沙漠研究 **22**-1, 267 -270 (2012)
Journal of Arid Land Studies

"ICAL 1 / DT X"
－Refereed Paper－

Investigation into Sand Movement around a Column Using a Wind Tunnel

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Abstract: In the present study, sand movement around a column was investigated in the laboratory using a wind tunnel and a high-speed digital video camera. The thickness of the sand layer in the test section was kept at 0.28 m. It was observed that the sand from upstream and also from both sides of the obstacle (column) moved faster due to accelerated sand-driving wind compared to those particles away from the column or downstream. This caused visible erosion of the sand layers in the upstream and also from both sides of the column. These eroded sand particles were scoured deeper than those at initial horizontal surface. However, movement of the sand became steadily slower when the scoured depth increased. The scoured area around the column fanned out from the column with time. The column began to oscillate as the sand below the bottom of the column was scoured, and finally, it overturned windward. In the present investigation, the relation between the scoured depth around the column and blowing time of wind, also the relation between the depth of the buried column and the time required until the column overturned, and the mechanism of the sand movement around and below the column were clarified in detail.

Keywords: Desert, Sand movement, Scour around column, Wind tunnel

1. Introduction

The effect of sand movement due to obstacles is very important for stability of civil structures and desert plantations. In desert plantations, it is known to have significant effect on survival rate and uprooting of trees. The movement of sand particles due to the wind in dry lands is affected by several factors, the major ones being:, wind velocity, inclination of the deposited sand, size of sand grain and most importantly, the position and geometrical nature of the obstacle. For example, when a wood, a stake, a seedling, etc. are standing on a flat sand surface, sand grain in surface is scoured or deposited around them in a very unique way. Sand movement patterns have been widely investigated and documented by (Bagnold 1938, 1954) who experimentally studied the relation between wind velocity and sand movement. Later, the creep motion in aeolian sand transport was studied using two granular flow models, Saint-Venant model and Navier-Stokes type equations (Wang and Zheng, 2004). Also, a method for measuring sand creep movement was experimentally developed using a high-speed digital camera (Wang *et al*., 2009). Patterns and dynamics of desert dunes were simulated by a computer (Hatano and Hatano, 2001). The hillslope evolution by nonlinear creep and landsliding was investigated (Joshua *et al*., 2001). Modeling and simulation method were proposed to synthesize sandy terrain with vegetation covers (Wang and Hu, 2009). But, phenomenon of sand pattern construction and movement at small scale around the obstacles on the sand surface has not yet been clarified in detail. The reason why the column in wind overturns windward is due to the fact that the sand on the upstream side of the column is scoured faster than the downstream side as investigated experimentally (Hayashi *et al*., 1994) and numerically (Kawamura *et al*., 1999). The sand movement around a cube on the flat sand surface was experimentally and numerically investigated under the approach of sand erosion and deposition (Tominaga, 2007). But, sand movement around obstacles has not yet been totally clarified in previous investigations. So, in the present investigation, the detailed mechanism of sand movement around a column was experimentally observed using a video camera and a laser distance meter. The present results are very important to optimize the strength required for civil construction and also for desert vegetation survival, etc.

2. Materials and Methods

A wind tunnel was schematically shown in **Figure 1**. Air from a blower entered into a test section through a convergent section with 1.82 m length, 1.90 m width and 1.00 m height. The test section was 2.78 m length, 1.18 m width, 0.76 m height and had a flat sand bed of thickness 0.28 m to ensure that sand movement in this experiment was similar to the natural one. So, air was discharged into atmosphere through the air channel with height 0.48 m. The test section had a side and upper walls made of transparent acrylic resin to observe sand movement from the side and top views. The outer and inner diameters of the column were 76 mm and 71mm,

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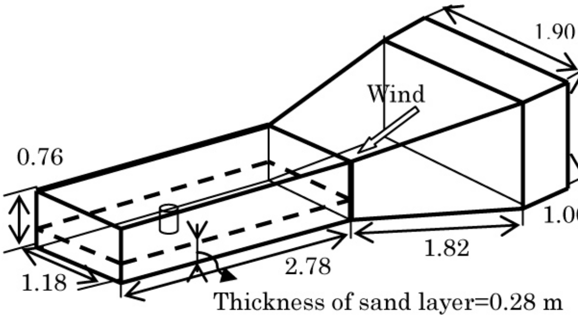

