STABILISATION OF AN EXISTING STRUCTURE USING A LIQUID DAMPER

Gilles OUDIN

MULTITECH VIBRATION CONTROL - Rueil-Malmaison, France

Email : multitech-fr@wanadoo.fr www.multitech-fr.com

ABSTRACT

This paper presents a practical example of the stabilisation of an existing structure using a liquid damper. The structure is a 44 m high conical tower made of Glass Reinforced Plastic (GRP) of unknown properties. Severe vibrations occurred in the tower with estimated amplitude of nearly 1.200 m .It was clearly establish that these severe vibrations were the result of vortex shedding; it was clearly The damper has to be located inside the mast and access through the damper was requested by the Client for further inspection and maintenance. The damper was placed at 29 m where the inside mast diameter is only 1.15 m. Because the mast is made of GRP whose mechanical properties may vary significantly with the age of the structure: an adjustable damper was required in order to keep the possibility of tuning the damper if necessary.

For all the above it was decided to adopt a Liquid Damper with strong trapezoidal cells instead of traditional rectangular or cylindrical cells.Precise in-situ measurement was impossible because the mast was temporarily stabilised by internal scaffolding: two frequencies measures were made giving 1.25 Hz for the first one and 1.50 Hz for the second one.Investigations were made and it was clear that on an extremely flexible structure all additional weight such as ladders, dead weight of the damper and dead weight of passive part of liquid would affect the frequencies so determination of the right damper became extremely difficult.

Taking into account the possible variation of E modulus, mass density for GRP material , having built a model to simulate the site observations, it was necessary to design a vibration damper working between 0,90 Hz and 1,50 Hz to cover all possible cases.The damper was made of an assembly of strong trapezoidal cells all of them having the same shape. A preliminary design was made and a half scaled model was built and tested in a laboratory. The model was used to determine the right tuning level of the fluid to fit all the frequency ranges of 0.9 Hz to 1.50 Hz and to determine the correlation between acceleration in the liquid damper and resulting damping.

1. INTRODUCTION

This paper deals with a case story concerning the stabilization of a conical tower subject to excessive vibration. As the mast is the pennant of a company, the damper has to be placed inside the structure. The mast has a height of 44 m; a bottom diameter of 2.800 m and a top diameter of 0.30 m., Figure 1. It is made of GRP. The GRP rowing and kind of material used for construction was not certain: it appears that the mast was made in two segments each one being made of two half parts re-assembled vertically. The junction between the two segments was made by sealing 6 vertical profiles above and below the connection. The mast was reinforced by 6 circular rings made of ply wood covered by resin.

The upper part of the damper had to be at a max elevation of 29.262 m to avoid the vertical stiffeners, Figure 2. Request was made to have a permanent access inside the mast leaving little space for the damper. The variation of skin thickness with high was not known and site measurement without damaging (visual impact) the shell was not possible. The Young Modulus of the GRP was not known. Due to the temporary scaffold placed inside the mast it was impossible to make precise measurement.

Figure 1 :The amplitude of vibration was observed to be as large as 1.200 m on either side of the mast.

