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Research Article

Instrumentation in Geosynthetic Reinforced Unpaved Road Models and Laboratory Calibration

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ABSTRACT

The first part of the paper discusses the state-of-the-art literature for the calibration methodology adopted since 1974 and the various instrumentations used in pavement testing by researchers since 1996 like EPC, LVDT, moisture gauge, strain gauge, and temperature sensors. The second part of the paper elaborates on the present work on laboratory calibration procedures performed at COEP Technological University for earth pressure cells, moisture sensors, and LVDT. This paper briefly examines and discusses the status, usage, maintenance, and recalibration of the instruments recovered from the previous study of the fully instrumented road model and the specifications, configuration, calibration, and interfacing of new instruments. The EPC and LVDT considered for the present work were retrieved from the two road models tested by full-scale accelerated pavement testing set up with a standard full axle load of 40kN to the design traffic of one lakh load cycles on unreinforced section and 1.5 lakhs load cycles on geotextile reinforced test section. Herein the cell effectiveness is assessed based on its position in the road model either at the interface or below the interface, and the maximum vertical stress induced during cyclic loading. The results reveal that the magnitude of the deflection on the surface of EPC does not exceed 1/2000 of its overall diameter, and the ratio of deflection to diameter is less than 1/5000. The laboratory calibration procedure for LVDT and earth pressure cells resulted in the calibration factor of (-0.5) for LVDT 07 and EP13, which is 0.9053 when tested for the instrument response until it reaches the maximum physical range with minimum fluctuations.

Keywords: Calibration, Earth Pressure Cell, Moisture gauge, Pavement

INTRODUCTION

The pavement is subjected to traffic and its response to wheel load is investigated by installing instruments like an earth pressure cell, linear variable differential transducer, strain gauge, and moisture gauge. Numerous studies have utilized various instrumentation to study the traffic response of the roads. Some of these studies have conducted full-scale testing of geosynthetics in pavements using instruments [1] – [7].

LITERATURE SURVEY

Researcher [8] determined the variation in base thickness with the movement in settlement plates from its original position which has hollow stems with caps to allow vertical compression. Marker studs placed at a close spacing in geotextile beneath the wheel and its final position upon trafficking reveal the strain in geotextile which is observed through a narrow trench in the base layer. Researcher [9] measured surface rutting by using an aluminum bar and micrometer caliper. The bar is positioned at several stations along the box length across the test section and the caliper is to measure the rut below the rod alignment.

Researcher [10] demonstrated an effective technique to attach and waterproof the micro measurement group EP-type strain gauges with superior elongation capabilities for severe environmental conditions. Silicon adhesives with high plasticity without affecting the working of the strain gauge are used to attach the strain gauges to the fabric matrix.

Researcher [11] noticed intelligent geotextile enabled with fiber optic sensors. It evaluates the performance of geotextile by measuring the strain on an optic fiber. The optic technique shows the strain which is related to the deformations of the geosynthetic [12]. Researcher [13] incorporated fibers with optical technology in geosynthetics for precise inspection. The measurement of the deformations both during construction and after completion verifies that the deformation is within the permissible limit. Researcher [14] installed 173 instruments like LVDTs to know the rutting, EPC at the interface, strain gauges to find the strain in HMA, TDR probe to measure moisture in the subgrade, thermocouple for variation in heat, pore pressure in subgrade using piezometers for geogrid reinforced roads tested under a wheel tracking system.

Researcher [15] installed 22 pairs of time-domain reflectometers to measure moisture content variation and temperature sensors. All the sensors were connected to a data logger with a multiplexer and a breadboard was preprogrammed to record data hourly. Researcher [16] used instruments like potentiometers to estimate the change in length at the midheight of the base layer.

In their 2017 study, researcher [17] presented an inspecting system and laser system to examine the deformation profile in the asphalt layer and the development of a deformation profile for every layer, major rut point, and pavement profile at the interface during accelerated pavement deterioration.

Table I summarizes the list of instruments commonly installed in road models to estimate the road response to traffic and environment. Table II summarizes the methodology adopted by the researchers since 1974.

