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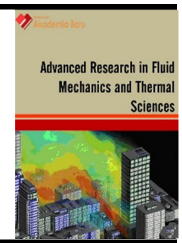

Experimental Study of UTM New Sport Complex

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ABSTRACT

Wind loading is generally dominated by the separated wind flow over the roof, which resulted in pressure distribution that varies greatly in both space and time. The objective of this project is to investigate the flow visualisation of UTM new sport complex roof in wind tunnel experiment. The UTM stadium model with the scale 1:40 was used in the wind tunnel test experiment. Two different methods were employed in this research which is flow visualisation test by using smoke generator and pressure measurements on the top surface of the roof. For flow visualisation, the images were captured by using digital camera while the pressure measurement data were measured using pressure scanner. The wind tunnel test has been done successfully and the results from both wind tunnel tests were compared for validation purpose.

1. Introduction

A stadium is a structure that surrounds a central field or a stage in which a spectator event takes place. The structure holds seating for spectators to view the event, either by standing or sitting. Usually, every seat gives a spectator a complete view of the field.

UTM Stadium is an outdoor football stadium on the south campus of the Universiti Teknologi Malaysia, Johor Bahru. It is the home field of the UTM football team. The stadium opened in September 2011. The natural grass playing field runs in the traditional north-south configuration and sits at an elevation of 1554 m above sea level.

Szucs [1] stated that Stadiums are prestigious buildings, symbols of towns blending sport and culture. These multifunctional building are the venues of very different features events, such as football matches, athletic events, concerts, religious gathering etc. That is why great care should be taken of their design, including the comfort of the users, in particular that of the spectators comfort. The effects of the wind, one of the environmental factors of prevailing importance, that modify the spectators comfort has been investigated through parametric wind tunnel tests.

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Besides that, in order to get the comfort of spectators at the stadium, another test has been conducted that is simulation of wind flow and wind driven rain shelter in sport stadium. Van Hoof [2-4] stated that spectator comfort is an important design parameter for stadium design. The protection from the weather influences such as wind and rain is one of the most important aspects of spectator comfort.

Wind loading is critical in the structural design of the wide-span roof structures of large stadium, and frequently controls the design. The loading is generally dominated by the separated wind flow over the roof, which results in pressure distributions that vary greatly in both space and time. These complex pressure distributions make the reliable estimation of the structural loads very difficult. In addition, the design of the main structural elements is highly dependent on how the wind load distribution changes with time due to the varying influence of loading on different areas of the roof. Therefore this wind tunnel test is to determine the flow visualization on the roof of the stadium.

Figure 1 shows the UTM stadium model that has been tested in the wind tunnel test to determine the flow visualisation on the roof of the stadium.

Fig. 1. UTM stadium model

Flow visualisation on the roof of the model have been test by using two different methods which are by using smoke wire technique and pressure measurements on the top surface of the roof [5-9]. For flow visualisation by using smoke wire technique, the images were captured by using digital camera while the pressure measurement of data is analysed in term of coefficient of pressure.

2. Wind Tunnel Experiment

2.1 Target Model

The wind tunnel tests were performed in Universiti Teknologi Malaysia Aeronautics Laboratory (UTM Aero lab). UTM Low Speed Wind Tunnel is closed circuit wind tunnel. The tunnel was set up to meet the Educational & Research needs of rapidly developing Aerospace industry in Malaysia. This tunnel equipped with instruments such as 6-component external balance, under floor turntable, 3-points strut support system.

For this project, the model used was UTM new sport complex. The scale of the model is 1:40. The width of the model is about 1.8 meter. The model has been installed on the turntable in the wind tunnel test. Figure 2 shows the complete installation of UTM stadium model in the wind tunnel test section.

