A Review on Transparent Soils

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***Abstract*— Transparent soils have emerged as a significant tool for physical modelling of soil structure interaction mechanisms. A suitable optical system is required to use transparent synthetic soil for geotechnical challenges, including transparent materials, sample preparation, geotechnical attributes, experimental methodologies and applications in physical modelling. In this review paper an introduction is given about transparent soils and its usage.**

Keywords: Transparent Soil, Optical Study, Silica gel ,Amorphous silica powder

1. INTRODUCTION

Natural soils are opaque to visible light, thus the only method to visualize internal deformations and flow routes is to employ expensive equipment like X-rays, computed tomography or magnetic resonance imaging cameras. Even while this technology exists, it is still prohibitively expensive and difficult to utilise, especially in educational surroundings. From recent years transparent soils have been produced as a solution to overcome these problems. Transparent soils are two-phase media created by matching the refractive index of solids that constitute the soil skeleton with the pore fluids. Transparent material have been effectively used in model studies; for example crushed glass was used by Konagai (1992,1994) to simulate soil embankments during earthquake. For comparing border soil displacement fields under a model footing in a transparent soil model with those from a natural soil model, the modelling capacity of transparent soil was examined. The transparent soils are made by several compounds like silica gel, amorphous silica powder, quartz, aquabeads etc with matching refractive index pore fluids which makes those compounds transparent. To optically slice a transparent soil model, an optical system with a laser light, camera, frame grabber, and computer was constructed. The interaction of laser light with transparent dirt produced a characteristic laser speckle pattern. Using an image processing technique called digital image correlation, the displacement field was calculated using two laser speckle pictures taken before and after a deformation. The comparative analysis reveals that transparency is useful. In Geotechnical engineering research differs from that of many other disciplines due to the need for larger test models, the development has been characterised to a large extent by the need to reduce the cost of the constituent materials through the use of low-cost industrial substances and the use of recycled materials. Transparent soil can be used to model natural soil in scaled experiment by other researchers (Welker et.al.1999;Gill and Lehane 2001;Toiya et al.2007;Zhao 2007). This paper will discuss about the different transparent soil and about optical study using these transparent soils, with matching refractive index pore fluid.

2. TRANSPARENT SOIL

Transparent soil makes the tracing of particle movement inside soil mass possible. Among several studies, Iskander et al. conducted extensive investigations on granular silica gel and powdered silica gel for modeling sand and clay respectively. Transparent soils are two-phase media made by refractive index matching of solids representing the soil skeleton and the saturating fluids. Dantu (1957, 1968) and Allersma (1982) used photoelastic stress analysis of polymeric discs to represent soil grains, Desrsues et al. (1991) used tomography to study strain localization in sand, and Konagai et al. (1992, 1994) used alcohol-saturated fused quartz as a soil surrogate to study changes in the soil fabric. As a result of the lack of documentation of the geotechnical behaviour of the soil surrogates in these early investigations, these techniques were not extensively used. Transparent soils appear white when completely dry and transparent when fully saturated. However, due to the discovery of novel transparent soil analogues and the development of complementing image processing techniques, there has been increased interest in the behaviour of surrogate soils and their use in geotechnical soil-structure interaction investigations, as this work reveals. Transparent soil are of different types and they belong to different family.

2.1 .Amorphous silica powder

Amorphous silica powder comes under the first family.For modelling clayey soils commercially available amorphous silica powder normally used as filler to fabricate paint, cosmetics, and paper is effectively used. Oil blend and brine solution prepared from mixing mineral oil and paraffinic solvent or calcium bromide brine were used as matching pore fluids. From several research it is indicated that amorphous silica powder representing the macroscopic geotechnical residences of ordinary low plasticity clay (Iskander et al. 1994; Mannheimer and Oswald 1993).

Fig 1. Amorphous Silica powder.

2.2. Silica Gel

Silica Gel comes under the second family. It became fabricated from particulate silica gel. Silica gel is typically used as a desiccant for leather-based goods, medication pills, and packaging. Silica gel may be used to version the static and dynamic conduct of sand (Iskander et al. 2003; Zhao and Ge 2014). More importantly, silica gel has the equal refractive index as amorphous silica powder, so for both similar pore fluids can be used. Silica gel may be received at diverse length distributions. Both spherical and angular silica gels had been examined for his or her bodily and mechanical properties. The primary disadvantage of silica gel is that the debris are incredibly soft, as may be visible from odometer.

