Detection of Hair-line Cracks in IITJ Buildings Using Ground Penetrating Radar (GPR)

A Project Report submitted by

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in partial fulfillment of the requirements for the award of the degree of

Bachelor of Technology

Indian Institute of Technology Jodhpur

Department of Civil and Infrastructure Engineering

November 2024

Declaration

I hereby declare that the work presented in this Project Report titled Detection of Hair-line Cracks in IITJ Buildings Using Ground Penetrating Radar (GPR) submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology, is a bonafide record of the research work carried out under the supervision of Proff Pradeep Kumar Dammala. The contents of this B.Tech. Project Report in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

Prince Sonker
B21CI033

Certificate

This is to certify that the Project Report titled Detection of Hair-line Cracks in IITJ Buildings Using Ground Penetrating Radar (GPR), submitted by Prince Sonker (B21CI033) to the Indian Institute of Technology Jodhpur for the award of the degree of B.Tech. is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. Pradeep Kumar Dammala

Acknowledgements

I would like to express my gratitude to the several individuals who helped enable this project. Firstly, I sincerely thank my project supervisor, Dr. Pradeep Dammala, Professor of Civil Engineering at Indian Institute of Technology, Jodhpur, for his invaluable guidance, feedback, and support throughout the duration of the project. I also thank Bharat Solanki, Junior Technical Superintendent at the Department of Civil and Infrastructure Engineering, Indian Institute of Technology, Jodhpur, for his support throughout the duration of the project.

I am grateful for the insights provided by various academic works and technical papers cited in the references, which tremendously benefited my literature survey and understanding on this topic.

It has been a great learning experience for me to apply surveying concepts I studied to study real-life infrastructure challenges.

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Problem Statement

The buildings and rooms at IIT Jodhpur face persistent water leakage issues, which worsen significantly during the rainy season. Non-destructive technique, Ground Penetrating Radar is used in discovering these hidden cracks usually found inside subsurface portions of concrete structures as they contribute to leakage highly. GPR identifies those internal weaknesses of a structure that result in leakage and aims to provide an effective solution for water leakage over the long period of time for structural integrity also.

Abstract

This report details the implementation of Ground Penetrating Radar operating at a frequency of 1600 MHz in detecting hairline cracks in concrete structures at IIT Jodhpur. The study was mainly aimed at investigating crack formation in the structural areas, such as the outer walls of the Y4 hostel, G3 rooms, and the O4 hostel walls, as well as the E03 Berm. Therefore, total of five locations were surveyed using the GPR. The major drawback of application of Jodhpur sandstone on outer walls retaining moisture is that water will go inside through inner layers to the insulation and thus brickwork, which may weaken structural elements. GPR scans with RADAN software were analyzed to detect cracks wider than 6 mm, but micro-cracks and pores could not be found, and further inspection techniques are required. The conclusions obtained here reveal the suitability and efficiency of GPR for large-scale structural inspections but also addressing shortcomings about inability to identify fine-scale cracks that cause water seepage.

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1. INTRODUCTION

Non-destructive testing (NDT) methods are the tools for the assessment and maintenance of large reinforced concrete structures, which are foundational elements of civil infrastructure. These methods, including ultrasonic, acoustic, and ground-penetrating radar (GPR) techniques, are commonly used to inspect structures such as foundation slabs, floors, piles, retaining walls, dam walls, and bridge abutments. By leveraging various NDT techniques, engineers can comprehensively assess a structure's strength, integrity, thickness, and the conditions of its contact with surrounding soil, allowing the identification of potential internal and external defects without causing any damage.

Concrete structures deteriorate over time, as there are continuous effects of the environment, climate change and normal wear and tear. This degradation is getting increasingly accelerated by hairline cracks which go undetected while causing the structure both a compromise of structural integrity and safety. If not treated they become micro cracks which result in the entry of water, corrode the reinforcing materials and ultimately destruction of structural strength.

