An Experimental Study Towards Development of Wind Resistant Rural Homes in Bangladesh

U K Roy
M A Ansary
S M Seraj
Bangladesh University of Engineering & Technology (BUET)

R L P Hodgson
University of Exeter, UK

1. Introduction

During the last few years, engineers have increasingly realized the importance of wind loads for all types of structures. Some recent disasters (such as 1991 tornado in the Bay of Bengal, 1993 Hurricane Emily, 1998 Hurricane George in USA) are vivid examples of what can happen if wind effects are not fully taken into account. Except by hurricanes and tornadoes, complete destruction of buildings by wind is rare. However, by local failures of roofs, claddings, and glass are both common and more costly in the aggregate than all the complete failures. Single-family houses in high-wind areas experience large, negative roof pressures that can lead to local failures. The shape of the roof seems to be a major factor in the extent of damage. Another major factor is the amount of the roof overhang. More information describing the wind loads on house roofs is needed so that roofs can be designed against such local damage.

Strong wind is an annual natural hazard in Bangladesh due to the geographical location on the earth. On the other hand, most of the existing houses and the houses which are going to be built in the next few decades are likely to be non-engineered, mostly with thatched roofs and vulnerable to wind. Strong wind is causing immense loses of rural dwellers by making their houses collapsed fully or partially by lifting of roof etc. With a view to assessing the vulnerability of collapsing of the rural houses due to strong wind, an experimental study has been conducted by measuring pressures at different locations on a typical Bangladeshi rural house model at different exposure conditions, wind directions, roof slopes and flow conditions. High lifting pressures were noticed at the leeward fence and roof of the house model with an exposure condition of door is opened and window is closed. Based on experimental results, roof slopes ranging from 25° to 40° are considered to be effective for the construction of rural homes.

With a view to improving the wind-resistance potential of rural houses, wind tunnel experiments have been conducted on a rural house model at different flow conditions with different bracing systems. The effect of turbulence and the bracing systems on the lateral displacement of the house model has also been discussed.

2. Status of Rural Homes in Bangledesh

2.1 Housing practice

The majority of houses in the wind hazard zones of Bangladesh fall under the category of non-engineered structures. These are the traditional self-built housing for the poorest class of people. These structures, mostly with thatched roofs, are not covered by any code. They exhibit little or no resistance to extreme winds. Collapse of this category is responsible for the majority of loss of life and injury during cyclonic storms. An improvement in their wind resistance potential will significantly contribute to minimize loss of life and property.

Traditional materials for domestic construction include bamboo and jute poles, woven bamboo, mud, thatch, timber, very often in combination with cgi sheet, and in varying combinations and preferences overall according to region and material availability. Generally, floor is composed of mud plinth or raised timber, frame is made of bamboo poles or jute poles, walls are made of woven bamboo, mud or cgi sheet and roof is composed of thatch or cgi sheet.

During the last few years, a number of projects have been undertaken in different parts of the world aimed at developing techniques for reducing the vulnerability of non-engineered construction against extreme winds (NBS, 1977). Most of the houses of rural Bangladesh are designed and built by owners or artisans. Well documented literatures regarding this type of housing is unavailable in Bangladesh. There is a necessity for bridging this gap by transferring technology to the people, mostly living in the rural areas, who are actually involved in non-engineered construction. Following steps are proposed by Choudhury (1996) which may be used: Translate the guidelines in Bangla; train the trainers by BUET, HBRI in association with NGOs; training programmes for the artisans (masons, carpenters etc.); use of mass media to demonstrate good practices. Experiences of other country shows that post-disaster reconstruction provides an excellent opportunity for introducing improvements in housing technology.

2.2 Wind risk areas

Recently a comprehensive National Building Code has been formulated (BNBC, 1993) in Bangladesh. Figure 1 shows the basic wind speed in km/h as presented in BNBC for any location in Bangladesh, having isotachs representing the fastest-mile wind speeds at 10 meters above the ground for a return period of 50 years. The minimum value of the basic wind speed set in the map is 130 km/h at Thakurgaon. The maximum value of the wind speed is found in the coastal region of Teknaf, Chittagong, Hatiya, Potuakhali, Borguna and Sundarban forest.

2.3 Improved domestic construction

According to a recent ADB report (Lewis and Chisholm, 1996), 82% of dwellings in Bangladesh are in rural areas, 75% of rural areas are of kutcha construction (non-masonry; bamboo, woven bamboo, etc.), and that 23% of urban and more than 40% of rural dwellings are of a temporary nature. Evidence from the field in cyclone-prone areas indicates that there is a socially perceived need for improved construction of domestic dwellings and that assistance to build stronger homes would be appropriate.

Lewis and Chisholm (1996) proposed several improvements. Buildings should be sited with trees so as to protect each other. Clustering achieves a degree of mutual protection that linear layouts do not. Protection from normal wind and weather as well from cyclonic winds is also advantageously achieved. Frame will be improved with the inclusion of cross bracings as shown in Fig. 2. Frame members are normally lashed together with jute rope, which can be substituted with galvanized wires. Walls and openings can be improved by placing door in the center of the wall and placing a small window opening in the rear. Roof system can be improved by increasing the pitch of the roofs to between 30 to 40 degrees, tying down the thatch, improved fixings for cgi sheet.

3.0 Pressure Distribution Characteristics of a Rural Home Model

3.1 Experimental set-up

The experiment was conducted in a wind tunnel of the school of engineering, University of Exeter, UK. The wind tunnel is an open circuit type and has a working section of 0.51m high, 0.76 m breadth and 1.5 m in length. The maximum wind speed of the tunnel is 30 m/s. Figure 3 shows the wind tunnel used in this study.

In the experiment a house model as shown in Fig. 4 was made based on a scale of 1:20 of a typical Bangladeshi rural hut. The model placed in the tunnel always partially obstructs the passage of air causing the flow to accelerate. When this obstruction or blockage is substantial, the flow around the model and the models aerodynamic behaviour are no longer representative of the prototype condition. Although the blockage in this experiment is about 10%, no corrections are made to the observed data. The model plan and elevation are shown in Figs. 5. The black dots in Fig. 5a denote the column locations.

