Use correct terminology!

ANALYTICAL COMPARISON OF PASSIVE CONTROL AND TWO SIMPLE ACTIVE CONTROL ALGORITHMS FOR A MULTI DEGREE OF FREEDOM STRUCTURE.

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Abstract: An analytical model of a multi degree of freedom tall building with an actively controlled tuned mass damper is studied. The analysis is used to compare one passive and two different simple active control algorithms. The building is loaded by wind loads obtained from wind tunnel testing of a rigid pressure-tapped model.

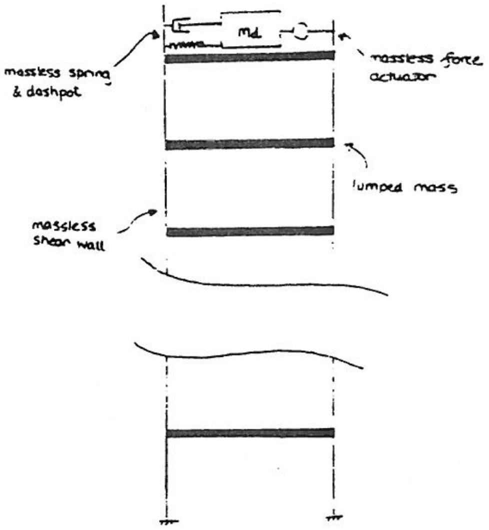
INTRODUCTION

Over the last few decades, buildings have become taller, slimmer, and they possess less structural damping than previously as masonry type cladding has given way to lighter weight materials such as glass. As a result, tall buildings have become more susceptible to motion induced by wind forces, particularly with respect to serviceability criterion. In the past, predominantly passive means have been used to reduce excessive motion. However over the last decade active control has also been extensively studied[1,2]. The need for active control has arisen as greater reduction of building response than passive control can provide is needed. Active control does provide a greater level of control without increasing the weight of the damper or significantly increasing its range of motion. Active control of the structure's motion involves using feedback to control a force actuator. The actuator is commonly attached to a mass damper on the top floor of the building or to tendons between floors. In this paper it is an actively controlled mass damper that is studied.

The area of active control which the authors are investigating in this paper and related work is a comparison of the effectiveness and efficiency of several different control algorithms (or methods of designing the control force from the feedback) acting on a tuned mass damper of a multi degree of freedom building. Work has been done in the past studying both the theoretical and experimental effect of active control, however this has been done predominantly on buildings which are loaded by earthquakes, and comparisons between different control algorithms has been limited[3,4].Until now no comparison of the different control algorithms which have been developed to date has been done for structures loaded by wind. In the design of an active control system the choice of algorithm is important; for example determining whether it is better to use acceleration, velocity, displacement, or a combination of these as feedback to the force actuator, and then deciding on a way to determine the gain for this feedback is a crucial design question. This paper analytically compares the effect of velocity and displacement feedback control on a multi degree of freedom model of a 200m tall square building with an aspect ratio of nearly 1:6 loaded by wind at the serviceability limit state speed.

ANALYTICAL MODEL

The analytical model that has been used is not a direct representation of a full scale tall building. It is an analytical model of a seven degree of freedom aeroelastic wind tunnel model, which represents a 200 metre tall square building. The analysis is done of the aeroelastic model rather than a full scale building as comparison between wind tunnel tests using the aeroelastic model and the analytical results will be made in the future. The aeroelastic model, and therefore the analytical model, is represented by six lumped masses representing building mass, with a seventh lumped mass representing the mass of a tuned mass damper, which is assumed to be located inside the building attached to the top floor. The stiffness is assumed to be concentrated in massless shear walls, and structural damping for the building section of the model has been neglected. The stiffness and damping of the TMD are modelled by assuming that the damper is optimally tuned according to the Den Hartog equations[5]. An actuator attached to the top building lumped mass is assumed to provide the control force to the damper. The figure below shows this schematically.



