



Monitoring of the Turag River Dyke in Dhaka City Using Ground Penetrating Radar (GPR): A New Approach of Flood Risk Reduction in Bangladesh

Reshad Md. Ekram Ali¹(✉), Fannian Kong², Rajinder Kumar Bhasin², Salma Akter¹,
Mohammad Zohir Uddin¹, and Shahtaj Karim¹

¹ Geological Survey of Bangladesh, 153 Pioneer Road, Segunbagicha, Dhaka 1000, Bangladesh

² Norwegian Geotechnical Institute, Ullevaal Stadion, P.O. Box 3930, 0806 Oslo, Norway

Abstract. The focus of this study is placed on inspecting the Turag River dyke in Dhaka by using the Ground Penetrating Radar (GPR) which is often damaged during the monsoon season due to erosion caused by flooding and overtopping. The dyke was inspected to identify the weak zones at several locations by using GPR which is a non-destructive investigation technique. It requires no physical penetration into the ground, can perform quick survey and hence low cost involved compared to other surveys.

GPR survey has been conducted in three selected stretches of the dyke. These selected stretches are Mirpur Sluice Gate, Rostampur Cross Dyke and Prottasha Bridge areas. GPR investigations on these particular portions of the dyke have done to monitor the health of the dyke and to locate any disturbed or weak zones which may need strengthening before monsoon.

Radargram of Mirpur Sluice Gate area shows four distinct reflection layers of pitch (tar) mixed with brick; brick chips with sand; pre-existing footpath and compacted soil. Compacted soil below the pre-existing footpath formed by silty clay to clay materials found with slight variation of materials types, materials compactness and wetness, indication comparative weak zones in silty clay to clay. The lines representing the reflections from the ground layers suddenly end from both sides in the radargram indicating the existence of the sluice gate. In Rostampur Cross Dyke three subsurface layers can easily be identified from the radargram. The uppermost unit is mainly composed of brick chips and silty clay materials. Below the top layer, lithology of second layer has not been identified. Underneath the second layer the main dam materials are silty clay to clay. Variation of materials, compactness and wetness are also observed here. Radargram from GPR measurement on the highway beside Prottasha Bridge clearly shows that the bridge structure of the section is different from the adjacent sections at both sides. Reflections from pipes or cables under the highway are strongly visible. Although dyke materials are comparatively fine textured and wet but results were satisfactory and encouraging.

Keywords: GPR · Dyke · Radargram · Compactness

1 Introduction

Dhaka is the capital and the largest city in Bangladesh. It is situated in the South Asia and the world's 11th largest megacity (UN 2016) with a population of 18.2 million living in an area of 1528 km² (Swapan et al. 2017) Presently, the city faces a number of environmental and other hazards such as river flooding, water logging, earthquakes, fire hazards, traffic congestion, etc. The city is surrounded by the Buriganga River to the south, the Turag River to the west, the Tongi khal to the north, and the Balu River to the east (Fig. 1). The city and adjoining areas are composed of alluvial terraces of the southern part of the Madhupur tract and low-lying areas of floodplain deposits. The elevation of Greater Dhaka ranges between 2 to 13 m AMSL and most of the urbanized areas are between 6 to 8 m covers about 75 km², while 170 km² of Greater Dhaka is below 6 m above mean sea level (JICA 1987). Flooding is the best-known hazard of Dhaka. In 1988 most of Dhaka has been inundated by prolonged record-setting flood, like other floods, which were clearly visible on space satellite photographs (Rasid 1993a).

