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林秉南先生近照

前　　言

本集收入了本人和师长及同事共同写作的大部分研究报告和论文，其中收入了输沙和水面蒸发两篇报告是因为这些报告有可靠的实验资料、可供研究分析。1950～1951 年，我在爱奥华水利研究所的 120 英尺长变坡槽上进行了近两年的输沙试验，发现需要长时间才能使水沙同时达到恒定均匀运动的境界；而且不到 1°的温度变化就要求调整坡降，才能使流动保持均匀；而一次测全套资料需要半天，其间温度往往改变了。为了捕捉精确的均匀流，曾为一组试验，一次连续放水 36h。1952 年我转去科罗拉多州大学工作。该校也要开展这方面的研究，我便将以前的经验移植到科大，后来写成了本集收入的报告。资料可靠，曾被广泛引用。因要回国未进行更多的试验。报告主要由我执笔。第一作者巴顿先生是我的好友，爱奥华学长。他是项目负责人，统筹全局。本集收入的其它文章大部分在国内完成。从一个侧面反映了我国水利（广义）建设的进展。

很荣幸本集的出版得到全国政协副主席钱正英老部长的关注，并题写了书名，谨致谢意。同样也感谢下列单位对本集的出版给予了大力资助：

中国水利水电科学研究院院部、水力学所，

清华大学水利水电系及泥沙研究室，

国际泥沙研究培训中心。

编印本集由中国水利水电科学研究院陆吉康、王连祥、刘树坤、何少苓、程晓陶、向立云及清华大学周建军和余锡平、华南环境研究所郭振仁等同志发起和推动的；他们还投入了大量时间、做了大量校对和联系工作，令人铭感。宿俊山同志从国外汇款支援，情意都很感人。中国水利水电出版社的责任编辑黄会明同志，在审校工作中认真负责，在此一并鸣谢。

林秉南

2000 年 11 月于北京

林秉南传

林秉南，水力学与河流动力学家，中国科学院院士。1920年4月21日出生于马来西亚，原籍福建省莆田市。1937年广州市立第一中学毕业，1942年交通大学唐山工学院土木系毕业，1947年美国艾奥瓦大学硕士研究生毕业，1951年在该校获博士学位。曾任艾奥瓦水利研究所副研究员及科罗拉多州立大学助理教授。曾为研究生讲授过明渠水力学，进级流体力学和泥沙运动。1956年回国，在中国科学院水工研究室任研究员。1958年起在中国水利水电科学研究院工作，1990年起任该院名誉院长、高级工程师。

在国外工作时最早提出两种指定时段构造特征线网法，并提出当时属于先进的明渠不恒定流计算法，被分别收入美国H.Rouse编《工程水力学》(1949年）和V.T.Chow著《明渠水力学》(1958年）及日本本间仁和安芸胶一编《物部水理学》(1962年）三部专著中。1956年回国后开展高坝水力学和明渠不恒定流研究。在高坝水力学方面，领导、发展了收缩式新型消能工（包括宽尾墩及窄缝挑坎）的研究，为高坝泄洪消能，特别是在高深峡谷建设的高坝泄洪消能，提供了有效方法。1979年还指出在一定条件下，宽尾墩下游的部分溢流面的剖面还可以采用非光滑面，从而简化施工。上述新型消能工已在国内多处工程应用。1985年该项研究成果曾集体获得国家科技进步二等奖。在不恒定流方面，率先在国内开展溃坝波的实验和理论研究；1958年首先应用大模型研究三峡水库水体突泄对下游广大地区的可能影响。对大面积海湾和河口，在国内首先应用二维特征理论和破开算子法，建立了符合实测资料的快速计算方法。泥沙方面，曾在国外研究含沙浓度和颗粒雷诺数对泥沙沉降速度的影响和进行过大量水槽输沙试验。1985年起至今担任三峡工程泥沙专家组组长。

