01 May 2013, 5:15 pm - 6:45 pm

# Effects of Arching on Measurement of Embedded Pressure Cell in Embankment Dam

Dorsa Elmi
*University of Tehran, Iran*

Ali Asghar Mirghasemi
*University of Tehran, Iran*

Commemorate the Legacy of Ralph B. Peck
Seventh International Conference on
Case Histories in Geotechnical Engineering
April 29 - May 4, 2013 CHICAGO
and Symposium in Honor of Clyde Baker

# EFFECTS OF ARCHING ON MEASUREMENT OF EMBEDDED PRESSURE CELL IN EMBANKMENT DAM

**Dorsa Elmi**
School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

**Ali Asghar Mirghasemi**
School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

## ABSTRACT

Field observation and monitoring earth structures is vital to design the structure safely and efficiently. Among different types of instruments, earth pressure cells (EPCs) are used to measure soil pressure in embankment dams, which are not proved to be entirely satisfactory. Presence of cells and installation methods usually affect the accuracy of total stress measurements. Since earth pressure cells are prone to damage by large and sharp stones or by using heavy compaction rollers, one excavates a trench and place EPC within fine grained soil which is compacted with light-weight machines. This nonconformity results in local arching between the installation trench and surrounding fill that transmits stress from flexible zone (installation trench) to surrounding fill. As a result the measured soil stress is less than real one. Moreover, pressure cell underestimates the stress in non homogeneous dams for the reason that transversal arching occurs between the core and shell. In this study numerical analyses were conducted to evaluate the contribution of local and transversal arching in stress underestimation and to further clarify the arching trend in the dam height. According to the obtained results, it is possible to calibrate the registered total stress during construction procedure in an earthfill dam.

## INTRODUCTION

Geotechnical monitoring of earthfill dam during construction and operation is critical to control static and dynamic stability of dam. For this purpose different instruments are used in a dam. Earth pressure cells are installed within earthfill dams to monitor stress in different directions. The accuracy of their measurements is important for anticipating destructive phenomena like hydraulic fracture in an earthfill dam. Earth pressure cells are difficult to monitor accurate total stress due to various reasons such as installation method. Dunnicliff and Green (1988) have expressed their concerns on factors affecting earth pressure cell readings such as cell dimension, stiffness ratio, aspect ratio and placement effects [2].

A report by the International Society for Rock Mechanics (ISRM, 1981) includes detailed recommendations for installation of embedment earth pressure cells [4]. The report recommends excavating a trench with a compacted and level base. Then, cells should be installed in small pockets at the base of excavation and protruding stones should be removed since earth pressure cells are prone to damage due to heavy loads. Although it is ideal that the soil within the trench have a density similar to that of the core, it should be backfilled using stone-free soil and compacted by hand-operated equipment.

Although the above procedure prevents damage of cells but many studies have been done to increase the accuracy of measurements. Matsuu et al. (2008), quantitatively evaluated measurement errors caused by embedding method and the trench geometry for earth pressure cells to be installed in the central core-type rock-fill dam [5]. Ahangari and Noorzad (2010) carried out laboratory tests, using a casing material for the cell to improve the accuracy of the results. Their study shows that when the casing material is softer than surrounding soil, the pressure cell underestimates the stress [1]. Shahbazian et al. (2007) indicated that measurement of total stress is not only affected by the inclusion made by the pressure cell, but the trench geometry and installation procedure also contributes to nonconformities in the medium. They concluded that the main dominating parameter in installation is over/under compaction of a backfill material [6].

Elmi and Mirghasemi (2012) concluded that changing of elastic modulus, friction angle and Poisson's ratio of soil material are main parameters which result in arching between the core and shell. From these, changing of elastic modulus has the most influence on stress transmission, while Poisson's ratio has the less [3]. The accuracy of stress measurement is evaluated by arching ratio, which is the proportion of registered stress to theoretical normal stress:

$$ArchingRatio = \frac{\sigma_v}{\gamma . z} \qquad (1)$$

Where $\sigma_v$ is total vertical stress registered by pressure cell, $\gamma$ is soil unit weight and z is earthfill height above the pressure cell.

