A TWO-DEGREE-OF-FREEDOM BASE HINGED AEROELASTIC (BHA) MODEL FOR RESPONSE PREDICTIONS

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ABSTRACT

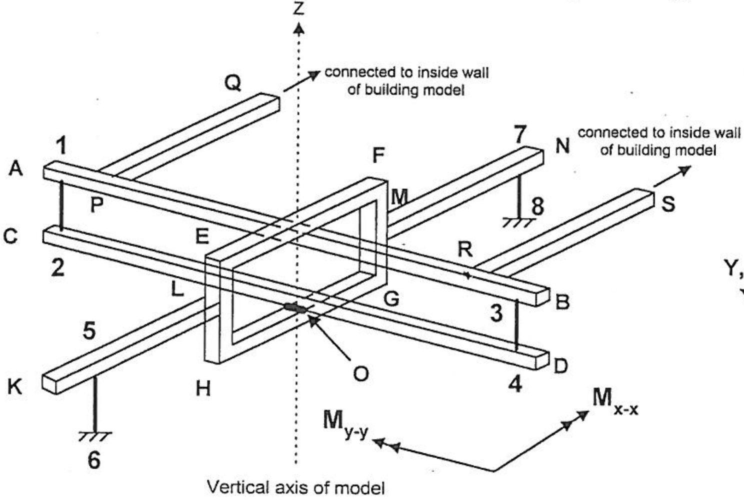
This paper describes the development of a two degree-of-freedom BHA model for aeroelastic model tests of tall building. The frequencies of vibration of the BHA model can be accurately predicted by means of a free-standing-cantilever model. The displacements at top of the standard CAARC tall building in along-wind and cross-wind direction, in the range of reduced velocity 2-8, observed by a BHA model are similar to those observed by a conventional "Stick" model and other published records.

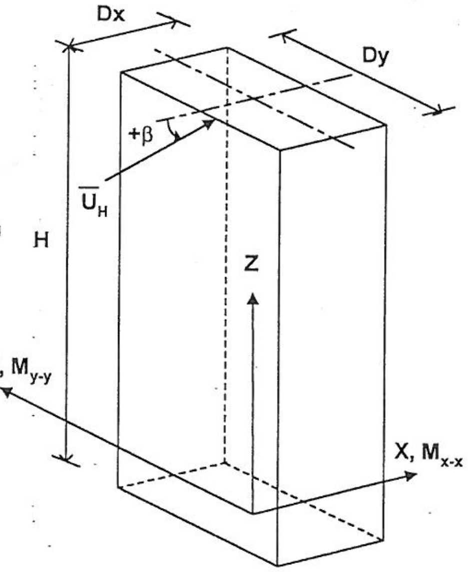
INTRODUCTION

In the study of wind induced response of tall building in two fundamental sway modes, a conventional "Stick" aeroelastic model has been normally employed in a boundary layer wind tunnel to estimate the maximum, mean, and root-mean-square (rms) responses. The modelling technique and the associated instrumentation system have been well documented by many researchers (e.g., Isyumov (1982)). The major advantages of this modelling technique are its simplicity and its ability to readily change the mass, stiffness, structural damping and geometric of building model in order to investigate the sensitivity of those effects on the responses. However, this technique does not model coupled translational-torsional motion which may be critical in case of tall building which has eccentricity between centre of mass and centre of stiffness. An alternative modelling technique is proposed, namely Base Hinged Aeroelastic (BHA) model, which has all advantages of the stick model and also the ability to model complex motion (coupling between translational and torsional motion).

DEVELOPMENT OF A 2 DEGREE-OF-FREEDOM BHA MODEL

-AB and CD are rigid members aligned in the same vertical plane.
-EFGH is a rigid rectangular frame, GH is attached to bottom of CD while EF runs above and perpendicular to AB.
-KL and MN are rigid members attached to frame EFGH.
-PQ and RS are rigid members attached to AB.
-1-2 and 3-4 are flexural elements designed to examine the overturning moment M_{y-y}.
-5-6 and 7-8 are flexural elements designed to determine the overturning moment M_{x-x}.





a) TWO-DEGREE-OF-FREEDOM BHA
b) BUILDING MODEL AND NOTATIONS

FIG.1 BASE HINGED AEROELASTIC MODEL FOR TALL BUILDINGS.

Kwok et. al. (1994) developed a Base Hinge Assembly for an aeroelastic model as shown in Fig.1. ABCD and KLMN are two perpendicular frames connected to each other at point O. The integral parts of each frame are flexural elements, i.e., 1-2, 3-4, 5-6, and 7-8, of which flexural elements 1-2 and 3-4 are specially designed to examine the overturning moment M_{y-y} and flexural elements 5-6 and 7-8 are designed to examine the overturning moment M_{x-x}. The rigid timber model is attached to a BHA at points Q and S forming a BHA model. According to this configuration, the line joining flexural elements 1-2 and 3-4 forms the first line of hinge and that joining flexural elements 5-6 and 7-8 forms the second line of hinge.

