Application of Tracer Techniques in Studies of Sediment Transport in Vietnam

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SUMMARY. The tracer techniques which have been applied since 1991 in Vietnam have provided maritime managers for a very efficient tool to obtain idea on the dynamic of sediment transport in estuarine and coastal environments where hydrological conditions are very complicated. The qualitative and quantitative information on suspended sediment movement and bedload transport in Haiphong harbour area under the effect of northeast monsoon and southeast monsoon was obtained by using Sc-46 and Ir-192 labelled glasses as radioactive tracers. The influence of dredging materials on sedimentation rate in Haiphong access channel at two dumping sites was estimated by radioactive tracer technique. Successful application of such an advanced technology in a developing country is presented. In bedload transport studies, apart from conventional methods for assessment of transport thickness, a new method using the ratio of photoelectric peak to Compton region in spectra acquired directly on the sea bed was put forward and applied.

I. INTRODUCTION

Vietnam is a country with tropical-monsoon climate and with high annual rainfall which condenses in rainy season. The network of rivers which are oriented in the NW-SE direction has rather high slope. As a result of intensive weathering and erosion processes under the humid tropical climate condition as well as of human activities destroying forests, grasslands and protective mangrove swamps most navigable estuaries in Vietnam suffer greatly from sedimentation. Though a large amount of money is spent annually on dredging, 10.000 draught weight vessels can not enter or leave the ports. For these vessels or heavier ones a part of their cargo must be transferred at the open sea before they can enter the port.

Efforts have been made by both national and foreign organisations to improve this situation (1, 2). However, owing to the complexity of sedimentation processes in estuarine areas under hydrometeorological conditions, information given by mathematical models is not good enough, especially in the case of lack of a reliable database that would result from a systematic hydraulic and sedimentary survey. In order to obtain an idea on the dynamic of sediment transport and to verify the modelling approach in the areas with such a complicated hydraulic conditions, the isotope tracer techniques have been developed and employed since 1991.

Using the case of the Haiphong port, this work describes technical aspects in the use of tracer techniques to study sediment transport, both suspension and bedload, in the coastal and estuarine environment. Some results are then briefly presented.

II. MATERIALS AND METHODS

2.1. Study of Bed Load Transport

In sediment transport studies using tracer technology, sedimentation dynamics can be investigated by observing the movement of tracer materials. Therefore, the tracer material should behave in the same way with respect to hydrodynamic effects as natural sediments when both are exposed to the same sedimentary or hydraulic transport conditions (3, 4). Scandium and Iridium-labelled glasses have been used as tracers in the studies of bed load transport. For easier interpretation of the measurement data, the granulometric distribution of the tracer was selected so that it could lie in the range of 30% either side of the median mass of the natural sediment. In tracer experiments carried out at Haiphong area, the selected size fraction in average is from 10 μm to 100 μm with the median mass (D_{50}) of 30 μm.

The mass and activity of the tracer were calculated relying on the equation put forward by Sauzay and Courtois (4) and on data of hydrodynamics in the region of interest. Generally, for the Haiphong harbour area, an amount of at least 80g tracer, which contains about 2.5×10^8 particles with grain-size distribution the same as natural sediment, with the activity of 2 Ci is required by most of bedload transport studies.

After irradiation, quartz ampoules containing radioactive tracer were put in injection devices with 5 cm thickness of lead. The injectors then were placed into the transport container with 10 cm thickness of lead. By rotating a stainless steel disk mounted in the injector, quartz ampoules were pressed and broken. This operation took place on the boat deck while the injection device was in the transport container. To release the tracer material onto the sea bed, the injection device was winched off the transport container, immersed in water and then the bottom of the injector was opened pneumatically at the distance of 1 m above sea bed. The detection was carried out by dragging a sledge mounted the detector NaI(Tl) 2" x 2". The boat was positioned by Global Positioning System 5000 DX. The detection frequency is about once a week.

The bed load discharge q across a section perpendicular to the result direction was estimated by the following equation (5):

$$q = \rho L V_m E_m, \qquad (1)$$

where q is given in t/d,

ρ is the specific gravity of sediment in situ,

L is the transport width,

V_m is the mean transport velocity,

E_m is the transport thickness.

The parameters to be determined are V_m and E_m. The mean velocity V_m of the bed material was determined by the ratio of the distance between centroids of the spatial tracer distribution to the time interval between the detections.