In an ideal measurement, when the stiffness of medium is equal with the surrounding, arching ratio is near to unity. Conversely, smaller arching ratio means the stress is transmitted from flexible zone to stiffer one.

Three types of arching are probable in an earthfill dam: First, transversal arching which happens between different zones (shell, core, filter,...) of an embankment dam. Second, longitudinal arching which is caused by steep slope of valley, usually V shape. This occurs between body and dam abutments. Third, local arching that is possible when the fill around pressure cells has different material compared to surrounding medium.

Presence of pressure cell installation trench with different material affects natural stress distribution. Total stress transmits from the trench to the core and pressure cell registers less stress at this location. This inaccuracy of field readings should not be considered in designing program. This paper, studies on changing of local arching during construction steps to calibrate total stress data of pressure cell.

## NUMERICAL MODEL

In this study the installation trench is modeled within an earth fill dam in ABAQUS which uses finite element method to analyze the problem. Figure 1 shows a 2D model of the non-homogeneous earthfill dam in which dam height, core width and shell slopes are assumed to be 128m, 66m and 1V:2.5H respectively. The trench is situated 4 meters above the bed. To simulate a real model with reliable results, dam sides are considered to be 600m and bed depth is about two times of dam height (Fig. 2).

Soil is assumed to be 100% saturated with Mohr Coulomb behavior. Table 1 presents soil mechanical properties of dam in different zones. To mesh the model, 4-node bilinear plane stress element (CPS4) is used. Figure 3 shows the grid mesh zone for the dam.

