

Chirp Sonar Survey for development of Jawaharlal Nehru Port

R.S.Wadhwa, C.K.Rani, M.S.Chaudhari, Raja Mukhopadhyay and N.Ghosh

Central Water and Power Research Station, Khadakwasla, Pune - 411 024

E.mail : wadhwa_rs@cwprs.gov.in

ABSTRACT

Underwater geoenvironmental survey deploying dual frequency echo-sounder and chirp sonar system (pulsed frequency modulation signal 500 Hz to 8 KHz) from a precisely positioned vessel was carried out along seven traverses at Jawaharlal Nehru Port near Mumbai where the existing harbour is to be dredged to -16.5m depth near the berths and to -12.5m depth elsewhere to accommodate larger size vessels. The lengths of the traverses varied between 175m and 415m. Isopach map of the sediment thickness drawn from the results of the chirp sonar system revealed that the sediment thickness from sea-floor varies from 0m to 11m. Rock at places was inferred to be exposed to sea-floor. The boundary of the rock outcropping patch was precisely deciphered and marked on the site plan. The quantity of rock to be dredged was worked out to be 1.95 Lakh cubic metres. The basalt rock for dredging will either require rock cutter dredgers or blasting. The rock levels evaluated using chirp sonar system matched remarkably well with rock levels inferred in few boreholes drilled in 1980. At some locations the superficial material with physical properties different from that of sea-floor was detected and was interpreted to be dumped material. The maximum lateral extent and thickness of the dumped material was 100m and 5m respectively.

INTRODUCTION

The port of Bombay is the largest Indian port and the natural harbour. To ease the traffic congestion at Bombay port, Jawaharlal Nehru port was commissioned in 1989. Jawaharlal Nehru port has a channel length of 7.2 km and shares 22.5 km long channel with Bombay port. This port because of increased container traffic is undergoing continuous expansion of its facilities. The future development plans for Jawaharlal Nehru port necessitate deepening of the main harbour channel to -16.5m depth close to existing container berth and to -12.5m depth elsewhere for movement of deeper-drafted vessels. For accommodating larger size vessels, it is also proposed to extend the existing container berth by 330m, to expand the guide bund by 160m and to construct a finger jetty of 50m length. A few boreholes at Jawaharlal Nehru Port were drilled in 1980, to establish rock levels. Since then a lot of activities like deepening of the channel, construction of container berth, Jetty etc have taken place. The geological setting and processes of the area have created a number of islands, ledges and an unpredictable and irregular rocky surface, mainly basalt, exposed or underlying the recent sedimentary cover in the harbour.

For engineering prefeasibility studies and for arriving at a techno-economically viable decision, subsurface stratigraphy information including rock levels is required. Two ways to get the subsurface strata information are by drilling holes and by seismic reflection survey. Though boreholes provide precise geological information at discrete locations but the procedure of drilling of boreholes in sea is both time consuming and expensive. Also, the interpolation of geological information between two holes in near shore environment is not advisable as rapid variations in strata can occur within the shallow geological sequence. It is therefore, desirable to undertake site specific marine geophysical surveys in conjunction with a programme of limited borehole drilling and core sampling. The great power and value of geophysical techniques lie in their use to extrapolate from 'point' ground truth, integrate all ground truth data, visualize trends and detect local anomalous conditions which escape detection by all but extremely close-spaced (hence prohibitively expensive) drilling program. The continuous subsurface strata information on the other hand at much lower cost and time can be obtained by seismic reflection technique. This method was developed by Hersey since 1942 (Hersey 1963; Ewing & Ewing 1970). Its advantage in relation to seismic

refraction method lies in the fact that, the reflection can be continuously recorded on the moving vessel, a simple, fast and cheap method. Disadvantage of the technique being that only sediment structures can be investigated and for precise depth evaluations either borehole should be drilled or seismic refraction method should be used. Data of borehole then can be used for evaluation of in situ compressional wave velocities.

This paper describes underwater seismic reflection survey using chirp sonar for deciphering subsurface geological information at Jawaharlal Nehru Port. The total quantity of rock to be dredged and the economics of the sonar survey are also worked out.