The mean transport thickness E_m was estimated in two ways: the direct technique is to take cores and subsequent counting of the slices obtained. The second method put forward by the Dalat Tracer Group is to use the ratio of the photoelectric peak to the Compton region in the gamma spectrum recorded in the field. The transport depth could then be determined after a previous calibration at laboratory. With this method, the mean transport thickness could be assessed by acquisition of a gamma spectrum while dragging the detector across the radioactive cloud.

2.2. Study of Suspended Sediment Movement

The study of the movement of suspended sediment was carried out at the Haiphong area in 1996 for the definition of dumping sites. The tracer material used was Ir-192 labelled glass with grain size selected in the same way as described above. Due to some reasons, it was not possible to label the full load of a suction hopper dredger, instead an amount of 80g Ir-192 glass was injected into a bucket containing 60 litters of mud at a concentration of 200 g/l which is the average density of spoils. After tracer material had been well mixed pneumatically with mud, the mixture was released at a distance of 1 m below sea water surface.

The detection procedure was in two ways: The first one was the same as that for bedload studies with the attention that the tracking should be performed after about 3 to 4 hours from the injection. The spatial tracer distribution could give the following information: (i) the path and drift caused by currents; (ii) the dilution of the sediment; (iii) the amount of sediment settled on a given area at a given distance from the injection point; (iv) the area over which the sediment was deposited. The second method was that two detectors were mounted on a wooden pillar, which was attached to the boat, at different depths. The detection was carried out immediately after the injection. The behaviour of suspended sediment under hydraulic condition could be known by employing a mathematical model for dispersion and sedimentation of fine particles (6, 7, 8). However, owing to the use of only one boat, the information obtained on suspended sediment was limited. Moreover, the weather condition was not good in the day of injection, at two dumping sites only the information recorded at 2 injection points among four was good enough. Thus, most of qualitative and quantitative information on suspended sediment transport for all injection points was derived from the spatial distribution of tracer settled onto the sea bed right after the injection.

III. A CASE STUDY ON HAIPHONG HARBOUR

3.1. Some Sediment Transport Problems in the Haiphong Harbour Area

Located 100 km east of Hanoi, on the coast and with a number of nearby navigable estuaries and waterways, Haiphong is a major port and important industrial harbour in the northern part of the country (Fig. 1). The hydraulic and sedimentary regimes of the water courses in the Haiphong area are influenced by two river systems. The first system, the Red River, flowing in the south of Haiphong, discharges a large amount of alluvium into the sea in the form of red mud (about 200 million tones a year). Under the influence of the south-east monsoon prevailing in summer and autumn, the river-transported red mud continues moving along the coast towards the Haiphong area. The second river system, with its estuaries located north of Haiphong, is not much muddy in its upstream and middle sections as the first one. However, owing to the interconnection between the two systems in the delta region, a huge amount of alluvium from the Red River is also transported to the nearby Haiphong estuaries of Cam and Namtrieu. As a result of these sediment transport processes, a 38 km long access channel through the Namtrieu estuary is suffering from heavy silting. The port authority and Vietnam Maritime Safety Agency (VMS) wanted to know reliable and full information on sedimentary processes in the region in order to make a decision either they should continue maintaining the navigation channel or construct a new one.

A number of engineering schemes were proposed to reduce the sedimentation rate along the access channel. Unfortunately, they were not supported by detailed and reliable sediment transport studies. Hydraulic and sedimentary surveys carried out in the past by different groups of researchers resulted in quite contradictory conclusions about the pathway of the sediment being deposited along the channel.

3.2. Determination of Silting Rate in the Access Channel

In order to verify the accuracy of data given by mathematical models and to estimate the bedload discharge in a navigation channel section where the sedimentation was thought to be the most serious, some investigations using Sc-46 glass were carried out on both sides of the channel between buoys number 10 and 12 (Fig. 1).

The first experiment was performed from Dec. 17, 1992 to March 7, 1993 on the southern side of the channel. About 4 Ci of Sc-46 were injected at point DT1 (Fig. 1) which is 800m far from the alignment of buoy 10 with buoy 12. The detections were carried out on Dec. 19, 23 and 30, 1992 and then on Jan. 6 and March 7, 1993. The results of bedload discharge and the azimuth of the sediment transport axis were given in Table 1.

To verify the results obtained from the first experiment and to get the information in a larger area as well as to redress some unexpected mistakes that may happen in the first use of tracer technique, next investigation was undertaken on Oct. 10, 1993 and lasted nearly two months. An amount of 4 Ci Sc-46 radioactive tracer was released at point DT2 (Fig. 1) on the alignment of buoy 9 with buoy 10 and 900m distant from buoy 10. The results of bedload transport under the effect of northeast monsoon were given in Table 1.

