INTERFERENCE EFFECTS BETWEEN TWO DIFFERENT DIAMETER STEEL STACKS - A CASE STUDY

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SUMMARY

This paper presents some results from a recent wind tunnel investigation of a double stack steel structure carried out by Vipac Engineers & Scientists for ICI Engineering Pty. Ltd. The structure comprises a 60m high steel stack, the "Prill Tower" (typical diameter 4.5m), which supports a 50m tall steel Exhaust Duct (constant diameter 2.5m). The wind tunnel investigation consisted of pressure model tests coupled with a series of aeroelastic model tests. Complex interference effects were observed related to the close proximity of the two stacks. In addition, the study evaluated the benefits provided by proposed Helical Strakes on the Prill Tower and Exhaust Duct.

INTRODUCTION

Structure Geometry

The structural configuration of the 60m high steel Prill Tower and adjoining 50m high steel Exhaust Duct, centred 7.35m from the Prill Tower, is complicated by:

(1) *two changes of cross-section* above the central 4.5m diameter section of the Prill Tower - a circular, 6.6m diameter Air Plenum, just under 5m in length, and then an octagonal, 8.8m wide Head House at the top, approximately 7.5m in length;

(2) the circular, 2m diameter Exhaust Duct being *attached* to the main Tower at Elevation 50m above ground level and *structurally bound* to the main Tower at several attachment points along its length;

(3) numerous connected minor structures, including a lift support mast and pipe and pipe rack support structure; and

(4) the 11.7m high, *7m square Base Support Structure* upon which the Prill Tower is rigidly supported.

Design Wind Speeds from AS1170-Pt.2

The project site is situated in Region C as per AS1170.2-1989. The Basic Design Gust Speed for ultimate conditions is thus 70 m/sec. Using the Code gust to mean wind speed versus height multipliers, the central, 4.5m diameter shaft of the Prill Tower experiences design level mean wind speeds along its length in the range 43.0 to 58.3 m/sec. With an estimated fundamental natural frequency of 2.0 Hz, the Prill Tower is thus prone to vortex shedding over the central, circular, 4.5m diameter portion of the Prill Tower.

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TEST PROGRAMME

Boundary Layer Modelling

The wind tunnel model tests were carried out at Vipac's Boundary Layer Wind Tunnel Facility in Port Melbourne, Victoria. The wind tunnel has a working section of 3m x 2m with a fetch length of just over 15m to achieve a fully developed boundary layer. The tunnel is powered by 10 x 10kW axial flow fans and is capable of producing mean ("gradient") wind speeds up to 22 m/s with correspondingly higher gust speeds. The approaching boundary layer is developed by an upstream two-dimensional trip fence and floor mounted "roughness" elements. For the present testing, the wind tunnel roughness elements were chosen to represent AS1170-Pt.2 Terrain Category 2 conditions.

Pressure Measurements - Local and Global

Wind pressure measurements on a 1:100 scale, rigid model of the Prill Tower were made at a total of 64 locations on the Tower, located at four elevations. The test length scale of 1:100 was chosen so that enough detail could be reproduced on the Tower, including the Stairs and Helical Strakes. Two series of pressure measurements were carried out in this first phase:

Series 1 - *Local "Discrete" Pressures*
Series 2 - *Global "Manifolded" Pressures*

In the second set of measurements, the taps comprising the different levels were manifolded together into Groups - A (Taps 1-8), B (Taps 9-16), etc. with the total instantaneous pressure recorded for each group. Pairs of the groups at the same elevation were (electronically) added to provide global pressure load estimates for all combined 16 taps at each Level. The pressure model could be rotated in such a way that the global reading from Group A plus Group B gave the total DRAG at that elevation. When rotated 90°, the combined Group A plus B reading yielded the total LIFT at the section.

Aeroelastic Study

The length scale of the aeroelastic model was chosen to be 1:200. Aerodynamic similarity is achieved by maintaining the equality of the following parameters between model and full-scale. The model scaled (a) all Lengths - D, H etc.; (b) the Density Ratio - $(\rho)_{building} / (\rho)_{air}$; (c) Damping - ζ; and (d) Elastic Forces - $(EI)/(\rho L^4 V^2)$. The equality of the elastic forces reduces to equality of the so-called "Reduced Velocity" - V/f_oD - the inverse of the Strouhal Number.

It is not possible to scale wind tunnel tests so that Froude No. (V^2/gD) and Reynolds No (VD/ν) equality is maintained. Also, corrections must be applied to convert wind tunnel test data to full-scale results since Reynolds Number matching is not possible between wind tunnel and full-scale.