CHIRP SUB-BOTTOM PROFILING

The chirp sonar is a digital calibrated Frequency Modulated (FM) sonar that provides nearly constant resolution with depth and produces high resolution images of sea-floor and sub-sea-floor. It uses wide band FM pulses that sweep over the frequency range of 500 Hz to 12 kHz. This wideband width ensures that sediment layers ~ 7 cm can be resolved. Some of the important advantages of chirp sonar are almost

constant vertical resolution with depth, calibrated pulse and no source ringing. In a conventional single frequency system, the pulse length of the transmitted waveform determines the limit of resolution. However, in a multi-frequency system, it is the band width of the transmitted pulse that sets the limit for the system's theoretical resolution.

SURVEY DETAILS

The underwater seismic reflection survey was conducted along seven traverses with lengths varying between 175 m and 415 m. Of these, three traverses were conducted perpendicular to the container berth and were spaced 120 m apart. The four profiles parallel to container berth were spaced 50 m apart. Fig.1 shows the location of these traverses. Few boreholes drilled in the area in 1980 to decipher subsurface stratigraphy have also been marked in the same figure.

Navigation of the survey vessel was carried out using a differential global positioning system with measurement accuracy of ± 1 m. Chirp sonar data were acquired at a transmission rate of 6 pings/second. An average speed of 4 km/hour was maintained for the