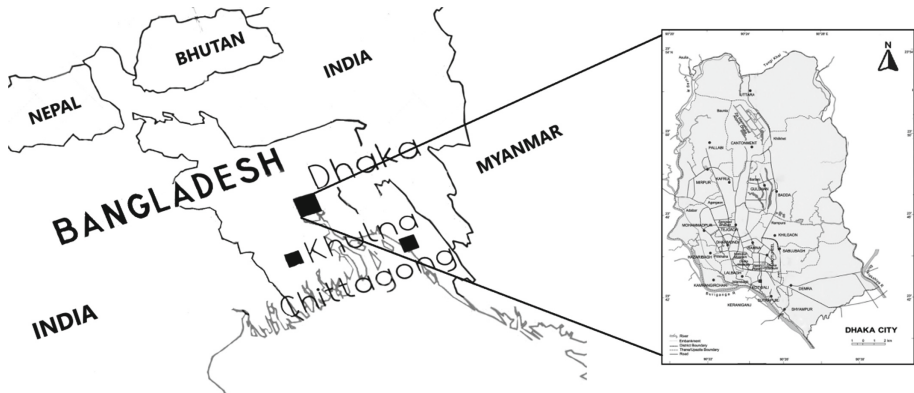


Fig. 1. Location map of Dhaka City

The main causes of flooding in Dhaka City are spill over water from the surrounding rivers and internal water logging. In recent history, Dhaka city experienced major floods in 1954, 1955, 1970, 1974, 1980, 1987, 1988, and 1998 due to the overflow of surrounding rivers. Among these, the 1988 and 1998 floods were catastrophic (Ahmed 1999; Chowdhury et al. 1998; Islam and Chowdhury 2002; Islam et al. 2008). Prof. Hye (1999) carried out a rapid appraisal of flood-affected people during the flood, dividing the flood-affected area into three categories: most severely affected area, severely affected area, and moderately affected area. It was found that the flood displaced or dislocated 94% of families in the most severely affected areas, 52% of families in severely affected areas, and 50% in moderately affected areas. It was also estimated that the total flood-affected population would likely be 4.55 million.

Ground Penetrating Radar (GPR) is a useful tool for geophysical survey, it has been using to solve different geological problems for long time (Doolittle and Collins 1995; Doolittle et al. 2006; Shih and Doolittle 1984; Benson 1995). Similarly, GPR can be

used to detect weak zones in the dyke that could be breached easily in the near future. GPR has similar record as seismic survey (Jol 2009; Baker et al. 2007). The main difference between GPR and seismic methods is that seismic reflection comes from a boundary where there is an acoustic impedance contrast and in the case of GPR the reflection comes from a boundary where there is a dielectric constant contrast. However, in seismic reflection method, the depth of penetration is very large so the geoscientists think about gross lithology but in case of GPR they have to think very minutely about the lithology and other variation within a very shallow depth in the range of 10 m. For any geophysical methods, the detection resolution is a portion (for example, one tenth) of the test distance. Therefore, GPR normally gives detection results with much higher resolution than the seismic method. The other advantages of using GPR are that for detection using electromagnetic wave, the sensors (or antennas) does not need to have good contact with the ground, which enables a fast survey speed, and that the GPR signal is generated by electronics, and is coherent and repetitive, which allows to use advanced signal and image processing methods. The most significant performance limitation of GPR is in high-conductivity materials such as clay soils and soils that are salt contaminated. Performance is also limited by signal scattering in rocky soils. Compare to the resistivity survey GPR can penetrates subsurface very little where the subsurface is conductive. Whereas, the main advantage of GPR over resistivity survey is that it can be run over hard surface that is not penetrable by electrode and resolution of radargram is very high compared to other geophysical methods.

2 Floods Mitigation in Dhaka

In 1864, the Buckland Flood Protection Embankment along the Buriganga River was the first attempt to mitigate flood damage in Dhaka City. Plans for comprehensive flood protection for Greater Dhaka have been under study and consideration for many years, but the catastrophic flooding that occurred in 1987 and 1988 brought into focus the urgent need to proceed with immediate action. In 1989, construction activities commenced on a “crash program” embank the western part of the city along the Turag River. It provides flood protection facilities to the western half of Dhaka and includes the most highly urbanized areas, covering about 87% of the population. This mitigation project has also encouraged urban invasion of the floodplain in an area (Rasid and Azim Mallik 1993b; Rasid and Mallik 1993; Rasid and Azim Mallik 1996; JICA 1991a). Presently, inside the embankment rapid urban expansion is continuing by both private housing companies and Rajdhani Unnayan Kartripakkha (RAJUK), important RAJUK projects are Uttara Residential Model Town Projects, especially 3rd phase, Uttara Apartment Project, etc. (<http://www.rajukdhaka.gov.bd/rajuk/webHome>). Although, the construction and maintenance costs and the operational requirements of the entire scheme are very heavy for the country. Unfortunately, the eastern part of Dhaka City is still unprotected.

Dhaka West have been encircled by embankments, floodwalls, raised roads to give protection against riverine flood (JICA 1991b). Approximately there are 30 km of earthen embankment along Tongi khal, Turag River and Buriganga River. A total of 11 regulators are at the outfall of khals to the surrounding rivers along the embankment. One regulator and 12 sluice gates on the khals at the crossings with Biswa Road, DIT Road, Pragati

Sarani, Mymensingh Road, and railway line at Uttar Khan. One pumping station is at the outfall of Kallyanpur khal to the Turag River and another one at the outfall of Dholaikhal to the Buriganga River. These pump stations are for draining rainwater from parts of Dhaka West. A special 10.53 km embankment is to surround the Zia International Airport.