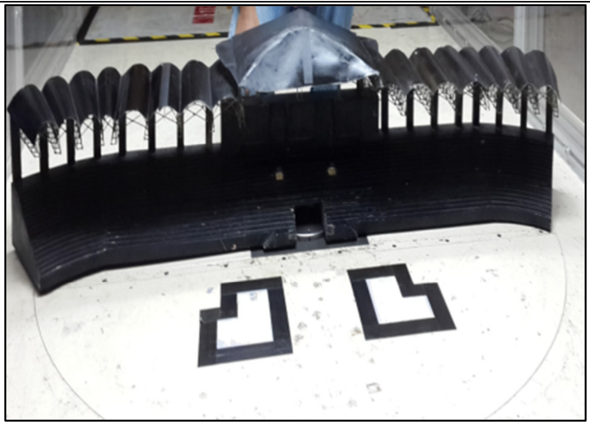

Fig. 2. Installation of UTM model in the UTM – LST

2.2 Flow Visualisations Test on the Roof of UTM Stadium Model by Using Smoke Wire Technique

Smoke wire technique is one of the techniques used in the wind tunnel test to determine the flow visualisation. For this study, the flow visualisation in the wind tunnel test by using smoke wire technique is important in order to achieve the objective. There are three location at the roof of the UTM stadium model have been tested. The locations are at the grandstand roof which is at the top and the side of the roof and lastly at the straight seat roof sections.

2.3 Flow Visualisations Test on the Roof of UTM Stadium Model by using pressure measurement

The UTM stadium model is divided into three sections with each section contains 10 pressure taps. Figure 3 below shows the section of the UTM stadium model for pressure measurements.

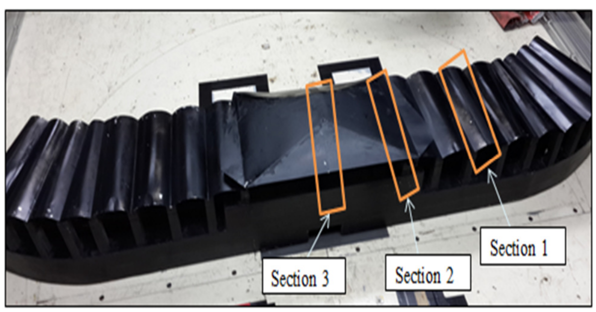

Fig. 3. Locations of pressure taps above the roof

To analyse the data easier, the pressure tabs for each section have to be numbered. The numbering starts with section 1 and finish at section 3 as shown via Figure 4 to Figure 6. The total pressure taps for the UTM stadium model is 30 which are 10 pressure taps at each section.

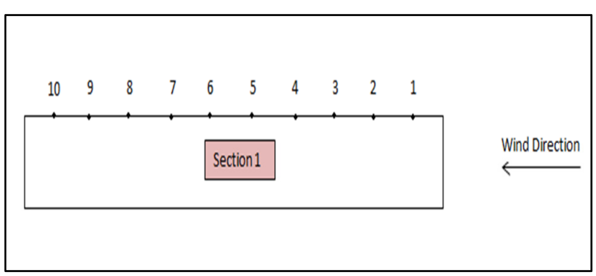

Fig. 4. Locations of pressure taps for section 1

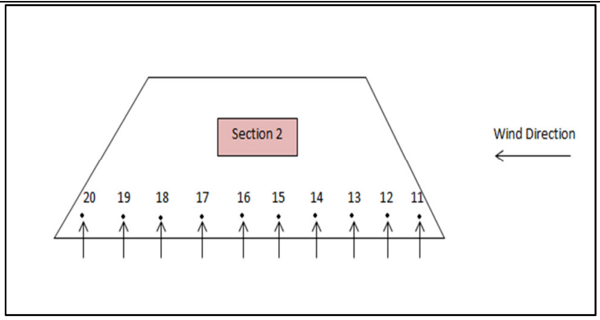

Fig. 5. Location of pressure taps for section 2

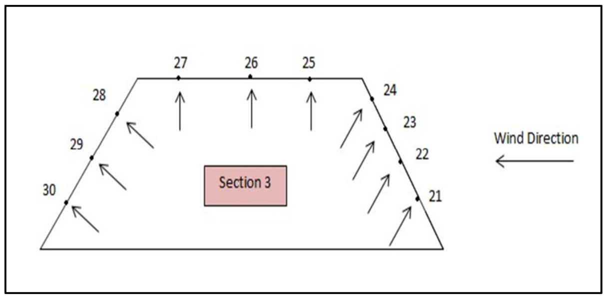

Fig. 6. Locations of pressure taps for section 3

As a result, a number of 30 pressure taps had been installed on the roof of UTM stadium model. Each section contains 10 pressure taps as shown in figure 7.