Therefore, an early detection of a crack is however a vital step for implementing preventive maintenance and for ensuring that the life of the structure is quite long. This method operates by sending high-frequency electromagnetic waves into various materials. When these waves encounter irregularities and variations in density, they are reflected back and in turn provide an accurate mapping of the internal structure with the greatest definition. The important factors to consider in the reflection or return of the waves are the travel time, amplitude, and frequency of the scintillated waves. These from subsurface conditions necessary in revealing probable defects or zones of weakness in the structure. GPR's efficiency and ability to cover large areas quickly have made it particularly valuable in structural assessments. Unlike invasive inspection methods, which can be time-consuming and may require structural modifications, GPR can provide a rapid, non-invasive overview of subsurface conditions. However, while GPR is effective in identifying larger flaws, limitations exist in its detection of smaller micro-pores and hairline cracks, suggesting that complementary methods may be necessary to achieve a complete diagnostic of the structure.

GPR technology has been put to use on the concrete structures of IIT Jodhpur in this study to identify micro-cracks around critical areas. The study focuses on checking structures like hostel buildings and retaining walls, where a small crack could have an influence on safety and durability. The high-frequency GPR antennas used in the study will allow for the identification of internal discontinuities that cannot otherwise be seen on the surface and, thus, to provide early measures for recommending maintenance-if needed. This approach would not only serve to achieve the structural integrity of IIT Jodhpur buildings but would further offer sustenance in developing an adaptive maintenance strategy for similar infrastructure projects. The research report reinforces such non-destructive tests such as GPR as fantastic in the modern maintenance of infrastructure and calls for integrated diagnostic techniques in order to assess and manage the health of structures holistically.

2. LITERATURE REVIEW

1. Ground Penetrating Radar (GPR) in Structural Assessment

Ground Penetrating Radar is a non-destructive technique that uses electromagnetic waves to detect subsurface anomalies. It is widely used in civil engineering to detect defects in concrete structures, inspect tunnel linings and retaining walls, among others. GPR information includes internal defects such as voids, cracks, and material thickness derived by analysis of reflected waves against the subsurface structures. [1]

Figure 1:- Image shows the GPR with antenna of 1600 MHz frequency

2. Principles of GPR for Structural Anomaly Detection

The effectiveness of GPR depends upon the frequency of the antennas, properties of the materials, and the existence of internal defects. High-frequency antennas are effective for detecting shallow and small-scale anomalies that are like hairline cracks. This mainly occurs above 900 MHz to 1600 MHz. Lower frequencies will penetrate deeper but provide fewer resolutions, making this useful for identifying larger features such as voids. [4]

3. Challenges in Detecting Hairline Cracks Using GPR

Detection of hairline cracks is challenging in itself because they are thin and may not create a reflection strong enough to be detected. Signals from thin layers overlap, and it is difficult to get the right thickness estimation. This requires additional signal-processing techniques to distinguish between closely spaced reflections. Cross-correlation and time-zero correction have been applied in similar applications to address these challenges. [5]

4. GPR in Tunnel and Building Inspection

Studies on the scans of tunnels and walls illustrated that GPR may be able to identify voids, cavities, and cracks in concrete. For example, research studies on concrete linings of tunnels reflect that GPR can identify an air cavity and understand the extent of the stability of the structure using two-way travel time measurements of the EM waves. This technique can allow the characterization of the defect dimensions despite partially overlapping reflections in hairline cracks. [1][4]

5. Signal Processing Techniques in GPR

High quality signal processing is important to accurately detect the hairline cracks. Two techniques applied are those of the Dewow filter and background noise removal in order to enhance the clarity of the signal by eliminating low frequency noise. Yet another method that promises enhanced accuracy in heterogeneous materials and was first developed in studies of historical masonry walls, is local frequency attribute extraction. This may be adapted to improve the detection of hairline cracks by refining the frequency
content of the GPR signal to allow higher resolution. [7]