The plinth of the house has been simulated with a 15 cm × 29 cm timber of 2 cm thick. The columns of the house model were made of bamboo stick of 6-8 mm in diameter. Round holes of 6-8 mm diameter are so drilled on the timber base that the columns can be tightly inserted into these holes. The joints where two or more member ends meet were tightly fastened each other by using cotton ropes of about 0.3 mm in diameter. The fences and the roof of the house model were made of solid cardboard papers of 1.5 mm thick.

Pressure measurements were done in two different approaching flow conditions described as smooth flow and turbulent flow, respectively. The turbulent flow has been generated by placing a piece of timber of 25 mm thick and 65 mm high right across the tunnel width. The piece of timber was located at a distance of 1.1 m upstream of the model center. The velocity gradient of both types of flow is shown in Fig. 6.

3.2 Measurement of pressure

Inside and outside pressures at different locations on the model fence and roof were measured at a gradient wind speed of 10 m/s with pressure taps. Inside and outside diameter of the pressure tap were 3 and 5 mm, respectively. There are ten locations of pressure measurement numbering from 1/11 to 10/20 as shown in Fig. 7. There were in total 20 pressure taps at ten locations. Ten of the twenty pressure taps numbering from 1 to 10 were used to measure the outside pressure and the rest ten pressure taps numbering from 11 to 20 was used to measure the inside pressure. Fig. 8 shows the measured pressure at different locations for a roof slope of 35°. Resultant pressures are calculated by deducting the inside pressure value from that of outside. Here from all the pressures as presented in this paper represent the resultant pressure. The negative value of the pressure indicates suction.

3.3 Effect of exposure conditions on pressure

Internal and external pressure were measured at all the locations at different exposure conditions. Four different exposure conditions were studied in the experiment. These are: (i) door (D) is opened but window (W) is closed, (ii) both door and window are opened, (iii) door is closed but window is opened, and (iv) both door and window are closed.

It can be seen from Fig. 9a that suction occurred at all the places except the locations 3 and 4 on the windward fence where pressures are registered for almost all the exposure conditions. At both the windward and leeward locations on the roof, maximum suctions are found for the exposure condition of door is opened but window is closed (exposure: i). Upon opening the window at the leeward side (exposure: ii) reduces the uplifting suctions at the roof but its magnitudes are still higher than the condition of both door and window are closed (exposure: iv) or door is closed but wind is opened (exposure: iii). Similar observations has also been found for the turbulent flow conditions as can been seen from Fig. 9b. Hence, it is concluded from this observation that if there were not sufficient openings on the fences on both windward and leeward side, it would be better to close the door and window during storms.

3.4 Effect of roof slope on pressure

Pressure measurements were done at all the locations for different exposure conditions for each of the roof slopes,θ of 25°, 35°, 40°, 45°. It can be seen from Fig. 10 that at the locations 9 and 10 on the leeward roof which is most susceptible to lifting off during storms, the pressures are more or less same of all the pitch angles under consideration with an exception of slight increase in suction at θ =45° in turbulent flow condition. Similar is the case for the windward roof. Hence roof slopes ranging from 25° to 40° are considered to be effective for the construction of rural houses.

3.5 Effect of wind yaw angle on pressure

Pressure measurement has been performed at different locations for different wind yaw angle. Here, wind yaw angle is defined as the horizontal wind incident angle from the normal to the fence with door. Fig. 11 shows the pressures at all the locations in smooth flow condition with the exposure condition of both the door and window are closed (exposure: iv) for, $\theta = 25°$. It has been observed that at location 9, the suction gradually decreases with the increase of wind yaw angle as expected. No specific trend has been observed at location 10. Wind yaw angle of around 0° is the most sever condition for the uplifting of roof at the leeward side.

4.0 Displacement Characteristics of a Rural Home Model

4.1 Experimental set-up

In the experiment a model of Bangladeshi rural hut was made based on a scale of 1:20. The model plan and elevation are same as shown in Fig. 5. Round holes of 25 mm diameter are drilled on the timber base at the column locations shown as black dots in Fig. 5a. The large diameter holes are provided to allow movement or displacement of the supporting columns. The holes are then filled up with re-usable adhesive commercially known as Blu-Tack. Bamboo-stick columns of 5-7 mm in diameter were inserted right into the Blu-Tack. The unconfined compression test of Blu-Tack has been performed and it has been found that the behaviour of Blu-Tack is similar to that of medium stiff clay. The joints where two or more member ends meet were tightly fastened to each other by using cotton ropes of about 0.3 mm in diameter. The fences of the model are made with woven plastic, which is flexible and has virtually no or very little bending resistance in and out of the plane it lies, but can take tension. The roof of the house model was made of solid card-borad papers of 1.5 mm thick.

Displacement measurements were done in two different approaching flow conditions described as smooth flow and turbulent flow, respectively as stated in Art. 3.1. Displacement of the model was measured with the help of a deflectometer dial gauge set at the mid-height of the middle of the leeward fence. As the deflectometer was set at the leeward face of the model, the interference would be minimum. The set-up of the experiment is shown in Fig. 12.

4.2 Effect of storm duration on the lateral displacement

To observe the effect of storm duration on the lateral displacement on the model, displacement was measured at different wind speeds for 180 sec in smooth flow conditions and the results are plotted in Fig. 13. During the experiment, it has been observed that the lateral displacement of the model is not stationary eventhough the wind speed does not change with time. It can be seen from the figure that initially the deflection increases rapidly and within 60 sec it attains about 90 percent of its long term deflection. To have a reasonably stable data, all the subsequent displacement were taken at 2 min after a particular wind speed has been achieved.

4.3 Effect of lateral bracing on the lateral displacement

In smooth flow condition, the wind speed in the wind tunnel was gradually increased from 0 to 11 m/s at different stages. At each stage the speed was kept constant for a duration of 2 min and then the lateral displacement was recorded. It has been observed that at the wind speed of 11 m/s, the model has undergone large displacement and then the speed was withdrawn gradually at different steps and similarly at each step the displacement was also recorded. This part of the experiment has been termed as expt.1. The results are shown in Fig. 14. It can be seen that the model has undergone a large displacement and upon withdrawal of wind speed, the displacement recovery is very small.
After finishing expt.1., all the columns are pulled out of the supporting materials. The Blu-Tack is freshly inserted into the holes, and the columns of the model are placed again. Care has been taken to have similar support condition. The displacement of the house model was measured at different wind speeds (expt.2). To have an idea of the reproducibility of the model response, this has been repeated for another two times (expt. 3, expt. 4). The results are shown in Fig. 15. It has been found that the displacement vary from one experiment to another. It is understood that the variations are mainly due to the variability of the compactness of the material and also the exactness of the column locations.

