International Journal of the Physical Sciences Vol. 5(10), pp. 1537-1543, 4 September, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Prediction of maximum swelling deformation for compacted bentonite

S. M. Shirazi[1]*, H. Kazama[2], J. Kuwano[2] and S. Tachibana[2]

[1]Department of Civil Engineering, Faculty of Engineering, University of Malaya 50603 Kuala Lumpur, Malaysia.
[2]GRIS, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama-shi, 338-8570 Japan.

Accepted 12 August 2010

Maximum swelling deformation of compacted bentonite is the most important parameter for designing nuclear waste disposal facilities. A series of swelling tests were carried out in the laboratory using different percent of bentonite (30 to 90%) and different initial dry densities (1.29 to 1.95 g/cm^3) under various loading condition. The experimental results showed that, the maximum swelling deformation of bentonite is mainly dependent on initial dry density, static load and bentonite contents in bentonite-sand mixture. Based on the experimental results, simple linear equations were developed for estimating the maximum swelling deformation of sodium bentonite. Maximum deviation between the estimated results and the measured ones is 15%.

Key words: Bentonite, swelling deformation, static load, initial dry density.

INTRODUCTION

Bentonite is extensively used either as original or as a component of mixture in many geo-environmental engineering applications, including the construction of barrier materials to provide sufficient isolation of nuclear waste and not to impose any undue burden on future generation. Based on the multibarrier concept, Japan Nuclear Cycle Development Institute proposed the geological disposal system in Japan (JNC, 2000). The engineered barrier system consists of the vitrified waste, over pack and buffer material. In buffer material montmorillonite mineral is the key component and very difficult to find out a single particle of bentonite. The buffer material effectively filters any possible radionuclide bearing colloids that might form radioactive waste (Dixon et al., 1996; Mollins et al., 1999; and Sato et al., 2001). The buffer material must have high swelling properties leading to the development of impermeability. Mechanical properties of bentonite and bentonite-sand mixtures have been reported by some researchers (Komine and Ogata, 2004, 1999; Shirazi and Kazama, 2004; Shirazi et al. 2006, 2008; Stewart et al., 2003; Onal, 2007). A material in which 70% bentonite and 30% sand mixed with a dry density with at least 1.60 g/cm^3 and for solely bentonite dry density of 2.00 g/cm^3 is selected as base line for the buffer (JNC, 2000). It is very time consuming for determining swelling deformation behavior of compacted bentonite. A simplified equation is essential to predict swelling deformation of compacted bentonite. The objectives of this research are: (1) To experimentally determine the maximum percent swelling deformation of bentonite and (ii) To develop an empirical equation to simply predicts these deformations.

*Corresponding author. E-mail: shirazi@um.edu.my.

MATERIALS AND METHODS

Super clay and Kunigel, and sodium type of powdered bentonite are used in this experiment. Index properties of bentonite are presented in Table 1. Grain size distribution of quartz sand and both types of bentonite are presented in Figure 1.

A wide range of initial dry densities of compacted bentonite 1.29 to 1.95 g/cm^3 by using special compaction device were used for the investigation of swelling deformation. Figure 2 shows the schematic diagram of sample compaction apparatus. Montmorillonite content in Super clay and Kunigel were 85 and 64%, respectively. Quartz sand No. 3 and 5 was mixed as a mixture material. The initial dry density of solely bentonite samples was about 1.33, 1.42, 1.52, 1.63, 1.70, 1.80 and 1.95 g/cm^3. Initial dry density of bentonite-sand specimens was 2.00 g/cm^3 and content of bentonite varied from 30, 40, 50, 60, 70, 80 and 90%. Specific gravity of quartz sand was 2.62. Oedometer test apparatus was used for swelling deformation under different loading condition of 0.16, 0.32, 0.64 and 1.28 MPa. To reduce the friction between the specimen and the wall, silicon grease was used at the inner wall of the vessel. Axial swelling rate was calculated compared to initial height of the specimen and

Table 1. Index properties of Superclay and Kunigel.