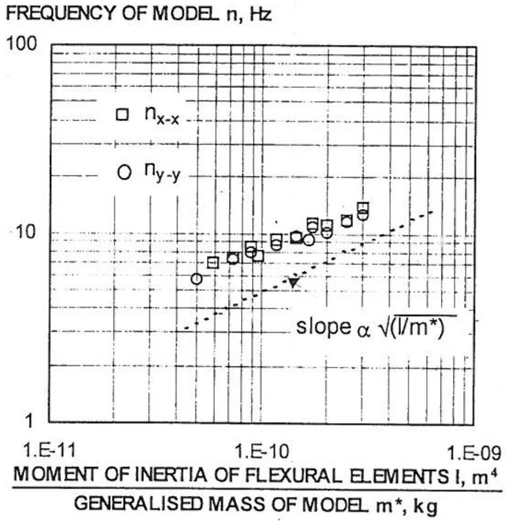


FIG. 2 EFFECTS OF STIFFNESS OF FLEXURAL ELEMENTS ON FREQUENCIES OF MODEL.

Frequencies of vibration of a BHA model in x and y directions can be accurately predicted by a free-standing-cantilever model where the generalised mass, m*, is approximately equal to the generalised mass of a timber model and the generalised stiffness, k*, is calculated from the stiffness of flexural elements. Therefore, the generalised frequency, n, of a BHA model would be proportional to $\sqrt{(I/m^*)}$, where I is a moment of inertia of flexural elements. The results of an investigation of frequencies of a BHA model in x and y directions which confirm the above approximations are shown in Fig. 2

EXPERIMENTAL PROGRAMS

A rectangular prismatic shape standard CAARC tall building corresponding to a prototype width (D_x) 30 m, length (D_y) 45 m, height (H) 180 m, natural frequency (n_0) 0.20 Hz in both directions, and structural damping (ζ) 0.01 in both directions, was selected for a detailed study.

The aeroelastic models, corresponding to a length scale, $\lambda_L = 1/400$, a frequency scale, $\lambda_n = 25$ and a velocity scale = 1/16, of a BHA model and a Stick model shown in Fig.3 were tested in a boundary layer wind tunnel in the Fluids Laboratory, University of Sydney.

The natural wind model classified by terrain category 2 (open terrain) in AS1170.2-1989 (power law exponent $\alpha \cong 0.15$, turbulence intensity at top of model $I_u \cong 0.10$) was simulated using a set of spires and roughness elements placed in the working section of the wind tunnel. A series of test cases based on a study of wind induced response, effect of wind direction and effect of change in structural damping on responses, were conducted and the results of two cases are presented in this paper.

RESULTS

The overturning moments observed by both BHA and Stick models have been converted to displacements at top of building model by calibration and then compared with those obtained by Melbourne (1980). The difference of wind model used in this study ($\alpha \cong 0.15$, $I_u \cong 0.10$) and that of Melbourne ($\alpha \cong 0.28$, $I_u \cong 0.10$) leads to the higher mean deflections in this study which can be seen in Fig.4 and Fig.5. In most cases, the displacements observed by both BHA and Stick models are in good agreement in the range of reduced velocity 2-8, except in case $\beta=90^\circ$ at which the along-wind deflections observed by both models show a more significant difference. The average difference between displacements observed by both models is approximately 7% in most cases and 15% in case of along-wind response shown in Fig.5(a).

CONCLUSIONS

Aeroelastic model tests of a CAARC standard tall building using a 2 degree-of-freedom BHA model were conducted. The main findings are :

a) Frequencies of vibration of the model can be accurately simulated by the stiffness of flexural elements.

b) The comparison of displacements at top of building model observed by a BHA model and a Stick model, in the range of reduced velocity 2-8, shows an average difference 7% in most cases, except in case of $\beta=90^o$ at which the along-wind deflections observed by both models show a difference of 15%.

It can be concluded that the responses predicted by a BHA model are consistent with those predicted by a Stick model.

Future development of a BHA model includes :

1) A comprehensive comparison of results obtained from a BHA model and a Stick model in the full range of reduced velocity from 2-22, including the effect of wind direction and change of structural damping.

2) The development of a BHA to examine coupled translational-torsional motion (complex motion) by either using different stiffness, or different material for each flexural element, and/or moving them along the axis to provide an eccentricity.

