Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Ultrasonic Removal of Clogging and Evaluation of Flow Capacity of Geotextile Drain

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Abstract. This paper presents an experimental investigation of the application of acoustic energy for the reduction of clogging of six varieties of commercially available geotextiles drain. The clogged embedded geotextile specimens were exhumed from two fine-grained soils, which were previously consolidated from slurry stage under a maximum consolidation pressure of 400 kPa. The physics of ultrasound and formation of micro-bubbles in a sort of "cold boiling" or "cavitation" within liquid medium has been explained. The extent of clogging was evaluated by the amount of fines entrapped within geotextile pores before and after cleansing in an ultrasonic water tub. Several terms, such as, clogging index, clogging potential, cleansing efficiency, have been explained based on the experimental data. The in-plane and cross-plane flow capacities of the clogged geotextile specimen have been evaluated before and after ultrasonic cleaning and results are presented in a plot signifying the beneficial effect of ultrasonic cleansing. Test results showed that cleansing efficiency for all clogged geotextiles was > 80% @ 5 minutes dipping time, which were irrespective of the type of geotextile selected and the severity of clogging. Compared to the clogged geotextile specimens' transmissivity and permittivity recovered nearly to 75% and above after ultrasonic cleaning. Based on the tests, the importance of geotextile drains under confinement and in-situ removal of it's clogging by ultrasonic are elaborated.

Keywords: Clogging index, Clogging potential, Hydraulic transmissivity, Permittivity, Poorly drained backfills, Ultrasonic cleaning, Cavitation

1 Introduction

Soft ground stabilization and reinforcement application of nonwoven geotextiles are increasing steadily over the years and stronger growth in the Geosynthetics market has been surging ahead for solid waste disposal, erosion, flexible storage, rain water harvesting, and sedimentation control. In waste barrier system nonwoven needle-punched geotextiles are useful as a cushioning layer to protect adjacent Geomembrane and their unique pore structure provides excellent filtration and drainage properties. In addition their strength properties function as reinforcement and separation layers to subgrade materials particularly in the railroad ballast foundation. Nonwoven geotextiles are also used as a filter to minimize clogging of granular drainage blanket, and as a component of a synthetic drainage system when replacing thick granular leachate collection systems. In all these applications clogging has to be minimum for effective and long term functioning of the geotextile drain.

Permeable Geosynthetics have been used extensively for the improvement of fine-grained soil back-filled earth-structures, such as, retaining walls, slopes, and embankments, when geotextiles are used directly within backfill clogging occurs. Clogging problems are widely recognized in the various water front structures, such as dams, reservoirs and also in various manufacturing industries. Mechanical as well as biological clogging of water filters and dirt or oily deposits in many components in brewing industry pose troubles. Fines entrapped within geotextile pores cause reduction in water drainage and thereby affects stability and serviceability of the structures in the long run. Ghosh and Yasuhara (2004) have shown that a thin sand mat around geotextile layers could prevent clogging. This thin sand mat not only prevents fines from clogging the embedded Geosynthetics layer, it also ensures generating interface friction, which is otherwise absent when geotextile layer is used in direct contact with the fine-grained soils.

Ultrasonic cleaning is used in narrow crevices and small holes that would not be easily accessible by turbulation, spray washing or other cleaning methods. This paper attempts explaining the principle of ultrasonic and application of this technique for the removal of clogged particles from the selected geotextile specimens exhumed from two fine-grained soils tested in the large consolidation cell.

The ultrasonic cleaning is one of the effective and gentle ways to remove dirt or oily deposits from different household and industrial items. In addition, ultrasound can destroy microbes and algae, thus having a simultaneous disinfecting effect. As for the application of nondestructive tests in Geosynthetics, ASTM (D7006-2003) provides a summary of equipment and procedures for ultrasonic testing of Geomembrane using the pulse echo method. Usually ultrasonic measurements are used to determine the nature of materials in contact with a test specimen. Ultrasonic seaming technology (Bove and William, 1990) is well established in the manufacturing and packaging fields and has recently been applied to Geomembrane. This technique is applicable for both factory and field seams for most types of Geomembrane. There has not been any reported application of ultrasonic waves to the cleaning of clogged Geosynthetics, specially when they are clogged during projected service period. Removing or replacing them altogether is not always plausible and therefore, it's attempted to evaluate the clogging status in a suitably designed laboratory set-up.

2 Drainage Applications of Geosynthetics

Some additional typical applications of geotextiles include:

a. Underneath rip rap or concrete revetment systems along inland waterways and coastal shorelines
b. Underneath armor systems; protecting spillways and embankment dams from overtopping flows.
c. Encapsulating cut-off drains and collection systems surrounding landfills, within dams, and adjacent to roadways and other critical structures
d. Encapsulating leachate collection systems under landfills while maintaining long-term clogging resistance
e. Encapsulating edge drains for critical structures in problematic soils

Control of water is critical to the performance of buildings, pavements, embankments, retaining walls, and other structures. Drains are used to relieve hydrostatic pressure against underground and retaining walls, slabs, and underground tanks and to prevent loss of soil strength and stability in slopes, embankments, and beneath pavements. A properly functioning drain must retain the surrounding soil while readily accepting water from retention), flow capacity, and clogging potential. These properties are indirectly measured by the apparent opening size (AOS) (ASTM D 4751), permittivity (ASTM D 4491), and gradient ratio test (ASTM D 5101). The permeability of most of the geotextiles decreases significantly under confining pressures. ASTM D 5493 recommends some guidelines for measuring permeability under load. The geotextile must also have the strength and durability to survive construction and long-term conditions for the design life of the drain. Additionally, construction methods have a critical influence on geotextile drain performance.

