Indian Geotech J (July–September 2012) 42(3):212–219
DOI 10.1007/s40098-012-0013-7

TECHNICAL NOTE

Universal Calibration Device for Fluid and In-Soil Calibration of Pressure Transducers

Trudeep N. Dave · S. M. Dasaka

Received: 10 February 2012 / Accepted: 2 May 2012 / Published online: 10 June 2012

Abstract Evaluation of stresses generated at soil-structure interface or within the soil mass influences the design decisions of substructures. Though many analytical techniques are available, actual measurement of these stresses is of prime importance from analytical and construction view point. The measurement of stresses also provides valuable information for validating constitutive theories of geo-material behaviour and computational techniques for examining soil-structure interaction problems. Calibration of pressure transducer involves application of known pressure to the transducer and obtaining the relationship between applied pressure and pressure cell output. In absence of such relationship, interpretation of data obtained using transducers is highly questionable. Present study describes details of indigenously developed universal pressure transducer calibration device, developed by modifying the conventional triaxial apparatus. It allows demanding task of fluid and in-soil calibration of pressure transducers, which was not possible with existing calibration devices. Performance of the developed device checked using three different types of transducers revealed accurate and repeatable results.

Keywords Calibration device · Simultaneous calibration · Pressure transducer · Modified triaxial cell · Fluid calibration · In-soil calibration

T. N. Dave · S. M. Dasaka (✉)
Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
e-mail: dasaka@civil.iitb.ac.in

T. N. Dave
e-mail: trudeep@iitb.ac.in

Background

Measurement of stresses within soil mass or at the interface of structure and soil is done with the help of pressure transducer. A properly instrumented structure gives information about variation of stresses with time and space. However, if an appropriate correlation between applied pressure and pressure sensed by a transducer is not available, measured stresses become unreliable, and the very purpose of measurement is lost. Calibration of transducers is very important as the calibration factors obtained from calibration process would give an idea about actual stresses at the point of measurement. The calibration of pressure transducer involves the investigation of the unique relationship between the applied pressure and pressure cell output [13]. Through calibration, the output from pressure transducers is related to normal stress (multiplying the output voltage (or strain) with the calibration factor will give rise to actual in situ pressure, that converts cell's electrical output to the pressure). To obtain calibration factors, the standard procedure is to calibrate the transducer in a fluid (air, water or oil) and to analyze the unique relationship between the input and output. However, it is understood from the previous studies that the results of fluid calibration of earth pressure cell (EPC) will be highly misleading, if the EPC are used in soil or at soil-structure interface for measurement of in situ stresses. Hence, it is suggested that the pressure transducers should be calibrated under the conditions identical to its intended use. In either case, it is important to note that the pressure is consistently applied, and precisely known.

Literature Review

Calibration of pressure transducer of interest around the world and many researchers had made an effort to obtain calibration factors through laboratory studies. Pang [10] calibrated boundary stress transducers both by using deadweights and by using the centrifuge and the results represented about ±2 % error at full scale (FS). Clayton and Bica [2] designed experimental set up to calibrate EPC, using water, by modifying conventional triaxial pedestal. Take [13] performed fluid calibration and centrifuge calibration of pressure transducer and adopted fluid calibration as base line for all other calibration outputs. Bao et al. [1] found that fluid column pressure calibration is precise, repeatable and proportional to actual pressure applied to pressure transducer. Labuz and Theroux [6] performed EPC calibration using all-around hydrostatic loading, uniaxial loading on the active face, and radial loading around the perimeter of the EPC. Authors observed that uniaxial calibration under uniform fluid pressure resemble calibration factors of EPC supplied by manufacturer. Dave and Dasaka [3] reviewed factors affecting earth pressure measurement and various laboratory calibration techniques for EPC. It was concluded that EPC needs to be calibrated near usage conditions for reliable use of experimental outcomes. Wachman and Labuz [16] highlighted that the EPC can accurately measure the average normal stress at the place of installation, if soil-structure interaction of EPC is considered, which is possible only when the in-soil calibration of EPC at a given density is performed.

Calibration using fluid is done to check (1) Instrument's physical condition (2) Response to applied pressure (3) Return to zero after removal of load. Fluid calibration can be done by applying fluid pressure as dead weight in large size tank, or application of pressure using pressurized fluid in a small-scale apparatus, or using centrifuge technique on scaled-down models, tested at high gravity loading. Large-scale tests require huge tanks, where the height of the tank varies with the maximum calibration pressure to be applied on the transducers, whereas fluid calibration using centrifuge suffers from meniscus formation, which results in non-uniform pressure application on the transducers.