Fig.1. Configuration of experimental apparatus.

respectively. The column was positioned at 0.55 m upstream of the exit and 0.42 m from the side wall of the test section. The height of the column over the sand surface was kept at constant of 23.5 cm to give the same wind power. The heights below the sand surface were 0, 20, 40, 60 and 80 mm to estimate the effect of the depth buried in the sand. Furthermore, sand movement around the column was observed by a camera (Casio Digital Camera, EX-F1). The upper and lower surfaces of the column were made of transparent acrylic resin with thickness of 5 mm to observe sand movement below the bottom of the column. Sand particles used in the experiment were sifted through several screens and weighted using an electronic balance (Type BL-320H). Sand grains of 99% in the sand bed were smaller than 0.3 mm in diameter. Wind velocity in the test section was measured by an Anemometer (Type SK-93F). The depth of scoured sand was measured by a laser distance meter (Type LS-411). Blowing time was measured by a stopwatch.

3. Results and Discussion

Before the observation of sand movement, wind velocity was measured at 0.4 m upstream of the column and between 0.2 m and 0.62 m from the side wall. The mean velocity was about 7.0 ms^{-1} and the margin of error is plus- minus 0.2 ms^{-1}. The direction of the wind was checked by measuring the geometrical shape and propagation of sand ripples. The pattern formation of the sand ripples was taken by the camera before all experiments. As a result, their directions were almost perpendicular to the side wall of the test section in the region between 10 cm and 60 cm upstream of the column During the experiment, since sand moves downstream in the test section, the height of the flat sand surface decreased little by little in the upstream region of the test section. So the experiment was stopped every fifteen minutes, after new sand was supplied, the experiment was started again.

Upper and side views of sand movement around the column and below the bottom of the column are shown in photos and their respective diagrams in **Figure 2**. Figures 2

