

Application of acoustic techniques for exploration of submerged area in connection with hydro-projects

The knowledge of geological environment prevailing in the foundation zone can enhance an engineering assessment for planning and designing. So far as submerged site is concerned only elementary methods, mostly based on probing or spot diving, is deployed to collect required data. The acoustic methods, primarily invented for offshore hydrocarbon prospecting very successfully, be applied for pre-feasibility surveys for various engineering projects, for example, dams or barrages, submarine pipeline route selection, developments of ports and harbours, etc. as also for post-constructional inspection like determination of exposed pipeline, or extent of siltation in reservoir.

The acoustic methods use sound waves of different characteristics to obtain required penetration and resolution for cross-sectional profile through prevalent stratigraphic column. While echosounder records changes in vertical axes, i.e. depth, side-scan sonar supplements data on horizontal axis on the seafloor. The sediment type and thickness can be inferred from shallow seismic profiles. These high resolution multi sensor surveys should be accompanied by proper position fixing system and followed by surficial sediment sampling and confirm the interpretation from underway data. A complete information on geomorphological variations and sedimentological regime can be obtained from synthesizing the survey data. Some case histories from gulf of Kachchh, Bombay harbour, Kosi barrage and Manori creek, Bombay are presented which show the usefulness of such surveys.

Introduction

The need for preconstruction information on prevailing soil and geological conditions for a large number of irrigation and power projects including dams, barrages, nuclear and tidal power projects, submerged pipelaying for cooling water intake from or discharge into sea, cannot be over emphasised. At times, post-constructional survey also is necessary to infer upon the safety or stability of the submerged structure. The information provided by divers or probing rod

method may be sparse, discontinuous or conjectural, leading to a very high degree of over designing, resulting in cost escalation or difficulties in execution.

The ultimate objective of the design engineer is to design a structure as cost effective as possible with adequate provision for the safety and maintenance of the same. Engineering experience on land has established the importance of a complete understanding of geological conditions both on site and in the adjacent area. It is generally recognized that a broad geological appreciation of the sediments, bedforms and landforms including information on their origin and geological history can enhance an engineering assessment.

The nature and characteristics of foundation play a vital role in designing a safe and economic civil engineering structure, specially, the characteristics of a particular site have a greater influence on the design of an earth dam than they do on any other engineering structures (Sherard et al. 1963).

For determining the foundation conditions of onland projects, well established standard methods are available for exploration and even in situ testing for various parameters that are required at planning stage; however, only rudimentary methods are used when foundations are submerged. Geological conditions for foundation as also the rate and pattern of siltation in a lake or reservoir may be useful. The prevailing geologic regime can also forewarn some causes of concern. Using data from the regional geological survey, a number of potential geological 'hazards' can be identified. The term 'hazard' may be used to include geological features or conditions that may adversely affect underwater installation such as (i) rapid variation in topography or sediment properties (ii) open or filled channels (iii) areas of rock platforms and mobile sediments (iv) steep slope (v) evidence of seismic activity (Fenin, 1980).

The need for the economical exploitation of the mineral resources of the seafloor, as a result of depletion of reserves of non-renewable natural resources, has led to recent expansion of the techniques for offshore exploration. As a direct outcome of these, there are many equipment available to decipher the submerged sub-bottom. These equipment are portable and can be deployed from a 10-15 m long wooden or

Mr. K.H. Vora, Scientist, National Institute of Oceanography, Dona Paula, Goa 403 004.

iron hulled boat. The present paper briefly describes these acoustic techniques and presents to some extent, how they can be used effectively for the purpose of underwater engineering studies.

Acoustic methods

The methods which primarily depend on generation and detection of acoustic waves are called seismic or acoustic methods. The basis of the method is the theory of elasticity which relates applied stress to the induced strain in any medium. In marine seismics, the stress may be applied by a variety of sources but most commonly piezo electric crystals and stress output is normally described by a number of parameters including frequency and energy level of sound.