In-soil calibration is performed to check (1) Hysteretic behavior upon loading and unloading (2) variation of coefficient of calibration with soil type (3) variation of coefficient of calibration with soil condition (4) variation of coefficient of calibration with stress history. The EPC calibration is not a linear relationship between output voltage and applied pressure like fluid calibration due to local arching effects around the pressure sensitive diaphragm [2, 4, 15].

Need for the Development

Triaxial testing systems are universally recognized in the field of geotechnical engineering and can be found in most of the geotechnical laboratories. Also, modified triaxial cells were used in the past to calibrate pressure transducers. However, the calibration set ups devised by previous researchers were suitable only for pressure transducer with dimensions for which it has been designed. Designing a unique calibration device, which can be used to calibrate various transducers, with different specifications, is highly demanding and difficult in traditional calibration methods. Also, simultaneous calibration of pressure transducers is challenging and was not possible with earlier devices. The intention was to develop a calibration device which can be fabricated by incorporating limited modifications in the existing triaxial cell, which is economically viable, having simple working mechanism, reasonably accurate, easy to adopt, and suitable to calibration pressure transducers using both fluid and soil.

Utility

The developed device (named universal calibration device) is able to calibrate new as well as used pressure cells of different specifications (dimensions and pressure range) and varieties (EPC and pore pressure transducer (PPT)), under both fluid and in-soil conditions.

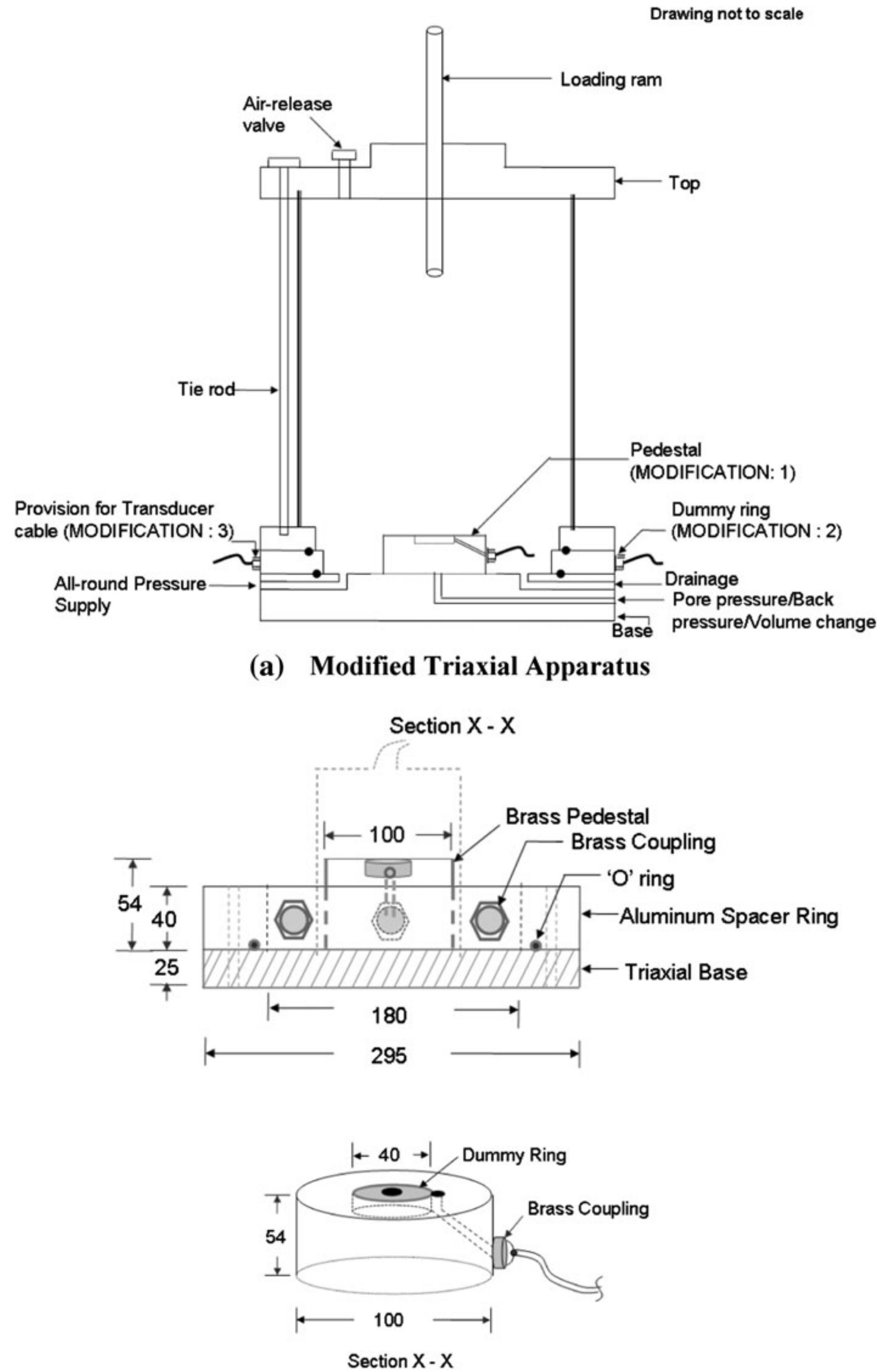
Development of Universal Calibration Device