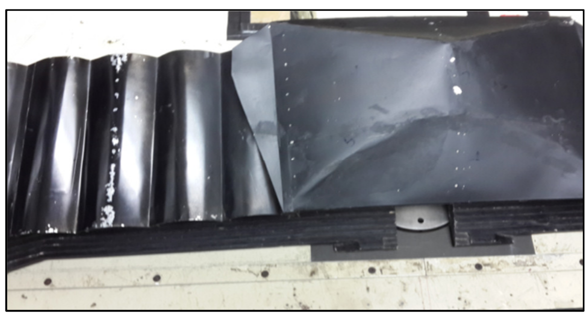

Fig. 7. Pressure taps

3. Wind Tunnel Experimental Results and Discussion

There were two types of wind tunnel tests performed on UTM stadium model. Firstly, the UTM stadium model was tested using the smoke wire technique to determine the flow visualisation on the roof of the UTM stadium model. For flow visualisation by using smoke wire technique, only one velocity was used at the wind speed of 8.33 m/s. There was no change in angle of incidence for this test and the model was fixed at zero angles.

The second test conducted was the pressure measurement on the roof of the UTM stadium model. In this test, some different speeds were used. There were four wind speeds used in this test; 5.56 m/s, 8.33 m/s, 11.11 m/s, and lastly 13.89 m/s. Besides, for every wind speed, the model had also been tested with different angle of incidence. The angles of incidence for this test were -25^o, -20^o, -10^o, 0^o, 10^o, 20^o and lastly 25^o. Figure 8 shows the conditions of the model in the wind tunnel with different yaw angles. Then Figure 9 shows the rough flow pattern on the straight seat roof sections.

Fig. 8. Flow visualisation on top and side of the Grandstand

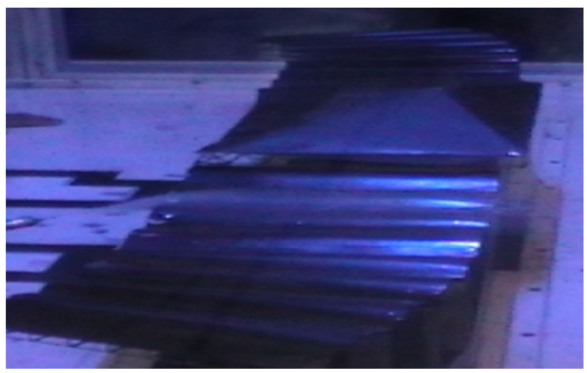

Fig. 9. Flow pattern on the straight seat roof sections

Figure 8 shows the flow visualisation on the top and side of grandstand roof by using smoke wire technique. At the top of the roof, as the flows come through the roof, the flow does not separate which means the flow is still attached to the roof. The flow start to separate at the peak of the roof and reattached back before going down the roof. Then, once again, the separation occurs as going down the roof. Lastly, at the end of the roof which is at the trailing edge of the roof, the flow start to reattached. For at the side of the grandstand roof, as the flow pass through the leading edge of the roof, no separation occurred which means the flow is attached to the roof [9-10]. Then, suddenly the flow turned into an unsteady and unstructured flow. The vortex flow produced as shown in figure 8 above. The vortex flow occurs until the trailing edge of the roof.

Figure 9 above shows the image of the flow visualisation on the roof by using the smoke wire technique. At the root of the roof, the flow separate to form separation bubble in the form of bump. In other words, the flow breaks away at the leading edge of the roof, leaving a zone of swirling air beneath it. This zone of swirling air is called flow separation. After that, the wind above the roof eventually comes back down and meets the roof. The point at which this happens is called the reattachment point.

The pressure measurements were done with four different Reynolds number and different yaw angles. Figure 10 below shows the results from pressure measurements experiment. The result shows the comparisons between the 25^{o} and -25^{o} yaw angles.