The different frequencies have different utilities in marine seismic profiling. As a rule of thumb the lower the frequency, higher the penetration and lesser resolution and vice-versa. The present discussion is confined, however, to high-resolution information which may have limitation on penetration and would require relatively higher resolution. Though primarily devised for marine applications, they can and are being utilised successfully in fresh water environment also. Seismic data is acquired using a system consisting of three main components: An input source, an array of detectors and a recording instrument. Each seismic record is a time record of the output signals which are generated at interfaces in a series of stratigraphic layers because of the changes in acoustic impedance which occur at such boundaries (Macmillan et al., 1979)

The working principle of acoustic system in general, uses a transducer to convert electric signals into a sound beam of specific characteristics which will travel through the water media and get reflected from various points below seabed depending on its properties; reconverted into electrical signals through same transducer or a receiver and printed on a graphic recorder (Fig. 1).

ECHOSOUNDER

The simplest application of the reflection method is known as 'echosounding' which records energy reflected from the interface between the water and soil. Echograms provide continuous measurements of depth below a floating vessel and also topographic variations of the bed. Present trend is to deploy a dual frequency, hull mounted transducer with a frequency of 210- 230 kHz for accurate depth measurement and 12-30 kHz to obtain sub-bottom information on recent clay deposits which can be operated simultaneously. The necessary transducer and tidal corrections are imparted to depth values digitized from echogram and a bathymetric chart prepared. Recently, penetration echosounder has been developed with an operating frequency selectable between 3.5-7 kHz to obtain sub-bottom penetration in soft, consolidated sediments. Modern multi-beam sonar system, when available, is an excellent method to survey a large area in a short time

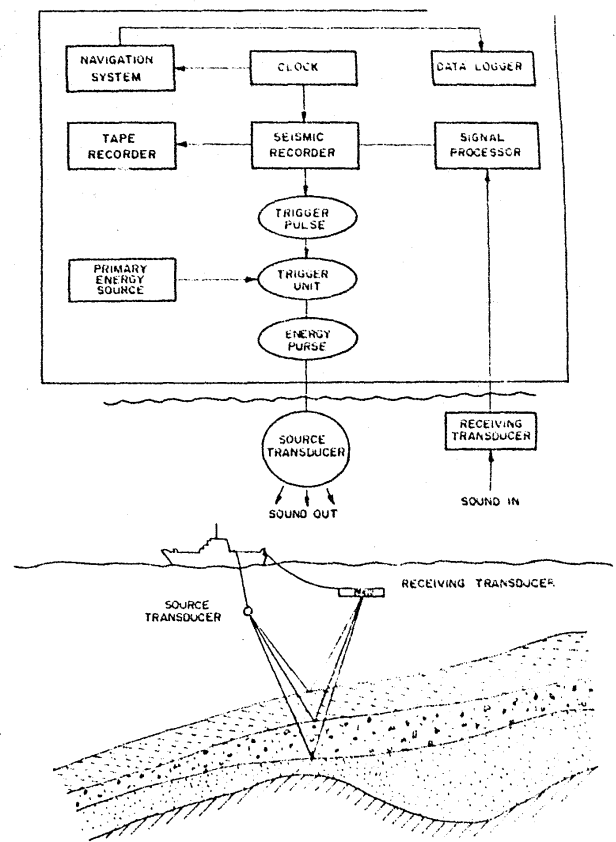


Fig. 1. Schematic diagram showing block diagram of various components involved in echo-sounding and shallow seismic profiling

with high degree of accuracy.

The echogram data can also be used to prepare a geomorphological map of an area where the type of bed, i.e. even, uneven or rugged can be demarcated besides showing accurate occurrence of submerged pinnacle, channel, scrap, ripples, sandwaves, rock outcrops, etc. A typical echogram from uneven topography, Fig. 2B, depicts offshore extension of the river Gomati, Dwarka water depth increases from less than 2 m to about 10 m.