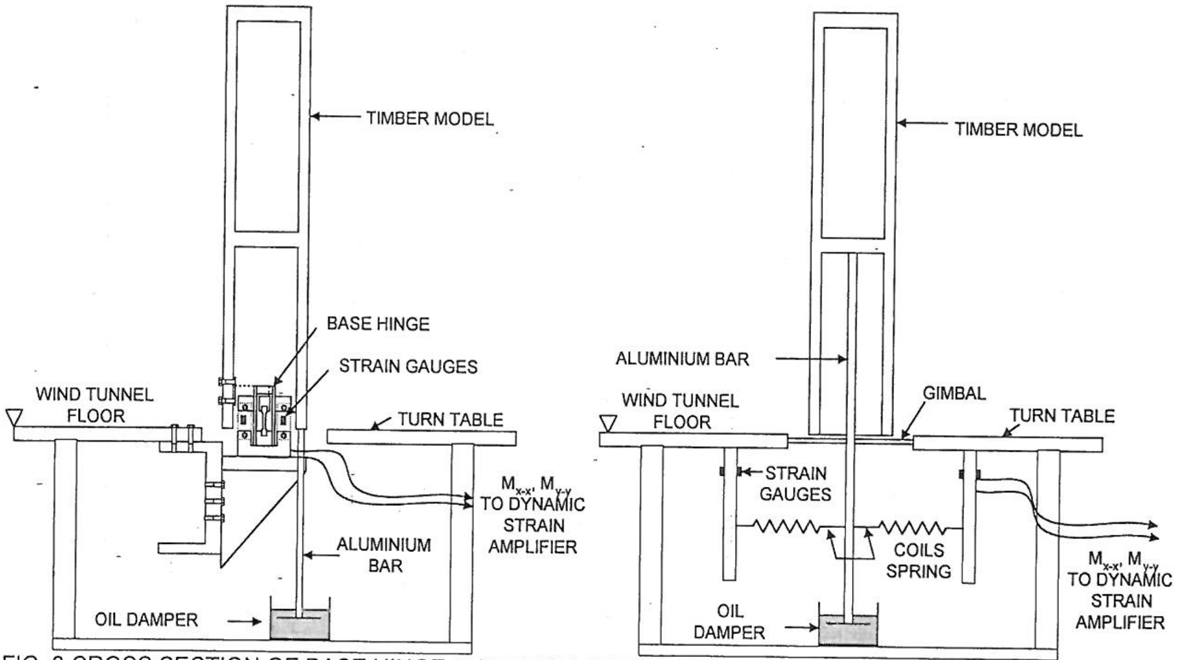


FIG. 3 CROSS SECTION OF BASE HINGE AND STICK AEROELASTIC MODEL OF CAARC BUILDING.