是1978年全国科学大会先进个人。获1978年水电部科学技术先进工作者。5至8届全国政协委员。1986年当选为美国艾奥瓦大学杰出校友;1993年当选为该校杰出校友工程院成员。1989～1993年任联合国发展署亚洲地区泥沙冲淤培训项目经理。1991～1996年任国际水力学研究协会(IAHR)亚太地区分会主席。1997年获国际水力学研究协会荣誉会员称号(终身)。1997年获美国土木工程学会干旱地区木利工程奖。

BIOGRAPHY OF LIN BINGNAN

Lin Bingnan is a member of the Chinese Academy of Sciences, being specialized in hydraulic engineering in general and fluvial hydraulics and hydraulics of structures in particular. He was born in Malaysia on 21 April 1920 of parents from Putian, Fujian, China, but was, however, brought up in Guangzhou, China. In 1937, he was graduated from the First Municipal High School of Guangzhou. Then broke the war to resist the Japanese aggression. During this period, he went to Guizhou and was graduated from the Department of Civil Engineering of National Jiao Tong University with BS in CE degree in 1942 with the election to the membership of the honorary scholastic Society of Phi Tau Phi, Tangshan Chapter. In 1945, close to the surrender of the Japanese aggressors, Lin was awarded a government scholarship to study in the United States through competitive examination. He was enrolled in the State University of Iowa in 1946 and awarded an MS degree in Mechanics and Hydraulics in 1947 and Ph.D. degree in 1951. From 1949 to 1952, he was research associate with the Iowa Institute of Hydraulic Research, conducting studies on the transport of sediment in open channel flow. Between 1952 and 1954, he was an assistant professor of civil engineering at Colorado State University, teaching graduate classes of open channel hydraulics, advanced fluid mechanics and engineering sedimentation while carrying out research on sedimentation and forced evaporation of water body by wind. He returned to China in 1956 to join the staff of the Institute of Hydraulic Research of the Chinese Academy of Sciences. Since 1958, he has been on the staff of the China Institute of Water Resources and Hydropower Research (IWHR). Presently he is the Director Emeritus and senior engineer of this institute.

While abroad, he was the first to formally publish two methods of designated time intervals for the construction of characteristic nets in the numerical analysis of unsteady flows. His methods were printed in the American books of Engineering Hydraulics edited by H. Rouse (1949) and Open Channel Hydraulics by Ven Te

Chow (1958) and also in the Japanese book of Hydraulics edited by M. Hom-ma and Aki(1962). On returning home in 1956, he was given the duty to initiate studies in the fields of hydraulics of high dams and unsteady flow in open channel. In the former field, he led the study to develop new devices for energy dissipation, featuring contracting structures that include flaring gate piers and flip buckets with convergent side walls. These devices are particularly good for energy dissipation of discharges from high dams built in deep and narrow canyons. They help reduce the risks of undermining the canyon walls by excessive scouring. Also, as pointed out in 1979, under appropriate conditions, a portion of the spilling surface downstream of the flaring gate piers may assume profiles of broken lines instead of the conventional smooth curves, thus simplifying construction. These devices have been employed in many high-dam projects. The working group won a collective National Award, 2nd class, for Progress in Science and Technology in 1945. In the field of unsteady flows, he pioneers in China the experimental and theoretical studies of dam-break waves. A large physical model was initially built and run in 1959 for the estimate of tbe consequences brought about by the fictitious sudden release of the Three Gorges Reservoir on the entire valley downstream. Rapid methods for the computation of tides in large estuaries as well as gulfs were developed under his initiation, employing both the characteristic theory in two space variables and the fractional step method. The computed results check quite closely with observed data. In the field of sedimentation, he studied the effects of sediment concentration and particle Reynolds number on the settling velocity of sediment particles. He also conducted a large amount of studies on transport of sediment in flumes. Since 1985, he has been the chief of various sedimentation panels in charge of the coordination of sediment studies for the Three Gorges Project.

