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Scientific Contribution
No.:INCOH/SAR-17/99

EXISTING METHODS OF COLLECTION OF SEDIMENT DATA IN INDIAN STREAMS/RIVERS

M.L. Baweja
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INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Ministry of Water Resources, Govt. of India)

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE-247 667, INDIA

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PREAMBLE

It has been estimated that the total world population will be about 6.5 billion by the year 2000, with the most rapid growth in the developing countries. By that time the countries within the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence, it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

Knowledge of the erosion, movement and deposition of sediment relative to land surface, streams, reservoirs and other bodies of water is important to those involved directly or indirectly in the development and management of water and land resources. It is also becoming more and more apparent that such development and management be carried out in a manner that yields or conforms to a socially acceptable environment. The required knowledge of sediment make necessary the measurement of suspended and bed sediments for a wide range of hydrologic environments. The complex phenomena of fluvial sedimentation make the required measurements and related analyses of sediment data relatively expensive in comparison with other kinds of hydrologic data. Accordingly, the purpose of this report is to help standardise and improve the efficiency of the techniques used to obtain sediment data, so that more knowledge can be obtained for a given investment of labour and resource.

In addition to an introduction, the report consists of two main sections. The section on "Sediment sampling equipment" includes a discussion of the characteristics and limitations of commonly used samplers and some of the modifications of this equipment for special measurements. The other section on "Sediment sampling techniques" includes a discussion of the characteristics of measurement sites, the selection of sampling verticals and transit rates, the methods of making sediment- discharge measurements, sampling quality control and timing and some of the requirements for sediment related data.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of UNESCO and is the National Committee for International Hydrology Programme (IHP) of UNESCO. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its erstwhile Panel on Water Quality, Erosion and Sedimentation has identified this important topic for preparation of this state-of-art report and the report has been prepared by Shri M.L. Baweja and Shri Roop Narain of Central Water Commission (CWC) . The guidance, assistance and review etc. provided by the Panel are worth mentioning.

It is hoped that this state-of-art report would serve as a useful reference material to practising engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilisation of the water resources of the country.

(S.M.SETH)
Executive Member, INCOH
& Director, NIH
Roorkee

CONTENTS

TERMINOLOGY

SEDIMENT LOAD :

The sediment load in a river is the total sediment which moves either in suspension or in contact with bed. It is the sum of suspended load and bed load.

SUSPENDED SEDIMENT LOAD :

That part of the sediment load of a stream which remains in suspension in the flowing water for considerable periods of time without contact with the stream bed, being kept up by the upward component of the turbulence or by colloidal suspension and which moves practically with the same velocity as that of flowing water.

BED LOAD :

The sediment in almost continuous contact with the bed while carried by rolling, sliding or hopping along the bed of the stream.

WASH LOAD :

That part of sediment load which is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of stream bed. It is in near permanent suspension and is transported entirely through the stream without deposition and consists of very fine particles.

COARSE SEDIMENT :

The particles of suspended load which have diameter greater than 212 micron.

MEDIUM SEDIMENT :

The particles of suspended load which have diameter between 75 micron and 212 micron.

FINE SEDIMENT :

The particles of suspended load which have diameter less than 75 micron.

CLAY :

It forms a major part of wash load and comprises of particles having size less than 2 micron.

BED MATERIAL :

The material, the particle sizes of which are found in appreciable quantities in the shifting portions of the river bed.

I INTRODUCTION

ORIGIN OF SEDIMENT

A flowing water body has a natural tendency to pick up silt, sand, pebbles etc. according to its capacity from the bed or the banks due to the presence of forces such as shear and turbulence. The capacity to pick up such particles increases with the velocity of flow and turbulence. However, the quantum of sediment in a flowing stream depends upon the availability of particles. the stream may be in an unsaturated condition if its capacity to pick up particles is more than the availability of particles at its bed or banks. In such cases the streams pick up particles at the first available opportunity and exhibit the scouring property. If the capacity of stream to carry a particular load of sediments equals the available sediment load in the stream then it is said to be in the 'regime' condition i.e. non-scouring non-silting. But if the capacity of a stream to pick up particles is less than the quantum of sediment particles carried by it, then the stream is in super saturated condition and it will shed (deposit) the particles on its bed or banks and exhibit a silting property. A stream could be scouring in regime or silting at different places depending upon its capacity to carry sediment and the availability of sediment in the flowing water and on its bed and banks.

Apart from the quantum of sediment particles carried by the stream, the nature and size of particles carried in a stream greatly depend upon the forces responsible for carrying the sediment particles and the availability of type of particles on its bed and banks. Basically the river is formed by combination of smaller streams which again get a shape by a combination of smaller channels flowing through fields, barren and forest lands and habitated areas. As the water of these smaller channels. mingles in the stream so it is the sediment carried in them, Thus the sediment carried by the streams provides the characteristics of the catchment in respect of geology, soil erodibility and the land use pattern in general.

The availability of sediment in a channel is also influenced by the frequency and intensity of rainfall. Intermittent rains cause more flow of sediment in comparison with the regular rains of same amount of precipitation due to breakage of soil aggregates during the intervals of dry spell. Similarly, heavy precipitation causes much more flow of top soil from the land.

EFFECTS

The sediment carried down by the river is either deposited into he flood plains or reservoirs but in absence of such places, the sediment enters the sea and settles at the bottom of the sea.

Generally a substantial amount of sediment is deposited in the deltaic regions due to loss in the carrying capacity of the streams. As most of the sediment flowing in the river has come by the erosion of top soil from the upper catchment, it is an established fact that the flood plains in the down stream areas where a layer of sediment is deposited annually are very fertile and give good agricultural yields.

The reservoirs impound the river water and most of the sediment carried by the rivers is also deposited in the storage areas of reservoirs. It is now established by the field investigations that most of such deposit takes place in the live storage capacity instead of in the dead storage capacity of the reservoir. The sedimentation (the process of deposition of sediment) is also known to cause loss of efficiency of navigability of channels and ports which require heavy expenditure on the desilting process. The Silting of canals similarly poses a severe problem to the irrigation engineers.

NEED FOR REGULAR & RELIABLE DATA ON SEDIMENT

Man lives in a developing society and for development, the harnessing of the water resources is an unavoidable necessity for meeting the various needs associated with the development. But in view of the extensive industrial, commercial and urbanization which require equally extensive development of water resources, it is expected that erosion, accumulation and deposition of sediment carried by the rivers could become a more serious problem in future. Therefore, it is desirable that the knowledge of physical laws influencing movement of sediment and the better knowledge of the nature and the amount of sediment carried by individual streams is gathered. The knowledge of quality and quantity of sediment flowing in the streams is very essential for (i) Planning, design and operation of water resources projects (ii) Study of river morphology, stream mechanics and channel erosion (iii) Afforestation in the catchment to reduce the direct inflow of sediment in the rivers (iv) Adopting other soil conservation measures in the areas which are highly susceptible to soil erosion (v) Providing adequate measures for desilting/flushing in the canals, navigational channels and ports.

AGENCIES COLLECTING THE DATA

It is a fact that the quality and quantity of the sediment transported in the streams varies considerably from river to river and season to season, year to year and from place to place in the same river. So it will be prudent to monitor the quality and quantity of sediment flow at several important places on a river over a long period. It is also obvious that such monitoring is basically a work of Research and Development. The length and breadth of river basin are quite large and such monitoring stations have to be established at the places where the flow conditions are suitable for monitoring. The location of such stations is generally at the places which are not very close to urban centres. This requires a suitable expenditure of building/sheds for the office and the staff. Moreover, the equipment such as navigational crafts, current meters and samplers are also quite costly.

