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# Aeroelastic effects for towers in group arrangement

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**SUMMARY:**
In this study, vortex-induced vibrations and aeroelastic instabilities of four towers in the 2x2 group configuration (two rows of side-by-side towers) are investigated at the spacings a/D = 1.5 and 1.875 ("a" is the axis-to-axis distance and "D" is the tower diameter). The flow around these four towers in such compact arrangements presents a transitional behaviour between single bluff body, reattachment and co-shedding regimes. Depending on the wind direction, vortex shedding from single towers in the group can coexist with a second and smaller Strouhal number associated with a wider wake behind the group. The high value of the critical velocity associated with the smaller Strouhal number enhances the aeroelastic interference between the towers and significantly extends the range of reduced velocities where an interaction between vortex induced vibrations and interference galloping takes place. The effect of the Scruton number is investigated in this work. Wind tunnel experiments show that the range of reduced velocities in which aeroelastic oscillations remain within admissible values expands considerably as the Scruton number increases beyond a sufficient level to attenuate vortex-induced oscillations.

*Keywords: Interference Galloping, Vortex Induced Vibrations, Interference Effects, Circular Cylinders*

## 1. INTRODUCTION

Interference induced oscillations are extensively described in literature for two cylinders in line (Alam&Meyer, 2013; Dielen&Ruscheweyh, 1995; Sumner, 2010; Zdravkovich, 1998). Interference effects in tower groups involve various aeroelastic phenomena, ranging from predominant vortex induced vibrations (VIV) for larger spacings to interference galloping (IG) for smaller spacings. The phenomenon of interference galloping on the downstream is related to the transition between two flow states: the state in which the second cylinder is completely immersed in the wake of the first one and the state in which there is a flow in the gap between the staggered cylinders. The main features of the gap flow are a displacement of the stagnation point and a very low pressure on the gap side. These cause a large transversal force. On moving cylinders, the gap flow starts later but persists longer. There is a hysteretic effect which maintains large amplitude of oscillation and this can be explained by the negative lag angle between oscillation and crosswind force (Ruscheweyh, 1983).

Four cylinders arranged in two parallel rows are scarcely described in the literature. This work includes an extensive wind tunnel campaign investigating the effects of the distance between the towers and of the Scruton number on the tower response. In particular, the tower response is characterized by strong interaction between vortex induced vibrations and interference galloping for small until moderate Scruton numbers.

## 2. WIND TUNNEL EXPERIMENTS

Aeroelastic wind tunnel experiments on oscillating models are performed at the WISt Boundary Layer Wind Tunnel of the Ruhr University Bochum. The models are cantilevered elastic circular cylinders connected to a force balance at the base. **Figure 1** shows the wind tunnel models and the tested group configurations. This paper focuses only on the 2x2 configuration for the distances a/D = 1.5 and 1.875.

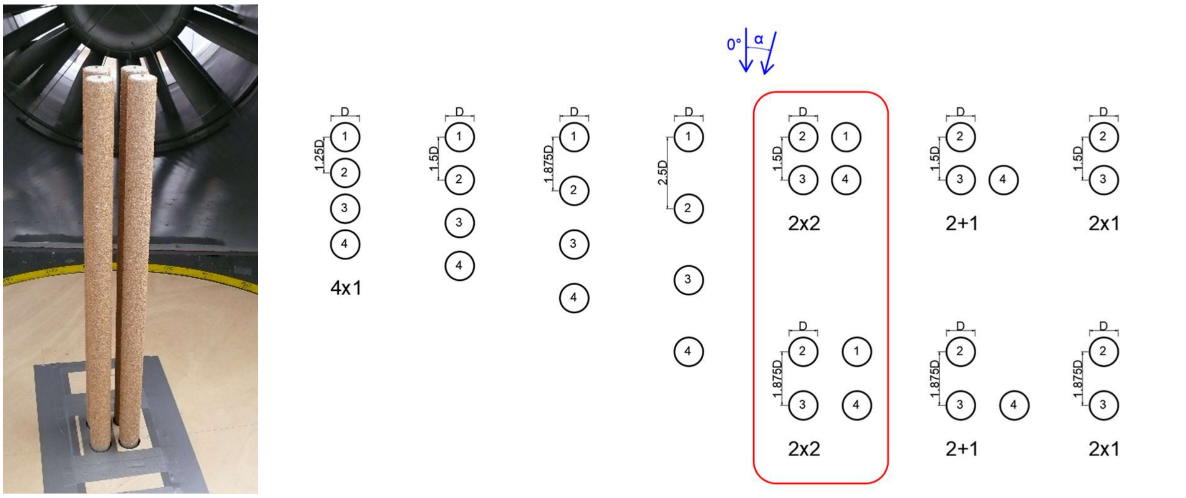


**Figure 1.** Wind tunnel models and group arrangements.

## 3. RESULTS

For small spacings (e.g., a/D = 1.5), two vortex shedding processes occur. One is the vortex shedding associated with vortex separation at the two sides of a tower, which Strouhal number is smaller than typical Strouhal numbers for standalone towers and can be estimated for example by the Eurocode. Resonance to this vortex shedding process occurs at reduced velocity about 10 and it is more pronounced for wind directions aligned or closely aligned to one of the main group axes. The second process occurs especially for inclined wind directions (10°-15° and close to diagonal). It is described by an even smaller value of the Strouhal number, which is probably related to the larger wake behind the group. These two Strouhal numbers result in two velocity ranges for vortex-induced vibrations. In addition, the gap flow between the towers can initiate aeroelastic instabilities such as interference galloping. An interaction between VIV and IG takes place for small until moderate Scruton numbers.