Fig 2. Silica Gel Angular and Round beads

Silica gel has been used to model pile penetration (Liu and Iskander 2010), shallow foundations (Iskander and Liu 2010), and to investigate soil deformation due to tunnelling.

2.3. Aquabeads

A third family of transparent soils was developed using a water based transparent polymeric hydrogel. It has the same refractive index as that of water, which makes it ideal for the study of flow.Aquabeads is capable of absorbing 200 times its own weight in water. Aquabeads is appropriate principally for study of flow in soils. The soils with a large vary of hydraulic conductivities is simulated exploiting this material. This could be achieved by varying the scale distribution of Aquabeads particles. Aquabeads particles can be simply crushed, permitting the formation of custom grain-size distributions (Fernandez Serrano et al. 2011).

Fig 3.Aquabeads

2.4. Fused Quartz

The fourth family of transparent soils is made of fused quartz or fused silica. Iskander (2010) identified fused silica as a potential transparent soil. Fused quartz and fused silica are non-crystalline forms of silicon dioxide. High purity fused quartz is manufactured by melting naturally occurring crystalline silica at temperatures in the range of 2,000^{0}C. Crystalline silica (silicon dioxide, SiO2) is found in siliceous/quartzite sand and rock. The melting process is conducted in a vacuum to prevent bubble formation, which helps enhance transparency. Crushed fused quartz is most often a byproduct of industrial processes for the manufacture of semiconductors, solar cells, telescope and microscope lenses, telecommunication equipment, and glass chemical containers. Several suppliers manufacture the material to a wide range of different particle size specifications. Regardless of source, the material is highly angular and possesses chemical composition similar to that of natural silicate sand. Ezzein and Bathurst (2011) were the first to demonstrate that fused quartz can be used as a transparent soil surrogate by matching it with a pore fluid made of a blend of two mineral oils similar to baby oil. A pre-manufactured. The ability to model sand using two immiscible pore fluids permits modeling multiphase flow problems, coupled flow deformation problems, as well as vadose area environmental hazard problems (Kashuk et al. 2015).

Fig 4. Fused quartz

2.5. Laponite

A new transparent soil family made of Laponite with properties somewhat similar to hydrogels is characterized for geotechnical properties in this special issue (Wallace and Rutherford 2015). Laponite are very soft materials. They are mainly used for the manufacturing of paints,inks, household cleaning materials,cosmetics etc.

3.PRACTICAL CONSIDERATIONS OF TRANSPARENT SOILS FOR MODELING

Commercially available materials are used as transparent soils. These commercially available materials are mixed with pore fluids with matching refractive index and they are made transparent. The transparent soil are used for further studies like optical study.

3.1. Changes in Refractive Index

The refractive index of transparent materials is difficult to measure directly, hence it is determined through immersion in fluids with known refractive index. For example, Fused quartz has a refractive index of 1.4585, according to reports (Weast 1985). Temperature and wavelength affect the refractive index of most transparent substances. In the visible wavelength range, the refractive index of fused quartz varies by only 0.001 degrees between 20°C and 30°C (Malitson 1965). As this change is smaller than the precision of a hand-held refractometer (0.001), the refractive index of fused quartz is presumed to be constant at 1.458 under standard laboratory settings. The matching fluid's refractive index, on the other hand, varies a lot with temperature. As a result, it is suggested that the best RI be determined through trial and error on a case-by-case basis.

3.2. Material Recycled and Used

For a variety of reasons, the capacity to reuse the granular media and pore fluid utilised in the creation of transparent soil models is crucial. Synthetic materials utilised as the soil skeleton simulant in transparent soils are derived from materials intended for other major industrial and commercial uses. While some transparent soils, such as precipitated silica, have a high level of quality assurance, other materials, such as fused quartz, are not always available at the high level of quality required for transparent soil modelling. The pore fluid in some circumstances, such as sodium thiosulphate-treated sodium-iodide, is expensive. Finally, there are clear environmental benefits to reusing materials from validated models. Carvalho et al. (2015) developed strategies to reuse pore fluids such as mineral oil.

4. TRANSPARENT SYNTHETIC SOIL FOR MODELING NATURAL SOILS

Transparent soils are formed up of transparent particles and pore fluids with a matching refractive index, which are simulated independently using two materials. The transparency of synthetic soil samples is determined by the refractive indices being identical, as well as the lack of contaminants and trapped air. The two parts of transparent synthetic soil are amorphous silica powder for modelling clay and amorphous silica gel, fused silica, and glass sand for modelling sand.