SCHEMATIC REPRESENTATION OF ANALYTICAL MODEL

The equation of motion of this system is given by:

$$M\ddot{x} + C\dot{x} + Kx = F + U$$

Where M, C, and K are the mass, damping, and stiffness matrices respectively. F is a vector representing the wind loading and U a vector representing the active control force provided by the actuator. When U is set to zero the system represents a passively controlled building, and setting the TMD parameters to zero represents a building with no added control. A time history of the model displacement vector is obtained by solving the equation of motion in the time domain by numerical integration. The initial conditions are set as a displacement of zero. Results are obtained for four cases: where there is no added control; passive control only; active control obtained by adding a gain to top building degree of freedom displacement feedback; and active control obtained by adding a gain to top degree of freedom velocity feedback.

WIND LOAD INPUT

Previous analytical studies of actively controlled wind loaded buildings have used an analytical model for the wind loading^6. This can lead to inaccuracy, particularly in the across wind direction. This study has used wind load coefficients obtained from wind tunnel tests of a rigid, pressure tapped model the same size (1m tall by .174m square) as the aeroelastic model being modelled. The interior of the model is fitted with 12 calibrated Honeywell pressure transducers which simultaneously measure the pressure at six levels on two opposite faces. Each transducer receives input from a 12:1 manifold which is connected to 12 pressure taps distributed evenly over an area corresponding to the tributary area of a lumped mass of the analytical model.

The testing was carried out in a boundary layer wind tunnel which simulated wind flow over a terrain category 2. The transducer output was low-pass filtered at 30 Hertz and sampled at 152 Hertz by the analogue to digital converter. 8192 samples were taken. The value of 30 Hertz was chosen as a low pass cut off as the analytical model's highest natural frequency is close to 25 Hertz, therefore frequencies above 30 Hertz will have an indiscernible effect on the building model. Sampling at 152 Hertz gives a record 52 seconds long, which corresponds to 11 minutes in full scale. Both along and across wind measurements were recorded.

By combining readings from opposite faces, and dividing by the dynamic pressure measured by a pitot tube in the tunnel a time history of the force coefficients acting on each lumped mass was obtained. These force coefficients were used to obtain the force input to the analytical model using a wind velocity corresponding to a reduced velocity of 4.3 which is the serviceability limit state of the building. As this is a relatively low reduced velocity, it is expected that errors arising from neglecting of aerodynamic damping by using a rigid model to obtain the wind loads will be negligible.

DISCUSSION OF RESULTS

Figures one to four are time histories of the top degree of freedom displacement and the active control force for both along and across wind loading. The results are presented in model scale. A time scale of 1:13 and length scale of 1:200 apply to convert these results to full scale. It is noted that as structural damping, except for that present in the TMD, has been assumed to be zero, the results for no control show a rapid build up of displacement.

Figures one and two are results for along wind loading. It can be seen that both velocity and displacement feedback active control are capable of providing additional control to the top degree of freedom compared to passive control. Indeed in both cases the standard deviation of the response has been decreased by 20% compared to the passive case. However, in the case of the velocity feedback algorithm, in order to provide the same quality of control as the displacement feedback algorithm the magnitude of the control force is seen to be approximately double that of the displacement feedback control force. The velocity feedback control force is of the order of 15% of the standard deviation of the wind loading to the top degree of freedom, and the displacement feedback about 8%. These control forces are of a realisable magnitude.

Figures three and four are results for across wind loading. Again both velocity and displacement feedback have provided a reduction of response standard deviation of about 20% compared to the passive control case. In this case the control forces are of a similar magnitude, indeed the displacement feedback algorithm calls for a slightly higher force than the velocity feedback algorithm. The control forces are of the order of 7% of the standard deviation of the across wind force on the top degree of freedom, again this is a realisable magnitude.

CONCLUSION

These results show that while both control algorithms result in control forces of realisable magnitude for a significant reduction in building motion compared to passive control the displacement feedback control algorithm has been shown to be generally more effecient than the velocity feedback control algorithm. This type of analysis can therefore be used to determine the relative effectiveness of different control algorithms and so is a useful design tool.

