ENHANCEMENT OF COLLAPSE BEHAVIOUR OF UNSATURATED KAOLIN GRADED COMPACTED CLAY USING XANTHAN GUM

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***Abstract*— Collapsible soils are any unsaturated soil that goes through a radical rearrangement of particles and greatly decreases in volume upon wetting, additional loading, or both. Wetting under load weakens the cementation, reduces the soil suction, and causes collapse. Collapsible potential test is performed under wet mix condition as per ASTM D533. Soil suction is one of the most important stress variables describing the behaviour of the unsaturated soils. The filter paper method calculates soil suction indirectly by measuring the gravimetric water content of filter paper as per ASTM D5298. In this study, the effect of matric suction in collapse behaviour of unsaturated compacted clay was determined and also investigates the possibility of using xanthan gum to enhance the behaviour of collapsible soil. Xanthan gum have stable behaviour under severe conditions and available with reasonable prices. It is found out that collapse potential varied inversely proportional to matric suction and flooding pressure upto OMC. It is found that xanthan gum can be used as an improving material for collapsible soil treatment. The collapsible potential has been reduced significantly when mixing the clay with 2% xanthan gum in the wet mix condition. It is found that there is a 4% reduction in OMC when xanthan gum is added, thereby suction increases with decrease in collapse potential.**

***Keywords*— Collapse behaviour; Collapse potential; Matric suction, Kaolin graded clay**

I. INTRODUCTION

Collapsible soils are also known as metastable soils. They are unsaturated soils that undergo a large volume change upon saturation. The sudden and usually large volume change could cause considerable structural damage. The volume change may or may not occur due to an additional load. Collapsible soils are found throughout the world in soil deposits that are aeolian, loessial, subaerial, colluvial, mudflow, alluvial, residual, or manmade fills. Collapsible soils are defined as any unsaturated soil that goes through a radical rearrangement of particles and greatly decreases in volume upon wetting, additional loading, or both. Typically these soils are found in arid or semiarid regions and have a loose soil structure, ie large void ratio and water content far less than saturation.

Collapsible soils are not confined to arid regions and have been encountered in most parts of the world. The conditions in arid environments tend to favour the formation of collapsible soils. Almost all naturally occurring collapsible soil deposits are either debris flows deposits or wind deposits (loess). Debris flows are at low density, but are relatively stiff and strong in their natural dry state. Cementation consists of dried clay and other chemical precipitates that may have been added after deposition. Wetting under load weakens the cementation, reduces the soil suction, and causes densification or collapse. Loessial deposits are comprised of a relatively narrow size range of particles, usually silt to fine sand, with coatings of small amount of clay being common cementing materials are often added after deposition or dissolved and re-precipitated at particle contacts. Loess exhibits low density, moderately high shear strength and stiffness when dry, and is subject to densification and collapse upon wetting under load.

Mohamed Ayeldeen, et al. (2017) aimed to investigate the possibility of using biopolymers to enhance the mechanical behaviours of collapsible soil. Two types of biopolymers were (xanthan gum and guar gum) used in this study due to their stable behaviours under severe conditions. The experimental program focused on three major soil properties, i.e. compaction characterizations, collapsible potential and shear parameters.

Snehasis Tripathy, et al (2016) presented suction measurements in case of unsaturated soils using a commercially available water potential sensor. The sensor uses ceramic discs of predetermined pore-size distribution (ie fixed-matrix) for suction measurement and a surface mounted thermistor to take temperature readings. The ceramic disc assembly of the sensor is brought in contact with a soil for which the suction measurement is required. The test results clearly showed that under predetermined conditions, the water potential sensor can be used to measure soil suction greater than 1500 kPa within a few hours.

Sudhakar M Rao, K Revanasiddappa (2007) examines the influence of variations in matric suction on the collapse behaviour of compacted Bangalore clay soil. The ASTM filter paper method measured the matric suctions of the compacted soil specimens. Comparison of the matric suction-gravimetric water content relations of various compacted soils showed that the soil with a higher liquid limit has higher matric suction at given gravimetric water content.

