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VORTEX SHEDDING INDUCED VIBRATIONS OF A LIGHT MAST

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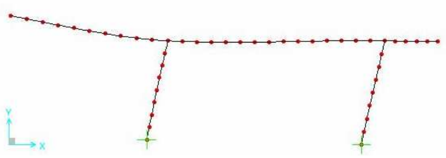
1 INTRODUCTION

In the summer of 2005 a frame type steel structure supporting flight control lamps for the approach control of incoming flights to the N-S runway of the airport in Reykjavik, Iceland, was installed. The optimal location of the new light frame interfered with a road intersection and therefore it was necessary to design a cantilever beam stretching out over part of the intersection, see Figure 1. The horizontal beam is made of welded ∩-profile (400x400mm) while the columns have a closed rectangular section. Soon after the installation of the light frame, significant across wind motion of the cantilever beam was observed in windy weather. The amplitude of deflection at the tip of the beam was estimated to be few centimetres, which the Aviation Administration considered unacceptable. In this paper the wind induced vibrations are analysed, full scale observations reported and the countermeasures devised to reduce the motions are described.

2 WIND INDUCED VIBRATIONS

The flow induced vibrations of the cantilever were traced to the much studied vortex shedding process [1], which can create problems in a variety of contexts in wind engineering. The vortices shed from a bluff body as the flow region is separated induce a fluctuating force on the structure that can lead to vibration. The intensity of this force acting on the structure controls the amplitude of vibration of the structure that primarily depends on the cross-sectional shape of the structure and the mean wind velocity [2]. Vortex shedding for rectangular sections is characterized by the Strouhal number of the flow. The vibration amplitude of a structure under the influence of vortex shedding depends on the Scruton number. The phenomenon is well described in the literature as well as in codes (see for instance EN 1991-1.4, Annex C [3]).

The critical velocity for vortex shedding can be deduced from the Strouhal number (~ 0.12) based on the natural frequency of the excited mode of the structure and the characteristic width of the structure. Finite element modal analyses of the frame revealed that the natural frequency of the critical mode of vibration with regard to across wind induced vibrations was 2.3 Hz. This value corresponds closely to the natural frequency for an equivalent cantilever beam fixed at the column connection (2.4 Hz). Since the width of the section is 0.4 m, the critical mean wind velocity was between 7 and 8 m/s, which is a common wind velocity level in Reykjavik. Open non circular cross sections such as U sections are also prone to galloping oscillations [3], but the onset wind velocity is higher or about 11 m/s for the case at hand.



Second mode of vibration
(f_2 = 2.33 Hz)

Figure 1: The frame with the cantilever beam stretching out over the inter-section to the left. The bubbles on the top of the beam are the flight control lamps. The critical mode of vibration is also shown.

3 FULL SCALE RECORDINGS OF RESPONSE AND WIND DATA

The frame was instrumented with a uni-axial vertical accelerometer located at the tip of the beam. The wind velocity and wind direction were monitored above the supporting column. The purpose was to confirm the source of the problem and to be able to compare vibrations before and after installation of countermeasures to judge their effectiveness.

Figure 2 shows the peak deflection at the end of the beam as a function of the 10 minute mean wind speed for all the recorded data. The displacements are evaluated from the acceleration recordings. This data clearly reveals the relation of the response to the wind velocity. As the wind velocity reaches 7 m/s, strong across wind vibrations of the beam are induced. This is in agreement with the vortex shedding behaviour discussed in Section 2. The maximum displacement during the 12 hours of recordings shown in Figure 2 was 6.4 cm, which corresponds to a peak-to-peak motion of almost 13 cm.

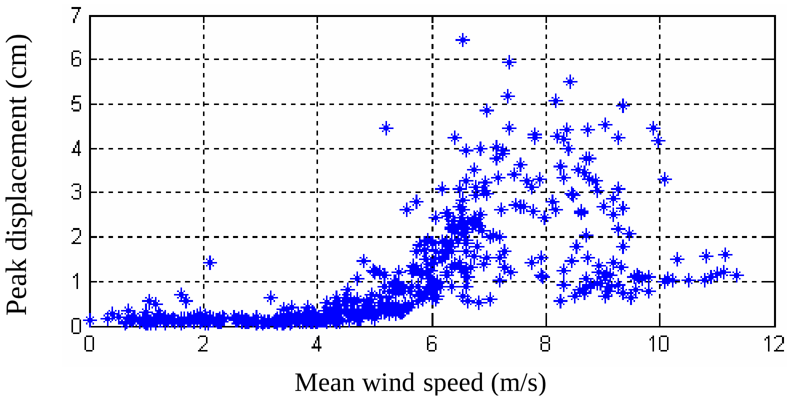


Figure 2: Peak deflection as a function of mean wind velocity.

An example of the recorded acceleration response is given in Figure 3. Looking at the recorded vibration signals on a smaller time scale revealed a motion dominated by a single harmonic vibration. System identification of the recordings gave a response frequency of 2.3 Hz and a critical damping ratio of about 1% for the relevant mode of vibration. The frequency corresponds quite well to the results of the modal analysis.

Knowing the critical damping ratio and the equivalent mass per unit length of the beam for the mode of vibration makes it possible to evaluate the Scruton number and estimate the maximum tip displacement of the beam due to vortex induced effects by using the formulation given in [3]. The result corresponded well to the measured value of roughly 6 cm.