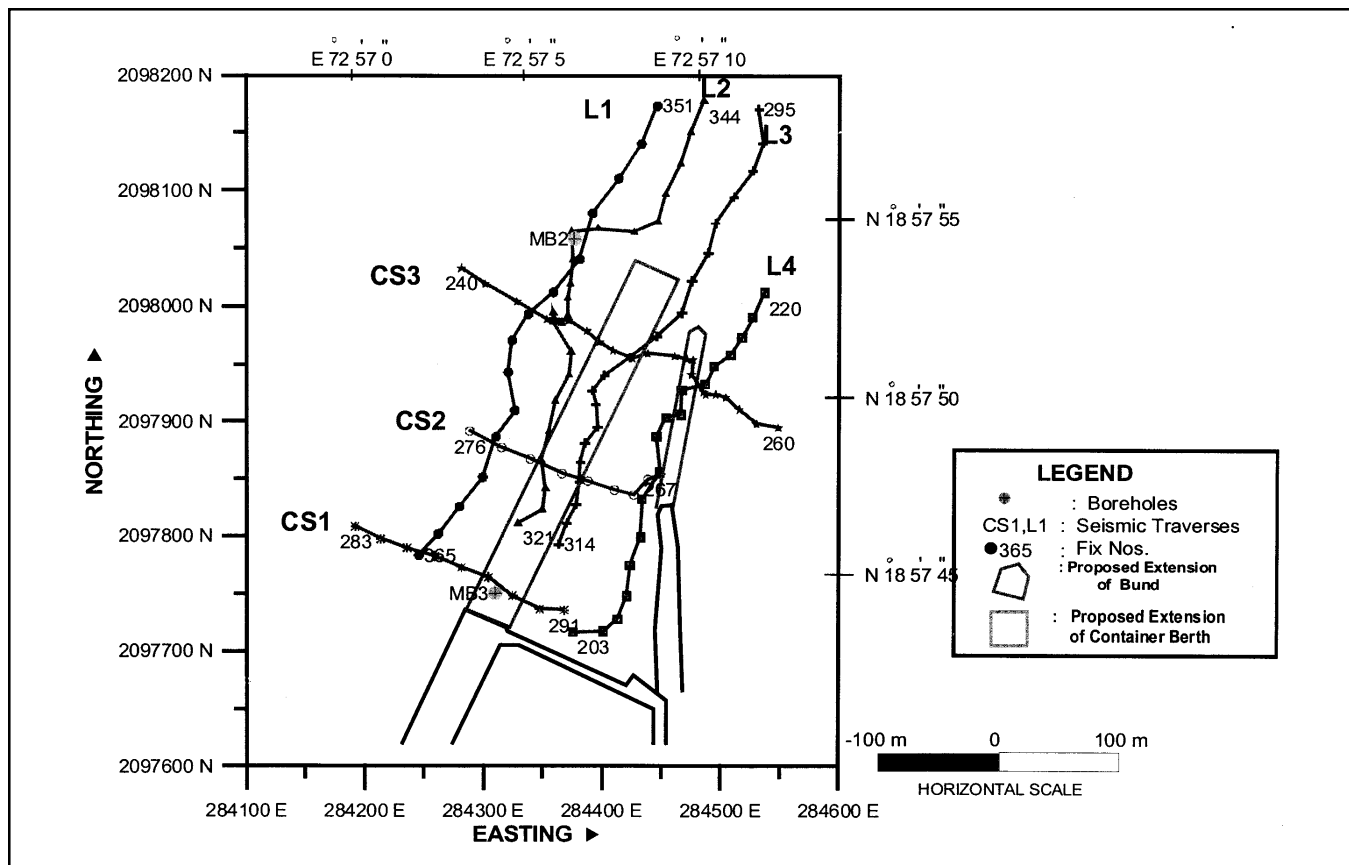


Figure 1. Site plan showing seismic reflection profiles

survey vessel. At this speed of the survey vessel and transmission pings selected, the chirp system provided one trace for every 0.19m of boat motion which is horizontal resolution achieved. The survey boat though monitored continuously during the course of the survey, the position co-ordinates were noted every fifteen seconds and the fixes are shown in Fig.1.

BATHYMETRY

A dual frequency (30 kHz and 210 kHz) echo-sounder was used to collect bathymetry data. Bar check was carried out before start of the survey to calibrate the echo-sounder (Trabant 1984). With echo-sounder, continuous water depths can be obtained with an accuracy of 15 cm in 30 m depth. During the course of the survey, tide variations were recorded every 15 minutes using tide pole. Water depths recorded on echo-sounder were corrected for tide variations and depth-sections with respect to chart datum were drawn.

RESULTS

Fig.2 is the chirp sonar record along traverse L1 conducted parallel to the container berth. This record

shows sea-floor, overburden, rock pinnacle, dumped material on sea-floor and rock topography in terms of two-way travel time in milliseconds (ms). The tow fish was towed at a depth of 3 m to 4 m from the water surface. The interpreted depth-section for the traverse from echo-sounder and the chirp sonar data is shown in the same figure.

It is seen from chirp sonar record in Fig.2 that the subsurface comprises two/ three subsurface reflectors including sea-floor and rock, except between fixes 351 and 358 where only one reflector is seen. Depth to sea-floor with respect to chart datum which was determined from echo-sounder record and later corrected for tidal variations, varied from -5.2m to -14.8m. From the reflection coefficient values between fixes 351 & 358, the only one reflector present was inferred to be basalt rock (Schock, LeBlanc & Meyer 1989 and 1992, Le Blanc et al., 1992). Also near fix 357, rock pinnacle directly resting on basalt rock was inferred. This area earlier was deepened by blasting the rock and therefore, some edges and corners were left out. This rock pinnacle may be result of the same. Further south of this traverse, three subsurface reflectors were inferred. Depending on the reflection coefficient value, first reflector in the south of the traverse was interpreted to be dumped material. The