SIDE-SCAN SONAR

The system comprises of two transducers mounted on either side of a tow fish which is towed astern of a survey vessel by a multiplexed cable and connects to a dual channel recorder and tape unit onboard the survey vessel. While echograms provide seafloor characteristics in the vertical axis, the side-scan sonar supplements the information on a horizontal plane analogous to aerial photographs on land by means of tonal variations. Demarcation of boundaries between two lithological units (Fig. 3A) as also the spatial extent and alignment of prominent geomorphic features can be mapped with the help of sonographs (Fig. 3B). Interestingly, the side-scan sonar can also detect exposed pipelines, debris of acro-

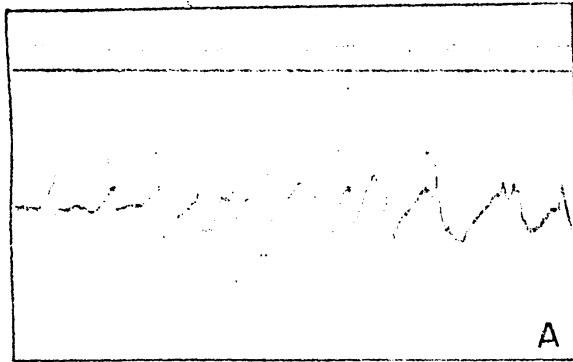


Fig. 2A. A Typical echogram showing uneven topography from Gulf of Kachchh. The vertical bar represents 2 m in 0 -20 range.

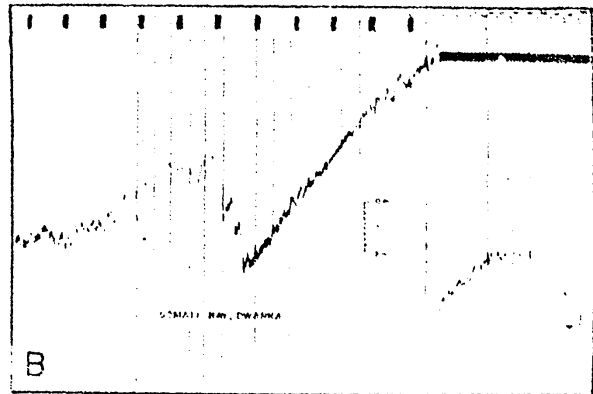


Fig. 2B. The offshore extension of the river Gomati. Note the deeper part of the channel has been eroded away. The dark line on right is due to shift in range from 20 -40 m to 10 -30 m.

plane/helicopter or any other items of significant dimension lying on the seafloor.

CONTINUOUS SHALLOW SEISMIC PROFILER

In principle, shallow seismic systems, also known as sub-bottom profilers, are basically similar to an echosounder; however, in practice, there are some variations besides changes in pulse characteristics, i.e. instead of a common transducer for transmitting and receiving signals, there are two separate transducers, generally referred to as source and receiver. There are different types of sources having varying frequencies and output power for meeting different requirements (Table 1.) They are supported by matching receivers, known as hydrophones and signal processors, filters and recorders.

The sub-bottom profiles depict cross-sectional view of the seafloor along a selected survey track. The thickness and stratal characteristics are discernible from reflector configuration. The acoustic basement or limit to penetration will depend on various parameters like type of system, its output

power and frequency and type of sediments. Fig. 4A shows clearly a channel cutting across 2-3 reflectors. The extent of erosion among clay horizon can be noticed. Fig. 4B shows sub-bottom profile from a highly uneven area carpeted by coarse sand and therefore without any significant penetration.