In slightly staggered arrangements, the resonant, predominantly crosswind oscillations of the downstream cylinder that is more exposed to the wind (where flow separation takes place) are strongly amplified by synchronization with the inwind oscillations of the adjacent downstream cylinder. This effect is enhanced by the gap flow between cylinders.

Wind tunnel experiments show that the range of reduced velocities in which aeroelastic oscillations remain within admissible values increases considerably when the Scruton number is increased beyond a sufficient level to dampen vortex-induced oscillations. As an alternative to increasing the Scruton number, increasing the distance between cylinders from 1.5D to 1.875D is also an effective means of suppressing vortex-induced vibrations at large reduced velocities caused by the smaller Strouhal number associated with the group effect.

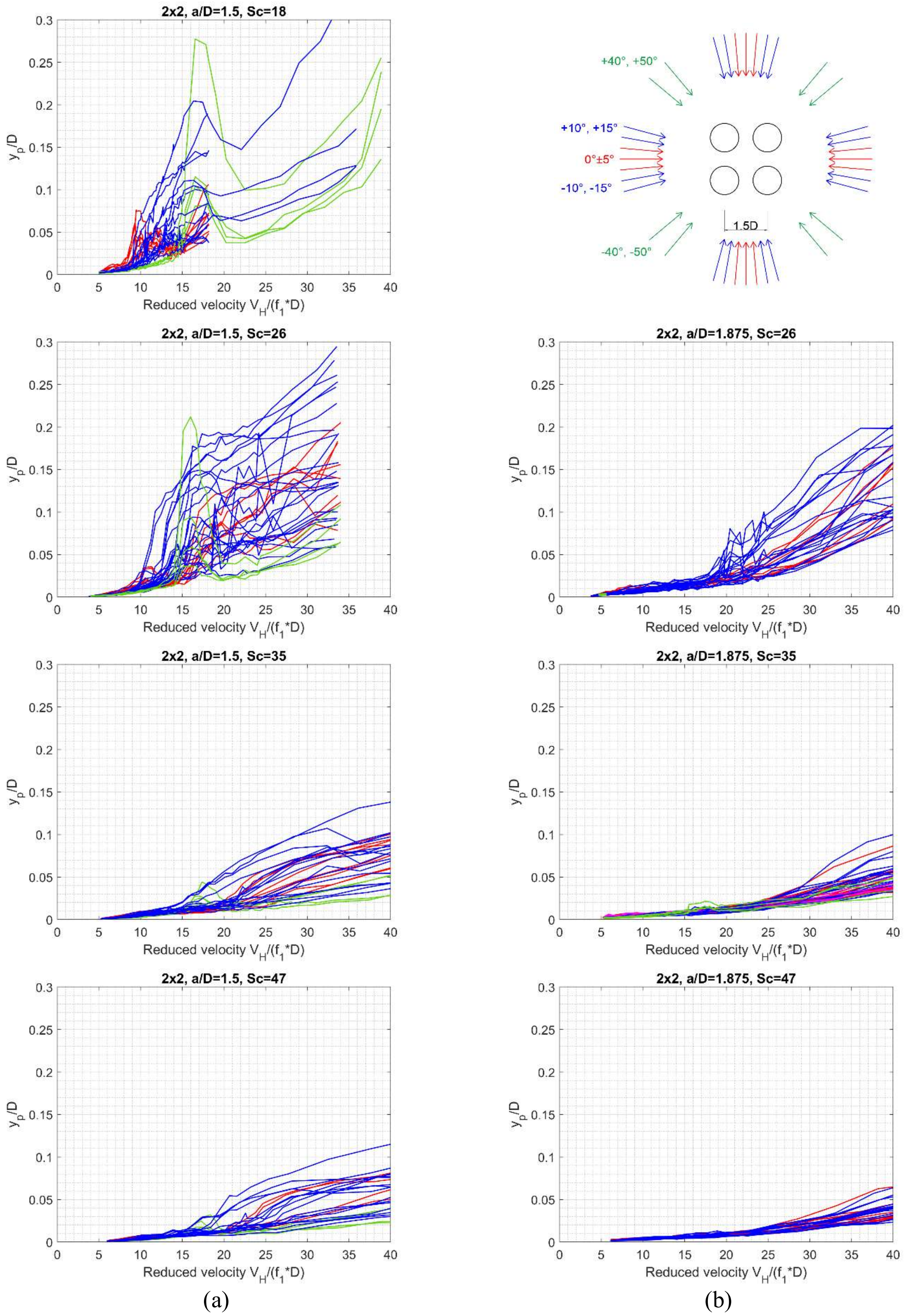


**Figure 2.** Cross-wind oscillations for varying Scruton numbers

## 4. CONCLUSIONS AND FUTURE OUTLOOKS

The experiments show that for small and moderate Scruton numbers ($Sc \leq 18$), large oscillations at low reduced velocities are primarily caused by vortex-induced vibrations. These are caused by small values of the Strouhal number, which are probably related to the larger wake behind the group. In addition, an interaction between VIV and IG takes place. Due to the interaction, it is not possible to identify a clear onset velocity for the interference galloping.

By increasing the Scruton number, vortex-induced vibrations are significantly reduced. For some angles of attack, this reduction is sufficient to completely avoid the trigger of interference galloping. For other wind directions, despite the onset of the interference galloping, the character of the galloping branch changes profoundly and the aeroelastic oscillation, while existing, remains below acceptable levels.

For these reasons, the design of wind turbine towers based solely on the estimation of onset velocity for interference galloping can lead to extremely conservative minimum damping requirements. Specific criteria based on the determination of allowable oscillations for certain velocity ranges are needed. These will be developed in future research.

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