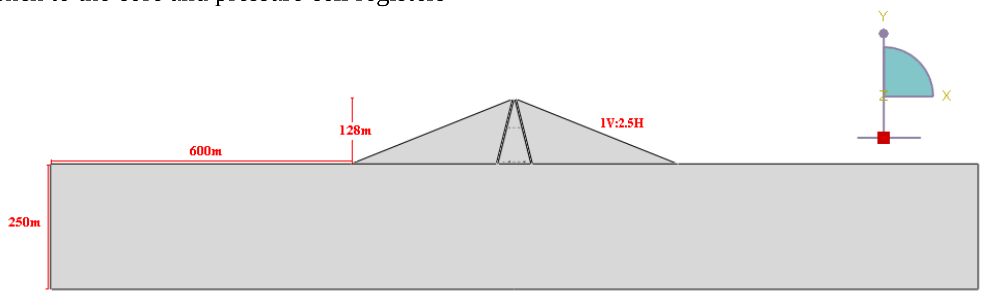


*Fig. 1. The view of dam-foundation model*

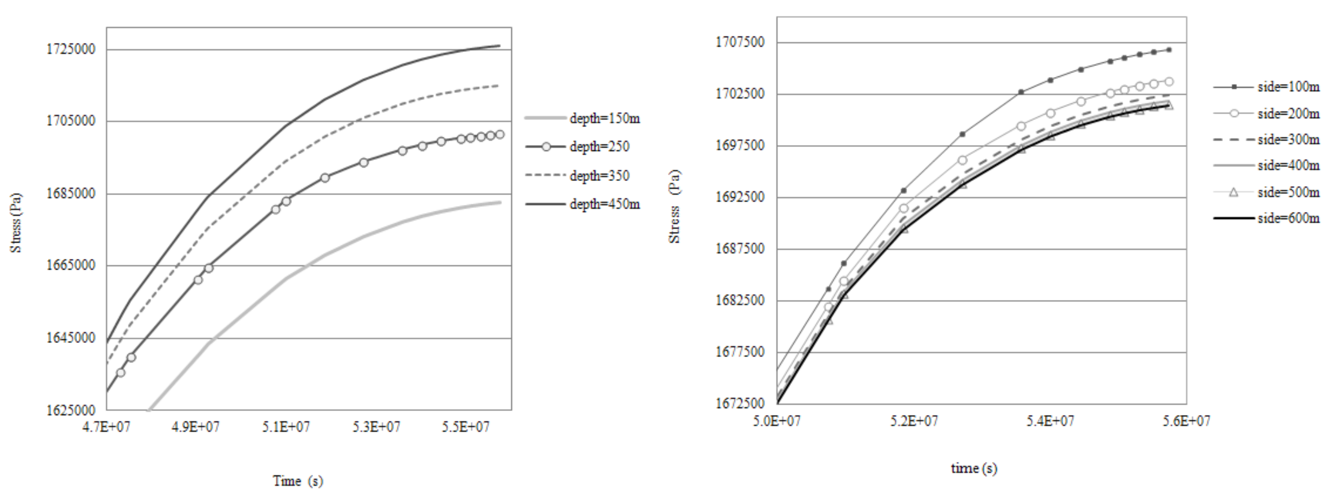


*Fig. 2. Effect of foundation dimensions on stress distribution during construction steps*

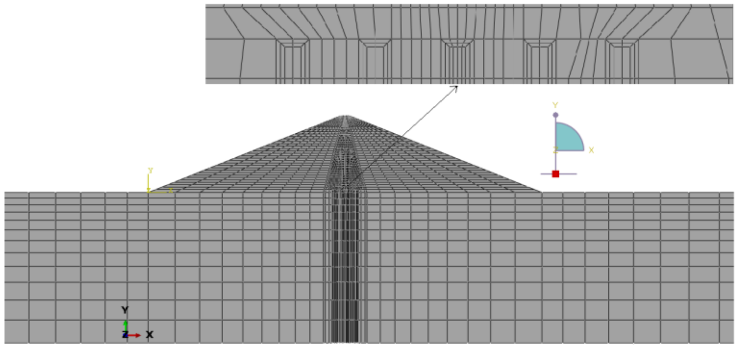

*Fig. 3. Quadratic mesh for different regions*

A basic concept in ABAQUS is the division of the problem history into steps. As depicted in Fig.4 dam is constructed in 46 layers within 2 years. Layers are generally 4 meters except at upper elevations and near to the crest. In construction steps the load changes linearly from one magnitude to another.

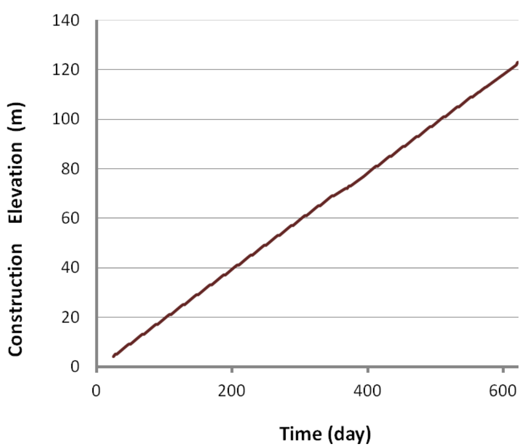


*Fig. 4. Dam construction period*

The choice of initial time step is important in consolidation analysis in ABAQUS. Due to the coupling of spatial and temporal scales, it follows that no useful information is provided by solutions generated with time steps smaller than the mesh and material-dependent characteristic time. This issue is discussed by Vermeer and Verruijt (1981) [7], who propose the criterion:

$$\Delta t \geq \frac{\gamma_w . \Delta h^2}{6E.k} \tag{2}$$

Where Δh is the distance between nodes of the finite element mesh near the boundary condition change, E is the elastic modulus of the soil skeleton, k is the soil permeability, and $\gamma_w$ is the specific weight of water.

To verify that the geostatic stress field is in equilibrium with the applied loads and boundary conditions on the model, initial stress condition of bed is considered. In this case, the loads and initial stresses equilibrate and produce zero deformations. Zero-valued boundary conditions are imposed on displacements to constrain the movement of the selected degrees of freedom of bed to zero. To specify the zero pore pressure at the surface of each layer during construction, pore pressure boundary conditions are imposed in each step.