Leachate collection systems (LCS) are designed to efficiently remove leachate from a landfill. This prevents ponding on the liner system and ultimately leachate migration into the environment. The permeability of the leachate collection system is a primary factor in determining the collection efficiency. The potential of the drainage materials (sand, gravel, and geotextiles) to clog as a result of biological growth and particulate clogging is an important issue that should be addressed in landfill design (Reinhart et al, 1998). Koerner and Koerner (1991) concluded that the filter should be the focus of concern in the leachate collection system because of a reduction in permeability over time. Filter clogging results from sedimentation, biological growth, chemical precipitation and/or biochemical precipitation, and is quite difficult to control. Clogging is most often experienced during the acidogenic period when organic substrates and precipitating metals such as calcium, magnesium, iron, and manganese are most highly concentrated in the leachate.

3 Clogging of Geotextiles

Many fine-grained soil backfilled earth-structures are constructed with Geosynthetics. These geotextiles have to function as drainage layer along with its seminal reinforcement function. Nonwoven geotextiles often clog or blind, and woven geotextiles may allow piping. Clogging may be characterized by measuring the permeability of the soil and geotextile. From the perspective of LCS clogging, it is desirable to analyze samples in the exact condition as found in the field. Collection of such samples in the field was not found to be possible for this work.

Details of the test procedures are given in Ghosh and Yasuhara (2003, 2004). Clogged geotextile specimens (120mm x 50mm wide) from Kanto loam and Silty clay-slurries were extracted after carrying out consolidation tests with staged loading from 20 kPa to 400 kPa. In order to assess the effect of clogging on the flow capacity of drains, both In-plane and X-plane permeability of the clogged specimens have been measured using apparatuses specifically developed for this purpose. After washing in the ultrasonic tub the flow capacities of the geotextile were obtained again.

4 The physics of Ultrasound

A filtration method using ultrasonic agitation decreases the clogging of filters (Nyffeler et al. 1988). It allows better than 100-fold concentration of particles from large samples of water, at a mean flow rate of 100–125 1/h using filters of the same size and porosity as those used in classical filtration. Laboratory experiments show a recovery rate of 92–93% of sediment injected into pure water. Clogging of filters by organic matter is decreased but remains a problem.

Separation and removal of fine particles from gases and liquids is a topic of permanent industrial attention (Serabia et al. 2000). The adequate application of power ultrasound may contribute to improve the efficiency and capacity of the separation methods presently used. The specific mechanisms to ultrasonically enhance separation processes basically depend on the medium to be treated.

In gas suspensions, where very fine particles have to be removed, ultrasonic action involves agglomeration of particles in order to increase their size and, consequently, to improve the collection efficiency of conventional filters (electrostatic precipitators, cyclone separators, etc.). These filters, while effective for large particle separation, are inefficient for retaining particles smaller than 2.5 µm. Therefore, acoustic agglomeration represents a means for separation of fine particles emitted from industrial, domestic or vehicle sources.
In solid/liquid separation, particle agglomeration may also be developed to prevent blocking of the filters and to increase separation efficiency but, in general, it is less efficient than in gases. Ultrasonic energy is useful to dewater fine-particle high-concentration suspensions such as slurries and sludge. In fact, ultrasonic stresses produce a kind of sponge effect and facilitate the migration of moisture through natural channels or other channels created by wave propagation. Other ultrasonic effects such as acoustic streaming, local heating, interface instabilities, agitation and cavitation may also be beneficial for solid/liquid separation. The aim of this paper is to check the effect of ultrasonic waves in the reduction of clogging status and thereby improving flow capacity (transmissivity/ permittivity) of exhumed Geosynthetics drains embedded within fine-grained soils.

4.1 The principle of ultrasonics

Ultrasonic processing" means "blasting" liquids, usually water, with very intense sound at high frequency, producing very good mixing and powerful chemical and physical reactions. The process, called "cavitation", is sort of "cold boiling" and results from the creation and collapse of millions of microscopic bubbles in the liquid. A distinction should be made here between the bubbles that are formed by cavitation and those, which occur naturally in the parent liquid or are induced by ultrasonic action (sparging). Cavitation bubbles, which range in size from infinitesimal to visible (40 µm and up) appear only when the surface is activated and vanish apparently instantaneously when the power is turned off (in actual fact, they vanish within a half cycle or 0.000025 sec. at 20 kHz). Naturally-occurring bubbles of entrapped air or other gases are most evident in freshly-poured hot tap water as a cloudiness or in still water as small bubbles adhering to the undersurface and the vessel walls. Sparged bubbles created by ultrasonic action at or near the gas-liquid interface (the surface) tend to float in the liquid and even cause foam.

4.2 Specification of ultrasound

Sound travels through a fluid as a three-dimensional pressure wave consisting of alternating cycles of compression and rarefaction. The frequency range of 20–100 kHz represents that most commonly used for power ultrasonics, while the range above 1 MHz is mainly used for diagnostic, non-intrusive purposes (medical scanning, nondestructive examination, particle size determination etc). During the rarefaction cycle, the negative pressure developed by power ultrasonics is sufficient to overcome the intermolecular forces binding the fluid, resulting in the formation of microbubbles. The succeeding compression cycle can cause these bubbles to collapse almost instantaneously, releasing a very large but very localised burst of energy. This process is known as cavitation and is the same as the formation and collapse of bubbles in the proximity of impellers, where cavitation was first observed. Temperatures of 5000 K and pressures of up to 1000 atm have been estimated for the collapse (Suslick and Mason, 1990). Lorimer (1990) gives a concise explanation of cavitation and the effect on it of temperature, pressure, viscosity etc.