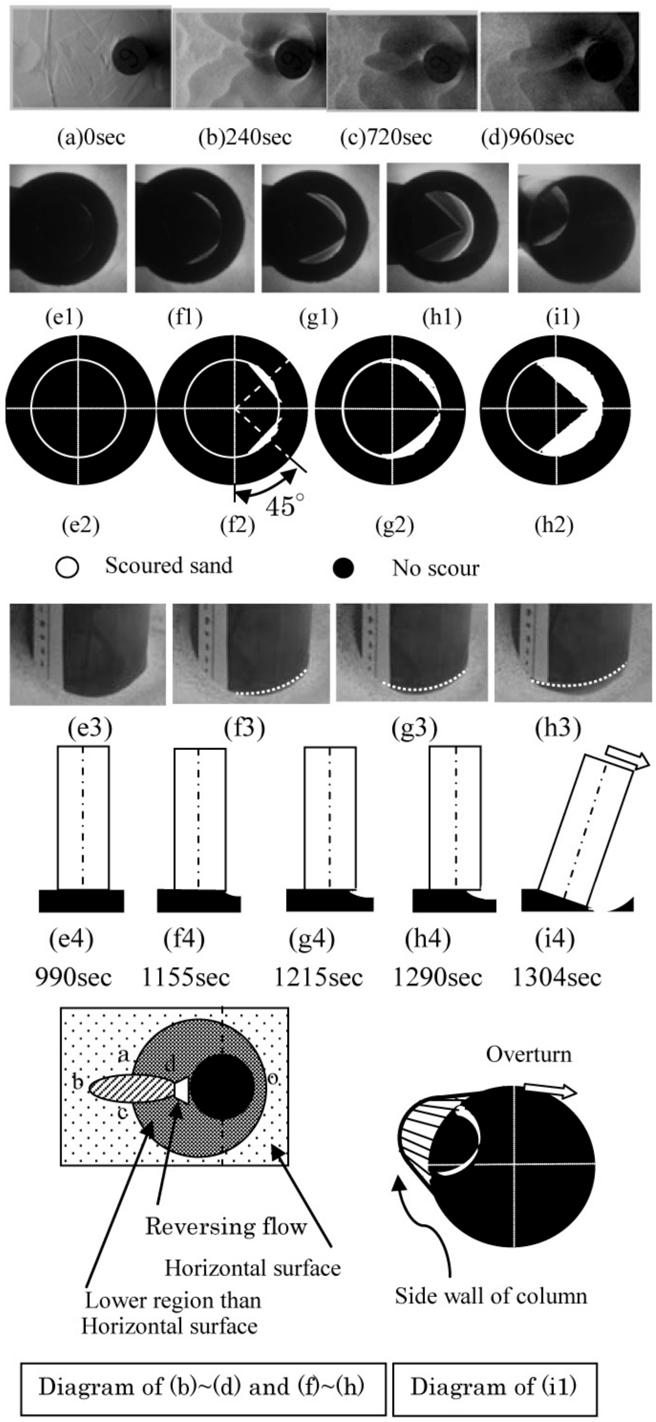

Fig.2. Sand movement around and below the column.

(a)~(d) are for the photos from the upper direction of the test section, and a diagram in below-left in Figure 2 indicates common sand movement patterns of Figures 2 (b)~(d). Figure 2 (a) shows the picture for no wind. Figure 2 (b) shows the picture at 240 second later from the start of wind blowing. In these figures, the sand layer is scoured in arc pattern in the region located in the side surfaces of the column. In the region from the side to back side surfaces, the sand is shallowly scoured in downstream direction. Behind the column, an elliptical pattern is observed in the region surrounded by "abcd" as shown by the oblique lines in the diagram. This pattern becomes larger in Figures 2 (c) and (d). The reason why this is formed is due to the fact that the sand moving from both sides of the column collides at this region and separates. Also, the sand reverses toward the column in the region shown in white between the elliptical region and the column. So the sand layer contacting the back side of the column becomes higher than those at the front- and side walls. In this way, sand is largely affected and scoured in the region of "oabco" around the column. Sand gradually fans out as shown by arrows in the diagram. In Figure 2 (d), sand that was in contact with the front half side wall of the column is totally scoured. But the column does not overturn in the present experiment. In previous investigations, it was described that the column overturned windward in the case of Figure 2 (d). The difference is explained in the following sentences.

After Figure 2 (d), the Figures 2 (e1), (e3) and their respective Figures 2 (e2), (e4) show at 990 sec the moment right before the sand start to scour at the bottom. After this moment, the sand movement below the bottom of the column starts and the sand is scoured as shown in Figures 2 (f1)~(i1) and their respective Figurse 2 (f2)~(h2), Figures 2 (f3)~(h3) and their Figures 2 (f4)~(i4) with time. In Figures 2 (e1)~(i1), the camera is focused in the bottom of the column. So the outer circle of the figures corresponds to the diameter of the upper surface of the column and the inner circle to the bottom surface. Figures 2 (e3)~(h3) are from oblique upward direction and their corresponding Figures 2 (e4)~(i4) and the Figure 2 (i4) are from the side direction. In Figures 2 (f3) ~ (h3), dotted lines are the circumference of the bottom. The sand is scoured and an air channel is generated below the lines. In the Figure 2 (f1) and the Figure 2 (f2), small arc regions shown in white at an angle of 45 degrees are observed, and in Figure 2 (g1) and Figure 2 (g2), these arcs are observed in the form of two clear crescents. These indicate that the sand scour below the bottom starts at the angle of 45 degrees from the upstream (right) end of the column as also shown in Figures 2 (f3)~(h3). This is due to the fact that the sand moves with the fastest velocity at 45 degrees. In (h1) and (h2), two crescents contact each other and combine. Two crescents correspond to caves in the Figures 2 (f4)~(h4) and do not support the column. In this way, the scouring of the sand below the bottom gradually expands and the column oscillates, and finally, as shown in Figure 2 (i1), the Figure 2 (i4), and the Figure 2 (i1), the column overturns windward, because the column loses the balance since the scoured sand area becomes larger than the no- scoured one (shown in black). At this moment the column overturns windward within about 45 degrees from the horizontal line of the column in Figure 2 (i1).

