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II-218 THE BEHAVIOUR OF SEDIMENT-LADEN BUOYANT JET IN HORIZONTAL CROSS FLOW

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INTRODUCTION

The main objective of this study is to develop a mathematical model of a buoyant plume caused by sediment particles. When particles are discharged vertically into flow at the water surface,their behaviour may be similar to that of negative buoyant plume in flow,at first, since the sediment-laden part of the fluid is heavier than the ambient one. In addition to this motion, the plume will be pulled down due to the settling of the particles. This is the unique point of the sediment-laden plume.

Special attention was focused on the effect of fall velocity on buoyant plume in cross flow. We treated the case where the fall velocity of the particles is not so high compared with the uniform flow. Assuming the similarity profile for both flow velocity and sediment concentration, we discussed the trajectories of plume and the variations of plume properties along the plume axis.

BASIC EQUATIONS

It is assumed that the flow is steady, fully turbulent and fluid properties are constant. Using the Boundary layer approximation and Boussinesq approximation, we have [1) 2)],

$$\frac{\partial u}{\partial s}+\frac{1}{r}\frac{\partial(rv)}{\partial r}=0 \quad (1)$$

$$\left(u\frac{\partial u}{\partial s}+v\frac{\partial u}{\partial r}\right)\sin\theta=\Delta\bar{\rho}cg-\frac{1}{r}\frac{\partial}{\partial r}\left(r\overline{u'v'}\right)\sin\theta+u^2\cos\theta/R \quad (2.1)$$

$$\left(u\frac{\partial u}{\partial s}+v\frac{\partial u}{\partial r}\right)\cos\theta=-u^2\cos\theta/R-\frac{1}{r}\frac{\partial}{\partial r}\left(r\overline{u'v'}\right)\cos\theta \quad (2.2)$$

$$\frac{\partial}{\partial s}\left\{\left(u+w_o\sin\theta\right)c\right\}+\frac{1}{r}\frac{\partial}{\partial r}\left\{r\left(v+w_o\cos\theta\right)c\right\}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\overline{u'c'}\right) \quad (3)$$

$$\tan\theta'=\frac{u\sin\theta+w_o}{u\cos\theta}=\tan\theta+\frac{w_o}{u\cos\theta} \quad (4)$$

$$R=-ds/d\theta \quad (5)$$

$$\Delta\bar{\rho}=(\rho_s-\rho_o)/\rho_o \quad (6)$$

$$F_{dc}=u_\infty/\sqrt{\Delta\bar{\rho}\,c_o\,g\,l_b} \quad (7)$$

$$l_b=\rho_o B/u_\infty^3\ ,\ B=\frac{\pi}{4}D_o^2(w_{oo})\,g\,(\rho_s-\rho_o)\,c_o \quad (8)$$

$$u_*=\sqrt{(u_m-u_\infty\cos\theta)^2+(u_\infty\sin\theta)^2} \quad (9)$$

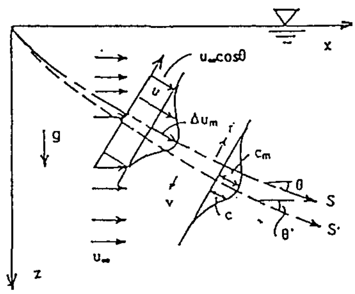

Fig.1. Definition sketch

$$\left.\begin{array}{llll}\bar{u}=u/u_\infty\ , & \bar{r}=r/l_b\ , & \bar{b}=b/l_b\ , & \bar{s}=s/l_b\\ \bar{u}_*=u_*/u_\infty\ , & \bar{A}=A/l_b^2\ , & \bar{w}_o=w_o/u_\infty\ , & \bar{c}=c/c_o\end{array}\right\}(10)$$

$$\bar{u}=(\Delta u_m e^{-r^2/b^2}+u_\infty\cos\theta)/u_\infty=\Delta\bar{u}_m e^{-r^2/b^2}+\cos\theta \quad (11)$$

$$\bar{c}=c_m e^{-r^2/a^2}/c_o=\bar{c}_m e^{-r^2/(\lambda b)^2}\ ,\quad \lambda=a/b \quad (12)$$

$$\frac{d}{d\bar{s}}\left(\frac{\bar{v}_*\bar{b}^2}{2}\right)=E_o\bar{b}\bar{u}_* \qquad \bar{v}_*=\Delta\bar{u}_m+2\cos\theta \quad (13)$$

$$\frac{d}{d\bar{s}}\left(\frac{\bar{v}_*\bar{b}^2}{4}\right)=F_{dc}^{-2}\frac{(\lambda\bar{b})^2}{2}\bar{c}_m\sin\theta+\alpha E_o\bar{b}\bar{u}_*\cos\theta \quad (14)$$

$$\frac{d}{d\bar{s}}\int_{\bar{A}}\left(\Delta u_m e^{-r^2/b^2}+u_\infty\cos\theta+\bar{w}_o\sin\theta\right)\bar{c}_m e^{-r^2/a^2}d\bar{A}=0 \quad (15)$$

$$\frac{d\theta}{d\bar{s}}=\frac{\frac{1}{2}(\lambda\bar{b})^2\bar{c}_m\cos\theta-\alpha E_o\bar{b}^2\bar{u}_*^2\sin\theta-c_d\sqrt{2}\,\bar{b}\sin^2\theta}{\frac{1}{4}\left(\bar{b}^2u_*^2-E_o\bar{b}^2\bar{u}_*^2\right)} \quad (16)$$