The simplest effect of the energy released by cavitation is to help clean the surfaces of minerals suspended in a slurry. A more complex effect may be to alter the surface chemistry of the mineral, thereby mediating its response to other substances in solution or to physical separation regimes such as high tension roll (electrostatic) separation. Finally, when used before or during flotation processes, cavitation may also change the chemical composition of some of the reagents and of the water itself (through the formation of peroxides). The effect of cavitation on solutions of dissolved chemicals has given rise to the relatively new field of Sonochemistry, where highly localized, high temperatures and pressures generate radicals resulting in reactions normally afforded only by imposing extreme conditions. Farmer et al. (2000) deals with the surface cleaning effect of ultrasound and some of the parameters affecting it.

4.3 Creating cavitation phenomenon

Historically, damages based on cavitation erosion have been observed on hydraulic machinery and ship propellers. By the time Lord Rayleigh (1917) developed a primitive model describing the behaviour of a spherical gap in liquid. Though what is cavitation: more or less turbulent flows with a local pressure below vapor pressure form a cloud of small gas filled bubbles which exhibit complex dynamics and erosive action on nearby surfaces. Investigations on the dynamics of a *single* cavitation bubble allows a systematical approach into the subject of cavitation.

Cavitation was discovered by investigating why propellers wear out in water turbine. This is also present in bridge piers when subjected to speedy water currents. Just as a paper clip can be broken by bending it back and forth slowly, one can break water (or most other liquids) by jiggling it back and forth as quickly as possible. By sticking a vibrating object into water, if it is oscillated far enough (a tiny fraction of an inch) and fast enough (around 10,000 times a second), then water also become" fatigue" and break the bond between the water molecules. So, thus water molecules move apart to reach a gaseous state and the gas of water is steam. A steam bubble is normally created by heating above the boiling point (100^0 C). But in the above process the gas is made by fast jiggling, not by heating, as if is a "cold boiled" the water. Therefore, a steam bubble wandering around in a cold liquid, and that just can't stay for long. The steam has to condense (the way steam from a kettle or hot shower frosts a glass or mirror) and that leaves an empty space behind, a "void" or "cavity", where the steam was. The surrounding water molecules rush in to fill that cavity; when they reach the center of the cavity, they collide with each other with great force. This is called "cavitation". That makes the molecules bounce back, creating a "shock wave" which runs outward from the collapsed bubble just like ripples in a pond when you throw in a pebble. The shock wave can wear away metal; like the edges of an outboard motor propeller.