Table I: List of instruments used in pavement testing and its purpose

Environmental response		Pavement response	
Purpose	**Instrument**	**Purpose**	**Instrument**
Pavement temperature profile variation	Thermocouple Temperature sensor/probe	Subgrade and surface rutting	Vertical LVDT
Subgrade moisture content variation	(a)Time domain reflectometry probe (b)Moisture gauge		Horizontal LVDT
Pore water pressure	Piezometer	Vertical pressure on subgrade top	Pressure cell (PC)
solar radiation	Pyranometers	To measure induced geotextile strain	Strain gauges
Number of rotation/wind speed	Anemometers	To measure wheel load	Load Cell

Table II: List of previous research and their calibration approaches

Researcher/year	Calibration method
[18] / 2018	Deadweight and fluid calibration adopted
[19] / 1980 [20] / 2005	Calibration using a fluid chamber
[21] / 2005; [22] / 1974; [23] / 2010; [24] / 1954; [25] / 1986	Used different setups for calibration using soil and fluid. The pressure is applied to DWC by using oil.
[26] / 2017; [27] / 2019	Calibration using loading frame
[28] / 1982	Calibration by placing the airbag above the instrument and then pressurizing it.
[29] / 2006	Calibrated using centrifuge technique with soil.
[30] / 1993; [31] / 2011	Calibration using the air pressure

Researcher [32] conducted an experimental study to investigate how temperature changes affect moisture distribution in the pavement using sensors comprising two elements to measure temperature and moisture. The first element measured temperature based on thermal resistance, while the second element measured moisture based on diamagnetic penetration. The sensors were calibrated using soils collected from the installation site. Researcher [27] investigated the geotextile-reinforced unpaved road model by using laboratory-calibrated earth pressure cells at the interface, LVDT in both horizontal and vertical directions and strain gauges for geotextile.

Researcher [33] state that the performance of road sections under heavy traffic and environmental stress is often evaluated through the construction and monitoring of instrumented trial sections. Pavement-embedded instruments help monitor the health of the road. Researcher [34] utilized multi-depth deflectometers, strain and compression gauges, earth pressure cells, WIM sensors, and pyranometers.

Present Investigation: Instrumentation Laboratory Calibration and Interfacing

In the present investigation, laboratory calibration is carried out for the earth pressure cell, linear variable differential transducer, and strain gauges by using the facility available at the COEP Technological University Pune. Some of the earth pressure cells and LVDTs are used ones that are retrieved from the old road model in COEP Technological University Pune.

Linear Variable Differential Transducer

The LVDT is an AC spring-loaded type with a body diameter of 22mm and a stroke length of 100mm. LVDT is calibrated and interfaced with the data acquisition system by connecting it to the data acquisition system DAS channel connector which is then connected to the terminal block then to the amplifier, and then to the analog input module. The appropriate channel number has been assigned and labeled for each LVDT of a total of 7 that needs to be configured to the respective channel connector in DAS as shown in Photograph 1. The program and software function sequence required to establish an interface between LVDT, and the data acquisition system is presented in Figure 1.

(a) (b)

Photograph 1: Displays (a) labeled LVDT and (b) LVDT to DAS connector

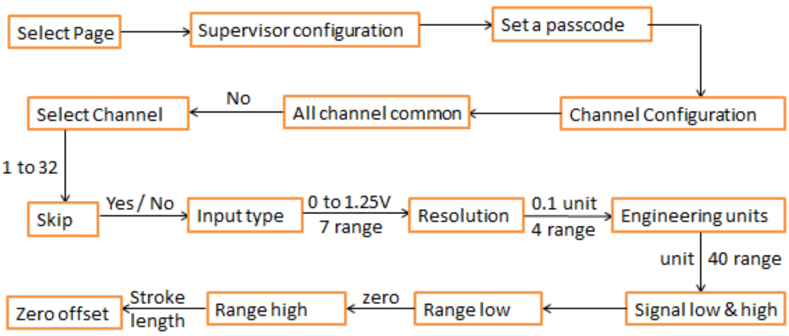


Figure 1: Software function in DAS to interface LVDT

The calibration of LVDT is performed in two positions: one in the extended position to set the high range and the other in the retracted position to set zero offset values as shown in Photograph 2. The first step to determine the calibration factor for every LVDT is to set the initial value of high range and zero offset as 100 and 0. The display is checked at the retracted position and extended position of the LVDT for high range and zero offset. If the initial value does not match the display value, then the second trial is performed, and the calibration process is continued until the value is close to the initial set value.

Photograph 2: Extended and retracted position of LVDT

If the previous display in DAS is less than 100, then the next high range value = Previous high range value + (100 - DAS display in the retracted position); if the previous display in DAS is more than 100, then the next high range value = Previous high range value - (100 - DAS display in retracted position). If the resulting value in the display is positive in the extended position, then subtract to get the final offset value, and if the value is negative in the DAS display, then add the value to the previous offset. After interfacing with DAS for channel 07, Table III summarizes the sample trials conducted to determine the calibration factor for LVDT 07.