SOIL SAMPLING

The acoustic surveys, being remote survey methods are necessarily to be supported by the ground truth by collection of surficial soil samples by grab or corer. The location of sampling station may be selected after a preliminary examination of the underway data wherein the seafloor is expected to be covered by clay, sand rock, etc. are demarcated as also some sub-bottom reflectors are seen outcropping at the seafloor. Generally, the reflector characteristics can be correlated with the sediment textures in a survey area if other parameters remain unchanged. Thus, integrated information from all three types of equipment supported by sediment analysis may provide requisite data for structural design. The soil samples so collected are generally disturbed ones; how-

TABLE 1 SUMMARY OF ACOUSTIC SYSTEMS CHARACTERISTICS AND PURPOSE

Sr. no	Acoustic system	Frequency in kHz	Purpose	Application and limitations
1.	Echosounder	210	Accurate depth measuring	Bathymetry and topography
2.	Echosounder	30	Very shallow (2-3 m) sub-bottom penetration	Information on recent soft clay, generally saturated
3.	Side-scan sonar	110	High resolution plan view	Geomorphology surficial geology, rock outcrops man-made objects if exposed on bed.
4.	Penetration echo-sounder	3.5-7	High resolution shallow sub-bottom profiling	Surficial and sub-bottom geology. Approximately 10-20 m penetration in soft clay, reduces in stratified or consolidated clay and almost no penetration in coarse sand.
5.	Boomer	5	-do-	Shallow sub-bottom penetration sometime in sand also and stratified sediments.
6.	Sparker	1-2	-do-	Deeper penetration though resolution may be affected.

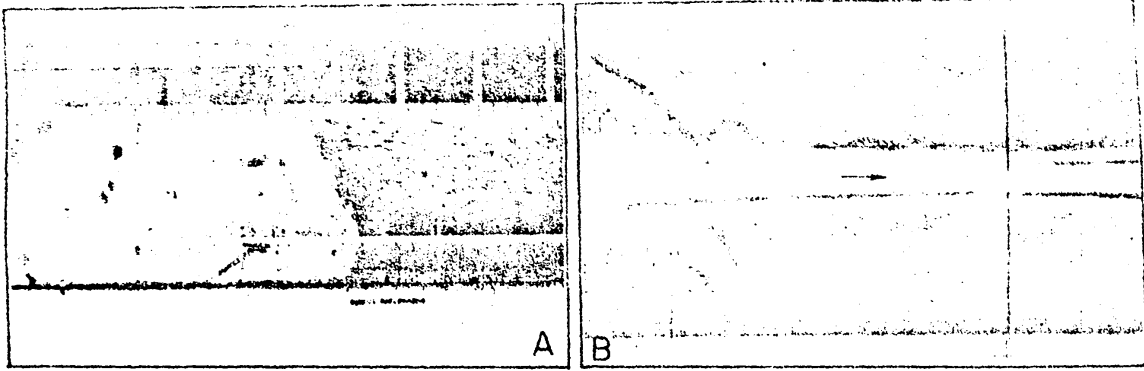


Fig. 3A. A typical sonograph depicting lithological boundary dark tone represents rock while light tone is due to sand. The boulders and rock outcrops within sand are also clearly noticed. The white line passing through the records represents survey tracks and upper portion denotes time marks to correlate subsequently with positions. Area scanned is 100 m strip across the track.

Fig. 3B. A typical sonograph showing sand ripples and sand waves. Each horizontal straight line represents 25 m across the ship's track shown by arrow, the vertical line is time mark. Area scanned is 500 m wide.

ever, they can be used to some extent for geotechnical testing. special care may be necessary to obtain nearly undisturbed samples. Even in situ measurement of various properties are now possible with state-of-the-art equipment available.

POSITION FIXING

No geologic survey, specially marine, are worth any consideration if they are not accompanied by proper position fixing. The selection of the system may depend on many factors including objectives and complexity of the area. If the survey area is close to some known geodetic reference point, perhaps visual system may be deployed; however, when accuracy and repeatability is required, shore based, radio electronic position fixing system may be ideal.

The output data collected by deploying acoustic systems after proper processing and corrections can be presented in

various types of maps and charts as described below which are necessary for proper planning and designing of a structure.