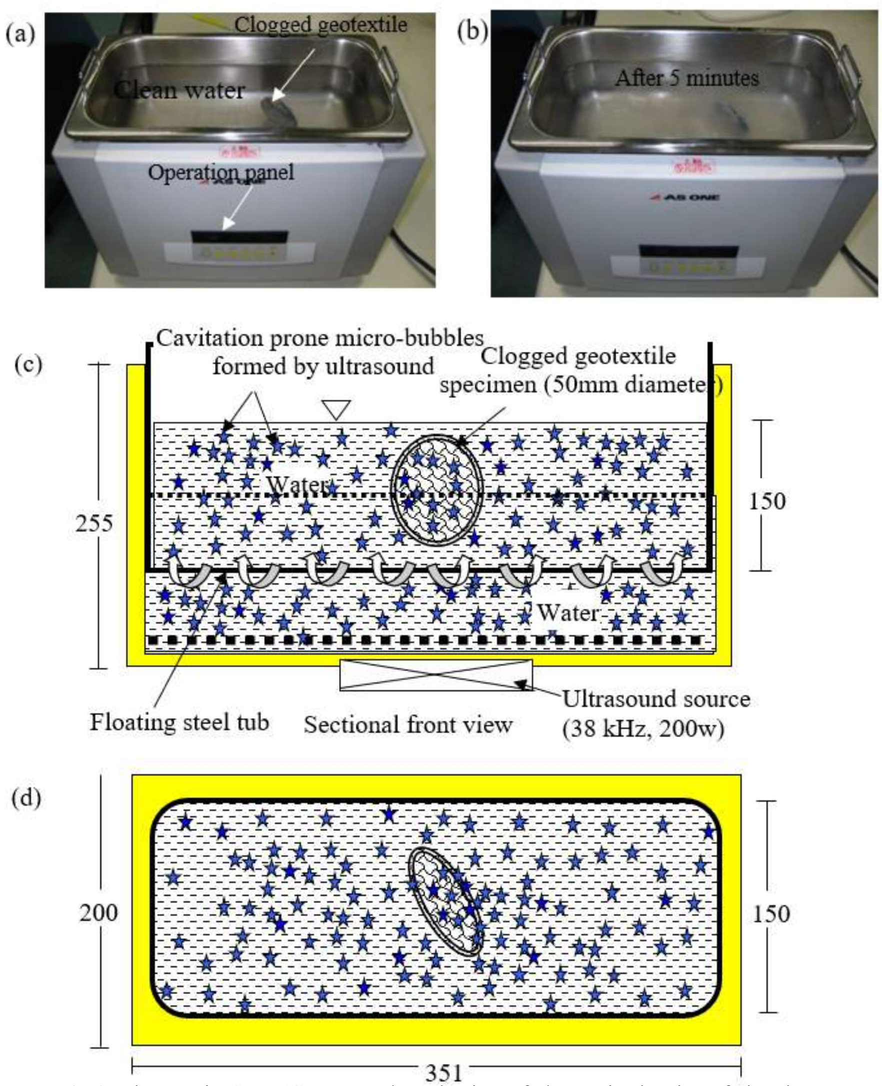


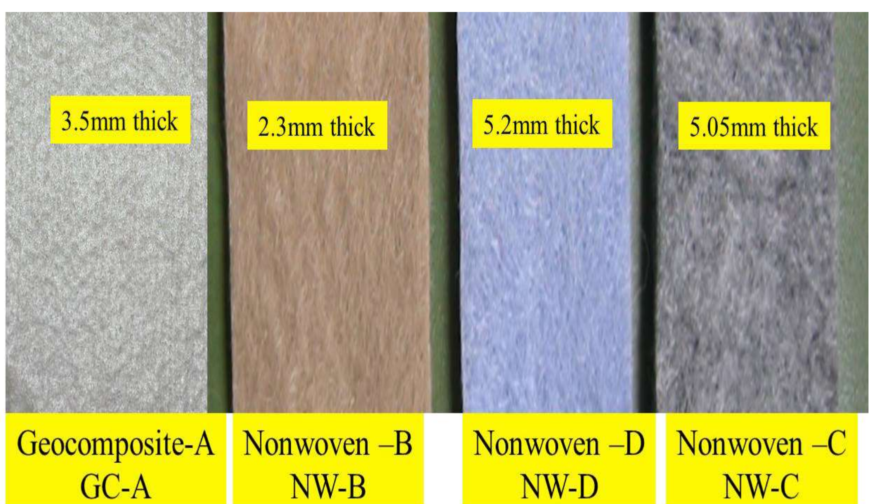
Fig.1. Ultra Sonic Test apparatus and mechanism of ultrasonic cleaning of clogging

4.4 Ultrasound cleaner

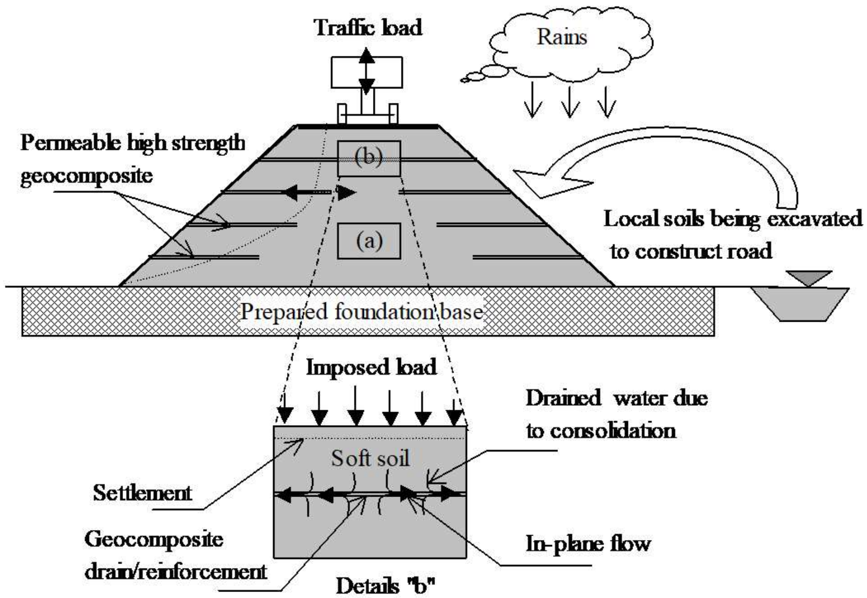
An ultrasonic cleaner is essentially a tub of liquid (Fig. 1), with an attached electronic device called a transducer, which generates high frequency sound waves and directs them into the liquid. As the sound waves pass through the liquid, they produce an effect known as *cavitation*, a rapid formation and instantaneous collapse of microscopic spaces throughout the liquid usually at a rate of millions per second. The use of ultrasonic cleaning baths ranging from the small laboratory and jewelers' units of 100–200 W to large industrial cleaning tanks of several kilowatts is well known. The same effect can be utilized to clean the surfaces of particles suspended in a slurry. Ultrasonic power can be applied externally as in a cleaning bath or by the insertion of an ultrasonic horn (a solid probe) into the slurry itself. The probe is particularly useful for introducing higher power (500 W) at very high intensities (0.5–2 kW/cm^2) into smaller volumes (50–200 ml).

4.5 Working principle of ultrasound

Ultrasound cleaning is the induction of high-frequency (usually between 20 and 80 kHz) sound waves that results in the formation of cavitation within the liquid. It is created by generators, which produce high frequency electricity. This high frequency electricity is then converted to sound waves through a transducer, which literally makes these waves vibrate. As these vibrating sound waves travel through water, microscopic bubbles form (Fig. 1) and repeatedly implode upon a given surface. This powerful action removes visible and even microscopic dirt particles making a dirty mini-blind or any other object cleaner than alternative methods.



(a)



(b)

Fig. 2. (a,b) Geotextiles drains used for clogging and flow capacity tests in laboratory an typical field application of geotextiles in marginal soils

5 Improvement of Flow Efficiency

Ultrasonic washing efficiency is defined as the amount clogged mass washed out by waves to the total amount of clogged mass attached with a particular geotextile specimen. In Fig. 2 four types of geotextiles are shown and typical application of the same in embankment constructed with fined grained soil necessitates an experimental investigation. Variation of normal pressure upto 900 kPa on the embedded drains are simulated in the laboratory. Fig. 3 presents various clogging images under a microscope for all the Geotextiles tested respectively with two kinds of soils, Kanto Loam (KL) - a natural soil collected from the Kanto plain region of Japan and an artificial Clayey Silt or Silty Clay (CS). Fig. 4 and Fig. 5 show the Permitivity of six types of Geotextile drain tested in KL and CS. After Ultrasonic cleaning, plots are shown under increasing normal pressure of Max 900kPa. As confining pressure increases flow capacity of the clogged drain specimens also decreases. After ultrasonic washing of the specimens for 5 minutes the flow efficiency of the drain layers improved. With increasing confining pressure washed specimens showed less reduction in the flow capacity. It is noted from the experiments that permittivity reduces with the increase in the normal pressure, which is a significant observation for all tests that not usually represented in the flow capacity index of drains. Out of the five non-woven geotextiles the A-type is the thinnest one and it was severely affected by clogging. Washing efficiency remained more than 80% (Fig. 4, 5) and above for all Geosynthetics tested. This signifies that ultrasonic washing method worked well in the cleaning of clogged Geosynthetics.

