J. Ind. Geophys. Union (January 2008)
Vol.12, No.1, pp.55-62

Delineation of cavities in a canal bed by Geophysical Survey in Navargaon Project Area, Maharashtra

R.S.Wadhwa, N.Ghosh, M.S.Chaudhari, V.Chandrashekhar and Rajib K Sinharay
Central Water and Power Research station, Khadakwasla, Pune 411024
E.mail: wadhwa_rs@cwprs.gov.in

ABSTRACT
28 km main canal and a dam are part of Navargaon medium irrigation project. Three cavities exposed in the canal-bed were noticed after release of water for the first time through canal. Ground penetrating radar, electrical resistivity imaging and electrical gradient techniques were deployed to get the exact dimensions of the exposed cavities as well as to delineate subsurface cavities, if any. Number of anomalies depicting trough (low) and crest (high) like pattern were noticed on GPR records. A plausible interpretation for this cluster of anomalies was a partially water and/ or clay-filled lows and partially air-filled (high) cavity system. The presence of some of these cavities was confirmed by electrical resistivity imaging and electrical gradient techniques.

INTRODUCTION

Water retention and distribution system can be classified into those designed to seep and those designed not to seep. Hazardous waste lagoons, settlement ponds and canals carrying water for irrigation are designed not to seep or leak. Seepage through such structures is a potential threat to public welfare and wastage of water. On the other hand, earth and rock fill dams are expected to seep and are provided with drainage system. However, excessive, unplanned or anomalous seepage may threaten the integrity of such structures and needs to be corrected (Dwain & Jose 1990). Formation of cavities in the stretches of canal passing over limestone terrain by percolating water is a common phenomenon. As the formation of cavities is not on a regular but on a random pattern, the detection of the same is not only a difficult task, but considered by many, to be like finding a needle in haystack. Regular pattern of drilled holes normally used for site assessment, because of localized nature of cavities will not be able to detect and decipher the disposition of cavities. Therefore, an assessment of cavities can only be successful by use of a planned and focussed search. The methods to be successful for cavities detection must therefore, provide a wide range of sampling and the resulting data should be used to reinforce one another. This implies that for cavity detection an integrated geophysical approach is most suitable than to rely on a single geophysical method. The great power and value of geophysical methods yielding various depths of investigation and resolution lie in their use to extrapolate from "point" ground truth data (i.e. single borehole results); integrate multiple point ground truth data, visualize trends which are often missed with ground truth data and detect localized anomalous conditions which escape detection by all but extremely close-spaced (hence prohibitively expensive) drilling program (Dwain & Jose 1990).

This paper describes the utility of ground penetrating radar (GPR), electrical resistivity imaging and potential gradient techniques for delineation of subsurface cavities in a one km long stretch of irrigation canal passing over limestone. These geophysical techniques for detection of cavities were chosen based on past experience, ease of operation and availability of equipment. The detection of cavities in the near ground surface and their treatment assumes vital economic significance as it will avoid wastage of water.

LOCATION OF STUDY AREA

28 km main canal and a dam are part of Navargaon medium irrigation project situated in Yawatmal district of Maharashtra State. The canal is designed to carry water for irrigation purposes. Limestone rock is exposed in the canal-bed for over a stretch of 1 km. Hollows or cavities are a geological hazard affecting limestone formations particularly when the formations come in contact with water. When water from the dam, for the first time, was discharged into the canal, three big cavities in the canal-bed were noticed. Of these three cavities one cavernous zone existed towards right bank of canal having height of 0.6 m (Fig.1). Towards left bank edge a huge cavity with 7.6 m depth was observed. Along central line of the

canal-bed the third cavity having dimensions 1m X 0.7 m X 0.6 m was seen exposed and the remaining part of cavity was back filled with boulders. The development of cavities in such a short span of time is indicative of soluble nature of limestone and their easy perception to rapid change.

The excavated canal site is located in part of Vindhyan super group of rocks belonging to precambrian age. The geological traverses taken along the excavated canal as well as in the vicinity, reveal the presence of alluvial type of overburden underlain by limestone. In general the stratigraphical sequence inferred along the excavated canal comprises alluvium, weathered limestone and fresh limestone. Chemical analysis of limestone revealed the presence of calcium as calcium carbonate 90.47% W/w.