Cross-bracings made of bamboo-cut-pieces of about 4 mm in diameter are then attached on two lateral sides. The ends of the bracing are tied to the frames with ropes. The displacement was measured at different wind speeds in a way similar to before and the experiment was repeated for three times. The experimental results are also shown in Fig. 15 as Brac1, Brac2, Brac3. It is seen that there are also variations in model response from one experiment to another in this braced condition. But, it is clear from the figure that the introduction of side bracing reduces the lateral displacement of the model to a great extent.

Diagonal tie ropes of 3 mm diameter tied to the frame were also tried in place of bamboo bracing. Average displacement of the house model were then compared with that of obtained in case of unbraced and braced model and the comparison are shown in Fig. 16. It can be seen that the tied ropes are most effective in suppressing the lateral displacement. The better performance of tie bracing than that of the bamboo bracing can be thought as the tie ropes could easily be placed more tightly than the bamboo bracing, otherwise the performance of both the bracings were expected to be the same.

4.4 Effect of different exposure conditions on lateral displacement

Figure 17 shows the displacement measured at two different exposures conditions of the house model. It is seen that when the door is opened, the response of the model increases largely than that of the closed door condition. Employing a shed of height and width equal to that of house model at a distance of about 40 cm upstream of the model, it has been observed that the model undergoes a large displacement as the model is in the wake of the shed. On the other hand, when the shed was located as close as a distance of 5 cm upstream of the windward face of the model, the roof has been observed to be lifted at the same gradient wind speed when the maximum displacement of the model house has been observed to be 5 mm. It is believed that the suction just downstream of the shed is mainly playing the role in producing large uplift force.

4.5 Hysterisis behaviour of the house model

Hysterisis behaviour of the house model is shown in Fig. 18. It can be seen from the figure that the displacement recovery is very small. Another important characteristics as can be observed is that for every cycle of loading the displacement of the house becomes larger than its previous cycle. This type of behaviour has also been noticed during full scale house test as described in Roy et al. (1999).

5.0 Concluding Remarks

A detailed wind tunnel experiment has been conducted to measure the pressures at various locations on a scaled model of a typical Bangladeshi rural homes for different exposure conditions. Based on the experimental results and reasoning, it has been thought that if there is not enough opening to pass the wind through the houses as is the usual cases, it is safer to close the doors and windows during strong winds. It has been observed that even without specific openings, a small amount of internal pressure exists because of passing of air through the small openings at different joint locations. Roof slopes ranging from 25° to 40° are suitable against strong winds as no significant difference of suctions were observed at the leeward side of the roof. Lifting forces on the roof are very much dependent on the wind yaw angle and large suctions are casued by the wind coming from the direction normal to the fence. Direction of wind has significant effect on the pressure distribution on the model and the effect is maximum for the wind normal to the breadth of the model.

This research work reemphasizes on the use of bracing/tie ropes to have a strong safeguard against wind. Lateral displacement of the house can be reduced by placing a wind breaker in front of the house, but it greatly enhances the risk of uplifting the roof/house as it falls in an extreme suction region.

Acknowledgement

The authors would like to thank the British Council for their financial support for travel and other grants under their Higher Academic Links program.

References

BNBC (1993). Bangladesh National Building Code, 1993. HBRI-BSTI.

Choudhury, J. R. (1996). Design and Construction of Houses to Resist Natural Hazards *In implementing Hazard-Resistance Housing*, Proc. of the Ist Int. Housing & Hazards Workshop to Explore Practical Building for Safety Solutions held in Dhaka, Bangladesh, 3-5 December 1996, Edited by Hodgson, Seraj and Choudhury, pp. 11-17.

Lewis, J. and Chisholm, M. P. (1996). Cyclone-resistant Domestic Construction in Bangladesh. *In implementing Hazard-Resistance Housing*, Proc. of the Ist Int. Housing & Hazards Workshop to Explore Practical Building for Safety Solutions held in Dhaka, Bangladesh, 3-5 December 1996, Edited by Hodgson, Seraj and Choudhury, pp. 29-38.

NBS (1977). 43 Rules: How Houses Can Better Resist High Wind. US National Bureau of Standards, Washington D.C.

Roy, U. K., Seraj, S. M., Roy, P. S. and Alam M. S., (1999). Some aspects towards developments of Hazard Resistant Rural Homes in Bangladesh. Proc. of 2nd Dhaka Housing & Hazards International Seminar, 6-8 February, 1999, Bangladesh, pp. 29-39

Biography:

Professor Salek M Seraj of BUET's Department of Civil Engineering was the founder of the BUET-Exeter link. He studied civil engineering at BUET and read for a doctorate at London's Imperial College. He has directed a series of studies into appropriate materials and methods suitable for building Bangladeshi homes. He is the co-author/editor of a series of books describing the outputs of the link and has organised three international conferences on Housing and Hazards.

