NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

A ROTATING FLUME FOR COHESIVE SEDIMENT TRANSPORT RESEARCH

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NWRI Contribution No. 91-82

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MANAGEMENT PERSPECTIVE

Fine-grained cohesive sediments are known to play a major role in the transport of a large number of contaminants that are toxic and persistent. For proper management of such contaminants and contaminated sediments, a thorough understanding of the transport processes of fine grained cohesive sediments is an essential pre-requisite. At the present time, our understanding of these processes is far from complete and there is a definite need for research in this area. To fulfil this need, NWRI has initiated a research programme on cohesive sediment dynamics. As a part of this research initiative, the world's largest rotating flume assembly has been designed and built at the Hydraulics Laboratory. This paper outlines the need and the constructional details of the rotating flume together with the characteristics of the flows that were generated in this flume. Preliminary results indicate that the flume is ideally suited for basic and applied research on fine sediment transport processes.

SOMMAIRE À L'INTENTION DE LA DIRECTION

On sait que les sédiments cohérents de faible granulométrie jouent un rôle important dans le transport d'un grand nombre de contaminants toxiques et persistants. En vue d'une bonne gestion de ces contaminants et des sédiments contaminés, une connaissance approfondie des processus de transport des sédiments cohérents de faible granulométrie est une condition préalable essentielle. À l'heure actuelle, nos connaissance de ces processus sont loin d'être complètes, et il y a un besoin très net de recherches dans ce domaine. Afin de répondre à ce besoin, l'INRE a entrepris un programme de recherche sur la dynamique des sédiments cohérents. Dans le cadre de cette initiative, on a aménagé le plus grand bassin tournant du monde au Laboratoire d'hydraulique. Le présent document met en évidence la nécessité et les détails de construction de ce bassin tournant ainsi que les caractéristiques des écoulements produits par ce bassin. Les résultats préliminaires montrent que le bassin convient parfaitement bien aux recherches fondamentales et appliquées sur les processus de transport des sédiments de faible granulométrie.

ABSTRACT

A rotating flume installed recently at the National Water Research Institute in Burlington, Ontario, Canada to undertake basic research on fine sediment dynamics is described. This flume is the largest rotating flume assembly in the world and it measures 5.0 m in mean diameter, 0.30 m in width and 0.30 m in depth. An annular top cover fits inside the flume and makes contact with the water surface. The radial clearance between the top ring and the flume side walls is 1.5 mm on either side. The flume and the top ring can be rotated independently at speeds ranging from 0 to 3 rpm.

The flume is equipped with a Laser Doppler Anemometer to measure the velocity components in tangential and vertical directions, a Laser particle size Analyzer to measure the in-situ size distribution of fine sediment flocs and a Prestor tube to measure the bed shear stress. The electrical power to the instruments is fed through a slip ring assembly mounted to the main shaft supporting the flume base. The mechanical details and the velocity and shear stress distributions measured in this flume are discussed.

Key words: Rotating flume, secondary circulation, fine sediment transport, contaminants, slip rings.

RÉSUMÉ

Le présent document décrit un bassin tournant nouvellement installé à l'Institut national de recherche sur les eaux à Burlington, en Ontario (Canada) afin d'entreprendre des recherches fondamentales sur la dynamique des sédiments de faible granulométrie. Il s'agit du plus grand bassin du monde avec un diamètre moyen de 5,0 m, une largeur de 0,30 m et 0,30 m de profondeur. Un couvert annulaire s'ajuste à l'intérieur du bassin et entre en contact avec la surface de l'eau. Le jeu radial entre l'anneau supérieur et les parois du bassin est de 1,5 mm des deux côtés. Le bassin et l'anneau supérieur peuvent tourner indépendamment à des vitesses comprises entre 0 et 3 tpm.

Le bassin est équipé d'un anémomètre Doppler au laser pour mesurer les composantes de la vitesse dans des directions tangentielles et verticales, d'un analyseur de la granulométrie au laser pour mesurer sur place la distribution des diamètres des flocs de faible granulométrie et d'un tube Prestor pour mesurer la contrainte de cisaillement sur le lit. Le courant électrique pour alimenter les instruments est transmis par une série d'anneaux de coulissement montés sur le bras principal de la base du bassin. Les détails mécaniques ainsi que la répartition des vitesses et de la contrainte de cisaillement mesurés dans ce bassin sont traités dans le présent document.

Mots-clé : Bassin tournant, circulation secondaire, transport des sédiments de faible granulométrie, contaminants, anneaux de coulissement.

INTRODUCTION

Straight flumes, commonly used for experimental research on non-cohesive sediments such as sand and gravel are not suitable for cohesive sediments (silt and clay) as the latter are usually transported in a flocculated form consisting of agglomerations of particles held together as a result of electro-chemical surface forces and other bonding mechanisms. The flocs are usually fragile and are susceptible to breakage by the impellers of recirculating pumps that are normally used in straight flumes. Furthermore, the transport processes of cohesive sediments are time dependent processes with time scales ranging from hours to days; investigations of such large time scale processes using straight flumes is not practical as they would require excessively long flumes. An alternate approach is to use circular flumes and to generate the flow by moving the flow boundaries rather than the fluid. In this paper, the existing circular flumes that have been used for cohesive sediment transport research are reviewed and a new flume built at the National Water Research Institute, Burlington, Ontario, Canada is described. Detailed measurements of velocity and bed shear stress distributions carried out in this flume are also described along with certain conclusions regarding the proper use of circular flumes for cohesive sediment transport research.

REVIEW OF PREVIOUS CIRCULAR FLUMES

Partheniades et al. (1966) were the first investigators to use a rotating flume for the study of cohesive sediment erosion and deposition. A schematic drawing of Partheniades' flume is shown in Fig. 1. The flume was made out of plexiglass and it measured 0.82 m in mean diameter, 0.10 m in width and 0.30 m in depth. It was supported on a 12.0 mm thick and 0.50 m diameter steel turntable driven by a variable speed, fractional horse power, D.C. motor. A plexiglass ring was made to fit inside the flume with a radial gap of 3 mm on either side and it was rotated in the opposite direction to that of the flume by a second D.C. motor. Partheniades et al. (1966) had shown that the simultaneous rotation of the flume and the ring in opposite directions was

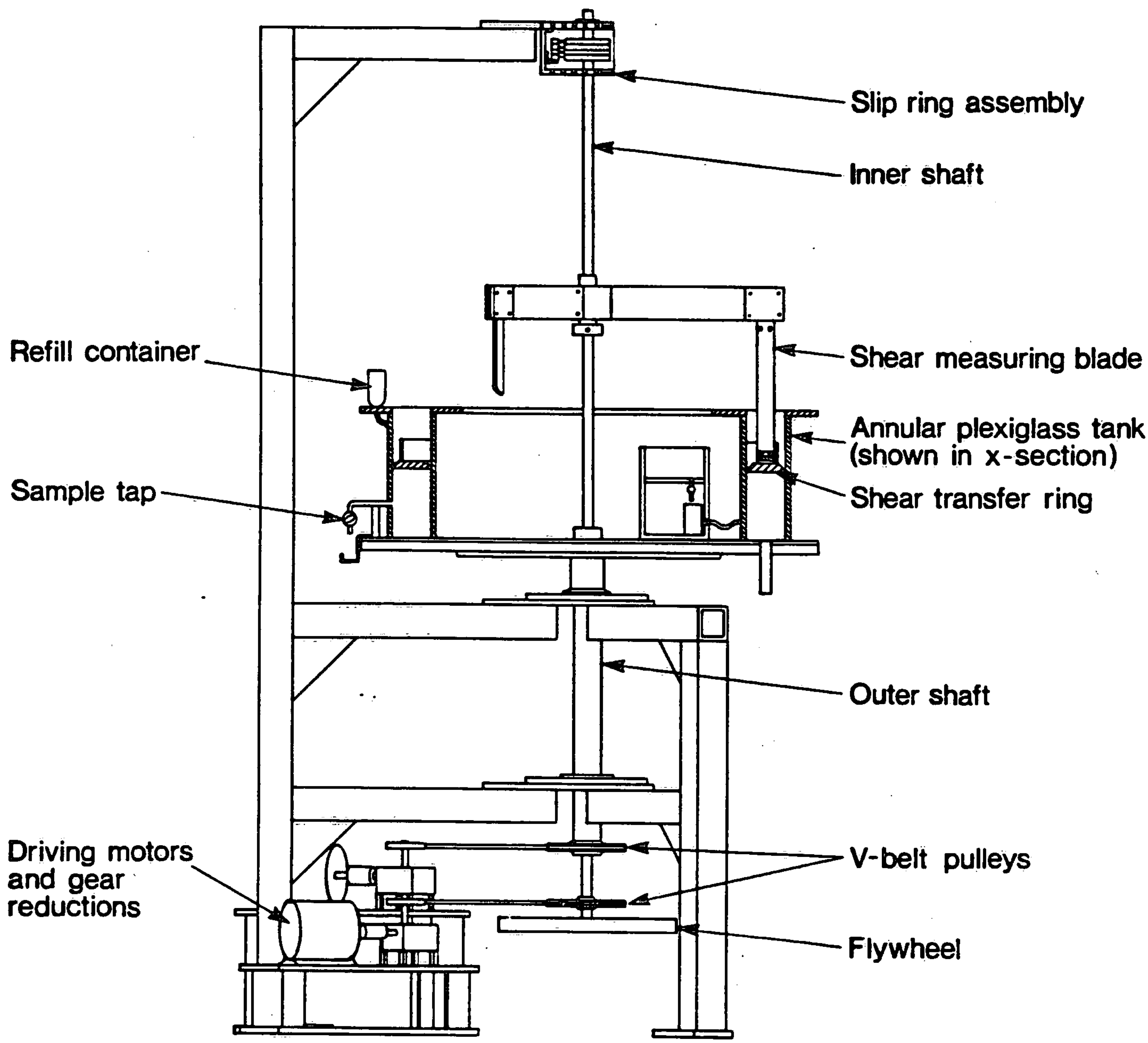


Figure 1 Schematic drawing of Partheniades' flume.

necessary to minimize the secondary circulations in the radial plane and to cause sediment to deposit and erode uniformly across the whole flume width.

