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A STUDY OF TRENCH TRAP EFFECTIVENESS ON THE COASTAL DUNE

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This study presents the results of field study that was designed to investigate the effectiveness of trench trap in trapping the sand transport by wind. The study was carried out in the Nakatajima Dune located on the Enshu-nada coast of Japan. The trench trap was developed in the eastern end of the dune. The dune had been migrated eastward by predominant westerly wind. The migration of edge in the eastern end of the dune had been monitored by differential GPS for three years period (2007-2009), before and after the development of the trench. Moreover the deflation and the accumulation in the trench were also measured once a month for one year period. The distribution of sand transport rate around the trench was also observed by sand trap experiment using vertical trap during winter time. We found that the trench was not effective in trapping the wind-blown sand. The eroded sand was higher than deposit sand in the trench with a total volume rate of approximately 8 m^3/m/year.

Key Words: *effectiveness, trench trap, sand transport by wind, vertical trap, transport rate*

1. INTRODUCTION

The previous study of Junaidi and Aoki (2009) and Junaidi *et al.* (2009) have revealed the topographic changes of the coastal dune due to the wind-blown sand and the limited sediment supply. The study was carried out in the Nakatajima dune which spreads from the West to the East with 1 km length and 0.6 km width on the Enshu-nada coast of Japan (Fig. 1).

The dune is being pushed eastward by predominant westerly wind, which has covered the coastal forest in the eastern end of the dune (Fig. 2). From the aerial photographs, the edge of the dune migrated eastward approximately 35 m during the period of 1989 to 2005. The edge of the dune formed as a result of wind-blown sand from the West and deposited in the eastern end of the dune.

The deposited sand near the eastern edge of the dune had been removed several times, which forms like a trench (Fig. 1 and Fig. 3), during the period of 2008 to 2009. The effectiveness of the trench in trapping the blown-sand, and the effect of the trench to decrease the volume of sand transport to the eastern edge of the dune are in the center of interest in this study. The field data presented in this study is associated with the trench developed in the second time (October 2008).

Fig. 1 Aerial photograph of Nakatajima dune in 2009 (Courtesy of Shizuoka Prefectural Government)

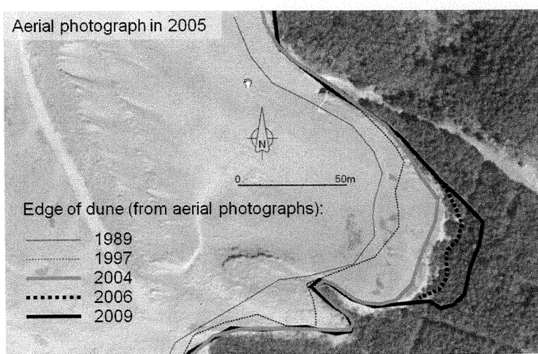

Fig. 2 The migration of edge in the Eastern end of the Nakatajima dune (1989-2009)

2. METHODS

The size of the trench is approximately 162 m length and 40 m width with height that ranges from 1 to 5 m in the West and East respectively, developed in October 2008 (Fig. 3). In order to investigate the effectiveness of the trench, three methods were employed. First, the migration of edge in the eastern end of the dune had been monitored by GPS with RTK (Topcon GB-500) for three years period (2007-2009), before and after the development of the trench. The GPS provides high-resolution control on topographical surveying with ± (1 cm + 1ppm x D; D is the distance between the base station and the rover receiver) and ± (1.5 cm + 1ppm x D) of horizontal and vertical accuracy respectively.

Secondly, the distribution of sand transport rate around the trench was observed by sand trap experiment using vertical trap during winter time (Fig. 4). The traps consists of a cylinder (diameter 5 cm, height 80 cm) closed on the bottom and have a vertical slot of 1 cm width. The back-side of the trap has an opening of 2 cm covered with 0.06 mm stainless steel wire mesh. Each trap is buried in the sand so that the entrance is at, or just slightly below the sand surface, and the trap is oriented in the wind direction. The inlet to the trap is blocked by a strip of gum tape, which can be pulled out quickly at the start of a run to begin sediment collection. At the end of a run the trap is turned 180° to stop sand entering the trap and then the gum tape is replaced. The trap is then removed from the sand. All the collected sand is shaken into the plastic bags for later analysis. Wind velocity and its direction were also measured with three-cup anemometer at 1-min interval mounted at 1 m above the ground near the vertical traps (Fig. 4).

Thirdly, the deflation and accumulation in the trench trap had been observed from cross section West-East (W-E) measured by GPS with RTK. The topographic changes of the trench had been measured once a month for one year period (Oct 2008 to Sep 2009). Thus the volume rate changes (m^3/m/year) in the trench can be calculated by using the continuity equation of sand transport (Eq.(4)).

