Time response of two types of porous blocks for suction measurement

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Abstract. Various types of porous blocks have been used for the indirect measurement of soil suction by various researchers, the usual experience being the importance of appropriate calibration, relatively low accuracy, and slow response. Two types of commercially available porous blocks were used. They were placed in samples undergoing either drying or inundation. Porous blocks were placed always with a tensiometer so that at the range of suctions measured by the tensiometer a comparison could be made between the response of the tensiometer and the porous block. The tests performed involved both slow drying in atmospheric conditions and fast inundation due to wetting. The experience gained from the tests performed is that in the three cases examined and contrary to common experience reported in the literature, the response of the porous blocks used was comparable to that of conventional tensiometers if not in fact faster.

1 Introduction

Earlier work by other researchers has indicated that porous block sensors can be used for the indirect measurement of suction in a wide range, yet often with relatively low accuracy and more importantly with quite slow response to suction changes actually occurring in the soil [1, 2, 3]. Three different tests are presented in the paper indicating that the two porous blocks that were used are quite accurate (in the range of suction values that a common tensiometer was used simultaneously) when calibrated sensors are used and have quite a fast response, certainly faster than that reported in the literature. Reference is first made to the porous blocks sensors used; then the tests performed are presented; finally the results are discussed in an attempt to identify common characteristics that allowed the performance of the sensors observed.

2 The porous blocks used and the tests performed

Two types of commercially available, off-the-shelf, porous blocks were used; the 5201 gypsum block by Soilmoisture Equipment Corp. and the MPS-2 frequency domain reflectometry (FDR) sensor by Decagon Devices, Inc. These sensors were installed in samples in the laboratory and in the field in combination with the Soilmoisture Equipment Corp. 2100F laboratory tensiometer and the 2725ARL jet-fill tensiometer respectively. Both tensiometers can measure suction in the range 0-90 kPa provided they have been carefully prepared with ceramic porous tips saturated and the tubes carefully deaired prior to their use.

Three tests have been performed and are reported in this paper. The first test involved the installation of gypsum blocks and a tensiometer in broken coarse sand undergoing inundation. The second test involved the installation of gypsum blocks, a tensiometer and other sensors in alluvial coarse sand undergoing inundation. The third test involved the installation of gypsum blocks, an MPS-2 sensor, a tensiometer and various other sensors in silty sand with gravel in the field, where both actual field variations, response after inundation and subsequent drying were monitored.

2.1 Gypsum blocks in a small-size sample of broken coarse sand undergoing inundation

The first test was performed in coarse sand. This was broken material of predominantly quartzitic sand with grains of limestone as well, passing through ASTM sieve No 4 (4.75mm) with only a small fraction of fines (0.5-1.5%) and usually poorly graded (Cu = 4-5, Cc = 1-2). The purpose of the test was to familiarise personnel with the use of the equipment and gain experience on the performance of the sensors used, in this case two gypsum blocks and the 2100F laboratory tensiometer.

The sample was hand-compacted using a hand operated compactor with standard Proctor test energy to an initial dry unit weight of 17 kN/m^3 at an initial water content of 3%. It was prepared in a 4 inch Proctor compaction mould with soil extending into the mould collar up to just a few millimetres below the end of the collar. Using steel tubes of the appropriate diameter, holes were opened from the sample surface for the gypsum blocks and the tensiometer to be installed approximately at the middle of the sample. Holes were

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backfilled using the material from the opening of the holes. Once the sensors were installed and the holes backfilled, the sample was covered with molten paraffin wax (Fig. 1a) and left for paraffin wax setting and insulation of the top surface of the sample despite cables and plastic tubing coming out (Fig. 1b). The sample was then left for sufficient time for sensor readings equilibration.

