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Dynamic properties of buffer materials by resonant column test

Propriétés dynamiques des matériaux tampons par test de colonne de résonance

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ABSTRACT: Bentonites (high plasticity clay) have been designed as the buffer material for deep disposal of nuclear waste due to its low hydraulic conductivities and high swelling potentials. However, the dynamic properties of bentonites are less studied. Therefore, resonant column tests on a bentonite (MX-80) were performed to obtain their dynamic properties including dynamic shear modulus and damping ratio. Different dry densities, degrees of saturation, and mix ratios with the coarse material are considered in the test program. Results show that the small-strain shear modulus increases with high dry density and low mix ratio. However, two unified set of modulus reduction curve and damping curve for different saturation conditions can represent the dynamic behavior under the different dry densities and the mixture ratios.

RÉSUMÉ: Les bentonites (argile à haute plasticité) ont été conçues comme matériau tampon pour l'élimination en profondeur des déchets nucléaires en raison de leur faible conductivité hydraulique et de leur fort potentiel de gonflement. Cependant, les propriétés dynamiques des bentonites sont moins étudiées. Par conséquent, des essais de colonne de résonance sur bentonite (MX-80) ont été effectués pour obtenir leurs propriétés dynamiques, y compris le module de cisaillement dynamique et le taux d'amortissement. Différentes densités sèches, degrés de saturation et rapports de mélange avec le matériau grossier sont pris en compte dans le programme de test. Les résultats montrent que le module de cisaillement à faible déformation augmente avec une densité sèche élevée et un rapport de mélange faible. Cependant, deux ensembles de courbes de réduction de module et d'amortissement unifiées pour différentes conditions de saturation peuvent représenter le comportement dynamique sous les différentes densités de séchage et les rapports de mélange.

Keywords: Bentonite; resonant column test; shear modulus reduction curve; damping curve.

1 INTRODUCTION

Bentonite has been used in waste containment applications in landfills across the world and proposed as a primary material for sealing shafts of nuclear waste repositories (SKB, 2000). The reason to use bentonite is because it possesses low permeability, chemical and physical stability, and compatibility with most host rock masses and groundwater chemistries.

As a buffer between the waste containers and the rocks surrounding the tunnels for the nuclear waste repositories, Bentonite blocks will be installed firstly in unsaturated conditions. Then, they will absorb ground water and get saturated after a long time period. Accordingly, these blocks will swell substantially. Although this procedure takes a long time because of its low hydraulic conductivity, after a long period the bentonite blocks will fill the entire space in an underground waste repository. As a result, the blocks will prevent leakage of toxic substances from the nuclear waste. The long life time of the buffer system makes it necessary to study the effects of some extreme conditions on the bentonite buffer. In addition, the influence of very strong earthquakes on the system needs to be evaluated, especially for the seismic active area such as Taiwan and Japan.

To evaluate the effect of dynamic loads on civil engineering systems, it is necessary to understand, measure, and quantitatively model the dynamic and cyclic properties of the soils involved. Typically, analysis of an engineering problem that involves dynamic loading of soils requires the determination of both the shear modulus (G) and damping ratio (D). These two parameters are usually determined either in the laboratory or in the field using various techniques. Numerous data on the dynamic properties of cohesionless and cohesive soils are available. However, none of them report the dynamic properties of clay with very high plasticity such as Bentonite. Although the idea of using bentonite as a buffer is feasible, it is very difficult to investigate its mechanical characteristics using laboratory tests.

Due to the lack of the dynamic properties of bentonites, this study performed series of resonant column tests on a commercial bentonites (MX-80) to obtain their dynamic properties including shear modulus and damping ratio. Different dry densities, degrees of saturation, mix ratios with the coarse material are considered in the test program. How these factors influence the dynamic properties are discussed and the representative values are suggested for the design purpose.