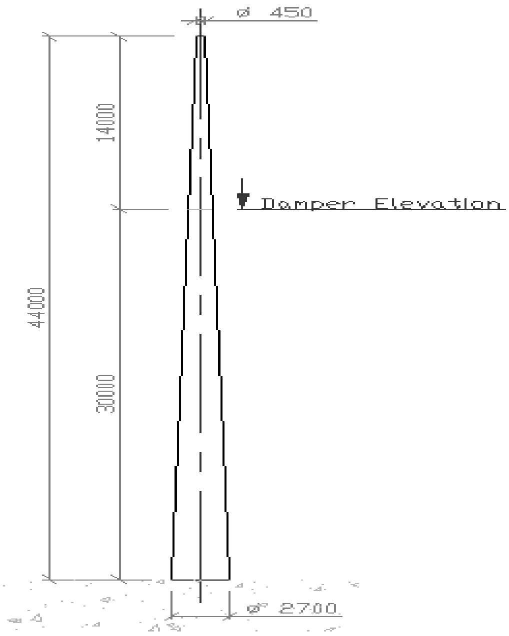

Figure 2: Sketch of the conical mast

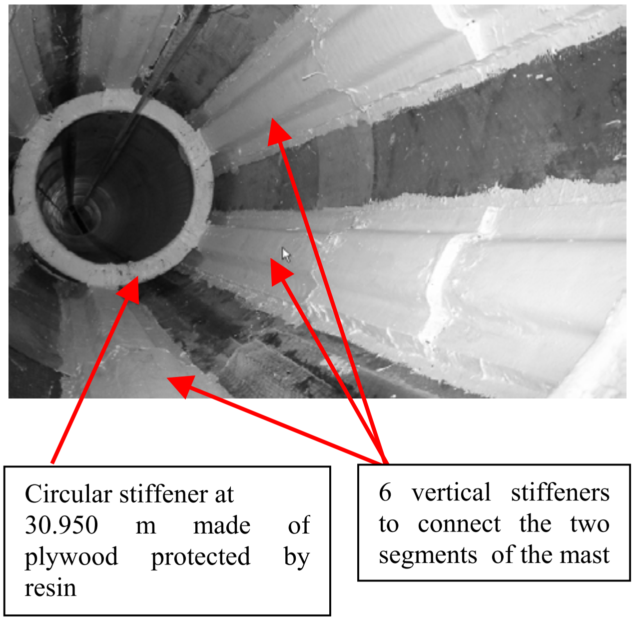

Figure 3: Inside view of the mast at damper elevation and view of the connection between the two parts of the mast

Two measurements were made with the scaffold. The first measurement indicate a value of 1.50 Hz. The second measurement with an accelerometer gave a value of 1.25 hz The estimated reduced mass at top was very small # 300 daN . So it was expected that the dead weight of the damper would have a big influence on the frequencies. Correct tuning of the damper was expected to be extremely difficult because the weight of the damper would greatly affect the frequencies. As a conclusion the design of the damper had to be done having no information on the material (large expected variation on the Young Modulus) and no information on the thickness of the mast according to the elevation, no reliable information on the frequency and no possibility to make further measurement before final erection. The damper design had to be made to cover a large band of frequencies.

Nota: the reduced mass or “modal mass” is an equivalent mass giving to the model without mass the same dynamical behaviour than the real structure. The damper has to be sized so that to avoid the vibration of the structure by counterbalancing the vibration of the “reduced mass”

2. DESIGN OF THE DAMPER

The first step before preparing the design was to calibrate a mast model for vortex shedding. A good approach of the observed phenomena was obtained with 12 200 Mpa for the Young Modulus and thickness varying from 20 mm at base to 6 mm at top. With these values the predicted vibration amplitude using Eurocode 1 part 2-4 – Appendix C was close from observations and frequency was near from measurement. The software used for this calculation has been developt for industrial stack design . The mast in cut in small sections each of them being modeled by an equivalent beam with adequate diameter, thickness, Young Modulus, density.

frequency	1.22 Hz
Top deflection during cross wind vibration	1.37 m
Scuton Number Sc	1.14
Critical wind speed	5.0 m/s
Structure acceleration at top without damper	81 m/s

Table 1:*Results of crosswind vibration according to Eurocode 1–part 2.4*

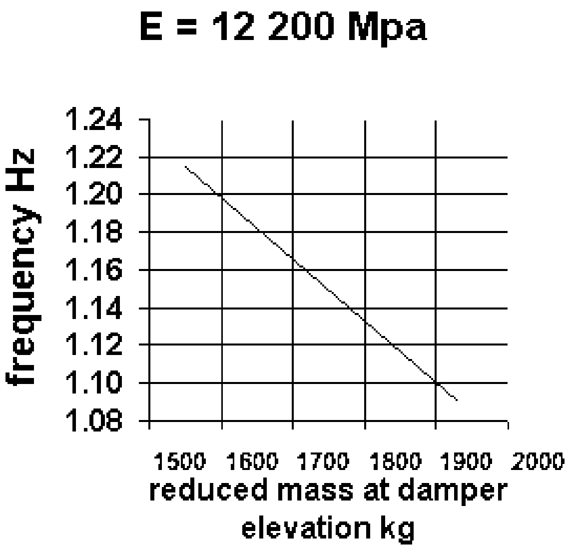

Figure 5:Structure frequency versus reduced mass

Figure 4 represents the evaluation of the frequency with respect to reduced mass at damper elevation. At the origin the reduced mass is 1550 kg and the frequency 1.21 Hz. Adding the damper and the ladder would increase the reduced mass and consequently decrease the frequency.