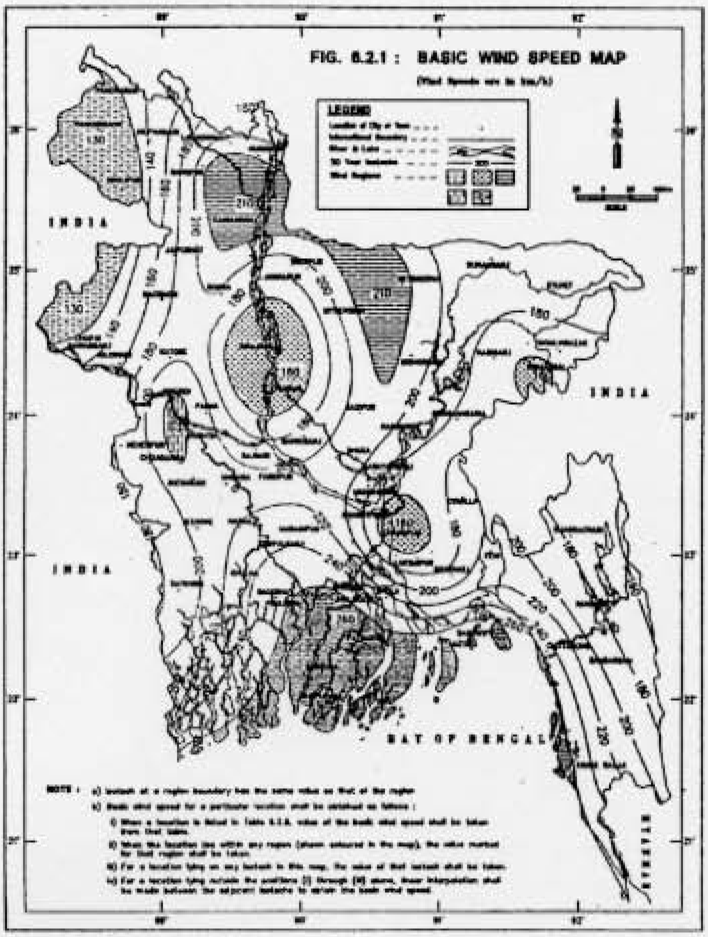


Figure 1. Basic wind speed map of Bangladesh (BNBC, 1993)

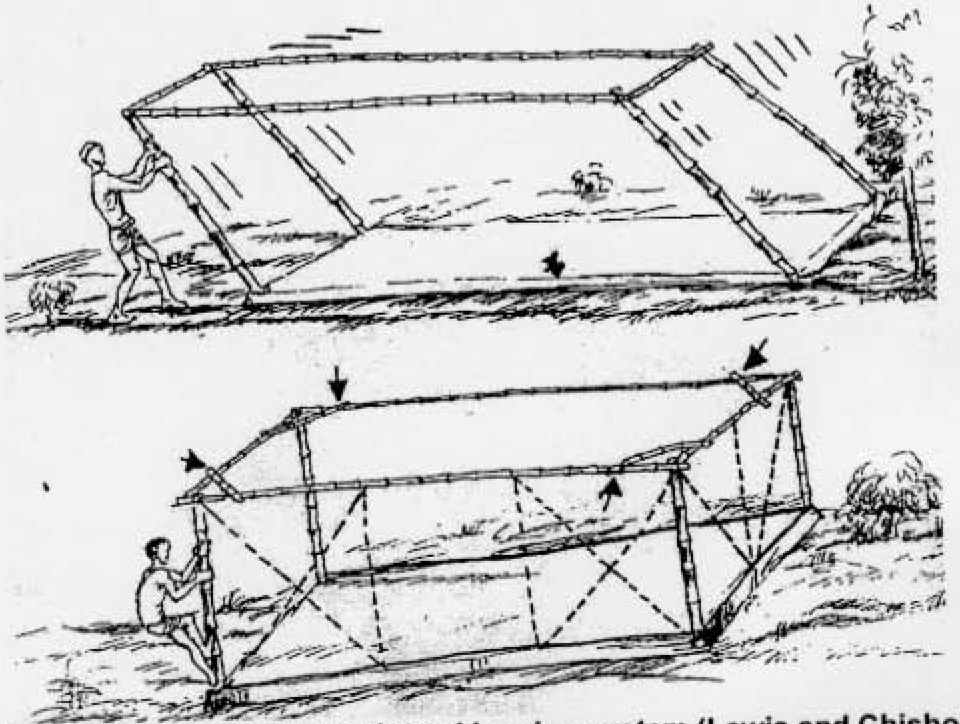


Figure 2. Frame with and without lateral bracing system (Lewis and Chisholm, 1996)