Bentonite	Specific gravity	Initial water content (%)	Liquid limit (%)	Plastic limit (%)
Superclay	2.857	10.10	690	43
Kunigel	2.797	7.20	497	26

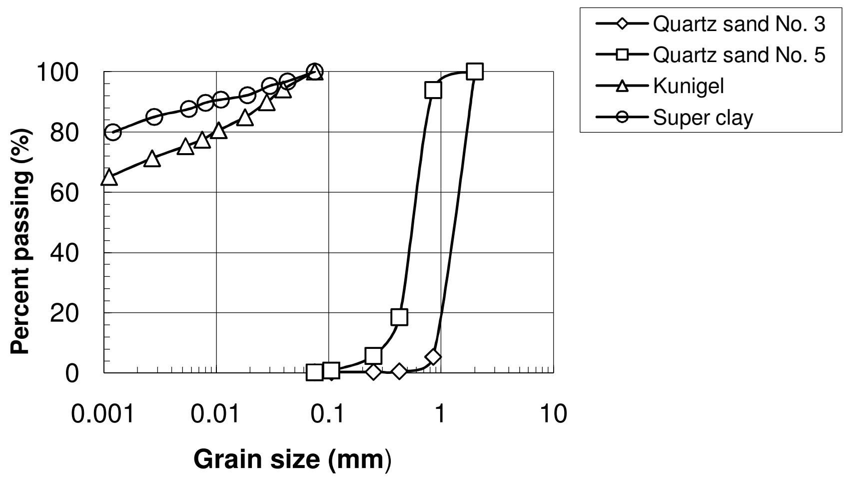

Figure 1. Grain size distribution of quartz sand and bentonite.

expressed in a percentage. Distilled water was supplied at the bottom and simultaneously prescribed vertical pressure was applied to the specimen. At the end of the experiment, the degree of saturation of specimens was about 100%.

RESULTS AND DISCUSSION

Relationship between maximum percent swelling and initial dry density of compacted bentonite under different static load are presented in Figure 3. It is exhibited that for same powdered bentonite, maximum swelling rate noticeably increased due to the increase in initial dry density with the decreasing of static load. Super clay specimens gave high maximum swelling rates than Kunigel at same density and static load. At lower density (1.29 to 1.40 g/cm^3) corresponding to the higher static load (0.64 to 1.28 MPa), Kunigel specimen is exposed to negative swelling rate. But in the case of Super clay, all specimen showed positive swelling rate. It might be due to content of montmorillonite.

Based on the maximum percent swelling and initial dry density relationships as shown in Figure 3, straight line equations (Equations 1 to 8) were obtained and are shown in Table 2. It expressed strong linear correlations of maximum swelling rate and initial dry density at different loading condition of compacted bentonite with r^2 values of 0.96 to 0.99. Exponential correlation was observed by Komine and Ogata (1999) and Shirazi et al. (2006).

Multiple regression analysis for all of the experimental data regarding different initial dry density and static load (Table 3) produced the following equation for predicting maximum swelling rate, S_R with r^2 = 0.96.

$$S_R = 32.97\rho_d S_L^2 - 66.35\rho_d S_L + 29.81C_m + 75.13\rho_d - 82.32 \quad (9)$$

Where, S_R = Percent swelling (%), C_m = Content of montmorillonite (%), S_L = Static Load (MPa) and ρ_d = Initial dry density (g/cm^3).

The swelling deformation predicted by Equation 9 was compared with the direct measured from experimental data of sodium type bentonite, as shown in Figure 4. Maximum swelling deformation rate for sodium type of bentonite may be predicted by using Equation 9 in respect to initial dry density with maximum difference 15% to measured data. But in case of calcium type bentonite, further experimentations are needed to validate this equation.

Relationship between maximum percent swelling and content of bentonite in bentonite-sand mixture using variable loading conditions are presented in Figure 5. All compacted bentonite – sand mixture specimens' initial dry density was about 2 g/cm^3. This figure illustrated that maximum swelling rate distinctly increased due to increase percent of bentonite in compacted bentonite-