In the present study, a device was developed by modifying triaxial apparatus (Fig. 1a) suitable for testing of 100 mm diameter triaxial specimen. The modification consists of (1) a dummy aluminum spacer ring with brass couplings (2) a brass pedestal with replaceable dummy ring (Fig. 1b).

Dummy aluminum spacer ring of 295 mm outer diameter (OD) and 180 mm inner diameter (ID) and with 4-replaceable brass couplings was placed above the base of triaxial cell. It provided platform to fix brass couplings in which openings were made of diameter slightly less than that of transducer cable. Such openings provided a secured passage to introduce transducer cables into triaxial cell as conventional triaxial cell do not have provision for introducing cables inside the cell. At the same time water leak proof system is ensured by providing rubber 'O' ring of diameter corresponding to that of cable as illustrated in Fig. 2.

Brass pedestal with replaceable dummy ring and inclined conduit to pass cables of transducer was placed at the centre of the cell to place transducer flushed with pedestal top as shown in Fig. 3. Recess of 40 mm diameter and 10 mm depth was made at the centre of brass pedestal so as to accommodate transducer of same dimensions. To fix the brass pedestal on the triaxial cell, three holes of

Fig. 1 Details of in-house calibration device: **a** modified triaxial apparatus; **b** details of modifications



(a) Modified Triaxial Apparatus

(b) Details of Modification

4 mm diameter were provided at its bottom in accordance with triaxial base. Calibration of pressure transducer of dia. 6.5 and 1 mm thickness was performed by fixing it flushed on a replaceable dummy ring. The replaceable dummy ring of 39.8 mm (OD) and 10 mm thickness was placed into the central recess of brass. The dummy ring had provision to bring cables of 6.5 mm transducer out of the pedestal. The dummy ring was able to fix in the central recess of brass pedestal for calibration of 6.5 mm transducer. Central 3 mm diameter hole in brass pedestal facilitate easy removal of pressure cell/dummy ring after performing calibration. The combination of dummy ring with pedestal was planned to allow transducers of two different diameters to sit exactly on the pedestal. Chances of arresting