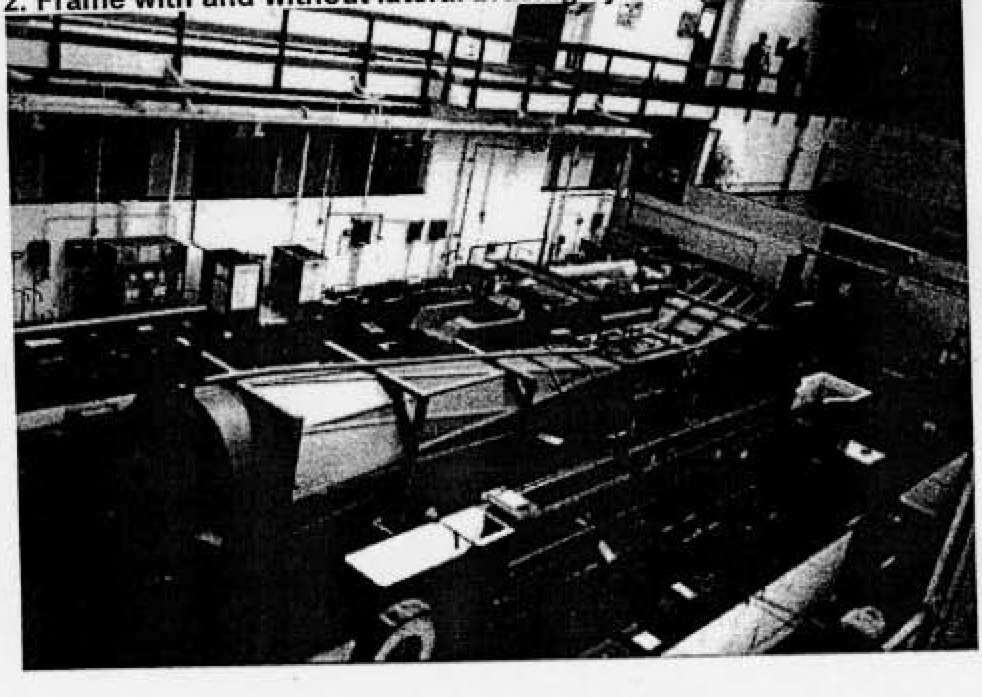


Figure 3: Wind tunnel used in the present study

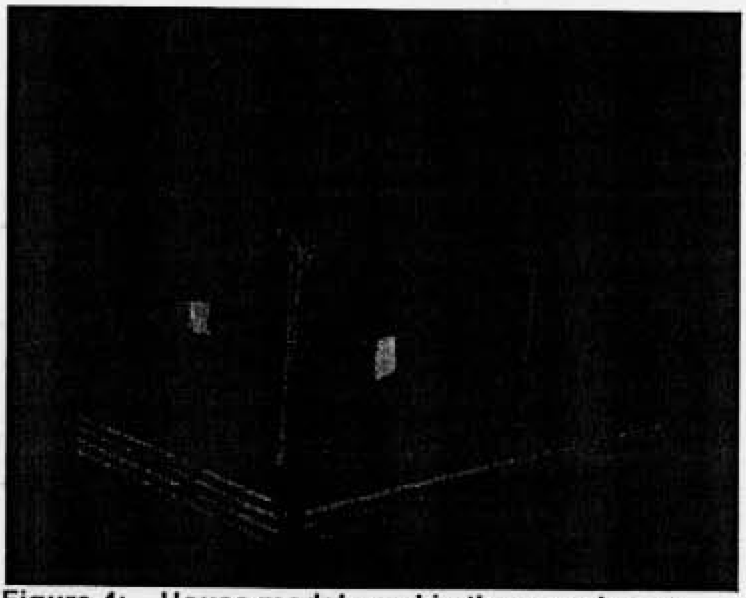


Figure 4: House model used in the experiment

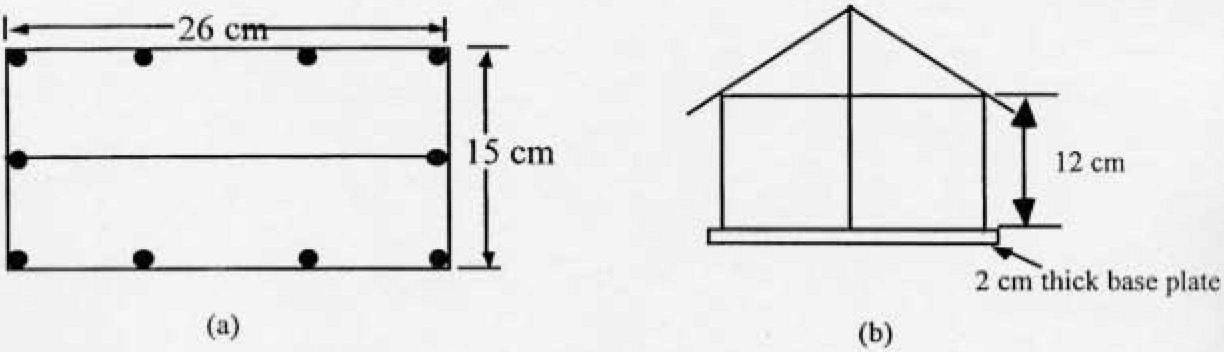


Figure 5: (a) Plan and (b) Elevation of the house mode

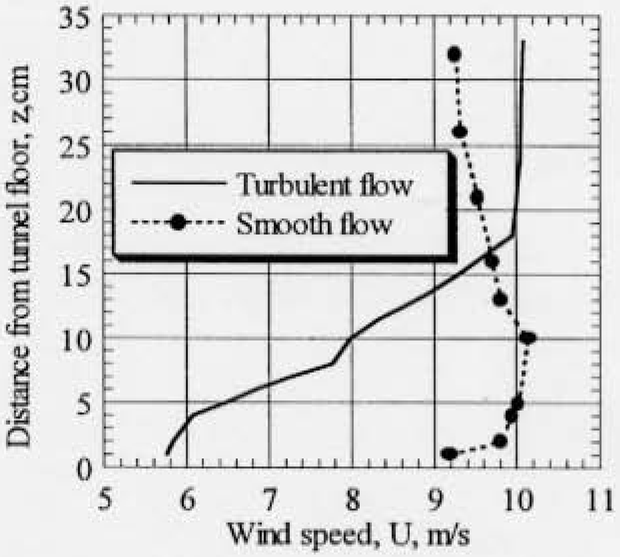


