MOIRÉ INTEFEROMETRY APPLIED TO SOIL DYNAMIC STUDIES

MOIRÉ INTERFEROMÉTRICO APLICADO A ESTUDOS DE DINÂMICA DO SOLO

ANTONIO JOSÉ DA SILVA MACIEL[1]
DANIEL ALBIERO[1]
INÁCIO MARIA DAL FABBRO[1]

ABSTRACT

This research work reports the application of a shadow *moiré* technique as a photoelastic method to support a qualitative stress distribution study on soil samples. The knowledge of stress distribution on undisturbed soil is of unquestionable value to tillage purposes as well as to the civil construction field. The name *moiré* has its origin in the French language, referring to *wave like pattern.* When screens of same mesh density are superposed, fringes are generated which move when its relative positions are displaced, it was reported that *moiré* fringes can be used to magnify displacements, being also suitable as a photoelastic method. The experimental setup for this work included a digital camera to capture the *moiré* patterns generated for the Ronchi grid and a light source. The images were processed by the softwares named IrfanView, and Idrizi. Five images were taken the sample of clay and they were submitted to varying axial loads kept under the failure stress. Undisturbed samples cylindrical were prepared at the dimensions of 60 mm of height and 60 mm of diameter. Results included the stress distribution maps for each case. It is concluded that the technique get to determine qualitatively the principal stress in soil cylindrical testing specimens.

Keywords: Soil Behavior; Optical Interference; Brazilian Test.

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[1] UNICAMP/FEAGRI – Depto. de Máquinas Agrícolas, C.P. 6011 - 13083-875 – Campinas, SP – Brasil.
Corresponding author : E-mail: daniel.albiero@agr.unicamp.br

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RESUMO

Este trabalho de pesquisa trata da aplicação da técnica de moiré de sombra como um método fotoelástico para auxiliar em estudos qualitativos na distribuição de tensões em amostras de solo. O conhecimento da distribuição da tensão sobre solos não perturbados é de grande importância para o trabalhos de preparo de solo, assim como na área da construção civil. A palavra moiré tem origem francesa e se refere a um padrão de onda, quando grades de mesma densidade de linhas são superpostas são formadas franjas que se movem quando as posições relativas dos deslocamentos mudam, sendo que as franjas de moiré podem ser usadas para aumentar a percepção do deslocamento, representando um método fotoelástico. O arranjo experimental adotado neste trabalho inclui uma câmera digital para capturar os padrões moiré gerados por uma grade Ronchi e uma fonte de luz. As imagens foram processadas pelos softwares IrfanView e Idrizi. Cinco imagens foram obtidas de amostras de latossolo vermelho distroférrico que foram submetidas a cargas axiais variáveis até o falha por tensão. As amostras de solo não perturbado foram preparadas com dimensões de 60 mm de altura e 60 mm de diâmetro. Como resultados foram obtidos os mapas de isodeformação das amostras, dos quais se conclui que a técnica conseguiu determinar qualitativamente a distribuição de tensões principais das amostras cilíndricas.

Palavras Chaves: Comportamento do Solo; Interferência Óptica; “Brazilian Test”.

INTRODUCTION

Specific projects and individual operation actions involving tillage faces a significant lack of information on soil behavior. Tilling tools design should be based on the natural soil failure pattern, as well as stress distribution during compression and traction in static and dynamic situations. Soil failure occurs when the bonds among the particles are overcome. The combination of shear, traction and impact loading associated o a complex stress distribution involving soil and tilling tool characterize the mechanical situation during soil failure (GILL, 1968).

The internal friction angle and cohesion are the soil resistance defining parameters (HILLEL, 1980). LOBO CARNEIRO (SBPC, 1998) developed a method to determine traction resistance of concrete material by applying diametrical loading to cylindrical specimens. That method lately named as brazilian test was officially adopted by the International Standards Association (ISO), (SBPC, 1998). This method is applied since 1959 to soil samples (HILLEL, 1980). KEZDI (1974) reports a tensorial analysis based on the LOBO CARNEIRO method (UPADHYAYA, 1994). Detailed observations in considering the soil as continuous body as required by the mechanics of continuous media (GILL & VANDEN BERG, (1968) and FUNG, (1994)).