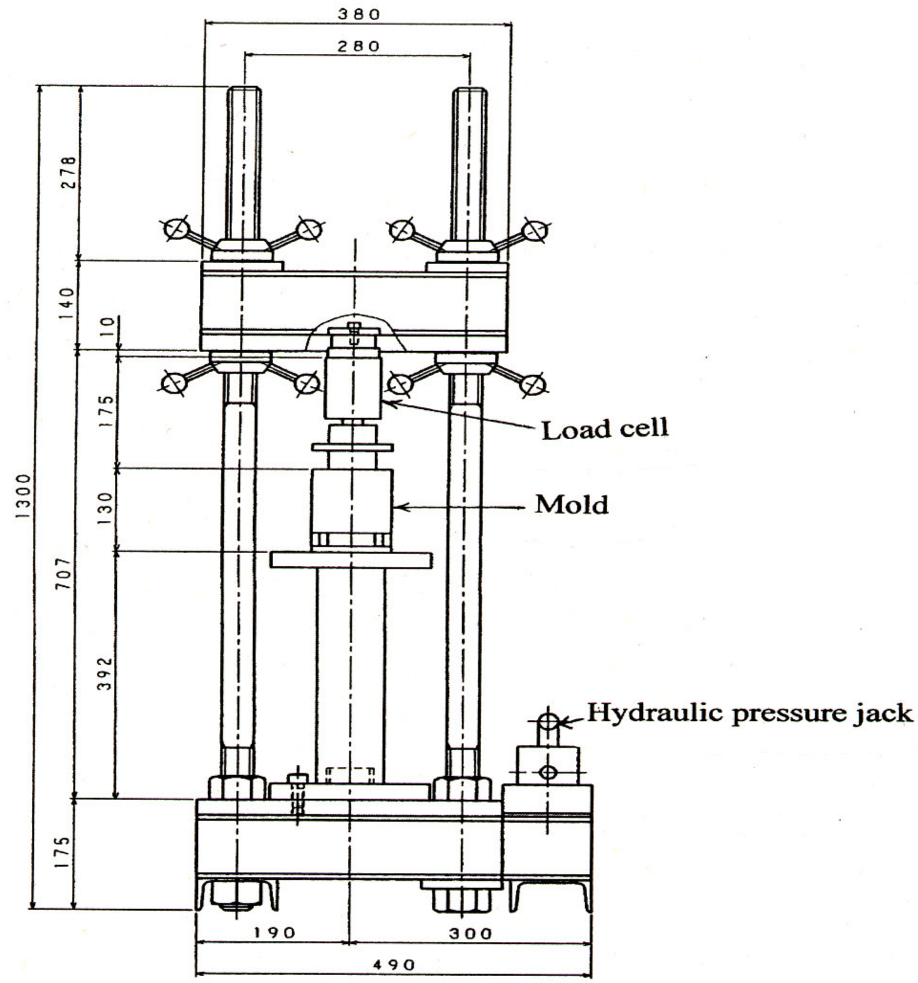

Figure 2. Schematic diagram of sample compaction apparatus (Model No. CLP-200KNB). All dimensions are in mm.

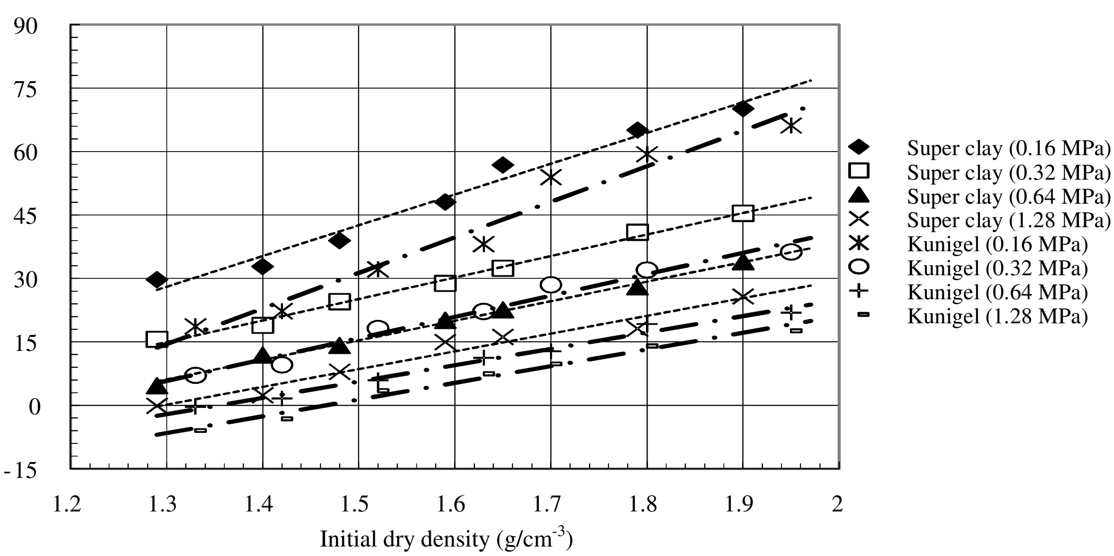

Figure 3. Relationship between maximum percent swelling and initial dry density of bentonite under static load.