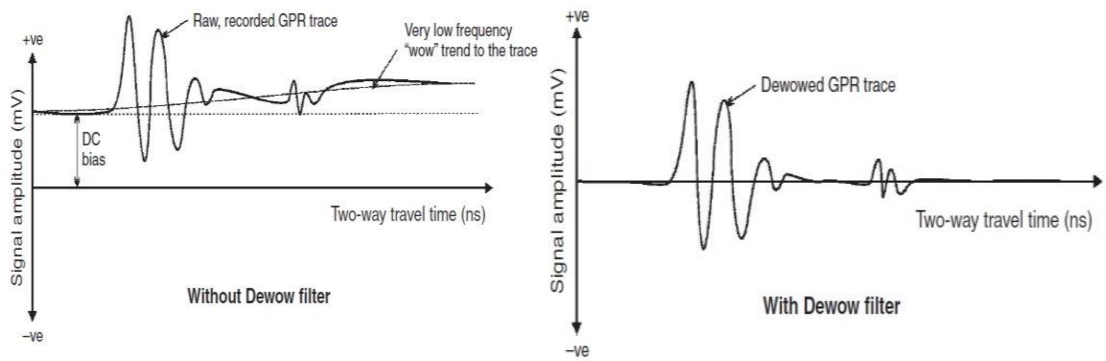


Figure 2:- Graph Without Dewow filter and With Dewow filter

6. Experimental Parameters that Influence GPR Performance

Several experimental parameters influence the efficiency of GPR for structural defects. These factors include some parameters such as antenna type-air-coupled or ground coupled, frequency, concrete thickness, and most importantly, the material properties. Thin cracks are always better resolved by high-frequency signals; however, it goes hand in hand with a penalty on the penetration depth. The results from several studies indicate that frequencies ranging from 400 MHz up to 1600 MHz are ideal for concrete inspections because they produce a compromise between depth and resolution sufficient for hairline crack detection. [4]

7. Case Studies and Validation Techniques

In the case studies dealing with Roman masonry and tunnel linings, GPR has been validated using other physical measurements, such as LiDAR, for thickness wall size. The integration of GPR with other technologies like LiDAR would upgrade the accuracy for depth structural integrity assessments. These validation techniques can be applied to the IITJ buildings project to validate results based on GPR.[2][1]

8. Future Prospects for GPR Hairline Crack Application

Research in this field is now directed towards tailored processing methodologies and the amalgamation of GPR with other combined non-destructive testing techniques. Further refinements in signal processing algorithms and calibration to standard known standards will, in due course, allow GPR to attain a higher resolution for the detection of defects at the minute scale. For IITJ, integration of GPR with any other technique, be it acoustic or ultrasonic tests, will help in the surety of the detection of hairline cracks.

3. OBJECTIVE

This project aims to utilize the Ground Penetrating Radar (GPR) model SIR 4000 fitted with a 1600 MHz antenna to evaluate hairline cracks and moisture-prone zones within the concrete structures of IIT Jodhpur. A good extension of established research on non-destructive testing, this study looks into GPR effectiveness in subsurface irregularity identification, such as structural degradation-related subsurface irregularities. It also aims at establishing limits of GPR in the ability to detect small defects that can lead to seepage and deterioration in the long term. Finally, analysis is set to highlight areas for potential improvement in GPR application for concrete crack assessment with precise targeting of moisture accumulation.

4. METHODOLOGY

4.1 Study Location

The investigation was held at the Indian Institute of Technology (IIT), and Jodhpur campus covers 852 acres and has three sections (A, B, and C) in the village of Jheepasani, Jodhpur, Rajasthan. IIT Jodhpur is one of the 23 premier Indian Institutes of Technology. Permanent campus operations date to 2018. The entire campus infrastructure gets done in phases (1, 2, 3A, and 3B). Currently, phase 3A is fully operational, covering an area of about 68,000 m^2; phase 3B, of an area square measuring about 92,500 m^2; is under established planning. After consequent completion of phase 3B, the total actual built-up area of the campus is expected to be about 390,000 m^2 within the next few years.