in which, s is the trajectory of maximum velocity, r is the radial coordinate taken from the s-axis,(see Fig.1). u and v are velocities in the s- and r-direction respectively. The densities of sediment particles and that of ambient water are denoted by ρ_s and ρ_o. w_o is fall velocity of sediment particles. These are equations of conservation of fluid (Eq.1), momentum in Z and X directions (Eqs.2.1, 2.2) and sediment particles (Eq.3). The trajectory of maximum sediment concentration is shown by (Eq.4). Substituting Eqs.7-12 into Eqs.1-6, we obtain Eqs.13-16. By integrating the Eqs.13-16, we obtain the behavior of sediment-laden negative buoyant plume.

Table 1. Experimental condition

RUN NO	C_0 %	U_0 cm/sec	U_∞ cm/sec	L_b cm	F_{00}	$\overline{W_0}$
1	4.89	19.57	3.48	51.92	$5.43*10^{-2}$	0.368
2	5.23	18.31	3.81	39.76	$6.57*10^{-2}$	0.336
3	8.42	14.86	3.53	66.23	$3.72*10^{-2}$	0.363
4	9.64	19.00	3.90	70.74	$3.71*10^{-2}$	0.328

EXPERIMENTAL FACILITY

The experiment was performed in a 0.5 m wide, 1.5 m deep and 5.0 m long circulating tank, in which the flow velocity was set uniform. The suspension of a given concentration was released vertically downward into flow through a nozzle.The sediment particles were seive sized and whose fall velocity is 1.28 cm/s. The flow was measured by electromagnetic flow velocity meter and the sediment concentration was obtained by siphoning. The experimenatal conditions are summarized in Table-1.

EXPERIMENTAL RESULTS AND CONCLUSION

The experimental results are plotted in Figs. 2-5 together with theoretical predictions. To give a better agreement to experimental results the value of α in Eq.14 is taken as 1.3. Fig.2 shows the normalized distribution of flow velocity and sediment concenration. For the velocity profile, the upper part of this distribution is not represented by the Gaussian distribution. The decay of additive maximum velocity is given in Fig.3. Fig.4 illustrates the decay of sediment concentration. The growth of plume width is shown in Fig.5. From Figs.3-5 it can be concluded that the numerical model is useful for a simple description of sediment-laden plume in flow when w_0 is small.

In this paper the plume properties were discussed by integrating over the cross-section normal to the plume axis, so that the complexity of the flow in the plume cross-section was eliminated. However, there are many reports on the complex flow properties of buoyant plume in flow. We are executing more precise experiment to extend this model.

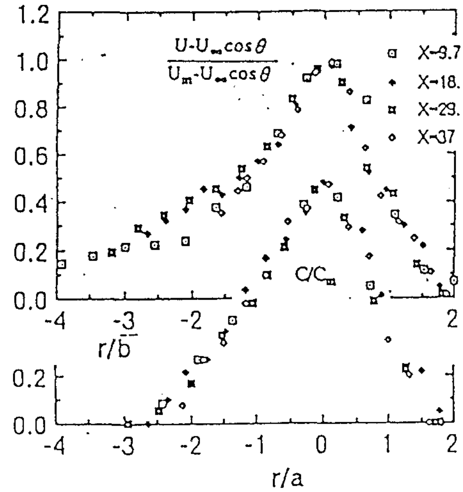

Fig.2. Similarity profile of velocity and sediment concentration

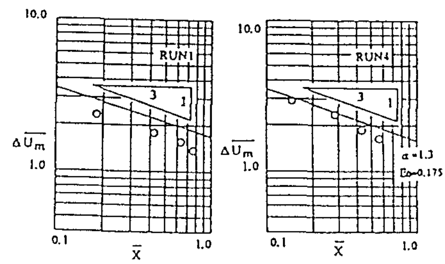

Fig.3. Decay of additive velocity along x

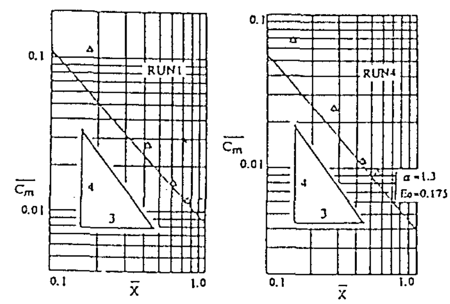

Fig.4. Decay of sediment concentration

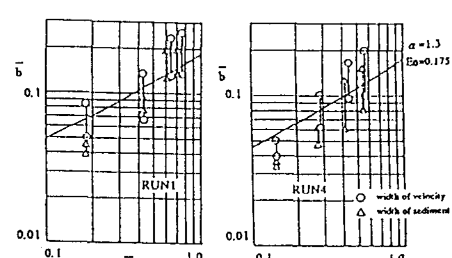

Fig.5. Growth of plume width

REFERENCES

(1) Wright S.J (1977). Mean Behaviour of Buoyant Jets in a Cross Flow. Jour. of Hydraulics Div.ASCE,Vol.103.No.HY.5,pp.499-513.

(2) Fujisaki K.,Kawano,N. and Awaya Y. (1994). Proc. of the 4th International Offshore and Polar Engg. Conf.1994,April 10-15,Osaka, Japan.