After implementation of the flood-control project in Dhaka West, unplanned and uncontrolled expansion of urban areas stretched rapidly toward the low-lying areas and floodplains adjacent to the flood-protection embankment and river. Evaluation of Phase I work revealed that the existing earthen embankment is unstable and cracking in large sections, though some parts have recently been stabilized and other parts of the earthen embankment have been converted to roads. Construction of embankments through low-lying areas without providing adequate drainage facilities has caused internal flooding, adversely affecting the residents in those areas (Huq and Alam 2003). Residents of these lowlands suffer from inundation due to accumulation of rainwater after heavy rainfall. Land development through land-filling processes in the low-lying areas is causing a drastic reduction in water storage areas. Floods are one of the main natural hazards affecting the city and are associated with river water overflow and rain water stagnation.

Performance of western dykes reveals that the design height of dykes was not adequate to tolerate the flood of 1998. Moreover, coordinated efforts from the organizations like Dhaka Water Supply and Sewerage Authority (DWASA), Bangladesh Water Development Board (BWDB) and Dhaka City Corporation (DCC) were not observed. As a result, some culverts and regulators along the raised roads were left open in the beginning of the flood of 1998. In 2004 condition flood protection dykes have deteriorated due to settlement activities around it. Internal flooding is surfacing as one of the disasters for protected Dhaka West in 2004 (Bala et al. 2009).

Moreover, the dykes were not properly maintained since its construction. Breaches of dykes may cause tremendous damage of properties and immense suffering of people. Now monitoring and maintenance of dyke are the prime important to protect Dhaka West from future floods.

3 Principle of GPR and River Dyke Monitoring

There are two types of the material properties, which have effects on the electromagnetic wave propagating inside the material. One is the relative dielectric constant ϵ_r , and the other is the resistivity. Tables 1 and 2 show respectively the dielectric constants ϵ_r and the resistivities R for common ground materials.

Wave speed and propagation attenuation are related to the ground material properties. The wave velocity can be written as

$$v = \frac{2\pi f}{k_{real}} = \frac{1}{\sqrt{\mu\epsilon_0\sqrt{\epsilon_r}}} = \frac{c}{\sqrt{\epsilon_r}} \quad (1)$$

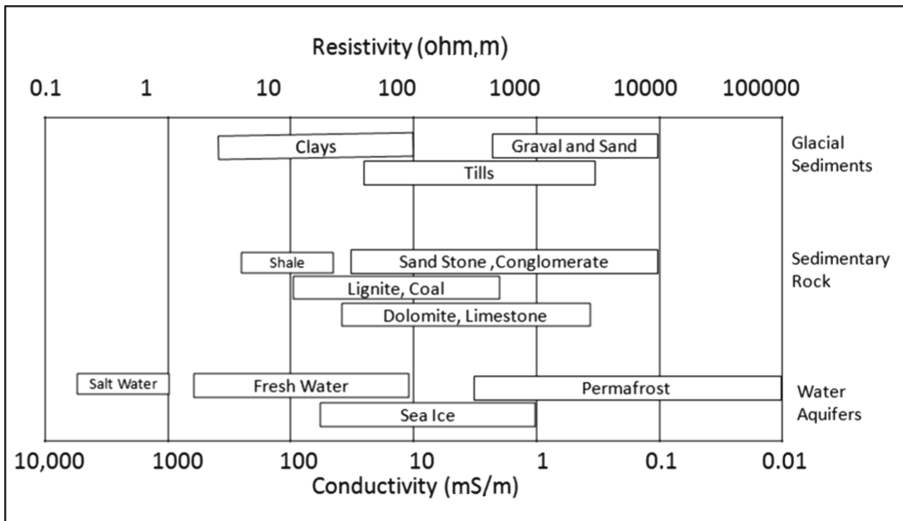
Where c is the speed of light in air and $c = 0.3$ m/ns. The list of wave speeds in ground materials shown in Table 1 is calculated by using the above equation.

A general rule is that for detecting deep targets one uses low frequency and long antennas and detection distance is 10 times of the antenna length. The above empirical relationship can help to choose antenna lengths according to the detection depth.

Table 1. Dielectric constants measured at 100 MHz of common earth materials (Cardimona 2002).

