

Turbulent sand jets in water

Les jets turbulents de sable dans l'eau

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Abstract

This Technical Note presents photographic observations of turbulent sand jets in water. Four sands, with mean diameters ranging from 0.17 to 1.47 mm, were used in combination with three nozzles of 8, 12.7 and 25.4 mm diameter. It was found that the linear growth rate of these sand jets increases with the parameter F_0 which is proportional to the ratio of the momentum flux of the sand jet at the nozzle to buoyant force on the sand particles. For the largest value of F_0 equal to about 15, the growth rate of the sand jet was 0.19 which is about 20% larger than that of turbulent water jets with Reynolds number larger than about 10,000.

Résumé

Cette note technique présente des observations photographiques de jets turbulents de sable dans l'eau. Quatre granulométries ont été utilisées, de diamètre moyen compris entre 0.17 et 1.47 mm, en combinaison avec trois injecteurs de 8, 12.7 et 25.4 mm de diamètre. Il est apparu que la croissance linéaire de ces jets de sable augmentait avec le paramètre F_0 qui est proportionnel au rapport du débit de quantité de mouvement du sable au droit de l'injecteur, à la poussée d'Archimède sur les particules de sable. Pour la plus grande valeur de F_0 égale à environ 15, le taux de croissance du jet de sable était de 0.19, ce qui est à peu près 20% de plus que celui des jets turbulents d'eau pour des nombres de Reynolds supérieurs à environ 10 000.

Introduction

Consider the flow of dry sand from a nozzle fixed at the bottom of a long tube of larger diameter that is filled with sand. Let us assume that the nozzle is located slightly above the water surface in a large tank. The sand from the nozzle travels through the water as a jet. In the experiments described herein, observations with dye and of the few air bubbles present in the sand jet indicated that the flow in the jet was generally turbulent. It was also observed that the sand jet entrained some of the surrounding water and grew in size as it travelled through the water column to the bottom of the tank. Observations of these jets were mainly photographic. These jets belong to the family of two-phase jets and are of interest in connection with the dumping of granular materials from barges in connection with island building operations and soil remediation where it is necessary to know the extent of spreading of the dumped material on the receiving bed. The results from this study may also be useful in studying the diffusion of slurry jets, which are water jets with large concentrations of sand, in mining industries.

Experiments

The sand jet experiments were performed in a jet tank, 1.25 m wide, 1.25 m long and 1.17 m deep, which was filled with tap water. A plexiglass cylinder, 100 mm in diameter and 330 mm long, fitted with a cone-shaped hopper at the bottom, was filled with dry sand of the desired size. Four different sands with median diameters D equal to 0.17, 1.47, 0.95 and 0.60 mm respectively and geometric standard deviations of 1.18, 1.22, 1.16 and 1.25 were used. These values for standard deviation are less than 1.35 and hence the gradation of these sands can be considered to be approximately uniform (Breusers and Raudkivi 1991). A nozzle

with an inner diameter of either 8, 12.7 or 25.4 mm was fixed to the bottom of the hopper and this sand feeder was mounted above the water tank with the nozzles located about 10 mm above the water surface. At the start of the experiment, a cork closing the nozzle was removed and the sand jet entered the water. The sand jets were photographed as they traveled through the water, from the front of the jet tank. For each jet, the radius of the jet was measured from these pictures at intervals of 50 mm by measuring the jet diameter at each location, as defined by the extremities of the jet where there were no sand particles. The error in the measurement of the radius of the jet and the axial distance was estimated to be about 2 mm.