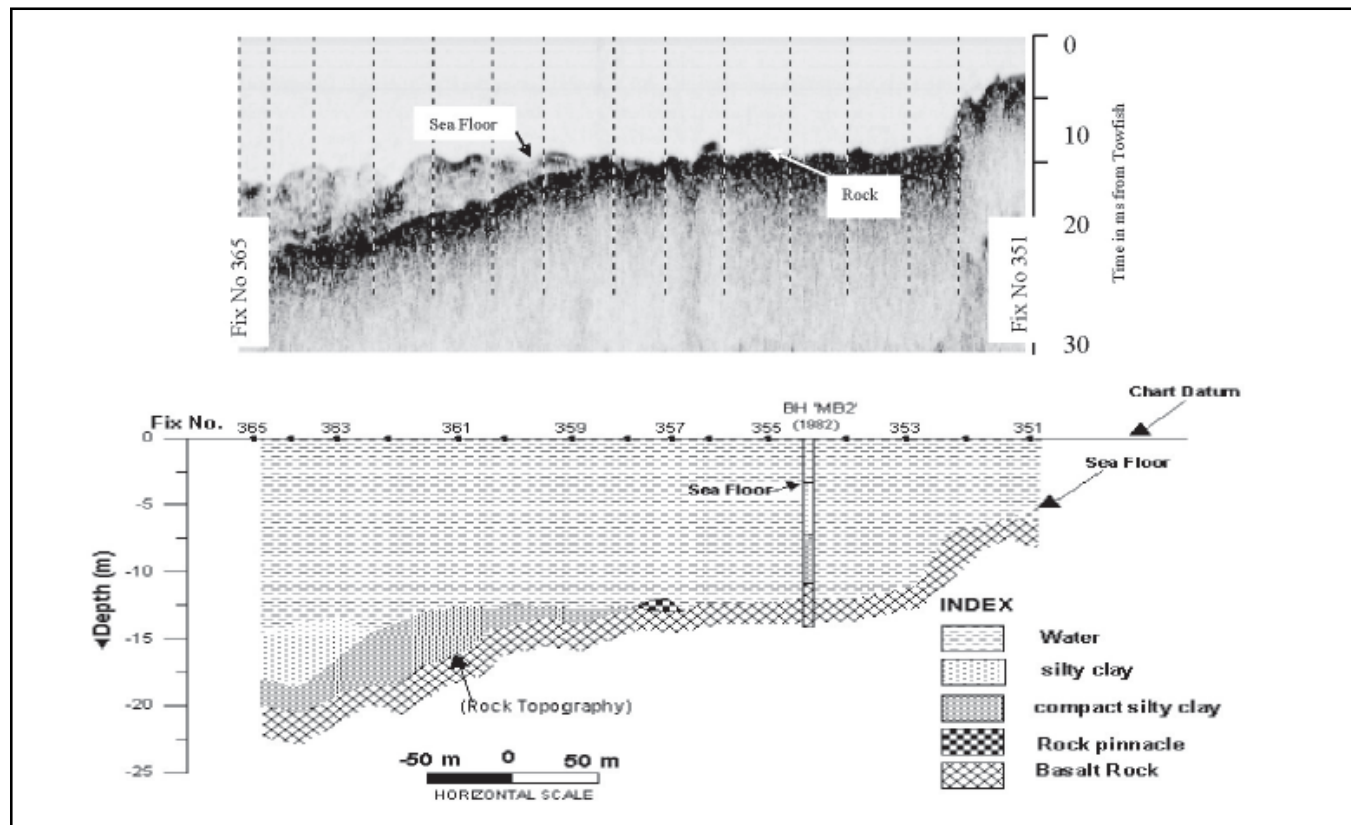


Figure 2. Chirp Sub-bottom Profiler Record and interpreted depth section with borehole data of Profile L1