Material	Typical dielectric constant	Radar propagation velocity (m/ns)
Air	1	0.30
Water	81	0.033
Granite	9	0.10
Limestone	6	0.12
Sandstone	4	0.15
Rocks	4-12	0.15-0.087
Dry sand	4-6	0.15-0.12
Wet sand	30	0.055
Dry clay	8	0.11
Wet clay	33	0.052
Dry soils	3-8	0.17-0.11
Wet soils	4-40	0.15-0.047
Asphalt	3-6	0.17-0.12
Concrete	9-12	0.10-0.087

Table 2. Typical ranges of electrical resistivity and conductivity of earth material (Samouëlian et al. 2005)



The resolution is also related to the wavelength used. Here we adapt the criterion that the detection resolution is $\frac{1}{4}$ wavelengths, i.e., half of the antenna length. Hence our 10 cm antenna is best suited for detection distance 1 m with a resolution 5 cm, while our 1.2 m antenna is best suited for detection distance 12 m with a resolution 60 cm.

The conventional GPR test mode uses the reflection wave, where two antennas with a fixed spacing are used, one for transmitting and the other for receiving signals. They are moved along the river dyke. Electromagnetic waves can be transmitted through the ground with the help of the transmitting antenna. The energy of the wave is reflected back towards the surface where the electric or magnetic properties change (due to the weak zones etc.) in the river dyke. A second antenna receives the reflected wave. The ground materials will attenuate the radar wave. The detection distance is therefore dependent on the types of river dyke materials. GPR reflection measurement on top of the river dyke is a commonly accepted method used for the dyke monitoring (Fig. 2).



Fig. 2. Layout of GPR (1.2 m) test where a pair of 1.2 m antennas are used.

4 Results and Discussion

The dyke is located in the north and north-western part of the Dhaka city on Turag dyke. This dyke is approximately 30 km of earthen embankment along Tongi khal, Turag River, and Buriganga River. Three locations (Fig. 3) on the Turag dyke have been selected for the study based on radargrams with the objectives to detect weak zones due to fractures/cracks, organic materials and void spaces.

Mirpur Sluice Gate Area

Mirpur Sluice Gate area have been selected for GPR survey on Tongi Dyke (Fig. 3). The starting and ending positions of data acquisition are $23^{\circ}49'48''\text{N}$, $90^{\circ}49'44''\text{E}$ to $23^{\circ}49'44''\text{N}$, $90^{\circ}20'39''\text{E}$. The main purpose of this survey is to locate the sluice gate zone with GPR. Figure 4 shows a radargram across the measurement line.

For collecting a radargram in the sluice gate area a pair of 1.2 m length antennas such as shown in Fig. 4 have been used with 1 m spacing between receiving and transmitting antennas.

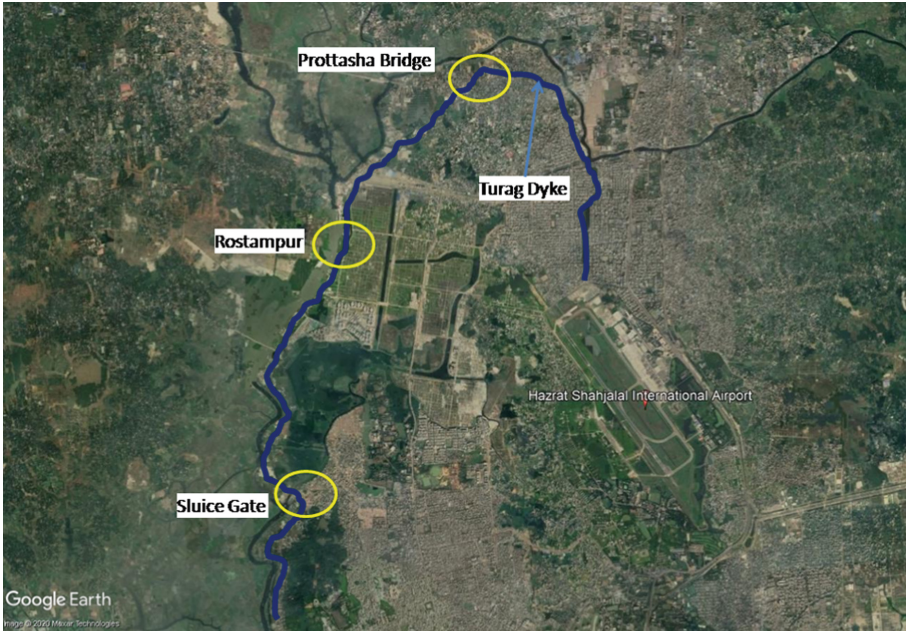


Fig. 3. Location map of 3 test study areas (Sluice Gate, Rostampur and Prottasha Bridge areas) on the Turag dykes in Dhaka.