Table 1. Material properties of earthfill dam

| | Trench | Core | Transition zone | shell | bed |
|---|---|---|---|---|---|
| Density (kg/cm$^3$) | 1740 | 1740 | 1950 | 2050 | 2100 |
| Young’s Modulus (MPa) | 35 | 35 | 70 | 102 | 900 |
| Poisson’s Ratio | 0.35 | 0.35 | 0.27 | 0.25 | 0.25 |
| Permeability (m/s) | $K_x$ =1e-8 $K_y$ =1e-9 | $K_x$ =1e-8 $K_y$ =1e-9 | 1e-5 | 1e-6 | 1e-10 |
| Bulk mod of fluid (GPa) | 2 | 2 | - | - | 2 |
| Friction angle (deg) | 20 | 20 | 35 | 39 | 39.4 |
| Dilation angle (deg) | 0 | 0 | 3 | 5 | 9 |

| | | | | | |
|---|---|---|---|---|---|
| Cohesion (kg/cm$^2$) | 0.3 | 0.3 | 0 | 0 | 0.85 |
| Void ratio | 0.35 | 0.35 | 0.45 | 0.3 | 0.4 |

## ANALYSES RESULTS

To clarify the influence of mechanical properties on local arching, in one analysis the proportion of trench to core was set to 1/2, 1/5, 1/10, 1/20, 1/35, 1/50 and 1/100. In other, the friction angle of trench decreased to 15, 10, 5 and 0 degrees.
In non-homogeneous earth fill dam, transversal arching happens between various zones due to nonconformity of material. By completing the construction steps core settlement increases and more stress transmits from flexible zone (core) to stiffer one (shell). As depicted in Fig. 5, analyses showed that maximum settlement and thus the minimum arching ratio happens within the core at 0.5 to 0.75 of dam elevation during construction.

It is helpful to study the performance of the pressure cells in the lower elevation of the dam during placement while there is 10 to 20 meters of fill over the instrument.
Analyses show that at lower portion of an embankment dam, the influence of transversal arching is negligible and just local arching happens between the core and the trench due to different material. By increasing dam elevation, registered total stress by pressure cell will be affected by transversal arching too. Figure 6 represents total stress distribution along a horizontal path in dam section at pressure cell elevation in different steps. It is clear that at the end of construction stress is significantly transmitted from core to the shell, while it is almost negligible when there is 10 to 20m backfilling above the cell.

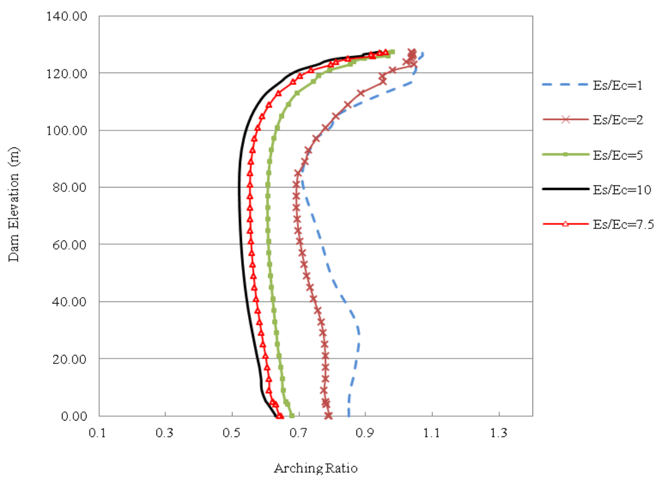


*Fig. 5. Changing of arching ratio on core axis*

Evaluation of stress and transversal arching is critical to guarantee safety of embankment dam; however, presence of trench with different material changes the natural stress field. To reach the natural field of stress in presence of trench, calibration should be done on pressure cell data to omit the local arching effects for designing procedure.
A study was taken on local arching ratio during construction steps to express total stress calibration. For this, the stiffness of trench material set equal to stiffness of the core. Thus, registered stress by pressure cell ($S_c$) was just affected by transversal arching. In other analyses, friction angle of the trench changed and the proportion of elastic modulus of trench to core material set to 1/2, 1/5, 1/10, 1/20, 1/35, 1/50 and 1/100. In this case stress distribution plotted for trench center with respect to construction level ($S_t$). By changing mechanical properties of the trench, registered total stress is affected by local arching as well as transversal arching. The difference between $S_t$ and $S_c$ ($\Delta S_L$) shows the local arching effects. Thus, coefficient k was defined as equation 3 to illustrate loss of stress due to local arching effects during construction steps. In this equation $S_c$ is total stress at the center of the trench when the core and the trench have the same material, $S_t$ is total stress at the center of trench when the trench is different from the core, and $\gamma.z$ is the theoretical stress above the cell.

