Studying Slow Displacements Of The Natural Slopes Using Particle Image Velocimetry Method.

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Abtract :

Particle Image Velocimetry is the velocity-measuring technique that was originally developed in the field of experimental fluid mechanics. This method has been used as a modified approach to implement in geotechnical testing in LIRIGM Laboratory to investigate Slow Displacements of The Natural Slopes.

Slow displacements of the natural slope were studied in laboratory using an experimental slope, and new PIV technology. This experimental program allows controlling direction speed and dimension of this phenomenon.

The phenomenon of slow displacements phenomenon is very complex and depends on many variables as for example : water content, plasticity index, height of the soil, angle of the slope, displacements etc.

The laboratory experiments have been done to investigate displacements (eg. triaxial tests, vane tests). The experimental program used in this paper, included micro-scale slope model which has been used to build and control a theoretical model of the slow deformations. This program included slow displacements that are very difficult for the observation; we can only observe the consequences of the experiments. For better understanding, the additional support system has been used to recognize slow movements in the experimental soil.

PIV is going to be an excellent measurement tool that can be use in a wide range of tasks in geotechnical laboratories; from tracing the slow progress of deformations of a specimen in a loading machine to particle tracking in soils.

Results obtained during the study presented in this paper could be a basic knowledge to continue investigation of this problem in the future.

Résumé :

La Vitesse Imagée de Particules est une technique de mesure de vitesse qui a été développée à l'origine dans le domaine de la mécanique des fluides expérimentale. Cette méthode, a été modifiée pour être appliquée aux essais de géotechnique du laboratoire LIRIGM consacrés aux déplacements lents des pentes naturelles. Ces phénomènes ont été étudiésen utilisant une pente expérimentale, et la nouvelle technologie PIV. Cet essai permet de contrôler la direction de la vitesse et la dimension de ce phénomène. Le phénomène de déplacements lents est très complexe et dépend de plusieurs variables comme la teneur en eau, index de plasticité, hauteur du sol, angle de la pente, déplacements etc...

Les expériences de laboratoire complémentaires ont été menées (par exemple essais triaxiaux, essais scissométriques).

Le phénomène de déplacements lents est très difficile à observer; nous ne pouvons seulement qu'en observer les conséquences. Le modèle de comportement utilisé comme support du programme expérimental décrit dans cet article, a été employé pour construire et contrôler un modèle théorique des déformations lentes. Ce modèle a permis une meilleure du phénomène de mouvements lents observé.

Key-words :

PIV; Slope; Displacements

1. Introduction

Saint Guillaume is a small village, 700 m over sea level, in Triéves depression, in Alps near to Monestier de Clermont in significant landslide risk zone. This area lays in the depression between two massifs : Vercors and Belledone. Geology of this region shows that Saint Guillaume area is a typical after glacier area. Glaciers (Würm) reach this area and form lakes at the same time. Glacier deposits are very clayey and include striped, round limestone and crystal pebbles which testimony that these materials derive from Alps as the effect of clay sedimentation. Glaciers in Würm II moved on clays deposed earlier, pull out some material and lift up and place higher. This explains the over consolidation of clay after glacier deposit. This clayey deposit has a main responsibility of slope sliding observed in this area. Sliding area is the area which have slope from 8^o to 12^o degrees. The depth of sliding surface was measured in 1987 by Azimi on 20 m. Now the depth is consider to be 35 m, according to inclinometers measurements.

Saint Guillaume is lying on the moving soil which is sliding to La Gresse river. Towards upper river course slope is from 10^o to 12^o, towards lower river course slope is from 8^o to 9^o. In the middle of the village there is a relative platter – from 5^o to 7^o of slope.

To investigate the phenomenon of the sliding slope, experimental studies have been carried out in the laboratory using an experimental slope, and new digital technology called Particle Image Velocimetry. PIV is a velocity – measuring technique. All work was divided into two parts: numerical investigation of slope displacements using theoretical model and laboratory investigation using the model of slope and PIV for recording very slow movements of the soil.