Mehta and Partheniades (1973) used a similar but slightly larger flume to study the depositional behaviour of cohesive sediments. Their flume was made out of fibreglass and measured 1.50 m in mean diameter, 0.20 m in width and 0.46 m in depth. The top ring was made out of plexiglass and it fitted inside the flume with a radial gap of 3 mm.

An even larger flume similar to the above two was built at the Delft Hydraulics Laboratory for investigating the estuarine sediment processes. This flume referred to as Carrousel is 2.30 m in outside diameter. Other dimensions of the flume are not readily available.

A number of other circular flume assemblies have also been reported in the literature. For example, Fukuda and Lick (1980) reported a circular flume which was 2.0 m in mean diameter, 0.15 m in width and 0.15 m in depth. The top ring fitted inside the flume with a radial gap of 5.0 mm. In this assembly, the flume was held stationary and only the ring was rotated to generate the flow. Lau (1990) used a flume similar in size and configuration, to study the effect of temperature on the settling behaviour of cohesive sediments. Delo (1988) studied the dynamics of the estuarine muds using a stationary circular flume measuring 6.0 m in mean diameter at the Hydraulics Research Station at Wallingford, England.

Experimental observations of Partheniades et al. (1966) and Mehta and Partheniades (1973) suggest that in circular flume assemblies in which only the ring is rotated to generate the flow, the secondary circulations resulting from the centrifugal force could be of substantial strength and hence such assemblies may not be suitable for studying the dynamics of cohesive sediments. Maa (1989) arrived at a similar conclusion based on his numerical solutions of flow in a "Sea-Bed" Flume. The "Sea-Bed" flume is similar in operation to a stationary circular flume with a rotating ring. It consists of two cylinderical shells forming the inner and outer walls of the flume. It has no bottom and can be lowered from a boat to penetrate into the sea-bed. An annular top cover fitted on the top of the flume can be rotated by an electric motor controlled from a boat to generate the flow.

Maa solved a set of simplified Reynolds equations expressed in cylinderical co-ordinate system with Boussinesq's eddy viscosity approximation. He presented the tangential velocity contours and a vector plot of secondary circulations for a channel with mean diameter of 2.30 m, width of 0.20 m and a depth of 0.10 m. The rotational speed of the ring was 7.0 RPM. His results show that the maximum secondary velocity could be as high as 4.5 cm/s. (about 15% of the nearby tangential velocity) which is about two orders of magnitude larger than the settling velocity of clay suspensions. Such comparatively high secondary currents would strongly influence the settling behaviour of fine sediment.

PRESENT FLUME

i) Need

In spite of a large number of investigations carried out using the various rotating flume assemblies described above, our understanding of the fine sediment behaviour is far from complete. Indeed, the flocculation process is largely unknown and there are still uncertainities with regards to the erosion and deposition processes. For example, there exists two different schools of thought regarding the interchange of particles between suspended sediment and bed sediment. Partheniades and co-workers postulated that there is no continuous exchange between suspended sediment and bed sediment and the occurrence of an equillibrium concentration during deposition of fine sediment under a constant shear stress was due to breakage and resuspension of weakly bonded flocs that could not withstand the high shear stress in the flow region near the bed. Lick and co-workers, on the other hand, argue that there is a constant exchange of suspended and bed sediment for certain intermediate size class of fine sediment. There is a definite need to resolve this controversy because it has implications in the development of mathematical models of sediment bound contaminant transport. According to Lick's hypothesis, since there is constant exchange of bed and suspended particles, the dispersion of the contaminated sediment in a stream will be high and the concentration of a sediment associated contaminant will decrease at a faster rate in the downstream direction compared to a model based on Partheniades' hypothesis. According to Partheniades, the sediment particles undergo either deposition or erosion and not simultaneous erosion and deposition and hence are likely to preserve their chemical identity over a long distance in the downstream direction.

To resolve such controversies and to improve our basic understanding of the transport processes of sediment - bound contaminants, a research programme on fine sediment dynamics has been initiated at the National Water Research institute at Burlington, Ontario, Canada (see Krishnappan and Ongley (1988)). As a part of this programme, a rotating circular flume has been designed and built at the Hydraulics Laboratory of the Institute. The flume is 5.0 m in mean diameter, 0.30 m in width and 0.30 m in depth and it rests on a rotating platform which is 7.0 m in diameter. A counter rotating ring fits inside the flume with a radial gap of 1.5 mm on either side. The general view of the flume assembly is shown in the photograph in Fig. 2 and schematic sketch of the sectional view is shown in Fig. 3.

ii) Constructional Details

The flume is designed according to a well known (to the antenna industry) "king post" configuration. The support system for the rotating axis, which is oriented in the vertical direction is shown in Fig. 3. Within the "king post" housing two tapered roller bearings supports the weight of the entire structure. The upper bearing is used to provide the stability of the vertical axis. The two bearings are held in a rotating hollow shaft that supports the lower rotating platform on which the flume is mounted. The hollow shaft also contains two inner bearings which are deep grove ball bearings supporting an inner solid shaft connected to the upper turntable for the ring assembly. The two shafts are fixed axially and are independently driven by two separate drive systems.

The two drive systems are identical in configuration. They are attached rigidly to the underside of the stationary king post housing. Each drive train contains a servo motor, coupled to a highspeed gear box and a final stage low speed worm gear drive. The wormwheels are directly attached to the shafts. For driving the outer shaft, a 3.0 hp,