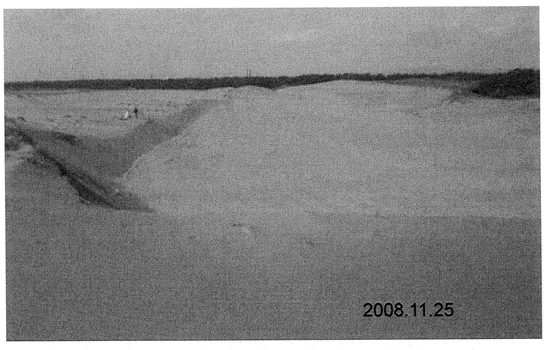

Fig. 3 Trench trap looking west

Fig. 4 Vertical trap looking east

(1) Topographic change caused by sand transport

In conditions of unidirectional constant winds and sand supply, it is well-known that transverse and barchans dune migrate downwind without changing their shapes (Bagnold 1941, Momiji and Warren 2000, Tsoar *et al.* 2004). Since the dune remains unchanged in shape and size, all the sand which emerge across the windward surface must be removed by the wind, carried forward over the summit, and distributed as a deposit on the lee side (Bagnold 1941). The geometry of migrating shape-invariant transverse dune shows in Fig. 5.

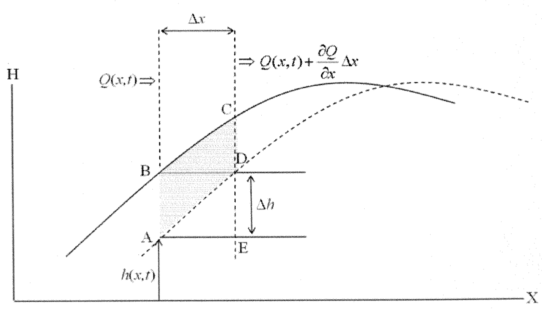

Fig. 5 Geometry of a migrating shape-invariant transverse dune

A system of sediment erosion, transport, and deposition is controlled by the sediment-continuity equation which expresses that a change in the volume rate of sediment transport dQ during a time lapse Δt results in a change in topographic height Δh over an interval Δx. From Fig. 5, the volume rate per unit width of removal from any small $ABCD$ is given by $QD - QA$; and if we denote this by dQ, we know that in unit time a volume of sand dQ has been removed from the area. If λ is the porosity of sand, the volume of this removed sand is $dQ/(1\text{-}\lambda)$. This volume is represented by the area of the parallelogram $ABCD$ in the Fig. 5, which is equal to that of the rectangle $ABDE$.

Now this volume must be exactly equal to that of the sand which has emerged during this unit time (Δt) from the surface between the levels of E and D. Calling this small different of level Δh, we therefore have the relation

$$(1-\lambda)\Delta h \cdot \Delta x = \left(Q(x,t) - \left(\frac{\partial Q}{\partial x}\Delta x + Q(x,t) \right) \right) \Delta t \qquad (1)$$

where λ is the porosity. Eq. (1) can be written

$$(1-\lambda)\frac{\partial h}{\partial t} = -\frac{\partial Q}{\partial x} \qquad (2)$$

Eq. (2) is the sediment continuity equation, which must always be satisfied regardless of dune form. The total volume rate of sand crossing all downwind windows yields the integral:

$$Q_{(x,t)} = -(1-\lambda)\int_{x=a}^{x=x} \frac{\partial h}{\partial t}\partial x + Q_{x=a} \qquad (3)$$

If we let $x = a = 0$ and $Q_{x=a} = 0$, integration Eq. (3) from $x = 0$ to $x = x$ gives:

$$Q_{(x,t)} = -(1-\lambda)\sum_{x=0}^{x=x} \frac{\Delta h}{\Delta t}\Delta x + 0 \qquad (4)$$

3. RESULT AND DISCUSSION

(1) Migration of edge of dune

From the measurement of edge in the eastern end of the dune (Fig. 6), we found the edge of the dune has migrated eastward. The migration of the edge was higher in winter to spring than in summer. The sand transport increased as wind velocity increased in winter to spring. Wind velocity and direction were measured with a propeller-type anemometer at 10 min intervals, mounted at 5 m above the ground, installed in the Nakatajima dune. As clearly shown in Fig. 7, the prevailing wind is WNW (North direction corresponds to an angle of 0 degree). The maximum 10-min averaged velocity for the period was 22.7 ms^{-1}. The average velocities for the 2007, 2008 and 2009 were 3.7 ms^{-1}, 3.6 ms^{-1} and 3.6 ms^{-1} respectively. The monthly averaged wind speed was higher in winter to spring (November to April) than summer to autumn (May to October). Moreover, the monthly averaged wind speeds tend to increase from October to February and decreased from February to June.