In view of large expenditure involved in the monitoring of sediment flow in rivers and the requirement of long term data for arriving at the conclusions, the work is better done by the concerned government or its agency. Involvement of private body for collection of such data does not appear proper and may not be workable.

In India, regular observations of flow of suspended sediment in the rivers are conducted by the Central Water Commission and also by some State Irrigation Departments.

TYPES OF SEDIMENT TRANSPORTED BY RIVERS

The total amount of sediment transported by a river is basically divided in two parts :

i) Suspended sediment load
ii) Bed load

Suspended sediment load is that part of the total sediment transported by a river which remains in suspension for a long time before coming into contact of river bed. Bed load is that part which moves near or on the bed by hopping or rolling or sliding. Depending upon the characteristics of stream, it is quite possible that the suspended sediment in the upstream areas may become the bed load at the downstream locations. In this report, the methodology of measurement of suspended sediment load and bed load are discussed separately.

PRE-REQUISITES OF SEDIMENT MONITORING

Before initiating the sediment monitoring, there are a few aspects which must be looked into. These are :

a) Selection of sediment monitoring station
b) Location of sampling points at the station
c) Frequency of sampling; and
d) Sampling depth.

SELECTION OF SEDIMENT MONITORING STATION

Certain criteria must be satisfied before a river section is selected for the purpose of sediment monitoring. These are briefly listed below :

1. The reach of river should be fairly straight and devoid of bank erosion both upstream and downstream of the station for a distance of about 3-4 times the width of river at the high flood level. This ensures almost perpendicular flow and eliminates cross slope at the cross section.

2. As far as possible, the flow should be restricted in one channel during lean season and compulsorily in one single channel during high stages in monsoon season.

3. The river bed should be uniform in slope and should have well graded sediment. The cross section having erupted rocks should be avoided as such conditions induce non-desirable turbulence and disturb normal characteristics in the sediment distribution. The presence of large pools at the cross-section causes errors in computation of discharge as there is negligible velocity in the pools and depths are increased.

4. The station should be away from the structures which are likely to affect the characteristics of water and sediment flow. If the location of station is selected at the upstream of a bridge, it should preferably be more than 2 kms upstream of structure so that it could be free from the afflux caused by construction due to structure and also that in case of any mishap such as failure of engine etc. the craft could be taken to either of the bank. In case the location of station is to be selected in the down stream of a bridge, it should be preferably 4-5 kms down stream so the disturbance in the sediment flow characteristics is stabilized during such distance.

5. The section which is affected by the back water effect due to a reservoir or a confluence of another stream must be avoided. The problem due to back water manifests if the velocity at the different verticals is not measured due to any reason and the discharge is calculated from the stage discharge relationship. Similarly, the sediment flow characteristics are also disturbed due to back water effect.

6. The flow in river should be contained within the banks even during high stages. In other works,both the banks should be sufficiently high. In case, either of the bank is quite low, there is every likelihood that during high stages, water will spill over the low bank and the width of cross section will become too large to be measured with reasonable accuracy.

7. The station should be easily accessible and the approach should be dependable at all time of year.

LOCATION OF SAMPLING POINTS AT THE STATION.

As the horizontal distribution of suspended sediment load normally varies from one point to another in the cross section, flow of the river is divided into a number of compartments and the concentration of sediment in each compartment is measured separately along with the discharge of compartment.

In the earlier days, the river flow was divided into three compartments of almost equal width. The concentration of sediment of each compartment was measured by taking one sample from the centre of the compartment. This practice could not provide the needed accuracy in wider river, wherever the flow was concentrated in one or two compartments of the cross section.

Presently, the location of sediment sampling points remains the same as those taken for measurement of velocity. The velocity measurements and sampling is done at the mid points between the piers in case of stations on the bridges. The segments are usually grouped into 5-7 compartments in such a way that all have almost equal discharge. The samples collected for a group are then mixed together for arriving at the mean sediment concentrations of the group. This arrangement gives better results as the separate compartment have more or less equal discharge and the suspended sediment load of every compartment is calculated separately.

FREQUENCY OF SAMPLING

Generally frequency adopted for the sediment monitoring is once in 24 hrs. The time of sampling is kept the same as for measurement of river discharge. The hydrological observations (of which measurement of discharge and sediment are a part) begin at 8.00 hrs. and last for about 2-4 hrs. depending on the width of the river, navigational equipment etc.

The rises and falls in water levels are fairly rapid during the rainy period. Consequently the sediment concentration also undergoes rapid changes during such phases. Under such circumstances, sampling of once in 24 hrs. may not be sufficient. For better assessments, the sampling is being attempted at more frequent intervals at some places.

SAMPLING DEPTH

Investigations have been done for assessment of sediment transport by taking samples at different depths. The samples taken on the surface give the least amount of sediment concentration. The sediment particles being heavier than water, tend to move downward. The concentration of coarser particles increases from the surface to the bottom. Therefore, two practices are being observed into the sampling.

i) Sampling at a point of mean concentration.
ii) Continuous sampling covering all depths of the vertical.

i. SAMPLING AT A POINT OF MEAN CONCENTRATION

Earlier mean depth i.e. 0.5 D was considered to represent the point of mean concentration. Later investigations showed that this point was near 0.6 D. It may, however, be mentioned that this is an approximate point of mean concentration and would vary for different sizes of sediment, as well as from one vertical to another at the same cross section. However a depth of 0.6 is being adopted for routine measurements even though regular vertical sediment experiments are regularly carried out.

In view of the above, the samples are sometimes collected at 2 or more points in a vertical and mixed together to get the mean concentration. As collection of samples at all these points in a vertical is quite cumbersome and time consuming and considering that there could be as many as 20-30 verticals at the cross-sections, the multiple sampling at all the verticals is not usually practicable. Sometimes double point sampling. i.e. at 0.2 D and 0.8 D is adopted.

ii. CONTINUOUS SAMPLING COVERING ALL DEPTHS OF A VERTICAL

In this method, a suitably designed sampler is immersed from surface to bottom at a uniform speed and raised at the same rate. During this process, a minute amount of water-sediment admixture enters the sampler. All along the vertical. This sample represents the average of the sediment concentration which has passed at the particular vertical during that span of time which is taken by the sampler in traversing from surface to near bottom and back. Such a sampling is termed as depth integrating sampling which is gradually finding increasing acceptability.

II SAMPLERS

BACKGROUND

For monitoring of sediment flow in a stream, the concentration of sediment is measured by taking a volume of water-sediment admixture and then measuring the concentration in three ways viz, hydrometer method, photo electric cell method and gravimetric method. In the beginning of the investigations the sampler used to be pail or a bucket which could take the sample from the surface only. Realization of the fact that surface sampling cannot give representative sample has led to further development of samplers.

The slip bottle, double slip bottle and horizontal trap sampler were developed for taking the instantaneous sample from the desired depth. The effect of the sampler on the stream flow and the accuracy of the instantaneous action were probably not considered at that time. Narrow mouthed bottles with provision of removing the stopper at a desired sampling depths were also introduced for trapping the water sediment admixture. Common water pump samplers were also introduced for sampling at the desired depths.

RECENT DEVELOPMENTS

During the course of investigations it has been realised that the concentration of suspended sediment is generally subjected to rapid fluctuations and so the average concentration at the point will not be correctly represented by a single instantaneous sample. It would be more desirable to secure the water sediment admixture from a point over a considerable period of time to get the average concentration. The samplers developed on this hypothesis are the modifications of ordinary slow filling bottle type sampler in which a due care has been taken to avoid the disturbances due to the design of sampler in the zone of filling and also to minimize the current drag on the sampler.