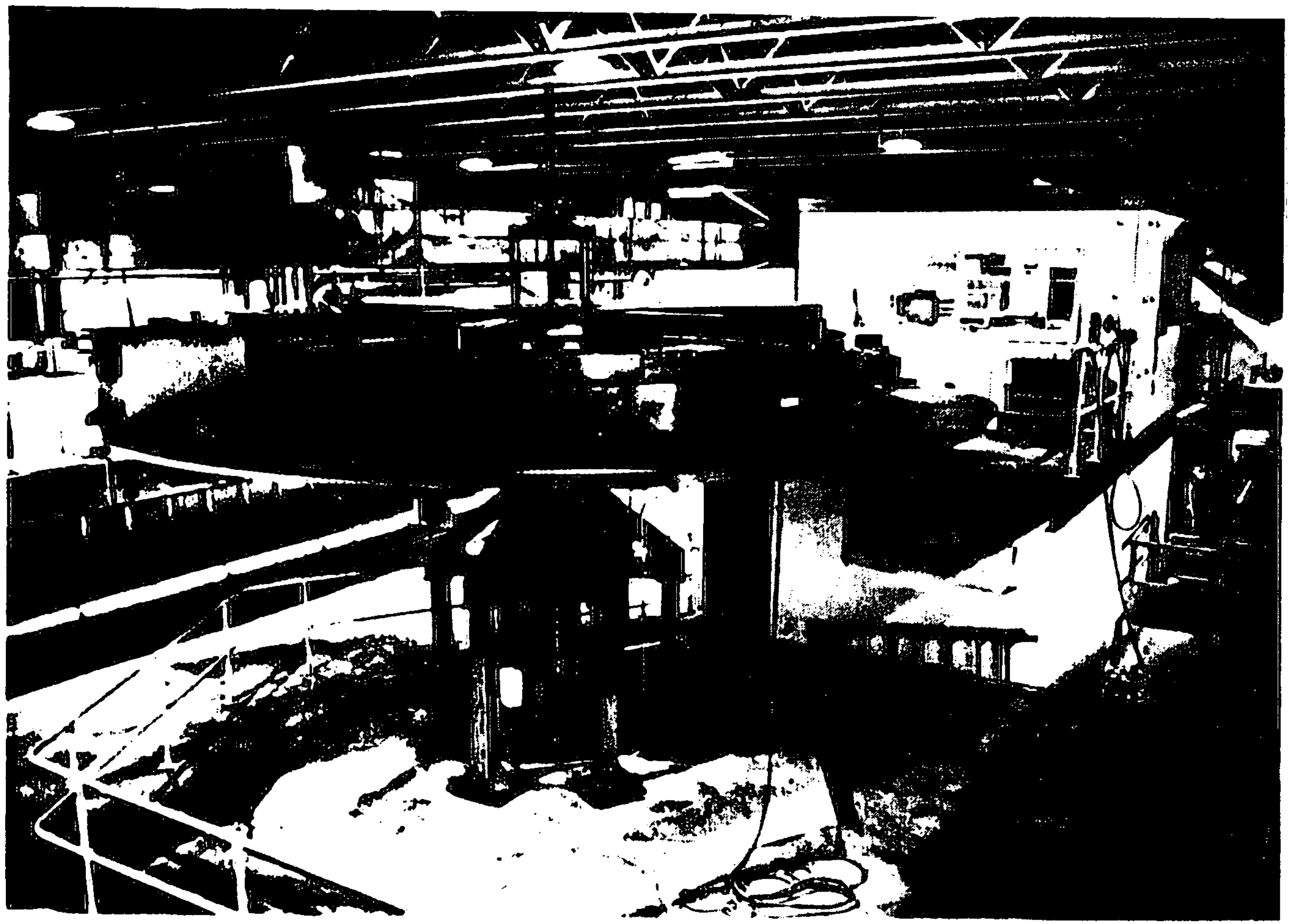


Figure 2 General view of NWRI's Rotating Flume

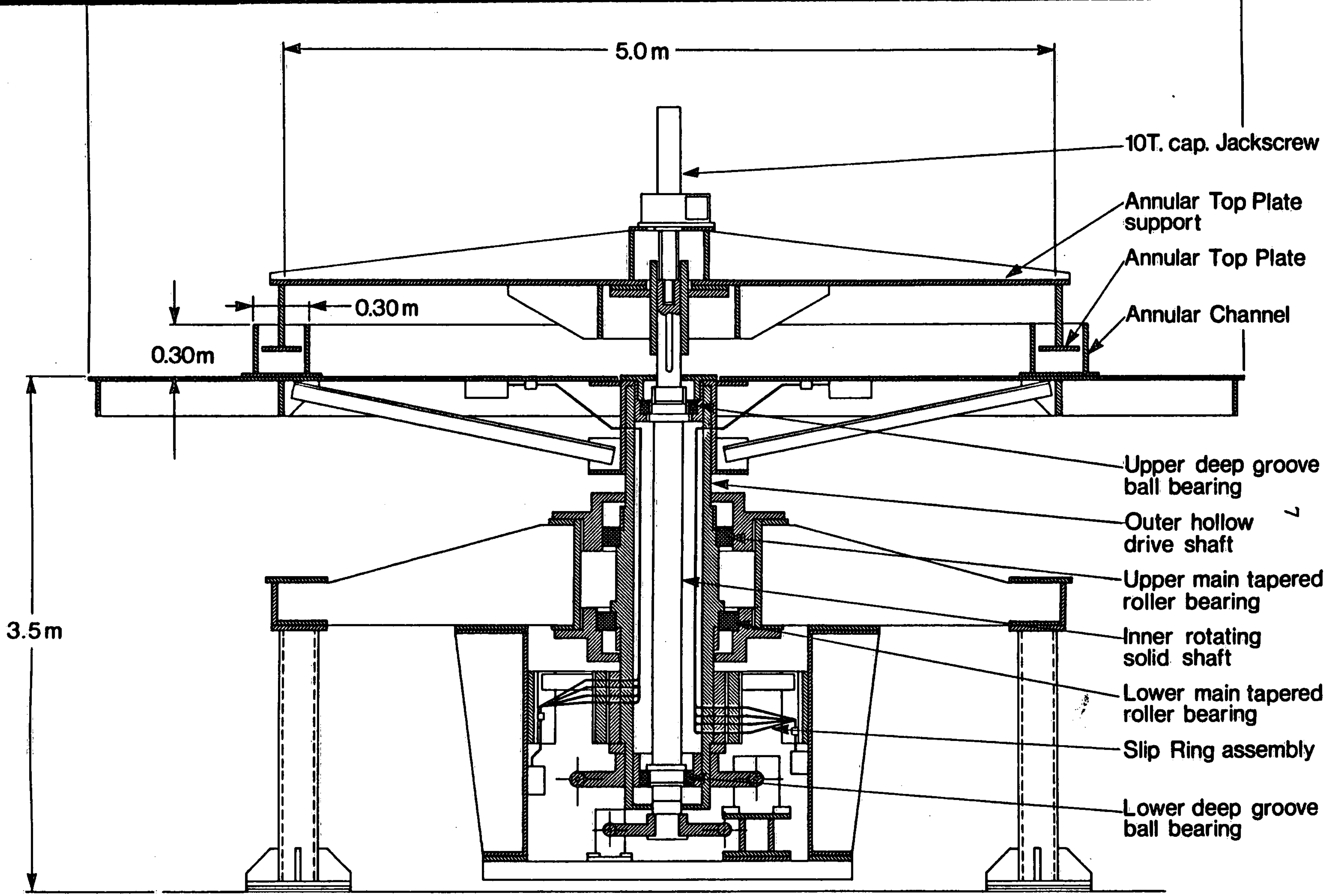


Figure 3 Sectional view of the rotating flume assembly.

controls is used. For the inner shaft a similar motor but with a 2.0 hp capacity is used. The overall drive ratio for both drives is 600: 1, giving a speed range of 0 and 3.0 rpm for both rotating units. The direction of rotation of both assemblies can be changed independently. Therefore, it is possible to rotate both the flume and the ring at different speeds in same or in opposite directions.

To vary the position of the ring within the flume or to remove the ring completely out of the flume for the purpose of emptying and filling the flume, a single jackscrew of 10 ton capacity is installed. The jackscrew is mounted on a flange at the centre of the upper turntable. The threaded attachment end of the jack is fastened to the top female threaded end of the inner rotating shaft through a keyed drive sleeve coupling which provides alignment and positive transmission of rotation from the inner shaft to the upper rotating turntable. The screw jack is operated by an electric motor through a gear box and the power to the motor is provided by a slip ring assembly (not shown in fig. 3).

Electrical power is provided to the lower rotating turntable to power the instruments such as Laser Doppler Anemometer to measure the flow field and a Malvern Particle Size Analyzer to measure the size distribution of sediment suspensions. This is done through a segmented slip ring assembly with a stator and a rotor; the rotor is mounted on the outer shaft directly beneath the lower main roller bearing housing. The stator is fixed to the king post housing and it contains the standard carbon brush contacts which ride on the slip ring surfaces. The cables from the slip rings are routed through the hollow shaft onto the lower turntable. Electrical signals from the measuring instruments are also routed through a separate set of slip ring assemblies mounted below the power slip rings. Altogether, forty channels of power circuits and ten channels of signal circuits are provided.

The flume is also fitted with glass windows for instruments and observation. The flume operates smoothly without any detectable wobble and vibration. The vibration from external sources is isolated from the flume assembly by providing vibration isolation pads between the machined footings and the foundation. The horizontal level of the flume bottom and the underside of the ring surface are true within plus minus 1.5 mm.

The total dead weight of the flume assembly is 10 metric tons and the total height of the flume structure is 3.5 m from the foundation level.

MEASUREMENT OF FLOW CHARACTERISTICS

Reported data in the literature on flow characteristics of rotating flumes is very sparse. Mehta and Partheniades (1973) measured the tangential velocity distributions at the centre-line of the flume for two different depths and for different rotational speeds of the flume and the ring using miniature propeller type current meters (10 mm & 4 mm probes). The measured profiles showed shear zones near the top and bottom boundaries and a relatively large middle zone of almost zero velocity gradient. The velocity gradients near the top ring were steeper than those near the bottom. The bottom shear stresses obtained by fitting a logarithmic law to the measured profiles did not agree with the direct measurement of shear using strain gauges. Mehta and Partheniades attributed the discrepancy to the lack of velocity measurements very close to the solid boundary because of the size of the propeller probes and the need to attach the meters to the rotating top cover.

Fukuda and Lick (1980) reported flow data in circular flume assembly in which only the top ring was rotated. They used hot film anemometry and measured vertical distributions of tangential velocity component at different radial positions for a range of ring-rotational speeds. They fitted the law-of-the-wall corresponding to the hydraulically smooth turbulent flow regime to the measured data and determined the bed shear stress from the best fit. The shear stress so determined at different radial positions showed significant variation across the flume. For some rational speeds the variation is as large as 75% within the central region covering 60% of the flume width. Fukuda and Lick (1980) calculated an average shear stress and used it as an effective shear stress of the particular rotational speed.

The above two studies are the major ones that dealt with the characterization of flowfields in circular flumes. Therefore, there is a need for further studies to examine the differences in flowfields generated by different modes of operation of circular flumes.

The present flume is instrumented with a Laser Doppler Anemometer and a Preston Tube and hence it is possible to obtain a detailed distributions of tangential and vertical velocity components in a cross-section and a measure of bed shear stresses. Therefore, this flume is ideally suited for studying flow fields generated by different modes of operation. For example, it can be used to compare the flowfield generated by rotating the flume and the ring in opposite directions with that generated by rotating only the ring. Such comparisons are not available in the literature.

To perform such a comparison using the present flume, a flow depth of 15.5 cm and a relative rotational speed of 2 rpm between the flume and the ring were selected. When the flume and the ring are rotated in opposite directions, the rotational speed of each components was 1.0 rpm. When the flume was stationary and only the ring rotated, the rotational speed of the ring is set at 2.0 rpm. At the beginning of each run, care was taken to remove all the air bubbles that were trapped underneath the top ring. This was done by allowing the ring to rotate at a faster speed for sometime when the trapped air escaped through the side gaps. When all the air buble escaped, the ring was slowed down to the required speed and the measurements of velocity distributions and bed shear stress were carried out.

The Laser Doppler Anemometer used for the measurement of velocity distributions is a two colour, two channel backscatter system manufactured by TSI, USA. The Laser and the optics were mounted on an optical bench which was traversed in the vertical direction using a hydraulic jack mounted on a table which can be moved in and out in the horizontal plane using a motor operated screwjack. The Laser used is an Argon-Ion Laser requiring cooling water that was supplied from a tank which also served as a dead weight to balance the Laser-Doppler anemometer and the associated instruments mounted on the rotating platform. A close up view of the Laser Doppler Anemometer set up is shown in Fig. 4. The entire set up is housed in a cradle cut out through the platform outside of the flume. The velocity measurements were carried out at nine