With a sprawling campus and construction still ongoing, urgent attention to maintaining existing structures is required in order to avert potential safety hazards and realize longevity in time. The affected structure requires inspections to discover damage, particularly fissures, diminishing structural integrity. Those disturbing cracks led to conducting a GPR survey at five locations on the premises to detect and analyze those in the walls of concerned structures, giving information every bit needed to work on approaching repairs. While managing maintenance, the GPR survey furnishes insights into the walls' detailed subsurface condition and thus allows for directed remedial work, rightly intended to preserve the safety and durability of the infrastructure facilities. Therefore, The selected buildings that are included in the study are as follows:

S-1	E-3 Berm	S-2	G-3 Hostel (terrace and rooms)
S-3	Y-4 Hostel (Exterior)	S-4	O-4 Hostel (exterior)

4.2 Data Collection

A 1600MHz GPR antenna was employed on the present project for detecting hairline cracks in different buildings on the campus of IIT Jodhpur. The GPR surveying used high-frequency electromagnetic waves to transmit into the concrete structure, taking back detailed reflections from its interior. These reflections gave critical information about internal cracks, voids, and possible sources of water infiltration during wet months, likely via hairline cracks and permeable wall sections. The scans observed locations with good subsurface reflections, allowing better determination of the internal discontinuities and corresponding air voids within concrete walls.

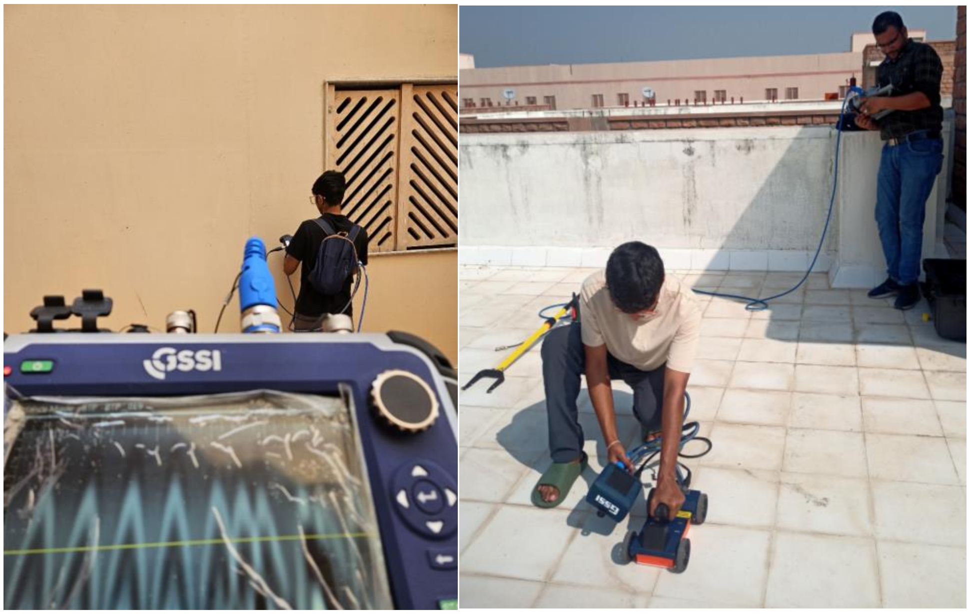


Figure:- Data Collection at IIT Jodhpur using GPR

4.3 Data Processing

The raw data collected from the sites were uploaded into RADAN, a specialized GPR data post-processing software, where detailed filtering and analysis were conducted. The software enhances the clarity of the images, thus helping the identification of subsurface features such as cracks and voids within the structures. The workflow involved several key steps:

1. Time-Zero Correction: Using the auto-peak method, this step removed errors from air gaps between the ground surface and the GPR cart.