THE REQUIREMENTS OF AN IDEAL SAMPLER

For an ideal sampler, the following requirements may be satisfied.

A. The sample collected must be representative of the water sediment in the immediate vicinity to the sampling point or sampling zone at the time of sampling.

B. The suspended sediment must not be separated from the water at the point of entry into sampler due to any sudden change of flow characteristics of the water; i.e. turbulence, velocity or direction of flow. Thus, there must be no appreciable disturbance by the sampler upon the flow which would increase or decrease the concentration of sediment in the sample collected in the sampler.

C. The sample collected at a point must not be contaminated by water or sediment at other depths in the stream section. That is, the sampler would be arranged to open at the desired point and to close when filled, preferably by manual control.

D. The volume of the sample must be sufficient to satisfy the laboratory requirements for the size analysis of the sediment as well as the regular "parts per million' determination.

E. The sampler must be adaptable for use in streams of any depth and for sampling at any desired depth of the water from the surface to the bottom.

F. The sampler should be portable and adaptable for use by an operator wading in a shallow stream or working from a boat or bridge in a deep river

G. The sampler should allow the entire sampling operation at a cross section to be made in a minimum of time.

H. The sampler should be streamlined and of sufficient weight to reduce, to a minimum, its deflection from the vertical due to drag when used in deep swift streams.

I. Simplicity of design and construction are important from the stand point of cost of the sampler and ease of maintenance and field repair.

J. It would be desirable to collect the sample in a container that can be shipped to the laboratory without transferring the sample to another container in the field. This would overcome the possibility of losing some of the sediment which might adhere to the sampler container.

K. The samples should be collected in a transparent container so that the degree of settlement may be observed in the laboratory. However, in some streams if would be necessary to protect glass containers from being struck by heavy, suspended matter.

L. The sampler should be designed to take a sample instantly or over a longer period of time.

CLASSIFICATION OF SAMPLERS

The samplers can be basically divided in three types :

i) Instantaneous
ii) Point integrating and
iii) Depth integrating

1. Instantaneous sampler

In this type of samplers, an instantaneous grab sample of water sediment admixture is obtained. Such samplers may vary from vertical to horizontal type with provision of trapping the sample by closing of flaps or valves or piston type arrangements. The following samplers are covered in the category.

(i) Vicks-burg district USED vertical trap sampler, (ii) Eckman sampler (iii) Forest sampler (iv) Slip bottle sampler (v) Eakin sampler (vi) Leitz horizontal sampler (vii) Collast horizontal sampler (modified) (viii) Jaukowsky horizontal sampler (ix) Sind sampler (x) T.V.A. horizontal sampler (xi) Vickburg district USED horizontal toggle sampler.

2. Point integrating smapler

Point integrating samplers mainly consist of a narrow mouthed bottle or a wide mouthed bottle fitted in a system allowing the water to enter the bottle through a nozzle. In narrow mouthed bottles, the stopper is opened at a particular depth, whereby the air inside the bottle bubbles out and the water sediment admixture enters the bottle. In such bottle samplers, the basic draw-back (among other points) is that such bottles are subjected to rapid rate of initial filling particularly at large depth until the internal and external pressures are equalized. Thereafter, the normal filling of the sampler begins. The purpose of including bottle samplers under the category of point integrating sampler is that since the filling of sampler takes time, the variable in the concentrations of sediment during the time of filling, are averaged. The opening and closing of stop cork of the bottles sampler is arranged with the help of a latch or a spring or messenger system. In case, the mouth of sampler is kept open after complete filling of bottle, there is every likelihood that some amount of additional sediment will also enter the bottle due to variation in the flow condition near the vicinity of sampling point. Three types of samplers could be included in the point integrating samplers.

i) Punjab bottle type sampler
ii) Air pressure type sampler
iii) Collapsible container type sampler

Punjab bottle sampler has a bottle which is placed vertically in the case and it is fitted with a cork which can be opened and closed at the desired depth. The water sediment admixture enters the bottle when the cork is opened. The cork is closed after some time to trap the sample. The use of bottle sampler would be in the case of coarser suspended sediment since the entrance velocity differs from the velocity of flow and the entrance port is not facing the flow direction. The influence of size upto 0.06 mm is found negligible on the entrance velocity but greater sizes of sediment show appreciable effect in sampling with different entrance velocity. The Punjab bottle sampler also causes disturbance in the sampling zone. But, nevertheless, the simple bottle sampler could be used if the suspended sediment in the flow is of very fine nature.

In air pressure type sampler, the water-sediment admixture enters the sampler horizontally and the intake in the sampler is controlled by raising and lowering of air pressure inside the sampler. The Punjab bottle sampler and Air pressure type sampler (Turbidisonde) are shown in Fig. 1 & Fig. 2.

The collapsible container type sampler consists of a collapsible runner bag/ balloon. The water-sediment admixture enter the rubber container basically in proportion to the stream velocity. The filling of container at low velocities is difficult since openings are small and the force which would be required to push the water into container may not be available at low velocities. However, such samplers are unaffected in their filling by the hydrostatic pressure at the depth of sampling.

Depth Integrating samplers

In this category, the sampler is lowered from surface to the bottom of flow and then raised again to the surface at the uniform rate. In this process, the water-sediment admixture enters the sampler continuously through out the stream depth. If the rate of transit is not very rapid, the pressure inside and outside the sampler is normally balanced and no initial rush of sample is observed. Also if the nozzle of the bottle faces the current and some provision is made for the exit of air without disturbing the zone of intake, the rate of filling would be almost proportional to the velocity of flow.

There are two types of depth integrating samplers viz.

A. Shallow depth integrating sampler (USD-48 type)
B. Depth integrating sampler (USD-49. type)

These samplers are shown in the Fig. 3 & Fig. 4.

III METHODOLOGY OF SUSPENDED SEDIMENT OBSERVATIONS

These observations are carried along with the regular measurements of discharge of the rivers. For this purpose, some stations are chosen along the river course and necessary arrangement are made for the observation of water and sediment flows.

(A) FIELD WORK

The samples are collected from all segments in a cross_section where velocity measurements are made. These segments may vary from 10-30 in number depending on the width and other physical characteristics of the river. The cross-section of the river is then divided hypothetically into 4 to 7 nos. of compartments having more or less equal discharges. The no. may increase or decrease depending also upon sediment concentration. The samples belonging to one compartment are mixed together for detailed analysis of their grain size distribution.

(a) Collection of samples

The Punjab type bottle sampler is lowered upto a depth of 0.6 depth where velocity observation has been made. The handle of the sampler, which is attached to the cork is then pressed to allow for water to rush in the bottle with the consequent exit of air bubbles. The opening is allowed only for such a time that would fill the bottle more than its half capacity but not full. This is achieved by some trials before making the actual sampling and the time is observed that would fill the bottle completely. For this purpose, the norms have been set to restrict the filling between 550 to 950 cc as per IS 4890.

Care is taken to ensure the leak tightness of the cork before actual sampling. For this purpose, the sample is lowered at a depth of 0.5 to 1 m. in water and it is kept as such for a period of 2-3 minutes. The sampler is taken out and its bottle removed. If on examination of bottle, it is seen that the volume of water which has entered in bottle is more than 5 cc. then every step is taken to ensure complete fitting of cork in bottle and necessary replacement of cork and adjustment of sampler's hooks is done for complete leak tightness. Where depth integrating samplers are in use, the collection of samples is done by uniform lowering and raising of samplers at such a speed that the bottle does not overflow during sampling. This is achieved with practice.