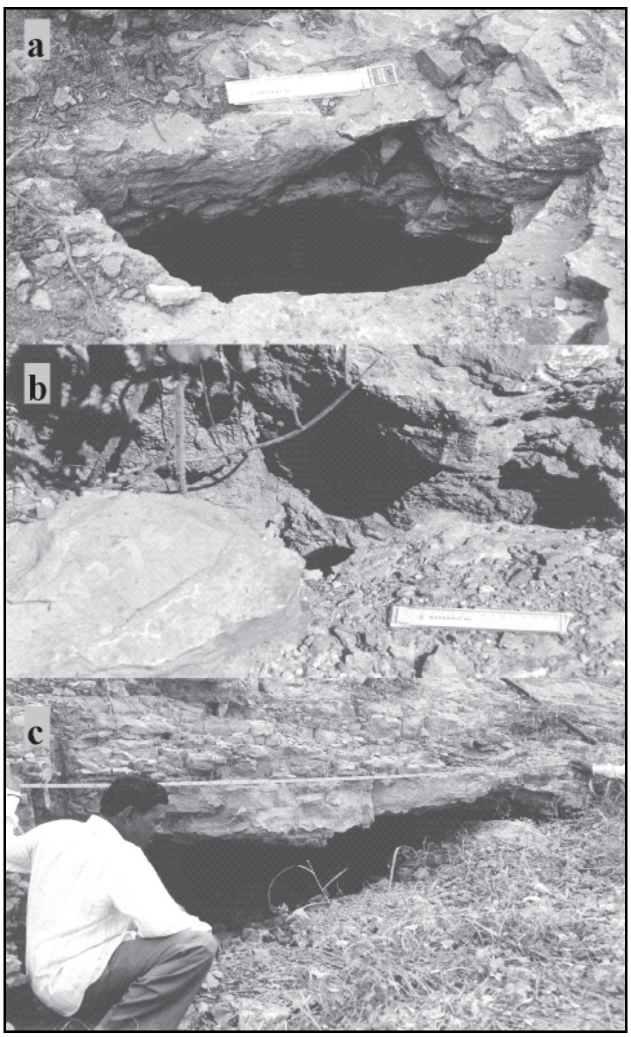


Figure 1. Exposed Cavities a. Central, b. Left Bank, c. Right Bank

FIELD METHODOLOGY ADOPTED

The conventional approach to define the hydrogeology or geology of a particular site has been to use drilling. Drilling requires use of both hydrogeologist/ geologist and drilling contractor on site for several days and is quite expensive (Humphreys, Linford & West 1990). Interpretation of geophysical anomalies may reduce the number of drill holes to obtain near detail subsurface information. Therefore, by mapping geologic structures using geophysics, a major saving may be made and usually the drilling required for a site can be minimized. A typical programme using geophysical methods for detection of cavities should include ground penetrating radar, electrical resistivity imaging and potential gradient surveys in association with a few boreholes.

GPR SURVEY

Ground Penetrating Radar (GPR) survey is a useful method for shallow engineering investigations (Morey 1974; Ulriksen 1982; Ballard 1983; Olhoeft 1984, 1988). The most important advantage of ground penetrating radar survey technique is that no physical contact between the transmitter and receiver antenna and the subsoil is necessary. The primary disadvantage of GPR is its extremely site specific applicability. The presence of high clay in soils in the shallow subsurface will generally defeat the application of GPR (Olhoeft 1984). When water content in soils exceeds 40 percent (Horton et al., 1981) the applicability of GPR becomes limited. In GPR survey dragging the antenna along the ground surface creates a continuous profile that gives the greatest resolution in data acquisition of all the surface geophysical methods. GPR data were acquired using 'RAMAC' GPR system equipped with 250 MHz shielded antenna. Frequency filters and triple time varying gains were used to get good quality data. The result of measurement in ground penetrating radar technique is primarily reflection of signal from subsoil structures, which is reproduced as an echogram. The amplitude of the time-dependent reflection signal is translated into grades of gray or in colours and drawn beside the preceding one, thus providing a qualitative cross-section of the subsurface below the survey line. The horizontal scale of the echogram is essentially the real time during the experiment, and therefore a distance scale. The vertical scale is a reflection time scale, which can be interpreted as a depth scale when the transmission speed of the radar pulse is known.

