

# The Use of Marine Geophysical Methods in Geo-Engineering Investigations of Dams/Barrages - A Case Study of Kosi Barrage

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## INTRODUCTION

Dams and barrages are such civil engineering structures where foundation is submerged. The impounded water column may be shallow or deep and flowing or static. Often investigations may be required for various purposes such as pre-construction survey to ascertain foundation characteristics or post-construction check up for verifying certain design parameters. The foundation, since covered by the waterbody, is neither accessible for direct inspection nor detailed investigation by divers is always feasible, due to constraints like non-availability of skilled diver, appreciable water depth, strong flows, poor visibility etc. Some other on the spot observations using pole and other elementary probing methods are in vogue. However, usually such investigations would provide only a generalised picture based on isolated data.

Advent of high technology, developed over the years, mainly for offshore oil explorations, has made it possible to obtain reliable data of better quality necessary for various underwater investigations. Vora and Raju (1986) and Raju and Vora (1987) have shown some examples of this. It is possible with these methods to find out continuous water depth, nature of topography, thickness and type of sediments, siltation, scouring pattern etc. applicable even to a fresh water reservoir. The paper aims at presenting how this primarily 'marine geophysical' technique can be helpful in design and maintenance of dams and barrages, with a case history from the Kosi Barrage, Birpur, Bihar.

## THE KOSI BARRAGE

The Kosi barrage is situated at the foot hills of the Himalayas at Hanumannagar in Nepal, near the Indo - Nepal border in the Birpur district of the Bihar state of India (Figure 1). The barrage was commissioned in 1963. The barrage has two canals on the either sides of banks. The drainage area of the river, prior to the barrage site, is about 65,000 sq. m. The catchment area includes Mt. Everest and Mt. Kanchanjunga. The sediment load, measured upstream of the project site is about 2000  $m^3/m^2/year$  while silt content is 3310 ppm (Rao, 1979). The irrigation area of the project in the Nepal is about 12,150 ha.

The Kosi barrage was constructed mainly to prevent the river from moving sideways by regulating the river flow as required and also for the purpose of irrigation and power generations. The barrage, about a kilometre long, consists of 52 sluice gates to control the flow of water which are opened as and when required. On upstream as well as downstream

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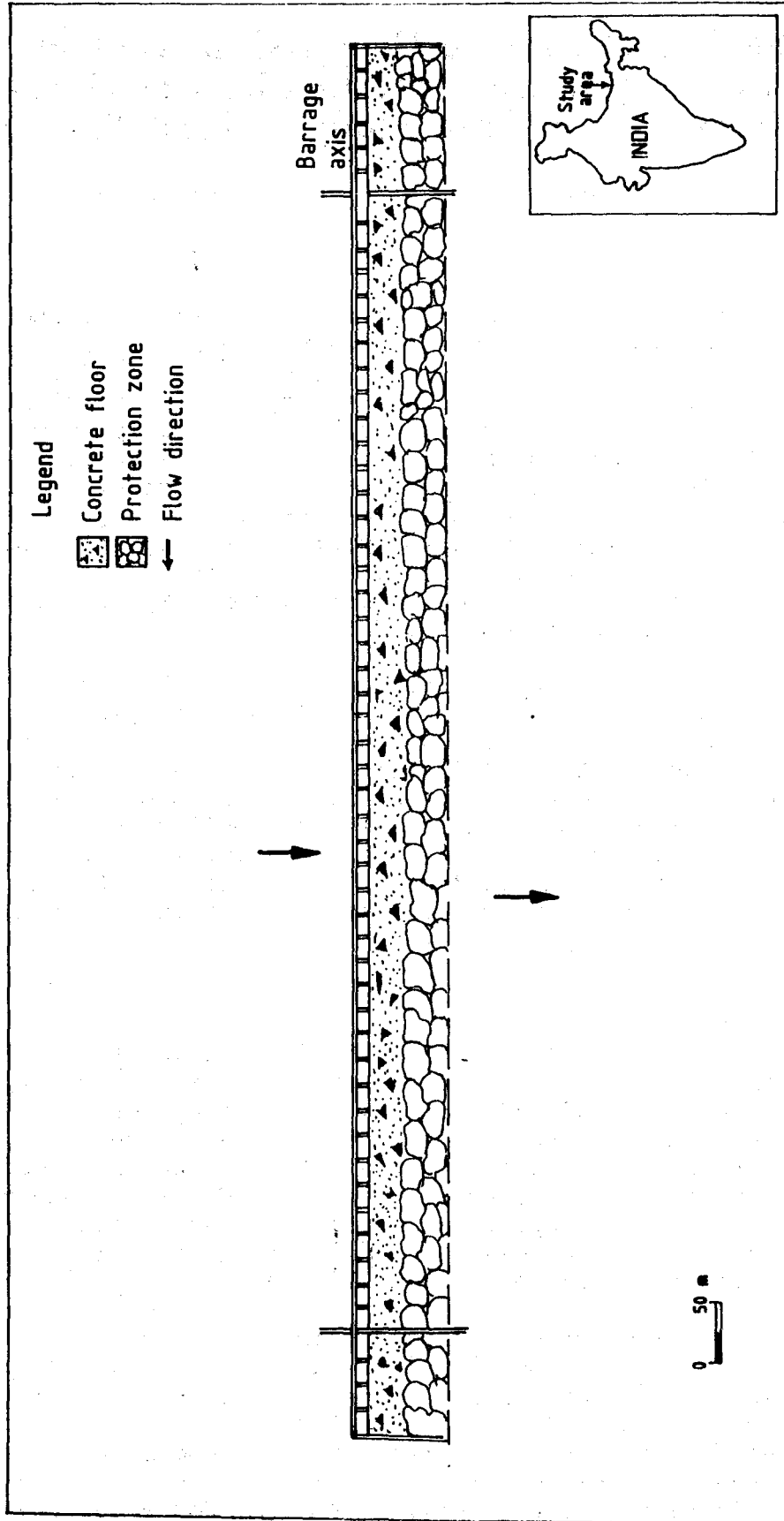