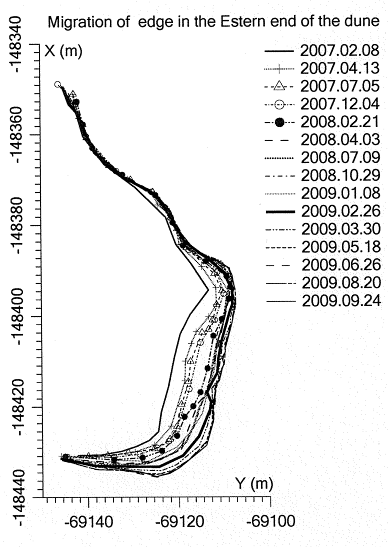

Fig. 6 Measurement points along the edge of the dune (2007-2009)

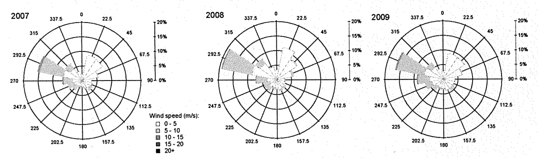

Fig.7 Yearly wind frequency rose of regional wind data in the Nakatajima dune (2007-2009)

From Fig. 6, the edge of the dune migrated 6-7 m from Feb 2007 to Feb 2008 and 3-4 m from Feb 2008 to Feb 2009. The migration of the edge in the eastern end of the dune had been decreased in the second year of the study. The decrease of the frequency of high wind speed in the second year of the study is most likely a main cause (Junaidi *et al.*, 2009).

It was noted that the trench had developed in October 2008. In order to know the effectiveness of the trench in trapping the blown-sand, and the effect of the trench to decrease the volume of sand transport to the eastern edge of the dune, we measured the cross section along West-East direction on measurement of the trench in every month for one year period. The sand transport in the trench and its direction had been conducted with the sand trap experiment by using the vertical traps.

(2) Sand transport in the trench trap

The deflation and accumulation in the trench trap can be observed from cross section West-East (W-E) as shown in Fig. 8. The accumulation appears in west sidewall of the trench. Simultaneously, the sand transported eastward deposited in the downstream edge of the trench in the east. In contrast the base of the trench had been eroded.

From Fig. 8, we can calculate the elevation changes in the trench for approximately one year period. Then the Eq. (4) is used to calculate the volume rate change in the trench trap (m^3/m/year). The elevation and volume change in the trench are shown in Fig. 9. For simplicity, in Fig. 9, we assumed there are no sand transport into the trench trap (Q_{in} = 0). We are sure some sand transport into the trench (see Fig. 11), but the volume of sand transport into the trench in that period (the period of cross section measurement in the trench) still remains unclear. Furthermore, we may conclude that the outgoing volume rate of sand transport in the trench was approximately 8 m^3/m/year + Q_{in}. The deposition and erosion were found in the trench, where the eroded sand was higher than deposit sand. It indicates the trench was not effective in trapping the blowing sand. The reason for this might be that the width of the trench which is parallel to the predominant westerly wind was too large, hence allowed the wind to blown the grains inside the trench out to the east.

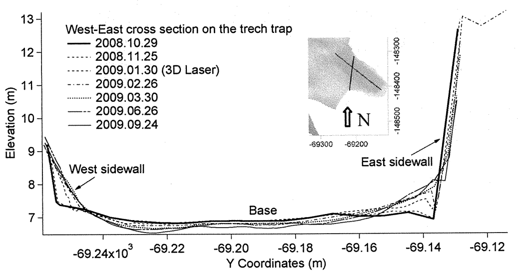

Fig. 8 Cross section West-East (W-E) on the trench trap

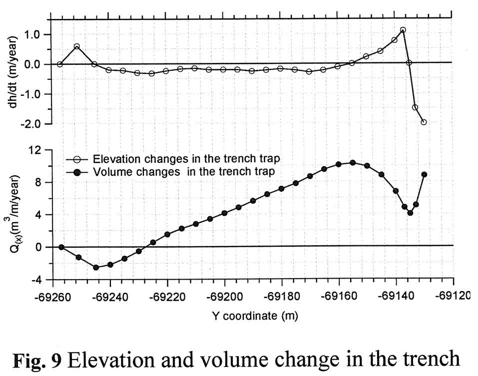

Fig. 9 Elevation and volume change in the trench

(3) Sand trap experiment

The experiment used 16 vertical traps placed as shown in Fig. 10 (T1-T16). Four traps were installed near the eastern edge of the dune, 5 traps inside the trench, and 7 traps placed in North and West, surrounding the trench. It was noted the trap No.15 (T15) was neglected in the analysis because some sand accidently enter the traps when we pulled the traps from the sand dune. We also monitored the scouring around the base of the cylinder traps that clearly shown the direction of blowing sand.