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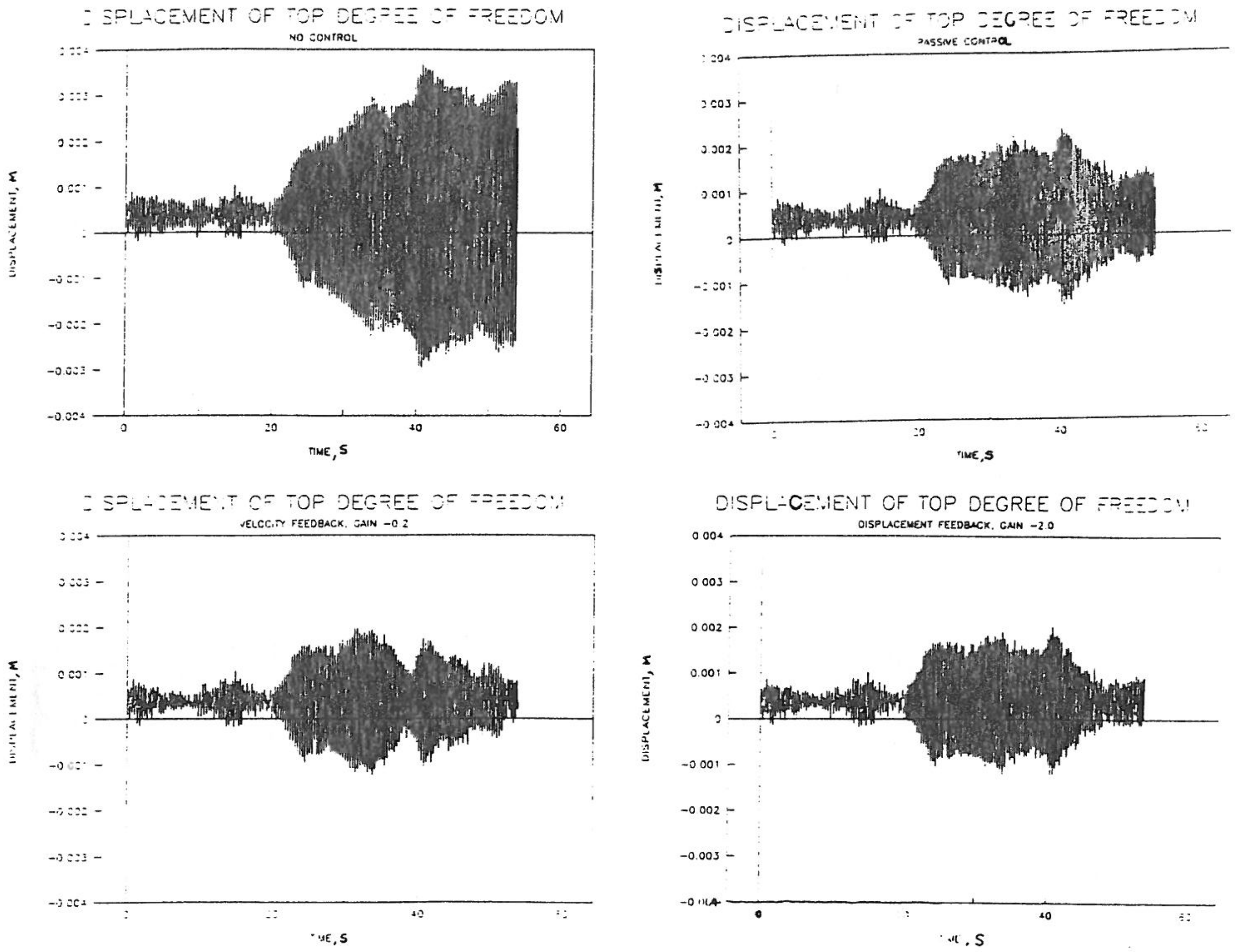

FIGURE ONE: ALONG WIND DIRECTION TOP DEGREE OF FREEDOM DISPLACEMENT, NO CONTROL PASSIVE CONTROL, & ACTIVE CONTROL WITH VELOCITY OR DISPLACEMENT FEEDBACK.