A total of 10 experiments were performed and the details of these experiments are shown in Table 1. Each experiment was repeated three times. In Table 1, the mass flow rate of the sand from the nozzle, m_o , was obtained by collecting the sand issuing from the nozzle for a given time and measuring its weight. The mass flow rate is equal to $[\pi r_0^2 (1-n) \rho_s U_s]$, where r_0 is the radius of the nozzle ($=d/2$), n is the porosity of the sand which was assumed to be equal to 0.4, ρ_s is the mass density of sand and U_s is the velocity of sand particles at the nozzle. The Reynolds number R of the sand jet soon after it enters the water was assumed to be equal to $[U_s d \rho_m / \mu_m]$ where ρ_m is the density and μ_m is the dynamic viscosity of the sand-water mixture. The dynamic viscosity μ_m was found to be 60 times that of the water, from the correlation of experimental observations on slurries (Wasp et al 1978). The Reynolds number R of the sand jets varied from 40 to about 300. Flow visualization with dye as well as observation of air bubbles present in the sand jets indicated that the flow in these sand jets was turbulent. Figs. 1(a-d) show four pictures of sand jets, with R equal to 43.3, 93.6, 304.5 and 69.4 with respective jet diameters of $d=8, 12.7, 25.4$ and 12.7 mm with the first three experiments with sand size $D=0.17$ mm and the last with $D=1.47$ mm.

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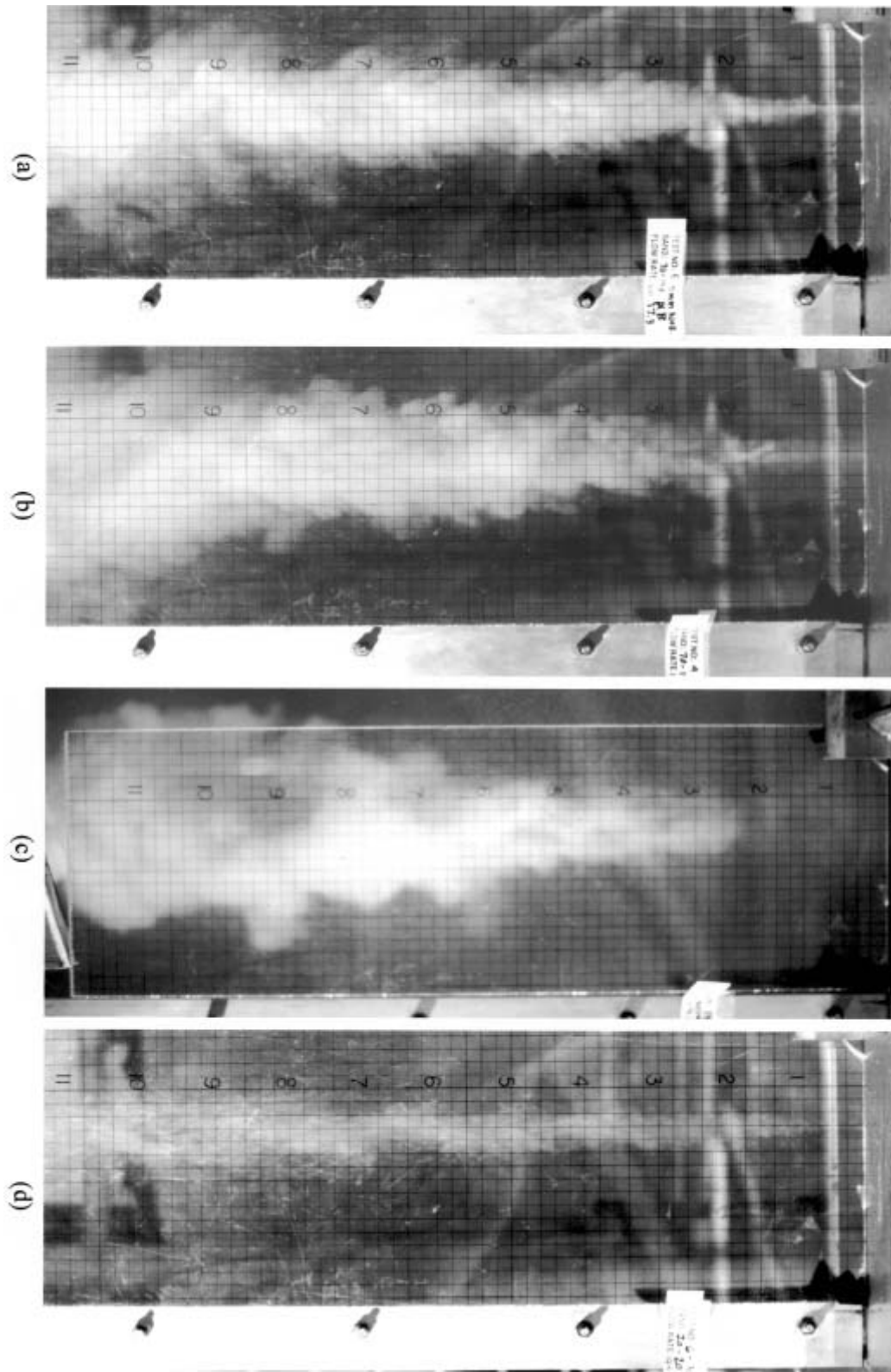