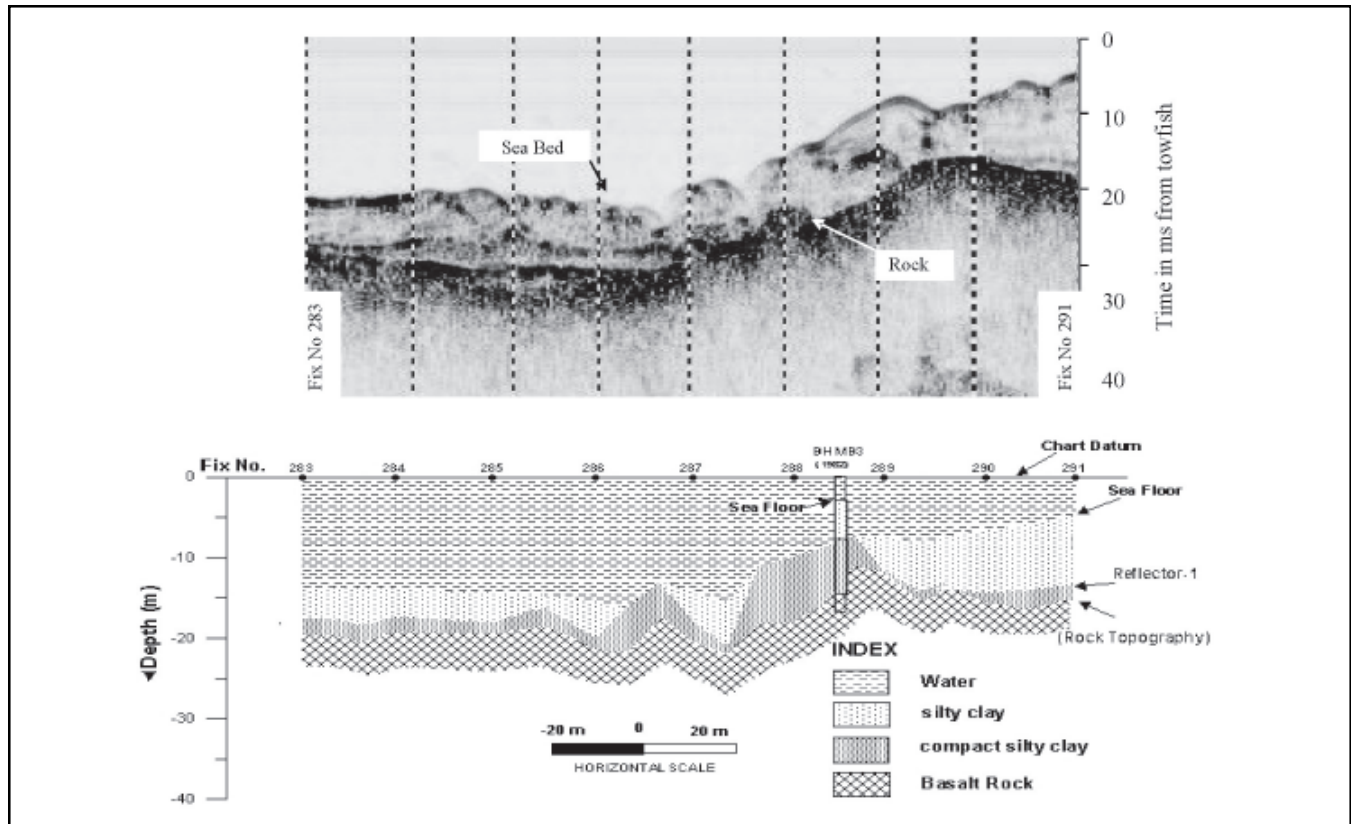


Figure 3. Chirp Sub-bottom Profiler Record and interpreted depth section with borehole data of Profile CS1

depth to rock with respect to chart datum varied from -6.0m to -20.6m. Results of borehole MB2 existing along this traverse are shown in Fig.2. A good match between the rock depth inferred in borehole and that evaluated by reflection technique is seen. It may be mentioned here that the boreholes used to infer subsurface geological information were drilled in 1980 after which a lot of developmental activities have taken place. For this, subsurface strata must have been dredged, to deepen the harbour. Therefore, while comparing the borehole data and chirp sonar results, emphasis was given only to rock depths.

Similarly, Fig.3 shows the chirp sonar record and the interpreted depth-section for traverse CS1. The results of borehole MB3 existing along this traverse are also shown in the same figure.

It was seen from the records of traverses conducted in the area that even along the same traverse the subsurface has varying number of reflectors. It was inferred from this that the subsurface strata occurs in the form of pockets and lenses and therefore, any number of boreholes won't be enough to decipher subsurface layers accurately.

The depth to sea-floor with respect to chart datum in the area surveyed varied between -1.0 m and -15.7 m. The depth to rock ranged from -6 m to -22.1 m. Along some traverses one weak reflector of limited lateral extent and thickness was deciphered above sea-floor. This reflector was interpreted to be dumped material on sea-floor. The lateral extent of the dumped material varied from a few metres to 100 m while its maximum thickness was evaluated to be 5 m.

Sea-floor was found to be shallower towards northeast as compared to southwest. At some places rock outcrops were inferred on echograms. Rock was also observed to be shallower towards northeast (-6m) as compared to southwest where the same was inferred to be at -22m depth from the chart datum (Fig.5). The isopach map of sediment giving lateral variation of thickness of sediment is shown in Fig.4. The sediment thickness from sea-floor varied from 0 m (where rock is inferred to be exposed to sea-floor) to 11 m. The area where rock is exposed to sea-floor (i.e. 0m contour) is marked in dark shade. The thickness of sediment is more towards southeast as compared to the remaining area.