Since the segments are already divided in a number of groups, the observer is aware of the number of segments falling in a particular group. If the number of RD's in one group falls shorts of 6-7 then it becomes necessary to take double sampling at some of the R.Ds. to ensure that total volume of water and sediment mixture in a group does not remain less than 4 lt. This volume has been fixed for a group to minimise the effect of potash alum on the total sediment load and at the same time eliminating detailed instruction on amount of alum and its effectiveness as a coagulating agent.

The bottle is taken out of the sampler and after shaking well , its content are poured in a measuring cylinder. If the volume of sample is between 550-950 cc. the figures are recorded in the field book and the contents of cylinder are emptied in an enamelled bucket marked for the group. Considering the period of useful life & cost, the enamelled buckets can be replaced with stainless steel buckets. The bottle and the cylinder are then washed with a jet of clean water and the washings are added in bucket and the enamelled lid is covered to avoid the loss of sediment from water-sediment admixture due to splashings. This procedure is repeated at all the RDs.

(b) Transportation of Samples

During sampling for suspended sediment flowing in the river, as many as 4-7 groups are formed depending upon various factors such as width of flow; quantum of discharge and the quantity of suspended sediment flow in the river. For each group an enamelled bucket and an enamelled lid is kept in the navigational craft. After all the segments are covered for silt sampling and the boat is anchored on the shore, all the buckets, previously given the markings for respective groups and duly covered with enamelled lids, are brought to the site-laboratory with maximum care to ensure that no splashings occur to cause loss of trapped sediment.

(B) LABORATORY WORK

(a) Arrangements and Cleanings

The covered enamelled buckets are kept on the cleaned floor in the laboratory in serial orders of group numbers. A general cleanliness in the laboratory is, however, to be maintained invariably. The apparatus required for separation of various grades of sediment, such as 212 micron sieve, enamelled dishes, Porcelain dishes, glass rod, beakers, wash bottle with jet, spare enamelled bucket etc,. are thoroughly washed with clean water before beginning of work. The porcelain dishes must be preweighed. Similarly, fitter papers of good quality must be dried, preweighed and kept in dessicator for ready use. The initial weights of porcelain dishes should be taken daily and recorded in the appropriate register. The potash alum solution which is required for coagulation of fine silt may be prepared in bulk and kept in well corked bottle.

5% potash alum solution may be prepared as given below :

i) Dissolve 25 gms of dry potash alum in 400 ml of water in a measuring flask.
ii) Add 12 ml of concentrated sulphuric acid slowly, along the sides of container and mix well.
iii) Make up the volume to 500 ml with clean water. Mix well and transfer the contents of flask 'hrough funnel to a bottle of 500 ml capacity and cork it.

(b) Coarse sediment (Particle size 0.2 mm Dia and above)

i. Separation

The content of bucket, pertaining to first group, are transferred in another empty bucket through a sieve having the net aperture of 212 microns. The sediment which remains stuck on the bucket is washed with a jet of clean water and the washings are also transferred through the sieve. The sieve containing sediment, is then kept in the enamelled tray, containing sufficient clean water, level of which is just above the level of sieve's net. The sieve is shaken in water so that any sediment of, finer size which has remained in it, may pass down under gravitational force. The contents of enamelled tray are transferred in bucket containing medium and fine sediment. The shaking of sieve in enamelled tray is repeated with another quantity of clean water till no finer silt passes through the sieve and the contents of enamelled tray are again transferred in the bucket. The residue of sieve's net, consisting of coarse sediment (and organic matter, if any) is transferred to a pre-weighed porcelain dish with the help of a jet of clean water. The sieve's net is rubbed with fingers as the same may distort the net's aperture.

The organic matter in the dish, if any, is taken out carefully with the help of finger and clean water. Utmost precaution is taken to ensure that on no account coarse sediment particles are removed while removing the organic matter. This procedure is repeated for all the groups.

In case the coarse sediment in one group appears very little, then the coarse sediment of all the groups, is transferred separately into one weighed porcelain dish and organic matter, as stated above, is removed after the addition of coarse sediment pertaining to the last group.

ii) Analysis

As far as possible the excess water is drained out of porcelain dishes, since the excess of water in dish will contribute to coarse sediment load on account of dissolved solids. The dishes are carefully kept in hot air oven (preferably electrically operated) and dried at a temperature of 100-110°C. After drying, the porcelain dishes are cooled in a desicator which contains active silica gel preferably self indicating or calcium chloride and weighed in a chemical balance upto an accuracy of 0.2 mg. with the help of a rider. The weights are recorded against the respective initial weights of porcelain dishes. On sub-traction, the weight of coarse sediment in different group is obtained. The concentration of coarse sediment in a particular group can be calculated by dividing the weight of coarse sediment by the initial volume of group and the sediment load can be calculated accordingly.

(C) Medium sediment (Particle Size 0.075 to 0.2 MM)

(i) Separation by 75 micron sieve :

The sediment plus water mixture, after the separation of coarse sediment is then passed through a 75 micron sieve and collected in another empty enamelled bucket. The sticking sediment in the bucket is washed down with the help of a jet of clean water and the washings are also passed through the sieve. The sieve containing sediment is then kept in an enamelled tray containing sufficient water, level of which is just above the level of sieve's net. The procedure of shaking the sieve, transfer of sediment to Porcelain dish is the same as in case of coarse sediment. Generally, there is no organic matter in this case; but if there is any, it is removed in the similar way.

(ii) Separation by using Stoke's law :

Stokes has established that rate of falling velocity of particles of given size under the force of gravity is constant in a given fluid at a particular temperature. In a liquid medium, the rate of falling velocity varies with temp-erature. This law has been used to separate the sediment particles of 0.075 mm diameter and above from the finer particles. For this purpose a table has been prepared which gives time at various temperatures, required by the particles of 0.075 mm diameter to fall down a vertical column of cm. in water. For separating the medium sediment from finer sediment by this method, the enamelled bucket containing the mixture of sediment and water (from which coarse sediment has already been removed) is allowed to stand still for 2-3 minutes. This ensures that all the particles of size 0.075 and above have settled to the bottom of bucket. Major portion of water in the enamelled bucket and the bottom portion which contains much of fine sediment and whole of medium sediment is transferred to a one litre capacity corning glass beaker. The sediment sticking to the bucket is washed with the help of a jet of clean water and the washings are added to the beaker. The glass beaker must have a permanent mark preferably with red paint at a height of 10 cm from the inner bottom. In case the column of water in beaker is more than the red mark, it is decanted till the level of water in beaker comes to the red mark and otherwise more clean water is added to the beaker and the level is brought upto the mark.

The temperature of water is noted at this stage.

With the help of a rubber bung attached glass rod (a policeman), the contents of the beaker are shaken in 8-wise direction. A stop watch is kept ready while shaking the content of beaker. The shaking is continued till most of sediment particles comes in suspension. At this moment the shaking is stopped by taking out the glass rod and the stop watch is started. The sediment particles are allowed to settle as per the time shown against temperature in the table. Immediately after the expiry of given time against the noted temperature, the water in beaker containing the sediment particles in suspension is withdrawn slowly but steadily by pouring in the enamelled bucket which has fine sediment. This separates more than 50% of fine sediment in beaker from the medium sediment.

In order to ensure complete separation, the beaker is again filled with clear water and the process of shaking and withdrawing the sediment in suspension is repeated. It requires another 2 or more repetitions till the water at the time of withdrawal remains clear. The contents of beaker are then transferred to a pre-weighed and numbered porcelain dish.

The medium sediment for all the groups is separated in this fashion and transferred to the respective porcelain dish, which are pre-weighed. The medium sediment of all the groups may be collected in one porcelain dish if the quantity of sediment is very small (of coarse sediment).