ICI Engineering carried out a dynamic analysis and provided Vipac with the modal frequencies and shapes of the first six modes of the Prill Tower. The scaled first mode natural frequency of the Tower was 85 Hz, and vortex shedding behaviour was observed in the wind tunnel model testing when the mean wind speed at Prill Tower top height was about 14.0 m/sec. The velocity scale used in the testing was $V_{f-s}/V_m = (f_oD)_{f-s} / (f_oD)_m = 4.71$.

TEST RESULTS

In comparing the wind response of an "isolated" Prill Tower to the actual geometry, the tests conducted in this investigation showed that the above features profoundly affected the wind response of the Prill Tower, in particular, the interaction between the Exhaust Duct, located at 135° relative to north, and the Base Support Structure whose sides run north–south and east–west.

Local Pressures

Some results from the study have been included in graphical form and discussed below. Figure 1, giving the variation of local mean pressure coefficient with circumference for Azimuth = 90°, 135° and 315° shows the shielding and interference of the Exhaust Duct on the Prill Tower. It was expected that the significant differences in qualitative pressure patterns for Level 3 (6.6m diameter cylinder) and Level 4 (8.8m wide octagon) compared to Levels 1 and 2 (4.5m diameter cylinder) would have a disruptive effect on the coherence of the vortex shedding behaviour of the Tower as a whole. Peak positive pressures ranged from 1.64 (Level 1) to 1.75 (Level 4), while peak negative pressures ranged from −2.53 (Level 4) to −3.21 (Level 1).

Global Pressures

In the Series 2 tests, multiple runs were performed for various geometry configurations – with and without the Exhaust Duct; with and without the Prill Tower Stairs; with and without the Helical Strakes. The mean drag and lift loads confirmed the anticipated interaction between the Exhaust Duct and the Prill Tower. Of greater interest however were the lift pressure spectra.

"Manifold" Pressure Spectra:

Drag and Lift pressure spectra were recorded for the various configurations tested. Some of the more critical cases have been chosen for discussion. Figure 2 shows graphically the dynamic character of the Tower Drag and Lift in several of the geometry configurations tested. The vortex shedding peak in the lift spectrum is clearly evident with no Exhaust Duct present. With no Exhaust Duct, these graphs indicate that the Strakes would have a significant impact in reducing the dynamic lift loads on a stand alone Prill Tower.

However, the pressure spectra with the Exhaust Duct included, paint a somewhat cloudier picture. The lift spectra at Level 1 with and without the Strakes have almost equal vortex shedding spectral peaks at the worst case wind azimuths. Figure 2 also shows that the vortex shedding at Level 3 is mostly unaffected by the presence of either the Stairs or the Strakes, but is greatly affected by the relative orientation of the Exhaust Duct, with a prominent peak in the lift spectrum at Azimuths = 45° and 225°. These tests suggest that the inclusion of the Helical Strakes would produce little substantial benefit to the behaviour of the Prill Tower.

Dynamic Loads

The geometry configurations investigated in the pressure manifold tests were repeated with the aeroelastic tests (with/without Exhaust Duct plus Stairs and with/without Strakes).

Prill Tower Alone

For the case of NO Exhaust Duct and NO Stairs and Strakes the following loads were measured for the two main directional loading cases:

Azimuth = 180°	Y-Axis Shear Force	=	1013 kNs	Peak
	X-Axis Shear Force	=	1044 kNs	Peak
Azimuth = 135°	X,Y-Axis Shear Force	=	1219 kNs	Peak

Prill Tower plus Exhaust Duct plus Stairs

The variation of mean and rms shear force with azimuth are shown in Figure 3. There is a sudden drop in the mean Y-Axis load in between azimuths 90° and 135°, caused by shielding of the wind by the Exhaust Duct. Interference to the vortex shedding behaviour is also seen when the Exhaust Duct is to the lee of the main Tower, where it disrupts the formation of eddies behind the Tower and produces lower rms values. The peak dynamic responses derived from these data were:

Peak Shear Force:	Y-Axis (north-south)	1430 kNs	75°
	X-Axis (east-west)	1400 kNs	345°
	Combined	1545 kNs	120°

The overall maximum response for the completed structure is approximately 20% greater than for the stand alone Prill Tower.