2. Engineering background

A lot of buildings in Saint Guillaume are founded on the upper part of the landslide, and as the result of the ground movements most of the constructions have an effects of instability like i.e. cracks. When the displacements had appeared, they start increasing year after year. The buildings which have destruction traces, and damages, are the buildings which are situated directly on the slope. On a lot of buildings we can see cracks (Fig. 1), interstices and reinforcements which were installed after few years when the buildings were constructed.

These reinforcements are not solving the problem, because the slope is still moving down and cracks are still appears. To control slide of the slope in Saint Guillaume inclinometers were installed. The inclinometers allow to measure displacements depending on depth and to show the direction of the slide.

3. Theoretical investigation

Continuous inclinometer observations on sensible areas provide data, which show that in some points the cause of the deformations is not only sliding on a surface but also soil slow mass deformation. During the observations, cracks appeared on building 15 to 20 years after constructed. This phenomenon can be due to the contracting – swelling soil sensitivity (when water content in soil changes which provides contraction or swelling). In clay area the beginning of disturbance is often attribute to the change of water content in soil. But not all clay areas are sensitive on contracting – swelling, hence there should be another cause of disturbance. Clay areas that lie on slope are very sensitive to contracting – swelling. On these areas where slidings of buildings towards downhill appear, similarly it can be found sliding of the superficially ground layer. Cinemorphose is sensitive to contracting – swelling phenomenon on the first meters of considered area. There are a lot of events when the soil drying and disturbance appear but very often crack appears on building without drying and we can observe that ground is sensitive to cinemorphose on a deeper level. Interaction of few different phenomenons may be the cause of ground movement under building. In that case soil movement is complicated and the test are required to describe cinemorphose and find if is only gravitational or superficially and depends on water content. Slow distortion of cover area is very dangerous for building owners because sometime cracks appear 20 years after building was constructed. In that cause the guarantee period is over and building owners are forced to repair at one's own expense without return from insurance.

The movement of phenomenon consist of 3 layers, such as: surface movement, where phenomenon contracting - swelling is the main reason of displacement. This layer sensitive to atmospheric conditions, change water level in ground, intermediate layer, where relationship between shear and distortion is elastic - plastic nature with particles rotation; resistance of swelled soil, deep layer with localization of deformation on a particular shear plane where relationship between shear and distortion corresponds either to a lowering of resistance (post-peak behaviour), or deformation at constant resistance (critical behaviour) where hydraulic pressure plays a driving role.

A theoretical slope analysis was used with varying inputs (slope, friction angle, cohesion, viscosity) to determine the various failure modes which could occur. The parameters of the viscous model was measured on laboratory vane tests. This analysis was carried out before undertaking the laboratory experiments. Fig 2 shows various failure displacements with the height of slope of 0.4 m and with soil contains 10% of clay in volume (k=0.7 kPa*s, c=0.4 kPa, ϕ=49°). Before 35° the theory shows that no displacements occurs, and when 35° is reached, large displacements should be observed.

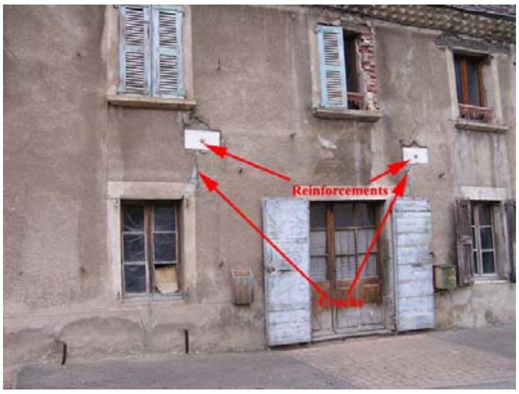

FIG. 1 Cracks and reinforcements on existing building in Saint Guillaume.

