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EFFECT OF END CONDITIONS ON THE UNIAXIAL COMPRESSIVE STRENGTH OF FROZEN SAND

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Four different platen configurations were used to determine the influence of some end conditions on the laboratory-determined uniaxial compressive strength of frozen sand. Cylindrical specimens of fine Ottawa sand (ASTM designation C-109), compacted at the optimum moisture content and saturated before unidirectional freezing, were tested at temperatures varying between -5 and -6°C. Each specimen was subjected to a constant strain rate of 0.7×10^{-3} min^{-1} using an Instron, universal testing machine (model 1127). A compliant platen designed to reduce friction between platen and specimen, to distribute the load uniformly, and to minimize stress gradients produced by eccentric loading, was found to be most desirable in determining the uniaxial compressive strength of the frozen sand specimens.

INFLUENCE DE LA CONFIGURATION DES EXTRÉMITÉS D'UN ÉCHANTILLON DE SABLE GELÉ SUR LA RÉSISTANCE DE CELUI-CI À LA COMPRESSION UNIAXIALE.

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On a utilisé quatre différentes sortes de plaques de pression, pour déterniner l'influence que peut avoir la configuration des extrémités d'un échantillon de sable gelé sur la résistance à la compression uniaxiale de celui-ci, dans les conditions du laboratoire. Les éprouvettes cylindriques de sable fin d'Ottawa (désignation ASTM C-109), ont été comprimées à leur teneur optimale en eau, puis saturées, avant d'être soumises à une congélation unidirectionnelle; puis on les a soumises aux essais de compression à des températures variant entre -5 et -6°C. On a utilisé un Instron, qui est un appareil universel d'essai de résistance des matériaux (modèle 1 127) pour soumettre chaque éprouvette à une vitesse de déformation constante de 0.7 x 10^{-3} min^{-1}. On a constaté qu'une plaque de pression souple, destinée à réduire la friction entre la plaque et l'éprouvette, et à répartir uniformément la charge, et aussi à réduire les gradients de contrainte produits par une charge excentrique, convenait parfaitement pour déterminer la résistance à une contrainte uniaxiale des éprouvettes de sable gelé.

ВЛИЯНИЕ КОНЕЧНЫХ УСЛОВИЙ НА СОПРОТИВЛЕНИЕ ОДНООСНОМУ СЖАТИЮ МЕРЗЛОГО ПЕСКА

Для определения влияния некоторых конечных условий на сопротивление одноосному сжатию мерзлого песка в лабораторных условиях использовались четыре плиты различной конфигурации. Цилиндрические образцы мелкозернистого песка /ASTM C-109/, уплотненные при оптимальном влагосодержании и насыщенные перед односторонним замораживанием, испытывались при температуре, колеблющейся от -5 до -6°C. Каждый образец был подвергнут деформации с постоянной скоростью 0,7 X 10^{-3} $мин^{-1}$ на универсальной испытательной машине Инстрон /модель 1127/. Испытания показали, что при определении прочности на одноосное сжатие образцов мерзлого песка целесообразно использовать мягкую плиту, конструкция которой позволяет уменьшить трение между плитой и образцами, равномерно распределить нагрузку и снизить градиенты напряжения, возникающие при эксцентрической нагрузке.

EFFECT OF END CONDITIONS ON THE UNIAXIAL COMPRESSIVE STRENGTH OF FROZEN SAND

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INTRODUCTION

In the conventional uniaxial compression test, force is applied to the ends of right circular cylindrical specimens through steel platens that make direct contact with the test specimen. Friction between the platen and specimen produces radial restraint, so there is a triaxial state of stress near the end planes. Insertion of a highly compliant sheet between platen and specimen will change the sign of radial end forces from compressive to tensile, but does not eliminate the triaxial stress state. Irregularities in the specimen end planes can create stress concentrations that could lead to premature failure of the specimen (IAHR, 1975). Stress gradients can be produced by eccentric loading and by lack of parallelism between specimen end planes or between specimen ends and loading platens.

One solution to the aforementioned problems would be to accept some frictional restraint at the specimen ends and to prepare specimens with large slenderness ratios (height/diameter). If the specimen is long enough, the mid-section is relatively free from end effects. Newman and Lachance (1964) showed that platens either more compressible than the specimen or less compressible than the specimen affect the specimen over an axial distance from the end planes of about one specimen radius. A slenderness ratio greater than two usually eliminates the effects of end conditions on compressive strength (Mogi, 1966). The relationship of platen/specimen compressibility and slenderness ratio and their effect on uniaxial compressive strength are shown in Fig. 1. The ideal relationship would be achieved when the platen and specimen have the same compressibilities and there is no relative movement between platen and specimen ends (Painting, 1974).

Specimens with large slenderness ratios require special care in preparation to ensure that the end planes are normal to the axis of symmetry and flat within strict tolerances. Flexure of the specimen must be avoided by strict alignment and high rigidity in the loading system to avoid rotation or lateral movement of the platens. Haynes and Mellor (1976) found it extremely difficult to obtain valid results when testing ice in the conventional uniaxial compression test, even when extreme care was exercised. Tests performed by the author on specimens of frozen sand were found to agree with some investigators, but disagreed with others. Figure 2 presents the author's data along with other investigations into the effect of applied strain rate on the uniaxial compressive strength of frozen sand in the same temperature range. Some discrepancy in the test results may be due to end effects, specimen variability and variability in the test conditions.