Prill Tower plus Exhaust Duct plus Stairs plus Strakes

The tests were repeated for the completed Tower with Strakes. The overall greatest loads (i.e. regardless of wind direction) were almost the same as the corresponding values for the case without Strakes.

It is surmised from the test results that the Base Structure constrains the Prill Tower to convert motion which is induced by the wind at any arbitrary angle into a combination of north-south and east-west preferred movements. With NO Exhaust Duct, it is possible to generate pure lift forces in the Tower (north-south,east-west winds). WITH the Exhaust Duct, north-south and east-west windflows are distorted and the vortex shedding pattern disturbed and diluted. Thus the Prill Tower & Exhuast Duct interaction, which was greatest at small offset angles to an axis line joining them (northwest-southeast) and perpendicular to this line (southwest-northeast), was seen to be a complex mix of drag and lift response, rather than distinct drag and lift. Since the strakes tend to increase the drag loads on the Tower and there is always some drag component of the load along any major axis, the Strakes ended up producing roughly the same loads compared to the No Strakes geometry. Of course, the Strakes play virtually no role in affecting the upper two circular and octagonal sections of the Prill Tower.

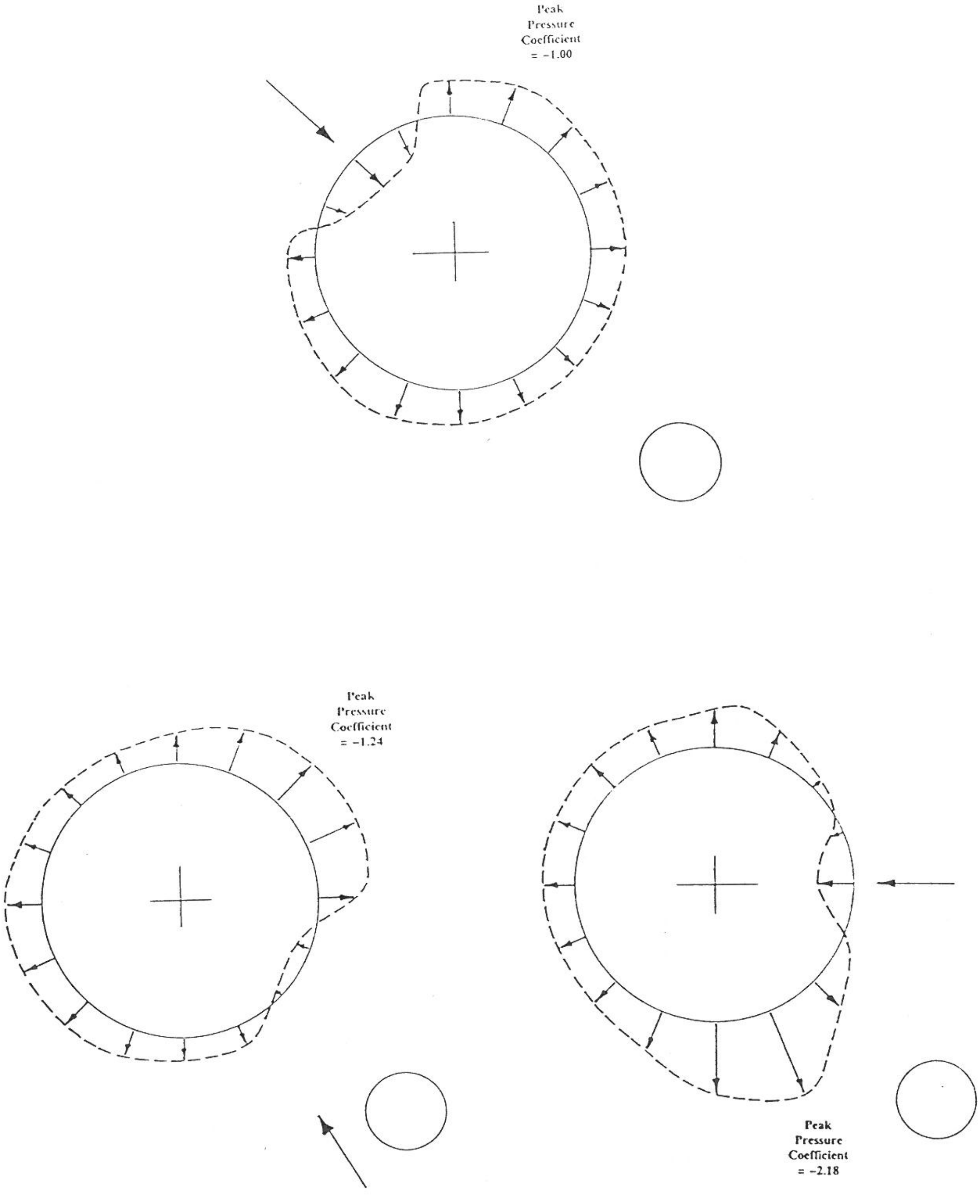

Figure 1 Local Pressures for Level 1 Taps, 90°, 135° and 315°.