The objective of this research work is to propose a method for a qualitative principal stress distribution in the lateral transversal direction on cylindrical monolithic soil samples under traction loading to failure, based on the method proposed by KEZDI, with shadow moiré technique that produce a qualitative deformation pattern on soil cylindrical testing specimens since the relative fringes magnification will generate different patterns during a continuous compression loading. Shadow moiré technique was selected to support the tests because fringes relative movement allows the generation of differentiated patterns associated to continuous specimen loading. These patterns are formed by the specimen deformations, which infers stress distributions.

MATERIAL AND METHODS

The experimental phase of this research work was carried on Campinas, SP, Brazil. Figure 01 shows the employed optical setup which consisted in a 500 W Sawyers Grand Prix 730RI slide project used as a light source, a 3.2 Mpixels Sony P32 digital camera and a 0.4 mm square grid.

The technique of shadow moiré is easily tested by illuminating the object in study after a grid by a light source, generating, that way, an optical interference between the grid and its shade. *Moiré* are used either as a perfilometric technique or as a photoelastic method. In this paper, electromagnetic and quantic light properties will be neglected and only wave theory considered understanding the undergoing optical phenomena. The wave function describes the light propagation as waves (SALEH, & TEICH, M.. 1991).

When two waves of same frequency and amplitude exist simultaneously in the same space region, the total wave function is the summation of theses waves and their phase relationship will generate fringe patterns of different light intensities (SALEH & TEICH, 1991).

When two grids or screens are superimposed, fringes are generated as a result of these grids line combinations. These fringes are named *moiré* patterns or *moiré* fringes and the phenomena called *moiré* effect. These fringes have displacement magnifying abilities (CLOUD 1988). Projecting and shadow *moiré* are the mostly employed shape surveying techniques due their simplicity and quickness (HU, 2001).

Moiré fringes can be sought as a superposition of two plane waves, which keeps an angle between their travelling directions. In the regions where the waves are on phase, a constructive interference is generated, showing clear patterns and in the case of destructive interference, dark patterns are formed (MALACARA, 1992).

Such an approximation is derived from the interference between fringe patterns by means of the relations so called initial transition model (PISAREV& BALALOV, 2004)

By employing the whole field subtracting method as defined by POST (1994), an isostrain field could be defined which would indicate the occurrence of stress concentration.

Moiré fringes are generated by points of equal height similar to contour lines of topographic maps, as seen on Figure 02. POST (1994) states that fringe shape obtained when bar
which are equal to the space between them, the grid is well defined at the edges of the

bars, the intersection angle between the light beam and observer lines are small and the ratio
1.

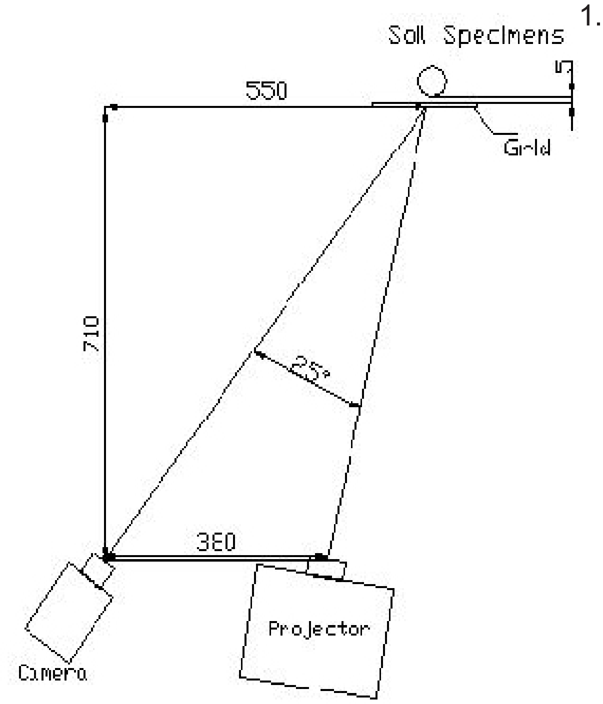

Figure 01 - Optical experimental setup employed

(a)