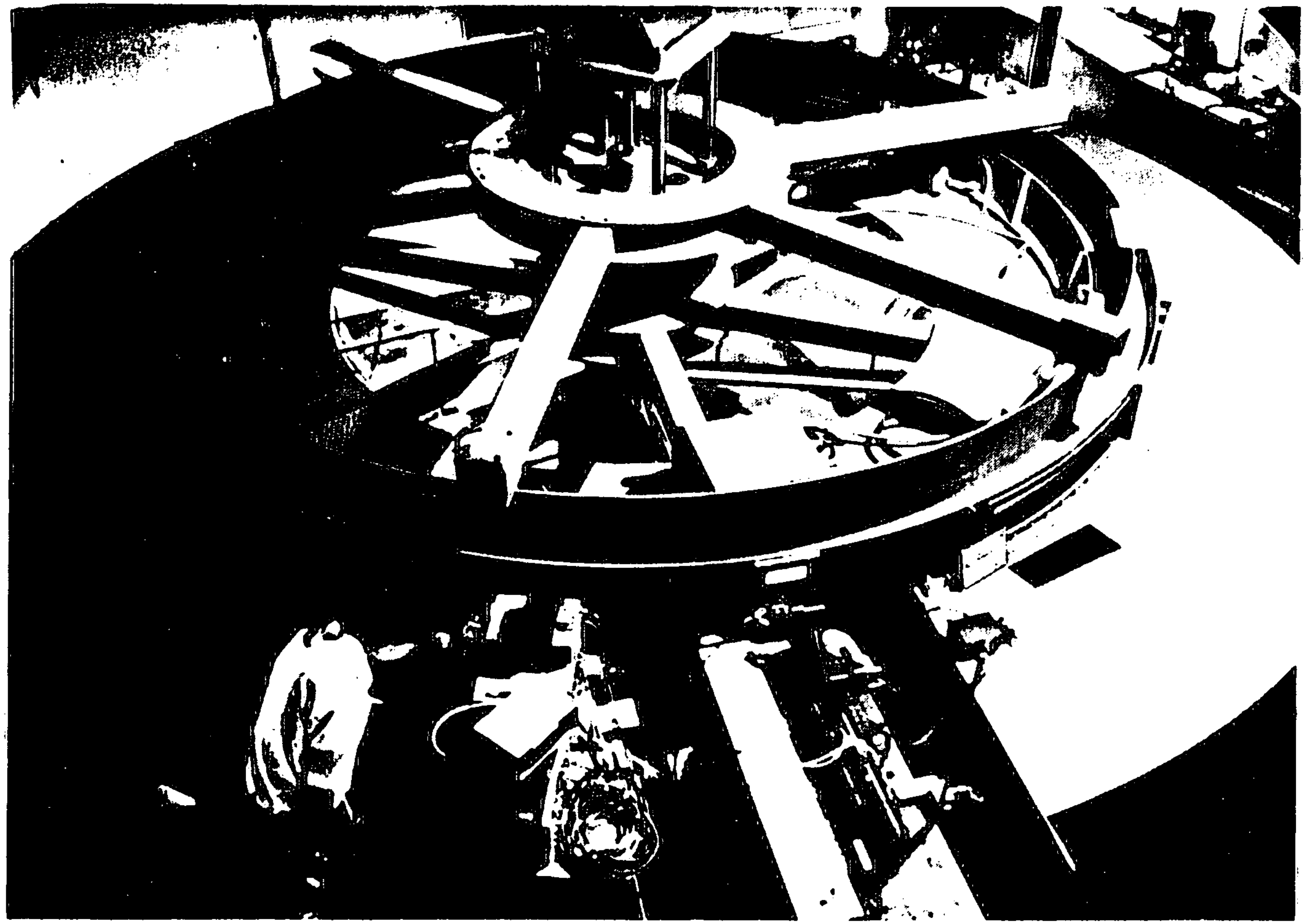


Figure 4 A close up view of Laser Doppler Anemometer mounted on the Roating Flume.

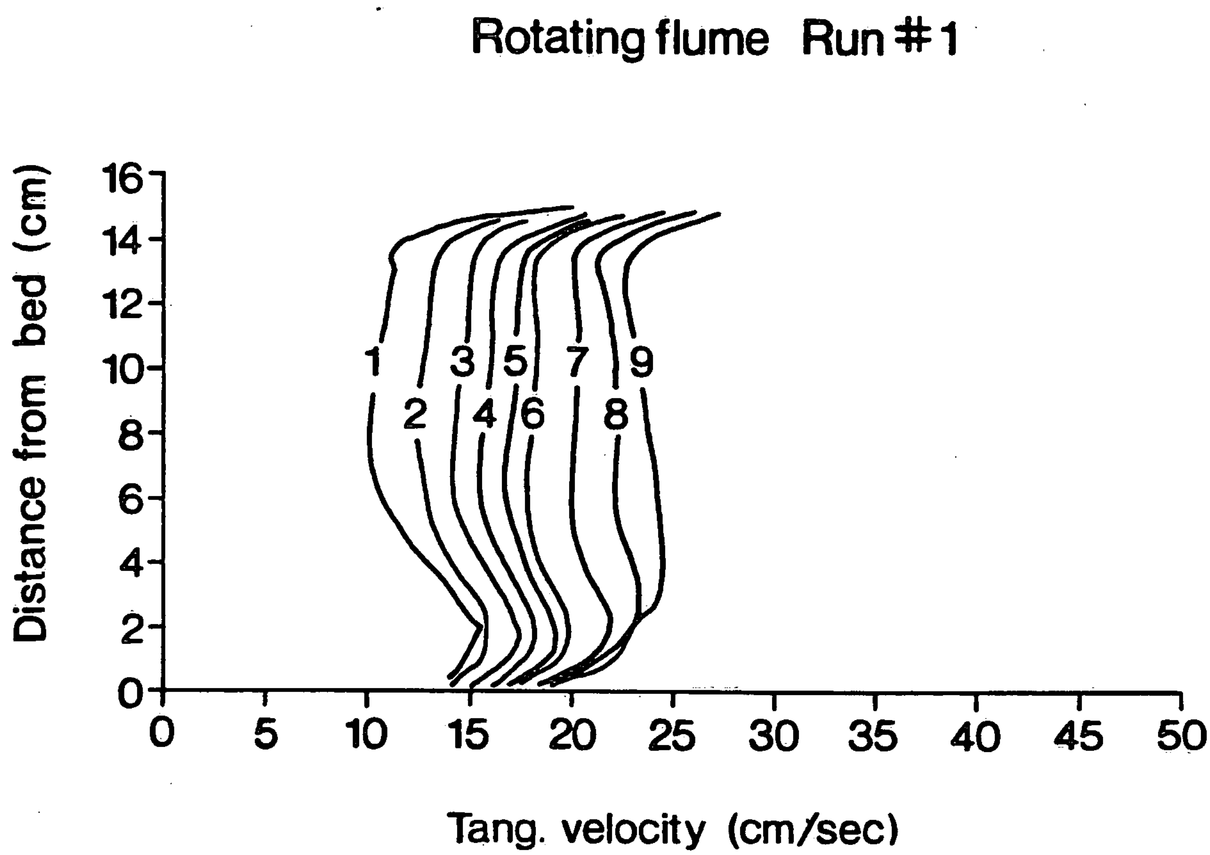
verticals in the measurement cross-section. The verticals were spaced at 3.0 cm apart starting near the inner wall and moving towards the outer wall. At each vertical, 20 to 25 velocity measurements were taken with measurement heights varying irregularly over the depth. Near the solid boundaries, where the velocity gradient is large more points were selected to delineate the distributions adequately. With the vertical traverse mechanism adopted in the present set up, it was possible to make measurements as close as 0.80 mm from the flume bed.

The Preston tube used which is a simple Pitot tube resting on the bed surface and which uses the law of the wall for the determination of the turbulence skin friction was a 2 mm tube and it is mounted through the outer wall of the flume. The position of the measurement point can be varied by moving the tube in and out. The assembly was made leak proof by a casing which was mounted to the sidewall with "o" ring seals. The calibration proposed by Patel (1985) was adopted to compute the bed shear stress from the pressure difference between pitot and static pressures. The pressure difference was measured using a diaphram pressure transducer.

RESULTS AND DISCUSSION

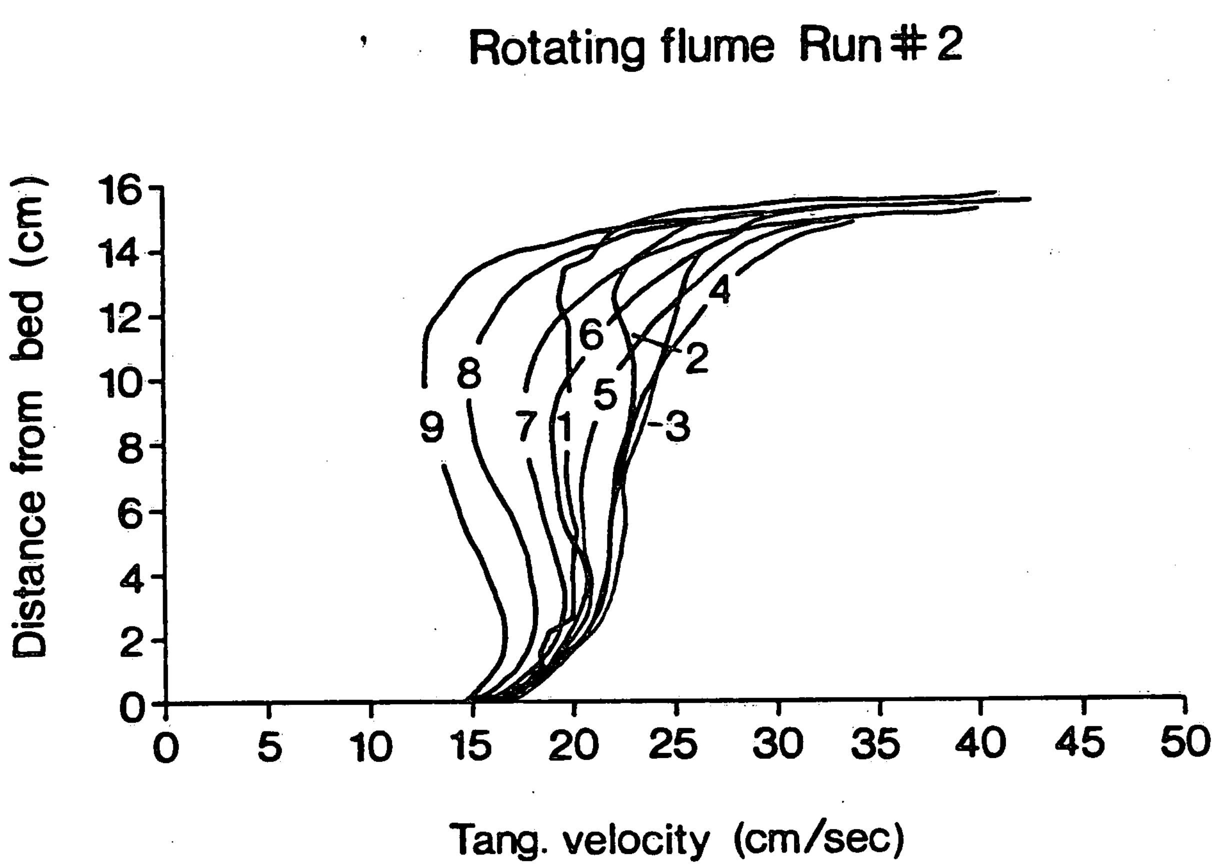
The vertical distributions of the tangential velocity at the nine verticals are plotted in linear scale in figures 5 and 6. Fig 5 is for run #1 in which the flume is stationary and the ring is rotated at 2.0 rpm and Fig 6. is for run #2 corresponding to both components rotating at 1.0 rpm in opposite directions. From Fig 5, it can be seen that the tangential velocities over the whole vertical increase as we move from inner wall to outerwall. This means that the velocity gradients near the bed increase monotonically from innerwall to outerwall implying a monotonic increase in bed shear stress in the radial direction.