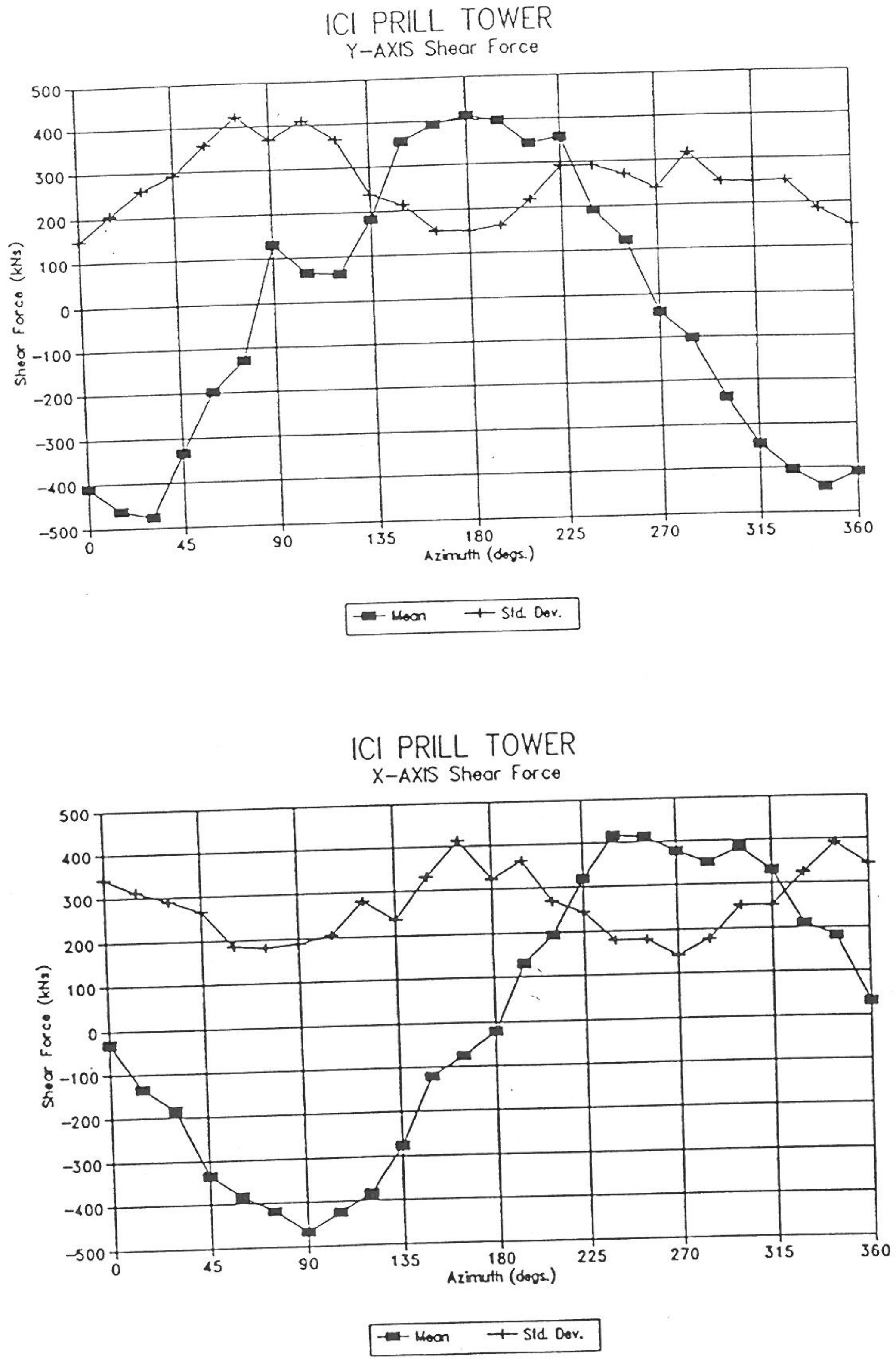

Figure 3 Total Shear Force Load – Completed Structure