Figure 1

side the barrage, about 33 m wide concrete floor followed by about 60 m wide protection zone consisting of concrete blocks and boulders as a protection against scouring and erosion have been provided.

#### **NATURE OF PROBLEM**

The settlement of flexible protections and the concrete floor were suspected due to scouring and erosion after about 20 years' operation. Regular methods of probing confirmed the same and some remedial measures were initiated to reinforce the foundation to prevent any serious damage. In order to assess the status of the concrete floor, settlement of flexible protections, and progress of remedial measures taken, high resolution, integrated surveys using echosounder, side scan sonar and subbottom profiler, aided by electronic position fixing system were carried out by the National Institute of Oceanography on the down-stream side of the barrage.

#### **GEOLOGICAL SETTING**

The Kosi river, for the most part of its length, flows through the geological formation known as Siwalik system. The Siwalik system is confined to Middle Miocene to Lower Pleistocene and is made up of sandstones, grits, conglomerates, pseudo conglomerates, clays and silts having character of fluviatile deposits of torrential streams and floods in shallow fresh water basins (Krishnan, 1968). The Siwaliks has been involved in the later phase of Himalayan orogeny for we often find them folded, faulted, overthrust and lying at steep angles against other formations.

The river Kosi is formed by the confluence of three rivers, the Sun Kosi, the Arun Kosi and the Tamur Kosi. The river, with high sediment load and steep gradient, flows with force and erodes the sediments available in the catchment area and transportation of bed load is aided by the favourable downward gradient.

#### **EQUIPMENTS AND METHODS**

##### **Echosounder**

An echosounder provides the accurate profile of the bed and is primarily useful for obtaining the continuous water depth prevailing in the survey area. Echograms also provide the topography of the area. During the present survey an Atlas deso-10 echosounder (Frequency 210 KHz) was operated.

##### **Side-Scan Sonar**

The system essentially gives a plan view of the floor and provides information on lithologic and topographic variations. In this system, the transducers are fixed on the either side of the tow-fish for the transmission and reception of the sonar signals and the interpretation is based on the tonal variation recorded. An EG&G Mark 1B Side-scan sonar system (with a model 259-4 dual channel recorder and a model 272 tow-fish) was deployed for the surveys.

### Shallow Seismic Profiling

The seismic reflection method, provides vertical cross-section of the bed with the sub-bottom information. The method involves generation of sound pulses having specific characteristics which varies with different purposes. For the purpose of high resolution sub-bottom profiling, 3.5 KHz frequency is ideal for which an O.R.E. Shallow seismic profiling system consisting of an EPC recorder, transceiver and side mounted transducer was used during the surveys.