The tangential velocity distributions for the case when both flume and the ring rotated in opposite directions (Fig. 6) show an altogether different behaviour. In this case, the near bottom velocities for all verticals tend to collapse into a single curve, suggesting that the bed shear stress is reasonably uniform across the flume. Differences among the



Ring speed = 2.0 rpm; Flume is stationary

Figure 5 Distribution of tangential velocity at different verticals (vertical 1 is near the inner wall; vertical 9 is near the outer wall.)



Ring speed = 1.0 rpm; Flume speed = 1.0 rpm.

Figure 6 Distribution of tangential velocity at different verticals (vertical 1 is near the inner wall; vertical 9 is near the outer wall.)

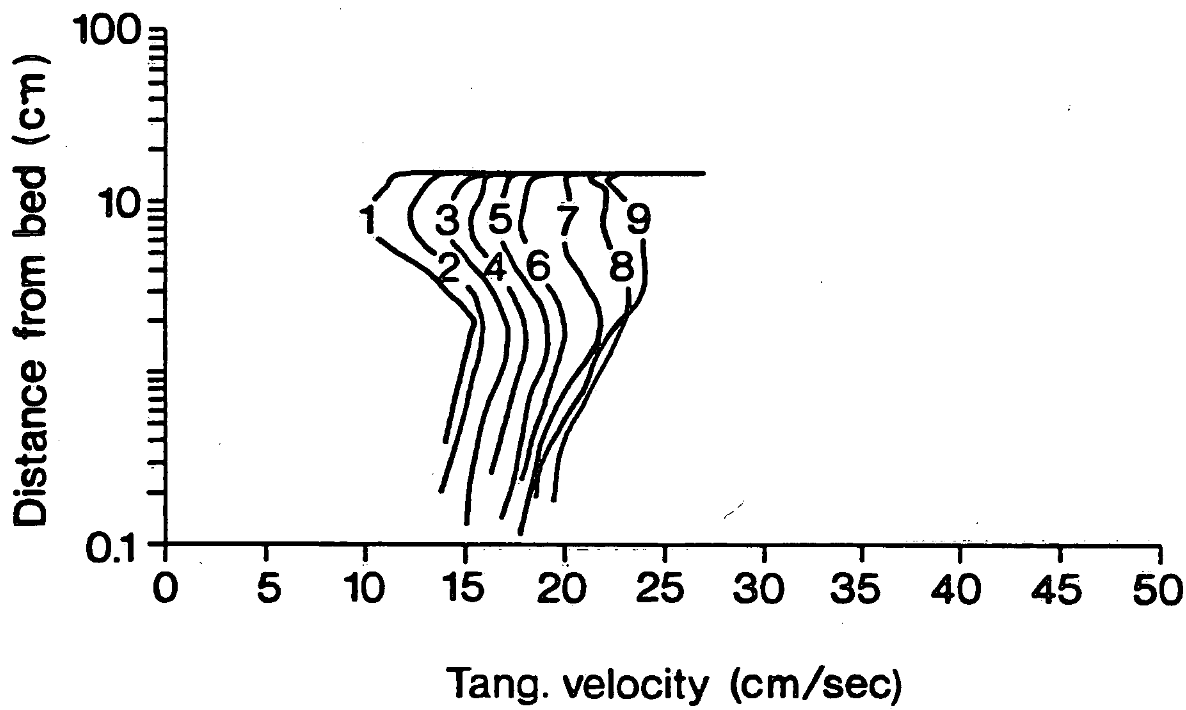
verticals are observed only in the central portion of the flow depth. The vertical distributions plotted in semi-log scale are shown in Figs. 7 and 8. Near the bed and the ring, the velocity distributions for both runs appear to follow the log law.

From the tangential velocity data shown in Figs 5 and 6, isovel (constant velocity lines) distributions were constructed and are shown in Figs. 9 and 10 respectively. The isovel distributions are useful for inferring the secondary circulation patterns in the transverse plane (see Schlichting(1968)). Fig. 9 shows the existence of a large circulation cell moving from the inner wall to the outer wall near the top ring and from outer wall to inner wall near the flume bed as postulated by Partheniades et al. (1966). As a result of this circulation pattern, the high momentum fluid is brought down from the top right portion of the cross-section to the bottom, giving rise to higher near bed velocities near the outer wall.

When the flume and the ring are rotated in opposite directions, the large secondary circulation cell vanishes (see Fig. 10) and a small circulation cell has formed near the lower right hand corner, moving the fluid from the middle region of the outer wall to the lower right corner. The extent of this cell is comparatively smaller and the isovels near the flume bed are very nearly parallel, implying near constant bed shear stress across the whole flume width. Isovel distribution, in this case, has a general resemblance to that of a flow in straight open channels.

The lateral distribution of bed shear stress measured using the Preston tube is shown in Fig 11. In this figure, the distributions for both runs are plotted. The triangles are for run #1 and the circles are for run #2. As expected, the bed shear stress increases from inner wall to the outerwall monotonically (except for the very last point near the outerwall) for run #1. For run #2, the shearstress is higher in the middle region of the flume and it decreases on either side. The decrease is more near the outer wall then near the inner wall. This non-symmetry may be attributed to the smaller secondary circulation cell that exists near the outer wall. The rotation of the flume appears to have over compensated the large secondary circulation cell produced by the rotation of the ring and has generated a smaller anti-clockwise secondary circulation cell near the outer wall. Since the wetted perimeter of the flume (flume bottom & two side walls) is larger than

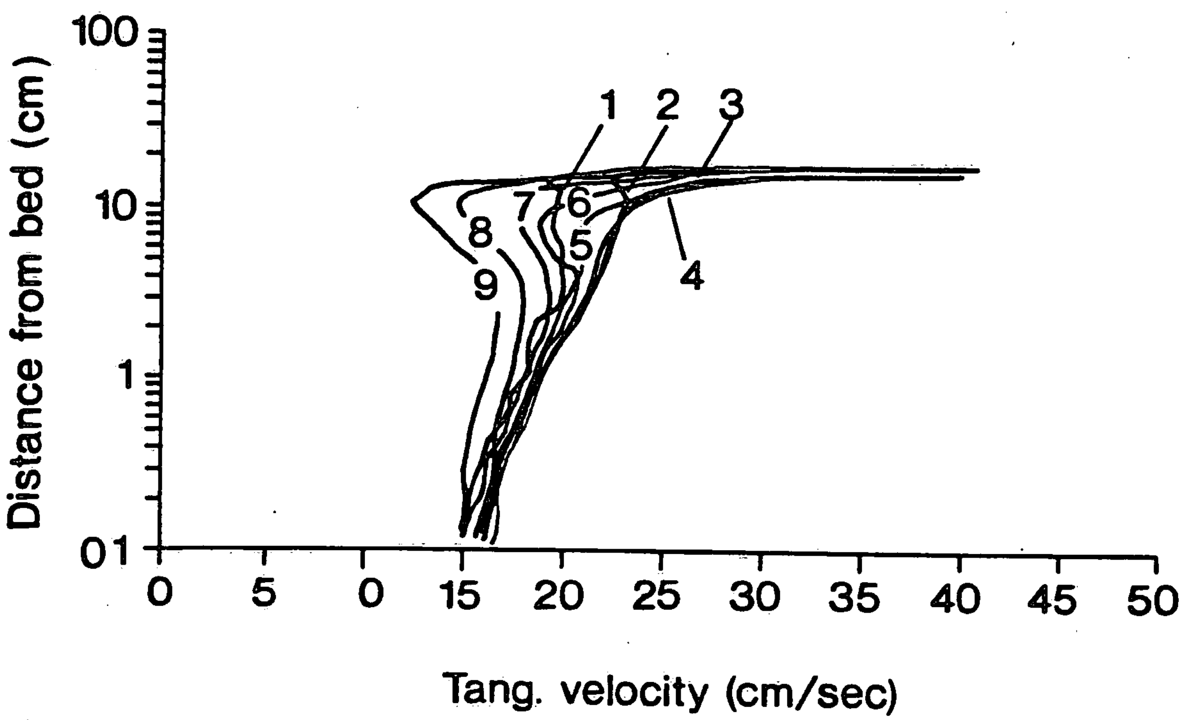
Rotating flume Run # 1



Ring speed = 2.0 rpm; flume is stationary

Figure 7 Semi-log plot of tangential velocity distributions over a number of verticals (vertical 1 is near the inner wall; vertical 9 is near the outer wall.)

Rotating flume Run # 2



Ring speed = 1.0 rpm; flume speed = 1.0 rpm.

Figure 8 Semi-log plot of tangential velocity distributions over a number of verticals (vertical 1 is near the inner wall; vertical 9 is near the outer wall.)