(iii) Analysis :

As far as possible, the excess water from the porcelain dishes is drained out and the dishes are kept in a hot air oven and dried at a temperature of 100-11 0°C. After drying, the porcelain dishes are cooled in a dessicator and weighed in the balance upto the accuracy of 0.2 mg. The weights are recorded in the register. The concentration and the load of medium sediment can be calculated accordingly.

(D) Fine Sediment (Particle Size below 0.075 mm)

(i) Coagulation :

No further separation of particle sizes is effected below 0.075 mm diameter of sediment particles. The sediment in this category are very fine particles and all of these cannot be retained on filter paper. Therefore, a coagulating agent is used, to form the aggregates of finer particles. During monsoon period, when substantial amount of fine sediment flows in the river, 5 ml of 5% potash alum is added to the mixture of fine sediment and water of each group. During non monsoon, when there is no coarse and medium sediment and fine sediment is present only in little quantity, 2 ml of 5% potash alum will be sufficient to coagulate the fine sediments in one group. The contents of enamelled bucket are then stirred well with a glass rod for thorough dispersal of alum in water. The glass rod is washed with a jet of clear water and washings are allowed to fall in the respective enamelled bucket. The bucket is left undisturbed overnight to enable the formation of aggregates (floods) to fine sediment and to let the flocs settle to the bottom. The hydrolysis of alum is represented by the following equation:

$$K_2SO_4Al_2(SO_4)_3 \xrightarrow{H_2O} K_2SO_4 + Al_2(SO_4)_3 + 24\ H_2O \text{ (Dissociation)}$$

$$K_2SO_4 \xrightarrow{H_2O} 2K^{+} + SO_4^{--} \text{ (Ionization)}$$

$$Al_2(SO_4)_3 \xrightarrow{H_2O} 2Al^{+++} + 3SO_4^{--} \text{ (Ionization)}$$

$$2Al^{+++} + 6H_2O \longrightarrow 2\ Al\ (OH)_3 + 6H^{+} \text{ (Hydrolysis)}$$

The Hydrolysis of $A1^{+++}$ takes place in water between pH range of about 4.5-9.5. $Al(OH)_3$ is insoluble and forms gel type structure. Fine sediment particles are trapped in such molecules physically and also by absorption. The precipitate forms flocs and becomes heavier due to trapped sediment. This process takes about 6-12 hrs.

(ii) Siphon/Filteration :

The next morning, clear water from the enamelled buckets is siphoned with the help of a polythene rubber tube which is kept in the centre of bucket to avoid draining of fine silt aggregates (flocs) which may be sticking to the sides of enamelled bucket. The siphoning is to be done very carefully so that no sediment which is at sides or at bottom is drained and in this process maximum water is run out of bucket. The concentrated mixture of water and fine sediment is collected in a corning glass beaker. The aggregate of fine sediments which may be sticking to the sides and bottom of the enamelled bucket are washed with a jet of clear water and the washings are transferred to the respective beaker.

A preweighed and marked filter paper is taken and fitted in the glass or plastic funnel with the help of a jet of water. The sediment and water mixture is added in the filter paper by sliding alongwith the glass rod; upto the 3/4 capacity of filter paper. The remaining water and sediment mixture is added subsequently in similar fashion after some water is drained out of filter paper. The beaker and glass rod are washed with jet of clean water and washings are added to filter paper for retention of fine sediment which is present in washings. The water is allowed to drain out from filter paper as far as possible. The procedure is repeated for all the groups.

(iii) Drying :

The filter paper which is wet and contains most fine sediment is taken out of funnel carefully and placed in hot air oven (preferably electrically operated). It is dried at a temperature of 100-110°C for a period of one hour and then cooled in dessicator having active self-indicating silica gel or dry calcium chloride for another half an hour. The filter paper containing fine sedimentsis then weighed in balance and weight is recorded in the field laboratory register.

In cases where fine sediment is appreciable say, about one to two grams or more, single heating does not ensure complete removal of moisture from filter paper and fine-sediment aggregates. Complete removal of moisture becomes essential as it will otherwise contribute to the erroneous excessive load of fine-sediment. For this purpose, the filter paper containing the fine sediment is heated again for another fifteen minutes at a temperature of 100-110°C and cooled in dessicator and weighed. This procedure is repeated till the two weights of filter paper with fine sediment do not vary by 1 mg. Care is taken in case of hot air oven which is operated on oil stove that filter paper does not get charred; as charring of the filter paper will spoil the complete observation. To avoid it, the filter paper containing sediment should be kept on the perforated porcelain plate and the heating should be controlled. The lowest weight of filter paper plus sediment is recorded for the purpose of calculations.

(E) CALCULATION OF FINE SEDIMENT CONCENTRATIONS :

The weight of filter paper is substracted from the weight of filter paper containing sediment (In no case mean of different weights of filter paper with fine sediment is to be taken). The weights of the sediment is then divided by total original volume of the group, as the volume contributed by washings of enamelled buckets, beakers etc. with jet of clear water does not contribute to fine sediment load; to get the concentration of the sediment in water. The fine sediment load is calculated accordingly.

(F) CALCULATION OF TOTAL SEDIMENT LOAD :

The sediment loads contributed by coarse, medium and fine sediment are calculated on basis of quantum of flow per second by multiplying the concentrations of a group with the respective discharge and a suitable factor is used for converting the sediment load per second into sediment of respective grade per day. The total load of sediment is arrived at by addition of load of different grades. Average concentration of sediment can be calculated from figures of total sediment load and discharge.

IV BED-LOAD

Such sediment particles which move almost in contact with river bed and are carried by rolling, sliding or hopping along the bed come under bed load. Bed load can be divided into contact load and saltation load, the former including the particles which move by rolling or sliding and latter considers the particles which move by hopping or bouncing along the bed.

TYPE OF BED LOAD

The particle size distribution in bed load characteristically depends on velocity of flow, slope, bed material and catchment geology. A single stream may have different type of sediment moving as bed load in its different reaches. For example, while passing through hills and gorges or near its origin the bed load of a stream may constitute mainly of boulders and gravels with most of smaller size particles being in suspension due to appreciable turbulence in such reaches. The same river, while traversing through the plains where slope and velocity are much less, may drive coarse sediment as bed load. This may be so due to fact that the decreased turbulence in river is unable to hop the bigger particles. Moreover, as the river stretches its way downwards the boulders and gravels are broken by collision with one another and by frictional forces, thereby decreasing the availability of such particles in the lower reaches. Also at given cross-section, particles which are a part of bed load at one stage (of flow) may become the part of suspended load at another stage. Thus there is an intimate relation between bed material, bed load and suspended load because depending upon the hydraulics of flow in various reaches of river (particularly in alluvium), particles may alternate between a part of the bed load or a part of the suspended load. Therefore, while making arrangement for measurement of bed load a careful account has to be taken for position of reach, slope and velocity of flow.

EXTENT OF BED LOAD

As the characteristics of bed load depend on certain riverine features such as slope, velocity and catchment geology, the amount of bed load which moves in a river mainly depends on the nature of river bed, banks and velocity of flow. In case of hilly terrain the river may not have substantial movement of bed load even at higher slope and velocity but if the river has comparatively less slope and velocity in a reach which has sandy bed and sandy banks the extent of bed load may be considerably more. This can be attributed to two reasons. Firstly the river flowing in upper reaches has gravels and boulders as bed material, which require greater force for movement and consequently the movement of such large particles is comparatively slow inspite of more slope and high velocity. Moreover the number of such particles is much less in comparison. Secondly, the bed material in lower reaches comprises of finer particles which are in abundance and require little tractive force for movement. The lower reaches are mainly sandy with sandy banks and it is observed that river water with a change in its regimes washes down much of the banks constituents and increase the suspended sediment and bed load. It generally assumed that bed load of a river is approximately 5-25%of suspended sediment load.