He received the title of distinguished worker awarded by the National Science Assembly of China in 1978. From 1978 to 1998, he was a member of the China People's Political Consultative Conference. In 1986, he received a Distinguished Achievement Award from the University of Iowa Alumni Association. In 1996, he was inducted to the Distinguished Engineering Alumni Academy of the University of Iowa. From 1991 to 1996, he was the chairman of Asian-Pacific Division of the International Association for Hydraulic Research(IAHR) founded in 1935. In 1997, he was awarded an honorary membersbip by IAHR and received an Arid Lands Hydraulic Engineering Award from the American Society of Civil Engineers.

目　　录

1 SEDIMENT CONCENTRATION AND FALL VELOCITY

Concentration of particles in suspension is shown both experimentally and analytically to affect the fall velocity to a significant degree. An extension of Smoluchowski' s analysis was employed in the determination of the magnitude of the concentration effect for uniformly dispersed particles of constant diameter for Reynolds numbers up to approximately 2.

Experiments were conducted using statistically homogeneous suspensions of sand particles and of glass beads in a vertical tube. The samples tested had been carefully selected by means of repeated hydraulic separation to insure constancy of fall velocity. Concentrations and fall velocities were determined indirectly from continuous measurements of the difference in piezometric head at two points along the tube.

The trend of the experimental points was found to coincide very closely with that obtained from theory. As a concentration of only 1% was found to reduce the fall velocity by about 20% the effect of concentration in analyses of sediment samples is seen to be important. For values of the Reynolds number between 0.1 and 2, the effect of concentration was found to decrease slightly as the Reynolds number increased.

LIST OF SYMBOLS

A	cross-sectional area of container
C	concentration of sediment
d	diameter of spherical particle
k	$V/2\nu$
P, Q	volumes as defined in text
R	radius of spherical volume equal to p
$\underline{R}$	Reynolds number Vd/ν
r	radius vector in spherical coordinate system
s	mean particle spacing
V	mean fall velocity for dispersed particles

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1. By john s. McNown and Bing nan Lin, Iowa Institute of Hydraulic Research.

2. Second Midwest Conference on Fluid Dynamics, 1951.

V_0	fall velocity of single particle
ΔV	$V - V_0$
v	velocity induced at any point in space by motion of a particle
v'	velocity induced at locus of reference particle by motion of a second particle
x, y, z	rectangular coordinate axes, z directed vertically downward
ν	kinematic viscosity
θ	inclination from z-axis
ψ	Stokes stream function

INTRODUCTION

Although particle concentration has long been known to affect those size analyses of sediment which are dependent upon the elutriation principle, neither the magnitude of this effect nor its dependence on the particle Reynolds number has been satisfactorily assessed. An approximate theory of the slow motion of uniformly distributed particles was first presented by Smoluchowski. Modifications of this theory make possible the evaluation of the effects of inertia, providing that the latter are small, by means of Oseen's linearized equations. Because restrictive assumptions are necessarily made in these derivations, the applicability of and the limitations on the results obtained must be determined through comparisons with the results of laboratory studies.

In the investigation described on the following pages are presented an extended theory and comparable laboratory measurements of the concentration effect for dispersed suspensions of particles of a constant diameter. The results obtained should be particularly useful in the planning and interpreting of laboratory analyses of sediment samples. This study forms a part of a continuing investigation of fall velocity conducted at the Iowa Institute of Hydraulic Research. It was submitted in dissertation form by the second author (Ref. 1) to the Graduate College of the State University of Iowa in partial fulfillment of the requirement of the Ph. D. Degree in the Department of Mechanics and Hydraulics.