2. Infinite Impulse Response (IIR) Filtering: The high-pass and low-pass filter values were set at 90 MHz and 700 MHz, respectively, to eliminate background noise, with an additional IIR filter applied at 90 MHz to 130 MHz for high-pass and 510 MHz for low-pass filtering.

3. Noise Band Removal: The full scan band algorithm was utilized to filter out unwanted noise bands, improving data quality.

4. Gain Adjustment: Exponential gain adjustment, with eight gain points, increased the visibility of weaker signals by enhancing contrast, helping to clarify image details.

5. Color Processing: The Dirt color setting and Color X form function (with LM 8 and LM 4 selections) improved visibility and contrast within the scans, especially in concrete structures.

6. Hyperbola Fitting and Migration: A ghost hyperbola was superimposed to the original data, optimized to locate an accurate target. Migration collapsed each side of the hyperbola, and the resulting dot indicated the top of the target, localizing cracks and other reflectors with accuracy. This serial processing scheme enabled the derivation of radar wave velocity, dielectric permittivity, and two-way travel time.

5. RESULTS AND INTERPRETATION

The data collected from various regions on the IITJ campus, that is E-3 Berm, G-3 Hostel terrace and rooms, Y-4 Hostel External and O-4 Hostel external is processed and interpreted through RADAN software in order to discover the presence of cracks, voids and moisture zones:

E-3 Berm:

This crack can be identified here through naked eye but after capturing it through GPR and then processing with RADAN, we can see here the inverted parabola (in right side image) which clearly shows that crack can be detected through GPR.

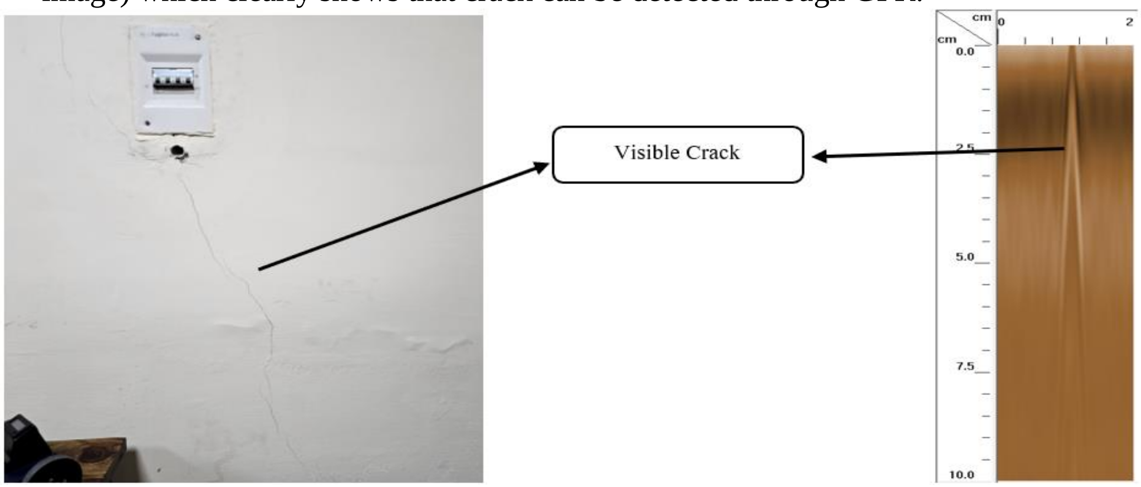


Figure 3 :- Image showing the visible crack on E3 berm wall and it’s detection

G-3 Hostel terrace and Room 225:

There could be cracks or voids on the terrace of the G-3 hostel building, and that could be causing the seepage. There should be a check on structural gaps so that no more moisture seeps in and does not disintegrate its building integrity.

