = 0$. The aerodynamic excitation can be expressed in terms of its non-dimensional form $-c_a$:

$$C_a = \rho ND^2 c_a$$

where c_a is dependent only on the shape of the structure, on the reduced velocity $V_r (V_r = V/ND)$, the Reynolds number, and the amplitude (the value of C_a decreases with amplitude). Substituting $V_r = V/ND$:

$$C_a = \frac{V}{V_r} \cdot \rho D c_a$$

84. It will be seen from the above that if V is reduced C_a is reduced and, since for similar structures C_s , D and V_r will be about the same, this reduction must result in a reduced amplitude.

85. The other brief point I wish to make concerns the statement in Appendix 1 to the effect that tapered stacks have less tendency to oscillate than those of constant diameter. This is true, but in fact the reduction in the aerodynamic excitation is not large for moderate amounts of taper, and both model experiment and full-scale observation appears to confirm this. It is probably not worthwhile incorporating taper in the design of a stack if the only reason to do so is the prevention of wind-excited oscillations.

Mr C. W. Brown, Freeman, Fox & Partners

In 1960 while working for the Contractors building the foundations for the Severn Bridge, I was involved in a similar problem—the oscillation of cylindrical sections in tidal river flow. In those days there was little information apart from a few obscure papers, and as frequently happens in such cases, we accepted that while there might be a problem we hoped that it would not be serious.

87. However, having lost some light bracing due to fatigue failure in the course of one tide, we decided to think again. Having studied what papers there were, we found references to the relationship between vortex shedding and oscillations, and

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in searching for a rapid solution to the problem it appeared to us that there were two approaches. One was to insert tubular bracing members, large enough to preclude oscillations, and the other was to use some form of lattice member. After investigating the tubes we decided on the lattice members which in themselves are not entirely satisfactory for two reasons; one being that they are extremely expensive to make, and the other that in a river such as the Severn there is a great deal of floating debris and the lattice members collected it.

88. I should like to ask the Authors whether they have discovered suitable and satisfactory ways of reducing the tendency of comparatively light tubes to vibrate in tidal flow. Shrouding of the tube would not have helped, since we could not have tolerated even a 50% increase in drag. Is it possible on tubular sections used as bracing to fill them with a material such as sand to dissipate the very large energy input from the water?

Mr H. C. Adams, Department of the Environment

The Authors mentioned that the drag coefficient is increased by 50% and 100% for shrouded and straked stacks. I am not sure whether that coefficient relates to the diameter as increased by shroud or strakes, or the original diameter.

90. Second, on the question of concrete shafts oscillating, two shafts which oscillate to my knowledge, are the Post Office towers in London and in Birmingham. The amplitudes in each case are small however, and the effects are mitigated by the low natural frequency.

Miss L. Chitty, Imperial College

The Authors mentioned the case of a stack which only started to oscillate some ten years after erection. Can this change in behaviour be fully accounted for? If so, could it have been predicted?

Mr Walshe and Mr Wootton

In reply to **Mr Sainsbury**, all existing circular section concrete stacks for which we have details would not be expected to oscillate because they have too high a value of C_s and, as far as we know, no such structures have responded to vortex shedding. However, oscillations of two concrete stacks of rectangular section have recently been reported.

93. Adding mass to steel structures that have experienced oscillations has been considered in detail as a method of reducing the motion on a number of occasions but generally not used. The question of the effect of increased mass as mentioned by **Mr Sainsbury** was largely answered by **Mr Scruton**. The point is that additional mass does not necessarily alter the value of C_s and hence the change in C_s is the important factor. We would like to point out that neither **Mr Sainsbury's** nor **Mr Scruton's** comments conflict with § 21 of the Paper. It should be made clear, however, that the term structural damping in § 21 refers to the value of δ_s .

94. **Dr Wyatt** put the problem of providing increased structural damping in perspective and it is to be hoped that his remarks will help to stimulate the development of such materials. Great benefit could accrue from their use. The drag of stacks at super-critical Reynolds numbers has, unfortunately, received comparatively little study. Reference 37 in the Paper is still probably the most recent paper on the subject.

95. The point raised by **Mr Brown** is an interesting one particularly since there has recently been considerable research into this subject on a full-scale test rig at Immingham with which one of the Authors has been closely connected. Most of the solutions discussed in the Paper are applicable to marine structures though there are many additional problems in the marine environment not found in air.

96. In reply to **Mr Adams**, the drag coefficients are based on the original cylinder

diameter. In reply to **Miss Chitty** the case of the stack that commenced oscillating after some years of untroubled existence cannot be completely explained. However, it is possible that the heat of the effluent dried out the lining and, over the years, gradually reduced the structural damping.

Corrigenda

In § 7, for C_{az} read $C_a \dot{z}$

In § 7, for ref. 35 read ref. 1.

In § 11 *transpose* Figs 4(a) and 4(b).