EFFECT OF BED LOAD MOVEMENT

The movement of bed load is a serious problem for the hydraulic engineers as it results in silting up of canals, channels, natural lakes and artificial reservoirs. The canal and channels can partially desilted by occasional pushings and also by removing the sand manually from the canal beds. But the bed load sediment of a river whose flow enters in a natural or artificial reservoir, deposits on the reservoir bed with a consequent decrease in the storage capacity. Since such deposited sand is spread over a large area, the removal of this is economically prohibitive. Estimated figures of amount of sediment moving as a bed load is 5% to 25% of total sediment flow as observed in artificial flumes. The planning for a reservoir can become absurd if a proper and reasonable estimate for extent of bed load are not taken in consideration. It is evident from the silting rates of some of the reservoirs executed during 6th to 7th decade of this century in India that the observed silting of reservoirs is much more than was envisaged in their planning and that their efficiency has reduced drastically.

The reservoirs which are silted up are either operated for nominal benefits or abandoned for good.

NEED FOR ESTIMATION OF BED LOAD

As already explained all the sediment as bed load deposit in reservoirs which are consequently silted up and such reservoirs with improper planning become of little utility. Since the construction of reservoirs require enormous capital and man power, the abnormal decrease in their storage capacity, irrigation utility and hydel generation demands serious consideration in planning stage. Such gigantic structures now appear to have eaten up the hard earned resources. So far bed load movement studies have been limited to artificial flume. The time has now come when all efforts should be made for regular study for quantity and quality of bed load sediment in major and concerned rivers.

TYPE OF INSTRUMENTS REQUIRED FOR MEASUREMENT OF BED LOAD :

In view of the movement of different sized particles on the river bed as bed load, some requirement of the instrument are :

i. It must have a flat and broad base.
ii. It should be sufficiently heavy to approach river bed without appreciable deflection from the point of suspension and also that it should not be abnormally heavy to create operational problems.
iii. It should be streamlined to experience minimum drag on account of flow velocity.
iv. It should be able to trap all the sediment moving through it as bed load.
v. The flow lines should not be disturbed in its u/s vicinity of the point of placement on river bed.

DIFFICULTIES IN MEASUREMENT OF BED LOAD

1. Presence of a sampler disturbs the bed load transport process.
2. Presence of bed forms varies the rate of bed load transport in horizontal direction across the profile of bed form.
3. Position of bed may change either in horizontal or vertical direction during passage of flood.
4. The efficiency of bed load sampler to trap particles may vary with the particle size and with stage of flow.
5. Bed load transport may not be limited to the top layer of particles in the bed as some particles in the under lying layers of bed may also be moving slowly.
6. Facilities of measuring the efficiency of bed load samplers are not available in India.

Some of the bed load samplers which have been used for bed load measurements are given below :

i. Box & Basket type samplers

a. Muhl-Hofer sampler
b. Nesper sampler
c. Ehrenberger sampler

ii. Pan or Tray type samplers

a. Losiebsky sampler
b. Polyakov sampler

iii. Pressure difference type samplers

a. Arnhem sampler
b. Russian sampler

iv. Pit or trench type samplers

a. Permanent installation
b. Portable sampler

In India, bed load measurement have been done on experimental basis with Russian type bed load sampler at Irrigation and Power Research Institute, Amritsar (Punjab), U.P. Irrigation Research Institute, Roorkee (U.P.) and Central Water Commission. Trench sampling has also been studied the extent for bed load in an ephemeral stream. But making trenches in big stream does not appear feasible unless there is appropriate method to remove the collected bed load completely on periodic basis to avoid over filling of trenches. The Russian type bed load sampler has certain advantages for use in alluvial rivers. But this sampler can not be used at the stations where the bed load consists of coarse sand and pebbles with gravel bed as there are chances that the pan may sit on some large gravels on the bed and coarse sand and smaller pebbles may pass beneath the floor of pan. In view of the problems accompanied with the choice of sampler at stations where the bed material generally consists of coarse sand mixed with pebbles and gravel, the bed load measurements initially could be restricted to the station where the river bed consists of coarse and medium sand. In view of this the details of Russian type bed load samplers are below :

It is made of sufficiently thick iron sheets to enable the instrument to sink to the bottom. There is very little resistance to the flow as most of the flow entering through it passes from the rear side and consequently this instrument experiences a negligible drag by flow velocity. Its broad base enables to settle and stick on the river bottom. The particles moving as bed load by hopping or sliding enter the instrument where the velocity is gradually decreased by various planks. The planks are placed at angular positions with increasing angles as the position of plank moves in. The particles moving as bed load are thus trapped in the instrument. The drawing of the sampler is shown in Fig. 5.

The instrument is kept at bottom for a specified period and then taken out. The amount of particle size gradation of bed load is then related to the discharge of the compartment/river.

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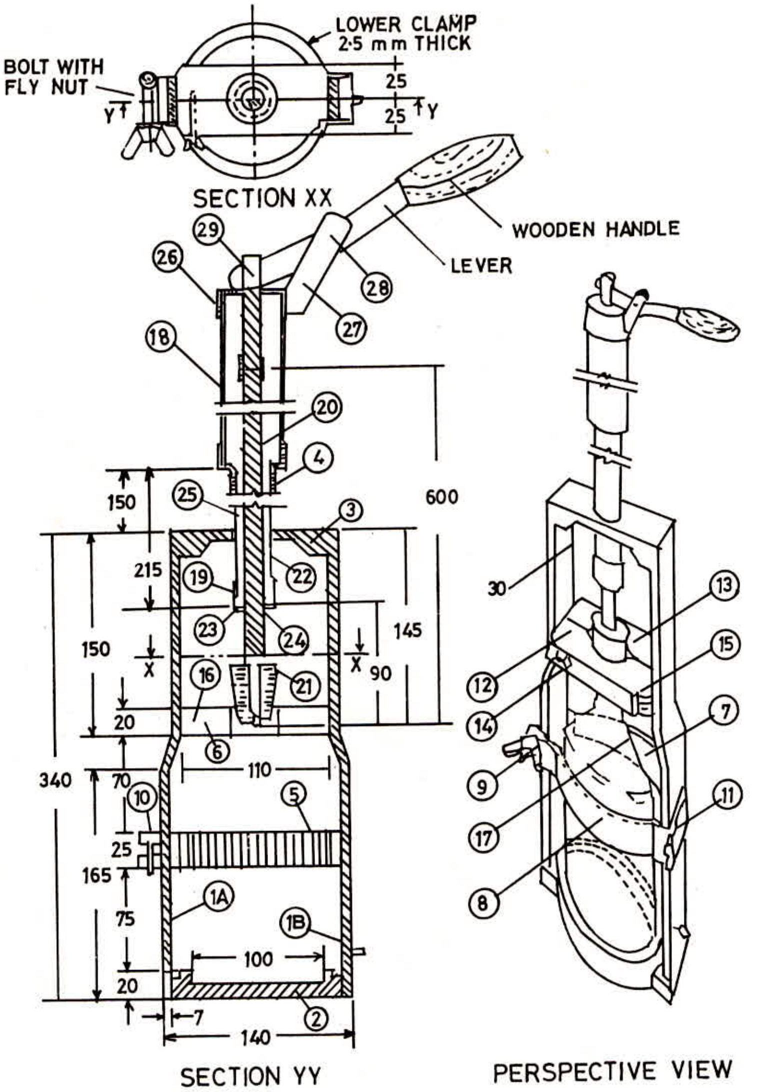
DIAGRAMS



Part No.