1. BATHYMETRIC CHART

The map showing depth variations, with reference to a suitable datum, in the survey area—generally in meters and decimeters and contours at required interval. In marine waters/nearshore areas generally the chart datum of the naval hydrographic charts is selected; however, in other areas suitable datum can be used.

2. GEOMORPHIC MAP

While the bathymetric chart itself may provide useful information on topographic variations, it is absolutely necessary to prepare geomorphological maps using echograms in conjunction with sonographs. The geomorphic features may provide useful information about the stability of seafloor. The

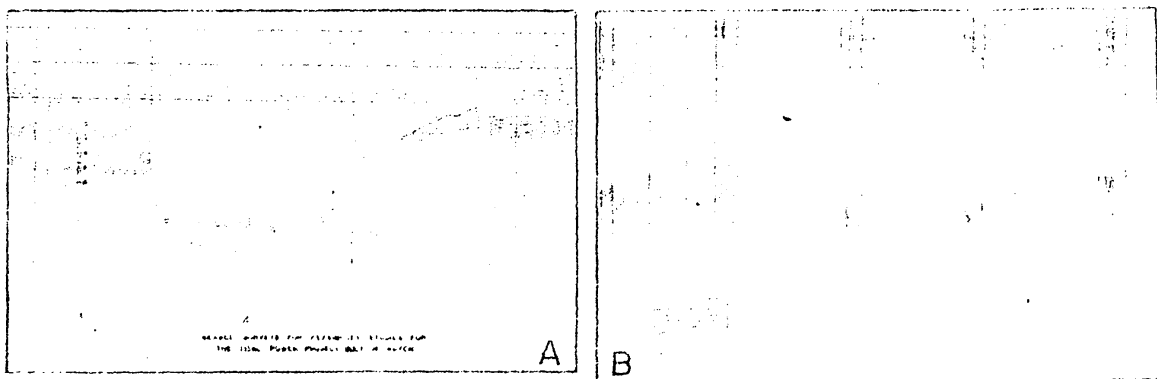


Fig. 4A. A sub-bottom profile from the gulf of Kachchh. Note the channel cutting due to erosion through thick sediment column. Total penetration observed is about 15 m. The vertical scale bar represents 6 m.

Fig. 4B. A sub-bottom profile from uneven zone from gulf of Kachchh which represent a typical record from area marked by sand occurrence resulting in virtually no penetration.

presence of unconsolidated, coarse to medium sediments and sandwaves—sand ripples in an area, for example, will indicate seabed mobility and high tidal range, wave height associated with appropriate current activity may aid scouring. Similarly, presence of scrap may mean tectonic movement or strong erosional phenomenon. A design consideration for pipeline, therefore, may be to bury it suitably, while for a structure additional strength or other precaution may be necessary.

3. ISOPACH MAPS AND CROSS SECTIONAL PROFILES

The sub-bottom profiles and isopach maps collected may provide information on overburden and also the pattern of sediment deposition. Here again, depending on the type of project under consideration, the data can be used accordingly to determine the requisite information, for example, cost involved in dredging or route selection and method of laying submarine pipeline may mainly depend on occurrence of rocks on the proposed route.

4. SURFICIAL GEOLOGICAL MAPS

A comprehensive map depicting surficial sediment distribution and other important geological features, utilizing all the information collected during the course of survey such as type of sediment and its thickness along with bathymetric contours, to arrive at appropriate decision is very useful in selecting pipeline route, etc.

Applications of acoustic techniques for engineering surveys with selected case histories

The selection of equipment to be used will depend upon the objective of the survey as well as geological condition prevailing in the survey area as each equipment has its own limitations. For example, foundation studies require deeper penetration where low frequency acoustic system like sparker can be used while post construction survey may need high-resolution equipment such as penetration echo-sounder. However, in mobile sand or compacted clay environment boomer

may be preferred.

