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Practical solutions to wake galloping in a group of cylinders

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Introduction

Wake galloping is a well known phenomenon in groups of cylinders. Well known, at least, in wind engineering circles, but a lot less commonly recognised by structural engineers. Consequently, this is still a commonly occurring source of failure in the field. This paper presents a case study of some practical solutions to wake galloping. The study resulted from a forensic investigation by Arup of localised failures on an architectural feature (Figure 1). Arup were then commissioned to develop rectification strategies. These solutions were developed following wind tunnel testing at BMT Fluid Mechanics.

Figure 1: Array of CHS members showing failures and temporary restraining ropes

Wind tunnel testing

The first tests were conducted to investigate the behaviour of the circular hollow section (CHS) members in their current condition. The vibrations were expected to be dependent on the presence of the surrounding members. Therefore, the experimental set-up in the wind tunnel comprised 5 CHS sections with the central member being the 'live' dynamic one on which measurements were taken. The other 4 members were merely static dummy sections. The test rig was designed to be able to investigate different wind incidence angles. The basic experimental apparatus is shown in Figure 2 below.

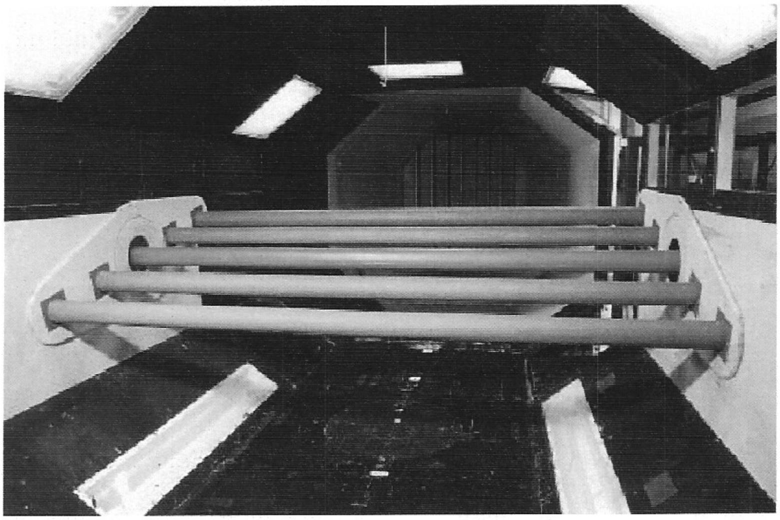

Figure 2: Basic test configuration

The central member was allowed to vibrate with mass, stiffness and damping appropriately scaled. The vibration amplitudes were measured and presented in terms of the amplitude of the vibration normalised by the member diameter. The maximum amplitude that could be accommodated by the rig was one tube diameter.

Figure 3 shows the wake-galloping response of the tubes with a structural damping ratio of 0.5%. It can be seen that around 10° (the angle of inclination of the tube array) the amplitude of vibrations exceeded 1 tube diameter, which was the limit of measurement of the apparatus. At 10°, this wake galloping instability started to occur below 15 ms^{-1}. The responses would be even larger for the lower values of structural damping that may occur in the field.

Mitigation measures

A number of mitigation measures were investigated to eliminate the aerodynamic mechanisms leading to instabilities. These included: increasing the mass of the sections; increasing the structural damping of the sections; the addition of strakes to change the aerodynamic characteristics of the sections; and removing every second member to eliminate the aerodynamic interference between adjacent sections. These tests were initially conducted for only one incidence angle in each case. The angle chosen was a critical angle determined in the basic tests.

CHS mass increases of 20% and 50% were investigated, and the results are shown in Figure 4. Two values of increased structural damping were investigated: 2% and 4% of critical damping. The results of these tests are shown in Figure 5. Figure 6 shows the effects of adding helical strakes. The effect of double spacing of members (in effect removing every second CHS member) was investigated with the results of the tests shown in Figure 7.

Discussion

It can be seen that even the lower increased structural damping value of 2% of critical damping was effective in mitigating the wind-induced aerodynamic instability. Structural damping could be increased in a number of ways, including alteration of the connection details or addition of small damping devices. The added damping option has the advantage that it need not impact on the aesthetics of the architecture.

The helical strakes were found to be effective in mitigating the vibrations at a structural damping ratio of 0.5%. They were then found to also be effective at a structural damping ratio of 0.08%.

The effect of double spacing of the members is seen to be effective for the case studied. However, only one angle was studied and one value of structural damping. The angle selected for the double spacing was 6°. This angle was estimated to place the live tube in the same area of the wake of the interfering upwind tube, as was the case for the closer spaced tubes at 12°. Further investigations would be required to determine the effectiveness of this measure at other angles of incidence and at lower values of structural damping.