Figure 4:- Using the GPR at G-3 terrace and room

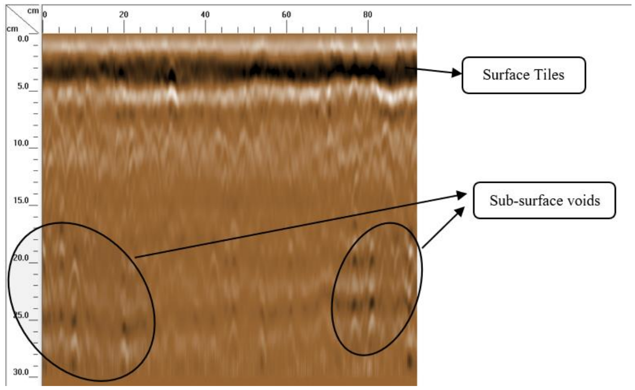


Figure 5:- Detection of void at subsurface

The analysis of room 225 of the G-3 building is probably due to voids or damp zones responsible for sustained water seepage. Compromised areas not only sponsor moisture infiltration but can also be safety risk

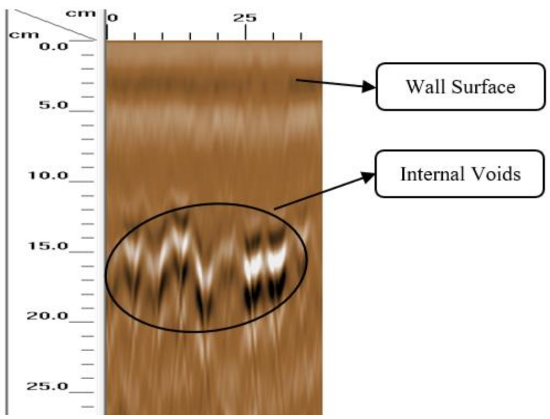


Figure 6:- Detection of internal voids

Y-4 Hostel exterior :

GPR scanning revealed surface cracks and subsurface anomalies on the exterior of Y-4 Hostel effectively. In damp areas where no visible crack existed, there was almost no output from GPR, though. This was partly because of the pore sizes which were so small that they were below the capability to be detected by the GPR within its sensitivity range.

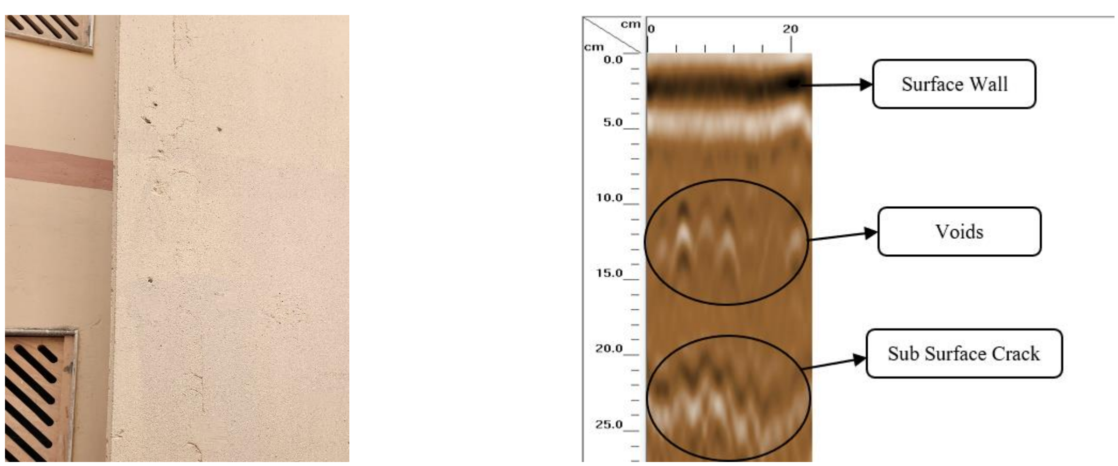
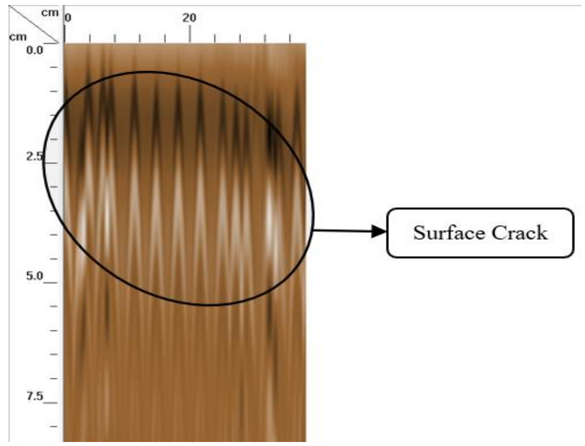