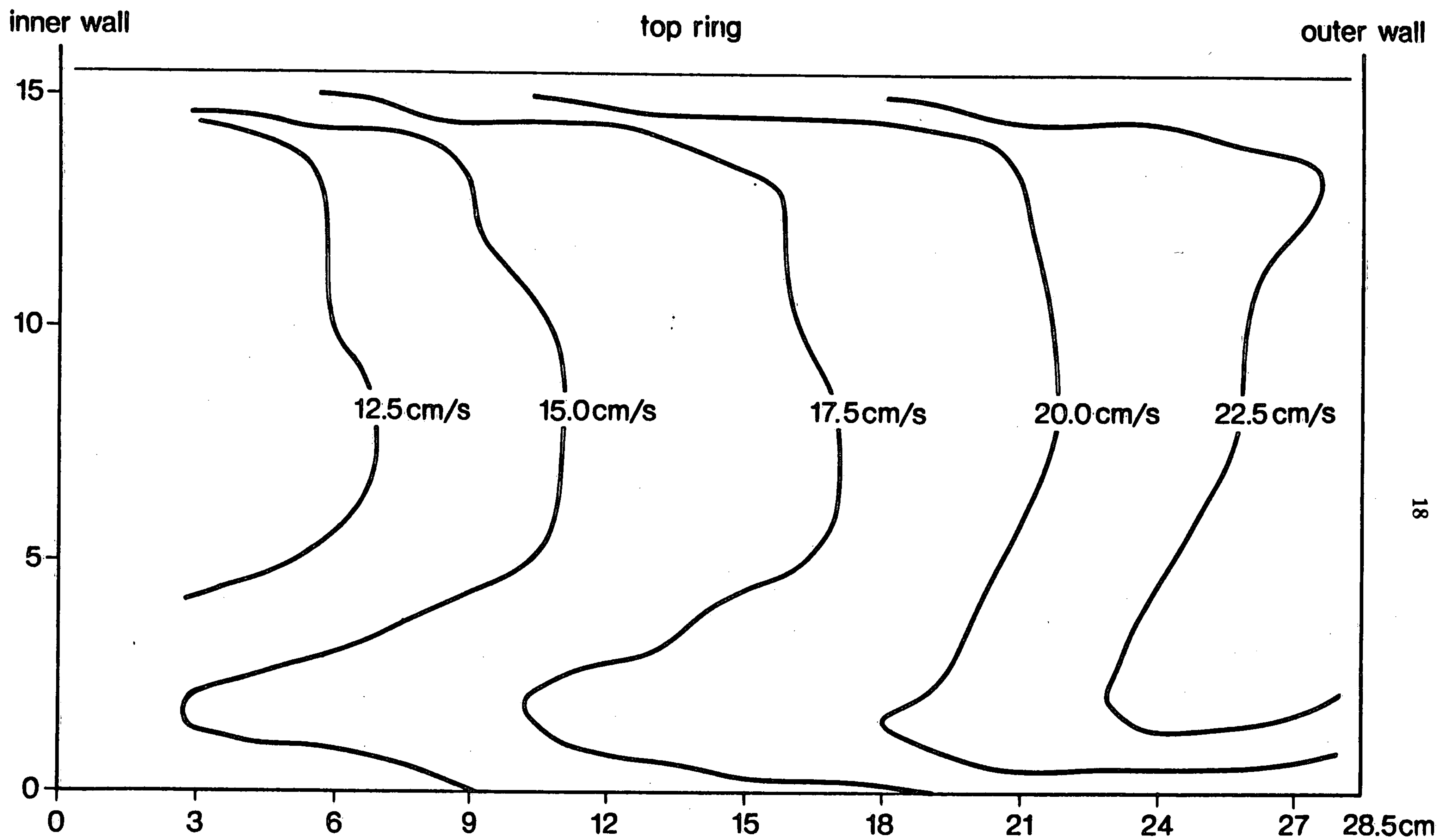


Figure 9 Isovel pattern when ring only is rotated.

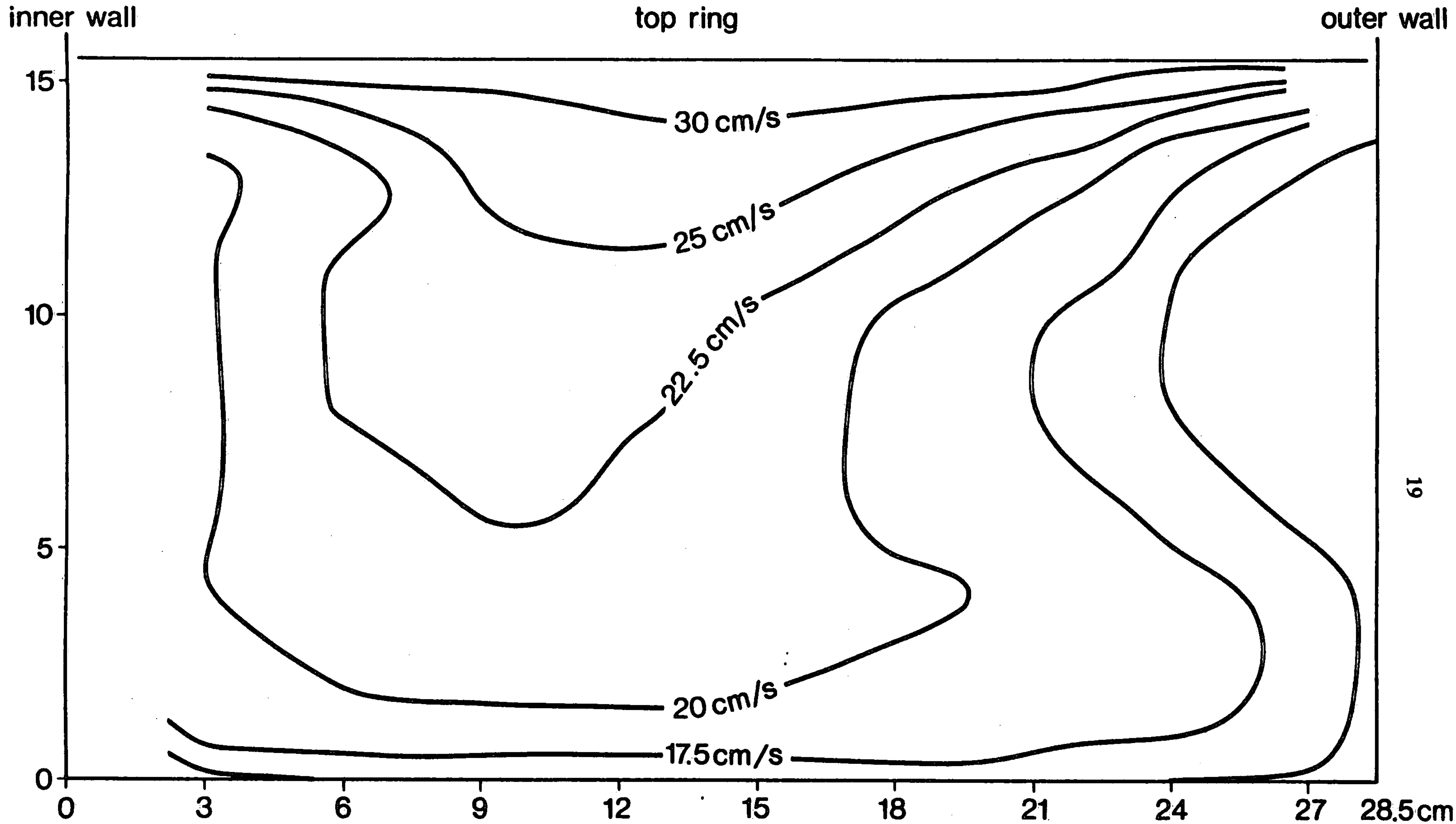


Figure 10 Isovel pattern when both ring and flume rotated in opposite directions.

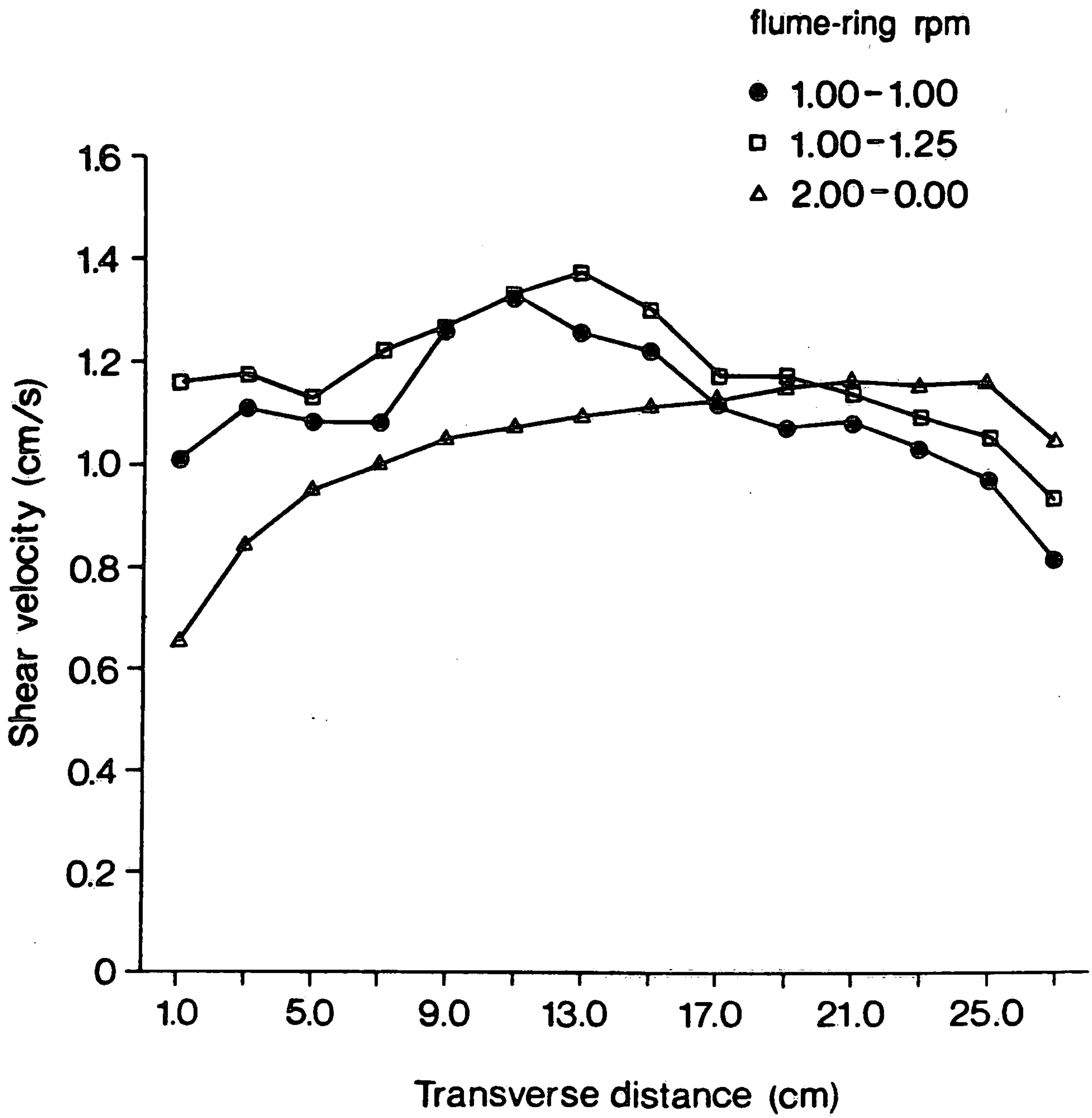


Figure 11 Shear stress distribution across the flume.