De'an Sun, et al. (2007) studied the mechanical behaviour of unsaturated soils exists, particularly on the collapse behaviour under general stress states, because of the technical difficulties and time-consuming nature of measuring suction and deformation. This paper presents the results of a series of controlled-suction triaxial tests on the collapse behaviour of unsaturated compacted clay with different initial dry densities and suctions. It is also found that the soil-water characteristic curve in terms of suction and degree of saturation shifts upwards with increasing density of the specimen.

A. Scope

Constructing structures on collapsible soil will have significant challenges due to sudden reduction in volume upon wetting. This study encounters the deformation characteristics, such as volume changes and hydraulic characteristics such as saturation changes. Matric suction is determined by ASTM filter paper method as per ASTM D5928-2004, accuracy can be improved with tensiometer. Collapse behaviour can be studied by using triaxial tests with different initial densities and controlled suction. Improvement in mechanical behaviour of collapsible soil are checked by conducting compaction tests, and oedometer tests

II. MATERIALS REQUIRED

Clay is collected from English India Clays Limited. Figure 1 show that clay is white in colour and are finely graded. It is an odourless white to yellowish or grayish powder. It is insoluble in water but darkens and develops an earthy odour when wet. Kaolin is an industrial product and thus, naturally, a commercial product as well. It is used in ceramics, paper, paint, rubber, fiberglass, medicine, cosmetics, food additives, and agriculture.

Fig 1 Kaolin graded clay

TABLE I. PRELIMINARY TEST RESULTS OBTAINED

S.No	Test Preformed	Results
1.	Specific gravity	2.59
2.	Percentage of silt	14%
3.	Percentage of clay	86%
7.	Optimum moisture content	38.5%
8.	Maximum dry density	1.42g/cc
9.	Liquid limit	62%
10.	Plastic limit	30.4%
11.	Plasticity index	31.6%
13.	Soil classification	CH

A biopolymer i.e. xanthan gum has been used in this study. This biopolymer is chosen due to the fact of their availability with real looking prices compared to different biopolymers. Moreover, their special practical houses include gorgeous cold water dissolving, pH stability, storage stability; ionic salt compatibility and pseudo plastic go with the flow characteristics. Xanthan gum is an anionic exo-cellular polysaccharide produced by means of aerobic fermentation of sugars by using the bacterium Xanthomonas campestris. Xanthan gum is a vegetarian thickening agent that is sourced purely from plants and also works as a stabilizer.

III METHODOLOGY

A. *Matric Suction using ASTM D 5298 Filter Paper Method*

Filter papers (Whatman No. forty two) are used as sensors to measure the matric suction of the soil specimens. The filter papers are equilibrated with the compacted soil specimens in a hundred and sixty mL potential specimen containers. The soil specimens are compacted in two layers in these massive specimen containers. Use of 200 – 250 g of moist soil mass ensured that the compacted specimens nearly filled the containers, accordingly reducing the equilibration time.

To intensify the contact between the filter paper and the compacted specimen, the filter paper is buried in the compacted soil mass. The filter papers have to be cooled in a desiccator, the clay soil specimens are prepared for compaction. The pre-wetted soil mass to be compacted in the specimen container is divided into two equal portions. One portion of the soil is compacted into the specimen container to the required density. Next, filter paper has been removed from the desiccator and positioned at the center of the compacted soil mass. The final half of the pre-wetted soil used to be filled into the specimen container and statically compacted to the required density. The container is closed with a lid and sealed with two wrappings of plastic sealing tape. The protective filter papers and the central filter paper were oven-dried at 110°C for 16 hours before using in experiment.

The filter paper and the soil specimen have been allowed to equilibrate for 10 days at 24°C. ASTM procedure mentions that a 7-day equilibration length is usually sufficient. After 10 days of equilibration, the moist filter paper is taken from the specimen container and now sealed in a pre-weighed plastic bag capable of an airtight seal. The sealed plastic bag is placed at some point of transit to the digital balance. After measuring the moist mass of the filter paper, the moist filter paper is oven dried at 110°C for 24 h. The mass of the oven dry filter paper was determined to the nearest 0.0001 g. The distinction between the moist and dry mass of the filter paper gave the equilibrium moisture content of the filter paper (wf).

As previously mentioned, three filter paper experiments are to be setup for each specimen. The three equilibrium filter paper water contents of a compacted specimen have been transformed to three matric suction values by way of referring to the ASTM calibration curve for Whatman No. 42 filter paper shown in figure 1. The three-matric suction values of a compacted specimen have been averaged. Generally, at any relative compaction, drier the soil used at compaction, the larger the experimental variant in the matric suction value.