In Fig. 4 there are four distinct reflections observed in the radargram: the 1st is the reflection at the interface between air and layer 1, the 2nd reflection is at the interface between layer 1 and layer 2, the third reflection is at the interface between layer 2 and layer 3 and the fourth reflection is at the interface between layer 3 and layer 4.

It is certain from our survey that the uppermost layer (layer 1) represents combine pitch (tar), brick, brick chips with sand. The layer 2 may represent the pre-existing footpath over which new pitch road has been made. The third layer may represent compacted soil below the pre-existing footpath. Below the third layer earth fill that is the layer 4 formed by silty clay to clay materials found with slight variation of materials, compactness and wetness. Results of GPR survey, confirmed by digging and hand auger where necessary.

Each division of the vertical axis is 20 ns representing a depth of 1 m with the assumption of the wave speed 10 cm/ns. So the approximate depth of layers 1, 2 and 3 are about 0.5 m each. Due to their thinness, it is very hard to differentiate among pitch, brick and brick chips zone within the uppermost layer (layer 1). Horn antenna or 60 cm length antenna may give good result for identification of pitch layer in the uppermost layer.

In the radargram shown in Fig. 5, two sets of anomaly are found. One is between the trace numbers 355 to 380 and the other is in between 320 to 340. The anomaly in the red circle represents the sluice gate. The lines representing the reflections from the ground layers suddenly end from both side of red circle indicating the existence of the sluice gate. The anomaly in between trace numbers 320 to 350 shows a different reflection

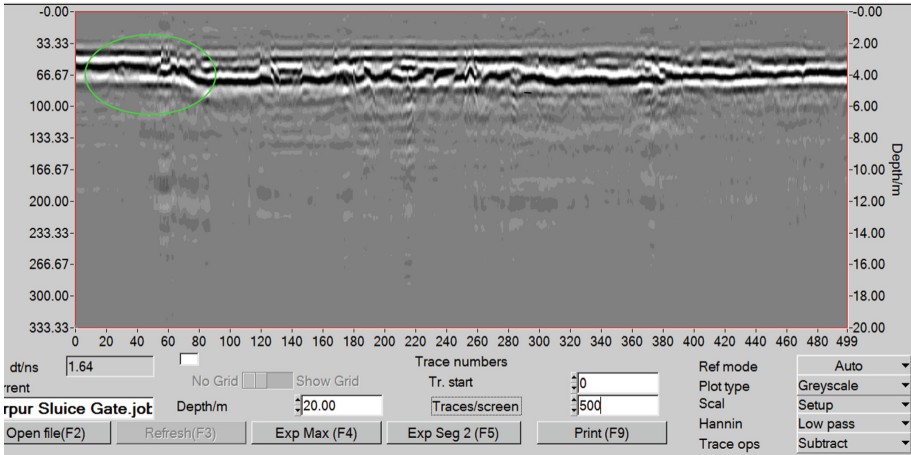


Fig. 4. Radargram Over Mirpur Sluice Gate.

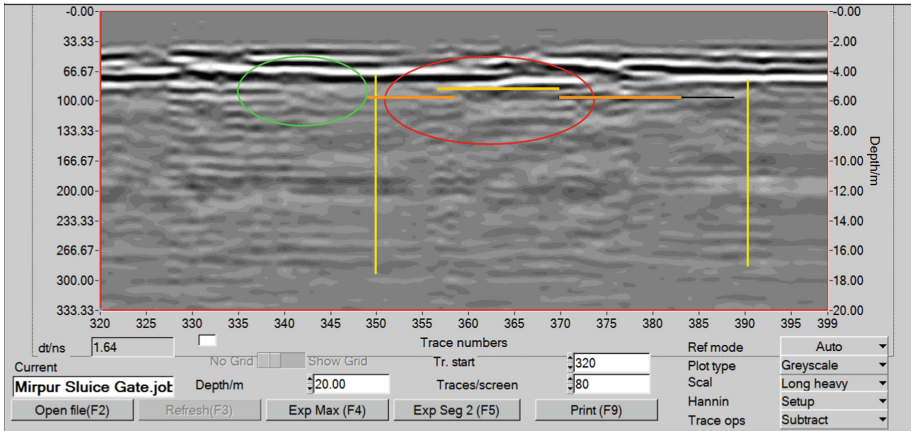


Fig. 5. The Sluice gate zone in between yellow mark (Red Circle).

pattern from the other one. This discontinuity of signal may be due to the beginning part of the sluice gate structure.