Plossel and Campbell (1980) and Gunsteiksrud and Rokengen (1980) have described the importance of regional geology from engineering implications viewpoint. Hovland and Indreide (1980) have discussed the usefulness of seabed surveys for pipeline across the Norwegian Trench.

The National Institute of Oceanography has carried out large number of seabed surveys for Oil and Natural Gas Commission (ONGC), various major and intermediate ports, Indian Navy and other organisations since 1976 and developed the expertise for such surveys. Some of the relevant case histories are described here in brief.

The surveys carried out in the Gulf of Kachchh for Tidal Power Project have helped in clearly identifying erosional and depositional zones. The erosion prone area is marked by highly rugged topography (Figs. 2A, 2B and 4A) channel cuttings through the soft clay (Fig. 4B) and generally varying thickness of clay, on the other hand, the depositional area is even and carpeted by 12-18 m thick clay (Vora and Chauhan, 1988).

MANORI CREEK PIPELINE LAYING

A pipeline route was planned across the Manori Creek, Bombay for fresh water transportation. Originally it was proposed to lay across the creek at the shortest distance (A - B), Fig. 5, to keep the project cost to a minimum. However, a detailed study of the bathymetry (Fig. 6) and isopach maps (Fig. 7) revealed large variations in water depth with steep gradients and the area is practically devoid of clay cover for protecting the pipeline from damage by anchors of fishing trawlers and ferries operating in the area. If the pipeline route is shifted about 300 m north of route C-D, the extent to which factors affect the stability will be considerably reduced.

POST-CONSTRUCTIONAL SURVEY OF KOSI BARRAGE

The settlement of flexible protections and concrete floor

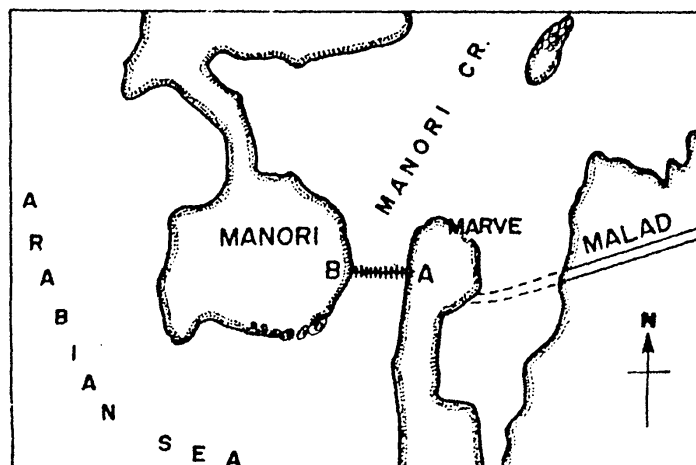


Fig. 5. A schematic map showing proposed submarine pipeline route (A-B) for fresh water transportation for Manori, Bombay.

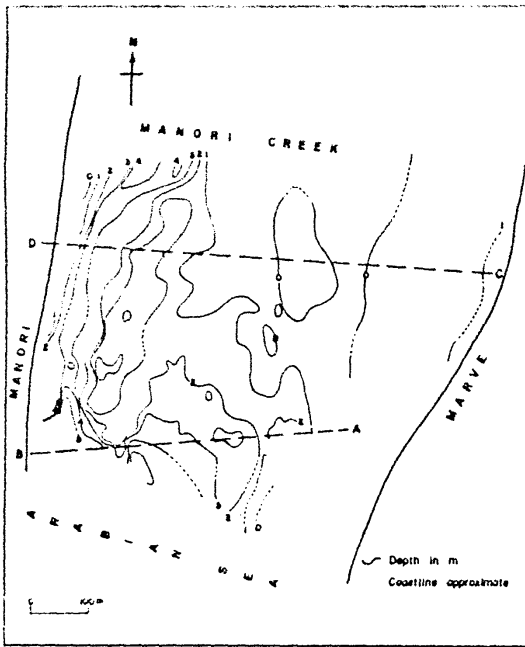


Fig. 6. The map showing bathymetric contours between Manori and Marve, as also proposed pipeline route A-B and route suggested after detailed survey. Note the wide fluctuation on route A-B and comparatively gradual changes on route C-D. However a channel is observed at Manori end on route C-D.