A testing program, using specimens of frozen sand, was initiated to investigate the influences of various end conditions employed in the uniaxial compression testing of brittle materials. Four platen configurations were considered.

1. Aluminum end cap. (Hawkes and Mellor, 1972)

2. Aluminum disk platen with a rubber insert. (Davin, 1956; Newman and Lachance, 1964)

3. Aluminum disk platen. (Hawkes and Mellor, 1970)

4. Maraset compliant platen. (Kartashov et al, 1970; Haynes and Mellor, 1976; Law, 1977)

Each specimen was subjected to a constant strain rate of 0.7×10^{-3} min^{-1} using an Instron universal testing machine (model 1127). This strain rate was chosen as it was in the middle speed range capability of the testing machine and was in a range where the data from the literature disagreed with the author's data.

SAMPLE PREPARATION

Fine Ottawa sand (ASTM designation C-109) was compacted into a plexiglas split mould in layers at the optimum moisture content (14 per cent by dry weight), as determined by a standard Proctor compaction test. The mould was evacuated and saturated with distilled water prior to freezing. Insulation was placed around the mould to ensure uniaxial freezing at a cold room temperature of -5°C. After complete freezing, which took about 3 days, the sample was taken out of the mould and the ends were machined and faced to the required specimen length. Fifty-one test specimens were produced with an average total moisture content of 19.2 per cent and a standard deviation of 1 per cent. A more detailed description of the procedures followed in the preparation of these specimens can be found in Baker (1976).

All of the test specimens used in this investigation were 76 mm in diameter and were machined and faced to the following lengths.

Length (mm)	Slenderness Ratio
57	0.75
76	1.0
152	2.0
196	2.6

DESIGN OF COMPLIANT PLATEN (LAW, 1977)

The compliant platen used in this study was developed within the Division of Building Research, National Research Council of Canada. Its design was based on the work performed by Kartashov et al (1970) and Haynes and Mellor (1976). The platen consists of a circular plug of compliant material surrounded by a metal ring. The design criterion determining the dimensions and properties of these platen components is as follows.

The compliant plug can be made from any material that is more compressible than the specimen. This relationship must satisfy the expression:

$$\frac{\nu_p}{E_p} > \frac{\nu_s}{E_s} \tag{1}$$

where E_s, ν_s = modulus of compression and Poisson's ratio of the specimen material. Frozen soil is a viscoelastic material so the secant modulus at failure was used.

E_p, ν_p = modulus of compression and Poisson's ratio of the compliant plug material.

The confining ring can be made from any material whose rigidity exceeds a certain limit given by the expression:

$$\frac{E_c}{1+\nu_c} > \frac{\nu_p}{1-\nu_p}\left[\frac{E_s}{\nu_s} - \frac{E_p}{\nu_p}\right] \tag{2}$$

where E_c, ν_c = modulus of compression and Poisson's ratio of the confining ring material.

The diameter of the compliant plug is made equal to the specimen diameter and the thickness of the plug is made equal to the radius of the specimen.

The thickness of the ring is designed so that the lateral expansion of the platen, under load, is the same as that of the specimen. Thickness of the ring is equal to:

$$T = b - a \tag{3}$$

where T = thickness of the ring

b = external radius of the ring

a = radius of the compliant plug (specimen)

The external radius of the ring is equal to:

$$b = \sqrt{\frac{1+C(1-\nu_c)}{1-C(1+\nu_c)}}\, a \tag{4}$$

where $$C = \frac{\nu_p}{E_c(1-\nu_p)}\left[\frac{E_s}{\nu_s} - \frac{E_p}{\nu_p}\right] \tag{5}$$

An epoxy resin, Maraset #638-45, was chosen as the compliant plug material used in the testing of frozen sand.

DISCUSSION OF RESULTS

The results of the tests using the four platen configurations are shown in Figs. 3 to 6. The horizontal line gives the mean strength obtained, the vertical line gives the standard deviation and the number denotes the number of tests completed for each slenderness ratio.

<u>Aluminum End Cap</u> (Fig. 3)

This type of platen was used by Hawkes and Mellor (1972) for testing dumbell shaped specimens of ice. The dumbell shape was designed to eliminate end effects using rigid end conditions. When using these platens with right cylindrical specimens the ends were completely restrained from lateral movement. Specimens of small slenderness ratio are actually being stressed triaxially. As the specimen length is increased, the effect of end confinement on the over-all strength of the specimen is reduced.