Fig. 1. (a-d) Sand jets in water: (a) $d=8\text{mm}$; $D=0.17\text{ mm}$ $R=43.3$ and $m_0=17.3\text{ gm/s}$ (b) $d=12.7\text{ mm}$; $D=0.17\text{ mm}$ $R=93.6$ and $m_0=59.1\text{ gm/s}$ (c) $d=25.4\text{ mm}$; $D=0.17\text{ mm}$ $R=304.5$ and $m_0=385.6\text{ gm/s}$ (d) $d=12.7\text{ mm}$; $D=1.47\text{ mm}$ $R=69.4$ and $m_0=43.9\text{ gm/s}$.

Experimental results and analysis

It was found that in all the experiments, the growth of the jet with the axial distance from the water surface (where the sand jet enters the water) was found to be approximately linear. Fig. 2 shows

a typical plot for the 8 mm nozzle for three sand sizes. The jet growth was measured for x/r_0 up to about 120. For sand jets from the same nozzle, the growth rate of the jets appeared to vary with the size of the sand grains in the jet, as seen in Fig. 2. This growth rate, defined as the ratio of the radius of the jet r (as obtained

Table 1: Details of Experiments

Test No.	d (mm)	D ₅₀ (mm)	m _o (g/s)	U _s (m/s)	M _o (kg m/s ²)	d/D	F ₀	R	r/x
1	8,0	0,17	17,3	0,216	0,0037	47,1	6,7	43,3	0,139
2	12,7	0,17	59,1	0,293	0,0173	74,7	9,1	93,6	0,151
3	25,4	0,17	385,6	0,479	0,1846	149,4	14,9	304,5	0,196
4	12,7	1,47	43,9	0,218	0,0096	8,6	2,3	69,4	0,060
5	25,4	1,47	321,4	0,399	0,1282	17,3	4,2	254,0	0,083
6	8,0	0,95	13,0	0,163	0,0021	8,4	2,1	32,5	0,034
7	12,7	0,95	54,0	0,268	0,0145	13,4	3,5	85,4	0,060
8	25,4	0,95	374,0	0,464	0,1736	26,7	6,1	295,6	0,093
9	8,0	0,60	16,1	0,201	0,0032	13,3	3,3	40,2	0,071
10	12,7	0,60	62,0	0,308	0,0191	21,2	5,1	98,0	0,090

from the pictures) to the axial distance x , was found to vary from about 0.03 to 0.19. For comparison, for circular, turbulent (submerged) water jets, Rajaratnam and Flint-Petersen (1989) found from photographic studies that for a jet Reynolds number greater than about 10,000, the jet growth rate r/x was about 0.16.