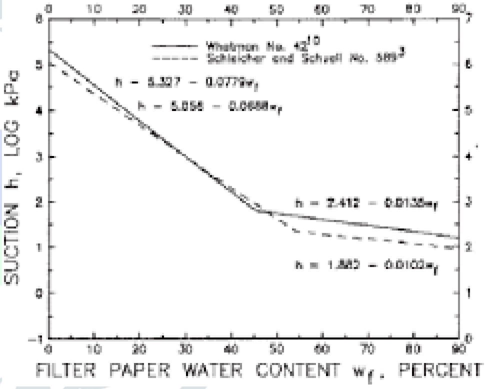

Fig 2 Calibration curve

B. *Determination of Collapse Potential using Oedometer Test*

The collapse potentials of the compacted clay soil specimens are determined by the oedometer test. In this test, the compacted specimen is incrementally loaded up to a specific state of stress without wetting the specimen. Equilibrium is attained by the unsoaked specimen under an applied stress in less than 45 min. On attainment of equilibrium under the applied stress, the compacted specimen is inundated with distilled water. Most of the collapse occurs in less than 5 min after inundation. The final deflection after 24 hour is used to calculate the collapse potential of a specimen. The collapse potential is calculated from the equation 1

$$\text{Collapse Potential} = (dh/H) \times 100 \quad \ldots (1)$$

dh = change in height of the compacted specimen on wetting under the applied stress after 24 h

H = height of the compacted specimen before water was added at that particular stress

C. *Collapse Behaviour of Clay using a Biopolymer*

Soil specimen is prepared by disturbing the collapsible soil with hand, then, air dried for one week, and then sieved by using 475 micron sieve. Two strategies have been used to mix the soil with biopolymer: dry combine and wet mix. The moist combine method is the essential technique in this study and has been used to put together the samples for all tests. In that method, the biopolymer solution was once organized first with specific concentrations, and then mixed with the air-dried soil to acquire water content. The solution concentration is once calculated as the ratio between the weight of the used biopolymer powder and the standard weight of the solution in percentage. The powder was once added to the water gently to avoid clumping, and then the solution was combined till a homogeneous solution used to be obtained. It used to be hard to reach a certain density for all specimens with countless concentrations and a range of kinds of biopolymers as the variation in the viscosities will have considerable impact on the soil densities. Increasing the awareness will lead to a reduction in the density. Therefore, all specimens were prepared at 75% of their maximum dry density in accordance to their compaction characterizations as the natural density was once approximately 75% of the maximum dry density. The dry mix method is used to put together samples used in the collapsible potential test, in order to find out about the impact of the mixing technique on the collapsible behaviour. In this method, the weight of the biopolymer is and blended directly with the air dried soil till homogeneity. The mixture was used to put together the required oedometer specimens, where water used to be brought to the specimens all through the test. All specimens are exposed to air after pouring in the oven at 30°C till tests began, to ensure the same curing condition (humidity and temperature) for all specimens.

Modified Proctor compaction check used to be performed following IS2720 part VII. The test used to be essential to determine the optimum percentage of xanthan gum.

Oedometer test is performed to estimate the collapsible potential. The vertical stress is once increased step by step until a value of 200kPa, where the sample is inundated with water for 24 h. The collapsible possible is once taken as the difference in the axial pressure (%) at a vertical stress of 200kPa after and before immersing according to the specification.

IV RESULTS

For this test, different cases are to be considered on the sample with different dry densities and water contents.

A. Matric Suction by ASTM D-5298 Filter Paper Method

Clay specimen is compacted and filled at optimum moisture content. Table 1 shown below is the clay specimen allowed to equilibrate for 10 days at room temperature.

Table 1 Matric suction of clay at different water content

Water Content (%)	Matric Suction (kPa)		
	at 80% of MDD	at 90% of MDD	at MDD
38.5(OMC)	3.4	4.9	8.21
34.5	43.05	58.60	97.14
30.5	686.8	1382.3	2742.8

B. Collapse Potential Measurements

The collapse potential of the clay specimen is determined at two different flooding pressures (The vertical stress at which a compacted specimen is inundated) ie at 200 kPa and 400 kPa which are shown in the table 2 and 3 respectively.