2 BASIC PROPERTIES OF TESTED MATERIAL

The soil tested in this study was one commercially produced clay, Montmorillonite Sodium, commonly known as MX-80. The sodium bentonite contains mainly smectite or montmorillonite and small portions of feldspar, biotite, selenite, etc. Typical bentonite has a tri-layer expanding mineral structure of approximately $(A1Fe_{1.67}Mg_{0.33})Si_4O_{l0}(OH_2)$ $Na^{+}Ca^{++}_{0.33}$. Sodium bentonite attracts sodium ions that are exchangeable with other cations, such as K^{+}, Mg^{2+}, or Ca^{2+}. A summary of consistency limits, liquid limit (LL), plastic limit (PL), plasticity index (PI), and specific gravity (Gs) of this clays is given in Table 1. The bentonite contains about 8.7 to 10.5% original moisture content, and can swell unconfined to 28 ml/g.

Table 1. Basic properties of MX-80 (Chepkoit and Ag-gour , 2000)

LL (%)	PL (%)	PI (%)	G_s
648	48	600	2.67

3 TEST PROGRAM

3.1 Resonant column test

To determine the dynamic properties, a resonant column device was used. The resonant column test method (ASTM D 4015-87) is a relatively nondestructive test, used to determine the shear modulus and damping of soils by means of propagating waves in a cylindrical soil specimen (column). The primary advantage of using this testing technique is that very accurate moduli can be evaluated for a strain range of 10^{-4}% to 10^{-1}% under various excitations (e.g. Drnevich 1978; Kim and Stokoe 1992). A Stokoe-type resonant column apparatus was used for this research. A detailed description of this apparatus and the theoretical model employed can be found in Kim and Stokoe (1992).

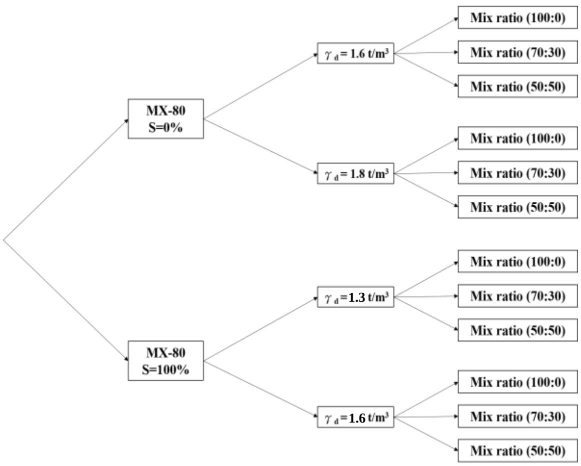

Figure 1 Test program

3.2 Control factors

The buffer material is tested under dry and saturated condition to mimic the initial installed condition of buffer system and long term condition after the buffer absorbs water. The dry condition has the natural water content about 10% without oven drying or adding additional water. The sample preparation for saturated condition is described in more detail later.

Dry density is used as an index for the swelling potential of buffer material. High dry densities indicate more swelling potential. Two sets of tests with different dry unit weights were tested for either dry or saturated condition as listed in Figure 1.

For each dry unit weight, three mix ratios (i.e. buffer to course material ratio) by weight were prepared. The bentonite mixed with course material is to mimic the backfill material of the construction/assess tunnel that requires less swelling potential. The course material used is Ottawa sand (ASTM) and mixed with bentonite up to 50 %. As summarized in Figure 1, a total of 24 tests were performed.

3.3 Sample preparation

All test sample were prepared by static compaction. For the dry condition, the target dry density (γ_d) is achieved by calculating required weight of soil (W_s) given the volume (V) as

$$\gamma_d = \frac{W_s}{\mathrm{V}} \tag{1}$$

The volume of soil sample is 594 cm^3. For the saturation condition, it is difficult to saturate the sample due to very low permeability of bentonite. Therefore, the required water content of saturation condition given a dry density is estimated in advance and added into the sample during the sample preparation. Given a target dry density, the required water content (ω) of saturated condition is estimated by

$$\gamma_d = \frac{G_S r_w}{1+Gs\cdot\omega} \tag{2}$$

Where r_w is unit weight of water and Gs is the specific gravity of MX-80. Then, moisture unit weight (γ_m) is calculated as follows:

$$\gamma_m = \gamma_d(1+\omega) \tag{3}$$

Therefore, the required weight of moisture soil (W) given the volume (V) is estimated as follow:

$$\gamma = \frac{W}{\mathrm{V}} \tag{4}$$

And the required weight of dry soil (Ws) is estimated as

$$W_s = \frac{W}{1+\omega} \tag{5}$$

Finally, the required weight of water W_w to be added is

$$W_w = \mathrm{W} - W_s \tag{6}$$

The soil samples were mixed with the required water content and waitted for 24 hours before compaction. During the mellowing period, mixed samples were kept in sealed plastic bags so that evaporation and carbonation were kept at a minimum. Figure 2 shows compacted soil samples with different mixture ratio. The sample became whiter with more coarse material. It is assumed that the prepared soil samples were saturated and no further saturation procedure was conducted during the test. Prior to the resonant column test, isotropic consolidation was performed on cured samples under confining pressures of 100 kPa.