Table 2. Equations obtained from the correlation of maximum percent swelling deformation to initial dry density of compacted solely bentonite under different static loads

Bentonite (Sodium type)	Static load (MPa)	Equation	r^2	Equation No.
Super clay	0.16	$S_R = 72.76\rho_d - 66.55$	0.98	1
	0.32	$S_R = 50.86\rho_d - 51.13$	0.99	2
	0.64	$S_R = 46.29\rho_d - 54.07$	0.99	3
	1.28	$S_R = 41.96\rho_d - 54.37$	0.96	4
Kunigel	0.16	$S_R = 84.20\rho_d - 94.99$	0.96	5
	0.32	$S_R = 50.46\rho_d - 59.84$	0.97	6
	0.64	$S_R = 38.71\rho_d - 52.41$	0.98	7
	1.28	$S_R = 39.52\rho_d - 57.89$	0.98	8

Table 3. Analysis of variance (ANOVA) table of different densities of compacted bentonite.

Parameter	T value	P Value	Level of significance	r^2
Intercept	-15.92	1.94E-21	0.01	0.96
$\rho_d S_L^2$	12.72	1.86E-17	0.01	
$\rho_d S_L$	-16.95	1.31E-22	0.01	
Dry density (ρ_d)	26.77	1.07E-31	0.01	
Content of Montmorillonite (C_m)	7.13	3.30E-09	0.01	

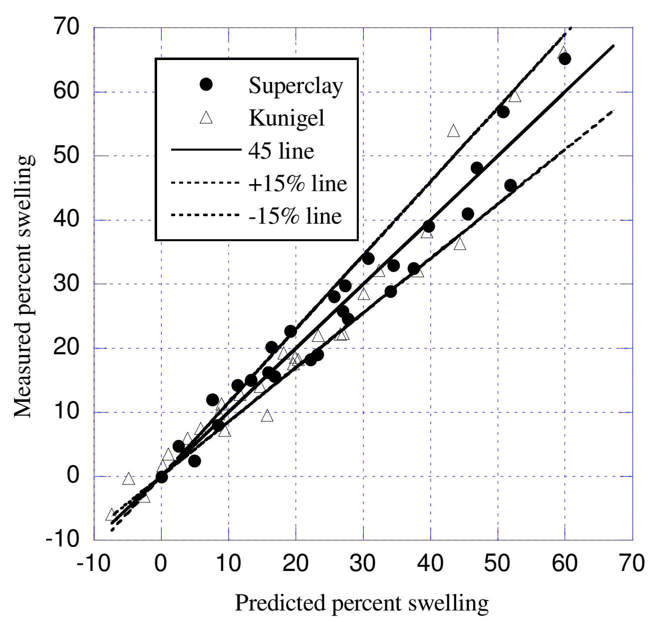

Figure 4. Comparison of measured / predicted percent swelling of different densities of compacted solely bentonite.