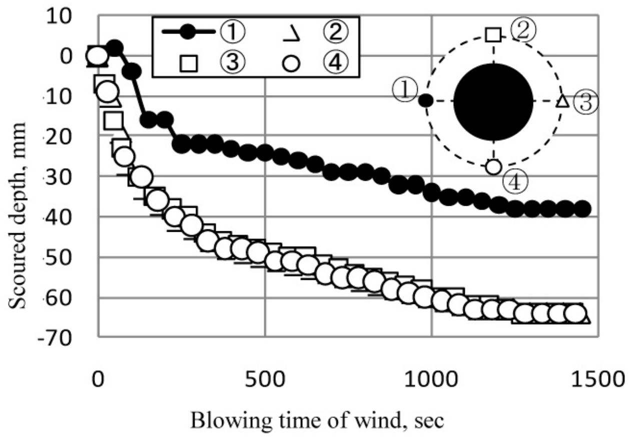

Fig. 3. Blowing time and scoured depth.

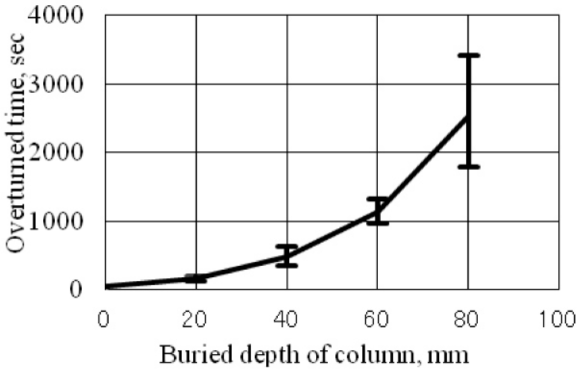

Fig. 4. Buried depth and overturned time.

Because sand around and below the column does not move symmetrically at the same time, the column does not necessary overturn windward. In this way, the detailed mechanism of overturn of the column was clarified for the first time in the present experiment.

Figure 3 shows the relation between blowing time and scoured depth at four points at the distance of 2 mm away from the column. The depth at the point ① is lower than the ones at points ②～④. This is due to the fact that the sand reverses behind the column as explained in Figure 2. The scoured depth fast decreases at first and slowly with time. This is due to the movement of the sand that became slowly with time in the scoured depth.

Figure 4 shows the relation between buried depth and overturned time of the column. Values at five measuring depths are shown by length connecting maximum and minimum values. Also though the value at 0 mm can not be clearly judged since it is smaller than other values, the mean value is about 45 sec. The overturned time gradually increases for the buried depth in a period shorter than 40 mm, but when time value is bigger, the buried depth increases. From the present results, it could be expected that when woods and seedlings are planted and stakes are stood in the dried sand land, the buried depth and the direction of wind are the most important factors.

In the present experiment, the fundamental mechanism of overturn of the column was described. But the wind velocity was fixed at about 7 ms^{-1}, therefore it is necessary to investigate cases with different wind velocities. Also, the outer diameter of the column was 76 mm and the height of the column over the sand surface was 235 mm. So it is necessary to conduct experiments to clarify the cases with different diameters and heights of the column. Furthermore, in the present experiment, the column was tested as the obstacle. But the shapes of the obstacles are more complicated in nature. Therefore it is necessary to take the shapes of the obstacles into consideration. Also, woods and seedlings have many branches, so the effects of branches on their stability should be investigated in future. Furthermore, since in some cases, woods, seedlings and stakes are planted or stood in near distance, it will be necessary to investigate sand movement including their interactions.

4. Conclusion

In the present investigation, the mechanism of sand movement around a column was described in detail. The sand layer around the column was scoured deeper in the front and both sides than those away from the column or downstream. The sand layer at the front and side wall surfaces of the column are scoured faster than one at the back side. Sand scouring below the bottom starts at 45 degrees from wind direction. When the sand below the column is scoured and the column loses the balance, the column overturns. When the buried depth of the column is bigger, the time when the column overturns is bigger.

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