the wetted perimeter of the ring, the rotational speed of the flume has to be lower than the rotational speed of the ring to produce an equal and opposite effect on the secondary motions. The ratio of ring speed to flume speed which produced the least variation of bed shear stress across the flume was considered as the "optimum" speed ratio for the given flow depth. Partheniades et al. (1966) determined this "optimum" speed ratio by observing the depositional pattern of "plastic beads" introduced into the flow. When only the ring was rotated, the beads collected near the inside wall. When only the flume was rotated, the beads collected near the outside wall. When, both components rotated in opposite directions, the beads accumulated at the centre of the tank. Partheniades et al. (1966) chose this position as a criterion for minimum secondary current effect.

The shear stress distribution measured when the ring and the flume were rotated at 1.25 rpm and 1.00 rpm respectively was plotted as square points in Fig. 11. From this figure, it can be seen that the variation of bed shear stress across the flume has indeed decreased when the ring speed is higher than the flume speed. Adopting the above speed ratio as optimum for the flow depth tested (16 cm), shear stress distributions were measured for a series of flume speeds ranging from 1 to 1.67 rpm and are plotted in Fig. 12. Note that the distributions are all similar and in general resemble that of the flows in straight rectangular open channels.

The optimum speed ratios were established for other flow depths ranging from 10 cm to 20 cm and the lateral distributions of bed shear stress were measured for various flume speeds. The results are shown in Figs. 13 to 15. The distribution, in general, are similar. Experiments are underway to measure the tangential velocity distributions of flows under "optimum" speed ratios and to study the effect of turbulent shear stress on the size distribution of kaolin suspensions in distilled water as a starting point for fine sediment transport research using this flume.

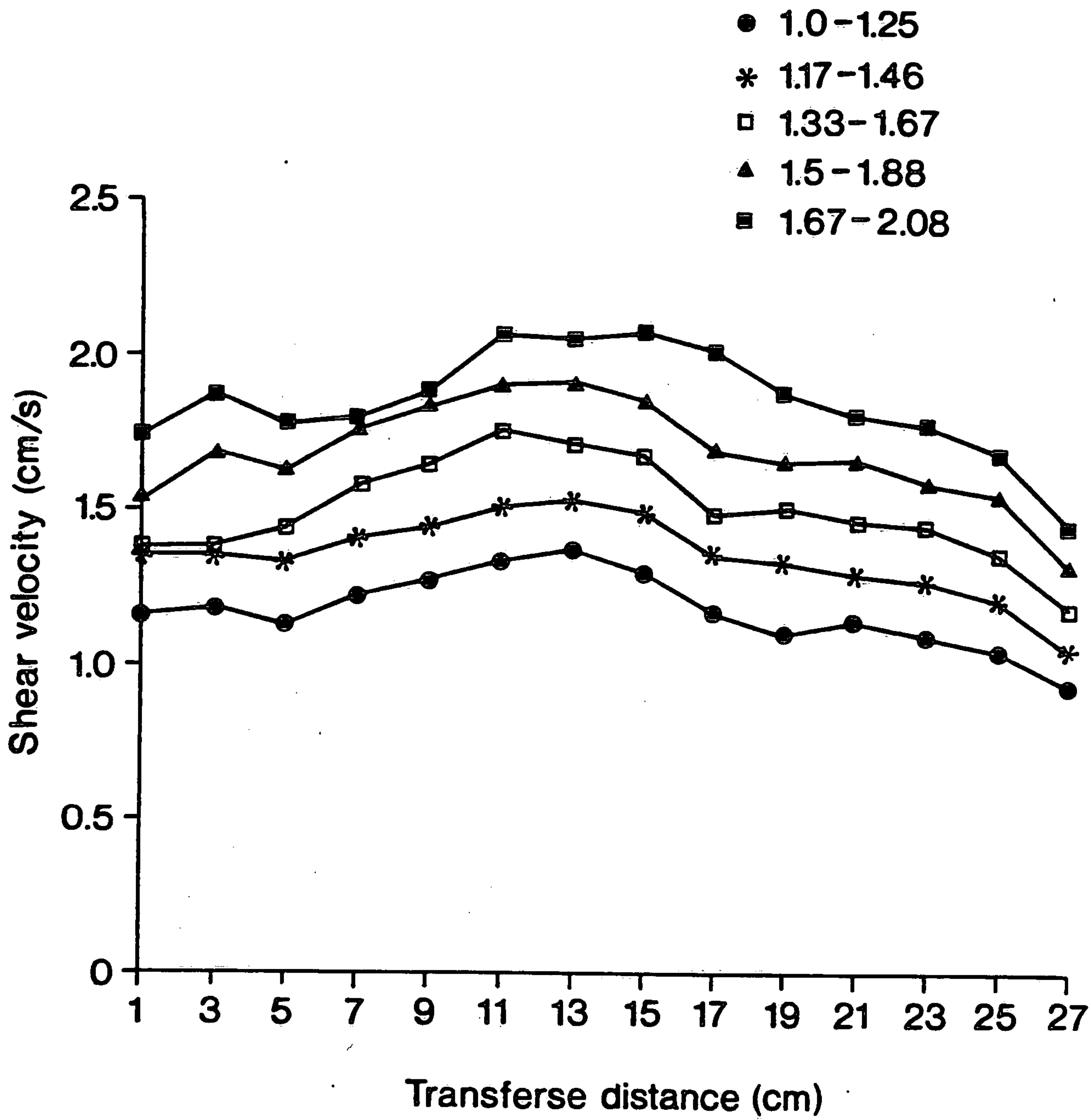


Figure 12 Shear stress distributions for various flume-ring rotational-speed combinations.

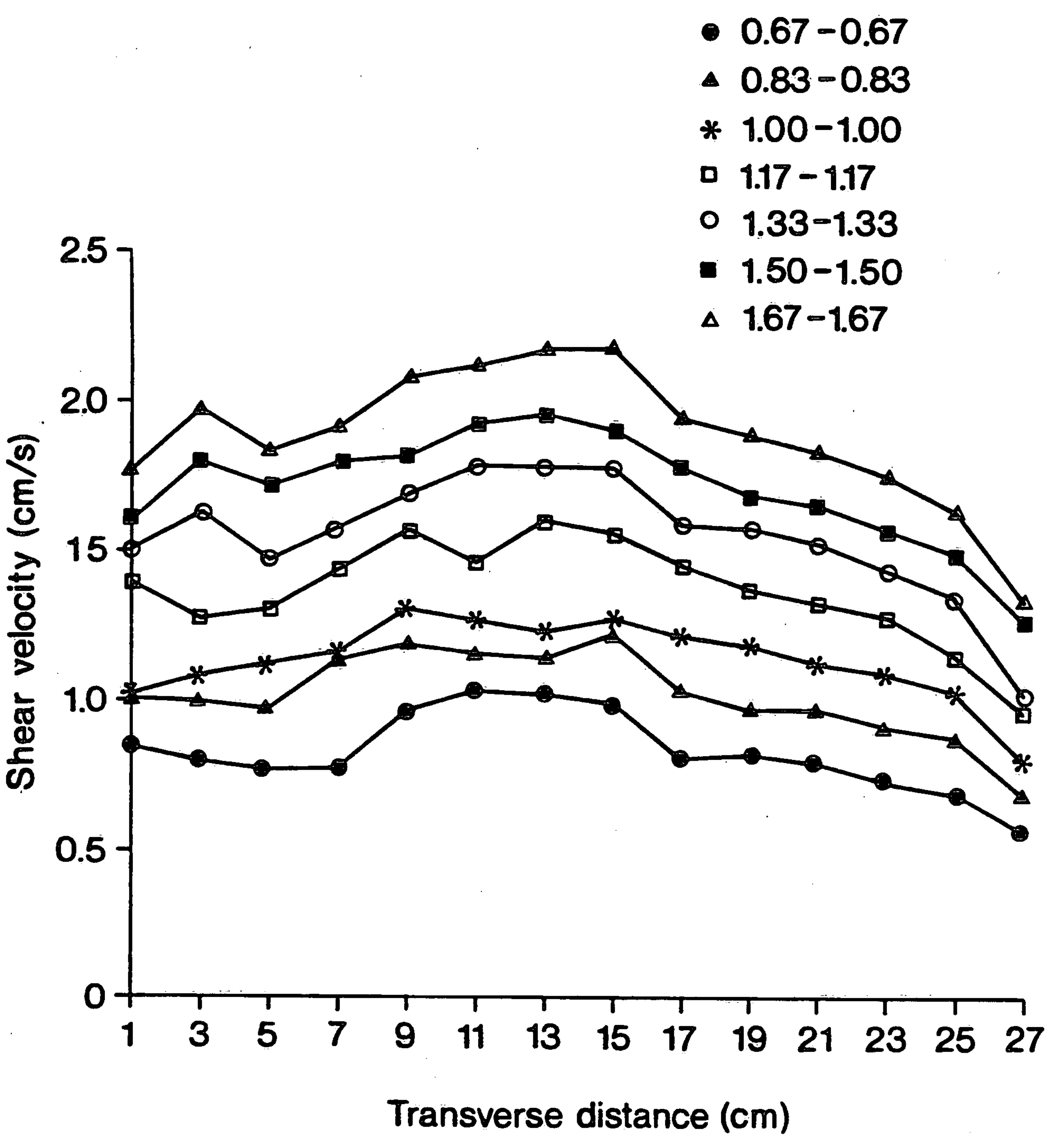


Figure 13 Shear stress distributions across the flume (flow depth = 10 cm)