### Miniranger Position Fixing System

Position fixing plays vital role in this type of multi-frequency, high resolution surveys where prime requirement is better accuracy as well as good repeatability. A Motorola Miniranger III system consisting of a Range console, Data processor, Complot track plotter, Track indicator, Base stations and Omnidirectional antenna was operated. When the system is in operation, the mobile station transmits microwave signals which are received and retransmitted by the base stations at shore to the mobile. The time elapsed is converted by the range console into distances from which the data processor works out co-ordinates at each fix.

### River Bed Samples

Collection of river bed samples is a critical requirement to confirm the interpretation of underway geophysical data. For the purpose, a Van-veen grab (area  $0.04 \text{ m}^2$ ) was used to collect the sediment samples from the survey area.

### Survey Vessels

In the absence of availability of a mechanised boat for surveys, a country craft was used. Total 46 tracks perpendicular to barrage axis and 4 tracks parallel to barrage axis were surveyed using these equipment (Figure 2). A base map with a scale of 1:1000 was prepared to which field data from different systems were transferred.

## RESULTS AND DISCUSSIONS

In the beginning the type of data obtained using different equipment are discussed in general in order to comprehend the data properly. Subsequently a synthesis is presented as to how these data provide the necessary inputs to understand the specific problems.

Echograms from the survey area showed that the water depth varied from minimum 0.5 m and 3 m, however, deeper depth of the order of 5 m was observed in scoured channels. The echograms from the area clearly reveal that the bed is by and large, uneven and undulating (Figure 3). However, whenever the vessel traverses across the concrete floor, the echograms are marked by straight, even and horizontal echo trace. The piers/dummy piers could also be identified when the vessel passed over the same.

Sonographs (record of side scan sonar) collected from the survey area clearly depict the barrage structure, concrete floor, piers and dummy piers