THEORY

Retardation of the settlement of dispersed particles in a limited fluid field can be approximated theoretically in various ways. In the original work of Smoluchowski (Ref. 2) and in a comparable study by Burgers (Ref. 3), the assumptions were made that (a) the particles were spherical and all of the same diameter, (b) they were uniformly dispersed throughout the fluid, and (c) that inertial effects were negligible. In other studies (Ref. 4, 5, 6), the effect of the neighboring particles was assumed to be the same as that of suitably placed solid boundaries. Although restricted in applicability, the results obtained from these analyses can be used to define approximately the effect of concentration on fall velocity for very small Reynolds numbers.

Smoluchowski's derivation can be modified so as to furnish results for motions in which inertia effects are small but not negligible. The functional relationship sought must express the effect of concentration and inertia on the mean fall velocity,

$$\frac{V}{V_0} = f(C, \underline{R}) \tag{1.1}$$

For any idealized arrangement of the particles, the ratio of the particle diameter to a characteristic spacing can be substituted for the concentration without significant alteration of the relationship.

The descent of each of a number of particles creates a velocity field throughout the fluid, and hence tends to increase the velocity of all other particles. In opposition to this, in a container of finite dimensions, the downward motion of each particle plus the downward motion of the entrained fluid must be compensated for by an equal upward flow which tends to decrease the velocity of each particle. If, on the one hand, the suspension is not distributed uniformly throughout the fluid, the resultant fall velocity can greatly exceed V_0, the compensatory upward flow occurring in regions in which there are few or no particles. On the other hand, if the particles are more or less uniformly distributed throughout the fluid, each will be retarded in much the same way as is a single particle in a cylindrical container (Ref. 5).

The vertical velocity induced at the position of a given particle by the motion of all others can be determined from an infinite summation. Only vertical velocities need be considered, because the mean horizontal velocity components remain zero as can be easily shown (Ref. 1). If s designates the side length for the assumed cubical spacing (or the distance between adjacent particles), r the distance from the reference particle to any other, and z the distance measured in the vertical direction, the summation is logically begun with the single particles below and above ($r = s$, $z = \pm s$) and the four other nearest particles in the horizontal plane through the reference particle ($r = s$, $z = 0$). The summation can then be continued as indicated in the following tabular arrangement.

Table 1.1

No. of particles	2	4	4	8	8
r/s	1	1	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{3}$
z/s	± 1	0	0	± 1	± 1

For particles large distances away, the summation can be performed as an integral, the concept of the discrete particle being replaced by that of a continuous distribution. The number of particles in an elementary volume $\Delta x \Delta y \Delta z$ can then be expressed as $\Delta x \Delta y \Delta z / s^3$ (actually a very small fraction). If the entire region is divided into two parts, P and Q, the summation is then completed over the volume P immediately surrounding the particle, and the integration performed throughout Q, the remaining space. The velocity induced by the other particles is indicated by the expression

$$\sum_{P+Q} v' = \sum_{P} v' + \frac{1}{s^3} \iiint_{Q} v' \mathrm{d}x \mathrm{d}y \mathrm{d}z$$

in which v' is the velocity induced at the locus of the reference particle by the motion of any of the other particles. Because continuous variation is assumed throughout Q, v' can be replaced by v, the velocity at any point in space induced by the motion of a single sphere.

The condition of continuity——that there be zero flow across any horizontal plane——becomes

$$\iint_A v\,dx\,dy = 0 \tag{1.2}$$

in which A is the horizontal cross section of the container. It follows that the triple integral of v throughout the entire space is also zero, so that the integral throughout P is negatively equal to that throughout Q. Finally, the change in fall velocity caused by the motion of the other particles can be expressed in the more readily calculable form,

$$\Delta V = V - V_0 = \sum_P v' - \frac{1}{s^3}\iiint_P v\,dx\,dy\,dz \tag{1.3}$$

Computation of ΔV thus depends upon the definition of v at a general point in space, and upon the subsequent evaluation of both the summation and integration throughout an appropriately selected region surrounding the reference particle.