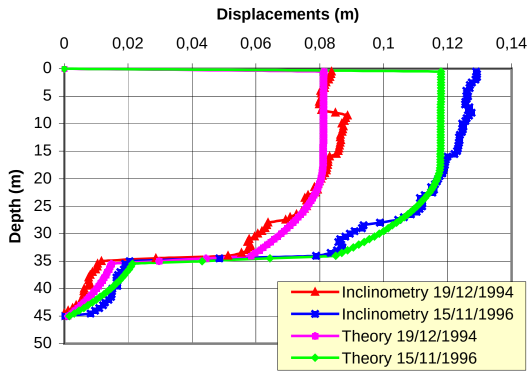

FIG. 2 Calculed displacements of the Saint-Guillaume slope using theoretical viscous model.

4. Laboratory investigation

Some laboratory tests on a slope have been done using artificial soil (sand mixed with kaolinite; 10%, 20%, 30% of kaolinite in volume) to measure properties of used soil.

4.1 Laboratory experiments.

Viscosity is the ability of the soil to deform at a constant level of shearing stress. Viscosity depends of the stress level and of the speed of deformation. To classify the viscosity of the used soil, vane tests have been performed using steel cylinder and Vane tip. Soil Viscosity has been classified as a: for dry soil k=0,0985 kPa*s (10% of kaolinite), k=0,1271 kPa*s (20% of kaolinite), k=0,2461 kPa*s (30% of kaolinite), and for wet soil k=0,700 kPa*s (10% of kaolinite), k=0,8392 kPa*s (20% of kaolinite), k=0,866 kPa*s (30% of kaolinite). There are no big changes in viscosity between soil with 20% and 30% kaolinite. For slope experiment fully saturated soil with 20% of kaolinite in volume has been used. Mean unit soil mass, has been calculated using standard Gauss variation (dry soil: ρ=1,577g/cm^3, wet soil ρ=1,747 g/cm^3).

To measure cohesion and friction angle, Triaxial Tests have been performed for each sample of the soil. For the soil used in slope experiment cohesion is: 9,79 kPa, and friction angle is: 32,15^o. All parameters obtained from laboratory experiments were used in theoretical model to calculate possibility of slope sliding.

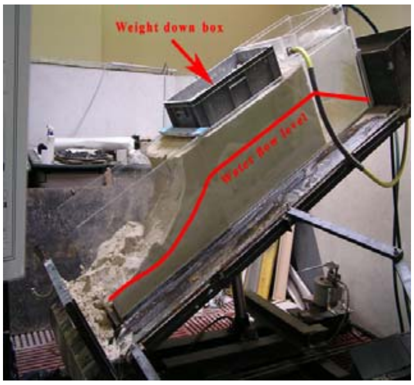

FIG. 3 Slope lifted up to 30^o with constant water flow, after sliding.

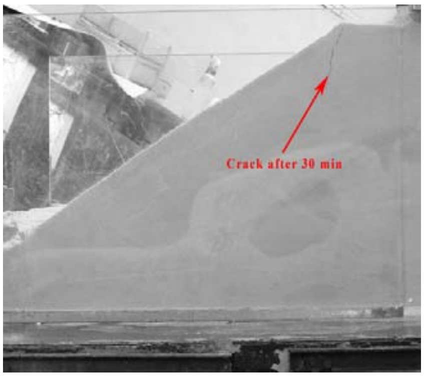

FIG. 4 First crack observed after 30 min.

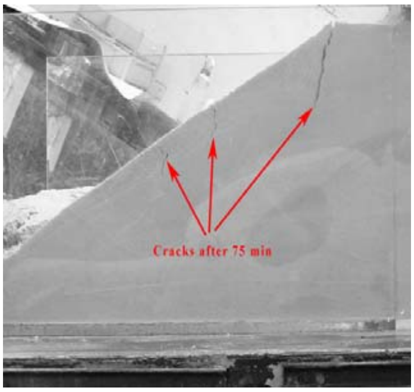

FIG. 5 Next cracks observed after 75 min.