Table III: Calibration factor for LVDT 07

Trials	**High range**	**Offset**	**DAS display**	
			Retracted	**Extended**
1	100	0	26.7	-36
2	100	36	62.8	-0.4
3	135	36	70.9	-13.5
4	135	49.5	86.3	-0.1
5	150	49.5	90.6	-5.7
6	150	55.2	95.5	-0.3
7	155	55.2	97	-2.3
8	155	58	97.9	0.6
9	158	58	100.5	-0.7
10	157.5	58.7	100.6	0.1
LVDT 07: Calibration factor				-0.5

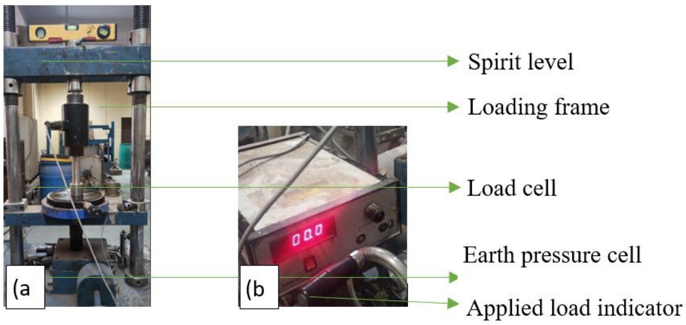
Similarly, the remaining LVDTs are also calibrated and interfaced with the data acquisition system. The reason for the positive calibration factor is when the high range is less than the stroke length or the offset is less than zero, and vice versa. If the resolution is changed, then the high range needs to be adjusted as well. During the field installation, the calibration factor procedure is repeated to ensure accurate and precise results during the full-scale accelerated pavement testing.

Earth Pressure Cell

Hydraulic earth pressure cells EPC are utilized to measure the vertical stress at the interface and pressure due to the swell nature of the subgrade soil found to be successful in previous studies [35] and [26]. There are 10 old EPCs in working condition with 700kPa which are recovered from the previous road model study and the other two types are new and consist of 4 EPCs with 1000kPa and 2 EPCs with 200kPa as shown in Photograph 3. The recommendation for selecting new hydraulic earth pressure cells is based on the procedure mentioned in the Indian standard code [36]. Hydraulic EPCs are filled with hydraulic oil [37]. The aspect ratio of the old and new EPC is 0.125 and 0.1.

Photograph 3: View of the old black EPC recovered from the previous study road model and new silver EPC

The EPCs must be calibrated before installation and its calibration is performed in the geotechnical lab at COEP Tech., using a loading frame, load indicator, and DAS. During calibration of the earth pressure cell, to distribute the stress uniformly over the active surface of the pressure cell, a steel plate 2mm thick and 195mm diameter was placed on the surface of the earth pressure cell. The load is applied over the pressure cell at an increment of 1.0 kN through the loading frame, and the corresponding reading is observed over the data acquisition system. Each incremental load is kept idle for 10 minutes to stabilize readings before proceeding to the next increment. The view of the laboratory calibration setup of the earth pressure cell is shown in Photograph 4.



Photograph 4: View of (a) laboratory EPC calibration setup and (b) load indicator

The calibration factor for each load increment is calculated based on applied stress to the observed reading and their relationship is unique for each EPC [38].

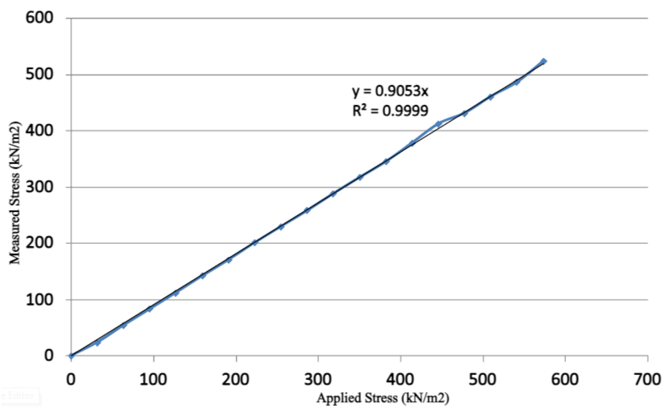


Figure 2: Relation between the applied stress and observed stress for EP13

The relation developed by plotting a graph between the applied stress and the observed stress for the applied load to determine the calibration factor for the earth pressure cell designated as EP13 is given in Figure 2 and the calibration factor is found to be 0.9053.