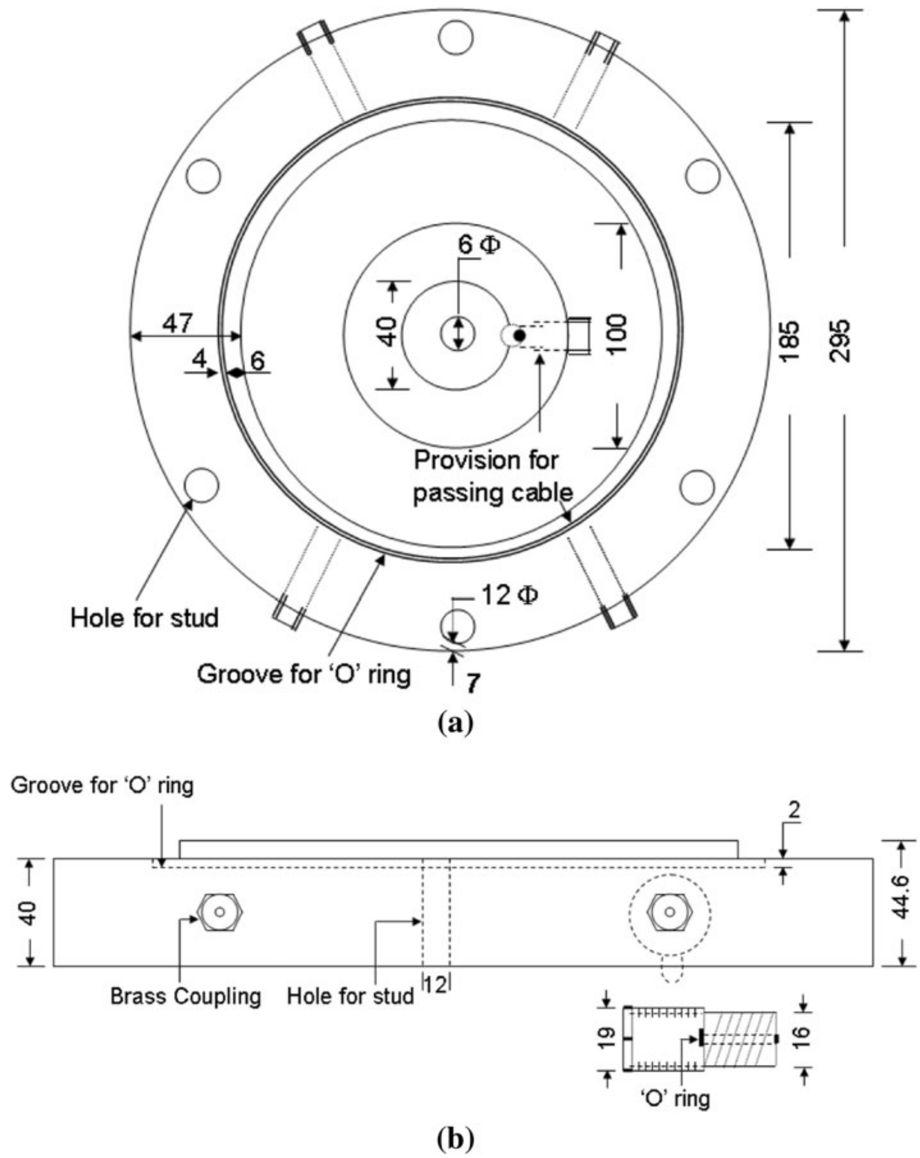


Fig. 2 Details of attachment in triaxial base with **a** combined top view of Dummy ring and Pedestal **b** elevation of Dummy aluminum ring with brass coupling (all dimensions are in mm)

water entry inside the cavity of pressure transducer were taken care by applying silicon rubber gel around the cables.

Universal calibration device was utilized for calibration of EPC of 6.5 and 40 mm diameter and pore pressure transducer of 5 mm diameter. Detailed specifications of transducers calibrated are given in Table 1.

Fluid Calibration Procedure

The calibration device was fully filled with de-aired water, and pressure was applied by an air–water bladder cylinder, using compressed air with an accuracy of 0.1 kPa. Data acquisition system NI cDAQ-9172 was used as source of input voltage to the pressure transducer and under pressure application corresponding output from pressure transducer was monitored and logged using NI Signal Express. The fluid pressure in the triaxial cell is increased so as to apply pressure on pressure transducer during calibration. Pressure in increments of 20 kPa is applied on transducer up to a maximum value of 180 kPa. From the maximum value, the pressure in the chamber is unloaded by decreasing the fluid pressure in 20 kPa steps back to zero gage pressure. The transducer data acquired using cDAQ is recorded in-terms of the output strain from the cell at each step of loading as well as unloading. Readings were obtained once the fluid pressure had stabilized, typically in 30 s. Total 5 loading/unloading pressure cycles were performed for calibration test on each transducer. Calibration factors obtained using universal calibration device are reported in Table 2. Non-linearity was measured in terms of deviation in pressure cell output between loading and unloading cycles for first cycle and first five consecutive cycles under the same applied pressure.