$$k = \frac{S_c - S_t}{\gamma . z} \tag{3}$$

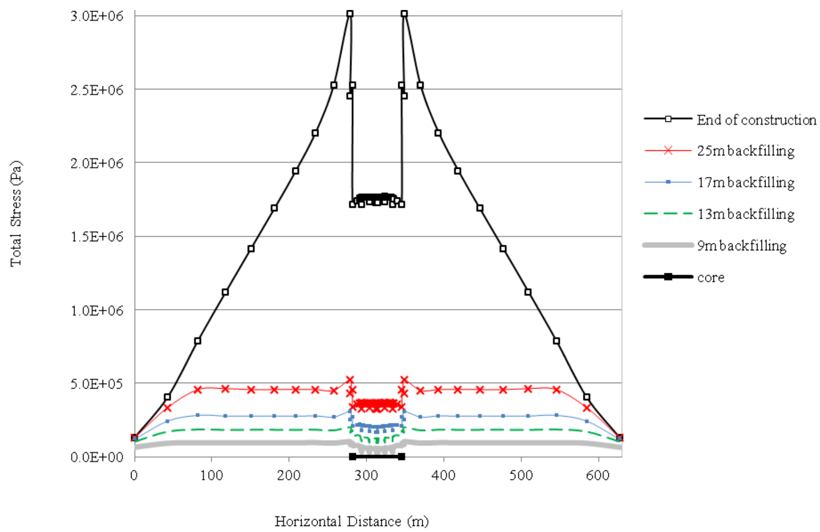


*Fig. 6. Total stress distributions along a horizontal path during construction steps*

The coefficient k ($\Delta S_L/\gamma.z$) is presented for the center of trench, in different modes of stiffness and friction angle during the construction procedure in Fig 7 and 8 to specify arching ratio changes. According to Fig. 7 when the elastic modulus of the trench was half of the surrounding medium, the transmitted stress to the core is about 5% of the normal pressure above the cell ($\gamma.z$) during backfilling. Analyses show that local arching remains approximately constant during construction procedure.

As it was explained above, during first steps of backfilling differential settlement between core and shell is minor and transversal arching does not occur. In this case $S_c$ becomes equal to the theoretical stress ($\gamma.z$) and its proportion is 1 as it is described in equation 4.

$$1-\frac{S_t}{\gamma.z}=K \tag{4}$$

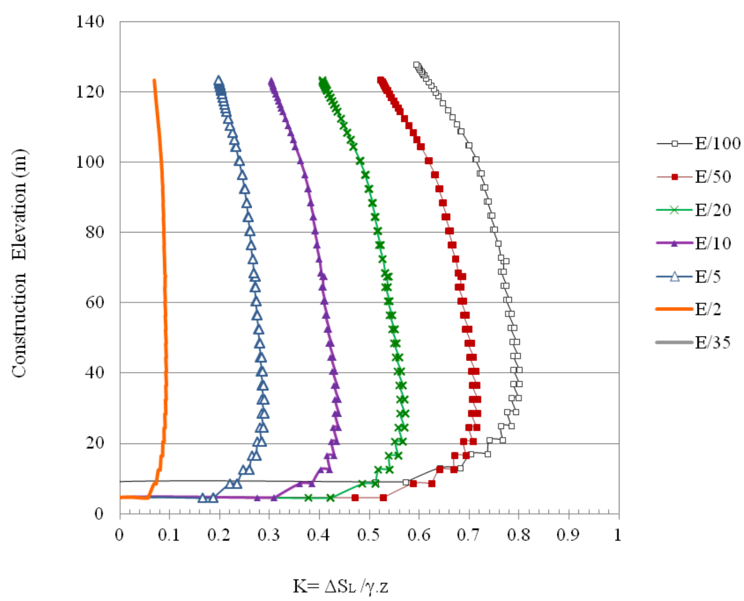


*Fig. 7. Changing of k with increasing the construction elevation in different modes of elastic modulus*