The Stokes stream function for the motion of a sphere in an infinite viscous liquid is well known (Ref. 7), and can be used in the functional definition of the general velocity V. With the Oseen modification, the expression for ψ in polar coordinates is as follows

$$\psi = \frac{3}{4}\nu d(1-\cos\theta)\{1 - e^{-kr(1-\cos\theta)}\} - \frac{1}{32}\frac{Vd^3}{r}\sin^2\theta \tag{1.4}$$

in which $k = V/2\nu$, and the reference coordinate axis is directed vertically downward. The vertical velocity at any point can be determined if the foregoing expression is used in conjunction with the following relationship:

$$\nu = \nu_r\cos\theta - \nu_\theta\sin\theta = -\frac{1}{r}\left(\frac{\cot\theta}{r}\frac{\partial\psi}{\partial\theta} + \frac{\partial\psi}{\partial r}\right)$$

Patterns of streamlines for representative values of $\underline{R}$ (or 2kd) are shown in Fig. 1.1, tbe marked differences indicating the increasing importance of the inertial terms as $\underline{R}$ increases. For $\underline{R}=0.1$ the asymmetry with respect to a horizontal plane through the center of the sphere, characteristic of flows affected by inertia, is apparent but slight. For $\underline{R}=0.4$, it has already become marked, and for $R=2$ it is striking indeed. Although the differences near the particle, which affect the drag, are small, the differences some distance away, which determine the concentration effect, are pronounced.

Evaluation of the integral in Eq. (1.3) is extremely complicated if a cubical boundary is assigned for P, so that a further approximation was made. The summation was completed for the cubical region (already indicated in Table 1.1), whereas the integral was evaluated for a spherical region of the same volume. Once the indicated operations, aside from the summation, have been performed, the relative change in velocity is given by the equation:

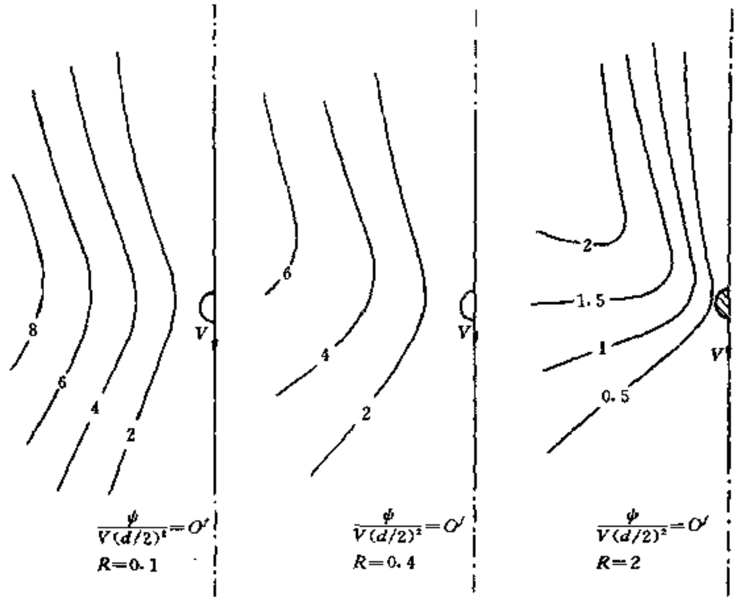

Fig. 1.1 Flow patterns produced by Falling spheres at various Reynolds numbers

$$\frac{\Delta V}{V} = \frac{3}{8}\frac{d}{s}\left\{\sum_P \frac{r}{s}\left(1 - \frac{z}{r} - \frac{z}{kr^2}\right)e^{-k(r+z)} - \frac{2\pi}{(ks)^2}\left[\frac{2s}{d}(e^{-kd} - 1) - \frac{s}{R}(e^{-2kR} - 1)\right] + \frac{2T(2R-d)}{s}\right\} \quad (1.5)$$

in which $P = 4\pi R^3/3 = (3s)^3$, so that $R = 1.86s$. The various values for z, r, and R can now be substituted and the calculation completed. As 2kd is the Reynolds number, Eq. (1.5) indicates the functional relationship expressed in Eq. (1.1). To a first approximation and with inertial effects omitted, this result reduces to the expression

$$\frac{V}{V_0} = \frac{1}{1 + 1.3\frac{d}{s}} \quad (1.6)$$

Figure 1.2 has been plotted from Eq. (1.5) for typical values of $\underline{R}$. Also shown for comparison are the curves obtained by Smoluchowski and by Burgers for the limiting case of very small $\underline{R}$-values. The small differences between the various curves obtained for $\underline{R}\to 0$ result from the use of