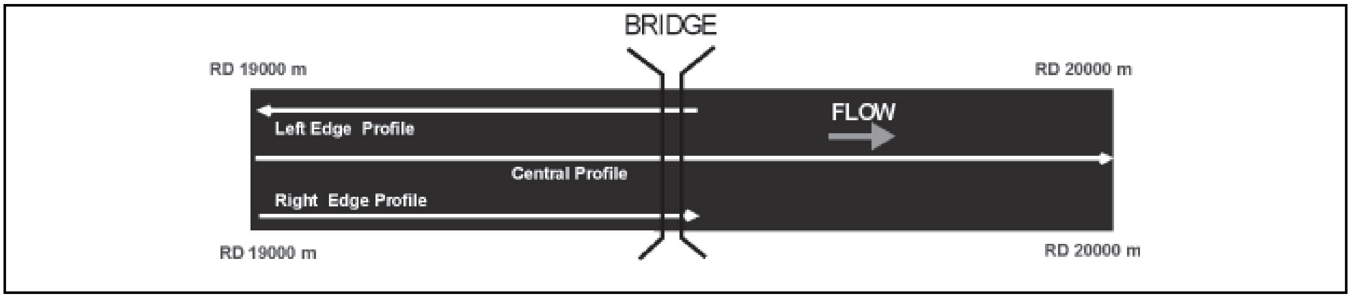


Figure 2. Layout of GPR profiles along the canal-bed

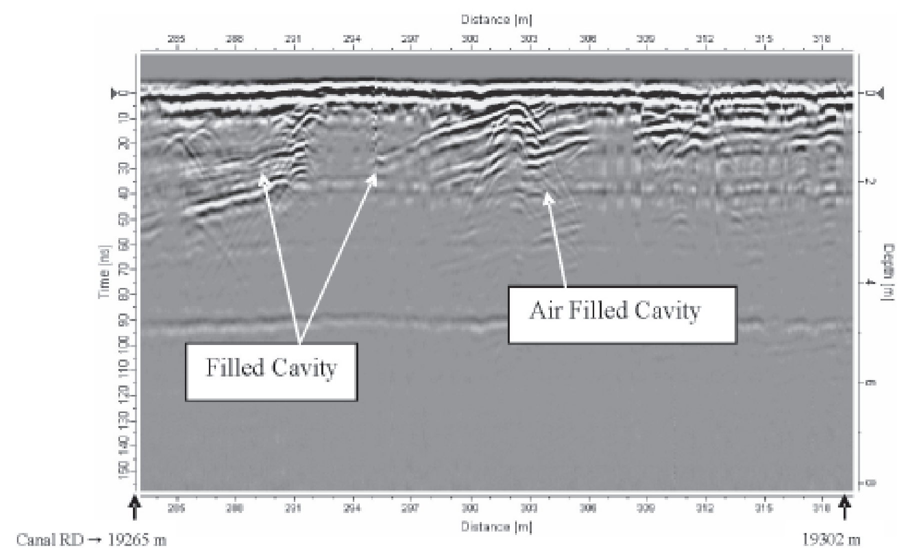


Figure 3. Typical GPR record along central line showing filled and air filled cavities from canal RD 19265 m to RD 19302 m.

RESISTIVITY SURVEY

Electrical resistivity imaging technique is suitable for investigation of areas of complex geology which can not be approximated to horizontal layers stratigraphy like bank of canal. The output of electrical resistivity imaging is a virtual cross-section of subsurface soil and rock layers. The field application consists of two separate steps : 1) measuring the apparent (weighted average) electrical resistivity of the ground over numerous stations and 2) computerized processing of the measured apparent resistivity data to obtain a virtual cross-section of the subsurface showing the estimated true resistivity and thickness values. For resistivity imaging survey, a large number of electrodes at fixed interval in a line are deployed. A computerized switching system is used to speed data acquisition and to choose the desired electrode configuration. Schlumberger electrode configuration was used for data collection. This is also called sounding-profiling technique as it involves both profiling and sounding measurements. The nature of anomaly in resistivity section will depend on whether or not the cavity is filled with fluid. Water or clay-filled and air-filled features produce low and high resistivity anomalies respectively. Resistivity imaging and potential gradient survey, was conducted using 100 Watt ‘Scintrex automatic resistivity imaging’ system manufactured by M/s Scintrex, Canada.