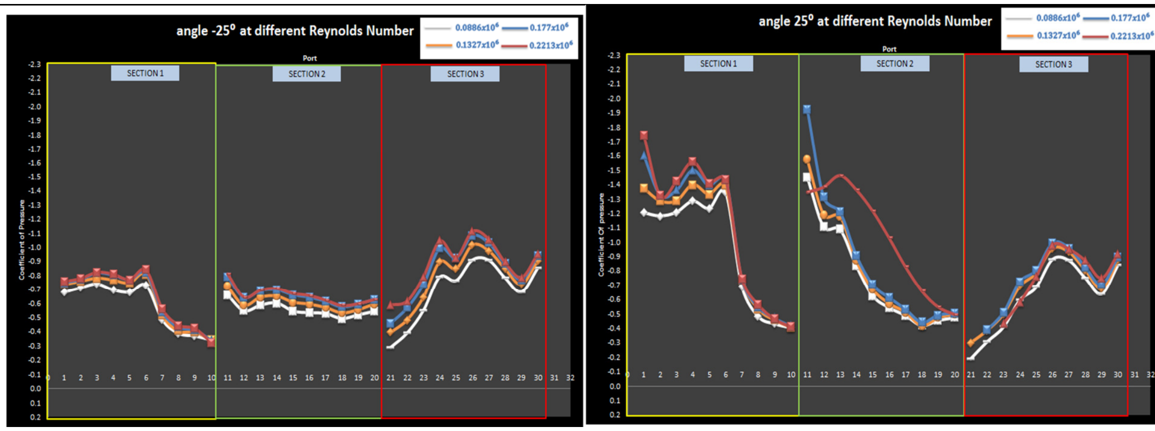

Fig. 10. Pressure measurements technique from 25^0 to -25^0 yawing angle

Figure 10 above shows the comparison of pressure measurements curve at yaw angle -25° and 25° at different Reynolds number. For section 1, the pressure taps location is from 1 until 10. The pressure curve pattern is slightly different at the leading edge section of the roof. The pressure was approximately constant at the leading edge area at the roof for section 1 at -25° yaw angles while for the yaw angle at 25°, the pressure at the leading edge area was unstable. The unstable pressure formed because at section 1 the flow of the air in the wind tunnel has been blocked by the grandstand roof. Therefore, the flows that pass through the section 1 leading edge area are unstable [13-16]. Then, the adverse pressure gradient begins to occur at the 6 location of pressure taps. This means the flow start to reattach at the roof at this stage. This pressure curve was same for the both yaw angles. Lastly, as the yaw angles become more negative, the coefficients of pressure become more negatives.

At section 2, the pressure curve pattern was exactly different. For yaw angles at -25°, the small positive gradient occur compare to the yaw angles at 25° with the large change in pressure at leading edge area of the roof. Then, for negative yaw angles, the flow start to separates from the roof because the pressure is approximately constant from pressure taps 12 until 20. This was different from the positive yaw angles, which the flow does not separate and attached to the roof but the change in pressure was large and cause the air flow to decelerates.

The pressure curve at the section 3 for the both yaw angles is approximately the same. Besides that, at the top of the roof, the pressure fluctuate at the yaw angles -25° while for 25° yaw angles, the pressure does not fluctuate. As going down the roof to the trailing edge of the roof, the pressure curve pattern for the both yaw angles is same which is the adverse pressure gradient occurs at this stage [11-14].

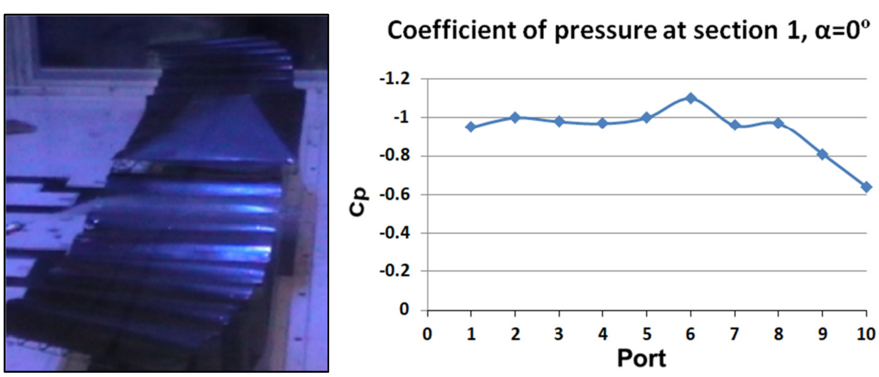

Fig. 21. Pressure data at section 1

Lastly, the result from the flow visualisations by using smoke wire technique and pressure measurements have been compare for section 1, 2 and 3. The smoke wire technique experiment on the roof of UTM stadium model has been done to determine the flow visualisation on the roof of the UTM stadium model which is section 1, 2 and 3 for the wind speed at 8.33 m/s.

Figure 11 shows the comparisons of wind tunnel results at section 1 between the flow visualisations on the roof by using smoke wire technique and pressure measurements [11-12]. Figure 11 illustrates that at the leading edge of the roof, the pressure is approximately constant which means the flow is separate at this stage. This can be observed at the flow visualisation by using smoke wire technique which is the flow start to separate at the leading edge of the roof in the form bump. Then at pressure tab locations at 6 until 10, the adverse pressure gradient occurs. At this stage, the pressure start to rises and the velocity is decrease. The flow still remains attached to the surface of the roof.