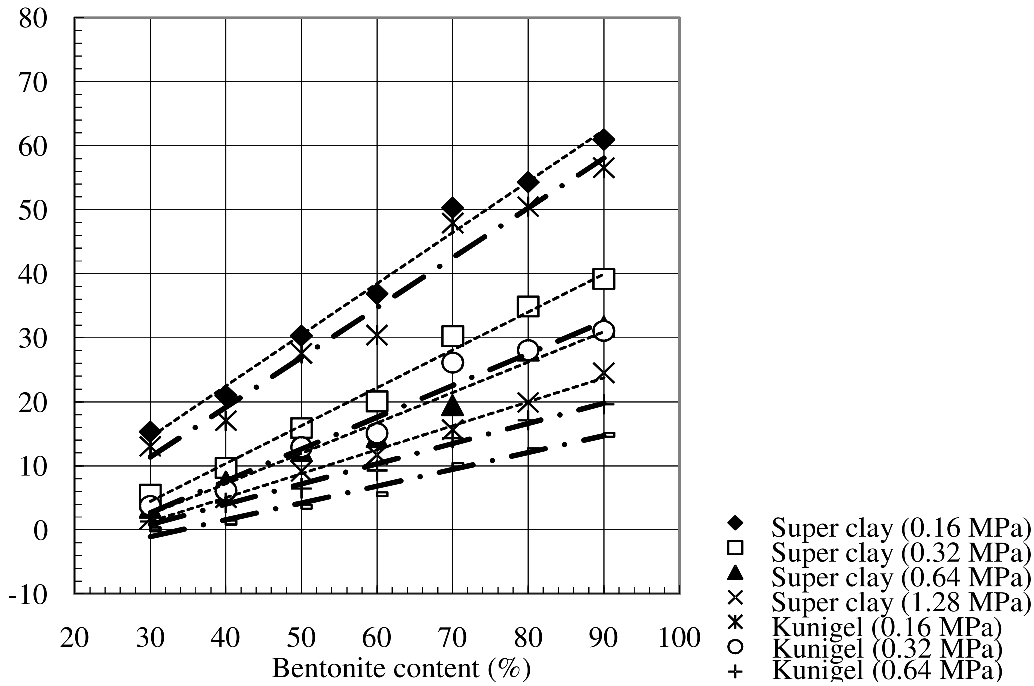

Figure 5. Relationship between maximum percent swelling and bentonite content under static load.

Table 4. Equations obtained from the correlation of maximum percent swelling deformation to content of bentonite in compacted bentonite-sand mixture under different static loads.

Bentonite (Sodium Type)	Static load (MPa)	Equation	r^2	Equation no.
Super clay	0.16	$S_R = 0.79C_B - 9.43$	0.98	10
	0.32	$S_R = 0.59C_B - 13.31$	0.99	11
	0.64	$S_R = 0.47C_B - 11.81$	0.98	12
	1.28	$S_R = 0.37C_B - 9.86$	0.99	13
Kunigel	0.16	$S_R = 0.77C_B - 11.94$	0.97	14
	0.32	$S_R = 0.49C_B - 12.18$	0.97	15
	0.64	$S_R = 0.32C_B - 8.61$	0.99	16
	1.28	$S_R = 0.26C_B - 8.89$	0.98	17

Table 5. ANOVA table of different content of bentonite in bentonite sand mixture.

Parameter	T value	P Value	Level of significance	r^2
Intercept	-6.79	1.16E-08	0.01	0.95
$C_B S_L{}^2$	10.71	1.16E-14	0.01	
$C_m C_B S_L$	4.90	9.90E-06	0.01	
$C_B S_L$	-14.41	1.28E-19	0.01	
Dry density (ρ_d)	27.01	7.00E-32	0.01	

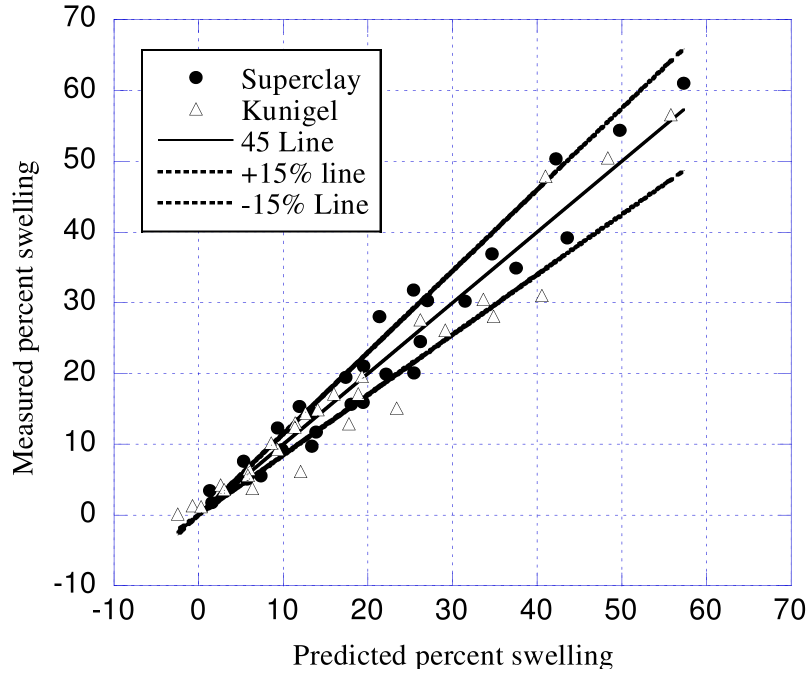

Figure 6. Comparison of measure / predicted percent swelling of different content of bentonite in bentonite –sand mixture.