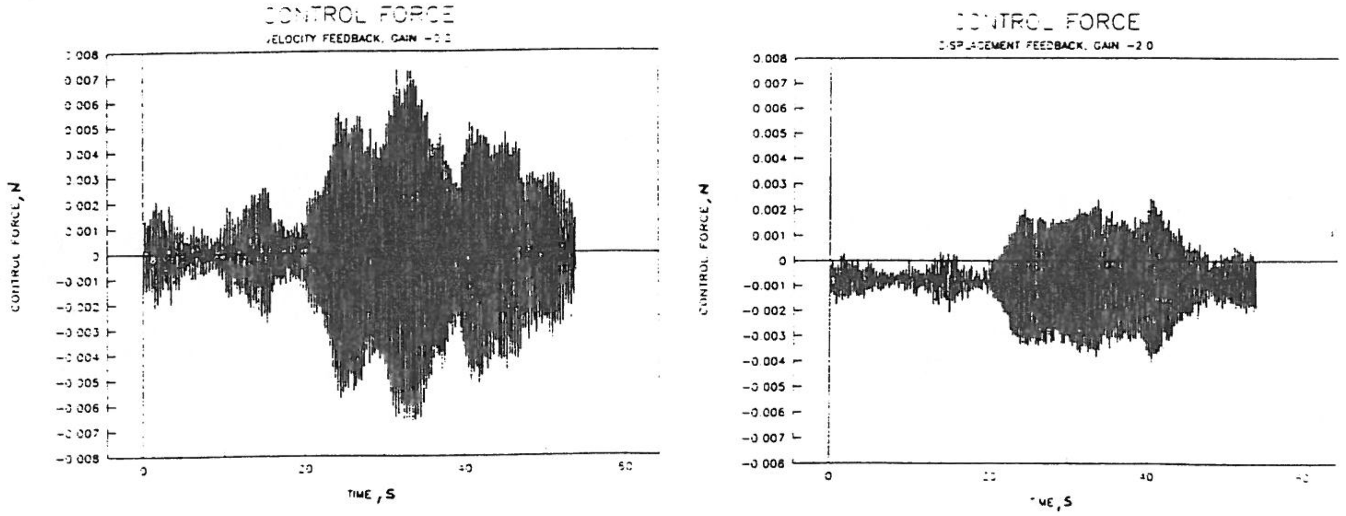

FIGURE TWO: ALONG WIND DIRECTION CONTROL FORCE FOR VELOCITY & DISPLACEMENT

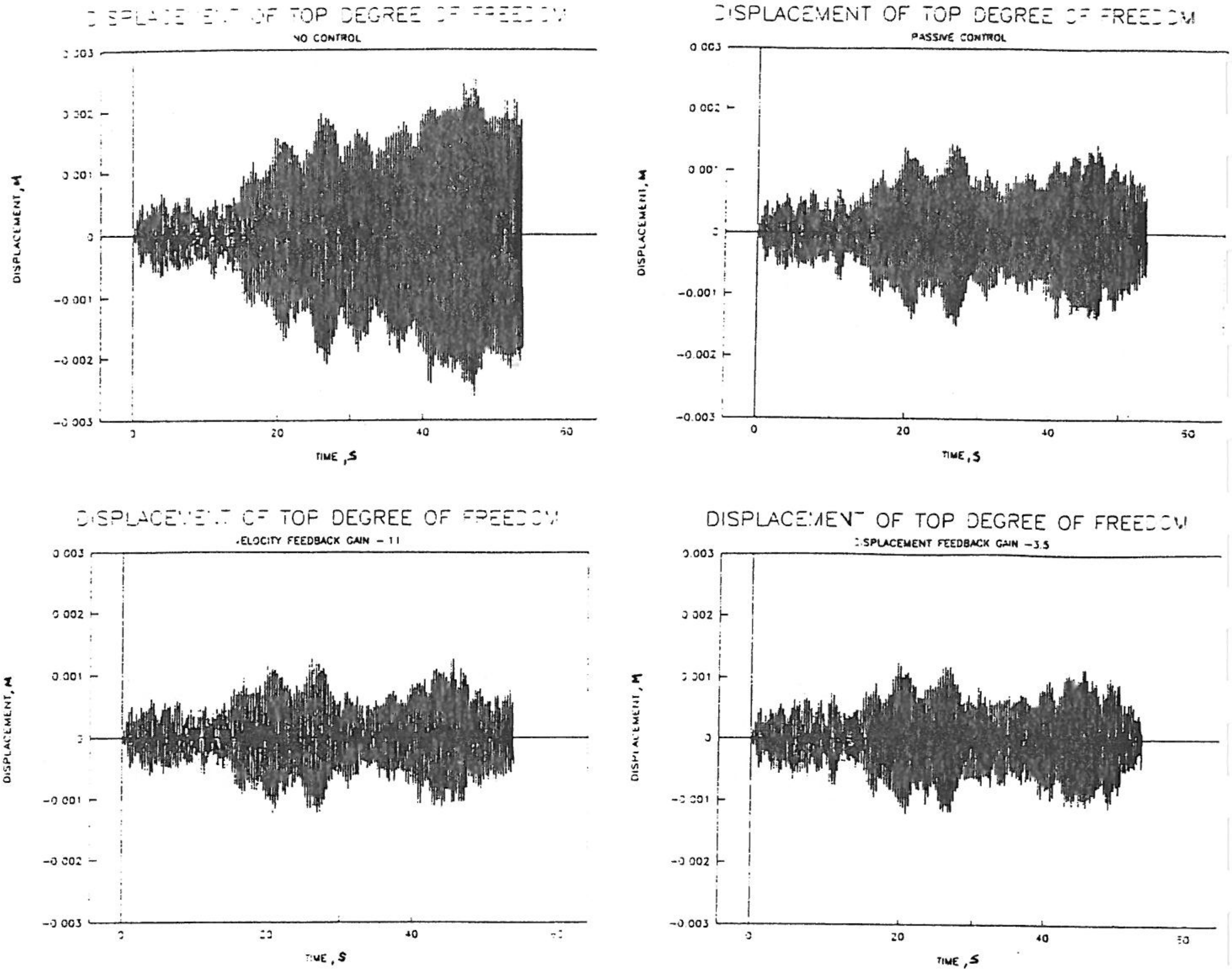

FIGURE THREE: ACROSS WIND DIRECTION TOP DEGREE OF FREEDOM