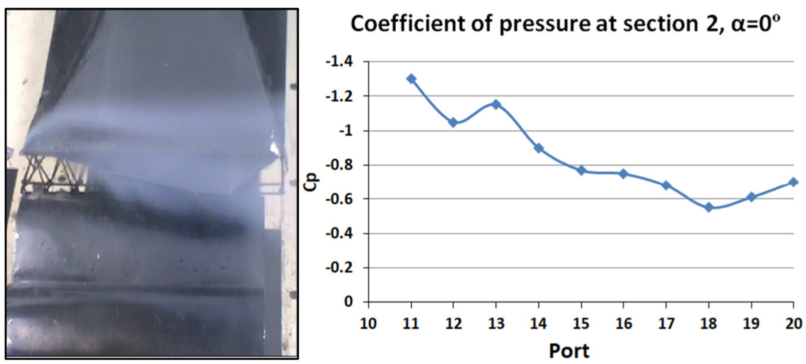

Fig. 32. Pressure data at section 2

Figure 12 above shows the comparisons of wind tunnel testing results between the flow visualisation on the top roof surface by using smoke wire technique and pressure measurements. Based on the figure, there is no separation occurs at this section. As the flow pass through the roof, the adverse pressure gradient occurs which means the pressure increase and the velocity of air will increase at the leading edge of the roof at section 2. The velocity of air start to recover at pressure taps locations at 12. Then, once again the velocity of the air starts to drop before reaching the trailing edge of the roof. Lastly, the velocity starts to recover at the two last pressure taps points before reaching the trailing edge of the roof. This phenomenon can be illustrated in the figure 12 with the smoke wire technique results in the wind tunnel test. The flows still remain or attached to the roof at section 2 and there is no separation of flow occurs.

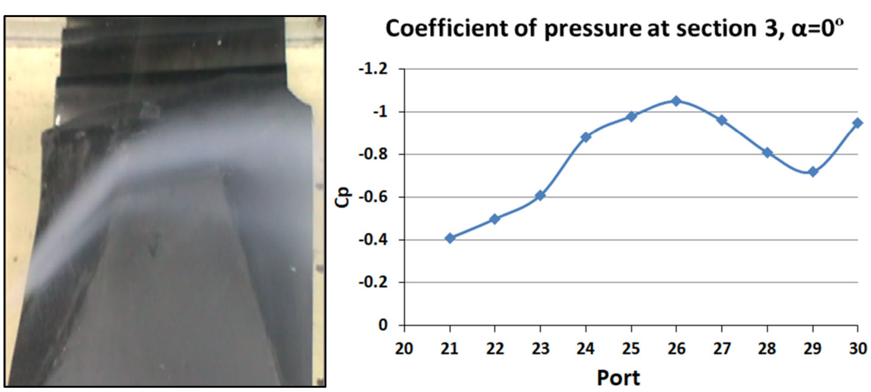

Fig. 43. Pressure data at section 3

Lastly at the section 3, the comparison of wind tunnel testing results between the flow visualisation by using smoke wire technique and pressure measurement is shown in the Figure 13 above. As the flow going up the roof, the pressure will decrease while the velocity is increase at this stage [15-18]. Based on the figure above, at the tip of the roof, there is small flow separation occurs. This can be illustrated in the figures above which are the results of wind tunnel test by using smoke wire technique. As going down the roof, the pressure is increasing and the velocity is slowing down. Basically, there is small flow separation as the air going down the roof. Based on the graph pressure curve above, it shows that, the adverse pressure gradients occurs in this stage and still remain attached to the roof but the velocity of air is slowing down. Lastly, before reaching the trailing edge of the roof, the velocity of air starts to recover or increase.

4. Conclusions

The flow visualisation on the roof of the UTM stadium model has been obtained. The wind tunnel test for flow visualization has been done successfully on the roof of UTM stadium model by using the smoke wire technique and pressure measurement on the top surface of the roof. Based on the experiment that has been conducted in the wind tunnel test, the pressure becomes more negatives if the Reynolds numbers increase. The flow separation does occur at the section 1. Besides that, based on the pressure measurements data, the negative pressure developed on the roof of the UTM stadium model and acts as leeward surface or suction surface. This caused by the loss of energy during flow separation.

The results from both wind tunnel tests were compared for the validation purpose. From this validation, the flow pattern or visualisation on the roof can be determined or validated.

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