The wind velocity and directions were measured at 1-min interval at 1 m above the ground using three-cup anemometer. Five anemometers were placed near the traps (A1-A5), but the anemometer A3 failed to record the wind data and was neglected in this experiment. The sand collected for 30 minutes, from 12:20 to 12:50. The wind direction was NW and WNW during the collecting sand dune with the traps with an averaged velocity was 10.5 m/s.

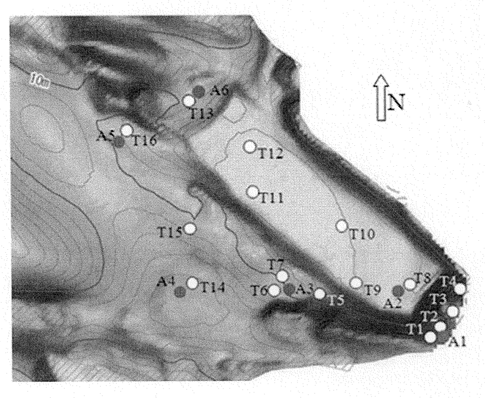

Fig. 10 Position of traps (T1-T16) and anemometers (A1-A6) on the sand trap experiment on 2009.03.10

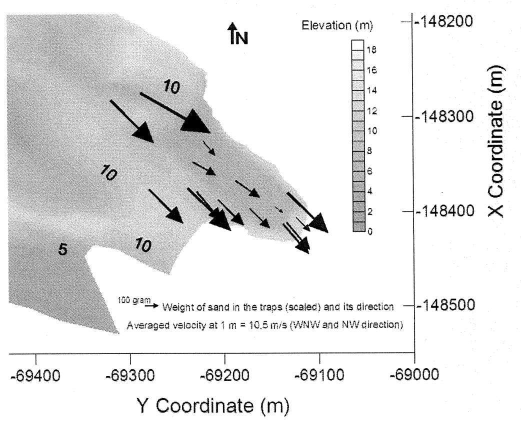

Fig. 11 Sand flux distributions and its direction in the trench

The wind speed and the sand flux from the vertical traps measurement are shown in Fig. 12. We found that in the high elevation (A1, A4 and A6) have a similar curve of the wind speed, but the sand transport rate was different. It might be due to the amount of sand supply from the upwind of the traps. The highest sand transport rate was in the west of the trench (T13). We also found the sand was transported eastward in the base of the trench (T8, T9, T10, T11 and T12), and climbed up the east sidewall of the trench. Moreover, small amount of sand deposited in the foot of the west and east sidewall of the trench. As clearly shown in Fig. 12 that the sand transport rate has dropped from 0.034 $kgm^{-1}s^{-1}$ in T13 to 0.008 $kgm^{-1}s^{-1}$ in T12 and 0.012 $kgm^{-1}s^{-1}$ in T10 to 0.004 $kgm^{-1}s^{-1}$ in T8. And this is agreed well with the cross section data shown in Fig. 8.

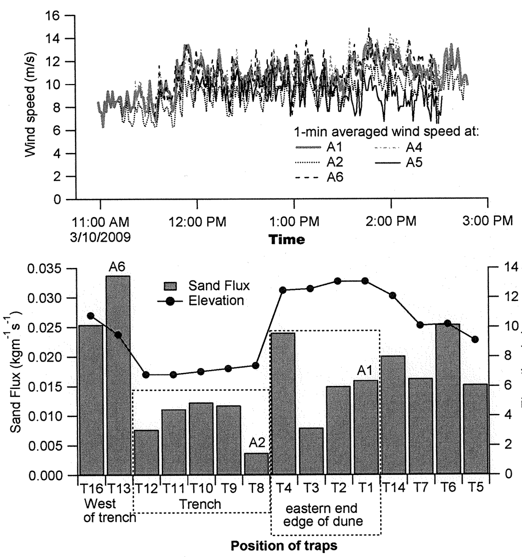

Fig. 12 1-min averaged wind speed (upper) and sand flux from the vertical traps measurement (lower)

4. CONCLUSIONS

In the monitoring area, near the eastern end of the dune, the migration rate of the edge of the dune decreased after the sand removal near the edge of the dune, which forms like a trench trap, but the effectiveness is not significant in trapping the wind-blown sand. The eroded sand was higher than deposited sand in the trench with a total volume rate of approximately 8 m^3/m/year + Q_{in} (volume rate of sand transport into the trench). We still found the sand was transported inside the trench, climbed up the east sidewall of the trench to the eastern edge of the dune. The reason for this might be that the width of the trench which is parallel to the predominant westerly wind was too large, hence allowed the wind to blown the grains inside the trench out to the east.

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