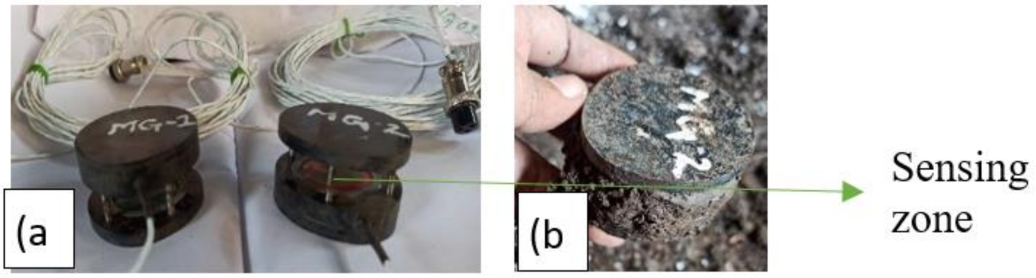
After applying the calibration factor for EP 13, the observed stress has been corrected and crosschecked with the applied stress as given in Table IV. The corrected value almost matches the applied stress. In a similar line, the calibration process is performed for the remaining earth pressure cells to evaluate and confirm the results.

Table IV: Corrected observed stress after applying calibration factor

Applied Load (kN)	Applied Stress (kN/m2)	Observed Stress (kN/m2)	Corrected observed stress (kN/m2),
0	0	0	0
1	31.84	26.1	26.17
2	63.69	57.6	59.70
3	95.54	87.4	91.57
4	127.38	116.6	123.66
5	159.23	146.5	156.57
6	191.08	173.8	188.22
7	222.92	203.9	221.63
8	254.77	232.5	253.39
9	286.62	261.4	284.65
10	318.47	291.6	318.07
11	350.31	318.6	349.82
12	382.16	347.3	380.70
13	414.01	378	417.54
14	445.85	412	455.09
15	477.70	431	476.08
16	509.55	459.9	508.61
17	541.40	486	536.83
18	573.24	523	577.70

Moisture Gauge

A moisture gauge is used to detect moisture fluctuations in the subgrade layer as shown in Photograph 5. The gauge's functionality is tested by measuring voltage in air and water. The gauge's sensing zone is colored green and red on the inner side.



Photograph 5: (a) Moisture gauges and (b) Sample filled in moisture gauge

To calibrate the gauge, a mixture of subgrade soil and water content ranging from 5% to 60% is filled into its sensing zone using hand pressure, as shown in Photograph 8 (b), and the gauge is connected to the DAS channel to record the display value while varying the moisture content. The calibration factor is known for the moisture gauges from the exact water added to the sample and the values displayed in the DAS.

CONCLUSIONS

- The calibrated instrument should be installed in a location that meets the following criteria: (a) little or no mechanical vibration, (b) no corrosive gases, (c) not directly exposed to radiant heat, (d) not exposed to strong electromagnetic field, (e) no direct exposure to water and (f) minimum temperature fluctuation and near average ambient temperature.
- The factors affecting the calibration methodology are the aspect ratio, stress concentration at the corner of the instrument, lateral compression, stress-strain relation, stiffness ratio, diaphragm deflection, non-uniform loading, temperature, corrosion, and moisture.
- The calibrated instruments evaluate exact stresses, moisture level, strains, surface and subgrade deformation within the pavement layers, and induced strain in geosynthetics, providing valuable information to validate theoretical suggestions and develop new construction processes.
- The calibration methodology adopted for any specific sensor depends on the information derived from the sensor, economy, accuracy, and experience. The limitations on earth pressure cells are aspect ratio, stress concentrations, and cell stiffness and for LVDT it is the stroke length. The relation in calibration varies with the soil density and location of the sensor.
- Pavement instrumentation and its calibration process play a crucial role in connecting theory and practice in pavement design approaches. The instrument calibration results are the precise data that help in validation before the implementation of constructing the roadways.
- The old instruments calibrated showed variation in the calibration factor to the initial calibration values due to its repeated usage and with its life. The linear response is observed in all the earth pressure cells.
- It is important to calibrate the earth pressure cell, LVDT, and moisture gauge frequently, especially after continuous usage. Any type of construction on a soil surface is highly reliable only after evaluating the design parameters like stress, deformation, and strain in the soil continuum for applied load which is achieved by using the calibrated instruments.