Electrical gradient technique is generally used for delineation of isolated subsurface targets e.g. cavities, voids. In this array two current electrodes are placed at comparatively large distance apart (in this case 75 m) and potential measurements are carried out in the middle one third distance (ch 25 m to ch 50 m) deploying two closely spaced electrodes (in this case 1m apart). If a hollow, either air or water-filled, is encountered in this one third region, the current distribution is perturbed, leading to abnormal fall or rise in its value, thus giving indication of cavity. Interpretation of gradient array data is done qualitatively only to decipher lateral extent of cavity.

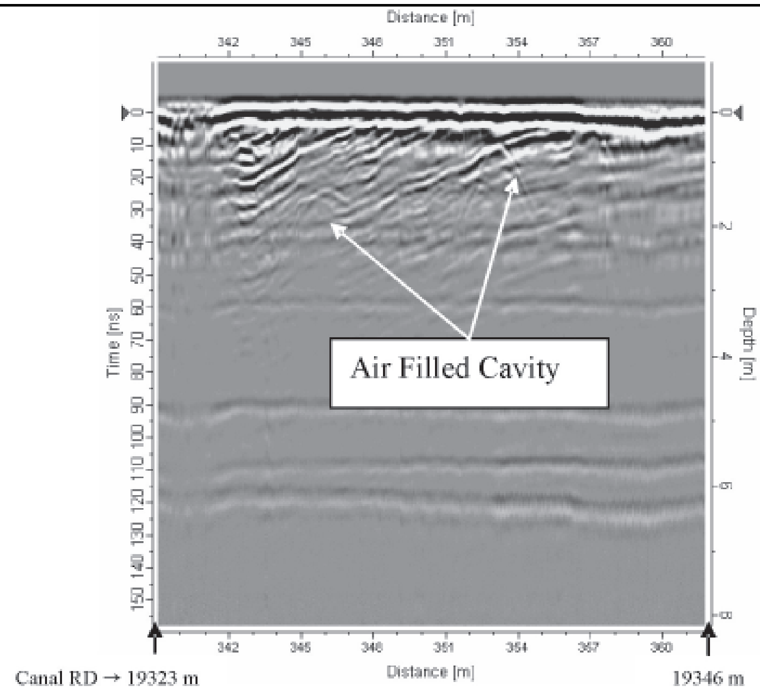


Figure 4. Typical GPR record along central line showing air filled cavities at different depths from canal RD 19323 m to RD 19346 m

DETAILS OF INVESTIGATIONS

GPR survey was conducted along three traverses in the canal-bed. One of these traverses was 1 km long and was taken along the central line of the canal-bed. Remaining two traverses were 500 m each and were located along the left and right bank edge of the canal-bed. Fig.2 shows the location of three GPR profiles. The triggering interval to achieve higher horizontal resolution was kept at 0.1 m. Electrical resistivity imaging survey was done along one traverse of 50 m length along the central line of canal-bed. For this 25 electrodes in a line at 2 m interval were deployed. Schlumberger electrode configuration was used for data collection. One potential gradient profile between ch 25 m and ch 50 m was taken along central line of canal-bed by planting current electrodes 75 m apart to confirm the findings of GPR survey.

RESULTS

The results of GPR survey conducted on the 1 km long profile situated along the central line of canal-bed revealed that after ch 500 m of the profile no significant anomaly existed hence the area was inferred to be devoid of any big cavity at shallow depth. However, in the first 500 m of profile many anomalies were noticed on the GPR record. A plausible interpretation for these anomalies was the presence of a partially water and/ or clay-filled lows and partially air-filled (high) cavity system. Fig.3 shows a typical GPR record from survey chainages (ch) 283 m to ch 319 m, where two subsurface cavities have been inferred. A trough like pattern of radar diffractions from survey ch 283.4 m to ch 292.67 m i.e. 9.27 m across and about 1 m deep recorded at this location has been inferred to be cavity filled with conducting material i.e. clay. Another cavity with high from ch 299.6 m to ch 305.6 m has been interpreted to be air-filled cavity. Similarly the GPR record between survey ch 339 m and ch 362 m along central line is shown in Fig.4. Two cavities showing trough like pattern from ch 344 m to ch 347 m and between ch 351.53 m and ch 354.20 m have been inferred to be clay filled cavities. In all 10 cavities (both air and clay-filled) along the central line were inferred. Along left and right bank edges of canal-bed 18 and 13 cavities respectively of varying dimensions were inferred.