Assuming that the Reynolds number of the turbulent sand jets is only of secondary importance (this assumption was supported by the present results), the main parameter appeared to be the ratio of the momentum flux from the nozzle, $M_o = \rho_s U_s^2 (1-n) \pi r_o^2$, to the buoyant force $[N g \Delta \rho (4/3) \pi (D/2)^3]$, where g is the acceleration due to gravity, $\Delta \rho$ is the density of sand relative to the density of water and N is the number of sand particles present in the sand jet at any section, which was assumed to be equal to the number of particles in the jet at the nozzle. Assuming that

$$N = [(\pi d^2 / 4)(1-n) / (\pi D^2 / 4)] \tag{1}$$

this dimensionless parameter can be shown to be equal to $3/2 F_0^2$ where F_0 is equal to $U_s / (g D \Delta \rho / \rho_s)^{0.5}$. The variation of the growth rate (r/x) of the sand jet with F_0 is shown in Fig. 3. In Fig. 3, the results for four different sands and three different nozzles are well correlated with F_0 and this variation may be described by the equation

$$\frac{r}{x} = 0.024 F_0^{0.815} \tag{2}$$

with a correlation coefficient of 0.93. Fig. 3 indicates that when the momentum flux is much larger than the buoyant force, the sand jet grows faster, indicating the intensity of the interaction between the turbulence and sand particles in the sand jet. For the largest value of F_0 equal to about 15, the growth rate of the sand jet is about 0.19.

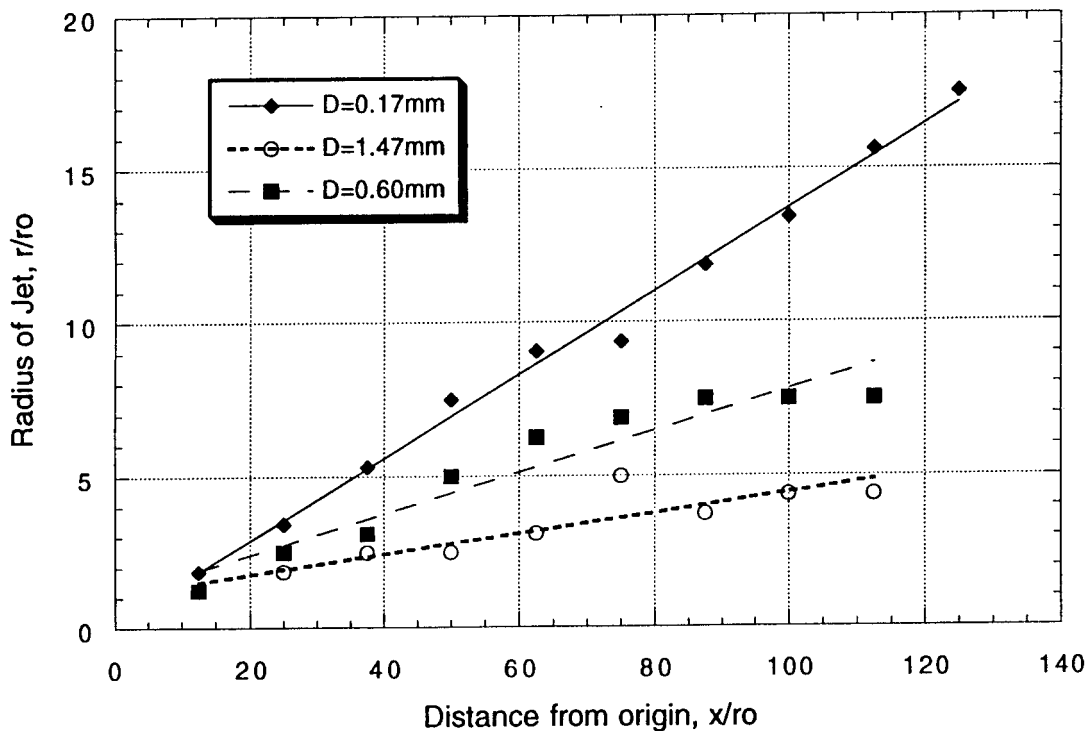


Fig. 2. Typical experimental results on the growth of sand jets ($d=8$ mm and $D=0.17$ mm(70-140); $D=1.47$ mm(20-40) and $D=0.60$ mm(sand 4).