Figure 6: Wind velocity profile at both smooth and turbulent flow conditions

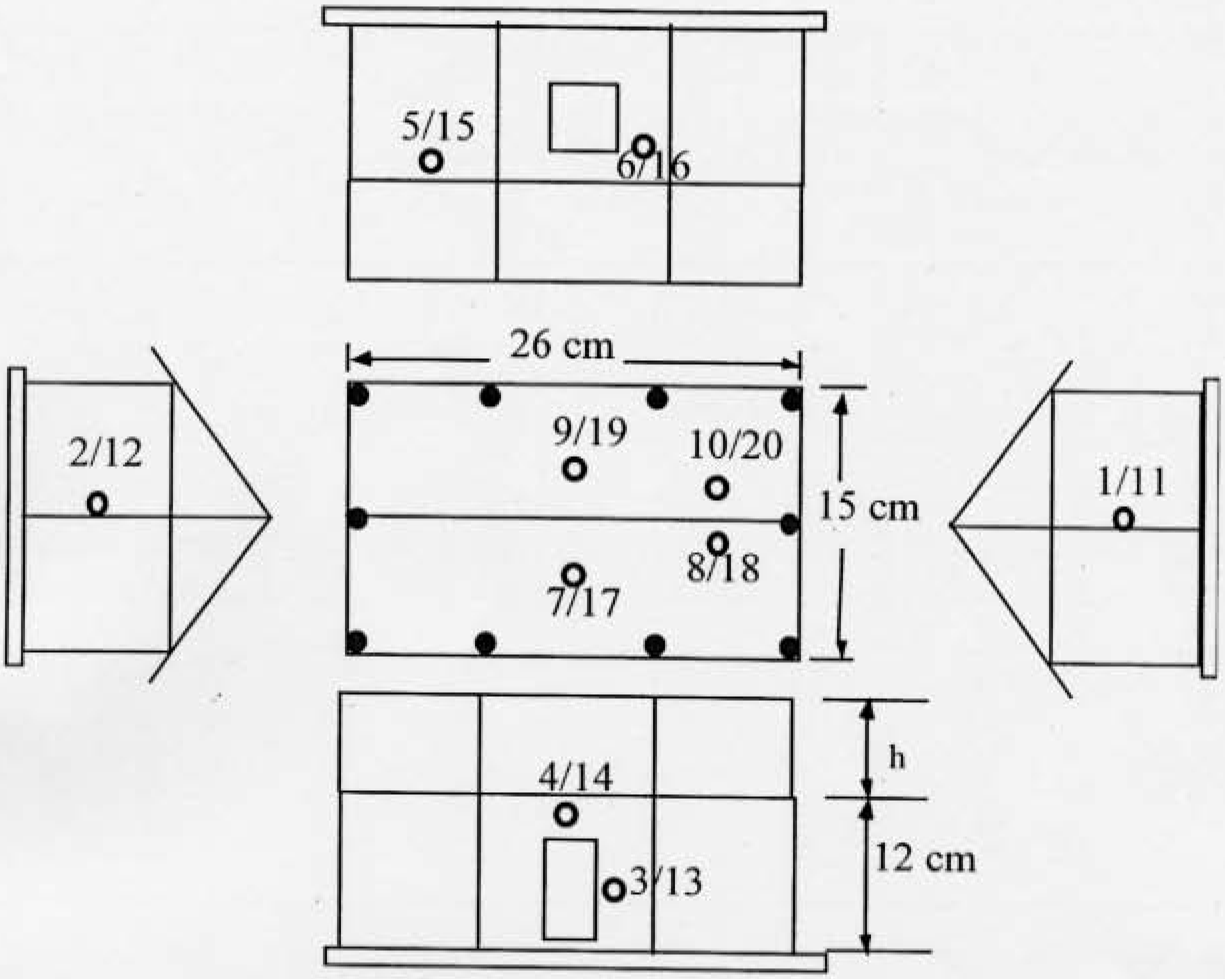


Figure 7: Schematic diagram showing locations of measurement of pressure on fence and roof of the model

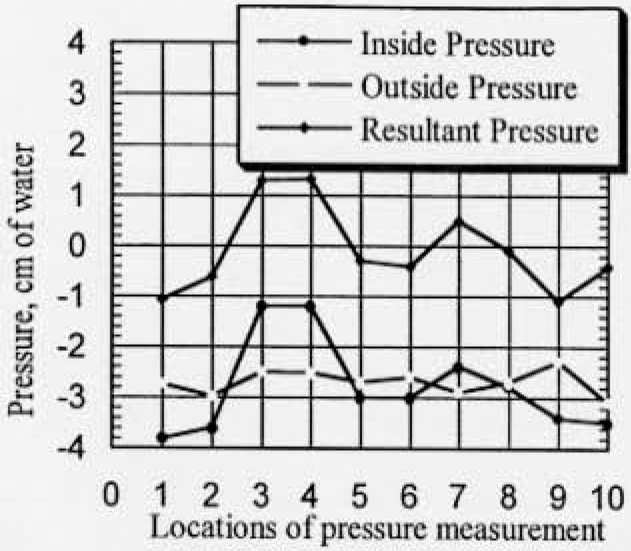
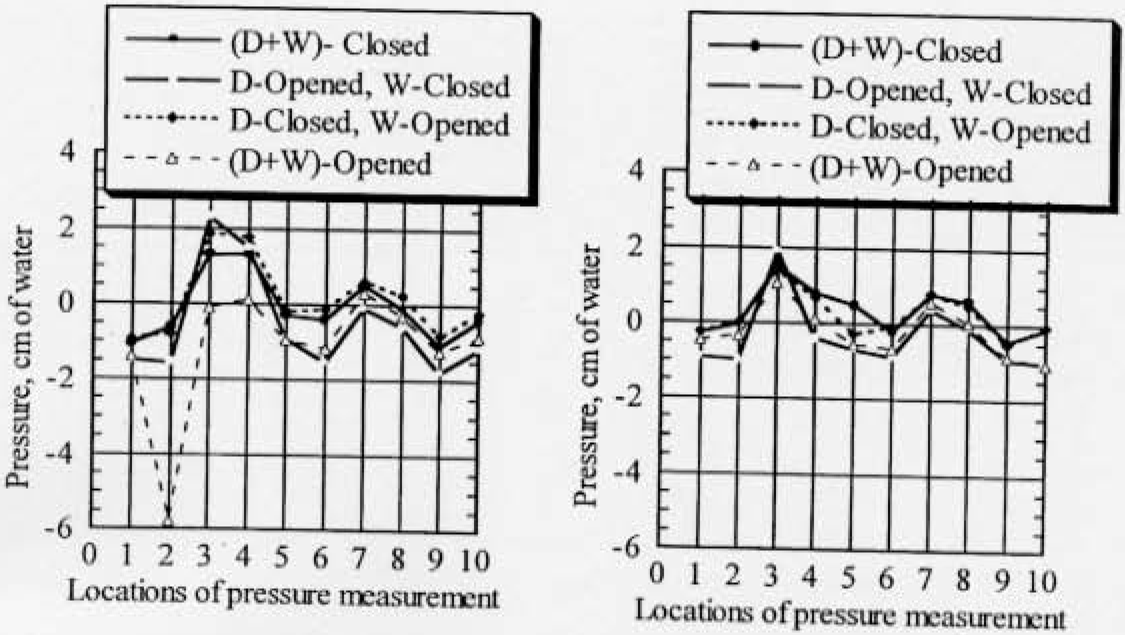
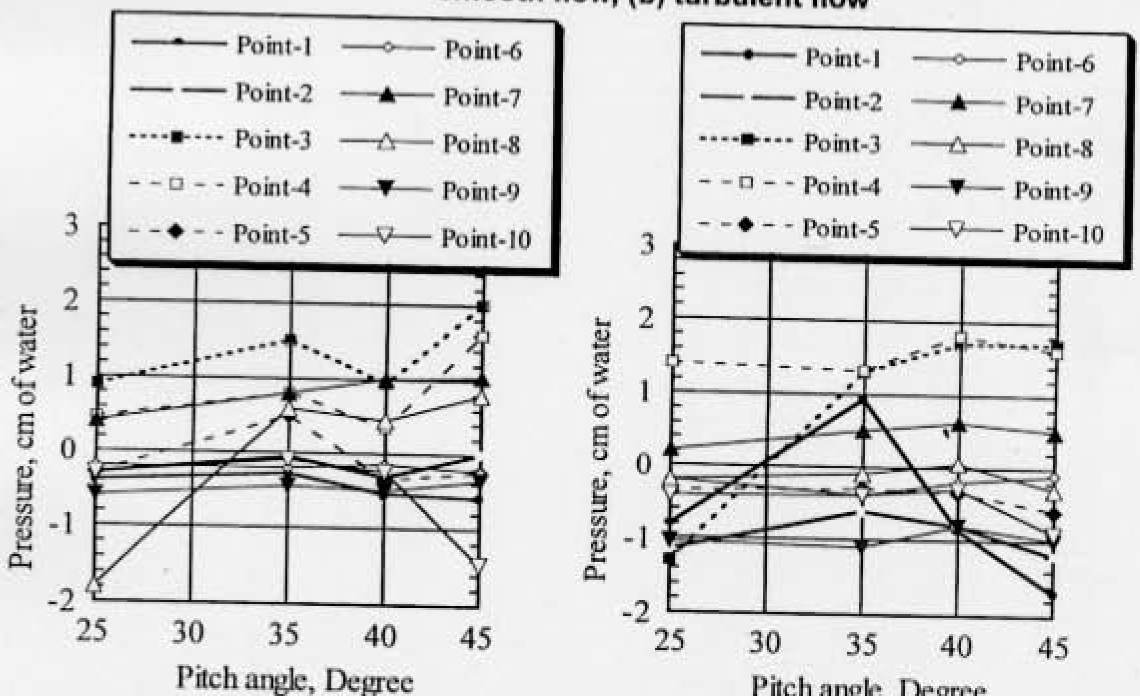