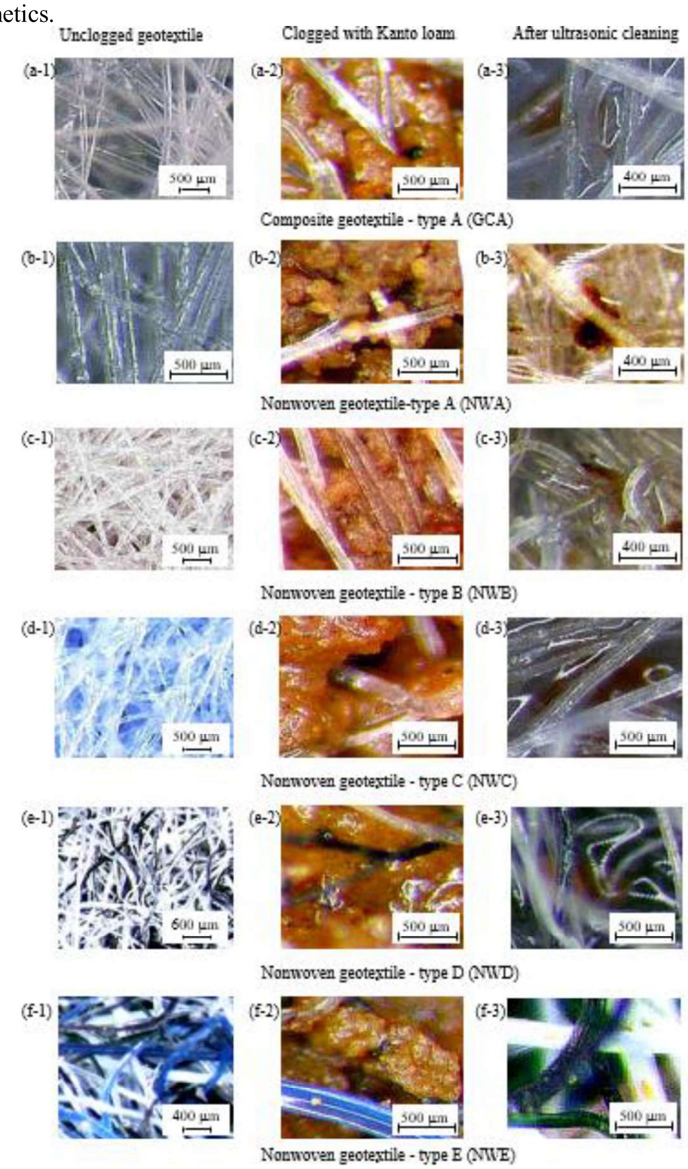


Fig.3. Clogging Images of six types of geotextiles in Kanto loam and silty clay

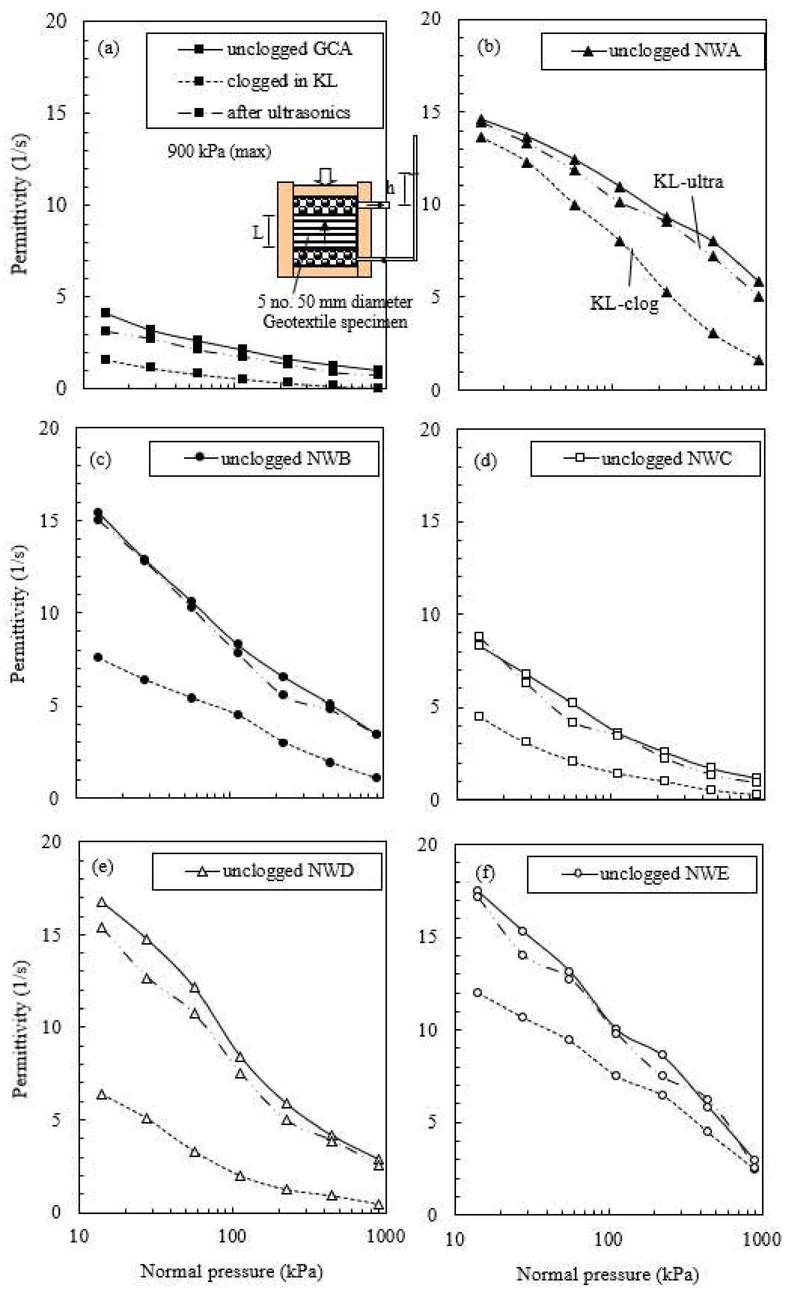


Fig.4. Permitivity of geotextiles under Kanto loam under Varied normal pressure

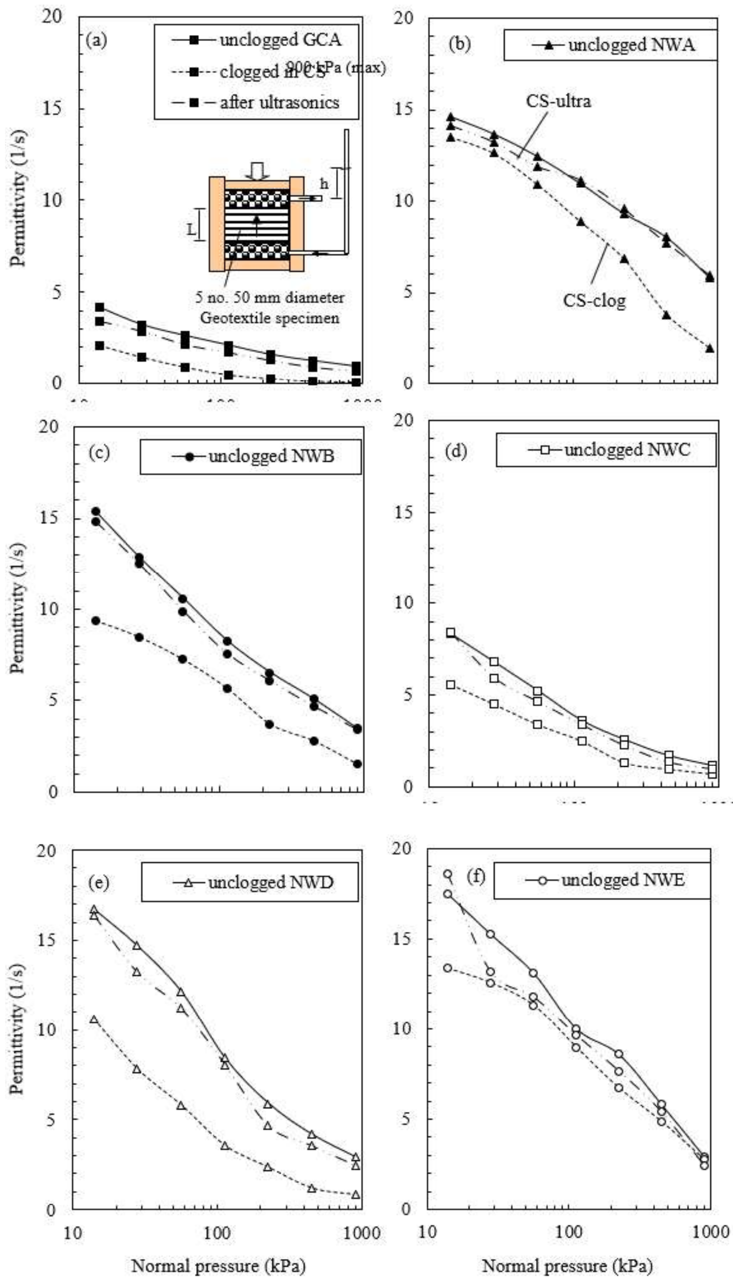


Fig.5. Permitivity of geotextiles under silty clay under Varied normal pressure

6 Clogging Potential of Drain

Clogging potential for all the six types of geotextiles are shown for both KL and CS (Fig. 6) and after ultrasonic cleaning same is plotted in Fig. 7. Clogging potential for Type-A is very high with increasing normal pressure on the drain. Trend is relatively lower in case of other five nonwoven geotextile drains. In Fig. 8, the in-plane water flow capacity for Type-A drain embedded in KL and CS as well as exhumed clogged and after ultrasonic cleaning are shown. The significant reduction of in-plane flow capacity under increasing normal pressure are noted.