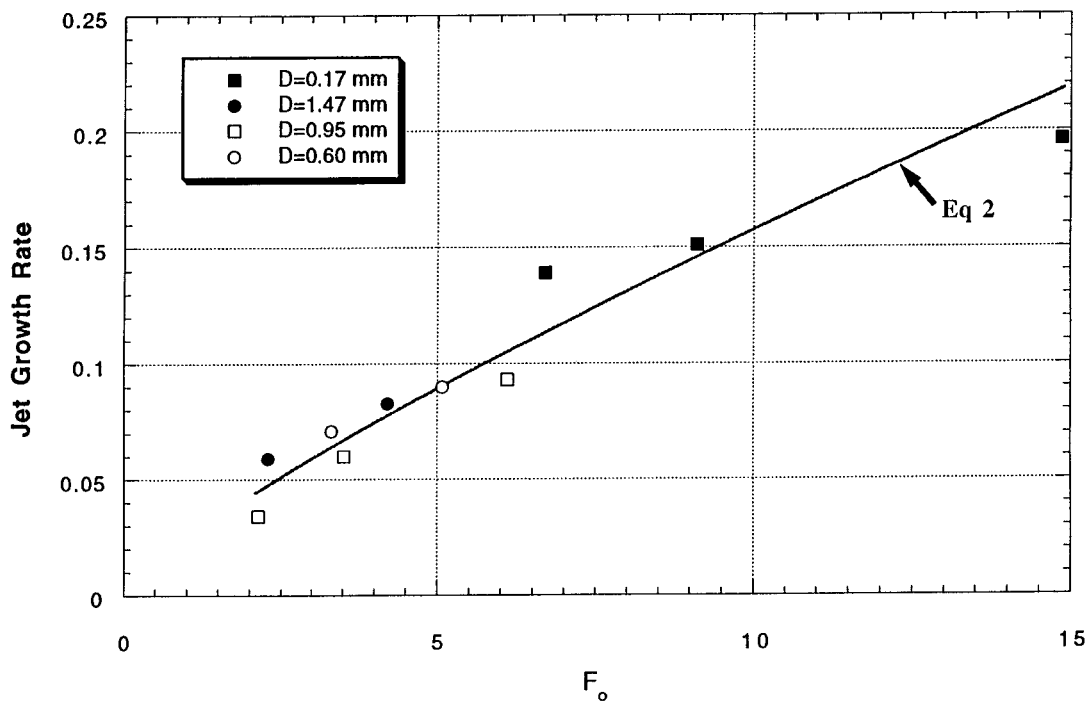


Fig. 3. Variation of the growth rate of the sand jets with the parameter F_0 .

Conclusions

Photographic observations of turbulent sand jets with four sizes of sand with mean size D from 0.17 to 1.47 mm in a water tank, from nozzles with diameters of 8, 12.7 and 25.4 mm have shown that these sand jets grow linearly, with the rate of growth increasing with the parameter F_0 which is proportional to the ratio of the momentum flux of the sand jet at the nozzle to the buoyant force on the sand particles. For the largest value of F_0 equal to about 15, the growth rate of the sand jet was 0.19 which is about 20% larger than that of turbulent water jets with Reynolds number larger than about 10,000.

Appendix I. References

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Appendix II. Notation

The following symbols are used in this technical note:

- d = diameter of nozzle
 D = mean diameter of sand particles
 g = acceleration due to gravity
 m_0 = mass flux of sand from nozzle
 M_0 = momentum flux of sand jet at nozzle
 $F_0 = U_s / (gD\Delta\rho/\rho_s)^{0.5}$
 n = porosity of sand
 N = number of sand particles in the sand jet at any section
 r = radius of sand jet at any axial distance
 r_0 = radius of sand jet at nozzle ($=d/2$)
 R = Reynolds number of sand jet
 U_s = velocity of sand particles at the nozzle
 x = axial distance from the nozzle
 μ_m = dynamic viscosity of sand jet at entrance in water tank
 ρ_m = density of sand jet
 $\Delta\rho$ = density of sand with respect to the density of water.