1A. Vertical Sides, 1B, 2. Base Plate, (3) Elbow Plate, (4)Lower Pipe - Spring Cylinder, (5) Lower Clamp, (6) Upper Clamp, (7) Semi - circular Shaped Strip (8) Semi-circular Shaped Strip, (9) Bolt, (10) Pin, (11) Pin, (12) Rectangular Piece, (13) Roctangular Piece, (14) Fly- Nut Hended Scrow, (15) Pin, (16) Holo (Threnaed), (17) Bottle, (18) Pipe Extension (19) Half Socket, (20) Rod, (21) Cork,(22) Spring Strong Coiled (22) Washer, (23) Rivet, (24) Screws, (25) Half Socket, (26) Elbow Shaped Flat Plates (27) Pin, (28) Boit,

For the sake of convenience details 5 and 6 ana have been numbered, which comprise of several smaller details which have also been numbered.

Note - Part numbers are given inside circles.
All dimensions in millimetres.

Fig. 1 Bottle Type Sampler

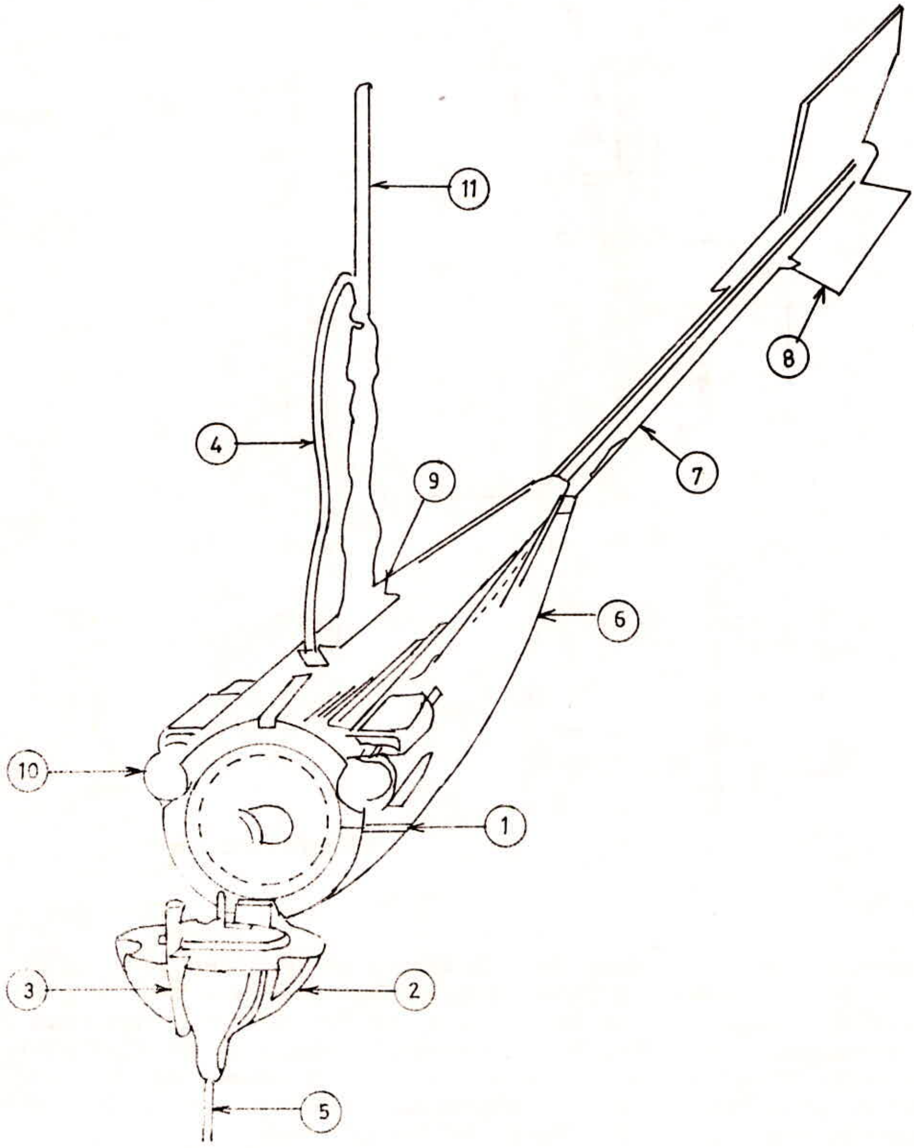


Figure 2 Turbidisonde Neyrpic L-80 sediment sampler-

(1) Sampling bottle, (2) Hinged bead,(shown open) (3) Locking device, (4) Comrressed air inlet, (5) Samping tube, (6) Body, (7) Tail (8) Stabilizing fins (9) Pivot (10) Venturi tube, (11) Special Cable.

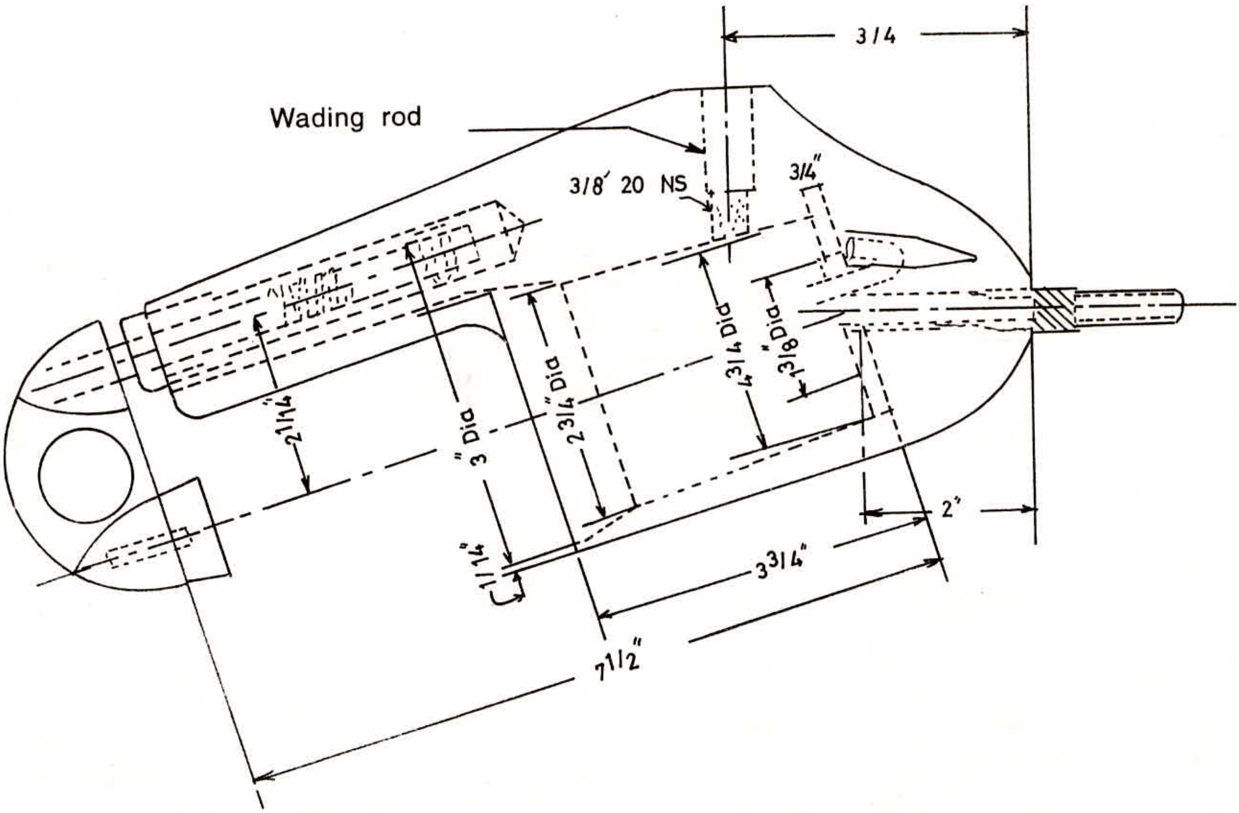


Figure 3 : **Depth Integrating Suspended Sespended Sediment Wading type hand sampley.**