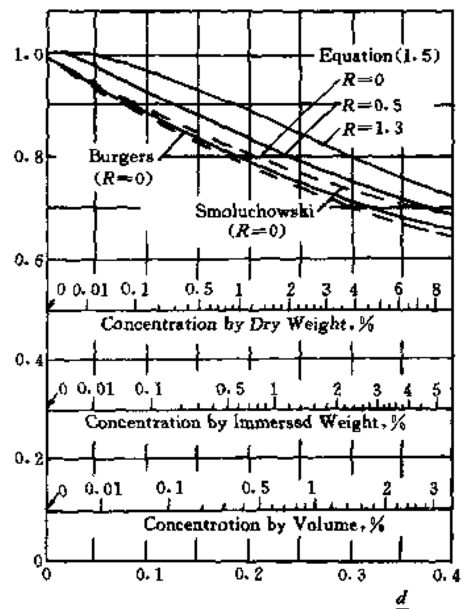

Fig. 1.2 Comparison of theories for effect of concentration on fall velocity

different approximations in the infinite summation. Somewhat different results would be expected if other particle arrangements than the cubical were assumed initially.

A surprising phenomenon established in calculations based on Eq. (1.5) is the existence of an interval for very small values of d/s (or c) in which the fall velocity is increased even for the assumed condition of uniformly dispersed particles. This occurrence, which diminishes in significance with decreasing Reynolds number, is a direct result of the asymmetry illustrated in Fig. 1. 1. The effect of the particles directly below decreases with distance much more slowly than does that of the particles above or in the same horizontal plane. Thus the neighboring particles below, which tend to increase the velocity, eventually become dominant in comparison with all others. As this occurrence is very small in magnitude and as it occurs only for very low concentrations, it is not a significant part of the analysis of the problem, and the foregoing discussion is presented only in explanation of an apparent anomaly.

LABORATORY INVESTIGATION

Conduct of experiments for comparison with the results of theory included preparation of uniform sediment samples and measurement of mean fall velocity for various particle concentrations. Because the results being sought are second-order effects, in that they involve the determination of comparatively small changes in a quantity rather than the measurement of that quantity, extreme care was essential in the securing of uniform samples and in the conduct of the experiments.

Two uniform samples were prepared, one from a Missouri River sand of which only the portion remaining on a 200-mesh sieve was used, and the other from a given size of commercially graded glass beads. Although restricted in size variation, neither sample was by any means sufficiently uniform for these experiments. In order to secure effectively uniform samples, repeated hydraulic separation by means of the standard bottom-withdrawal tube was necessary. Small samples were introduced at the top of the long vertical tube, and only that portion of each sample reaching the bottom after a predetermined and narrowly limited interval of time was retained. After repeated refinements the remaining samples were judged finally on the basis of the results obtained in the actual determinations described in the following paragraph. Only a few percent of the original samples were used.

The experiments for the evaluation of the concentration effect were conducted in a vertical glass tube shown schematically in Fig. 1.3 (a). A statistically homogeneous dispersion of the sediment sample was first obtained hy stirring the mixture with a slender brass rod to which numerous copper wire rings had been appended. After the rod was removed, both the concentration of the sediment and the mean fall velocity were determined from precise readings of the difference in piezometric head between two lateral connections (A and B). As this difference varied directly with the quantity of sediment in suspension between the connections the reading