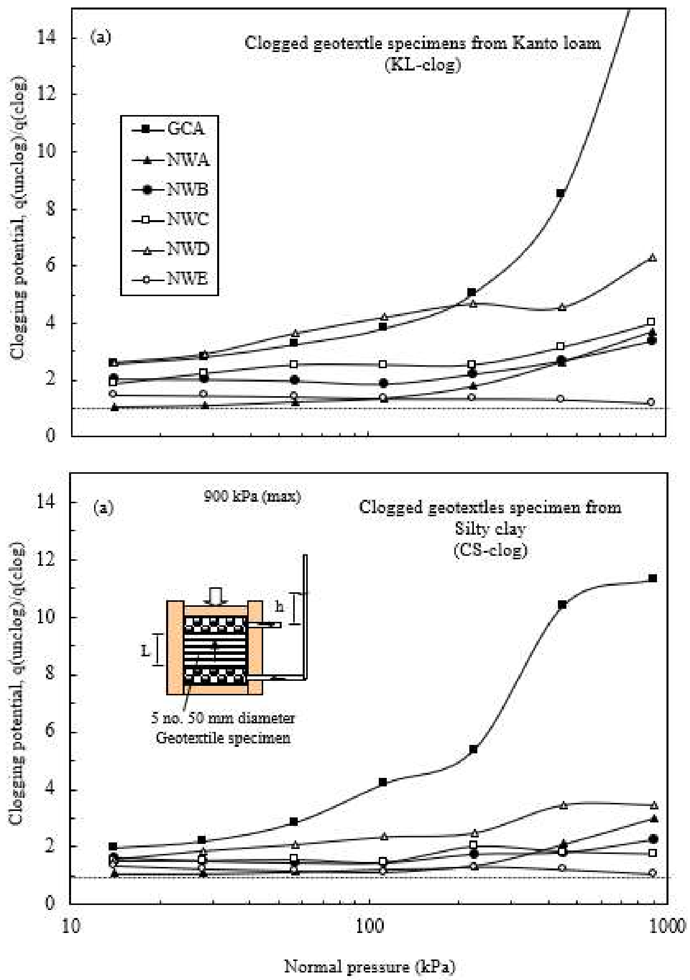


Fig.6. Clogging Potential of Geotextiles in Kanto loam and Silty Clay under varied normal pressure

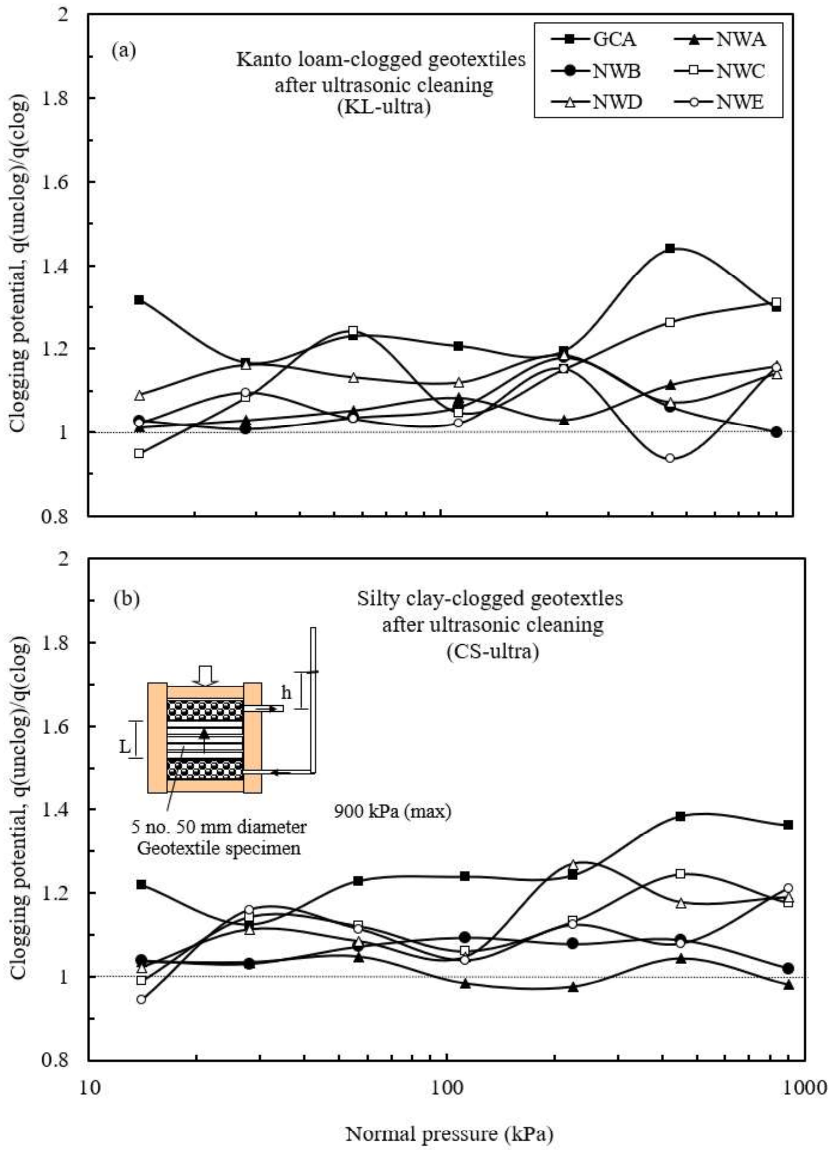


Fig.7. Clogging Potential of Geotextiles in Kanto loam and Silty Clay (ultrasonic test) under varied normal pressure