REFERENCES

[1] S. L. Webster, "Geogrid-Reinforced Base Course for Flexible Pavements for Light Aircraft, Test Section Construction, Behavior Under Traffic, Laboratory Tests, and Design Criteria," Report GL-93-6. Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Miss, 1993.

[2] T. L. Brandon, I. L. Al-Qadi, B. A. Lacina, and S. A. Bhutta, "Construction and Instrumentation of Geosynthetically Stabilized Secondary Road Test Sections," In Transportation Research Record 1534, TRB, National Research Council, Washington, D.C., 1996, pp. 50–57, 1996.

[3] F. Moghaddas-Nejad, and J. C. Small, "Effects of Geogrid Reinforcement in Model Track Tests on Pavement," Journal of Transportation Engineering, Vol. 122, No. 6, 1996, pp. 468–474, 1996.

[4] S. S. Perkins, "Evaluation of Geosynthetic Reinforced Flexible Pavement Systems Using Two Pavement Test Facilities," FHWA/MT-02 008/20040. FHWA, U.S. Department of Transportation, 2002.

[5] L. Al-Qadi, S. H. Dessouky, J. Kwon, and E. Tutumluer, "Geogrid in Flexible Pavements: Validated Mechanism," In Transportation Research Record: Journal of the Transportation Research Board, No. 2045, Transportation Research Board of the National Academies, Washington, D.C, pp. 102–109, 2008.

[6] K. Henry, J. Clapp, W. Davids, D. Humphrey, and L. Barna, "Structural Improvements of Flexible Pavements Using Geosynthetics for Base Course Reinforcement." ERDC/CRREL TR-09-11, Engineer Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, Miss, 2009.

[7] S. R. Jersey, J. S. Tingle, J. S. Norwood, J. Kwon, and M. Wayne, "Full-Scale Evaluation of Geogrid-Reinforced Thin Flexible Pavements." In Transportation Research Record: Journal of the Transportation Research Board, No. 2310, Transportation Research Board, National Research Council, Washington, D.C., pp. 61–71, 2012.

[8] R. J. Fannin, and O. Sigurdsson, "Field observations on stabilization of unpaved roads with geosynthetics," Journal of Geotechnical Engineering 122, no. 7, pp. 544-553, 1996.

[9] J.G. Collin, T.C. Kinney, and X. Fu, "Full scale highway load test of flexible pavement systems with geogrid reinforced base courses." Geosynthetics International, 3 (4), pp. 537–549, 1996.

[10] Warren, A. Kimberly, Jeremy A. Brooks, and Isaac L. Howard, "Foil strain gage attachment techniques for geotextile and geogrid," In Geo Congress 2006: Geotechnical Engineering in the Information Technology Age, pp. 1-6, 2006.

[11] Koerner, M. Robert, and G. R. Koerner, "Recommended layout of instrumentation to monitor potential movement of MSE walls, berms, and slopes," GRI White Paper 19, no. 04, 2011.

[12] Nancey, L. Briancon, and P. Villard, "Geodetect: The first "intelligent" geosynthetic for the measurements of strain in soil and the survey of reinforced earth construction," Proceedings of Railway Engineering, July, London, UK, 2004.

[13] L. Briancon, A. Nancey, F. Caquel, and P. Villard, "New Technology for Strain Measurements in soil and the Survey of Reinforced Earth Constructions," 3rd European Geosynthetics Conference, January, pp. 471–476, 2004.

[14] Al-Qadi, L. Imad, Samer H. Dessouky, Jayhyun Kwon, and Erol Tutumluer, "Geogrid-reinforced low-volume flexible pavements: Pavement response and geogrid optimal location," Journal of Transportation Engineering 138, no. 9, pp. 1083-1090, 2012.

[15] J. Han, and X. Zhang, "Recent advances in the use of geosynthetics to enhance sustainability of roadways," In Vol. 1 of Proceeding Conference on Advances in Civil Engineering for Sustainable Development, edited by S. Horpibulsuk, A. Chinkulkijniwat, and C. Suksiripattanapong, pp. 29–39. Nakhon Ratchasima, Thailand: Suranaree University of Technology, 2014.

[16] Xiaochao Tang, Murad Abu-Farsakh, Shadi Hanandeh, and Qiming Chen, "Performance of reinforced stabilized unpaved test sections built over native soft soils under full-scale moving wheel load." Journal of the Transportation Research Board no.2511, 2015.

