ASSOCIATION INTERNATIONALE DE RECHERCHES HYDRAULIQUES

INTERNATIONAL ASSOCIATION FOR HYDRAULIC RESEARCH

NEUVIEME ASSEMBLEE GENERALE
NINTH CONVENTION

Dubrovnik 1961
Yougoslavie

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INTRODUCTION

La Neuvième Assemblée Générale de l'Association Internationale de Recherches Hydrauliques a eu lieu à Dubrovnik (Yougoslavie) du *4* au *7* Septembre *1961*. L'organisation du Congrès a été confié à l'Association Yougoslave de Recherches Hydrauliques, membre de l'Union Yougoslave des Ingénieurs et Techniciens. Au Congrès assistaient *241* participants et *56* dames de *33* pays. Le programme du Congrès comprenait:

A. THEMES PRINCIPAUX

1. Effets de turbulence sur des constructions hydrau-hydrauliques (*27* mémoires)
2. Mécanique des courants d'eaux souterraines (*37* mémoires)
3. Problèmes hydrauliques pour les machines à calculer (*43* mémoires)
4. Modifications de courants naturels causées par des ouvrages (*27* mémoires)

B. CONFERENCES GENERALES

1. Problèmes hydrauliques du Karst
2. Ecoulement en trois dimensions à travers la couche de limite
3. Transformation de l'énergie dans les zones de séparation

C. SEMINAIRES

1. Hydraulique de petites constructions dans l'irrigation et le drainage (*10* abrégés)
2. Hydrodinamique fondamentale des écoulement à surface libre et des écoulements non uniformes (*38* abrégés)

D. SYMPOSIUM

— Machines hydrauliques

E. SEANCE ADMINISTRATIVE

— Rapports concernant l'activité de l'AIRH entre les deux dernières Assemblées et l'élection des nouveaux conseils d'administration et d'exécution

Le Congrès a été ouvert le *4* Septembre à *10h 00* par le Président du Comité d'organisation Prof. Bogić Knežević. A la séance d'ouverture les congressistes étaient salués par le délégé du Conseil Exécutif Fédéral Yougoslav, M. Vinko Hafner et le maire de la ville de Dubrovnik, M. Vinko Betica. Les discours d'ouverture ont été prononcés par le président de l'AIRH, Dr. Arthur Ippen et le secrétaire Dr. J. H. Schoemaker.

Les séances du Congrès ont été tenues dans deux salles: les conférences générales, les mémoires relatifs aux thèmes *1* à *4* avec leur discussions et la Séance administrative ont eu lieu dans la grande salle, tandis que les deux séminaires et le Symposium se déroulaient dans la salle de séminaire.

Après la clôture du Congrès deux excursions — »A« et »B« — ont été organisées. La première, excursion »A«, comprenait la visite de l'aménagement hydroélectrique »Trebišnjica«, du port maritime de Bar, des aménagements hydroélectriques »Perućica« et »Bistrica«, du barrage »Kokin Brod« et du Laboratoire d'Hydraulique situé au pied du mont Avala, près de Beograd. La seconde, excursion »B«, consistait en visites des aménagements hydroélectriques »Split« et »Peruča«, de l'Institut de l'Hydrodinamique Maritime de Zagreb et du Laboratoire Hydraulique de la Faculté Technique de Ljubljana.

Ces Comptes-rendus contiennent les mémoires selon les thèmes principaux avec leur discussions, conférences générales, rapport généraux sur les abrégés de deux séminaires ainsi que leur régistres, et le rapport sur le Symposium.

La publication de ces Comptes-rendus a été possible grace à la subvention du Conseil Exécutif Féderal Yougoslave, de l'AIRH, de l'UNESCO et de diverses institutions et entreprises hydrauliques yougaslaves.

Le Comité d'organisation tient à exprimer sa profonde gratitude à tous ceux qui ont contribué au succès de la Neuvième Assemblée Génerale de l'AIRH.

INTRODUCTION

The Ninth Convention of the International Association for Hydraulic Research was held from September *4* to *7, 1961*, in Dubrovnik (Yugoslavia). The Yugoslav Association for Hydraulic Research, a member of the Yugoslav Union of Engineers and Technicians, was in charge of its organisation. The Congress was attended by *241* participants and *56* ladies from *33* countries. The Program of the Congress was as follows:

A. MAIN SUBJECTS

1. Effect of turbulence on hydraulic structures *(27* papers)

2. Mechanics of groundwater flow *(37* papers)

3. Hydraulic problems for computers *(43* papers)

4. Modifications of natural streams by engineering structures *(27* papers)

B. GENERAL LECTURES

1. Hydraulic problems of the Karst

2. Three-dimensional boundary layer flow

3. Energy transformation in the zones of separation

C. SEMINARIES

1. Hydraulics of small structures in irrigation and drainage systems *(10* concise communications)

2. Fundamental hydrodynamics of free surface flow and unsteady flow *(38* concise communications)

D. SYMPOSIUM

— Hydraulic machinery

E. BUSINESS MEETING

— Reports concerning the activity of the IAHR between the last two congresses and the election of the new executive and administrative boards.