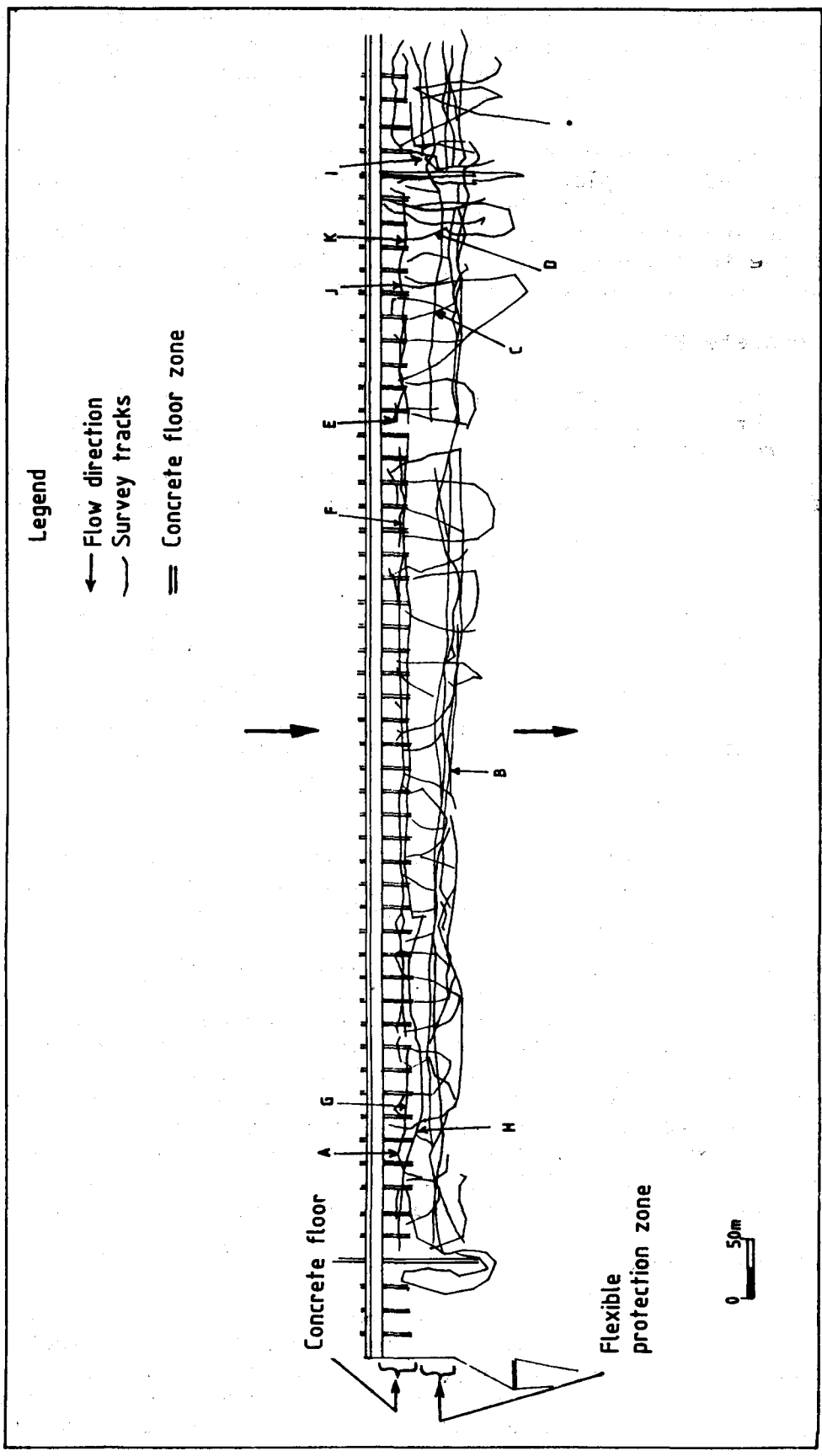


Figure 2.

(Figure 4E) identifiable due to their geometrical pattern and strong contrast. The extent of dumping operation is marked on the sonographs by their strong tonal contrast and irregular shape while the silt/sand occurrences are conspicuous by their light contrast and the natural shapes. The sonographs data are in confirmation with the echograms.

The shallow seismic records collected from the area show limited penetration of 2-3 m at places (Figure 5H and 5I). The information on sub-bottom is restricted due to the presence of coarse sediments and further, is masked by multiple reflections due to shallow depths and hyperbolic reflections due to close by spaced piers. However, in spite of these, the concrete floor and dumped material can also be identified.

### **Status of Concrete Floor**

In the Kosi barrage the concrete floor was laid at 67.7 m from datum. The depths obtained from echogram were corrected in order to obtain the depth with respect to this datum. For the purpose water levels on down stream side were recorded at every half an hour interval. Considering accuracy of the method of  $\pm 0.2$  m, it was observed that the bed level at places was higher than the original level or at the same level, i.e. at 67.7 m within the zone of concrete floor (Figure 3 c and 3 d). The higher values indicate the siltation on concrete floor. At no places the bed shows value lower than  $67.7 \pm 0.2$  m or unevenness near the location of floor which may suggest depression or erosion. The sonograph do not show any depressions in the zone of concrete floor. The sub-bottom profiler records help in identifying the concrete floor at the original level even when buried by about 2 m thick sediment (Figure 5J). This implies that, in general, the concrete zone is not seriously damaged or eroded.

### **Status of Flexible Protections**

The flexible protections, i.e., concrete blocks and boulders were laid at same levels as concrete floor initially. The shallow seismic profiles were studied to ascertain the depth at which they are now lying.

It was presumed that the boulders will form the acoustic basement which will indicate the settlement of the flexible protections, if any. However, in practice the presence of coarse sediments (generally coarse sand) has considerably reduced the penetration. Also, as the boulders might have settled to different depths, the uniform, coherent interface, which may result in strong reflector is absent. Hence, the maximum depth recorded on the echograms and the deepest reflectors observed on the subbottom profiles are considered to work out the minimum level of settlement/scouring (Figure 5 H to K). Based on these, the locations where settlement of protection material is inferred are shown in Figure 6.