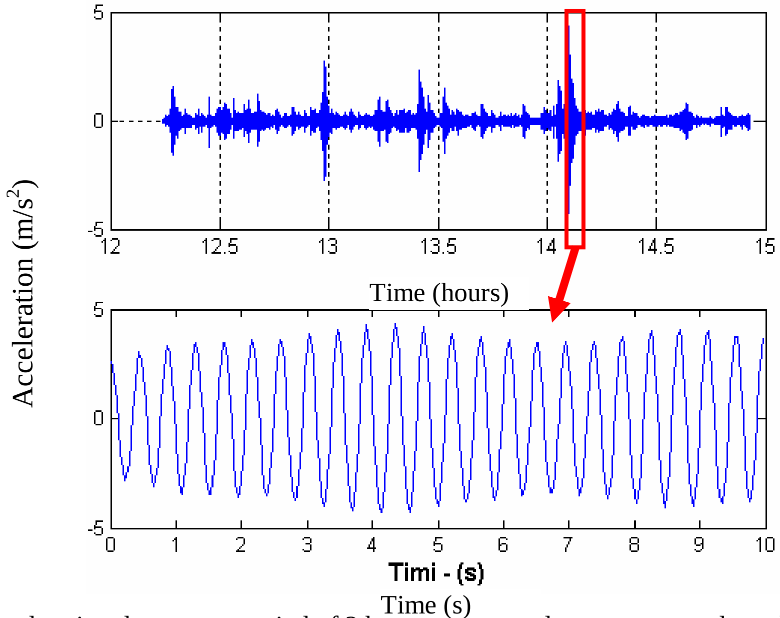


Figure 3: Acceleration data over a period of 3 hours and a 10 s long segment enlarged from the upper graph.

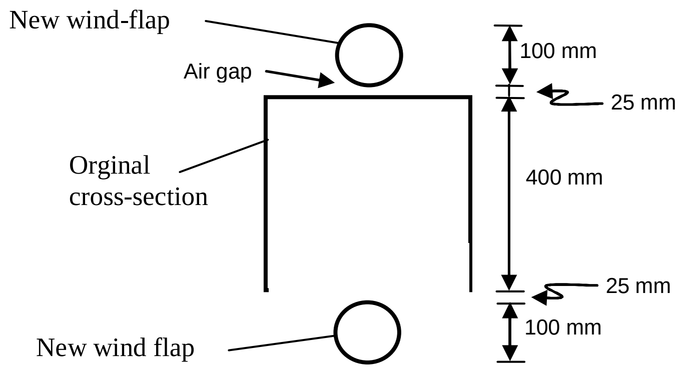


Figure 4: The original U-profile of the horizontal beam in the light mast, and the new cylindrical wind flaps for reducing vortex excitation.

4 AERODYNAMIC COUNTERMEASURES

Several measures to reduce the effects of vortex shedding have been suggested in the literature (see for instance [4] and [5]) and many have been successfully applied. In evaluating the possible solutions, issues like cost and change of the appearance of the structure were of concern, in addition to the expected efficiency of the method chosen. Eventually it was decided to install cylindrical wind flaps on the top and bottom of the cantilever beam. This rounds of the cross section and may introduce a positive Reynolds number effect. In addition a 25 mm air gap was intentionally designed between the original beam and the cylinders in order to allow the wind to bleed through the section and thereby counteract the formation of vortices. This implementation does not require redesign of the original cross-section and provides an opportunity to try another solution if the vibration amplitude is insufficiently reduced.

In order to see the effects of the circular wind flaps data was recorded after their installation. The flaps added some weight to the structure and the response frequency of the recorded data was slightly reduced to 2.2 Hz. The peak deflection of the beam versus 10 minute mean wind velocity is shown is shown in Figure 5. Comparison with the data in Figure 2, demonstrates that the flaps are effective and reduce the vortex induced motion by about 70%.

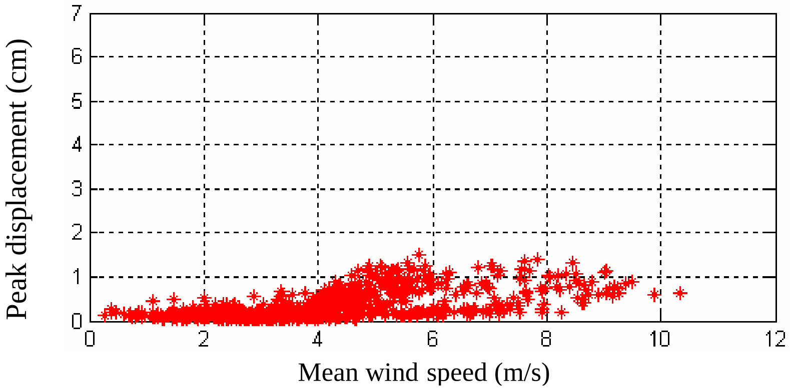


Figure 5: Peak deflection as a function of mean wind velocity after installation of cylindrical flaps.

5 CONCLUSIONS

A steel frame structure supporting approach lights for air traffic control was installed at Reykjavik airport. The frames substructure, a cantilever beam, showed significant across wind motion in windy weather.

Analysis and measurements revealed that this behaviour was due to vortex shedding effects.

The phenomena are well documented and the formulation given in codes and the literature was found to give an accurate prediction of the observed behaviour.

Countermeasures in the form of cylindrical wind flaps on the top and bottom of the cantilever beam to reduce the induced vibration amplitude were proposed and implemented.

The recorded motions before and after installation of the flaps clearly indicate significant reduction in the vibration amplitude of the cantilever light mast. Recorded peak deflections were roughly 6 cm before the installation of flaps but were reduced to less than 2 cm after the implementation.

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