Once the readings of all sensors had come to equilibrium, the sample was inundated, bottom to top. As soon as the water surface covered the sample, small bubbles started coming out of a small hole at the periphery of the collar of the mould indicating the entrapment of air as inundation was taking place only from the bottom of the sample (Fig. 1c). The layer of the paraffin wax was therefore torn and removed (Fig. 1d) revealing collapse of the soil that had taken place under the paraffin wax layer. Removal took place within approximately two minutes from the beginning of the inundation. Suction readings from the tensiometer and the gypsum blocks are plotted in Fig. 2 with time. In Fig. 2a gypsum block readings have been turned into suction by use of the manufacturer's universal calibration curve for the gypsum blocks and in Fig. 2b by use of a sensor-specific calibration curve developed in the laboratory [4]. It can be seen that the manufacturer's universal calibration curve does not necessarily give values close to actual suction in the soil (assuming that the tensiometer in this particular range of suction values measures accurately). A sensor-specific calibration curve however gives values of suction fairly close (at least on average) to those measured by the tensiometer. Regarding time response, irrespective of the calibration curve used, equilibration with the new value after inundation corresponding to zero was comparable (if not faster) to that of the tensiometer. Gypsum blocks equilibrated within 15-16 minutes whereas the tensiometer equilibrated within 25 minutes.

It must be pointed out that the range of suction at the beginning of the inundation process in the particular test corresponded to a range of saturation close to full saturation for the gypsum block. Also, both blocks had been carefully saturated prior to their installation in the sample. The two gypsum blocks were placed in deionised water for 48 hrs prior to their installation in the sample. As it may be seen in Fig. 3, gypsum residue was observed at the bottom of the glass jar holding the gypsum blocks which at the time had become softer enough to require very careful handling during their installation in the sample. Finally, the whole test took place in a laboratory environment with the corresponding care, time, and personnel competence, that cannot necessarily be expected in field applications related to everyday agricultural or geotechnical practice. On the other hand the very fast response observed came as a surprise, given the experience reported in the literature, and served as motivation for further study of the time response of this particular type of sensors and other porous blocks currently available.

a) b) c) d)

Figure 1. a) Proctor test mould with the paraffin wax immediately after it was poured over the coarse sand, and b) after it set, c) after inundation of the whole mould (bubbles from a tiny hole can be seen), and d) after the wax layer was cut and partially removed (settlement of the sand pointed by arrow).

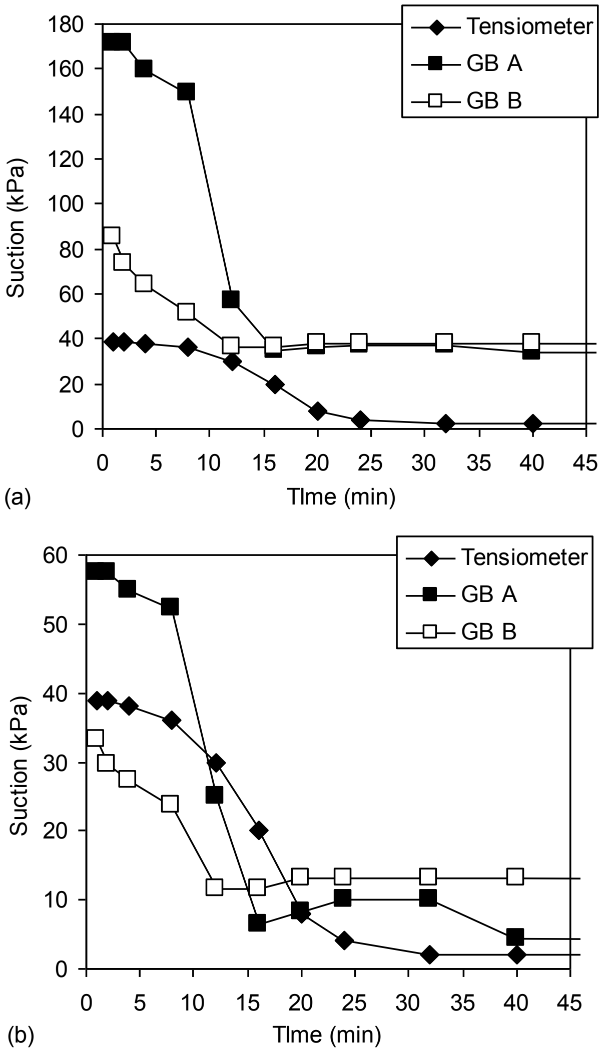

Figure 2. Suction measured by tensiometer and gypsum blocks GB A and GB B using a) manufacturer's universal calibration, curve and b) a sensor-specific calibration curve obtained in the laboratory.

Figure 3. Gypsum blocks used in the first test at the end of their saturation prior to their installation in the sample. Gypsum residue may be clearly seen at the bottom of the glass jar holding the gypsum blocks in deionised water.