[17] Yu Tian, Jusang Lee, Tommy Nantung, John E. Haddock, "Development of a mid-depth profile monitoring system for accelerated pavement testing." Construction and Building Materials 140, pp. 1–9, 2017.

[18] V. K. Gade, & S. M. Dasaka, Calibration of earth pressure sensors. Indian Geotechnical Journal, 48(1), pp. 142–152. 2018. https://doi.org/10.1007/s40098-017-0223-0.

[19] E.T. Selig, "Soil stress gauge calibration," ASTM Geotech Test J 3(4): pp. 153–158, 1980.

[20] M. Talesnick, "Measuring soil contact pressure on a solid boundary and quantifying soil arching," ASTM Geotech Test J28(2): pp. 1–9, 2005.

[21] J. F. Labuz, B. Theroux, "Laboratory calibration of earth pressure cells," ASTM Geotech Test J 28(2): pp. 1–9, 2005.

[22] G. E. Triandafilidis, "Soil-stress gauge design and evaluation," ASTM Geotech Test J 2(3): pp. 146–158, 1974.

[23] Ramirez, J. Nielsen, F. Ayuga, "On the use of plate-type normal pressure cells in soils," Part 1: Calibration and evaluation, Comput Electron Agric 71(1): pp. 71–76, 2010.

[24] S. C. Redshaw, "A sensitive miniature pressure cell, Journal of Scientific Instrumentation," 31, pp. 467-469, 1954.

[25] P. L. R. Pang, "A new boundary stress transducer for small soil models in the centrifuge," Geotechnical Testing Journal, 9(2), pp. 72-79, 1986.

[26] G. S. Ingle, and S. S. Bhosale, "Full-scale laboratory accelerated test on geotextile reinforced unpaved road," International Journal of Geosynthetics and Ground Engineering, Vol. 03, No.33, pp. 1-11, 2017.

[27] G. S. Ingle, and S. S. Bhosale, "Development of full-scale laboratory accelerated pavement testing facility: a step toward performance assessment of geosynthetics reinforced pavement," Innovative Infrastructure Solutions 4, pp. 1-12, 2019.

[28] W. A. Weiler, and F. H. Kulhawy, "Factors affecting stress cell measurements in soil, Journal of the Geotechnical Engineering," ASCE, 108(12), pp. 1529-1548, 1982.

[29] W. Chen, and M. F. Randolph, Measuring radial total stresses on model suction caissons in clay, Geotechnical Testing Journal, 30(2), pp. 1-9, 2006.

[30] C. R. I. Clayton, and A.V.D. Bica, "The design of diaphragm-type boundary total stress cells," Geotechnique, 43(4), pp. 523-536, 1993.

[31] T. N. Dave, S. M. Dasaka and H. D. Rane, "Universal calibration device for pressure transducer calibration," Geo-Frontiers 2011, pp. 13-16, Dallas, Texas, USA, March 2011.

[32] B. B. Teltayev, and E. A. Suppes, "Temperature in pavement and subgrade and its effect on moisture," Case Studies in Thermal Engineering, Volume 13, March 2019.

[33] Neves, José, Ana Cristina Freire, Issam Qamhia, L. Imad, Al-Qadi, and Erol Tutumluer, "Full-scale accelerated pavement testing and instrumentation," In Advances on Testing and Experimentation in Civil Engineering: Geotechnics, Transportation, Hydraulics and Natural Resources, pp. 163-186. Cham: Springer International Publishing, 2022.

[34] Karimi, Mohammad Najib, and Rajib Basu Mallick, "Flexible Pavement Instrumentation: A State-of-the-Art Review," Journal of Transportation Engineering, Part B: Pavements 149, no. 2; 03123001, 2023.
[35] X. Tang, "A Study of Permanent Deformation Behavior of Geogrid-Reinforced Flexible Pavements Using Small Scale Accelerated Pavement Testing," PhD dissertation, Pennsylvania State University, University Park, Pa, 2011.
[36] IS: 12208-1987, "Method for measurement of earth pressure cell by hydraulic earth pressure cell," Bureau of Indian Standards, New Delhi.
[37] T. N. Dave, and S. M. Dasaka, "A Review on Pressure Measurement using Earth Pressure Cell," International Journal of Earth Science and Engineering, vol 4, pp. 1031-1034, 2011.
[38] W. A. Take, "Lateral earth pressure behind rigid fascia retaining walls," M. Sc thesis, The University of New Brunswick, 1997.