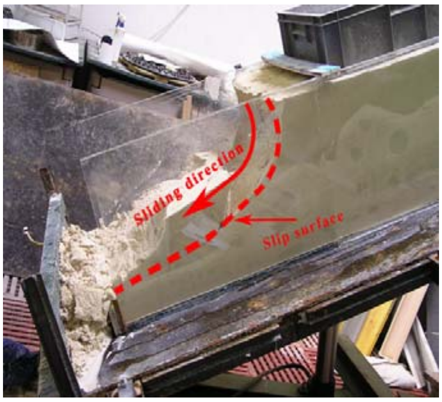

FIG**.** 6 Slip surface from one side of tank.

4.2 Slope apparatus.

Slope experiment was performed in the Perspex tank: 1.5 m length, 0.4 m high and 0.4 m wide. Slope was constructed inside tank with 10 cm layer using standard compaction effort. After construction, slope was fully saturated and constant water flow was applied. Then tank was lifted up using hydraulic jag to 30^o. Plastic box with mass inside was used to push the water level deeper and protect the outflow of water (Fig. 3). First cracks were observed after first 30 min from the beginning (Fig. 4). Next cracks appeared after 75 min from the beginning of the experiments (Fig. 5). Finally after 210 min surface from the top of the slope started sliding down and the slip surface was created (Fig. 6 and Fig. 7).

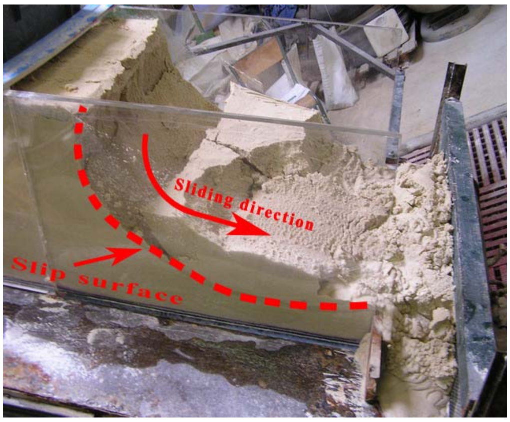

FIG. 7 Slip surface from the second side of tank.

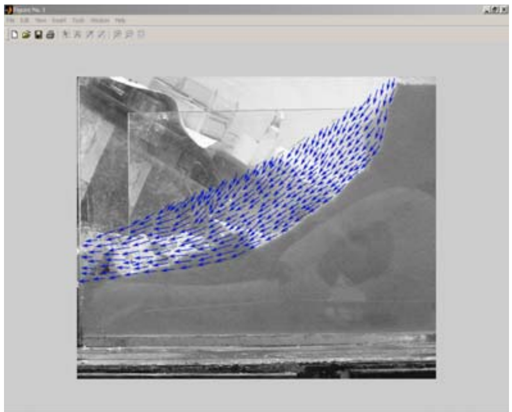

FIG. 8 Particles movement directions calculated by MPIV.

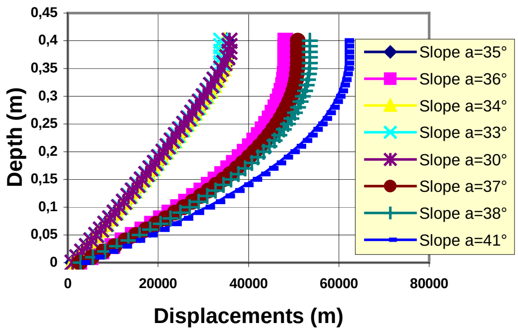

FIG. 9 Theoretical viscous displacements of the laboratory experiment

4.3 PIV observations.

Particle Image Velocimetry (PIV) technique appears over the last two decades, much owing to the developments in digital camera and solid state laser technologies. PIV is a velocity-measuring technique that was originally developed in the field of experimental fluid mechanics White (2003).