Resistivity imaging section obtained using Schlumberger electrode configuration along central line of canal-bed and passing over the day-lighted central cavity is shown in Fig.5. In the centre of the section two isolated high resistivity anomalies inferred to be air-filled cavities are seen. The location of these cavities matches with the central day-lighted cavity. Though along the central line of canal-bed only one

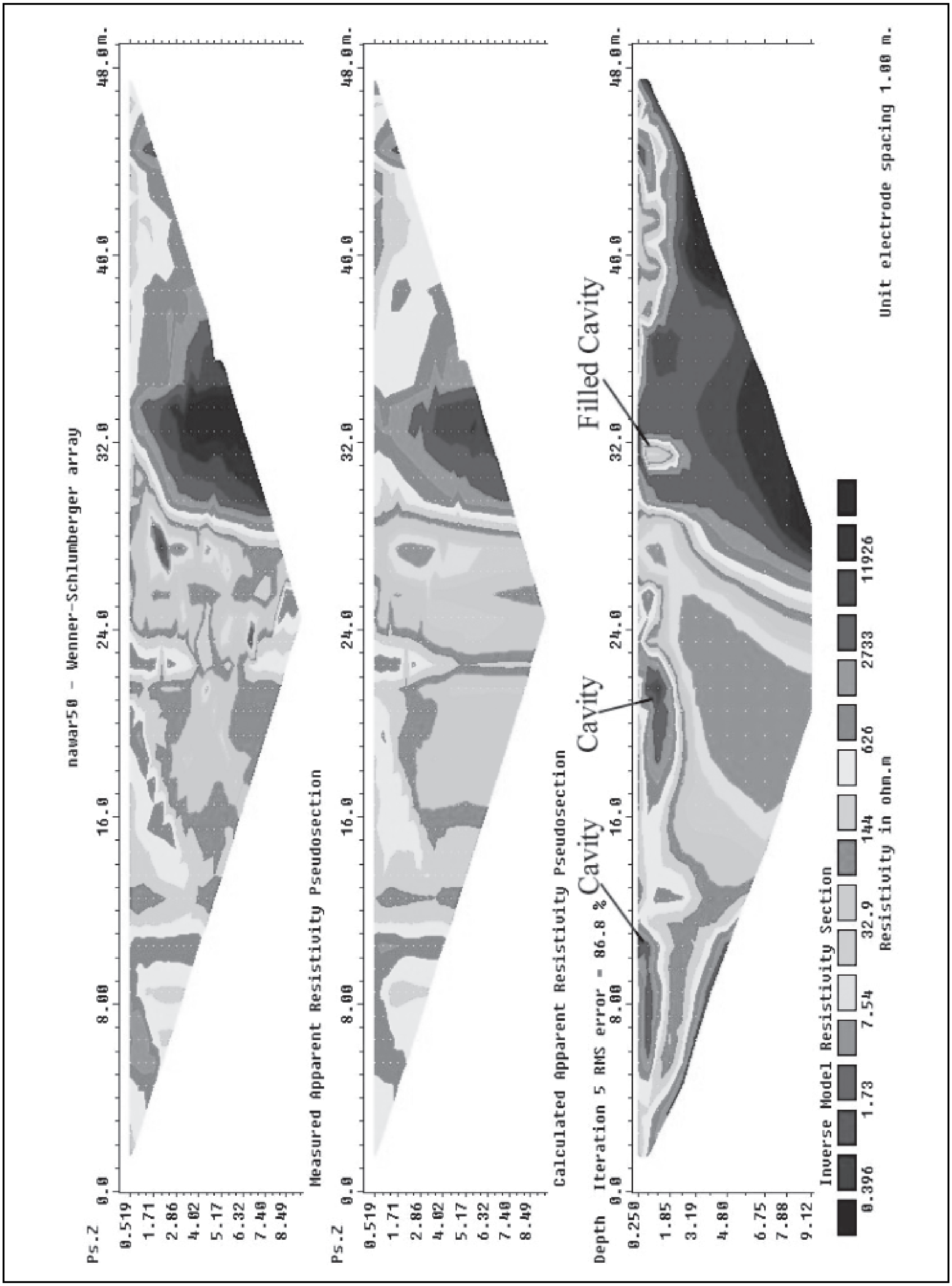


Figure 5. Resistivity Imaging Section with Cavities

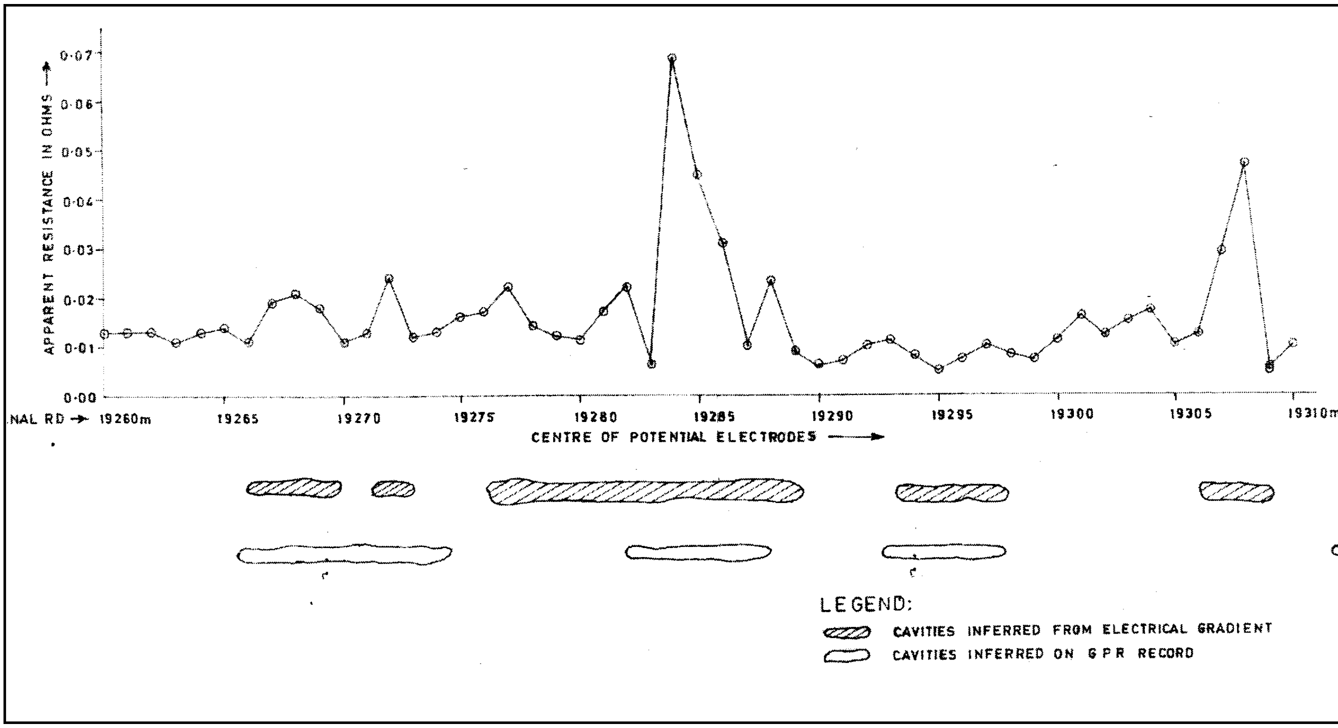


Figure 6. Apparent resistance curve and detected cavities

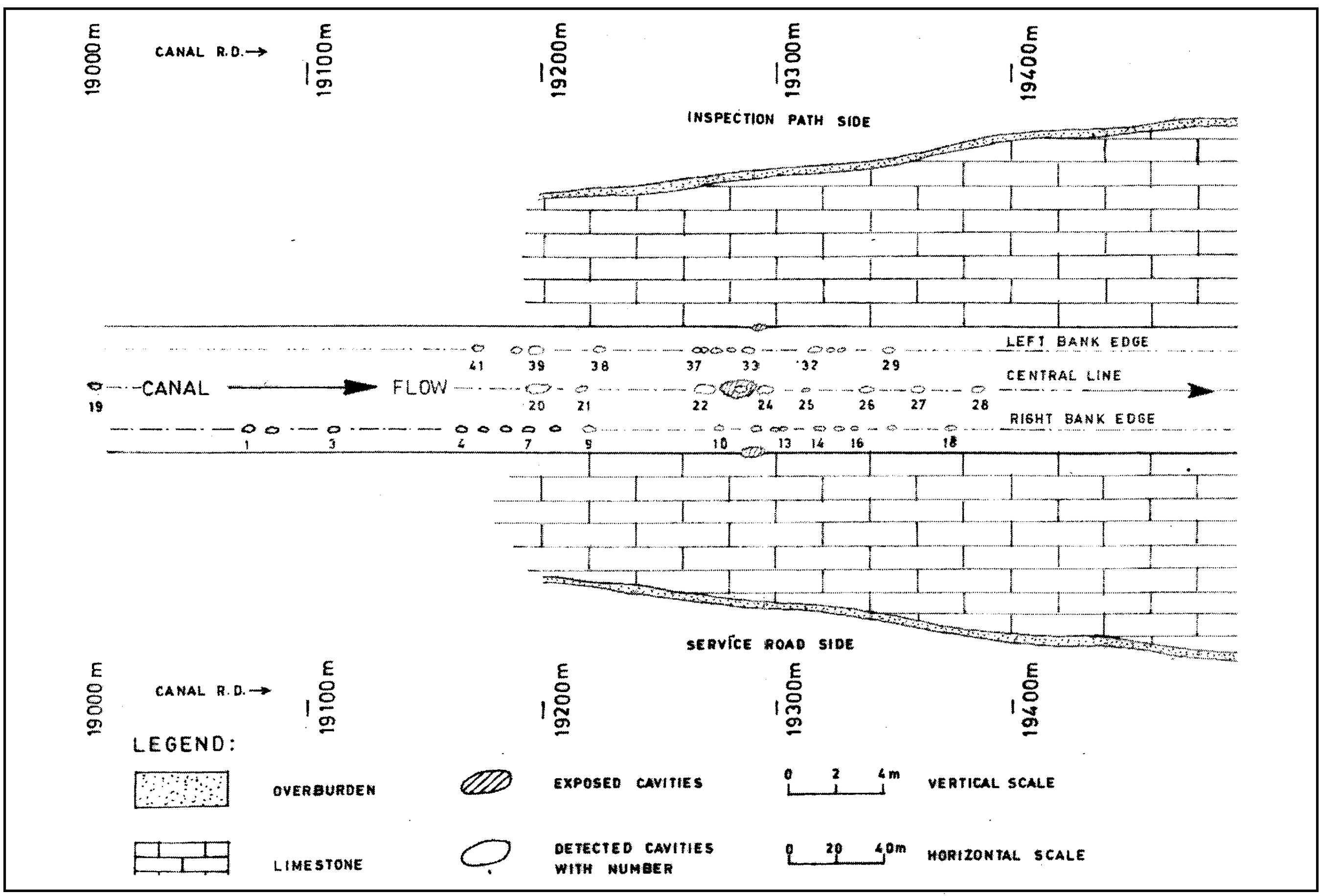


Figure 7. Plan of Canal with exposed and detected cavities

big exposed cavity is seen but may be in the central portion the cavity is filled with some foreign material, thus dividing one cavity into two as far as electrical properties are concerned. Low resistivity zone between ch 31 m and ch 32 m corresponds to filled cavity. The chainages of cavities inferred along this line match with those deciphered using GPR data; thus confirming the findings of GPR survey. As conducting resistivity imaging survey in situations where rock is exposed, is very tedious as compared to GPR, more imaging profiles were not attempted.

Electrical gradient data obtained using current electrodes spaced 75 m apart and moving potential dipole (1 m) at 1m interval between ch 25 m and ch 50 m of the profile are shown in Fig.6. A big cavity (high resistance) inferred at canal RD 19285 m matches with the position of exposed central cavity. Of the five cavities inferred along this traverse four were inferred to be air-filled (high resistance) and one clay-filled (low resistance). The lateral extent of cavities inferred both by potential gradient and GPR survey along this traverse are shown in Fig.6. The good match between the lateral dimensions of cavities inferred by GPR and electrical gradient surveys proves the efficacy of potential gradient technique for detection of cavities. Fig.7 gives the plan of canal along with the locations of 41 cavities inferred through geophysical survey.