The reduced mass at damper elevation is dependent on the added masses such as ladder and steel structure dead weight of damper. It is a very sensitive structure due to the very low Young Modulus.; In other words: adding the damper dead weight and the liquid weight would affect the frequency and require new tuning of the damper.

The range of Young Modulus was expected to be rather large: from 8 800 Mpa to 18 000 Mpa depending on the GRP rowing and method of manufacturing.

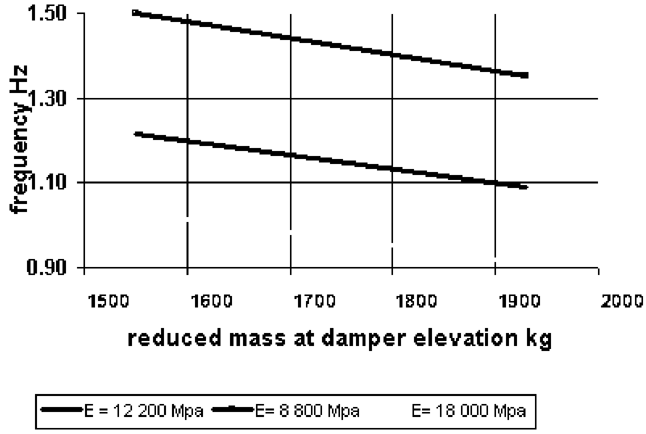

Figure 5: structure frequency versus reduced mass for different Young Modulus

The tuning of the liquid damper would require quite different masses of liquid affecting a lot of the frequencies. As a result it was decided to design a damper working for frequencies covering the band from 0.90 Hz to 1.50 hz.

3. PRELIMINARY LABORATORY TEST

It is to be noticed that liquid damper, especially in this special case, have no linear behaviour. Parameters such as frequency and/or structures accelerations may affect the effectiveness of the liquid damper. This liquid damper had a partial annular shape and has to be design so that to be effective in all directions for a large band of frequencies. In the laboratory a lot of tests have been carried out to determine the best shape (damper width, angle between two parttion walls, filling level,….) of the damper unit.

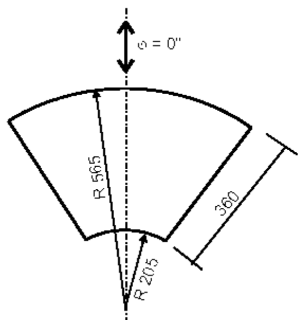

Figure 6 : Typical cross section of a damper

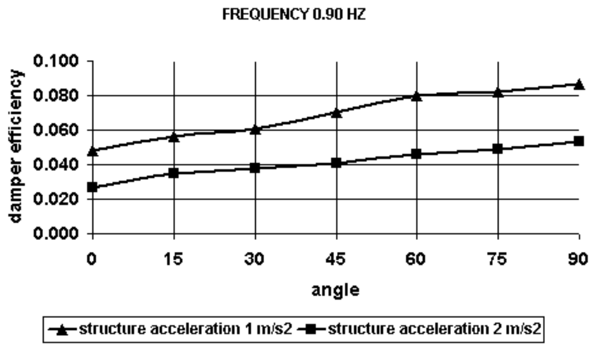

Figure 7 : damper efficiency versus angle of wave in the damper unit for an exciting frequency of 0.90 Hz at a different acceleration rate

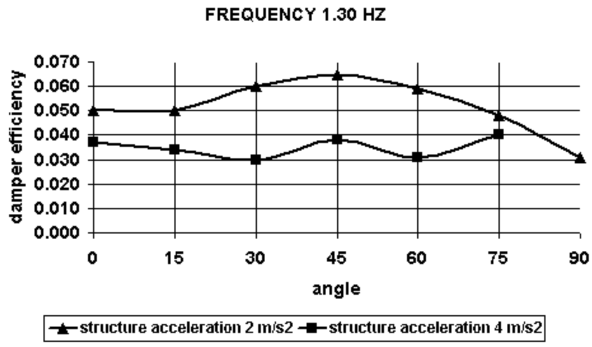

Figure 8 : damper efficiency versus angle of wave in the damper unit for an exciting frequency of 1.30 Hz at different acceleration rate

The damper efficiency is the logarithmic damping decrement of the test damper unit per liter of fluid inside the container.