Figure 2 Sample with different mix ratios

4 TEST RESULTS

4.1 Influence of mix ratios

Figure 3 compares the G vs shear strain curve for different mix ratios. Interestingly, as the coarse contents increase, the G decrease. This might be due to the mixture of coarse material results in lower a "relative density" given the same dry density. However, when the curves are normalized by the G_{max} at the small strain, all modulus reduction curves become similar as shown in Figure 4. As a result, the damping for different mix ratios are also similar as shown in Figure 5.

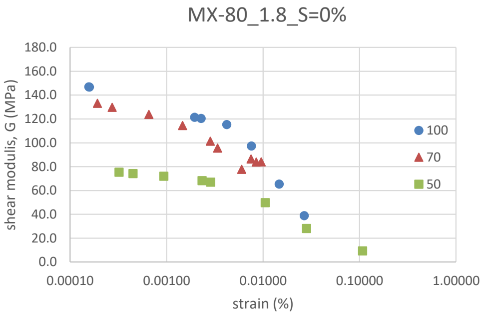

Figure 3 Shear modulus vs shear strain for different mix ratios

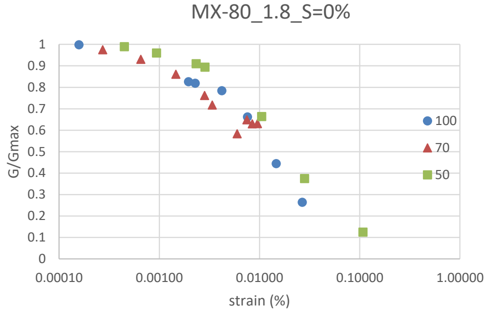

Figure 4 Shear modulus reduction curve for different mix ratios

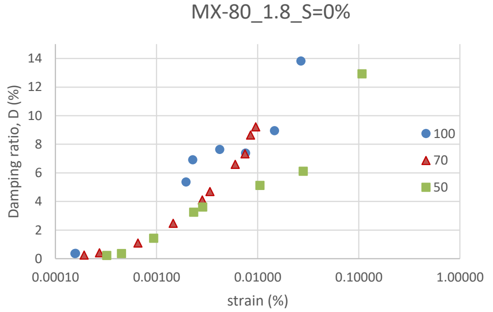

Figure 5 Damping curve for different mix ratios

4.2 Influence of dry densities

Figure 6 compares the G vs shear strain curve for different dry densities given same mix ratios. As the dry density increases, the G increases. However, when the curves are normalized by the G_{max} at the small strain, which is a typical way to present modulus reduction, all curves become similar (Figure 7). As a result, the damping for different dry densities are also similar as shown in Figure 8.