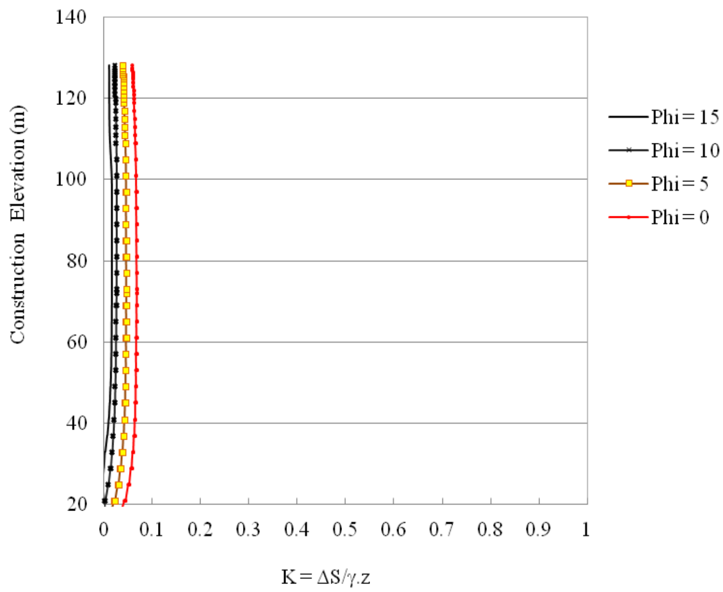


*Fig. 8. Changing of k with increasing the construction elevation in different modes offriction angle*

$S_t$ is the monitoring total stress of earth pressure cell when 15 meters of backfilling is done. Thus, k is known by monitoring earth pressure cell in 15 meters of backfilling.
As construction proceeding goes on transversal arching takes place. To obtain calibrated total stress without local arching errors ($S_c$) equation 5 is used.

$$S_c = k(\gamma . z) + S_t \quad (5)$$

$S_t$ is monitored total stress by cells in each step, $\gamma$.z is the theoretical stress above the cell, k is known from the first 15 meters of backfilling and $S_c$ is the calibrated total stress without local arching effects and is unknown parameter.

## CONCLUSION

Earth pressure measurements are carried out in order to determine stress distribution occurring within the dam. The reliability of these measurements is significantly reduced, however, by many factors such as presence of installation trench with material different from the core. Therefore, local arching changes the natural stress field and transmits total stress from the trench to stiffer zone (core).
This paper studied on local arching trend by increasing the construction elevation. The study concluded that monitoring an earth pressure cell in first steps of construction and while there is 15 meters of overburden specifies the local arching since transversal arching doesn't take place. Also analyses show that the stress which was underestimated due to local arch actions remained approximately stable during construction steps. It is possible to calibrate total stress without local arching effects by monitoring first 15 meters of construction.

## REFERENCES


Ahangari, K. and Noorzad, A. [2010]. "Use of casing and its effect on pressure cells," Mining Science and Technology, 20(2010) 0384-0390.

Dunnicliff, J. and Green, G. E. [1988]. "Geotechnical instrumentation for monitoring field performance," John Wiley and Sons Inc. New York, ISBN-0-471-09614-8, pp 165-177

Elmi D. and Mirghasemi A. A. [2012]. "Influence of trench soil properties on the accuracy of pressure cell measurements in embankment dams" 10$^{th}$ international congress on advances in civil engineering,Ankara,Turkey

ISRM, [1981]. "Suggested Methods for Pressure Monitoring Using Hydraulic Cells," Rock Characterization Testing and Monitoring, ISRM Suggested Methods, Pergamon Press, Oxford, pp. 201-211

Matsuu, M. Takashi, A. Uchita, Y. and Ohta, H. [2008]. "Improvement of earth pressure measuring method in rock-fill dams," International commission on large dams 76th annual meeting, Sofia, Bulgaria.

Shahbazian, H. Fakharian, K. and Jamshidi Chenari R. [2007]. "Numerical investigation of trench geometry and soil property effects on the accuracy of embedded pressure cell measurements," OttawaGeo2007: The Diamond Jubilee Conference, Ottawa.

Vermeer, P. A. and Verruijt, A. [1981]. “An Accuracy Condition for Consolidation by Finite Elements,” International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 5, pp. 1–14.