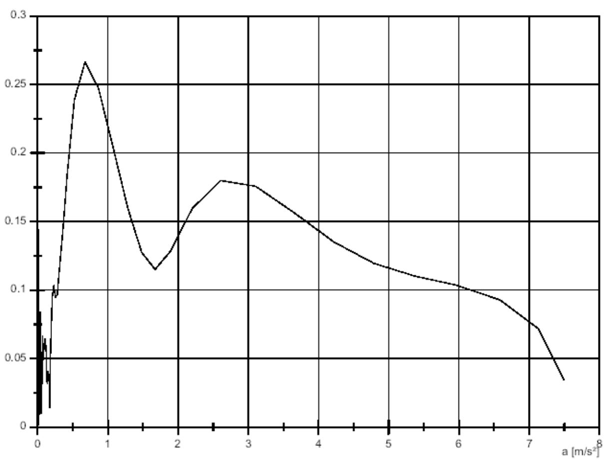

Figure 9 : typical curve representing the damper efficiency as a function of structure acceleration.

Figure 10: typical wave in a liquid damper

Generally speaking a liquid damper uses the energy of the liquid wave to absorbe the energy of disturbing forces such as in this case the energy of the vortex shedding or in other cases the energy produced by pedestrians on a footbridge. The liquid is anti freeze mixed with water so that avoid any risk of freezing.

Figure 11: general view of the damper after manufacturing with nozzle for filling and internal space for ladder

Figure 12: general view of the damper after site erection with permanent access using a safety ladder.

4. TESTS ON SITE

The structure equipped with an empty damper has been site measured. An operator placed at the damper level excited the structure at a frequency near from the estimated structure frequency. When the vibration amplitude is big enough, the operator stop exciting the structure and the decay curve is recorded. Reading the decay curve permit to check both structure frequency and structure damping.

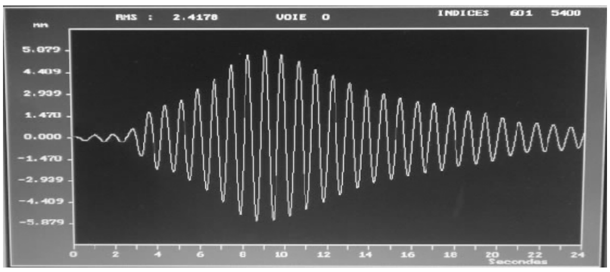

Figure 13 : damping curve of the structure with an empty damper

The estimated damping was very small and estimated to be as low as 0.1 % about. Having measured the original frequency and structure damping the appropriate filling level was determinated using the calibration curve obtained from the laboratory testing and the same operationof structure excitation and recording was carried out.

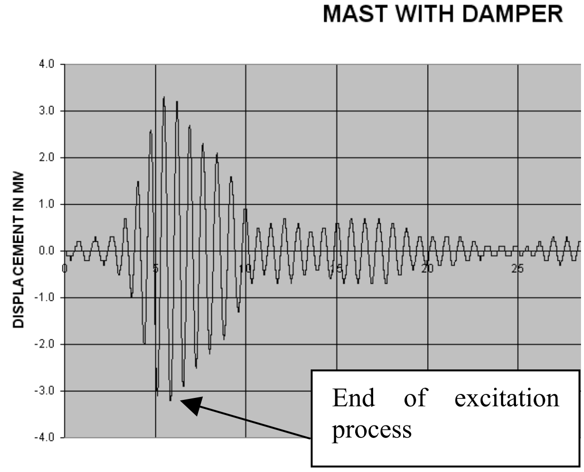

Figure 14: damping curve of the structure with a filled damper.

The damping of the structure with the damper properly filled with liquid was 3.8 % much above the requested values to avoid any cross wind vibration

5. CONCLUSION

The liquid damper has been successfully installed in the conical mast of unknown properties. The pre design was made to allow easy tuning between 0.90 Hz and 1.50 Hz, which is rather a large frequency band for the effectiveness of a damper. The difficulty comes from the fact that a large frequency band has to be covered and that any additional weight would affect both frequency and reduced mass. If the reduced mass is increased, then additional active liquid in the damper would be required, resulting in modification of frequency. Also liquid dampers do not have linear behavior which makes the pre-design more complicated.

6. REFERENCES

Eurocode 1: Basis of design and actions on structures and national application document –Part 2-4 : Actions on structures – Wind actions – Appendix C: vortex shedding