### **Status of Remedial Measures**

Remedial measures, by way of dumping of boulders in rope - crates of about  $1.2 \text{ m}^3$  had been initiated at some places by the barrage authority based on their own investigations prior to present surveys. Accordingly, it was intended to verify the horizontal and vertical extent to which the work has progressed. The echograms show the height to which the dumped

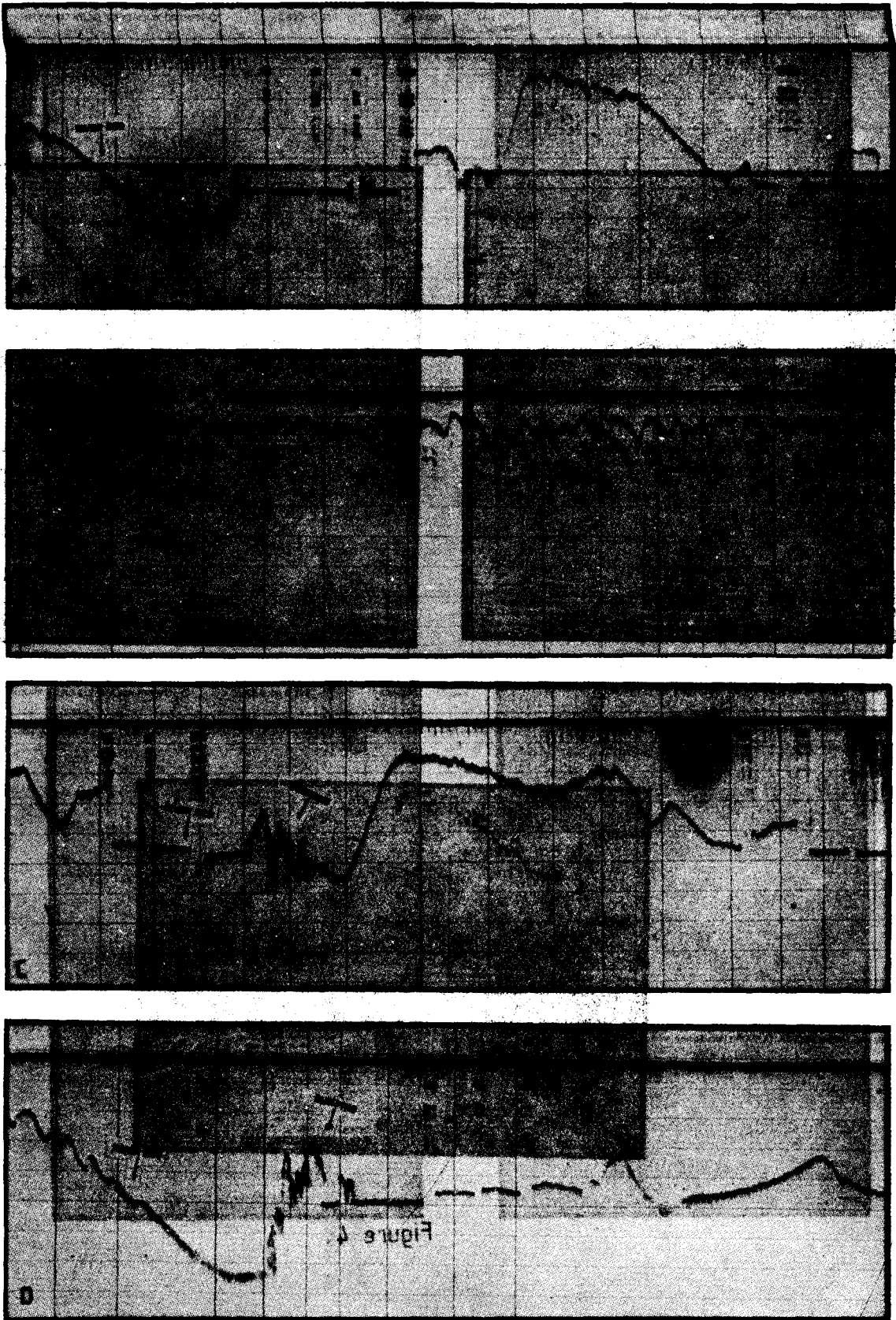


Figure 3.