In addition to the measures described above, two further practical options were considered: removal of all the CHS members and addition of strapping between the members.

The effectiveness, visual impact and cost of implementing each of the above options is summarised in the table below.

Option	Description	Effectiveness	Visual Impact	Likely costs
1	Increased mass	Not effective	N/A	N/A
2	Increased damping	Effective	None	High
3	Addition of helical strakes	Effective	Yes	Low-medium
4	Double spacing of members	Effective for variables tested – confirmation needed	Yes	Low
5	Removal of all CHS members	Effective	Yes	Low-medium
6	Strapping CHS members together	Effective	Yes	Low-medium

Addition of helical strakes is a simple and effective method of mitigating the motions. This could be done cheaply with rope (which would need occasional maintenance or replacement) or more expensive permanent measures. There would be a visual impact associated with this, and the straked sections could be expected to induced some slightly higher drag loads on the supporting structure than the bare tubes.

Double spacing of members would have the advantage of being straightforward and economical to implement but would have some visual impact. Removal of all the members obviously solves the problem and significantly reduces the loads imparted to the main structure. A few members would, however, have to be retained to brace the longitudinal trusses.

Strapping the members together has been shown to work in the field. Other solutions, such as the use of perforated tubes were considered but rejected due to cost and maintenance issues.

Conclusion

A number of practical solutions to wake galloping in groups of cylinders have been investigated. It was shown that the instability could be prevented by the introduction of small amounts of supplementary damping, increasing the spacing between cylinders and adding strakes to the cylinders. Less subtle practical approaches, such as strapping the cylinders together, also prove successful.

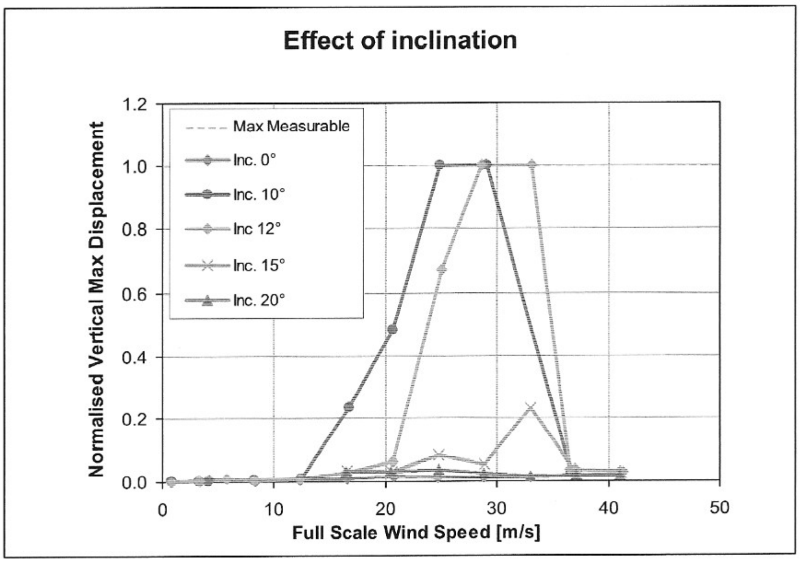

Figure 3: Wake galloping response of CHS members

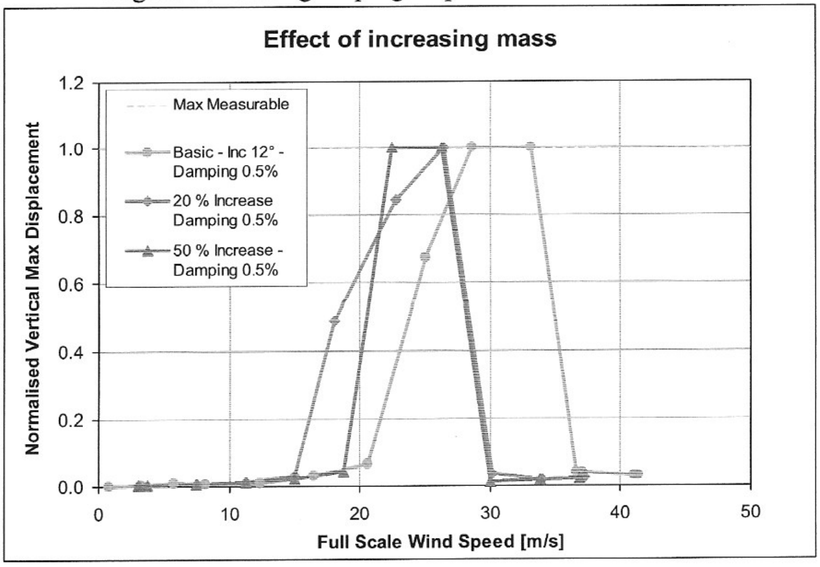

Figure 4: Effect of increased mass.