sand mixture specimen. At the same time, bentonite content in bentonite-sand mixtures maximum swelling rate increases with decreasing static load. At static load of 1.28 MPa negative swelling rate was observed for 30% bentonite content but other specimens exhibited positive swelling rate under static load. Figure 5 depicted that maximum percent swelling have strong linear relationship with percent of bentonite in bentonite-sand mixture. Based on Figure 5, the maximum percent swelling and bentonite content relationships straight line equations of 10 to 17 are shown in Table 4. Those equations expressed as high correlation values of r^2 (0.97 to 0.99). A multiple regression analysis including all experimental data of different percent of bentonite in bentonite-sand mixture gave the following correlation with r^2 value of 0. 95:

$$S_R = 67.31 C_B S_L^2 + 42.15 C_m C_B S_L - 163.57 C_B S_L + 94.34 C_B - 10.76 \quad (18)$$

Where, S_R = Percent swelling (%), C_m = Content of montmorillonite (%), S_L = Static Load (MPa) and C_B = Percent of bentonite.

Table 5 summarizes the regression analysis results of bentonite specimens as mixture material. To estimate the maximum swelling deformation of sodium type bentonite as a mixture material Equation 18 can be successfully used. The swelling deformation predicted by Equation18 was compared with the direct measured from experimental data of sodium type bentonite, as shown in Figure 6. Caution should be needed for using calcium type bentonite due to its different chemical reaction.

Conclusions

The experiments simulate well the maximum swelling deformations of compacted bentonite under different initial dry density, static load and percent of bentonite in bentonite sand mixture and content of montmorillonite. Based on the experimental results, two equations have been proposed for the prediction of maximum swelling deformation of different density for solely bentonite and bentonite content in bentonite-sand mixture. The proposed equations are valid only for sodium type bentonite and should be update/revised for calcium type bentonite.

REFERENCES

Dixon DA, Gray NM, Graham J (1996). Swelling and hydraulic properties of bentonite from Japan, Canada and the USA, Proc. of 2nd Intl. Congress Environ. Geotechniques (IS-Osaka 96), 1: 43-48.

JNC (2000). H12 - Project to establish the scientific and technical basis for HLW disposal in Japan, Japan Nuclear Cycle Development Institute, JNC TN1410 2000-003, 1-10.

Komine H, Ogata N (1999). Experimental study on swelling characteristics of sand-bentonite mixture for nuclear waste disposal, Soils Found., 39(2): 83-97.

Komine H, Ogata N (2004). Predicting swelling characteristics of bentonites, J. Geotechnical Geoenviron.l Eng. ASCE, 130(8): 818-829.

Mollins LH, Stewart DI, Cousens TW (1999). Drained strength of bentonite-enhanced sand. Geotechnique, 49(4): 523-528.
Onal M (2007). Swelling and cation exchange capacity relationship for the samples obtained from a bentonite by acid activations and heat treatments, Appl. Clay Sci., 37: 74-80.
Sato T, Okada T, Iida Y, Yamaguchi T, Nakayama S (2001). Observation of pore generation due to interaction between bentonite and high pH solution, Clay science for engineering, A.A. Balkema, P.O. Box 1675, 3000 BR Rotterdam, Netherlands, pp. 593-598.
Shirazi SM, Kazama H (2004). Swelling properties of bentonite and bentonite-sand mixture for nuclear waste disposal. Aust. Geomechanics, 39(4): 71-79.
Shirazi SM, Kazama H, Chim-oye W (2006). Temperature and density effect on swelling characteristics and permeability of bentonite. Aust. Geomechanics, 41(2): 89-100.
Shirazi SM, Kazama H, Chim-oye W, Kuwano J (2008). Effect of void ratio on swelling and permeability of bentonite. Aust. Geomechanics, 43(2): 9-19.
Stewart DI, Studds PG, Cousens TW (2003). The factors controlling the engineering properties of bentonite-enhanced sand, Appl. Clay Sci., 23: 97-110.