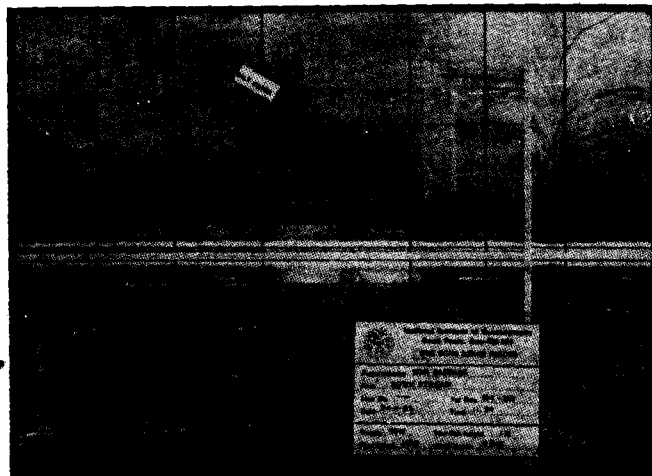
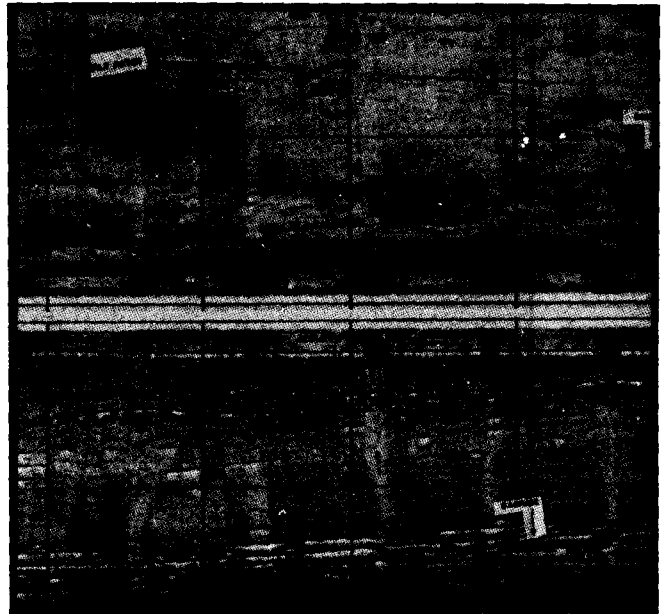
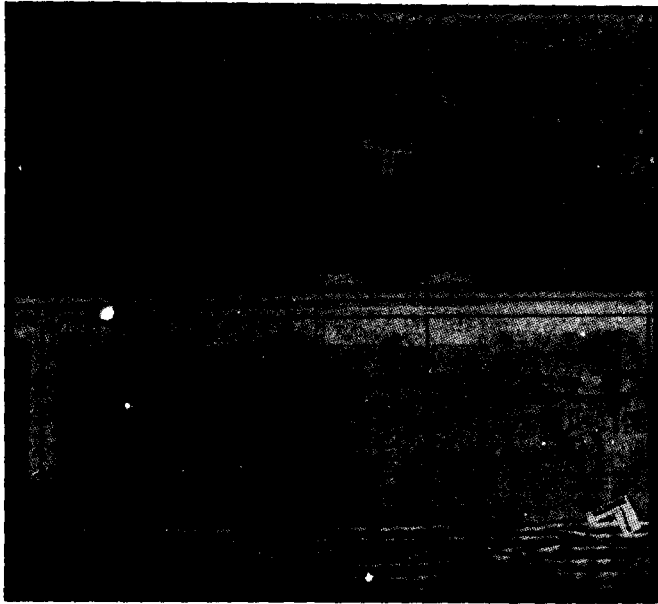


Figure 4.