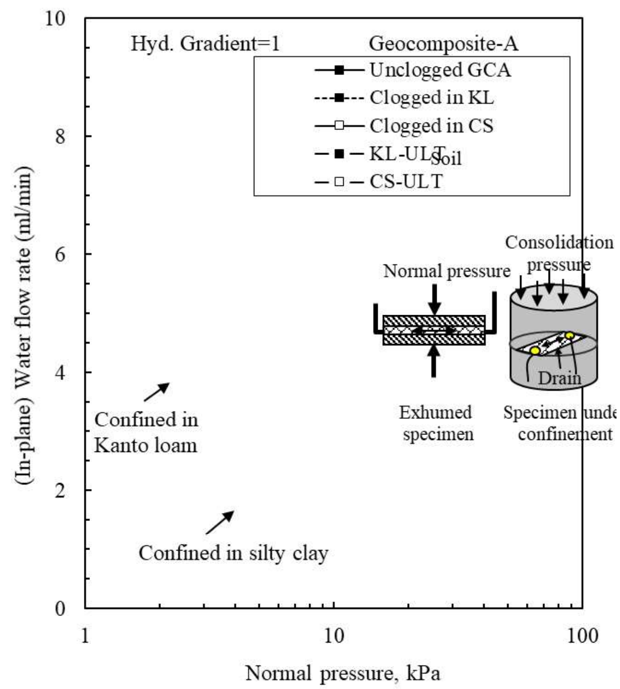
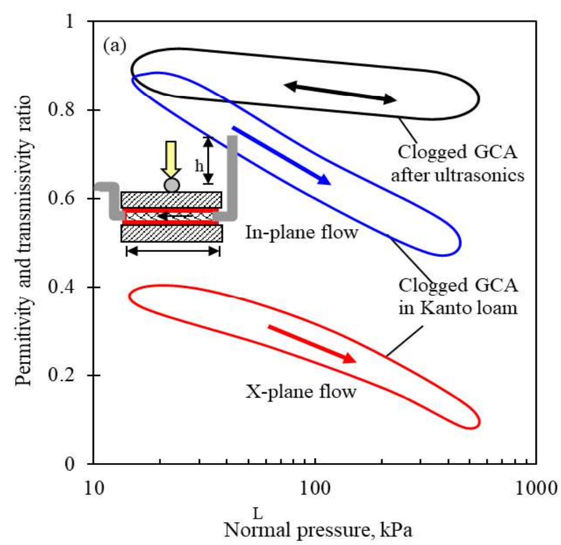
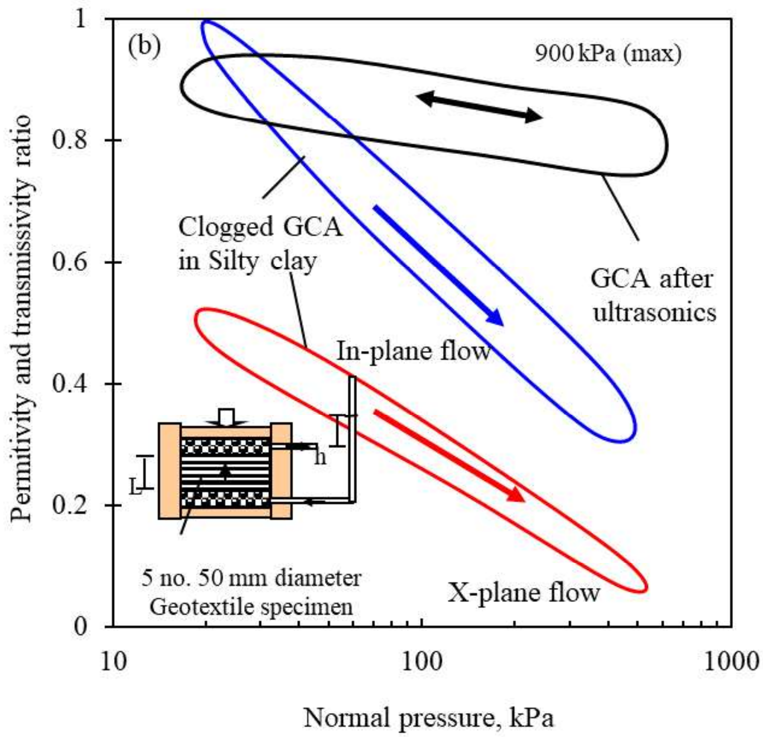


Fig. 8. In-Plane water flow rate for Kanto loam and Silty Clay (Type A Geotextile)



(a)



(b)

Fig. 9. Permitivity and transmissivity variation for type-A Geotextile and comparison of Ultrasonic cleaning efficiency for Kanto loam(KL) and Silty Clay (CS)

7 Effect On Transmissivity And Permittivity of Geotextile

The permittivity and transmissivity of washed specimens have been derived. Fig. 9 presents the variation of the permittivity and transmissivity ratios corresponding to geo-composite-A Geosynthetics. Tests results indicate that ultrasonic cleaning of the exhumed geotextile specimen have increased flow efficiency significantly. Similar test have been conducted on non-woven-A.

8 Conclusions

Based on the investigation carried out on six types of Geosynthetics respectively tested with two fine-grained soils it is confirmed that ultrasonic waves are effective in cleaning the clogged geotextile drain. In the present case, cleaning of clogged drains are done with an ultrasonic probe in presence of some fluid medium (water in most cases). A proper methodology has yet to be derived to use the same technique in a distressed field structures such as reinforced retaining wall constructed with fine-grained soil backfills. From the study performed it is found that a)Washing efficiency for all clogged geotextiles is more than 80% @ 5 minutes dipping time, b) Transmissivity and permittivity of washed specimen improved nearly to 75% and above, and c) Among five nonwoven geotextiles, type-A, was severely affected by clogging, however, ultrasonic cleaning of the same removed clogging efficiently.

Acknowledgements

This work was carried out at the Ibaraki University, Faculty of Engineering, Japan, with active research collaboration and financial assistance to the first author by M/s Okasanlivic Co. Ltd., Japan. The geotextile materials were supplied by M/s Mitsui Petrochemical Co., Tokyo, Japan and M/s NAUE Geosynthetics Co. Ltd., Germany. Valuable discussions, comments and co-operation received from Prof. H. Komine and all members of Y`s Laboratory, Ibaraki University, Hitachi, Japan are gratefully acknowledged.

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