Figure 8: Inside, outside and resultant pressure at different locations



(a) (b)

Figure 9: Resultant pressure at different locations with exposure condition of no openings in the model (exposure: iv) and horizontal wind yaw angle (a) smooth flow, (b) turbulent flow



(a) (b)

Figure. 10 Resultant pressure at all locations for different roof slopes with the yaw angle of 0° and exposure condition of all closed (Exposure: iv), (a) smooth flow, and (b) turbulent flow

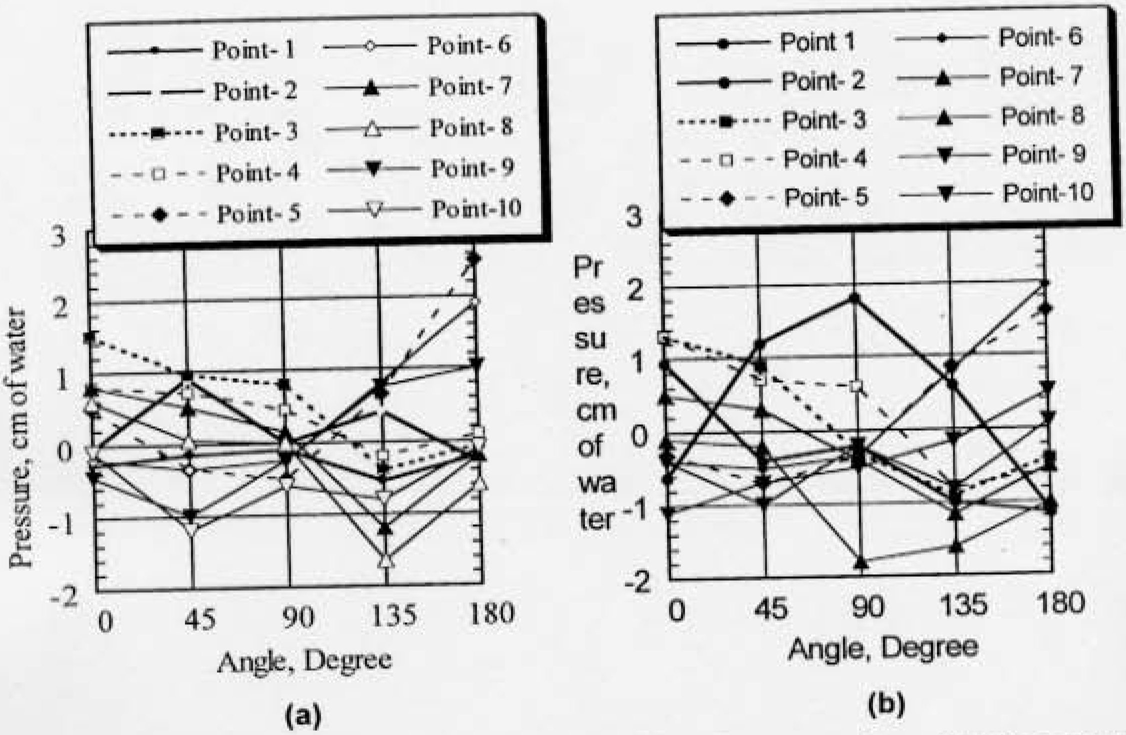


Figure 11: **Pressure at all locations for different yaw angles with the exposure condition of both door and window are closed (exposure: iv) (a)smooth flow, (b) turbulent flow**