Rostampur Area

A GPR Survey was performed in Rostampur Cross dyke ($23^{\circ}52'32''$ N, $90^{\circ}21'01''$ E) to identify subsurface lithology (Fig. 3) and the test result is shown in Fig. 6. In this survey the 1.2 m antenna has been used. Between the trace nos. 1 and 110, three lithological layers can easily be identified from the radargram. The uppermost unit is mainly composed of brick chips and silty clay materials with a thickness 0.5 m. Below the top layer there is another layer of thickness 0.5 m. The lithology of this layer has not been identified. Below the second layer the main dam materials silty clay to clay are found. From trace no. 111 to the end of the radargram, we can only see two layers.

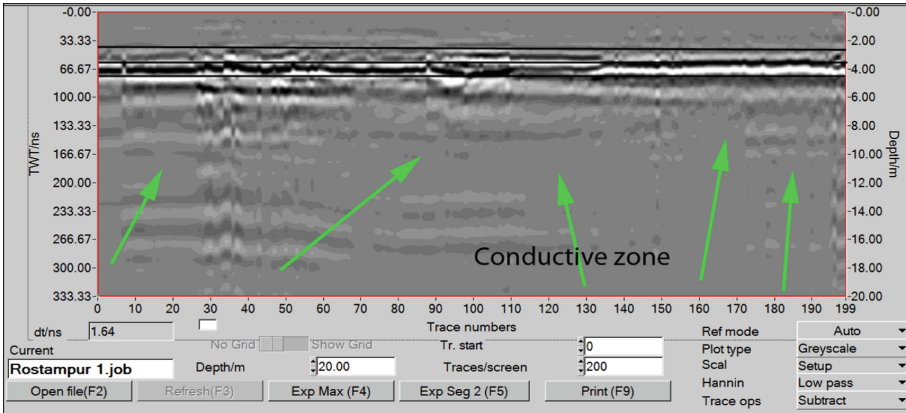


Fig. 6. Test result in Rostampur area.

Prottasha Bridge and on Highway Nearby

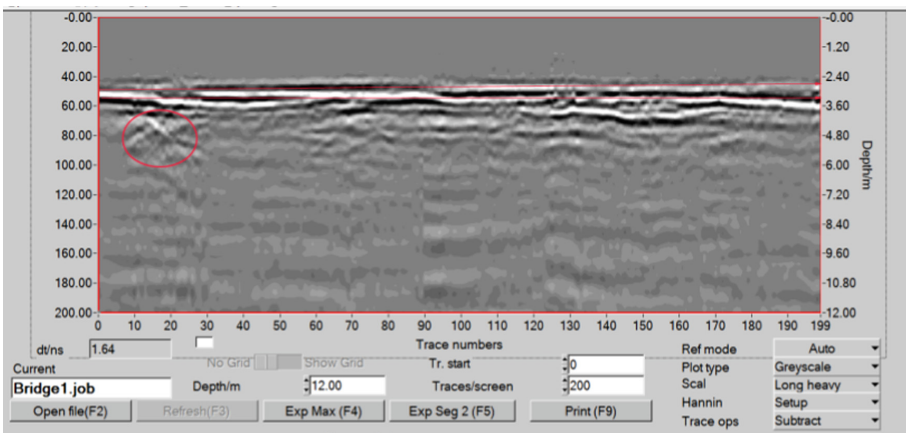


Fig. 7. Radargram along connecting road of Prottasha bridge.

Figure 7 shows the GPR survey at Prottasha Bridge ($23^{\circ}54'21''$ N, $90^{\circ}22'35''$ E) (Fig. 3) using the 1.2 m antenna used in all of the outdoor tests. In Fig. 7, the uppermost red line represents the response from base of pitch and stone chips. The 2nd red line marks the response from base of brick and below this the whole material might be silty clay.

The area within trace nos. 10–25 marked by the red circle may indicate the junction between the highway and the bridge connecting road which can be identified by the criss-crossed nature of the signal. Here, on the sloping side of the highway, new materials have been dumped for the bridge connecting road construction. From trace nos. 133–173 the signal shows a concave nature. The area within this section might be more compacted compared to its adjacent sides.

Figure 8 shows the radargram for GPR measurement on the highway beside Prottasha bridge. From this figure one can clearly see that the ground structure of the section between two yellow lines (trace nos. 125 to 265) is different to the adjacent sections at both sides. This is the section when the GPR moves close to the bridge connecting road. The red lines show the reflections from a shallow layer (brick to sand interface?). At trace nos. 30, 85, 330, there may be reflections from pipes or cables under the highway.