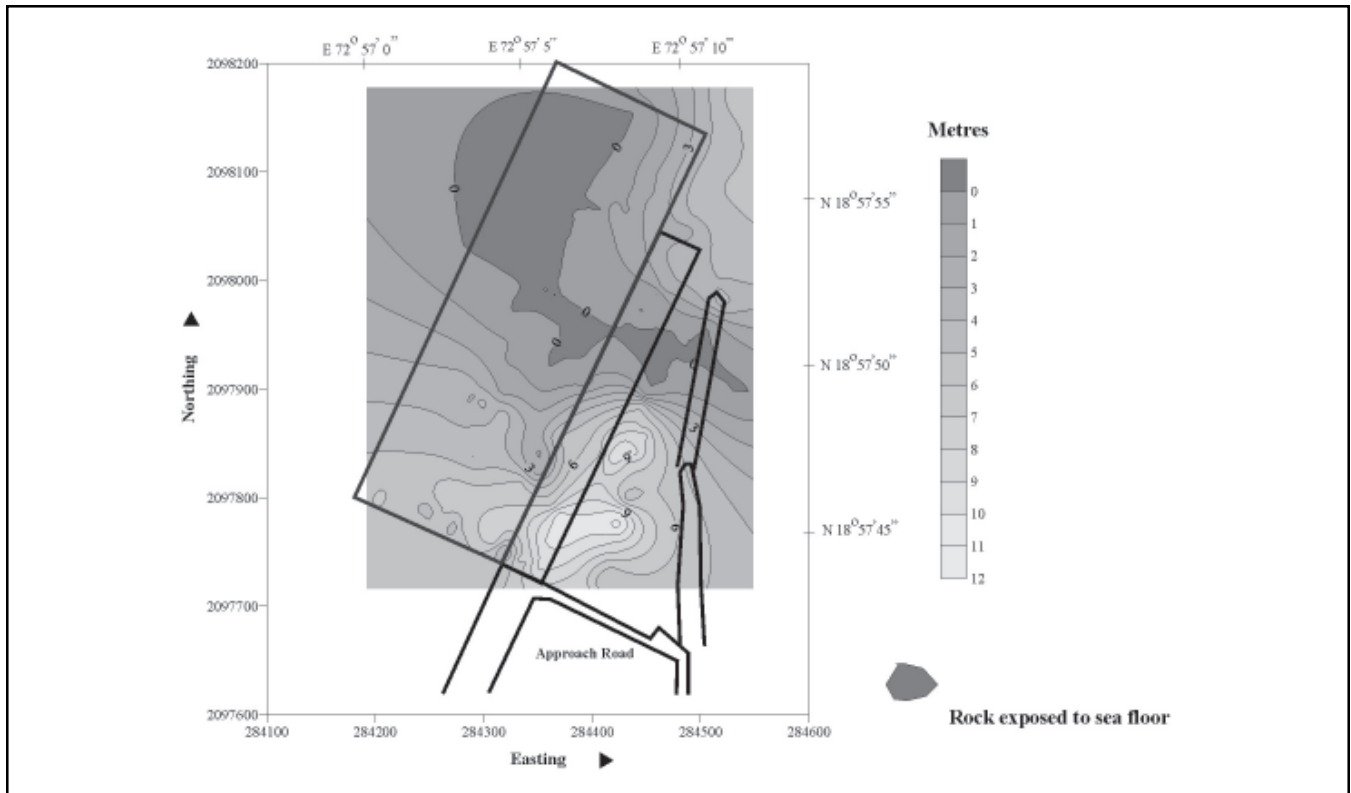


Figure 4. Isopach map of sediments

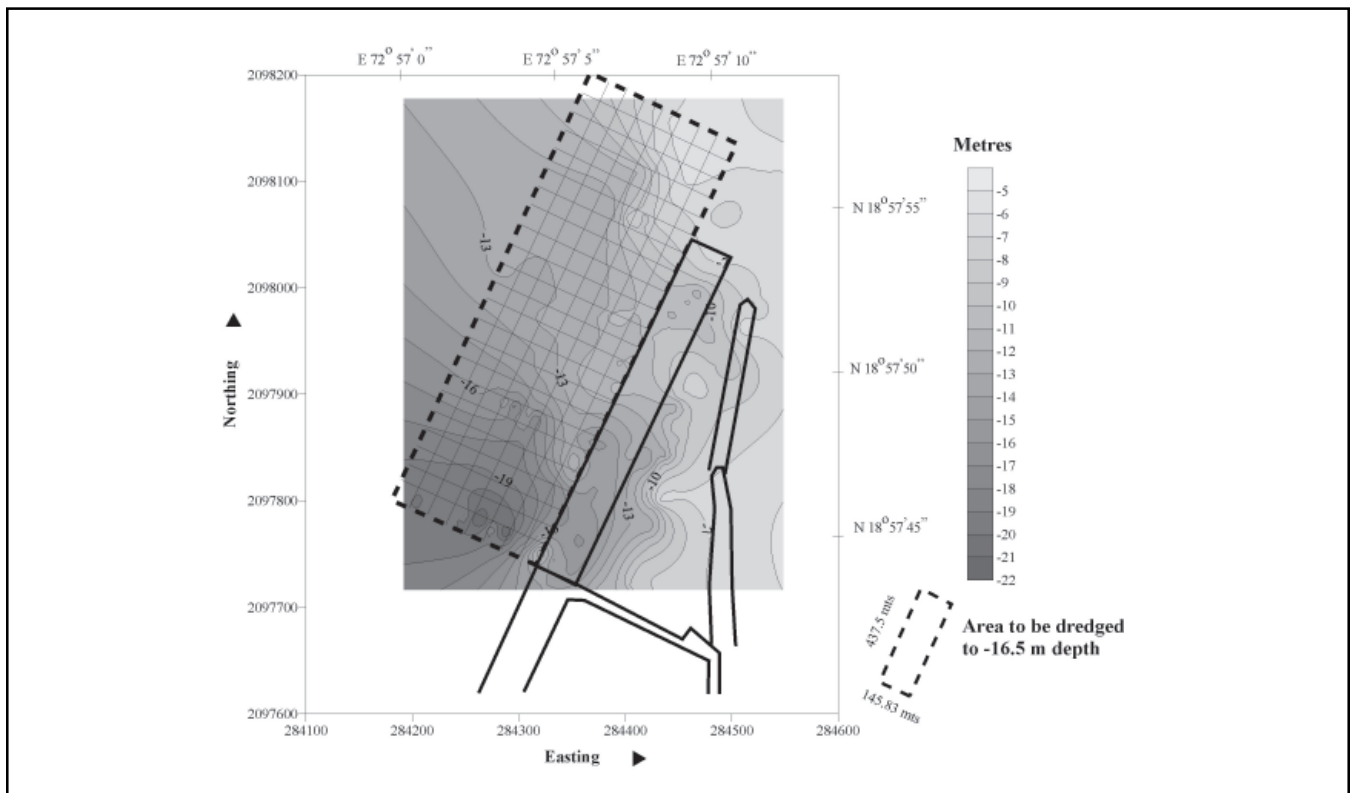


Figure 5. Rock depth contours with grids used for evaluation of rock dredging

ROCK QUANTITY DREDGING

Fig.5 shows the area near the existing container berth which is to be dredged to -16.5m depth for accommodating larger size vessels. For evaluating the quantity of rock to be dredged this area was divided into square grids of 18.75m X 18.75m. Taking the contour of rock passing through the grid as the average rock level in that grid the volume of rock to be dredged in each grid was worked out. Adding the volume of rock to be dredged for all the grids, the total quantity of rock dredging in the area was worked out to be 1.95 Lakh cubic metres. The rock dredging will either need rock cutter dredgers or blasting.

ECONOMICS OF SURVEY

All geotechnical tests including boreholes provide information from point to point and values are interpolated in between places. Chirp sonar survey helped to fill the information gap, from sampling much larger in volume and to tie together the data obtained at discrete points (Sarman & Palmer 1990), by borehole drilling or other geotechnical tests.

Even though chirp sonar survey yields continuous subsurface geological information including rock topography, it does not eliminate the need to drill holes. But it helps to minimise the number of boreholes for an adequate definition of the subsurface thus saving both on cost and time. At sites where subsurface strata occur in the form of pockets and lenses, any number of boreholes won't be adequate to define the subsurface precisely. To get the subsurface strata