The Ninth Convention was opened by the president of the Organizing Committee, Prof. Bogić Knežević, on September *4th* at *10.00* a. m. At the opening session the Congress was addressed and welcomed by the delegate of the Federal Executive Council, Mr. Vinko Hafner and the mayor of the city of Dubrovnik, Mr. Vinko Betica. The introductory speeches were delivered by the president of the IAHR, Dr. Arthur Ippen and the secretary, Dr. H. J. Schoemaker.

The Congress sessions were held in two halls. The general lectures and the papers involving subjects *1* to *4* were presented and discussed in the main hall where the business meeting was also held, while the seminaries and the symposium took place in the seminary room.

After the close of the Congress two excursions — »A« and »B« — were organized. The first one, excursion »A«, included visits to the hydroelectric power plant »Trebišnjica«, the seaport of Bar, hydroelectric power plants »Perućica« and »Bistrica«, the barrage »Kokin Brod« and the Laboratory of Hydraulics, situated at the foot of Avala Hill, near Beograd. The second one, excursion »B«, included visits to the hydroelectric power plants »Split« and »Peruča«, the Institute of ship hydrodynamics near Zagreb and the Hydraulic Laboratory in Ljubljana.

This Congress publication contains papers on the main subjects together with their discussions, general lectures, general reports of the chairmen of the two seminaires, registers of the concise seminary communications and the report on the symposium.

The publication of the Proceedings of the Ninth Convention was financially supported by the Yugoslav Federal Executive Council, IAHR und UNESCO, as well as by several Yugoslav hydraulic institutes and enterprises.

The Organizing Committee gratefully acknowledges the services of all those who contributed to the success of the Ninth Convention.

Conseil de l'AIRH

Le Conseil pour la période 1er janvier 1962 — 31 décembre 1963 a été élu conformément aux articles 17—21 des Statuts précédents et l'article 15 des Statuts approuvés par l'assemblée général à Dubrovnik au 7 septembre 1961.

Les membres du Conseil élu sont:

Président:		
	A. T. Ippen	**(Etats-Unis)**
Vice-présidents:		
	D. V. Joglekar	**(Indes)**
	F. H. Allen	**(Grande-Bretagne)**
	L. Escande	**(France)**
Secrétaire:		
	H. J. Schoemaker	**(Pays-Bas)**
Membres:		
	R. Boucher	**(Canada)**
	J. P. Duport	**(France)**
	P. Canisius	**(Allemagne)**
	B. V. Proskouriakov	**(U.R.S.S.)**
	M. Hom-ma	**(Japon)**
	A. Schlag	**(Belgique)**
	O. J. Maggiolo Campus	**(Uruguay)**

Council of AIRH

The Council for the period January 1st, 1962 — December 31st, 1963 has been elected, according to the articles 17—21 of the former Constitution and the article 15 of the Constitution adopted by the general assembly at Dubrovnik on September 7 th, 1961.

The members of the elected Council are:

President:		
	A. T. Ippen	**(U.S.A.)**
Vice-president:		
	D. V. Joglekar	**(India)**
	F. H. Allen	**(U. K.)**
	L. Escande	**(France)**
Secretary:		
	H. J. Schoemaker	**(Netherlands)**
Members:		
	R. Boucher	**(Canada)**
	J. P. Duport	**(France)**
	P. Canisius	**(Germany)**
	B. V. Proskouriakov	**(U.S.S.R.)**
	M. Hom-ma	**(Japan)**
	A. Schlag	**(Belgium)**
	O. J. Maggiolo Campus	**(Uruguay)**

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TURBULENT FLOW IN OPEN CHANNELS

N. V. CHANDRASEKHARA SWAMY

INDIAN INSTITUTE OF SCIENCE, BANGALORE 12, INDIA

The velocity distribution in open channels has been analytically studied by dividing the flow region into three zones — (i) the upper zone where the eddy viscosity due to tubulence is predominant, (ii) the intermediate zone where the eddy and the kinematic viscosities are of the same order, (iii) the lower zone where the eddy viscosity is negligible and only the kinematic viscosity and wall shear are the controlling factors. Series solutions have been derived for the first two zones and are found to agree with the Prandtl Universal Logarithmic distribution as well as experiment. The lower zone corresponds to the well-defined region of the turbulent boundary layer. Approximate limits have been indicated for the extent of the three zones.

Distribution des vitesses en canaux ouverts est analytiquement étudiée par la division de la région de l'écoulement en trois zones:

(1) zone supérieure où la viscosité du tourbillon due à la turbulence est prédominante;

(2) zone intermédiaire où la viscosité cinématique et celle du tourbillon sont du même ordre;

(3) zone inférieure où la viscosité du tourbillon étant négligeable, la viscosité cinématique et la traction à la paroi sont les seuls facteurs de contrôle.

Une suite de solutions en dérivent pour les deux premières zones, s'accordant avec la Distribution logarithmique universelle de Prandtl tout aussi bien qu'avec les expériences. La zone inférieure correspond à la zone bien définie de la couche limite tourbulente. Des limites approximatives sont indiquées pour l'extension des trois zones.