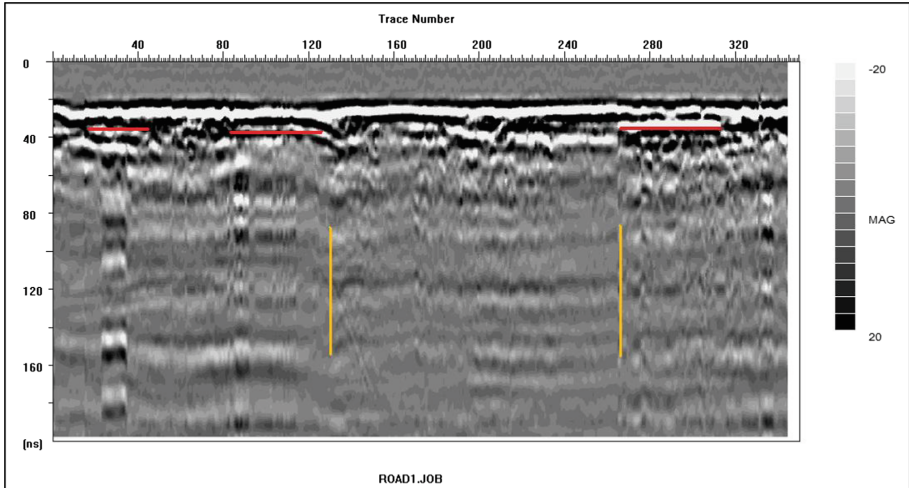


Fig. 8. Results of GPR measurement on the highway beside Prottasha bridge

5 Conclusions

GPR provides an efficient and resourceful means for shallow subsurface studies. Radargram of GPR show that on top of the dyke there is 6 cm thick asphalt carpeting with stone chips. Below the asphalt layer there is 13 cm thick compacted layer of brick chips mixed with sand (Locals inform maximum thickness of the brick chips layer is about 40 cm). Below brick chips there is sand. There is no brick soling below the brick chips layer. GPR test using 1.2 m antenna cannot resolve the layers with thickness 6 cm and 13 cm. However, Figs. 3 and 5 show that using 10 cm antennas can detect those layers.

GPR can be used to detect the material discontinuities along the measurement direction (e.g., see Figs. 3 and 7). Those discontinuity locations may suggest that the ground is built by different materials or the ground is deformed, and may indicate weak locations of a dyke.

In the Turag River dike the weak zones include loosely compacted layers, joints in different ground materials within the dykes, presence of highly compressive layers, etc. Generally speaking, materials such as concrete, sand, rock, gravel, sandy soil etc. are good materials for radar wave to penetrate. However, silty clay and wet clay etc. are the difficult materials for radar wave to penetrate. For good materials the GPR detection distance can be longer than 10 m. Even though the detection distance is limited in clay material etc.

The tests show that GPR can make quick and continuous measurements on river dyke etc. GPR can provide high-resolution image of the ground layering information. Moreover, GPR survey is a non-destructive investigation method, as well as being quick. Survey speed can be as fast as 2–3 km/hour. For an experienced operator, the interpretation of the survey results can be made on site without further data processing (inversion etc.). Hence, the GPR survey is low cost geotechnical investigation method.

The western part of Dhaka city is protected from river flooding by an encircling embankment. During most of the monsoon period, the water level of the river remains higher than the water level inside the city area. Adaptations to climate change and to economic development are important drivers in designing flood management schemes. Flood risk management is strongly related to spatial planning: the location of new developments, flood proof structures and space for rivers. Risk communication is a valuable approach to promote flood awareness and improve agile flood mitigation systems.