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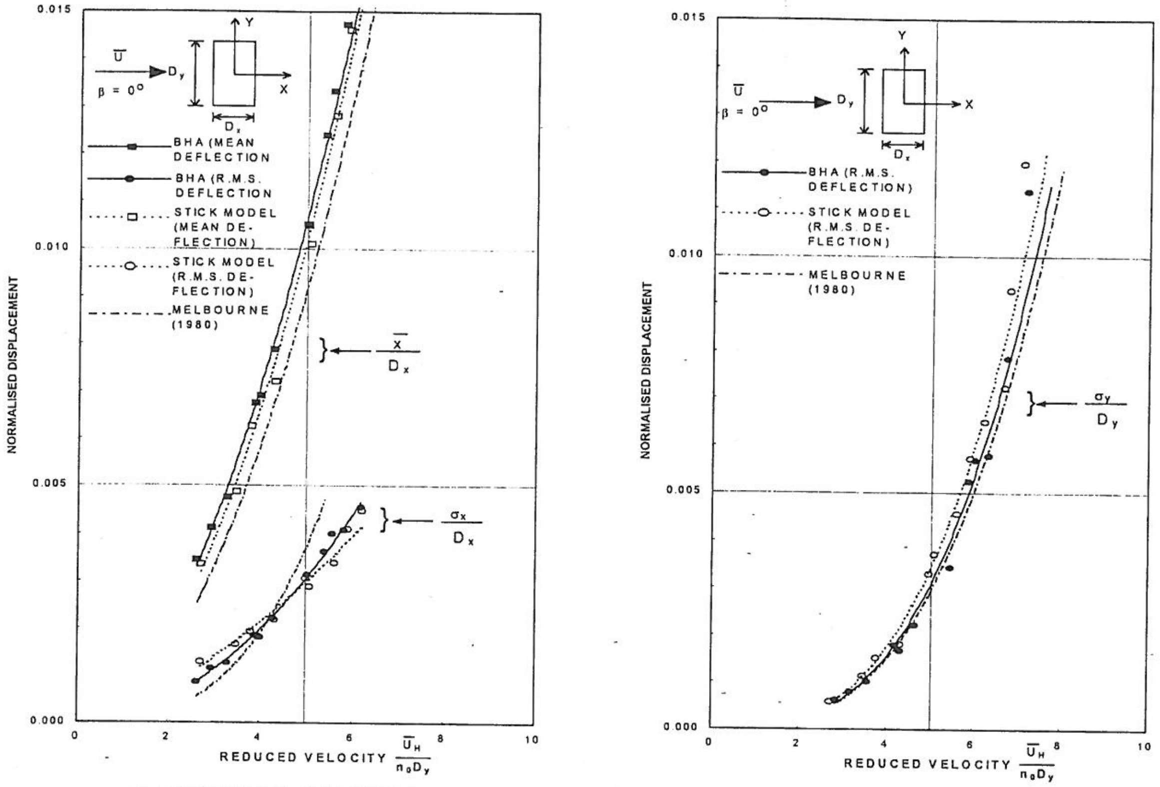
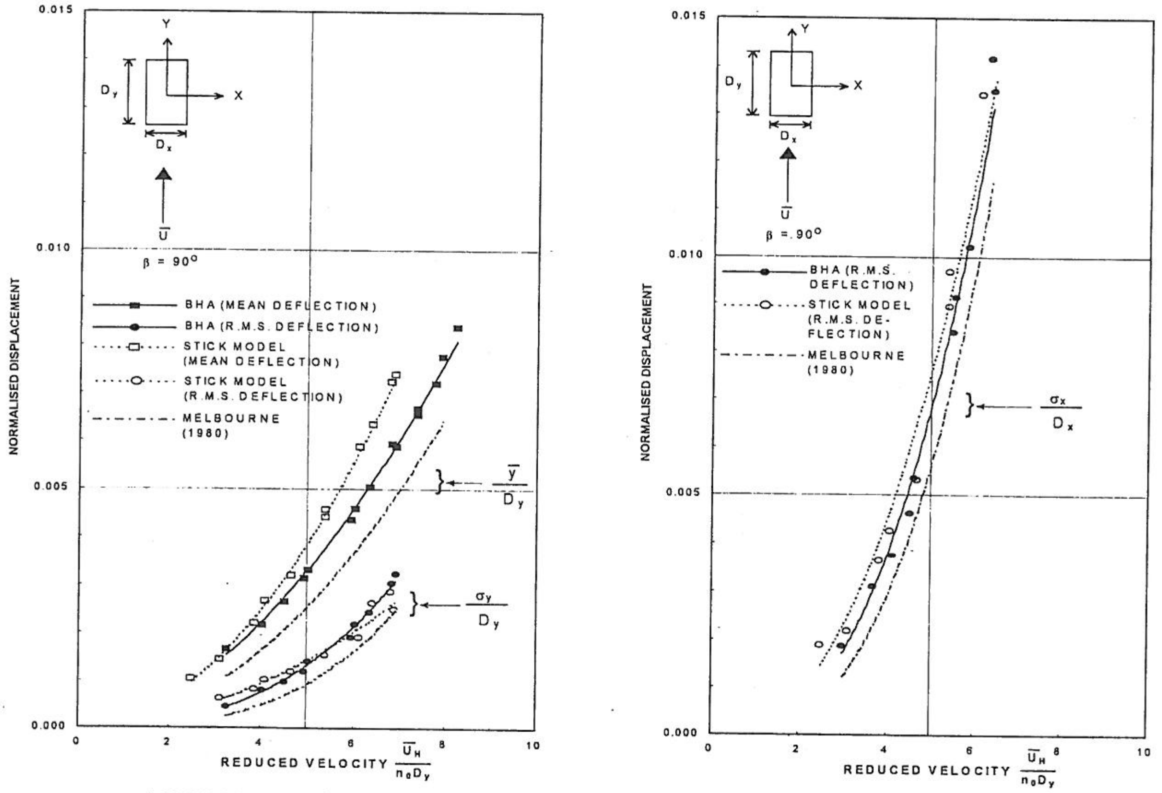


a) ALONG-WIND RESPONSE

b) CROSS-WIND RESPONSE

FIG.4 DISPLACEMENTS AT TOP OF CAARC BUILDING MODEL AS A FUNCTION OF REDUCED VELOCITY FOR $\beta = 0^\circ$ AND DAMPING $\zeta = 0.01$.



a) ALONG-WIND RESPONSE

b) CROSS-WIND RESPONSE

FIG.5 DISPLACEMENTS AT TOP OF CAARC BUILDING MODEL AS A FUNCTION OF REDUCED VELOCITY FOR $\beta = 90^\circ$ AND DAMPING $\zeta = 0.01$.