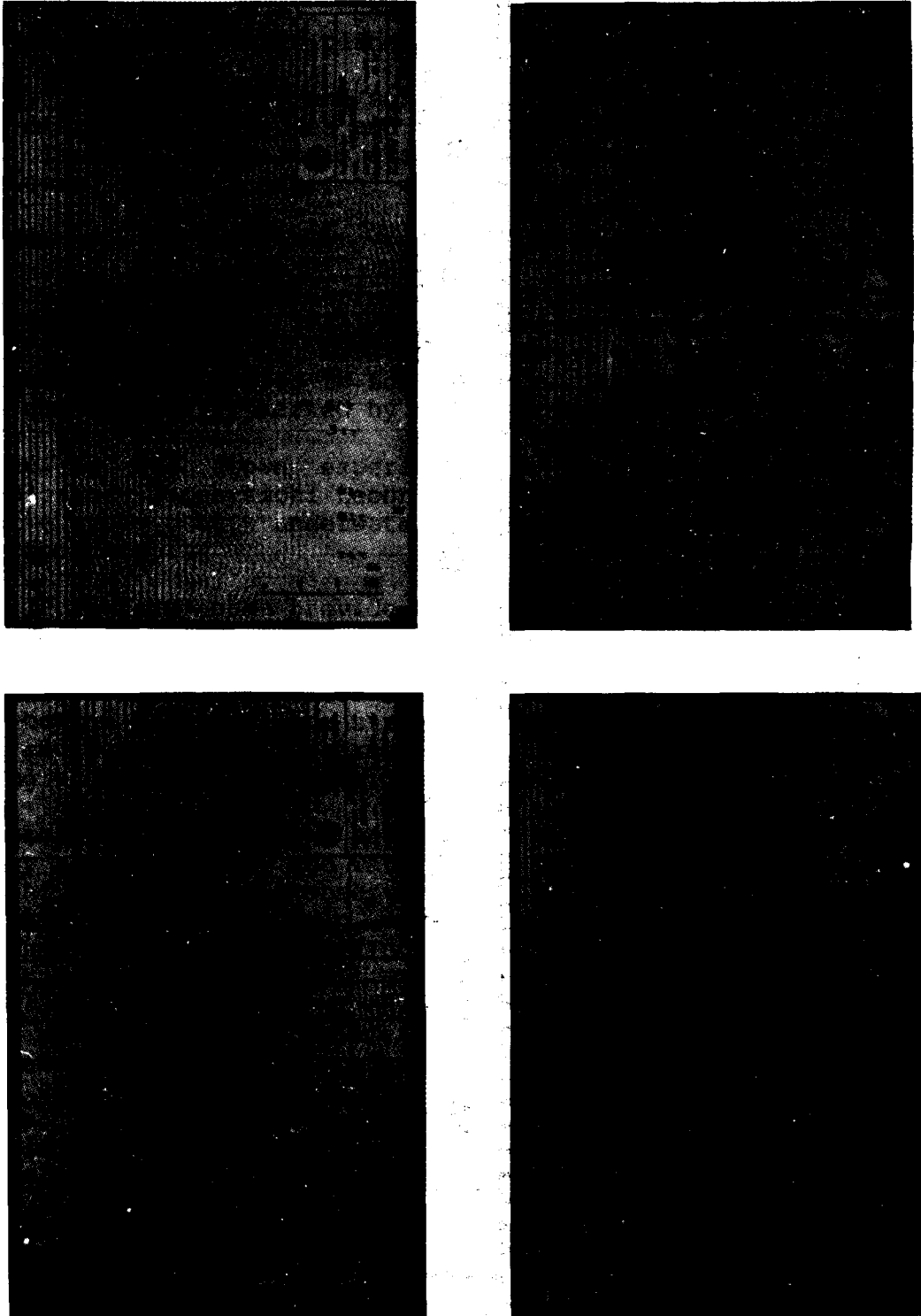


Figure 5.