DISPLACEMENT; NO CONTROL, PASSIVE CONTROL, & ACTIVE CONTROL WITH VELOCITY & DISPLACEMENT FEEDBACK.

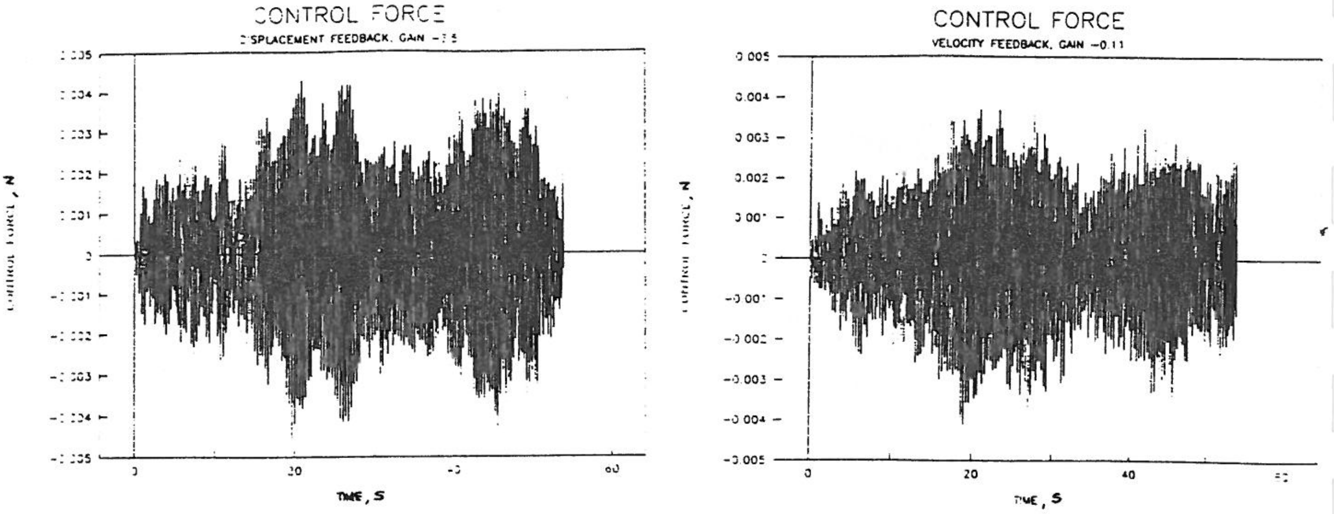

FIGURE FOUR: ACROSS WIND DIRECTION CONTROL FORCE FOR VELOCITY & DISPLACEMENT