information of an area measuring 600m X 400m on a grid of 100m, 35 boreholes will be required. The cost of drilling 35 boreholes underwater will be about Rs 20 Lakhs depending, of course, on the strata encountered and the depth to which the boreholes are to be drilled. Drilling time for 35 boreholes will be about four months depending again on the number of drilling machines deployed and the sea conditions. Furthermore, drilling information will correspond to discrete locations and interpolation of geological information between boreholes particularly when the strata exist in the form of pockets and lenses is not advisable. The geological information derived through interpolation may affect the design of foundations and in turn the structure itself. Contrary to this the continuous subsurface geological information by chirp sonar survey was obtained in one day and at a much lower cost.

CONCLUSIONS

The sonar records have enabled to successfully locate and map the dumped material 5.0 m thick and helped in identifying different subsurface strata up to -22.1 m depth including rock topography. The subsurface strata at site occur in the form of lenses and pockets. Basalt rock at places is exposed to sea-floor while at other places the same is overlain by two/three overburden layers of maximum 12.0 m thickness. To decipher subsurface geological information at such sites using boreholes, even a large number of boreholes will not be able to define the subsurface layers precisely. Based on the results the following are suggested. The rock dredging to the tune of 1.95 Lakh cubic metres will have to be carried out to accommodate larger size (draft 16.5 m) container vessels.