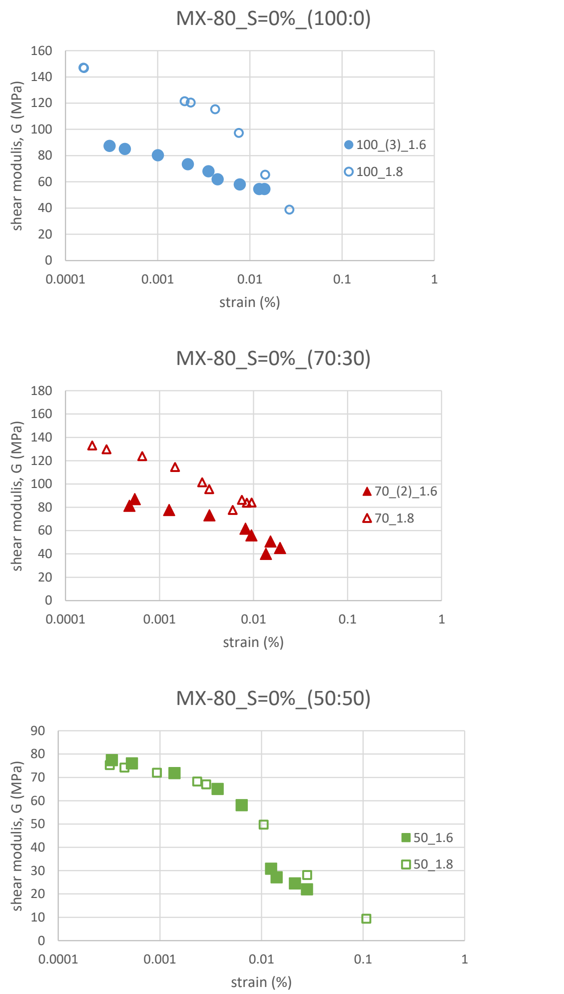

Figure 6 Shear modulus vs strain for different dry densities (a) mix ratio=100:0, (b)70:30, (c) 50:50.

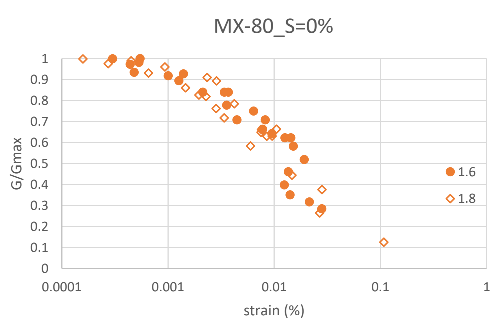

Figure 7 Shear modulus reduction curve for different dry densities.

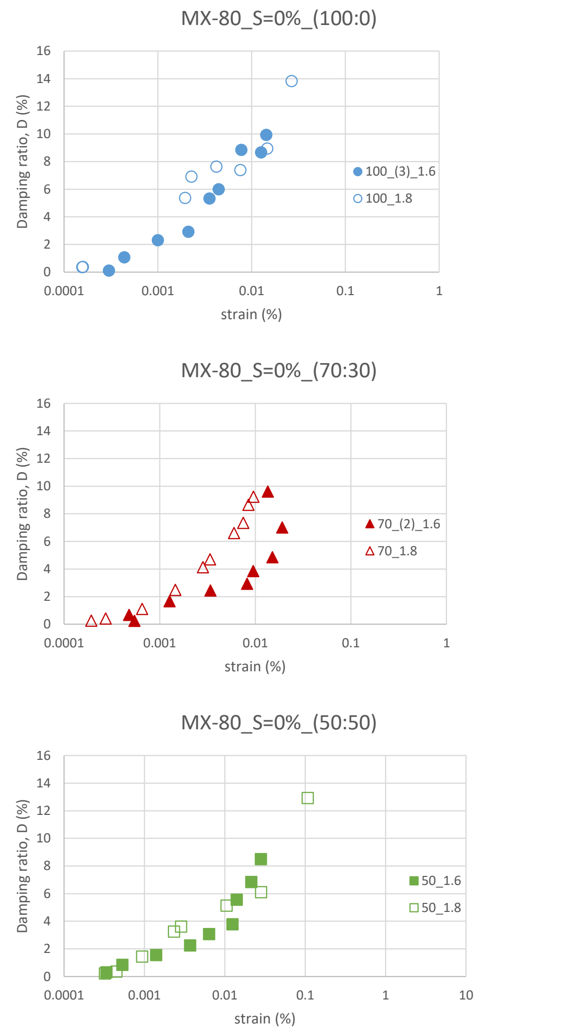

Figure 8 Damping curve for different dry densities.

4.3 Influence of saturation

Figure 9 compares the G vs strain curve for different water contents. Generally, the G value is higher for the dry condition. This might be due to the water softening the Bentonite. However, when the curve is normalized by the Gmax at the small strain, modulus reduction curves for dry and undrained conditions become similar (Figure 10). On the other hand, the damping for different saturation condition are similar as shown in Figure 11.