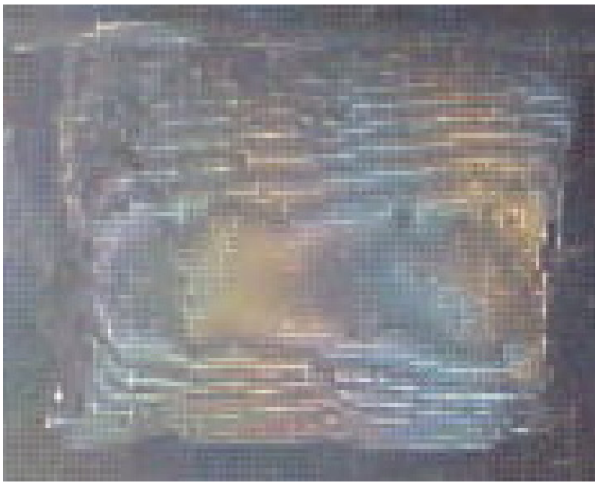

Figure 02. (a) Grid setup employed in the shadow *moiré* tests; (b) *Moiré* fringes appearing as Contour lines on the cylindrical soil specimen.

The studied soil was classified as clay (USDA, 1967), constituted by 57% clay, 11% silt, 22% sand, and 10% Organic Material, apparent density of 1270 kg m^{-3}, 24.9 % of moisture content and cone index of 1500 kPa. The soil sampler consisted of articulated steel ring as

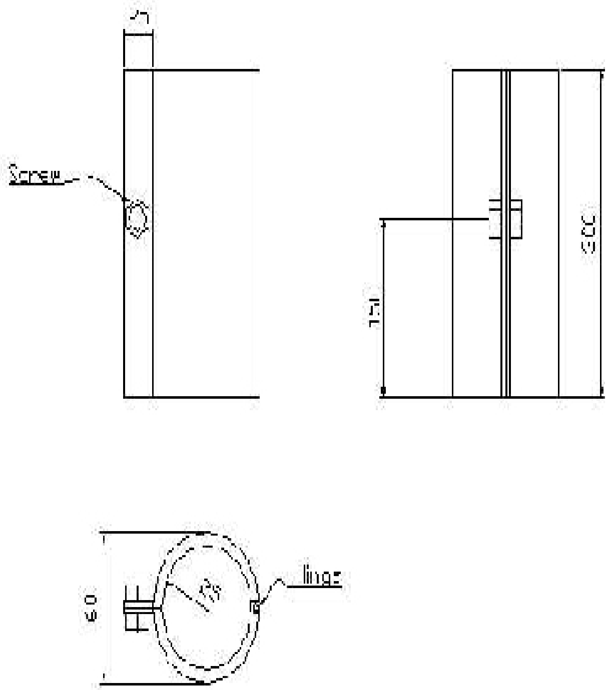

Figure 03 - Articulated steel ring soil sampler.

A 5000 N OTTOWA TEXTURE MEASURING SYSTEM testing press was employed to carry the compression tests coupled with 2500 N load cell and connected to a HBM SPIDER 8 signal conditioner. Digital interface was monitored by the 1.2 version HBM CATMAN. Ramp strain loading at a strain rate of 0.36 mm/s were imposed to the specimens at 05 different situations, characterized limiting forces of 0 N, 6.63 N, 16.07 N, 25.38 N and a maximum force of 46.07 N.

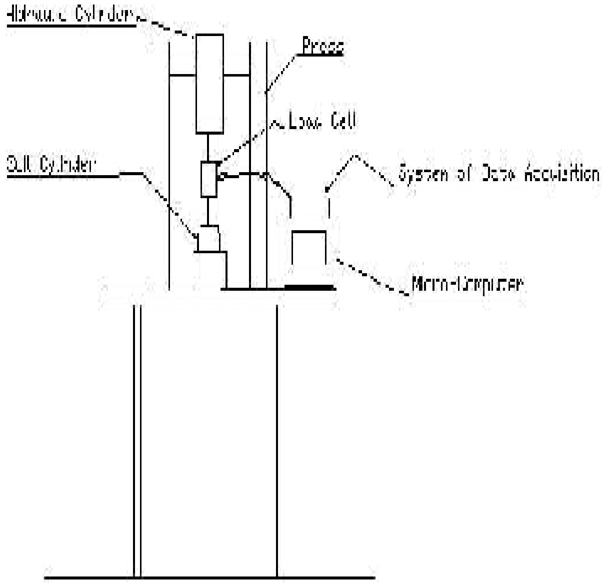

Figure 04 - Experimental setup employed in the compression tests.

Digital picture were expressed in JPEG format and converted to gray levels in BMP by means of the GIMP software where the number **0** refers to dark color and the number **255** for white color. Picture were processed by means of the IDRISI software and noise as well as errors eliminated by employing specific filters.