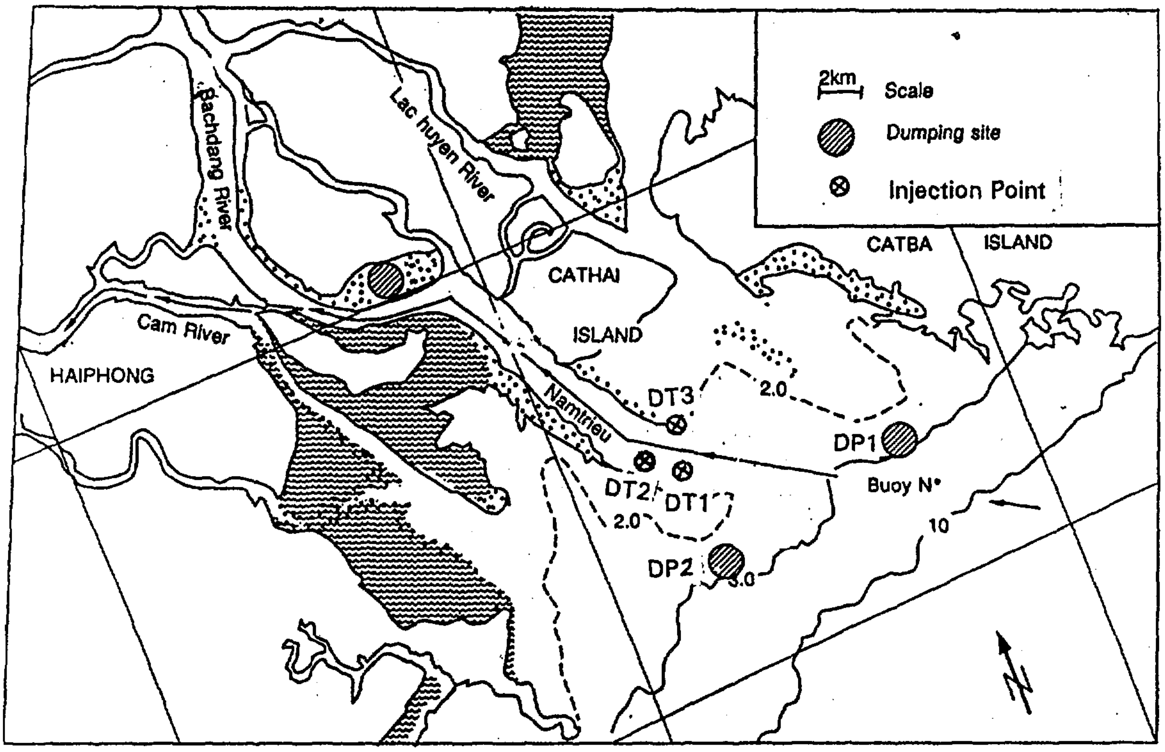

Figure 1. The Haiphong estuarine area

The investigations mentioned above took place under the influence of the northeast monsoon predominating from October to February of next year. In order to study the effect of southeast monsoon prevailing from April to August on the movement of bed materials in the section, an amount of about 4 Ci of Sc-46 glass was injected at point DT3, on the northern side of the section (Fig. 1), on May 23, 1995. The detection was implemented from May 29, 1995 to July 5, 1995. The movement direction, the transport rate and sediment discharge were shown in Table 1.

The results proved that the bedload discharge varies from site to site and depends on monsoon season. However, the movement direction of bed material is of a little bit of difference.

3.3. Study of Dumping Sites

In order to maintain the necessary depth for the 7.000 tons vessels entering and leaving the port, a large amount of bed material, about 2 million tons, needs to be dredged annually from the channel bed. Dredging spoils were usually dumped at two sites DP1 and DP2 (Fig. 1). However, no evidence was obtained on whether the dredging material came back or not. At the request of VMS, the experiment on the study of fate of the dredging spoils under different tidal conditions was carried out from Nov. 20, 1996 to Jan. 20, 1997 using Ir-192 labelled glass.