4.1. Amorphous Silica Powder for Modeling Clay

The interior of amorphous silica powder has a two-pore structure and is made up of ultrafine particles. It is a colourless substance that resembles a white powder. Silica powder has a refractive index ranging from 1.41 to 1.46. Iskander et al. shown that this material is suitable for modelling natural clay (2002). The pore fluid is a 1:1 blend by weight of mineral oil and a normal-paraffinic solvent with a refractive index of 1.447 at 24^0C.

4.2.Amorphous Silica Gel for Modeling Sand

Silica gel is a porous inert substance made up of a huge network of small pores that are interconnected. It comes in diameters ranging from 0.5 to 5 mm and comes in either a round beaded or granular shape. The geotechnical properties of silica gel have been studied, and Liu et al. (2009) discovered that it may be used to imitate natural sand and measure 3-D internal soil deformation.

4.3. Fused Silica for Modeling Sand

Fused silica is a calcined product under high temperature and exhibits low thermal conductivity, excellent thermal stability and excellent optical qualities. The physical properties, including the specific gravity of 2.21, Mohs hardness of 7.0, and pH of 6.0 are extremely similar to natural sands and make fused silica an appropriate material to model natural sands. Compared to the two-pore system amorphous silica, fused silica exhibits a better capacity to model natural sand as its one-pore system is more similar to that of natural soils.

5. OPTICAL STUDY USING TRANSPARENT SOIL

Geotechnical difficulties have been effectively investigated using transparent soils. Oswald,Iskander,Wu and many others has demonstrated that transparent soil was similar to normal soil in their foundational investigation. Furthermore, using transparent soil technology, Xiang et al. (2018) investigated the impact of surrounding rock strength and depth on the deformation and failure process of shallow tunnels. Digital image technology and optical equipment have recently become quite popular in industry and academia. Tang et al. (2019) used digital image technology and optical equipment to establish a method for autonomously creating 3D distorted images of the surface under low cyclic loads. The optical study is conducted with the help of a model box ,cameras, computers and so on. By using these cameras we get the speckel images and using the speckle images different studies are conducted.

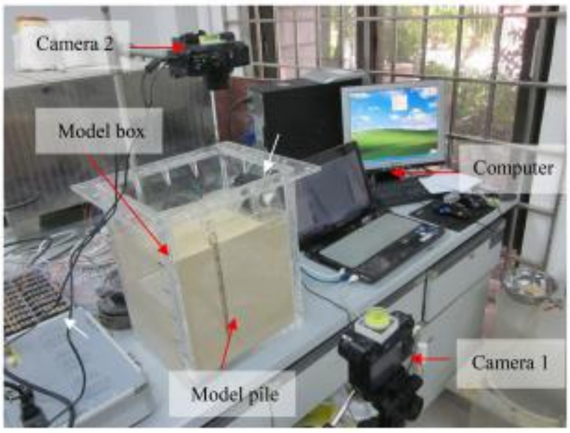

Fig 5. Optical Study Set Up

Horizontal and vertical soil displacement fields can be calculated in the laterally loaded pile modelling test using two pairs of sequential photos recorded during pile movement. The understanding of internal soil problems such as deformation mechanisms within the soil and failure mechanisms has significantly improved thanks to the feasibility of transparent soil in physical models and the ability to visually represent internal 3D deformation and flow movements non-intrusively. Transparent soil approaches, on the other hand, have drawbacks that limit their applicability in the research of geotechnical properties and modelling tests. This technique cannot be used to examine many large geotechnical projects that are related to solving geotechnical engineering difficulties. Further more, acheiving good transparency in translucent soil is a difficult challenge. The models used in modelling testing are typically tiny in size. Obtaining proper soil transparency for a large model would provide challenges, such as transparency degradation and transparent samples turning opaque.

6. CONCLUSION

No one can predict what the future may bring. Nonetheless, the different authors believe that the transparent materials and technology discussed in this research provide the necessary foundation for studying spatial deformation patterns and flow using optical techniques. The reaction of a transparent continuum, model may be assessed using non-intrusive optical viewing techniques, visual augmentation and depiction of deformation and flow properties inside a soil mass are achievable in model tests. The geotechnical properties of transparent materials have been studied through several testing. The internal deformation of soil can be accurately examined using contemporary optical instruments and image processing techniques.

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