Whole field subtraction method was employed as defined by POST (1994), by subtracting pixel to pixel of a picture referring to a X_i loading from a picture at X_{i+1} loading level. That method allows determining the deformation experienced by a testing specimen between two loading level situations by means of both image superposition.

RESULTS AND DISCUSSION

Figure 05 exhibits fringe patterns for a non-loading situation presented to compare with loaded specimens fringes after image processing. Fringes for remaining loading cases are displayed from Figure 06 to Figure 09

Isostrain maps indicates points of same strain values, having the same pixel, expressed in gray levels but they can also be represented in color scales

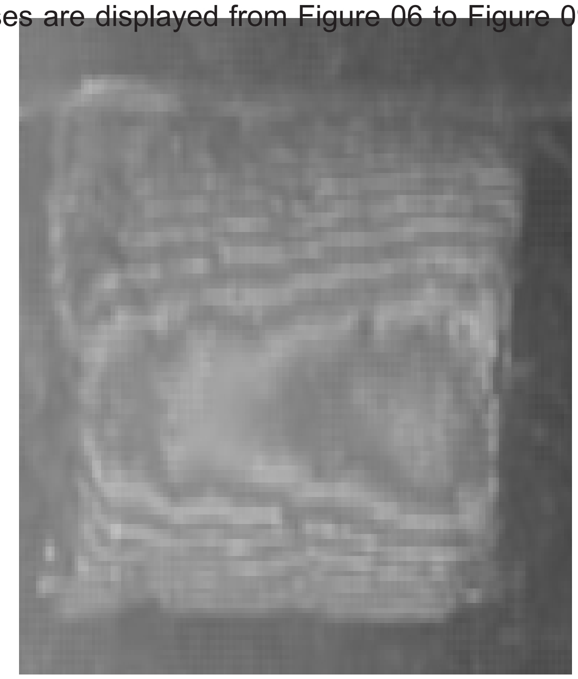

Figure 05 - Fringe pattern on a cylindrical soil testing specimen loaded at 0 N.

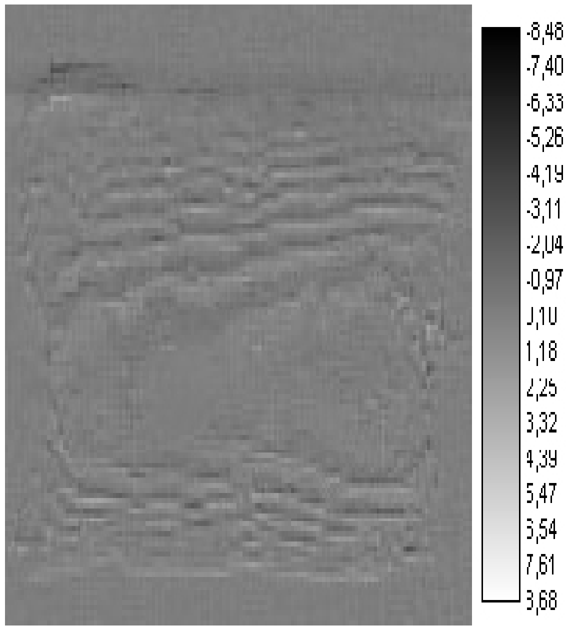

Figure 07 - Isostrain map on a cylindrical soil specimen loaded at 16.07 N, scale in gray level.

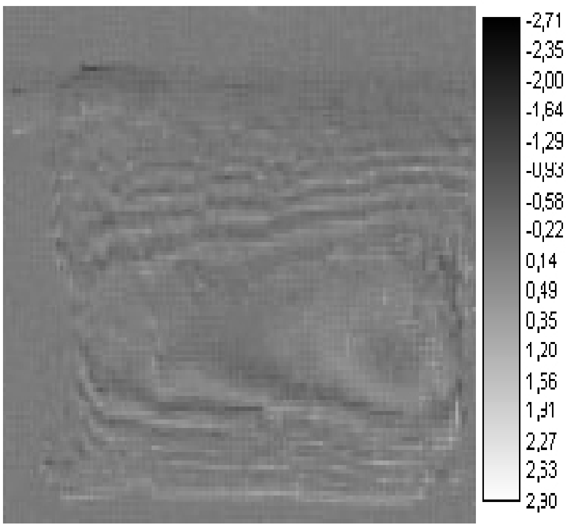

Figure 06 - Isostrain map on a cylindrical soil-testing specimen loaded at 6.63 N,scale in gray **level.**