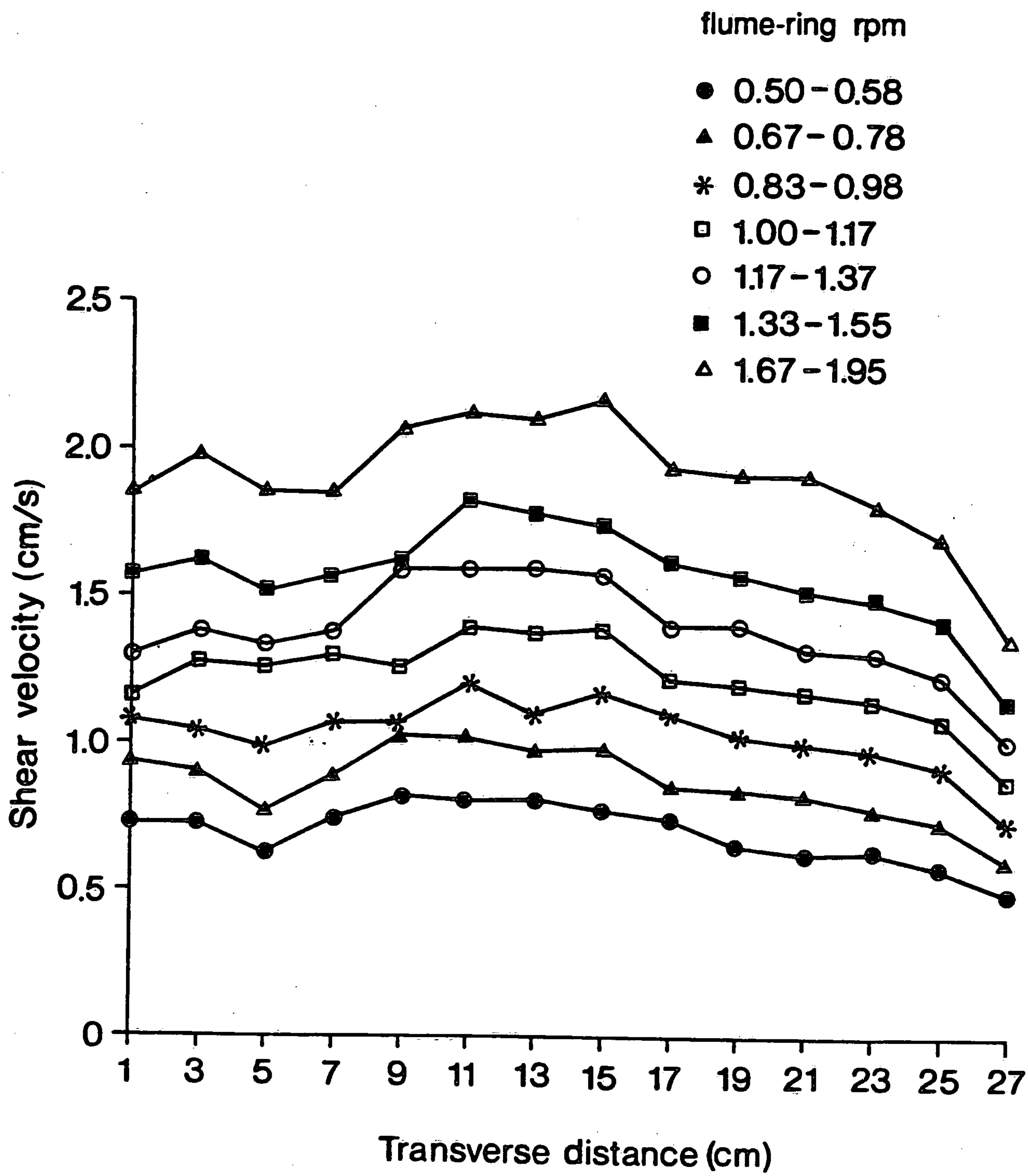


Figure 14 Shear stress distributions across the flume (flow depth= 12.0 cm)

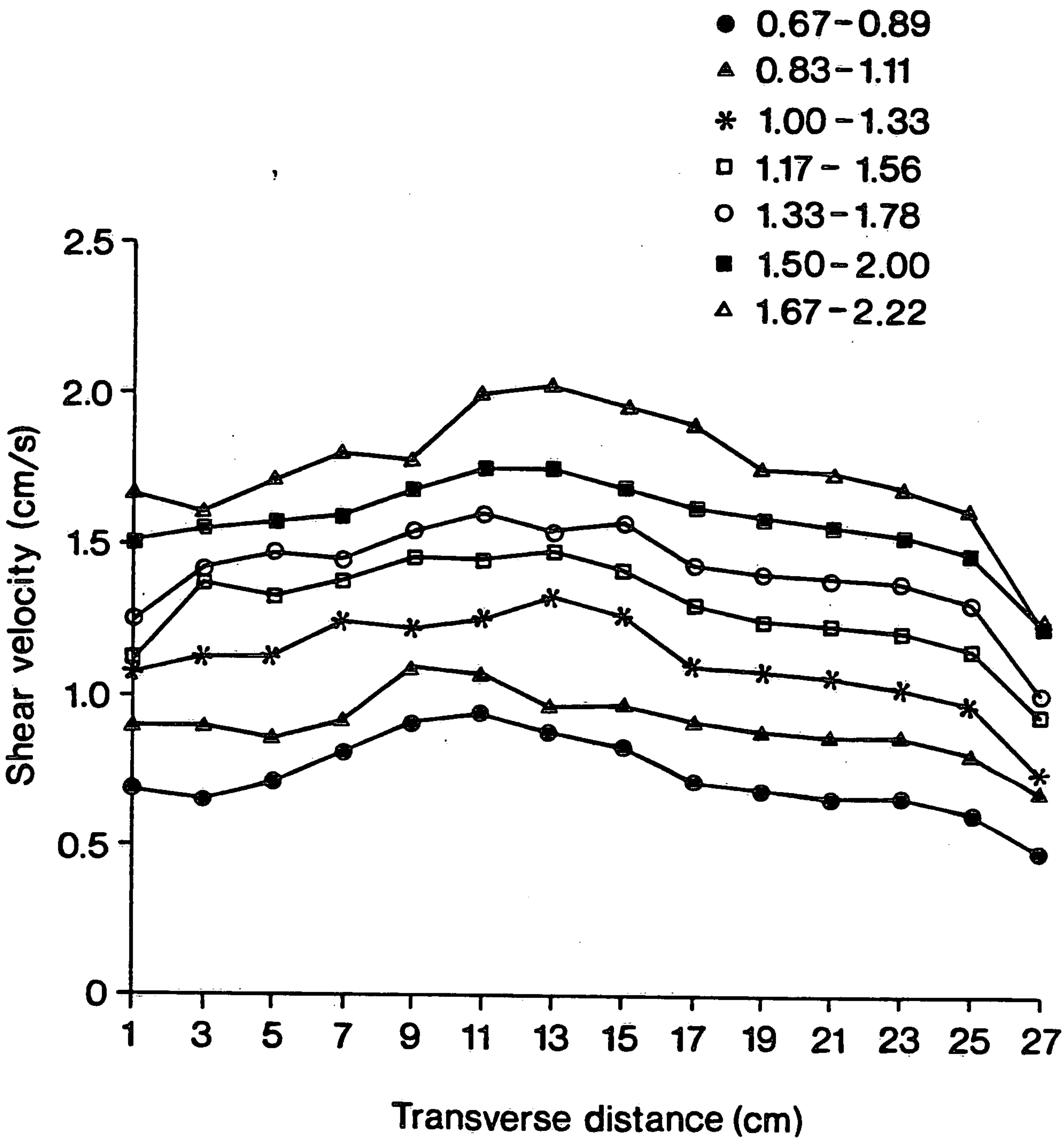


Figure 15 Shear stress distributions across the flume (flow depth= 20 cm)

SUMMARY AND CONCLUSIONS

A rotating flume recently installed at the National Water Research Institute in Burlington, Ontario, Canada to undertake basic research on fine sediment dynamics is described.

The hydraulic characteristics of flows generated in this flume are examined. The flume was operated in two different modes. In the first mode, the flow was generated by keeping the flume stationary and rotating just the ring at 2.0 rpm. In the second mode, both the ring and the flume were rotated in opposite directions with the rotational speeds of 1.0 rpm each. The flow depth was kept constant at 15.5 cm. For these two flows, detailed measurements of tangential velocity and the turbulent shear stress at the flume bed were carried out at a representative cross-section. The measured data clearly show the existence of a large secondary circulation cell and a large systematic variation of bed shear stress across the flume in mode one operation. In the second of operation, the large secondary circulation cell vanishes and the bed shear stress tends te become reasonably uniform over the entire flume width.

Uniform bed shear stress across the flume width and the minimum secondary circulation in the flow cross-section are desirable flow characteristics for fine sediment transport research and hence the present rotating flume is ideally suited for this purpose.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. E.D. Ongley, and the NWRI science management for supporting this new (to NWRI) research programme on fine sediment Dynamics. The author acknowledges the useful discussions that he had with Prof. E. Partheniades of the University of Florida with regard to the design of the flume. Periodic discussions with colleagues Drs. Y.L. Lau & S. Beltaos were very useful. The technical support of Robert Stephens of Research and Application Branch at NWRI in carrying out the experiments is greatly appreciated.

APPENDIX I - REFERENCES

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LIST OF FIGURES - CAPTIONS

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