2.2 Gypsum blocks in a large sample of alluvial coarse sand undergoing inundation

The second test performed involved the installation of gypsum blocks, a tensiometer and other sensors in alluvial coarse sand undergoing inundation. The sample was of much larger size than in the previous test as it was prepared inside the cell of a large diameter direct shear device (45cm diameter by 30cm height). This device has already been presented as well as results from tests with it [5, 6, 7]. In the previous tests, the material used was broken sand from a quarry. In this test the readily available at the time fraction of the Ilarion dam rockfill passing through ASTM sieve No 4 was used. This material is an alluvium from Aliakmon river in northern Greece with grains rounded to well-rounded with varying lithological origins. In order to evaluate the performance of the sensors, vertical stress in the device was kept very low so as not to affect the sensors at this stage of the research (only 50 kPa). For similar reasons, compaction was limited only to that achieved by hand-compacting the material and not using an electric compactor used in the particular device in order to achieve high densities [5, 6].

A sample of the material was prepared in the cell of the apparatus with initial dry unit weight of 15 kN/m^3, and an initial water content of 5%. In the middle of the sample were installed: a laboratory tensiometer, two gypsum blocks and a Delta-T Devices volumetric water content sensor (ML-2 known as 'Theta Probe'). The gypsum blocks were again saturated prior to their use and then immersed in a slurry prepared by the non-plastic fines of the sample they would be installed in (Fig. 4a & 4b) in order to achieve better contact with the surrounding material (in a manner similar to the treatment of the porous tips of vibrating wire piezometers before installation). Once covered by the slurry, the gypsum blocks were carefully installed in the holes opened (Fig. 4b) and all holes were backfilled after sensors' installation before the rest of the sample was prepared in the cell (Fig. 4c).

After installation of the sensors and preparation of the sample, time was left for all sensors to come in equilibrium. Suction was small, measured 22-23 kPa by the tensiometer and 19-20 kPa by the gypsum blocks, and volumetric water content was 7.0 to 7.5%. These values exhibited negligible change due to the application of 50 kPa of vertical stress. After application of the vertical stress for 24hrs, inundation of the sample took place by filling the carriage of the direct shear device with water and the settlement due to collapse of the sample and the values of properties in the various sensors were monitored. In Figure 5a the vertical strain calculated from the settlement measured by displacement transducers placed on the top plate above the sample and the height of the sample before commencing inundation is plotted with time since commencing inundation of the sample. In Figure 5b, suction measured from both types of suction measurement sensors and volumetric water content are plotted against time during the same timeframe. The evolution of vertical strain due to inundation, suction and volumetric water content are in absolute agreement between them. In fact the time interval that rapid changes

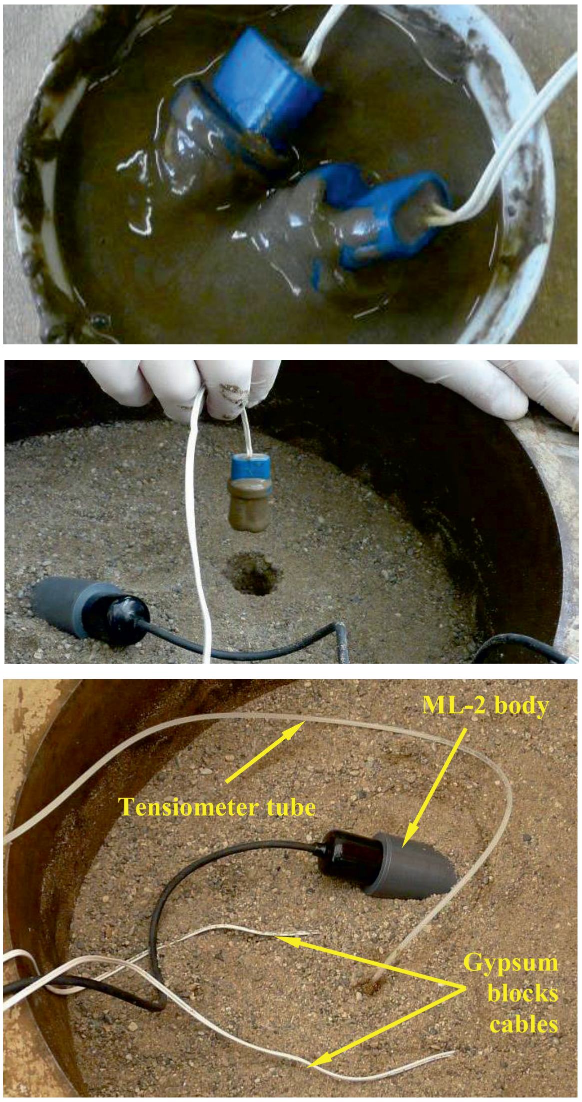

Figure 4. a) Gypsum blocks placed in a slurry of the fines of the sample after their saturation, b) slurry-covered gypsum block installed in the sample, and c) surface of sample at the level of sensors' installation.