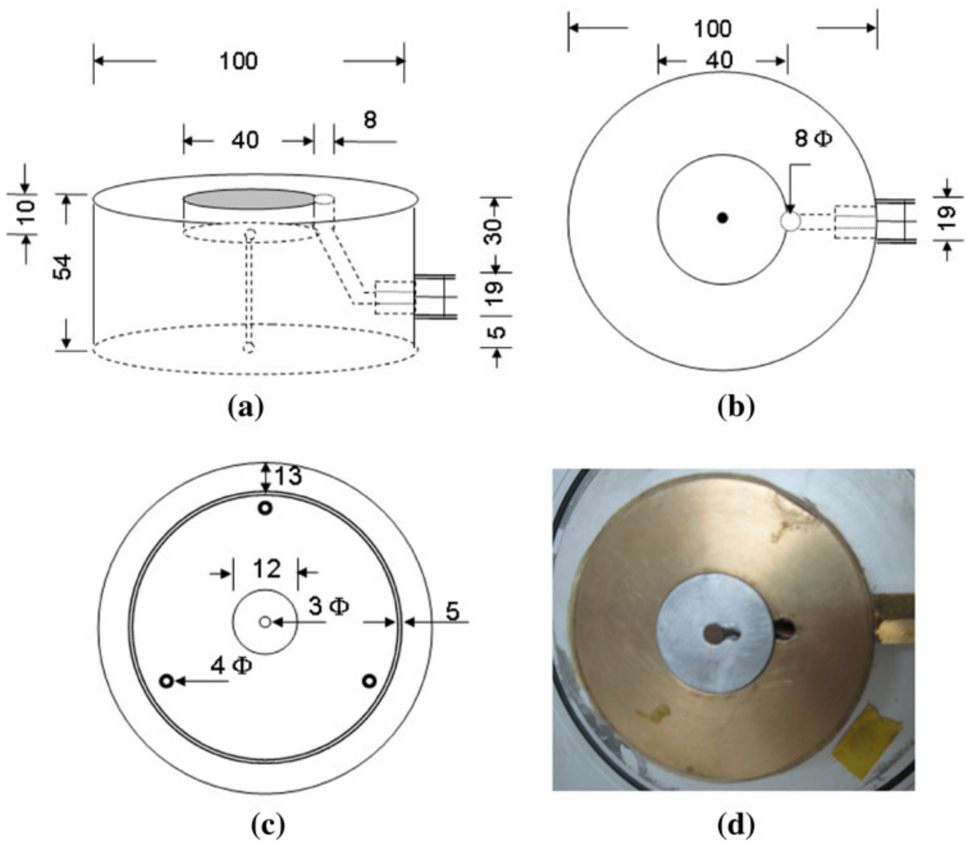


Fig. 3 Details of Pedestal for transducer mounting **a** sectional elevation **b** top view **c** bottom view **d** pictorial view (all dimensions are in mm)

Table 1 Detailed specifications of transducers used for calibration

Terminology	Transducer		
	Druck PDCR81 (type 1)	Haris Earth pressure cell (type 2)	TML PDA PA (type 3)
Pressure range	0–15 kg/cm^2	0–2 kg/cm^2	0–2 kg/cm^2
Sensitivity	1.146 mV/V/bar	1.420 mV/V at FS	+946 μV/V
Non-linearity and hysteresis	0.4 % of FS	0.5 % of FS	0.5 % of FS
Thermal sensitivity shift	±0.2 %/°C	0.1 % of FS/°C	1 %/°C
Dimensions	5 mm Φ × 10 mm	40 mm Φ × 10 mm	6.5 mm Φ × 1 mm

Table 2 Fluid calibration factors obtained using universal calibration device

Transducer	1st Cycle		5th Cycle	
	Loading	Unloading	Loading	Unloading
Druck PDCR 81	0.1775	0.1779	0.1776	0.1784
	(Y = 5.6336X; R^2 = 1)	(Y = 5.6215X; R^2 = 1)	(Y = 5.6288X; R^2 = 1)	(Y = 5.6064X; R^2 = 1)
Haris EPC	0.4868	0.4859	0.4868	0.4853
	(Y = 2.0543X; R^2 = 0.9998)	(Y = 2.058X; R^2 = 0.9999)	(Y = 2.0544X; R^2 = 0.9998)	(Y = 2.0604X; R^2 = 0.9998)
TML Transducer	0.4053	0.4025	0.4037	0.4096
	(Y = 2.4672X; R^2 = 0.9999)	(Y = 2.4842X; R^2 = 0.9997)	(Y = 2.4771X; R^2 = 0.9997)	(Y = 2.4414X; R^2 = 0.9999)

Y = measured strain (με); X = applied pressure (kPa)