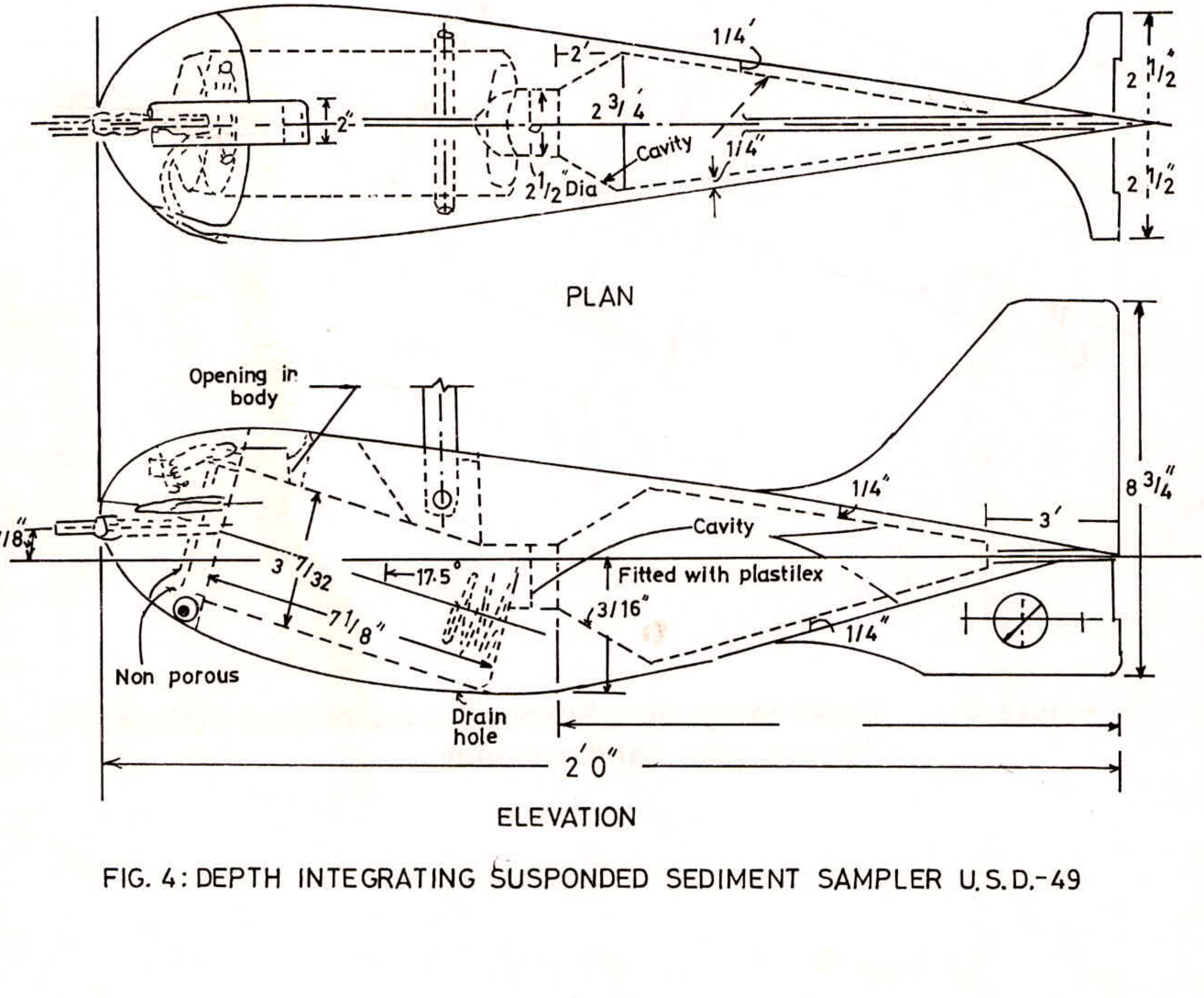


FIG. 4: DEPTH INTEGRATING SUSPONDED SEDIMENT SAMPLER U.S.D.-49

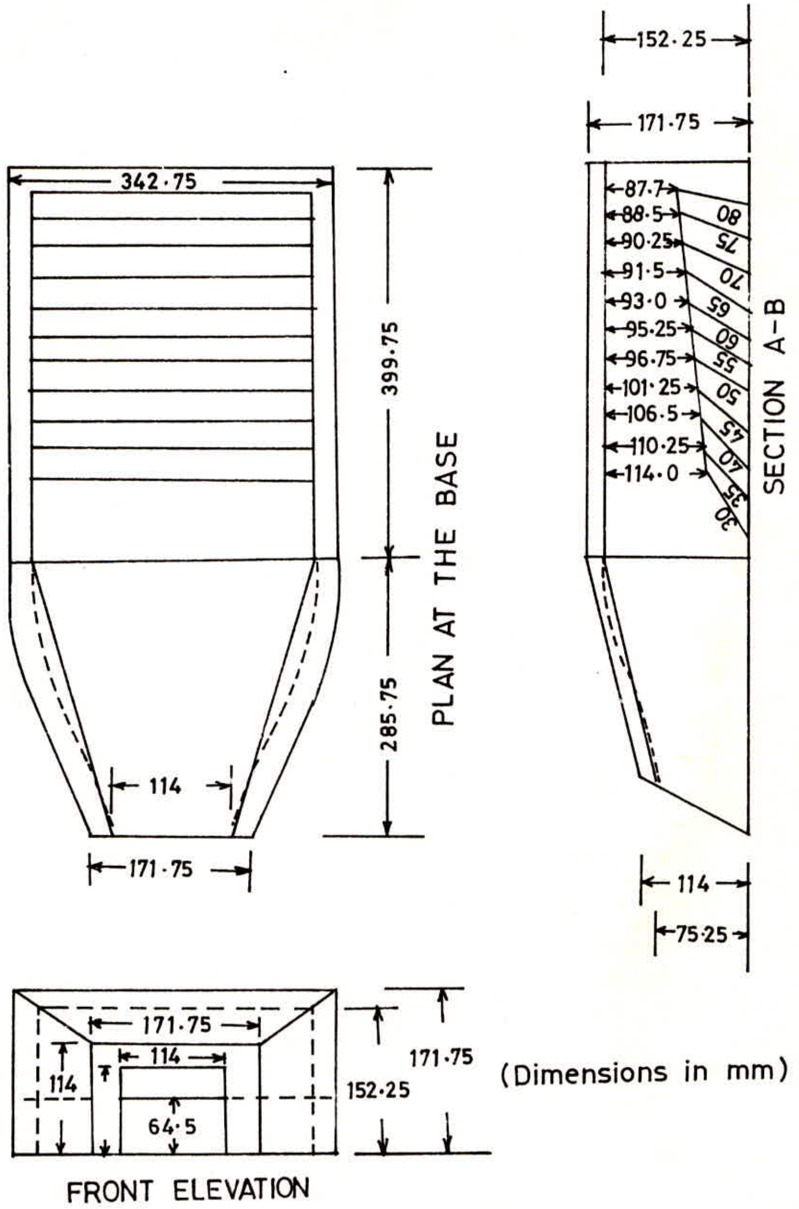


FIG. 5 : RUSSIAN TYPE BED LOAD SAMPLER (3/4 SIZE)

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