CONCLUSIONS

The results of ground penetrating radar traverses conducted along central line of canal-bed and along traverses close to left and right bank edges of canal-bed revealed in all 41 cavities in limestone. Lateral extent of these cavities varied as some of these were small isolated cavities while others were quite big in nature. Resistivity imaging survey along 50 m long profile located along central line of canal-bed revealed three cavities, two resistive and one conductive. The resistive and conductive anomalies were inferred to be air and clay-filled cavities respectively. 50 m long potential gradient profile conducted in two stretches across central line of canal-bed yielded one big anomalous resistive zone which matched with the exposed central cavity. Other cavities along gradient profile were interpreted to be either air or clay-filled depending on whether the same appeared as resistive or conductive anomaly. The lateral extent of cavities deciphered using resistivity imaging and electrical gradient techniques matched with those inferred using GPR survey. The geophysical surveys helped in precisely demarcating the cavernous zone in limestone.

ACKNOWLEDGEMENTS

Authors are grateful to Mrs V.M.Bendre, Director, Central Water and Power Research Station for constant encouragement and for permission to publish this paper. The help and cooperation extended by project authorities during collection of data is acknowledged.

REFERENCES

Ballard, R.F., 1983. Cavity detection and delineation research Rep.5, Electromagnetic (radar) techniques applied to cavity detection, Tech. Rep. GL-83-1 U.S.Army Engr. Waterways Expr Station, Viksburg, MS

Dwain K. Butler and Jose L.Llopis, 1990. Assessment of anomalous seepage conditions, in Geotechnical and Environment al Geophysics, (Ed) Stanley H.Ward, Vol 11, SEG, Oklahoma, 153-173.

Horton, K.A., Morey, R.M., Isaacson, L. & Beers, R.H., 1981. The complementary nature of geophysical Techniques for Mapping Chemical Waste Disposal Sites: Impulse Radar and Resistivity, In Proc (2^{nd}) National Conference on management of Uncontrolled Hazardous Waste sites, Hazardous Materials control Research Institute, Silver Spring, MD, 158-164

Humphreys, G.L., Linford, J.G. & West, S.M., 1990. Application of Geophysics to the Reclamation of Saline Farmland in Western Australia, in Geotechnical and Environmental Geophysics, Ed. S.H.Ward, Society of Exploration Geophysicists, P.O.Box 702740 Tulsa, Oklahoma, 175-186

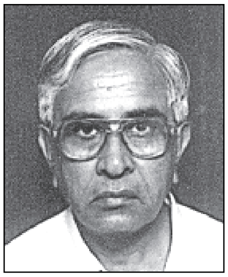
Morey, R.M., 1974. Continuous subsurface profiling by impulse radar, Proc. Engr. Foundation Conference Subsurface Exploration. Underground Excavation and Heavy construction, Am. Society Civil Engineers, 213-232

Olhoeft, G.R., 1984. Application and limitations of ground penetrating radar: 54^{th} Annual Intrnational Meeting. Society Exploration Geophysics, Expanded Abstracts, 147-148

Olhoeft, G.R.,1988. Selected bibliography on ground penetrating radar: Proc. Of Symposium on Application of Geophysics to Engineers and Environmental problems, Society of Engineers and Mineral Exploration Geophysics, 462-520

Ulriksen, C.P., 1982, Application of impulse radar to civil engineering: Ph. D dissertation, Dept of Engineering Geology, Lund University of Tech, Sweden.

(Accepted 2008 March 13. Received 2008 March 3; in original form 2007 December 3)



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 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 N.Ghosh, 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 pf University of Houston's Alumni and Best Teaching Assistantship Awards. He also received several scholarship 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.

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.

V.Chandrashekhar, working as Assistant Research Officer in CWPRS, since 1996, obtained his M.Sc (Tech) in Geophysics from Osmania University. He specializes in Engineering Geophysics related to Electrical Resistivity Imaging and Underwater seismic reflection technique. He has worked on about 50 real time problems using various geophysical techniques. He has 15 technical papers in national and international conferences and journals.