In-Soil Calibration of EPC

It is well recognized that the results of fluid calibration of EPC will be highly misleading, if the EPC are used for stress measurement in soil or at soil-structure interface [5, 6, 8, 9, 11, 12, 14, 17]. The same modified triaxial set up outlined above and suitable for fluid calibration, can be used to calibrate the EPC under in-soil conditions, with use of an additional rigid plastic tube of 2.5 mm thickness and 100 mm internal diameter (ID) placed tightly on the brass pedestal, as shown in Fig. 4. Greased polyethylene sheets of 60 µm thickness were pasted to inner surface of plastic tube in order to reduce side wall friction. A rigid wooden block overlying a rubber pad was placed on sand layer for transfer and uniform distribution of pressure between load cell of triaxial apparatus and EPC as shown in Fig. 4. To demonstrate the feasibility of the modified triaxial set up developed in this study for in-soil calibration, performance studies were conducted on type 2 EPC (Diameter of EPC = 40 mm) with two different materials, viz., sand and Kaolin. The gradation of the materials is presented in Fig. 5. For in-soil calibration of EPC, soil layer of specified thickness was placed in the plastic tube, overlying the EPC, to obtain relation between applied pressure and measured strain.

Advantages of the Developed Device Over the Existing Facilities

The following are the major advantages of the developed device, compared to those previously used for the calibration purpose.

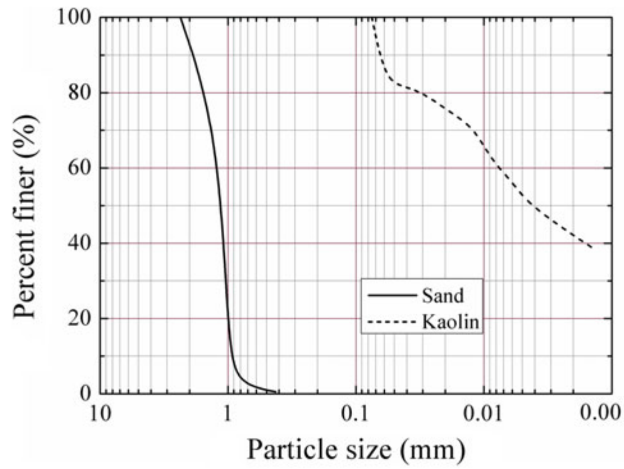
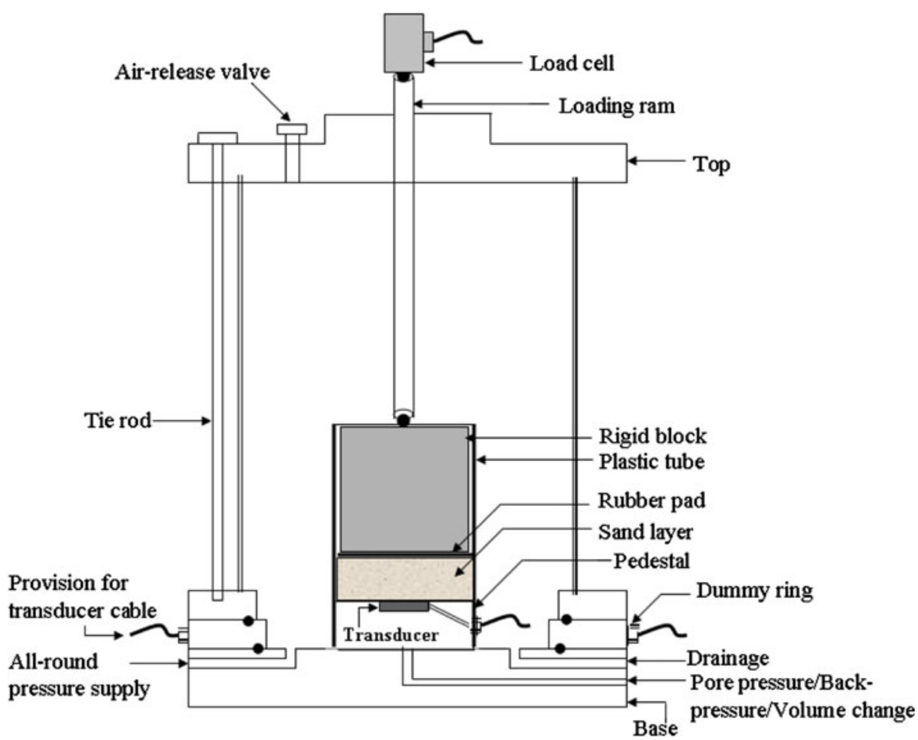


Fig. 5 Gradation curves of the materials used in the present study

(a) In its present form triaxial set up, which is widely used by geotechnical engineers for estimation of shear strength parameters of soils under confining conditions, is not suitable to carry out the calibration tests of pressure sensors, as there is no provision to bring the wiring of the sensors to connect to a digital reading unit or a data logging system.