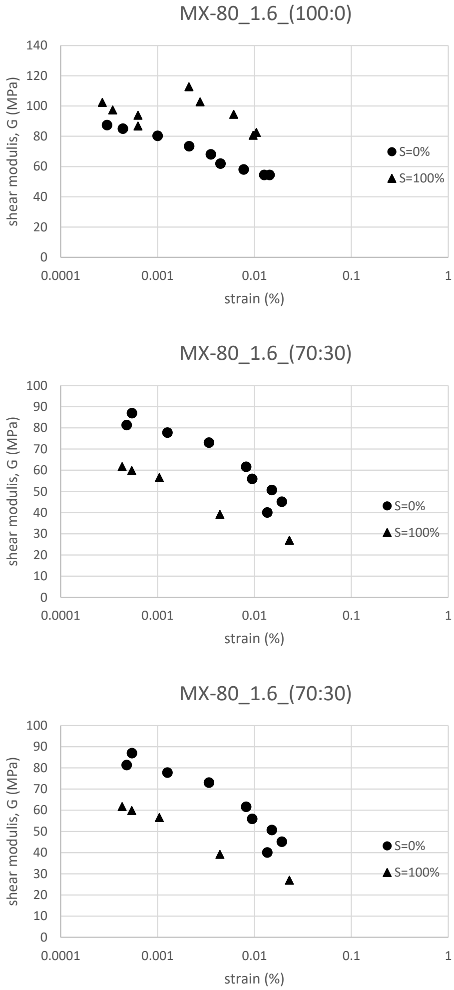

Figure 9 Shear modulus vs strain for different saturation condition (a) mix ratio=100:0, (b)70:30, (c) 50:50.

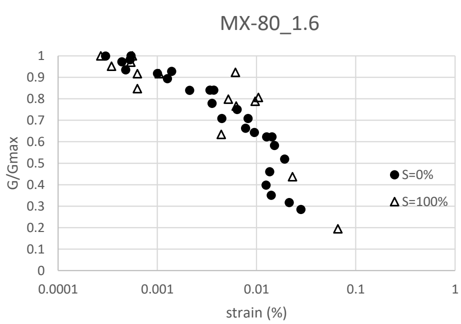

Figure 10 Shear modulus reduction curve for different saturation conditions.

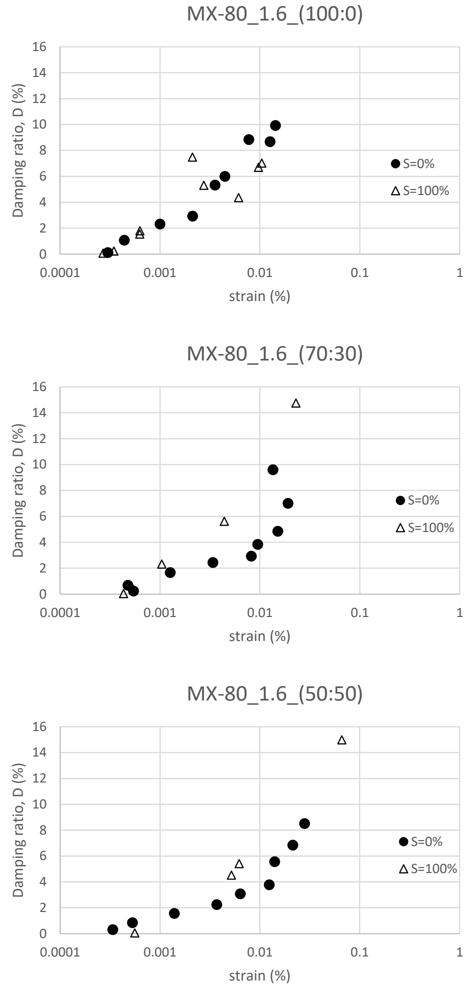

Figure 11 Damping curve for different saturation conditions.

4.4 Summary and discussion

Test results indicate the G value increases with dry density but decreases with mix ratios of coarse material and water contents. However, when the G curves are normalized by the G_{max} at the small strain, all moduli reduction curves become similar except for the condition of different saturations. As a result, the damping for different conditions are also similar. Therefore, two unified sets of modulus reduction curve and damping curve are suggested for different saturation condition based on the regression analysis assuming hyperbolic curve as shown in Figure 12.