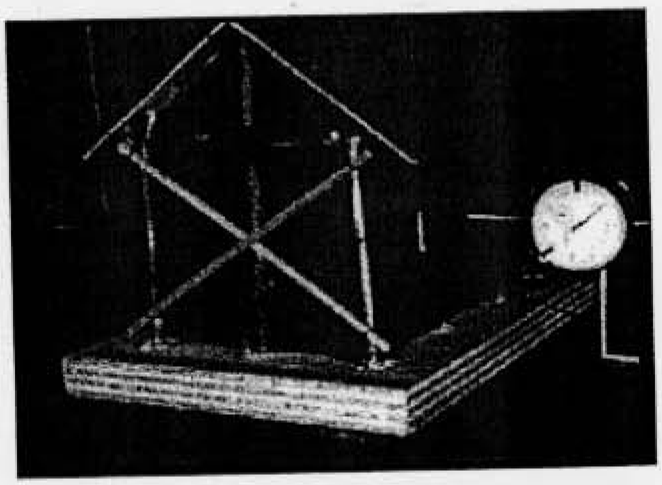


Figure 12: **Set-up of the experiment for measuring deflection of the model**

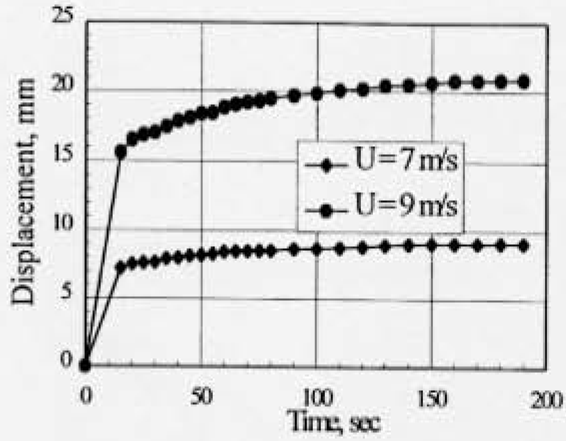


Figure 13.: Variation of displacement with time

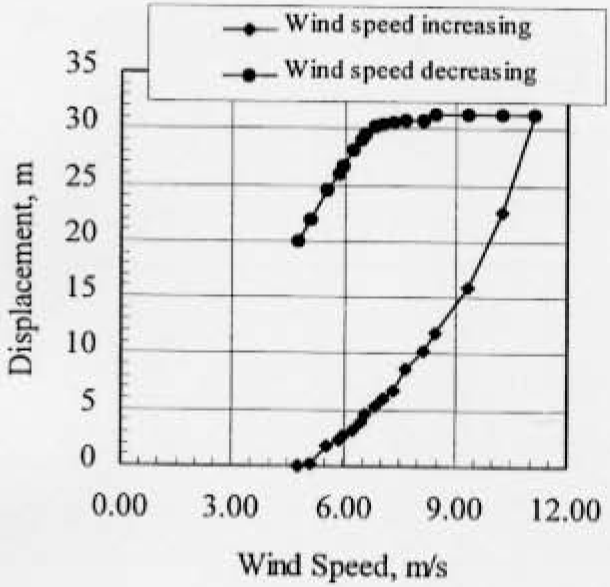


Figure 14. Displacement of the model at different wind speed

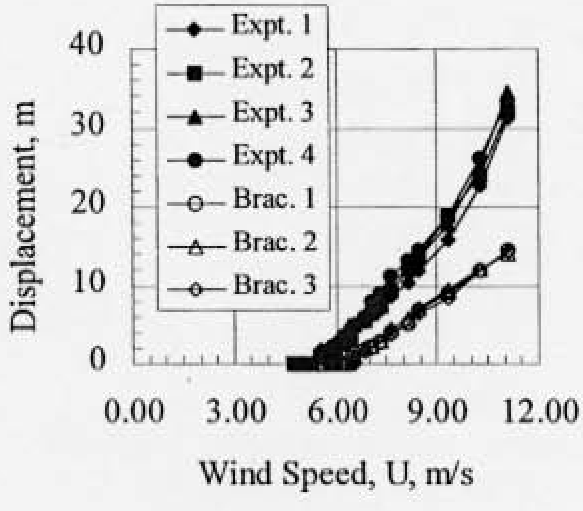


Figure 15. Effect of lateral bracing on the lateral displacement

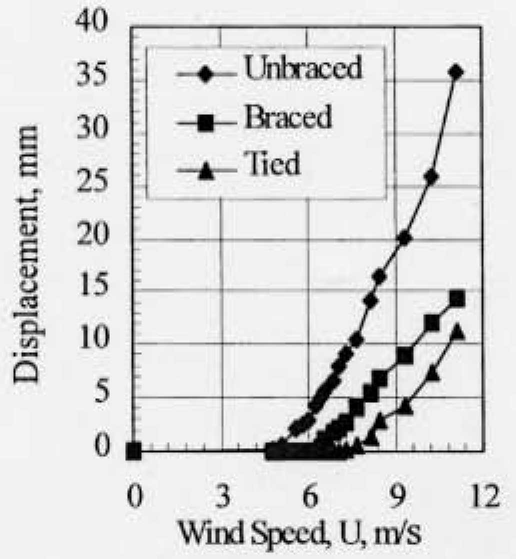


Figure 16: Effect of tied rope on the lateral displacement

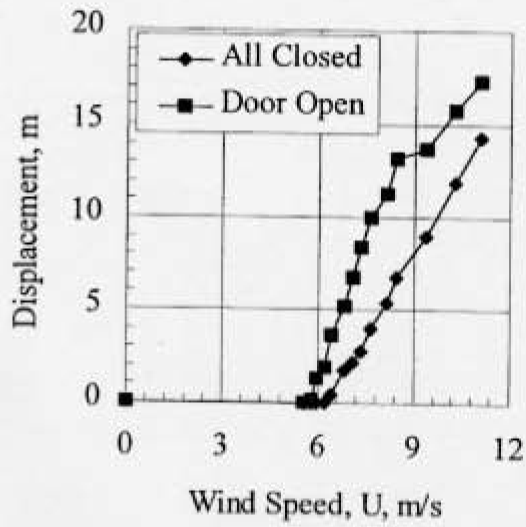


Figure 17: Effect of exposure conditions

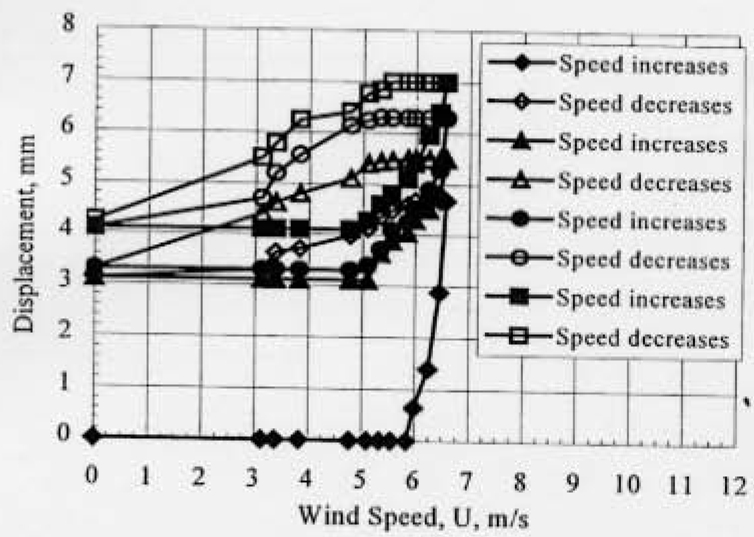


Figure 18: Hysteretic behaviour of house model