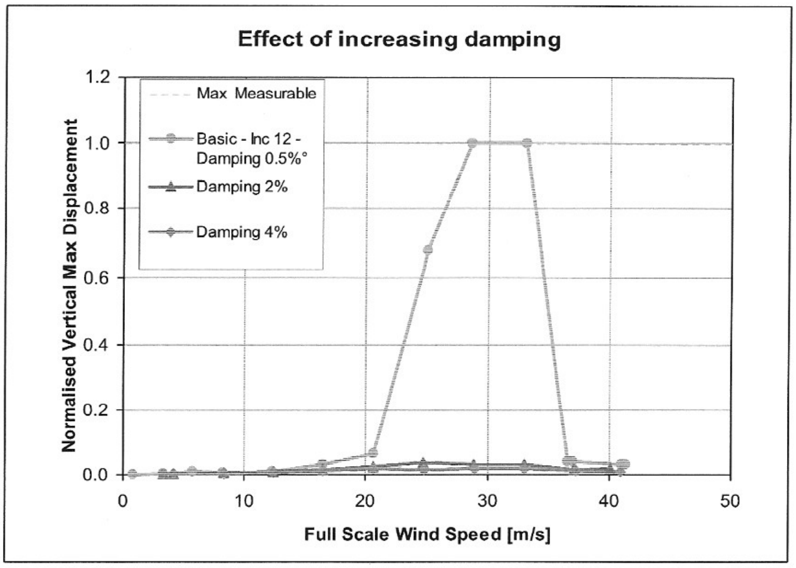

Figure 5: Effect of increased structural damping

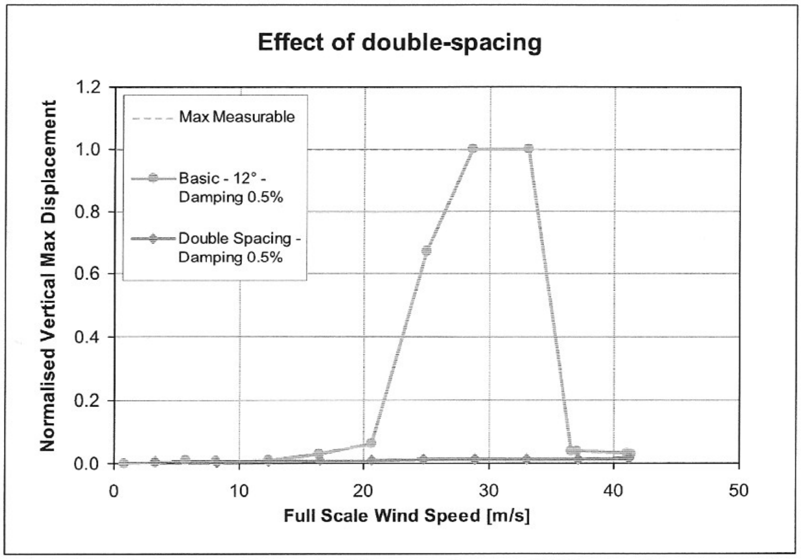

Figure 6: Effect of adding strakes to CHS members

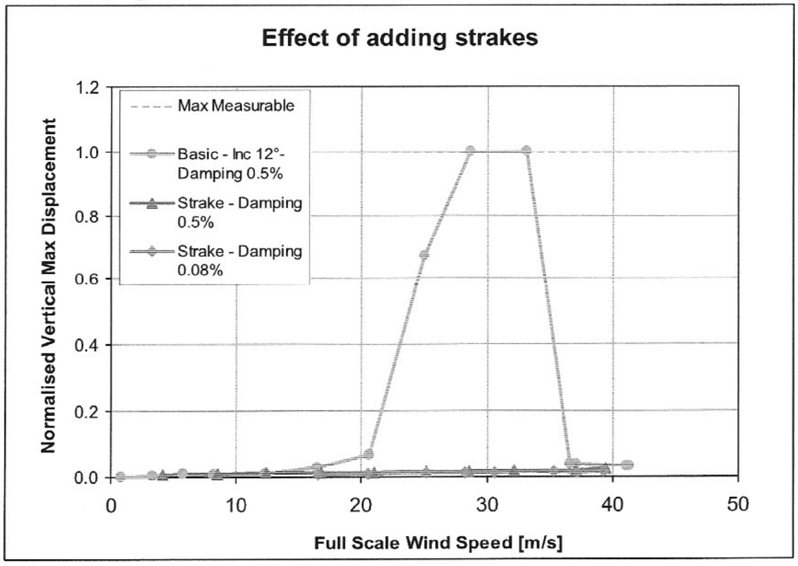

Figure 7: Effect of double spacing of CHS members