PIV can essentially be looked upon as an application of pattern matching principles to experiments. Technique of PIV has proven to be valuable method for quantitative, two-dimensional flow structure evaluation. It enables the measurement of the instantaneous in-plane velocity vector field within a planar section of the experimental field. Due to the large accessible amount of quantitative vectorial velocity data, the PIV method is of great interest to engineers and researchers, allowing them the calculation of spatial gradients, speed of the process, spatial correlations, and others. The classical PIV technique uses multiple-exposure images and optical autospectrum or autocorrelation analysis Hesselink (1988). The precision of PIV over small displacement increments was initially evaluated by White et al. (2001), and was considered in greater detail by White (2001) and Take (2002).

It is very easy to get confused over the fact that to use PIV, it is indispensable to have a grasp of digital cameras, particles, lasers (or other illumination devices) as well as the physics of the experiment. The first step to work with the PIV is to add some tracer into phenomenon field. To measure the motion of this tracer normally it's necessary to illuminate it and take picture or film it with the camera. To accomplish this we may need to use optics, and to film it we may need some technological insight (like knowing how to use a video camera), but at the end we can go thought all these steps in order to generate a pattern in the phenomenon field and registering the motion of it.

This pattern is subsequently used for pattern matching which will tell us something about displacements. If we divide the displacement by the separation time between our images (we assume we have taken two images in order to match patterns between them) we end up with direction of particle movements and velocity (Fig. 7). Images which were analysed in PIV were taken by OLYMPUS C-740 digital camera with interval of each 30 sec. This experiment using digital technique showed us that it is possible to observe slow displacements in the soil. However the velocity of the particle movements has not been measured in this experiment.

The results with slope failure were obtained after slope was fully saturated for 24 hours and constant flow of water was applied for experiment. The mix of the soil used in this research was composed of 20% of kaolinite in volume and 80% of fine grained sand.

The theoretical viscous model was applied first to study the natural slope (Fig.2) and allows to predicts the actual inclinometer displacements with a fine agreement. When it is applied on the laboratory experiment, it predicts a slope failure at 35° (Fig.9), whereas the experimental failure is a classical slope instability observed at a slope of 30° (Fig.7-8). This can be explain by the condition of scale between natural slope and experimental one, by the soil which is different, and by the fact that the level of stress in the experiment is much smaller than in the Saint-Guillaume slope.

4 Conclusions

Explanation of the phenomenon which occurs on the Saint Guillaume is a viscous phenomenon with slow displacements of the natural slopes. The laboratory studies have shown that, using the artificial material, it is possible to reproduce a sliding failure mode in the laboratory test. This phenomenon is composed of lot of factors (atmospheric, mechanic and tectonic) and soil parameters. The good connection between theoretical and experiment can be observed in the natural slope, but not in the experimental one. This research used a new technology called Particle Image Velocimetry. Simultaneously it is possible to observe very slow displacements of the slopes. The method (PIV) which was used and presented here gives us a lot of ability to measure movements which cannot be observed with human eyes. For best results, and precise measurements it is suggested to use two cameras for a movie (of the slow displacements phenomenon in progress) from two different positions. The Particle Image Velocimetry allows us to analyse many micro phenomenons, which can be applied to macro phenomenon's. The results, obtained from the PIV, as i.e. tracers of the particle movements, can be used in the other investigations of the soil particles analysis like foundation analysis and so on… The PIV is not an expensive method, it is very useful and precise, and gives satisfied results.

References

Hesselink, L., (1988), Digital image processing in flow visualization. *Ann Rev Fluid Mech 20 : 421-485*

White D.J., Take W.A., Bolton M.D., (2003), Soil deformation measurement using particle image velocimetry (PIV) and photogrammetry., *Geotechnique 53, No. 7, 619-631*

White D.J., Take W.A., Bolton M.D., (2001), Measuring soil deformation in geotechnical models using digital images and PIV analysis., *Proc. 10th Int. Conf. on Computer Methods and Advances in Geomechanics. Tuscon, Arizon. Pub. Balkema, Rotterdam 997-1002*

White D.J., Take W.A., (2002), GeoPIV: Particle Image Velocimetry software for use in geotechnical testing., *Technical Report, CUED/D-SOILS/TR322, Cambridge University Engineering Department*