Table 2 Collapse potential values at flooding pressure 200 kPa

Water Content (%)	Collapse Potential (%)		
	at 80% of MDD	at 90% of MDD	at MDD
38.5(OMC)	-5.16	-7.6	-10.48
34.5	-6.25	-8.5	-12.41
30.5	-6.84	-9.25	-17.7

Table 3 Collapse potential values at flooding pressure 400 kPa

Water Content (%)	Collapse Potential (%)		
	at 80% of MDD	at 90% of MDD	at MDD
38.5(OMC)	-6.4	-8.5	-10.28
34.5	- 6.53	-9.06	-12.41
30.5	-7.4	-9.26	-17.71

C. Effect of matric suction on collapse potential of clay

The collapse potential of soil increases with the increase in degree of saturation. Figure 2 and 3 shows the collapse potential depends upon the degree of saturation, pressure which they are inundated and also the dry density of specimen whereas matric suction depends on the degree of saturation and also the dry density of specimen.

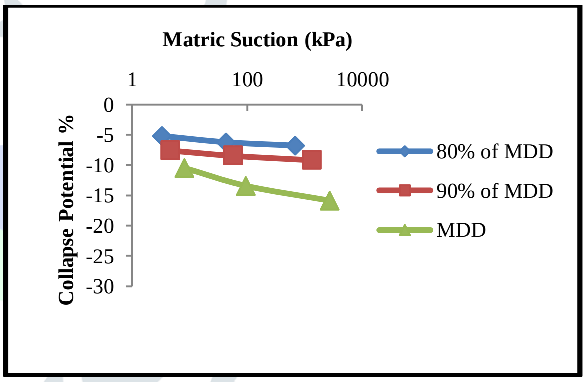

Fig 2 Influence of matric suction on collapse potential of specimen at 200kPa flooding pressure

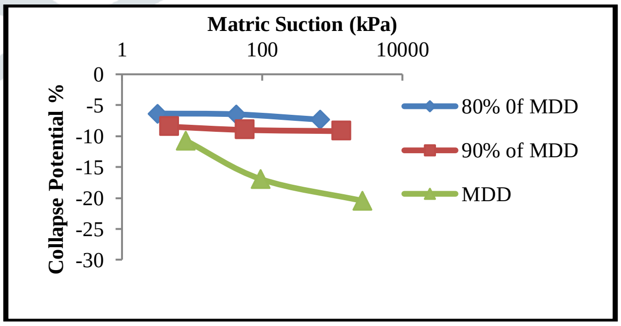

Fig 3 Influence of matric suction on collapse potential of specimen at 400kPa flooding pressure

D. Collapse Behaviour of Kaolin Clay using a Biopolymer

1. Compaction characteristics: The density achieved after compaction will affect the mechanical characteristics of such as settlement and bearing capacity. To know the compaction behavior and also to obtain the optimum percentage of xanthan gum, it is mixed with different concentrations to the clay specimen. Figure 4 shows the compaction curves of clay specimen with different proportions of xanthan gum.

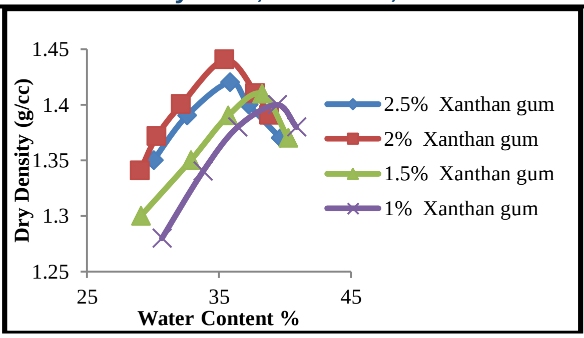

Fig 4 Compaction curves of clay specimen with different proportions of Xanthan gum

Xanthan gum is added to clay at 1%, 1.5%, 2% and 2.5%. From the compaction curves, the minimum optimum moisture content with maximum dry density is obtained at 2% Xanthan gum.