of suction and volumetric water content occur is more narrow than the time interval that strain increases from 0 to 1.65%. This is attributed to the fact that the displacement transducers record strain from the beginning of the inundation when parts of the sample relatively far away from the location of the sensors start collapsing due to wetting, while the sensors record the changes essentially only when the wetting front reaches their location. In fact, the time the changes start to be recorded by the sensors is the time that the level of water in the carriage outside the cell has approximately reached the middle of the sample height where the sensors are located. Therefore, the macroscopic observation of collapse strain occurring due to inundation in the particular sample is in full agreement with the loss of approximately 20 kPa of suction and an increase of the volumetric water content from 7.5% to 35.5%. In this test too therefore the response of the gypsum blocks was very fast, again as in the previous test, at least as fast if not faster than that of the laboratory tensiometer.

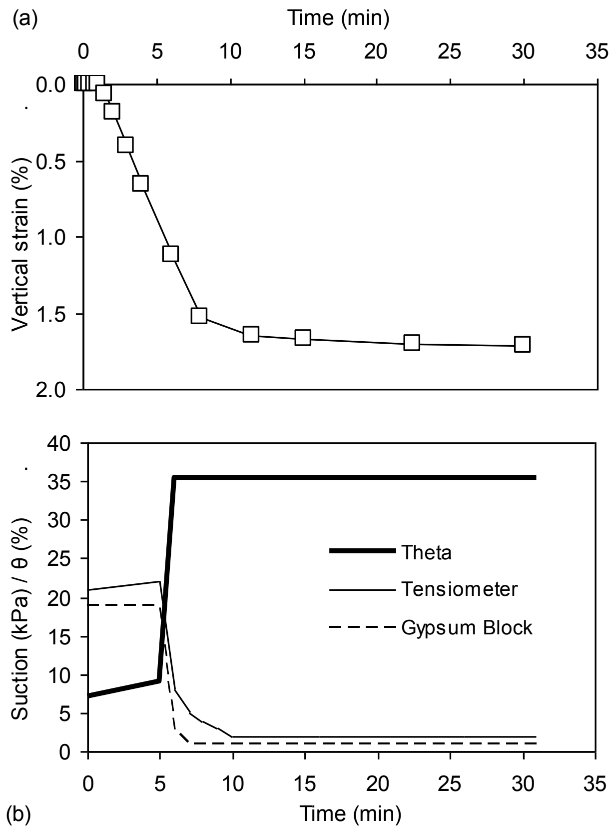

Figure 5. Evolution with time after start of inundation during the second test of a) collapse vertical strain, and b) suction from gypsum block and tensiometer and volumetric water content.

2.3 Porous blocks in silty sand with gravel undergoing inundation and drying in the field

The third test involved the installation of gypsum blocks, an MPS-2 sensor, a tensiometer and various other sensors in silty sand with gravel in the field, where both actual field variations, response after inundation and subsequent drying were monitored. A field array for measuring suction and volumetric water content was installed in shallow depth in silty sand with gravel at a semi-urban area close to Athens, Greece, Artemida region with climate typical of central Greece and in general of areas around the Mediterranean sea. Suction and volumetric water content were monitored for approximately one month in August 2013. The sensors installed included one gypsum block, one MPS-2 sensor, a jet-fill tensiometer, and two volumetric water content measurement sensors; the Delta-T Devices ML-2 'Theta Probe' and the Decagon Devices GS-3 (Fig. 6a & 6b). These constituted the main array. A smaller array only with one MPS-2 and one GS-3 was installed very close for reference of the conditions of the dry soil in the field during the wetting test in the main array. All sensors were installed at a depth of 25 to 30cm from ground surface.