(b) Also EPC should be fixed in the triaxial cell in such a way that the sensing surface of the EPC is flush with the surrounding surfaces, for uniform pressure application, to reduce the arching, and for obtaining reliable data from the pressure cell, during the in-soil calibration. This is only possible with provision of

Fig. 4 Details of modifications to the triaxial setup for in-soil calibration of pressure transducers



modification 1 to the base of the triaxial cell, as shown in Fig. 1.

(c) Many previous studies used direct shear test as well for calibration testing [7]. However, in direct shear test, pore pressure transducers cannot be calibrated, as it is not possible to fill the shear box with water, and pressurize the water to the required levels. Also, special provisions should be made to the shear box to fix the EPC flushing with the surrounding surface.

Results and Discussion

Fluid Calibration

The Universal calibration device was developed by incorporating modifications in triaxial set up was used for calibration of pressure transducers. The device can be used for calibration of most of the transducers used in the experimental studies by just changing the combination of dummy ring, brass coupling and at the most the brass pedestal used in the present study. As the conventional triaxial cell is modified, in this invention, to calibrate multiple transducers simultaneously, the limitations of the triaxial cell are inherently applied to this device as well.

Calibration studies on three different transducers, viz. type 1, type 2, and type 3, using universal calibration device have been performed. Results of calibration performance of each of transducers are presented in Table 2. Calibration factors were obtained by linear regression analysis of test results during first loading–unloading cycle and five consecutive loading–unloading cycles. Regression analysis of calibration results represents reliability and consistency of calibration device. A linear regression curve fitting was done to obtain Statistical constant for linear Results were compared with transducer specifications to obtain non-linearity and hysteresis. For type 1 transducer, maximum non-linearity of 0.6 and 0.79 % was acquired against 0.4 % non-linearity as supplied by manufacturer. As the transducer was loaded to about 15 % of its FS, negligible variation in output was expected. For type 2 transducer, maximum non-linearity of 0.31 and 0.4 % was observed against 0.5 % non-linearity mentioned by manufacturer, well within the range. However, for type 3 transducer, maximum non-linearity of 2.64 and 2.67 % was depicted against 0.5 % non-linearity suggested by manufacturer. The transducer was used for experimental studies with sand; there were chances of change in pressure cell diaphragm sensitivity during course of time.

In-Soil Calibration Device

The results of the in-soil calibration of type 2 transducer are presented in Fig. 6, for Sand and Kaolin. The calibration studies were conducted for various thicknesses of soil overlying the EPC. However, for the sake of brevity, the in-soil calibration results for the case of soil thickness equal to the diameter of the EPC (D_{EPC} = 40 mm) are presented here. The in-soil calibration results are compared with that of fluid calibration, and presented in Fig. 6. From the figure, it can be noted that the calibration factor (the slope of the linear best fit between applied pressure and measured strain) obtained from fluid calibration is much higher compared to that of in-soil calibration. The reduction in the measured strain in case of in-soil calibration is due to the soil-structure interaction effect, as reported by Wachman and Labuz [16]. The soil-structure interaction may result in the mobilized shear resistance of the soil, side wall friction, arching effect, particle reorientation, etc., and lead to non-uniform normal stress. In case of fluid calibration, the distribution of contact normal stress is uniform across the diaphragm of the EPC, whereas it is non-uniform in case of soil, and the degree of non-uniformity greatly depends on the interaction between the soil and structure (EPC). Further, test results with sand layer thickness in the range of D_{EPC} to $2.5D_{EPC}$ showed sensed pressures in the range of 60–80 % of that obtained from fluid calibration, in line with the observations of previous researchers. Hence, it is noted that the developed calibration device can be useful not only for fluid calibration of various pressure transducers, but also for in-soil calibration of EPC.

