The Effects of Open Passage on Reducing Wind Response of Tall Buildings

by
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ABSTRACT:

An open passage design on tall buildings is investigated to reduce the wind dynamic responses resulted from the periodic vortex shedding of building corners. Initial results of a dynamic balance wind tunnel test for a square section model with sharp edges at an aspect ratio 8:1 and with only a very small opening ratio 1.5% on its 4 walls show a significant reduction of the across-wind dynamic deflection by about 20-25%. The results also indicate that the arrangement with open passages on all its 4 walls is the most effective way comparing to cases with openings either on the side walls or on the back wall being sealed.

Key Words: Wind Response Control
Tall Buildings
Open Passage
Vortex Shedding

1 INTRODUCTION

With the building height increasing rapidly in recent years, the sensitivity to wind excitation has increased dramatically. The need for effective means to control the building dynamic response in the across-wind direction becomes increasingly urgent. In Japan, a plan to build hyper-rise buildings is on the government and construction industries' agenda. One of the most serious challenges associated with this hyper building concept is to reduce the wind induced instability. Apparently, the most effective way to reduce the wind induced instability would be to eliminate the excitation source. It is well known that wind induced vibration of high-rise buildings comes from the periodic vortex shedding at building corners. Therefore, if the vortex shedding process can be somehow disrupted, the periodic loads acted on the building resulted from this vortex shedding process will be reduced and the wind induced motion in the across-wind direction will be controlled. Architectural modification of building configuration would alter the flow pattern around the building, and could lead to the breaking of the vortex shedding system. Open passages at appropriate positions of a building would allow high pressure air to bleed into regions close to the side edges where the vortex shedding is generated, and to the back region of the building which has a strong relation with the across-wind dynamic force as explained by Bearman[1]. Optimisation of this design would possibly be able to eliminate the vortex shedding system completely. Kwok and Bailey[2] have tried various venting slots and corner treatments in an attempt to reduce wind dynamic responses. Dutton and Isyumov[3] conducted a similar investigation by using various gaps. But they used static force balance in their tests. Because it has been considered that results from actual dynamic test and results from static measurement may be quite different regarding to the model dynamic response, the present test used a

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dynamic balance, designed for this project to measure the actual dynamic deflection of the building model.

2 EXPERIMENT

The preliminary investigation of this research has concentrated on using open passages at centre regions. 3 high-rise building models, respectively with sharp edge corners, round corners and cut corners are tested in the boundary layer wind tunnel in the Building Research Institute of Japan. All models are rigid and have an aspect ratio 8:1 with a square cross section. The width of the 3 models is the same at 70mm. Only the sharp edge model has open passages on its 4 walls, which centred at 80% of the building model height. The size of the opening can be varied if required. The first test was conducted with the sharp edge model for two conditions, without any open passage and with open passage of 30mm×20mm on some walls of the model. This gives an 1.5% opening ratio defined as the opening area of the wall over the total area of the same wall. A dynamic balance is made for this test to allow the model to have two degrees of freedom in both the along-wind and across-wind directions. Two laser displacement sensors are mounted to record the time histories of the model deflections in both directions. Two pairs of springs are selected with one pair at a spring constant $19600\times2kg/s^2$ in the across-wind direction and another pair $68600\times2kg/s^2$ in the along-wind direction. The use of different springs is a consideration of eliminating the beating phenomenon, which otherwise would happen if the two pairs of springs have the same spring constant. The natural frequencies of the model set-up are 13.2Hz in the across-wind direction and 20.0Hz in the along-wind direction. The original damping coefficient of this set-up is 0.38% in the across-wind direction and 0.42% in the along-wind direction. The damping coefficient can be varied by using a liquid damper. The liquid used here is silicone with a density of $10000kg/m^3$, which gives a damping coefficient 2.6% in the across-wind direction and 0.94% in the along-wind direction. During the test, different open passage arrangements are used to see their effects on reducing the dynamic response of the model. The test is carried out in an atmospheric boundary layer flow corresponding to an urban area condition $V= V_o(z/z_o)^{0.25}$, where the boundary layer thickness z_o is about 1000mm, and the free stream wind velocity is varied from 5m/s to 17m/s. The power law boundary layer profile is generated by a spire and roughness system. Based on scale analysis according to a full scale consideration, a data sampling frequency of 500Hz is chosen and a sampling period of 5 seconds is taken. For each test condition, 6 records are made, and this gives a total data length of 15000.

3 RESULT AND DISCUSSION

Some results of the dynamic response for the sharp edge model in the across-wind direction for different open passage arrangements with and without the $10000kg/m^3$ silicone damping are shown in Figure 1 and Figure 2. The y axis is the rms value of the model tip dynamic deflection σ, and the x axis (V/fD) is the wind velocity at the model height position over the product of model natural frequency f in the across-wind direction and the model width D. Figure 1 is the result for the test condition of damping coefficient 0.38% in the across wind direction, and Figure 2 is the result with the $10000kg/m^3$ silicone at a damping coefficient 2.6%.

As expected, the rms value of the model dynamic deflection for the open passage configuration is much smaller than that of without any open passage.