References

- Ahmed, F.: Impact on water supply sanitation and waste management. In: Nishat, A., Reazuddin, M., et al. (eds.) *The 1998 Flood: Impact on Environment of Dhaka City*. Department of Environment in conjunction with IUCN Bangladesh (1999)
- Baker, G.S., Jol, H.M. (eds.): *Stratigraphic analyses using GPR*, Geological Society of America Special Papers, vol. 432, 181 p. The Geological Society of America, Boulder, CO (2007)
- Bala, S.K., et al.: Performance of flood control works around Dhaka City during major floods in Bangladesh, Institute of Water and Flood Management, Bangladesh University of Engineering. In: 2nd International Conference on Water & Flood Management (2009)
- Benson, A.K.: Applications of ground penetrating radar in assessing some geological hazards: examples of groundwater contamination, faults, cavities. *J. Appl. Geophys.* **33**(1–3), 177–193 (1995)
- Cardimona, S.: Subsurface investigation using ground penetrating radar. In: 2nd International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, Los Angeles, California (2002)
- Chowdhury, J.U., Rahman, R., Bala, S.K., Islam, A.S.: *Impact of 1998 Flood of Dhaka City and Performance of Flood Control Works Dhaka*: Institute of Flood Control & Drainage Research, Bangladesh University of Engineering & Technology (1998)
- Doolittle, J.A., Collins, M.E.: Use of soil information to determine application of ground penetrating radar. *J. Appl. Geophys.* **33**(1–3), 101–108 (1995)
- Doolittle, J.A., Jenkinson, B., Hopkins, D., Ulmer, M., Tuttle, W.: Hydrogeological investigations with ground penetrating radar (GPR): estimating water-table depths and local ground-water flow pattern in areas of coarse-textured soils. *Geoderma* **131**(3–4), 317–329 (2006). <http://www.rajukdhaka.gov.bd/rajuk/webHome>
- Huq, S., Alam, M.: *Building Safer Cities: The Future of Disaster Risk Flood Management and Vulnerability of Dhaka City* (2003)
- Hye, A.: Effect on livelihood. In: Nishat, A., Reazuddin, M., et al. (eds.) *The 1998 Flood: Impact on Environment of Dhaka City*. Department of Environment in conjunction with IUCN Bangladesh (1999)
- Islam, A.S., Chowdhury, J.U. (eds.): *Hydrological Characteristics of the 1998 flood in major rivers*, Engineering Concern of Flood. Bangladesh University of Engineering and Technology, Dhaka (2002)

- Islam, A.S., Haque, A., Bala, S.K.: Hydrological Aspects of Flood 2007. Dhaka, Bangladesh: Institute of Water and Flood Management (IWF), Bangladesh University of Engineering and Technology (BUET) (2008)
- JICA (Japan International Cooperation Agency): “Study on Storm Water Drainage System Improvement Project in Dhaka City.” Supporting Report, Local Government Division of Ministry of Local Government Rural Development and Cooperative, Dhaka (1987)
- JICA: Master Plan for Greater Dhaka Protection Project (Study in Dhaka Metropolitan Area), FAP 8A, Main Report and Supporting Reports I and II. Flood Plan Coordination Organization. Dhaka: Japan International Cooperation Agency (1991a)
- JICA: Master Plan for Greater Dhaka Flood Protection Project. Flood Action Plan 8A, Main Report and Supporting Reports I and II. Flood Plan Coordination Organization (Presently WARPO), Dhaka (1991b)
- Jol, H.M. (ed.): Ground Penetrating Radar: Theory and Applications, 524 p. Elsevier, Amsterdam (2009)
- Rasid, H.: Areal extent of the 1988 flood in Bangladesh: how much did the satellite imagery show? *Natural Hazards* **8**(2), 189–200 (1993a)
- Rasid, H.: Preventing flooding or regulating flood levels? Case studies on perception of flood alleviation in Bangladesh. *Natural Hazards* **8**(1), 39–57 (1993b)
- Rasid, H., Azim Mallik, A.: Poldering vs compartmentalization: the choice of flood control techniques in Bangladesh. *Environ. Manage.* **17**(1), 59–71 (1993)
- Rasid, H., Azim Mallik, A.: Living on the edge of stagnant water: an assessment of environmental impacts of construction-phase drainage congestion along Dhaka City Flood Control Embankment in Bangladesh. *Environ. Manage.* **12**(1), 89–98 (1996)
- Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., Richard, G.: Electrical resistivity survey in soil science: a review. *Soil Tillage Res.* **83**(2), 173–193 (2005)
- Shih, S.F., Doolittle, J.A.: Using radar to investigate organic soil thickness in the Florida everglades. *Soil Sci. Am. J.* **48**(3), 651–656 (1984)
- Swapan, M.S.H., Zaman, A.U., Ahsan, T., Ahmed, F.: Transforming urban dichotomies and challenges of South Asian megacities: rethinking sustainable growth of Dhaka, Bangladesh. *Urban Sci.* **1**, 31 (2017). <https://doi.org/10.3390/urbansci1040031>
- UN: The World’s Cities in 2016. World Urbanization Prospects: Data Booklet (ST/ESA/SER.A/392); United Nations, New York (2016)