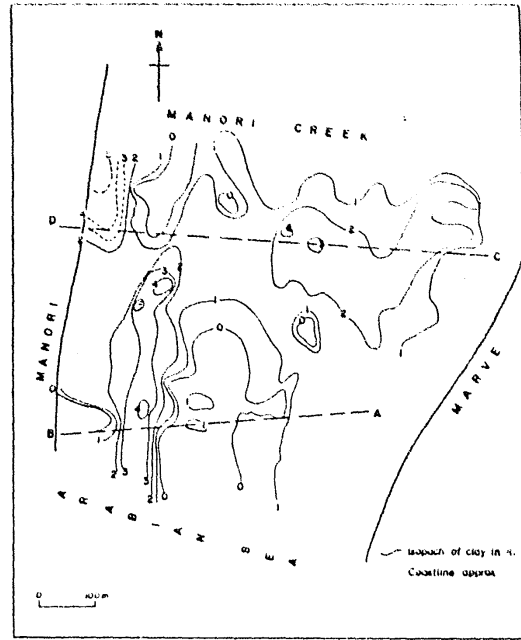


Fig. 7. The map showing isopachs of clay between Manori and Marve A-B and C-D as explained in Fig. 6. Note virtual absence of clay on route A-B and generally 2 m or more thick clay on alignment C-D.

were suspected due to scouring and erosion after about 25 years of operation. Echogram from the survey area (Fig. 8 A) confirmed that the floor has not settled. Sonograph from the area (Fig. 8 B) clearly shows extent of remedial dumping operation. However settlement of the flexible protection could be inferred to some extent. (Vora and Naidu, 1990).

A large number of offshore engineering projects are in consideration within Bombay harbour for crossing the pipeline

for oil and gas, disposal of sewage and construction of trans-harbour link through tunnel or bridge. The multi-sensor surveys carried out by Bhattacharya et. al. (1981) have helped in preparation of surficial geological map and identification of the nature and type of basement, generally basalt weathered and altered to varying degree and other consolidated sediments. Raju and Vora (1987) have provided information on exposed parts of submarine pipeline laid between Butcher Island and Trombay.

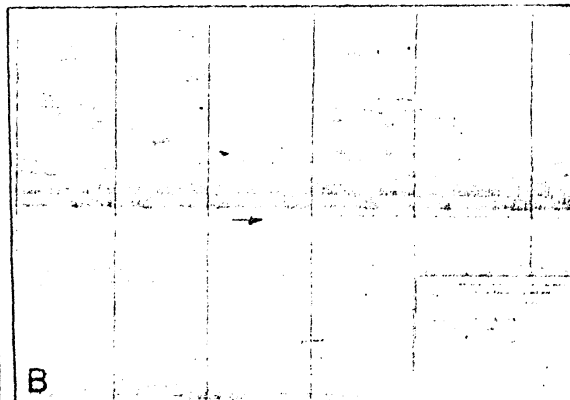
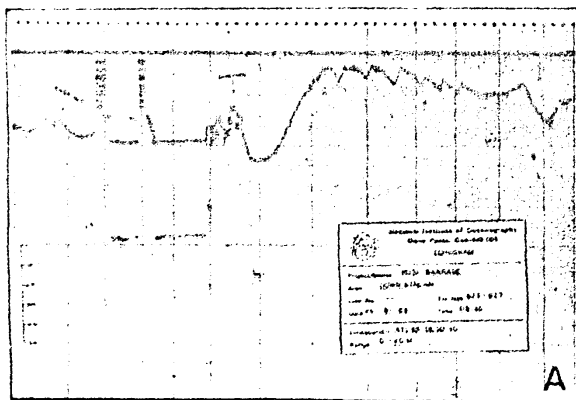


Fig. 8A. The echogram from Kosi barrage survey showing river bed, concrete floor (horizontal part), extent of dumping operation and a channel formation.