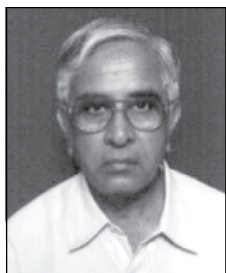
ACKNOWLEDGEMENTS

Authors are grateful to Mrs V.M.Bendre, Director, Central Water and Power Research Station, for encouragement and according permission to publish this paper. Our sincere thanks to all project officials who were involved in data acquisition.

REFERENCES

- Ewing J. & Ewing, M., 1970. Seismic reflection - In A.E. Maxwell (Ed), The sea 4, Part I, 1-51, New York
- Hersey, J.B., 1963. Continuous reflection profiling - In M.N.Hill (Ed), The sea 3, 47-72 New York
- LeBlanc, L.R., Mayer, L., Rufino, M., Schock, S.G. & King, J., 1992. Marine sediment classification using chirp sonar. J.Accoust. Soc, Am, 91, 107-115
- Sarman Rakesh & Donald F. Palmer, 1990. Engineering Geophysics: The need for its development and application, 6th International IAEG Congress, Balkema, Rotterdam, 1017-24
- Schock, S.G., LeBlanc, L.R. & Mayer, L.A., 1989. Chirp Sub-bottom profiler -quantitative sediment analysis, Geophysics, Vol 54, 445-450
- Schock, S.G., LeBlanc, L.R. & Parda, S., 1992. Sediment classification using Chirp Sonar, offshore Technology Conference, (OTC) paper 6851, 363-368
- Trabant, P.K., 1984. Applied high resolution geophysical method, offshore geoengineering hazards, International Human Resources development Corporation, Boston, USA

(Accepted 2007 July 24. Received 2007 July 23; in original form 2005 December 1)



R.S.Wadhwa, working as Chief Research Officer in CWPRS since 1998, did his M.Sc in Physics from Kurukshetra University in 1972. He had Post Graduate training in applied geophysics at the University of Birmingham, U.K. from October 1986 to April 1987. He worked as a consulting geophysicist for Walayat Samail and Shinas groundwater recharge schemes in Sultanate of Oman. He has been working in the field of engineering geophysics for the last 30 years. He has solved about 100 real-time problems involving different geological settings. He has published 50 technical papers including six in international journals.



Dr (Mrs) C.K.Rani is a Senior Research Officer in Central Water and Power Research Station, Pune. She obtained her M.Sc. and Ph.D. in Physics from Andhra University, Visakhapatnam. She specializes in the field of geophysical investigations in Engineering Projects apart from application of tracer technique for water resources projects.



M.S.Chaudhari (Research Officer, CWPRS) took his Masters degree in Physics with specialization in Electronics from University of Pune. He did AMIE in Electronics & Telecommunications from the Institution of Engineers. He specializes in Engineering Geophysics related to Shallow Underwater Seismic Reflection technique applied to Coastal and Offshore engineering projects. He has 30 technical papers in national and international conferences and journals.



He obtained his B.Sc (Hons) in 1970 and M.Sc. in Exploration Geophysics from Indian Institute of Technology, Kharagpur in 1972. He was awarded fellowship by CSIR and was at IIT Kharagpur up to November 1974, after which he joined Central Water and Power Research Station (CWPRS) as 'Research Officer'. He was offered a United Nations Fellowship and he obtained his M.S. in Geophysics in 1982 from University of Houston and completed his degree requirement in record time. He was the first recipient of the Milton B.Dobrin memorial award. He was also offered outstanding student. He received his Ph.D. in Geophysics from University of Houston in 1990. He was the recipient of University of Houston's Alumni and Best Teaching Assistantship Awards. He also received several scholarships to mention a few Conoco, Tenneco, Exxon Oil Cos, Houston Geological Society and Society of Exploration Geophysics, USA. His area of profession and specialization is shallow geophysics and he has over 25 years of experience in the application of geophysical techniques to real time problems in river valley, nuclear, thermal and coastal and offshore engineering project sites. He has 19 research papers in national and international peer reviewed journals, in 6 priced books, monographs and 41 research papers in national and international seminars/symposium. He is presently Additional Director CWPRS and also the Nodal Officer of CWPRS of World Bank funded Hydrology Project II.