2. Matric suction and collapse potential of clay: The soil collapsible behaviour has been significantly changed when using different percentages of xanthan gum. Xanthan gum produces ionic bond between xanthan gum and soil particles accompanied with high degree of aggregation and large voids filled with air or biopolymer gel. The values of collapse potential and matric suction are shown in table 4, 5 and 6 below at 200 kPa and 400 kPa flooding pressure.

Table 4 Collapse potential values at flooding pressure 400 kPa

Water Content (%)	Collapse Potential (%)		
	at 80% of MDD	at 90% of MDD	at MDD
35.3(OMC)	-7.21	-8.98	-11.20
31.3	-8.36	-9.51	-14.86
27.3	-9.14	-10.06	-17.43

Table 5 Collapse potential values at flooding pressure 400 kPa

Water Content(%)	Collapse Potential (%)		
	at 80% of MDD	at 90% of MDD	at MDD
38.5(OMC)	-8.50	-10.43	-12.43
34.5	- 8.98	-11.16	-18.59
30.5	-9.46	-11.89	-23.41

Table 6 Matric suction of clay at different water content and dry density

Water Content (%)	Matric Suction (kPa)		
	at 80% of MDD	at 90% of MDD	at MDD
38.5(OMC)	38.60	43.08	66.71
34.5	95.48	121.64	156.10
30.5	851.05	1546.1	3546.3

3. Effect of matric suction on collapse potential of clay: Figure 4.9 and 4.10 shows the relation between collapse potential and matric suction with different dry densities and water content

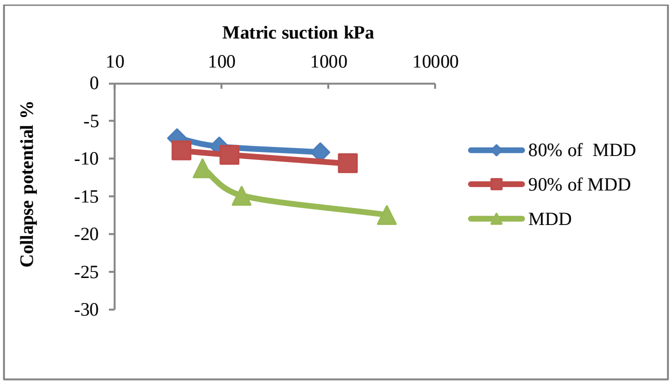

Fig 5 Influence of matric suction on collapse potential of specimen at 200kPa flooding pressure

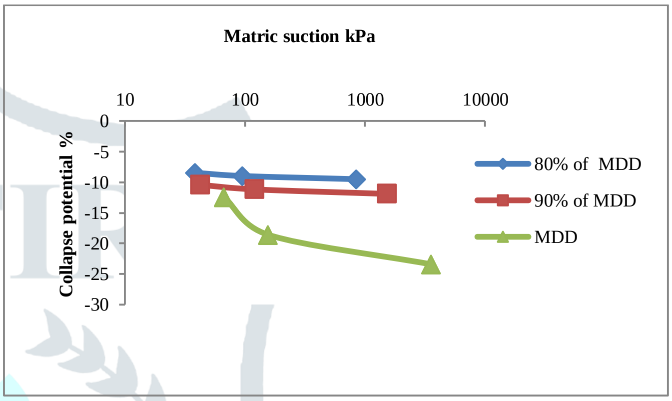

Fig 6 Influence of matric suction on collapse potential of specimen at 400kPa flooding pressure

At MDD, variation in reduction of collapse potential is much more as compared to other dry densities. With the addition of xanthan gum, there is much reduction in collapse potential also increment in matric suction.

V. CONCLUSION

- The preliminary tests were completed and it includes the index properties like consistency limits, specific gravity, particle size distribution and compaction characteristics as per Indian standard codes. From particle size distribution curve, the soil is classified as CH as per plasticity chart.
- It is inferred that collapse potential decreases as matric suction increases. Matric Suction decreases with the increase in water content. Therefore collapse potential and water content are directly proportional.
- Also collapse Potential decreases with increase in flooding pressure (upto OMC). At particular water content, collapse potential increases with decrease in dry density. At a particular water content, matric suction decreases with decrease in dry density.
- Optimum percentage of Xanthan gum obtained for enhancement of mechanical behaviour of kaolin graded clay is 2%.There is a reduction of 5% to 15% of collapse potential when 2 % of xanthan gum is added at different dry densities and water content.

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