INTRODUCTION

The application of the theories of turbulence to problems in hydraulics has been instrumental in solving many as yet unsolved problems in hydraulics. Hydraulics has till now been an empirical science, lacking in the conciseness and richness of the more logical sciences. Most problems of everyday occurrence in hydraulics have been studied only empirically without any analytical background. This has led to several controversies which could easily be averted if the subject is studied from a more rational point of view.

One such controversy in the field of hydraulics is the extent of a hydraulic jump. It is known that a hydraulic jump gets formed when a supercritical flow encounters a subcritical flow. But what exactly is the extent of this jump has been a disputable point. Innumerable empirical formulae are available and are being proposed periodically which all the more confuses the practical designer. The reason for this state of affairs is that our knowledge of the phenomena occurring inside a hydraulic jump is negligible. Rouse, Siao and Nagaratnam *[1]* have made certain turbulence measurements in the hydraulic jump. On the basis of this work, the author has given an expression for the extent of a hydraulic jump *[2]*, which has agreed well with experiments. This was made possible by incorporating certain basic ideas regarding turbulent flow into the mathematics of the hydraulic jump.

Another interesting but as yet unexplored field of research in hydraulics is the velocity distribution in an open channel. Even though a large amount of work has been done on the resistance to flow in open channels for smooth or rough conditions, it is surprising that very little attention seems to have been paid the fundamental problem of velocity distribution in open channels. The universal logarithmic velocity distribution of Prandtl and von Karman based on the momentum transfer theory has been modified by Vanoni *[3]* for the case of an open channel in the form

$$u = V + \frac{1}{K}\sqrt{gys}\left(1 + 2{,}3\log_{10}\frac{y'}{y}\right) \qquad (1)$$

where u is the velocity at any height y' from the bed, y the depth of flow in the channel, V the mean velocity for the entire section of flow and K is von Karman's constant having a value of *0.40*. The agreement between the experimental values and equation *(1)* was found to be very close except near the bed where the logarithmic law fails. But this is not a rational analysis of the problem.

The present author *[4]* attempted to solve this problem of open channel flow by resorting to the fundamental Navier-Stokes equations of motion and simplifying them to a certain extent by making the usual assumptions of turbulent shear flow. The problem was attacked in two ways — *(i)* by considering the entire depth of flow to be governed by a single law, *(ii)* the flow region being divided into two regions, the upper portion with predominant eddy viscosity and the lower one with predominant kinematic viscosity. Even though the velocity distributions obtained agreed fairly well with experiment and the universal logarithmic velocity distributions, the analysis contained some serious short-comings. The fundamental aspect of turbulence is momentum transfer which was not taken into considerations in the previous work.

In this paper, the problem has been attacked by an entirely different method by dividing the channel into three distinct regions. It is a well established fact that turbulent flow gives rise to an eddy viscosity which is not an intrinsic property of the fluid like the kinematic viscosity. Also, the eddy viscosity is not constant like the kinematic viscosity for any fluid at any given temperature, but happens to vary widely over the flow field. Inspite of these complications, the eddy viscosity is a useful concept which has been often used in studies on turbulence.

In the case of an open channel, the eddy viscosity and the kinematic viscosity play important roles in any region depending upon the location of that region with respect to the boundary. Very near the boundary, the eddy viscosity is small and we can consider only the kinematic viscosity. On the other hand, near the free surface, the eddy viscosity is much more predominant. In between, there is a region where both the viscosities are of the same order. On this basis, we divide the region of flow in an open channel into three distinct parts:

(1) Region of high viscosity near the bed (Lower region).

(2) Region of low viscosity near the free surface (upper region).

(3) Region where the kinematic and eddy viscosities are of the same order (intermediate region).

It is the object of this paper to study these three regions separately by using the fundamental equations or motion.

EQUATIONS OF MOTION

We assume that the Navier-Stokes equation holds good for both the mean — and turbulent — velocity components. We also assume the fluid to be incompressible. To eliminate density from the equation, kinematic quantities are used *(5)*.

The Navier-Stokes equations are given in the tensorial form by

$$\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \vartheta\nabla^2 u_i \qquad (2)$$

where repeated indices denote summation from *1* to *3*. Both the indices i and j range from *1* to *3*. The velocities u_i and u_j and the pressure p can be considered to be made up of the mean and the turbulent components. Let

$$u_i = U_i + u_i'$$

$$u_j = U_j + u_j' \qquad (3\,a, b, c)$$

and

$$p = P + p'$$

where U_i, U_j and P are the mean components, and u_i', u_j' and p' are the turbulent components. Substituting this in equation *(2)*, we have

$$\frac{\partial}{\partial t}(U_i + u_i') + (U_j + u_j')\frac{\partial}{\partial x_j}(U_i + u_i')$$

$$= -\frac{\partial}{\partial x_i}(P + p') + \nu\nabla^2(U_i + u_i') \qquad (4)$$