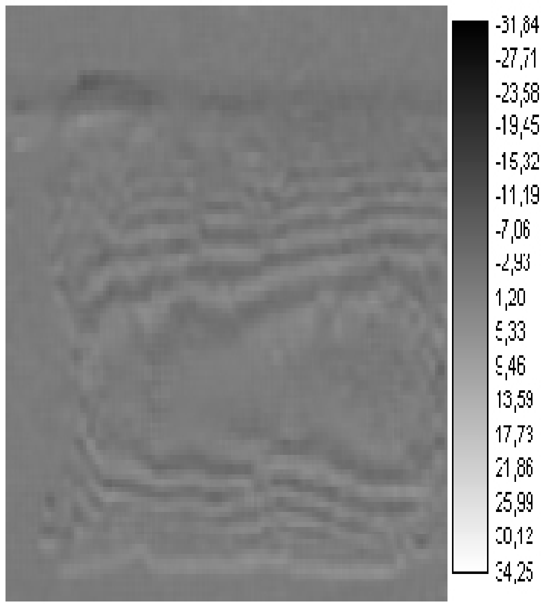

Figure 08 - Isostrain map on a cylindrical soil specimen loaded at 25.37 N, scale in gray level.

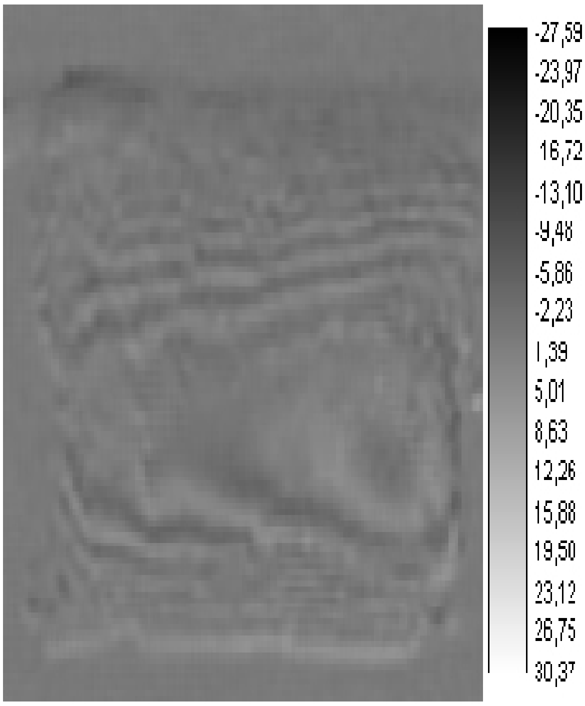

Figure 09 - Isostrain map on a cylindrical soil specimen loaded at 46.07 N, scale in gray

POST (1994) stated that shadow *moiré* technique captures out of plane deformations experienced by a loaded specimen. Soil material is not homogeneous then will experience distinct deformation patterns, generating distinct fringe patterns.

Gray levels observed on Figure 06, 07, 08 and Figure 09 discloses increasing deformation tendencies revealed by pixel-to-pixel subtraction from the image generating matrices. Each image pixel is defined as a light intensity referenced in gray level, from 0 to 255 level of gray in such a way that the subtraction of a pixel from undeformed specimen image by a deformed specimen image pixel will generate a qualitative pixel, which informs the deformation level experienced by the specimen region under consideration.

These scales exhibit a qualitative character rather than a quantitative one, showing the signals (+) and (-) to emphasize larger and smaller deformations, respectively. These figures show lager deformations at the specimen right side, which could be explained by a not adequate compressing plate horizontal position.

As it was explained before, this technique captures out-of-plane deformations inferring a stress level in that principal direction. KEZDI em 1974 developed a graphical technique to obtain the principal stresses in diametrical loaded cylinder as function of the applied load and of the cylinder dimensions (UPADHYAYA, 1994).

The results of this work include a qualitative map of the principal stresses, which non-uniformity can be explained by the non-isotropism exhibited by the soil material. GILL (1968) emphasizes that soil non-continuous conditions suggests some cautions in employing the above description.

CONCLUSIONS

Shadow *Moiré* technique showed to be useful in magnifying relative fringes displacements generated from continuous loading allowing to obtain sample relative displacement for each loading level. Future studies should include the determination of relative deformation quantitative value by means of a correlation between light intensity for each pixel.

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