This indicates the effectiveness of the open passage in reducing the dynamic wind response of the building model. Generally, it is seen that all 3 open passage arrangements reduce the model dynamic response significantly considering that the opening ratio is only 1.5% in the present test. Clearly these results show that for both cases with damping ratios 0.38% and 2.6%, open passage on all 4 walls is most effective comparing to either the side walls or back wall having no open passages. On the average, it can be seen that open passage on the side wall is more effective than the open passage on the back wall especially for the 2.6% damping case. This is considered to be due to the reason that open passages on the side walls would allow high pressure air to disturb the vortex generating process directly. Therefore, the authors think that bleeding high pressure air into the edge regions of the side walls where the vortex shedding is actually created should be more effective. In reality, it is always convenient to have open passages on all 4 walls, because first, this is most effective and second, the wind could be from all directions. It is also believed that a larger opening ratio should result in a much bigger reduction of the dynamic response of the building. This will be investigated in the next step.

Apparently, the lock-in phenomenon occurred in the test when the wind speed reaches around 8.5m/s. During the test, for all test conditions in the boundary layer flow, whenever the wind speed gets to this value, the vortex shedding frequency is seen to be controlled by the model natural frequency. However this lock-in phenomenon does not seem to disappear even when the wind speed increases to over 15m/s at the model height. The Strouhal number for this square section model is about 0.91, so based on the model natural frequency 13.2Hz in the across-wind direction and the model width 70mm, the critical wind speed should be about 10m/s where the resonance would occur. But the model dynamic response increases monotonously even when the wind speed reaches over 15m/s and the vortex shedding frequency is still dominated by the model natural frequency. There are two possible explanations. The first is that the lock-in region maybe become wider in a boundary layer flow than that of in a smooth flow. The second explanation is that galloping is happened immediately after the vortex induced vibration or within the lock-in region. Kawai[4] presented some results and analysis which are quite similar to those of the present test. In spite of this, the effectiveness of the open passage arrangement is shown clearly with a reduction of 20-25% of the model dynamic deflection at large wind speeds. It should be mentioned here that the same test is also carried out in a smooth flow condition, and the results do show that in the smooth flow, a clear lock-in region exists between 8m/s and 12m/s.

The power spectra of the model tip dynamic deflection are calculated for some test conditions. A sample is given in Figure 3 for the damping coefficient of 0.38% at two test conditions, without any open passage and with open passages on all 4 walls at a wind speed 10.8m/s at the model height. The y axis is the power spectral density of the model dynamic deflection $S_d(f)$ and the x axis is the frequency f. Apparently, this is inside the lock-in region because only one peak is appeared in the spectra at the model natural frequency of 13.2Hz. From this figure, it can be also seen the effectiveness of the open passage arrangement as the peak value of $S_d(f)$ without any open passage is more than 2 times of the peak with open passages on all its 4 walls and all other $S_d(f)$ values at both lower and higher frequencies are greater as well. For these two particular tests, the difference of their rms value of the model dynamic deflection σ is about 25%. Another example of the power spectrum is shown in Figure 4 for a wind speed 5m/s at the model height without any open passage and with a damping coefficient 0.38%. Obviously, this test condition is not in the lock-in region yet because there are two peaks appeared on the spectrum. One is the vortex shedding frequency at about 7Hz and the other is the model natural frequency of 13.2Hz.

4 CONCLUSION

Some results of an on-going research project on reducing the dynamic response of high-rise buildings by an open passage design are presented and discussed. The main points from this investigation can be summarised here:

(1) The open passage configuration results in a significant reduction of the dynamic response of the building model in the across-wind direction induced by the periodic vortex shedding on building corners. The model dynamic deflection reduces about 20-25% even for a very small opening ratio 1.5% on all its 4 walls.

(2) The condition with open passages on all its 4 walls tends to be the most effective way in reducing the dynamic response of the building model comparing to the arrangements of either only the front and side walls or front and back walls have open passages.

(3) For the building model used in this test, the Strouhal number is about 0.91. The lock-in phenomenon starts when the wind speed reaches around 8.5m/s. However this lock-in phenomenon does not disappear even when the wind speed gets to over 15m/s at the model height. There are two possible reasons: a longer lock-in region in a boundary layer flow condition, or galloping happened within the lock-in region.

The authors consider that with a combined arrangement of both open passage and cutting corners on the building model, a further reduction of the model dynamic response would be possible. Models with larger opening ratios at different positions and with several open passage arrangements on one model will be used in the continuing investigation. Flow visualisation is also considered to check the flow configuration on the corner regions of the model for these different open passage arrangements. The authors also plan to see if open passages on the corner regions would be able to eliminate the vortex shedding system completely. The same idea is also considered to be applied in an active way by discharging high pressure air into these regions.

REFERENCES

[1] Bearman, P.W., "The effect of base bleed on the flow behind a two-dimensional model with a blunt trailing edge", The aeronautical Quarterly, Vol. XVIII, Aug. 1967.

[2] Kwok, K.C.S. and Bailey, P.A., "Aerodynamic devices for tall buildings and structures", Jnl. of Engrg Mechanics, Vol. 113, No. 3, March 1987.