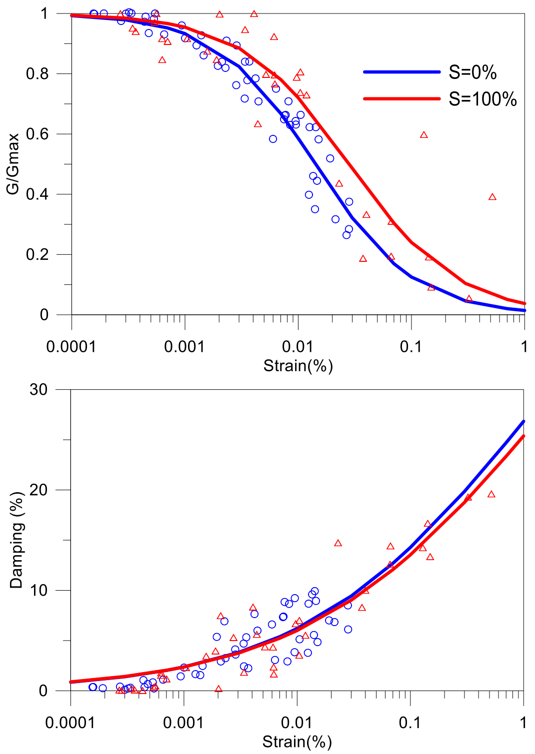

Figure 12 Recommended shear modulus reduction curve and damping curve for different saturation conditions.

The represented curves are also compared with the previous studies. The curves for bentonite obtained in this study should be close to the clay curve with high PI (Vucetic and Dobry 1991), However, it is close to sand curve (Seed and Idriss 1970) or clay curve with no plasticity instead. The possible reason is that tests performed in this study are under dry condition or not fully saturation condition while the previous study tested on completely saturated sample. Because the sample is dry or not fully saturated, it behaves more like granular material and the influence of PI cannot be reflected. This hypothesis can be proved in in Figure 13, where saturation condition shows less degradation compared with the dry condition and is closer to the curve of high PI.

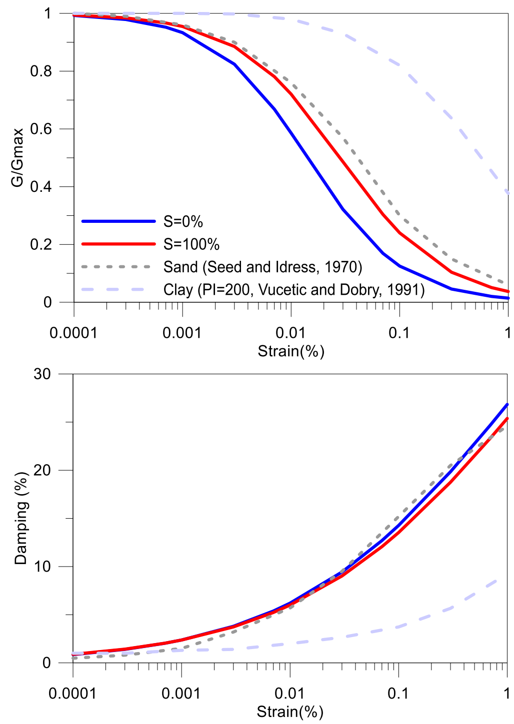

Figure 13 Comparision of recommended curves with previous studies.

5 CONCLUSIONS

Bentonites (high plasticity clay) have been designed as the buffer material for deep disposal of nuclear waste due to its low hydraulic conductivities and high swelling potentials. However, the dynamic properties of bentonites are less studied because it is very difficult to investigate its mechanical characteristics using laboratory tests. In this study, resonant column tests on bentonite (MX-80) was performed to obtain their dynamic properties. Different dry densities, degrees of saturation, mix ratios with the coarse material are considered in the test program.

Test results indicate the G value increases with dry density but decreases with mixture of coarse material and water contents. However, when the G curves are normalized by the G_{max} at the small strain as the typical way of presenting dynamic properties, all modulus reduction curves become similar. As a result, the damping for different conditions are also similar. Only saturation condition influences the curves. Therefore, two unified set of modulus reduction curve and damping curve are suggested for the dynamic behavior of the different degree of saturations.

6 ACKNOWLEDGEMENTS

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