Fig. 8B. The sonograph (record of side-scan sonar) from Kosi barrage survey showing reflections due to barrage, extent of dumping operation and a patch of siltation. The arrow mark represents boat track. The range operated is 50 m either side.

Similarly, it is possible to determine the amount of siltation that has taken place in a reservoir to decide if the rate of sedimentation is as expected and remedial measures like dredging are necessary after a dam is in operation for quite some time.

Acknowledgements

Author is thankful to Dr. B.N. Desai, Director N.I.O. for granting the permission to publish the paper and to Shri R. R. Nair, Deputy Director and Head, Geological Oceanography Division, for his constant encouragement. Thanks are also due to Dr. M. Veerayya for critically going through the manuscript and suggesting improvements.

References

- Bhattacharya, G. C., Almeida F., Vora, K. H. and Siddiquie, H. N. (1981): "Multi-sensor surveys for offshore construction off Bombay Island." Proceedings of Indian National Conference on Ocean Engineering, Goa., VII - 29 -34.
- Fanin, N. G. T. (1980): "The use of regional surveys in the north sea and adjacent areas in the recognition of offshore hazards", in Offshore site Investigation. (Ed. D. A. Ardu) Graham and Trotman Limited, London, 5-22.
- Gunsleisrud, T. and Rokengen, K. (1980): "Regional geological mapping of the Norwegian continental shelf with examples of engineering applications", in Offshore Site Investigation (Ed. D. A. Ardu) Graham and Trotman Limited,

London. 23 - 36.

Hovland, M. and Indreide, A. (1980): "Detailed Seabed Mapping for a Pipeline Across the Norwegian Trench". *International Hydrographic Review*, LVII (2), 101 -117.

McQuillion, T.R., Bacon, M. and Barclay, W. (1979): An Introduction to Seismic Interpretation. Graham and Trotman Limited. pp 199.

Ploessel, M. R. and Campbell, K. J. (1981): "Northwestern gulf of Mexico — Engineering implications of regional geology"; in Offshore Site Investigation (Ed. D. A. Ardu) Graham and Trotman Limited London 61-76

Raju, L. V. S. and Vora, K. H. (1987): "Surveys for marine inspection near the Bombay Harbour Area". Proceedings of Second Dock and Harbour Engineering Conference pp 339.

Sherard, J.L., Woodward, R. J., Zienski, F. G. and Clevenger, W. A. (1963): *Earth and Earth-Rock Dams*, John Wiley and Sons. New York pp 725

Vora, K. H. and Chauhan, O. S. (1988): "Surficial geology of the environs of the Kachchh Tidal Power Project, India". International Symposium on Tidal Power Development, New Delhi, 29-33.

Vora, K.H. and Naidu, P.D. (1990): "The use of Marine geophysical Methods in Geo-engineering Investigation of Dams/barrages - A case study of Kosi Barrage". *Journal of Irrigation and Power*, 47 (5) 85-96.

INDIAN JOURNAL OF POWER & RIVER VALLEY DEVELOPMENT SPECIAL NUMBER ON SARDAR SAROVAR NARMADA PROJECT

This special issue carries 31 technical contributions from the top executives and engineers actively engaged in the construction of the most prestigious multi-State multi-purpose river valley project. The articles deal with design and construction of dams, underground powerhouse, canal system and environmental aspects of the project. The special issue an indepth study on the biggest river valley project in the world.

Price per copy : Rs. 125.00; 30.00 or US \$50.00 (Seamail)

Place your orders with :

The Manager

BOOKS & JOURNALS PVT. LTD.

6/2 Madan Street, Calcutta 700 072

Phones : 271711 & 275867