[3] Dutton, R. and Isyumov, N., "Reduction of tall building motion by aerodynamic treatments", Jnl. of Wind Engrg and Industrial Aerodynamics, Vol. 36, 1990.

[4] Kawai, H., "Vortex induced vibration of a tall building in smooth and turbulent boundary layer flow", Annual Meeting of Japan Institute of Architecture, Sept. 1991.

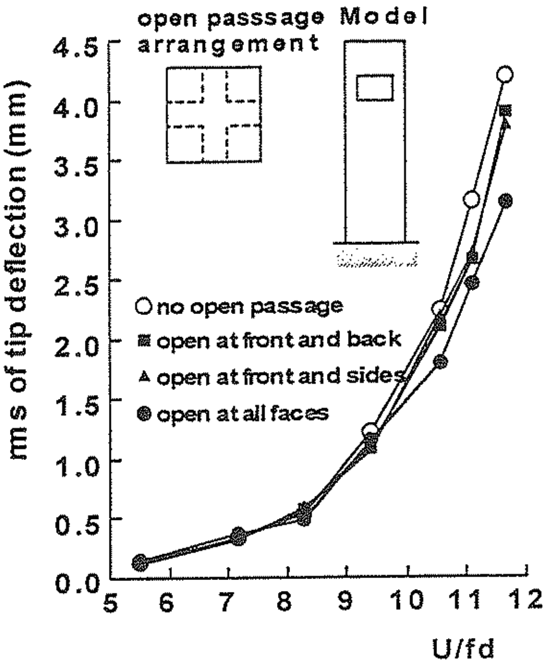

Figure 1 Model dynamic deflection with a damping coefficient 0.38%

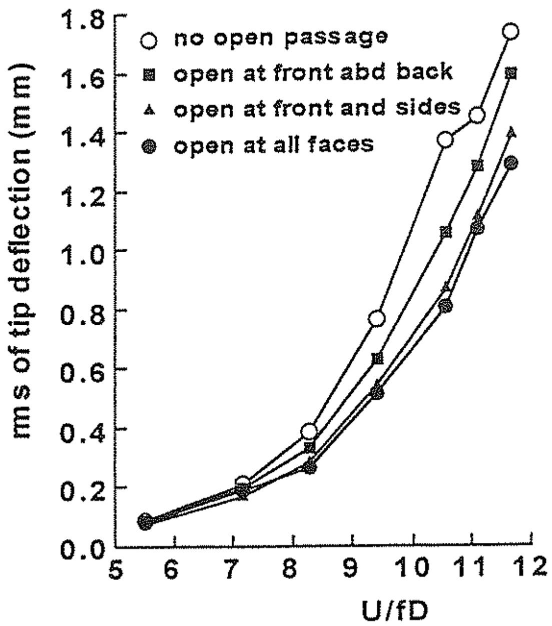

Figure 2 Model dynamic deflection with a damping coefficient 2.6%

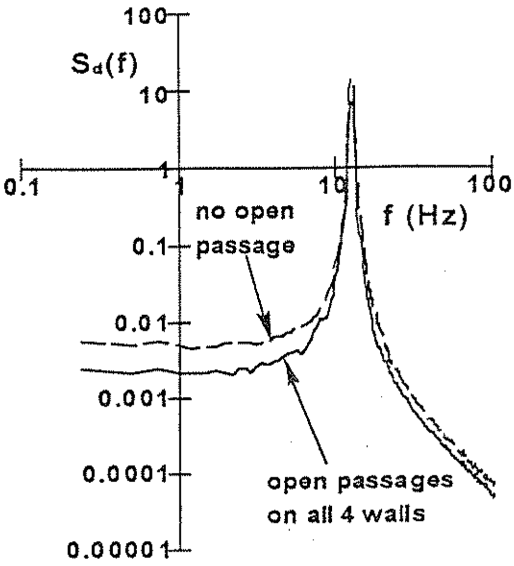

Figure 3 Comparison of the power spectra with and without open passage inside the lock-in region

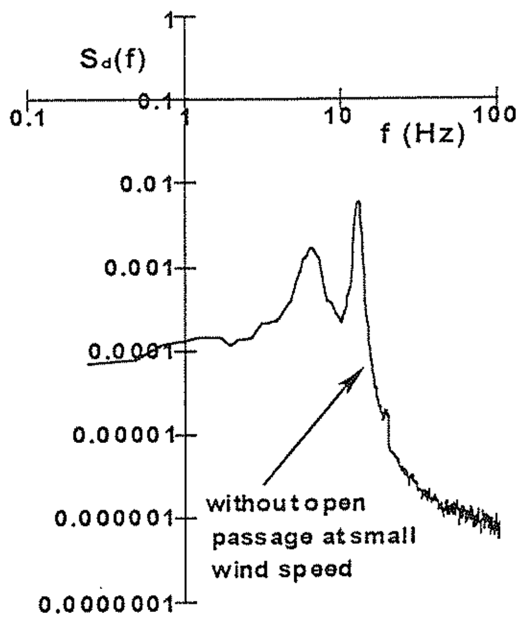

Figure 4 A sample power spectrum outside of the lock-in region