The material the sensors were installed in is a silty sand with gravel and only traces of clay. Classification tests were performed on three samples taken during excavation of the main and the reference array location in order to remove the sensors from the ground. Gravel was mostly fine gravel with traces of coarse gravel amounting

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to 22% on average. Sand was on average 46% practically evenly shared between fractions of fine, medium and coarse sand. The fines were on average 32% and the clay content was found only 2.5-3.0% using the hydrometer test. Specific gravity was 2.68 and organic content 2.5-3.0%. The material is non-plastic. Classification according to USCS is SM. At the time of sensors removal that samples were taken, gravimetric water content of all samples was found 4% on average, with values ranging between 1.5 and 6.0%. Using the sand-cone method the dry unit weight was found to be 14 kN/m^3.

Prevailing meteorological conditions of the specific site have already been reported in detail [8]. These generally led to measured values of suction during monitoring period 2.5 MPa which never dropped below 1.4 MPa (Fig. 7a). Daily fluctuation of suction was in the order of 300 kPa, not matched by similar fluctuation in volumetric water content given the nature of the soil the sensors were installed in. A complete wetting test at the surface (Fig. 6c) revealed a time period of 11 days until prevailing suction and volumetric water content prior to wetting were obtained again (Fig. 7a).

What is of particular interest is again the response of the porous blocks used for suction measurement. Inundation took approximately 30 minutes. For the first twenty, none of the suction sensors recorded any change (as well as the volumetric water content sensors) indicating that the wetting front from the surface had not yet reached the depth of the sensors. Then, within a matter of 10 minutes, all sensors recorded zero values of suction and volumetric water content sensors practically the maximum values they ever recorded. Once again therefore both the gypsum blocks and the MPS-2 sensor responded as fast as the tensiometer during inundation, in this case a field one.

In this test however there was not only inundation but subsequent drying as well. As seen in Fig. 7b where the suction measurements from all sensors are plotted with time in the range of suction corresponding to the range measured by the tensiometer, the MPS-2 sensor responds similarly to the tensiometer with the measurements matching closely those of the tensiometer without the fluctuations observed in the tensiometer, while the gypsum block shows a similarly fast response but with the values of suction obtained from the manufacturer's calibration curve lying at a constant distance from the suction values obtained from the tensiometer. Once again therefore and in this case, two types of porous block sensors responded as fast as the tensiometer and in this case not only during inundation but also during drying.

3 Discussion of results

If one attempts to identify common features in the response and general performance of the porous block sensors used in the tests presented these may be:

- Both types of sensors responded as fast as the tensiometer (either laboratory or field one) both during inundation in three different cases presented and during drying in one case presented. In fact it may be supported on the basis of the two first examples that

a)
b)
c)

Figure 6. a) Open hole for the installation of the first set of sensors in the Artemida field array (top: MPS-2, middle: GS-3, bottom: Gypsum Block), b) dry surface of the field array before wetting, and c) after wetting (water seeped outside the plastic ring used to contain the free surface of water).