Figure 7:- Y-4 exterior wall and it's analysed data

O-4 Hostel exterior :

O-4 hostel's exterior readings were also same as Y-4 hostel. Again, there were surface cracks and many subsurface anomalies that resolved well. Where water was present but no cracking occurred.



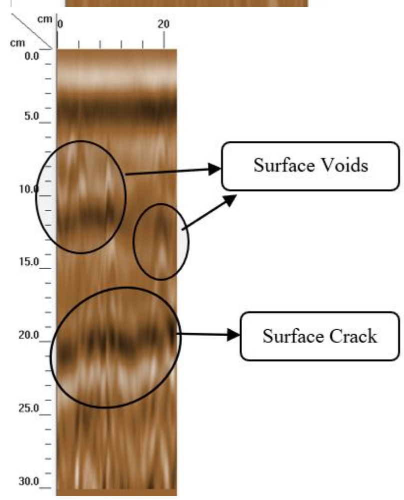


Figure 8:- O-4 exterior walls and it's data after analysi

6. CONCLUSION

In conclusion, our study demonstrates GPR to be a valid non-invasive diagnosis tool to identify surface cracks and detect structural weaknesses in concrete, especially cracks larger than 6 mm. Critical issues have been revealed through GPR scans on several key areas at IIT Jodhpur, such as the structural weaknesses in the E-3 Berm and visible cracks of the exterior walls of Y-4 and O-4 Hostels. However, at areas prone to moisture not visibly damaged, the GPR had its own limitations, and for instance, specific parts of the G-3 Hostel terrace and Room 225 have water penetration due to smaller cracks and micropores that the frequency sensitivity of the device did not detect. This work identifies the utility of GPR in large-scale structural assessments but makes it evident that this sort of inspection cannot identify finer defects and micro-level anomalies responsible for water infiltration. These facts point out the necessity for supplementary inspection techniques capable of detecting smaller scale flaws, making it a case for combining GPR with other specialized tools to achieve comprehensive structural diagnostics in moisture-prone areas

7. FURTHER RECOMMENDATIONS

1. Integrate Complementary NDT Techniques

Use GPR with other NDT techniques, such as ultrasonic pulse velocity or acoustic emission testing. These methods would hopefully enhance the resolution of GPR in tracking microcracking and moisture ingress. For instance, GPR for surface-level detection and ultrasonic testing for internal micro-crack assessment may yield a more integrated structural analysis.

2. Establish a Comparative Performance Analysis

Compare GPR with other inspection methods in order to gauge its performance on certain characteristics such as detection accuracy, depth penetration and resolution of micro-crack for example. Table or graphical comparisons will be effective to do this task.

3. Regular Monitoring Protocols

There should be protocol for regular surveys of buildings at IITJ by GPR. Record the recommended frequency, for instance, bi-annual or yearly, and which are critical locations and need to be inspected first.

4. Discuss Future Scope for Algorithm Development

Outline the potential for future work on GPR data algorithms tailored specifically for detecting micro-cracks and analyzing moisture-induced deterioration.

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