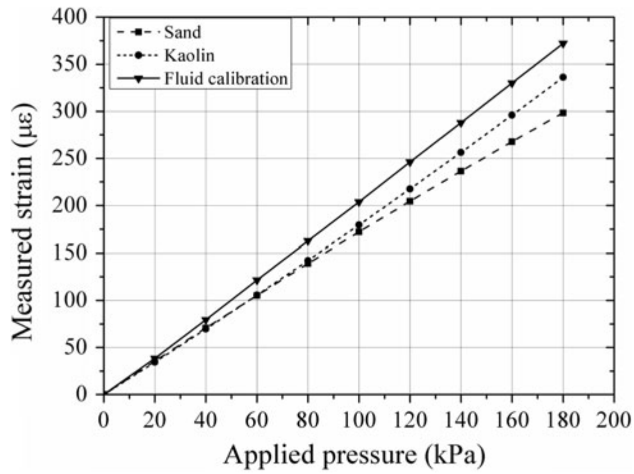


Fig. 6 Comparison of performance of fluid and in-soil calibration of type 2 transducer

The developed universal calibration device which was fabricated by incorporating limited modifications in the existing triaxial cell involves simple working mechanism, works reasonably accurate and easy to adopt. However, as conventional triaxial set up was modified to develop a calibration device, limitation in accuracy of applied pressure is inherent in the device.

Conclusions

Calibration results reveal that the universal calibration device developed in the present study is a versatile set up for fluid and in-soil calibration of pressure transducers. The device is able to calibrate new as well as used pressure cells of different specifications and varieties. The device can be used for calibration of most of the transducers used in the experimental studies by just changing the combination of dummy ring, brass coupling and at the most the brass pedestal used in the present study.

Acknowledgments The work reported in this paper is substantially supported by the Department of Science and Technology (DST), India (Project No. SR/FTP/ETA-69/2008).

References

1. Bao M, Sun Y, Yang H, Wang J (2003) ‘A fast and accurate calibration method for high sensitivity pressure transducers’. Sens. Actuators A Phys. 108(1–3):218–223
2. Clayton CRI, Bica AVD (1993) The design of diaphragm-type boundary total stress cells. Geotechnique 43(4):523–535
3. Dave TN, Dasaka SM (2011) A review on pressure measurement using earth pressure cell’. Int. J. Earth Sci. Eng. 4(6 SPL):1031–1034
4. Frydman S, Keissar I (1987) Earth pressure on retaining walls near rock faces. J. Geotech. Eng. 113(6):586–599
5. Ingram JK (1968) ‘Development of a Free-Field Soil Stress Gage for Static and Dynamic Measurements’, Technical Report No. 1-814. US Army Waterways Experimentation Station, Corps of Engineers, Vicksburg
6. Labuz JF, Theroux B (2005) Laboratory calibration of earth pressure cells. Geotech. Test J. 28(2):1–9
7. Madabhushi SPG, Khokher YR (2010) Physical Modelling in Geotechnics. In: Springman S, Laue J, Seward L (eds) ‘Dynamic Earth Pressures and Earth Pressure Cell Measurements’. Taylor and Francis Group, London, pp 493–498
8. Mason HG (1965) ‘Effects of Structural Compressibility on Active and Passive Arching in Soil-Structure Interaction’, Defense Atomic Support Agency 1718. URS, Pasadena, pp 645–648
9. McNulty JW (1965) ‘An Experimental Study of Arching in Sand’, Technical Report No. 1-674. US Army Engineer Waterways Experiment Station, Vicksburg
10. Pang PLR (1986) A new boundary stress transducer for small soil models in the centrifuge. Geotech. Test J. 9(2):72–79
11. Selig ET (1980) Soil stress gauge calibration. Geotech. Test J. 3(4):153–158
12. Selig ET (1989) In situ Stress Measurements: State-of-the-Art of Pavement Response Monitoring Systems for Roads and Airfields. US Army Cold Regions Research and Engineering Laboratory, Hannover
13. Take WA (1998) ‘Lateral Earth Pressure Behind Rigid Fascia Retaining Wall’, M.S. Thesis. Dept. of Civil Engineering, The University of New Brunswick, Vicksburg
14. Terzaghi K (1943) Theoretical Soil Mechanics. Wiley, New York
15. Trollope, H., Lee, I. K.: ‘The measurement of soil pressure’. In: Proceedings of 5th International Conference on Soil Mechanics and Foundation Engineering, vol. 2, pp. 493–499. Paris (1961)
16. Wachman GS, Labuz JF (2011) Soil-structure interaction of an earth pressure cell. J. Geotech. Geoenviron. Eng. 137(9):843–845
17. Weiler WA, Kulhawy FH (1982) Factors affecting stress cell measurements in soil. J. Geotech. Eng. Div. 108(12):1529–1548