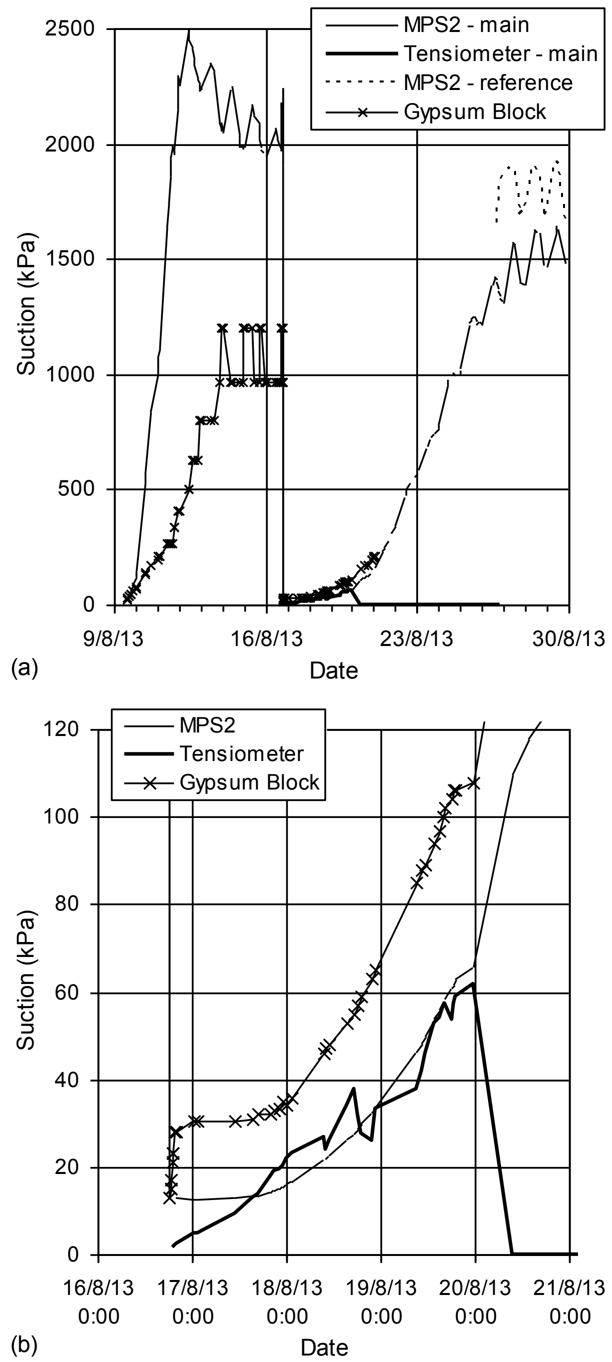

Figure 7. Suction measurements from all sensors: a) full scale, and b) reduced scale.

the gypsum blocks responded a little faster than the laboratory tensiometer.

- The MPS-2 sensor obtained values of suction very close to those of the field tensiometer in the third test. The gypsum blocks on the other hand did not obtain values close to the tensiometer (laboratory or field one) when using the manufacturer's calibration curve. Using a sensor specific calibration curve obtained for the particular sensors in the first test allowed much closer values of suction to be obtained on average from the two gypsum blocks installed.
- It must be pointed out that observed performance of the sensors was obtained using slurry-covered, carefully saturated sensors prior to their installation. Also all tests presented involved relatively coarse grained soils. Given however that expected changes in these soils are faster than those in clayey materials, it is anticipated that the response of the sensors used should be adequate –if not better– for more fine-grained materials too.
- Finally it is also pointed out that all the tests presented, although long in duration, did not reach the timeframes mentioned in the literature as insufficient for continuous use of gypsum blocks and required replacement of the sensors with new ones (approximately 2-3 years [2]).

4 Conclusions

Two types of commercially available, off-the-shelf, porous blocks were used in three different tests (two in the laboratory and one in the field). All sensors used were carefully fully saturated prior to their installation. All the tests also involved relatively coarse-grained soils (coarse sand and even more coarse-grained than that). Both types of sensors responded at least as fast as the tensiometers installed with them for comparison; the MPS-2 yielding values of suction fairly close to those of the tensiometer; the gypsum block not so when using the manufacturer's universal calibration curve, although was much better when using a sensor-specific calibration curve.

References

1. G. D. Aitchison, B. G. Richards, Moisture in Soils beneath Covered Areas, Butterworths, Australia, 1965, pp. 198-204.
2. A. J. Pullin, Comparative investigation of various soil water content measurement techniques for small scale agriculture, Seminar, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, South Africa, 2004.
3. A. M. Ridley, 1993, PhD Thesis, Imperial College of Science, Technology and Medicine, University of London, 281 p.
4. M. E. Bardanis, 2016, PhD Thesis, in progress.
5. M. E. Bardanis, S. Cavounidis, G. Dounias, A new direct shear testing device for coarse grained soils and soils with large-size agglomerates. Measurement of shear strength and volume changes, Proc. 2nd Hell. Conf. on Dams and Reservoirs, Athens, Greece, 7-8 November 2013 (in greek).
6. M. E. Bardanis, Collapse of coarse grained materials due to inundation under one-dimensional compression conditions, Proc. 6th Int. Conf. on Unsaturated Soils, Sydney, Australia, 2-4 July 2014.
7. M. E. Bardanis, S. Grifiza, P. Kokkali, Shear strength of very coarse-grained materials and measurement of their coefficient of earth pressure at rest, Proc. 7th Hell. Conf. on Geotech. Engineering, Athens, Greece, 5-7 November 2014 (in greek).
8. M. E. Bardanis, Proc. Int. Symp. Shrink-swell processes in soils - Climate and constructions, 18-19 June 2015, Marne-la-Vallee, France, pp. 463-472.