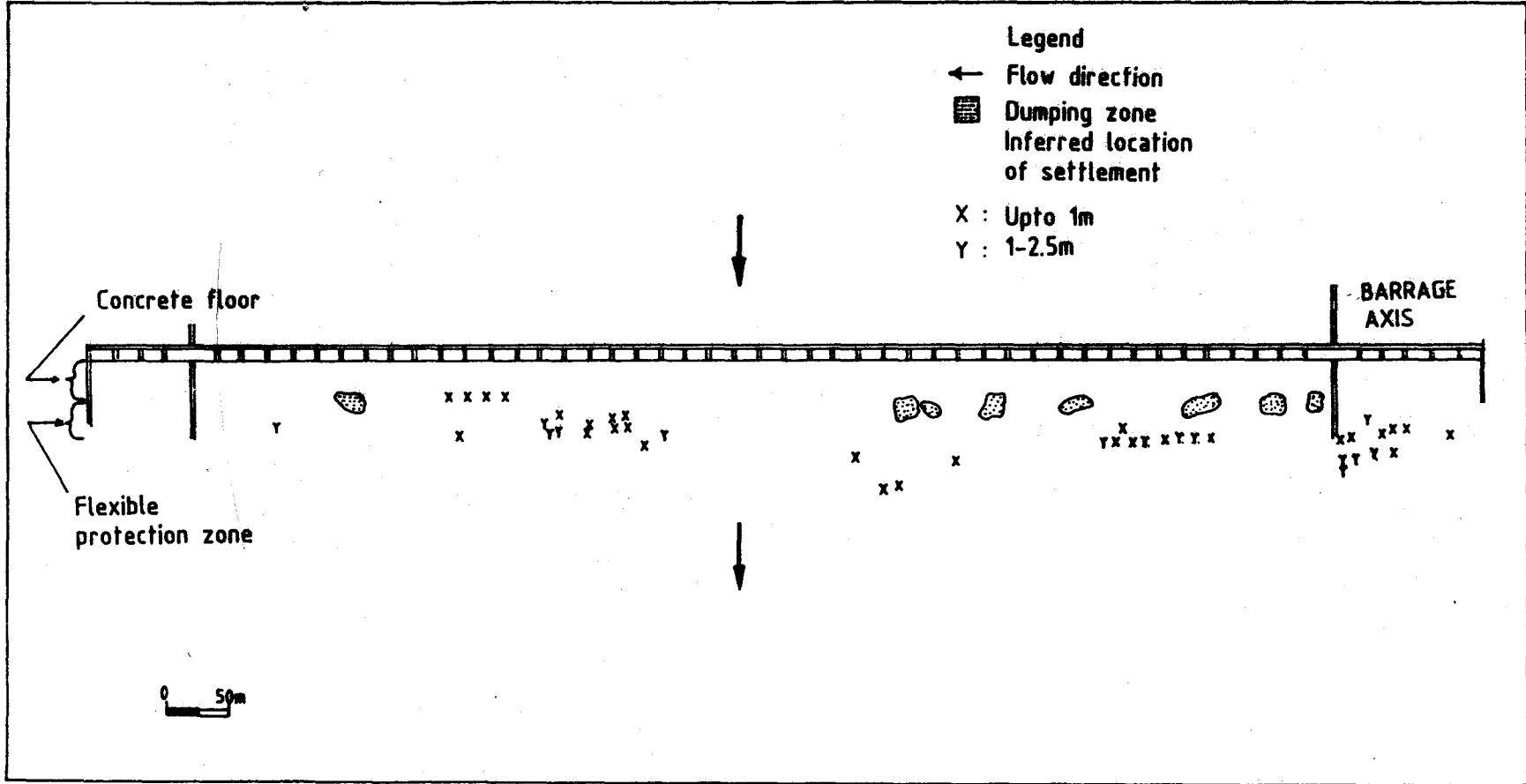


Figure 6.

material has reached (Figure 3 C and 3 D). The area where dumping is carried out is made free of sediments by flushing with water which also can be observed on the echograms. Shallow seismic records also confirm the same (Figure 5 J and 5 K). Sonographs depict the horizontal extent to which the dumping has taken place (Figure 4 E and 4 F).

Both, the echograms and sonographs provide qualitative idea on the progress of remedial measures and can help in determining further course of actions. Theoretically, it is also possible to quantify the amount of work done, however, better positional control is required for the purpose.

## CONCLUSIONS

The analysis and interpretations of the geological and geophysical data collected from the area do not indicate any apparent damage to the concrete floor of the Kosi Barrage. However, settlement of the flexible protection can be inferred to some extent. The progress of the remedial measures can be clearly marked by the data collected.

Based on the above experience, it can be concluded that marine geological and geophysical techniques can be deployed advantageously in different types of underwater investigations including one for dams/barrages also.

The echograms can provide continuous depth variations and the geomorphic nature of the area. If the depth obtained can be correlated with local datum then information on accurate levels of submerged features also can be deduced. Repeated over the years, preferably in conjunction with sub-bottom profiler, the study may provide much needed information on dynamic sedimentological character of the area, especially, on the prevailing erosional or depositional phase.

Sub-bottom informations are clearly discernible if the sediments in the study area are finer and water depth is say, more than 5 m or so. If significant penetration is observed, then the thickness of sediments can be ascertained which can help in estimating sedimentation rates and depositional pattern beside finding the levels of any buried object or settlement, if any.

The sonographs can supplement the above information to great extent and can indicate presence and absence of any natural features like periodic bedforms, sand - clay boundary etc. This again may provide the much needed input on the prevailing hydrodynamic regime, litology etc. The confirmation of presence of man-made features by sonographs also may have its own value depending on nature of the problem.

The integration of this high resolution, multi-sensored data can help in solving many typical problems of the barrage/dams in pre or post constructional stage.

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