At each dumping site, the tracer material was injected at two points, 2 Ci of Ir-192 for each point, with a distance of 400m far from each other. The injection was carried out during ebb tide for the first point and during flood tide for the second one. The movement of suspended sediment was followed in the day of injection. Besides, the movement of bed material was investigated for two months. The procedures for preparation of tracer material, injection and detection were described above. Results obtained about the movement of dredging spoils after deposition on the sea bed at four injection points, which are A1, A2 in dumping site DP1 and B1, B2 in dumping site DP2 were given in Table 1. The information on movement of suspended sediment gained from the investigation was given in Table 2.

Table 1. Main results obtained with bottom sediment transport studies

Injection points	Time interval considered	Bedload transport rate (kg.m^{-1}.d^{-1})	Azimuth of the sediment transport axis	Angle between the sediment transport axis and the alignment of the channel
DT1, Winter	19/12/1992 to 07/03/1993	459	350°	45°
DT2, Winter	10/10/1993 to 21/11/1993	380	340°	35°
DT3, Summer	23/05/1995 to 05/07/1995	276	330°	25°
A1, Winter	20/11/1996 to 20/01/1997	173	345°	40°
A2, Winter	26/11/1996 to 20/01/1997	238	357°	52°
B1, Winter	29/11/1996 to 20/01/1997	204	335°	30°
B2, Winter	01/12/1996 to 20/01/1997	272	40°	95°

Table 2. The percentage of tracer material settled on the region of interest along the drift direction at two dumping sites DP1, DP2

Region of interest from the injection point	Dumping site DP1				Dumping site DP2			
	Injection point A1, ebb tide	Azimuth of the drift direction	Injection point A2, flood tide	Azimuth of the drift direction	Injection point B1, ebb tide	Azimuth of the drift direction	Injection point B2, flood tide	Azimuth of the drift direction
from 0 to 100m	56.6%	240°	33.3%	355°	58.0%	180°	38.7%	38°
100m - 200m	15.2	240°	18.0	355°	12.6	180°	16.3	38°
200m - 300m	8.3	240°	10.0	355°	4.3	185°	13.5	38°
300m - 400m	6.1	215°	4.7	350°	2.7	190°	11.1	38°
400m - 500m	7.4	215°	5.7	350°	4.1	190°	10.6	45°
500m - 600m	4.2	230°	5.2	330°	3.4	190°	5.5	55°
600m - 700m	2.1	230°	4.5	330°	3.7	190°	4.2	55°
700m - 800m			4.4	330°	3.5	190°		
800m - 900m			4.3	330°	3.0	190°		
900m - 1000m			3.2	330°	2.3	190°		
1000m - 1100m			4.2	330°	2.0	190°		
1100m - 1200m			2.5	330°				

IV. CONCLUSIONS AND RECOMMENDATIONS

Though the tracer technique has been applied recently for study of sediment transport in Vietnam, it nevertheless has proved its effectiveness to the port authorities and hydraulic and sedimentary specialists. The most important advantage of the tracer method is that it is able to integrate the effect of all hydrodynamic agents that have acted upon the sediment for a period of time. However, tracers can only give the information in a restricted area during the investigation. In hydraulic and sedimentary surveys the tracer technique is combined with other methods such as the modelling approach and conventional procedures to acquire data in a large area. In this case, tracers can be used as an efficient tool for calibrating models.

From 1991 to 1996, the use of radiotracer technique in studies of sediment transport was carried out in collaboration with a group of Transport Engineering Design Inc. (TEDI) that had implemented the UNDP project VIE/88/014 on hydraulic and sedimentary surveys at Haiphong harbour area. At that time there was also a project undertaken by HEACON-Harbour and Engineering

Consultants, Belgium to solve the sedimentation problem in that area. The tracer technique provided the experimental data on suspended sediment movement and bedload transport in some pivotal regions in Haiphong harbour area for maritime managers and specialists.

Although the radioactive tracer technology for investigating sediment transport has now been successfully applied in a wide range of coastal engineering, the quantitative estimate of rates of bed-load transport, particularly the thickness of mobile layer, need to be studied further for improvement. We had some difficulties in using the "count rate balance method" for determination of transport depth. The loss of tracer material near the boundary area owing to the dilution of tracer as well as the loss in the hottest area of radioactive cloud due to the omission during detection are the main obstacle in the use of that method. Moreover, knowing the exact radioactivity of tracer is not easy for us in that period of time. Beside the radioactive tracers, identifying the element which can serve as the activable tracers seems rather attractive. This work has been done in Haiphong harbour area. However as the number of sediment samples collected and analyzed are still insufficient, the conclusion is not presented in this paper.

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