<u>Aluminum Disk with Rubber Insert</u> (Fig. 4)

Low modulus inserts and lubricated friction reducers have been employed in compression testing to reduce stress concentrations at the end faces of specimens with rough texture. Tensile forces are produced at the specimen ends by the lateral movement of the insert. As the compressive stress is increased, vertical tensile cracks appear in the specimen radiating from the centre of the loaded face. Vertical stresses are concentrated at the centre of the loaded face and vary in magnitude with the compression modulus and thickness of the insert material. Similar behaviour is observed if the ends of the specimen are convex, or if the loading platen in contact with the ball seating is not rigid enough. The influence of this end condition is greatest on specimens with small slenderness ratios.

<u>Aluminum Disk Platen</u> (Fig. 5)

Aluminum was chosen over steel as it had a lower compression modulus. The elastic match between platen and specimen determines the end condition imposed on the specimen. Steel and frozen sand have a modulus ratio of about 0.001. Aluminum and frozen sand have a modulus ratio of about 0.005. An ideal match would have a modulus ratio of 1.0.

The thickness of the platen is important as its rigidity must be high in order to prevent bending stresses. This can also be prevented by using a spherical seating arrangement having a larger radius than the ball seat used in this investigation. The platens used during these tests showed no sign of bending.

Some friction appeared to be occurring between the platen and specimen at smaller slenderness ratios. At a slenderness ratio of 2.0 the compressive strength appears to level off to a value of 12,500 kPa. This would appear to be an average value for the first three platen configurations and specimens having large slenderness ratios. From previous investigations of end effects on compression testing of materials (Newman and Lachance, 1964) this value would be reported to be the true compressive strength of the material.

The large standard deviations in strength for each slenderness ratio may indicate the effect of surface roughness and resulting stress concentrations. Surface roughness would be different for each sample tested and cause a large variation in the resulting strengths.

Maraset Compliant Platen (Fig. 6)

The variation in uniaxial compressive strength with increasing slenderness ratio is very small. This small variation can be explained by the differences in moisture content between specimens. The variation of compressive strength with the moisture content of specimens tested with the Maraset platens is shown in Fig. 7. Specimens with a slenderness ratio of 2.0 had a lower moisture content than those with a ratio of 2.7. Strength appeared to decrease with increasing moisture (ice) content in the range of moisture content tested. The relationship of moisture content to strength of frozen soil has been explained by Tsytovich (1975).

The compressive strength of the frozen sand was found to be about 25 per cent higher using the Maraset platens than with the other platen configurations at high slenderness ratios (≥ 2.0). At a slenderness ratio of 2.7 the first three platen configurations had an average strength of 12,300 kPa and the Maraset platens would have averaged about 15,700. Haynes and Mellor (1976) found similar results using compliant platens to test cylindrical specimens of ice having large slenderness ratios (2.2 to 2.5). The strengths they obtained from testing cylindrical specimens with compliant platens agreed well with those obtained from testing dumbell shaped specimens. They attributed this higher strength to the reduction of stress concentrations resulting from rough specimen ends in contact with the loading platens. Kartashov et al (1970) found a similar result in their tests on rocks.

CONCLUSION

Law (1977) proposed a procedure for designing compliant platens to match the characteristics of the specimen being tested. His design equations are based on the elastic parameters of the materials involved. Frozen sand is a viscoelastic material and exhibits non-elastic features prior to yield. All the specimens tested in this study exhibited a ductile type of deformation. The secant modulus at yield, determined using a standard compression test with steel platens, can be used as the modulus of compression for the specimen (E_s). This value inserted into the design equations would provide a platen that could be used in testing specimens to the yield point and remove the dependence on slenderness ratio as shown by the results obtained from this study.

Compliant platens would reduce the effect of rough ends on specimens and simplify procedures for specimen preparation. Smaller slenderness ratios would eliminate the possibility of buckling and tilting. This would generally reduce the expense of sampling and testing and may reduce some of the variability due to the test conditions.

Platens of this nature may lead to an improved comparison of results obtained by other investigators and may permit the standardization of procedures of testing (frozen) materials.

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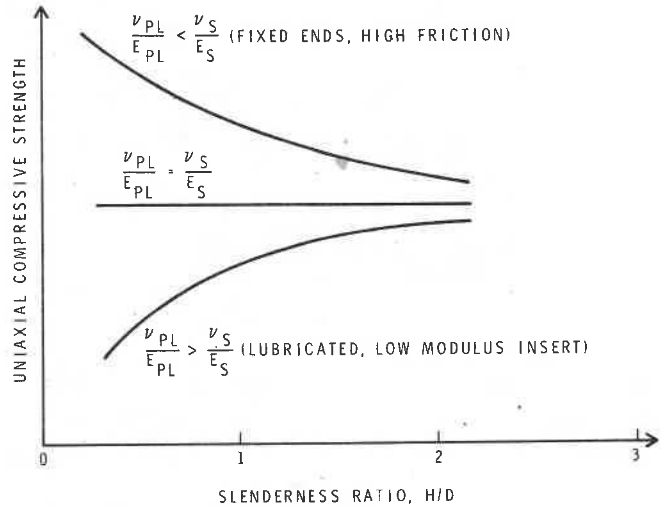

FIGURE 1

UNIAXIAL COMPRESSIVE STRENGTH RELATED TO PLATEN/SPECIMEN COMPRESSIBILITY AND SLENDERNESS RATIO

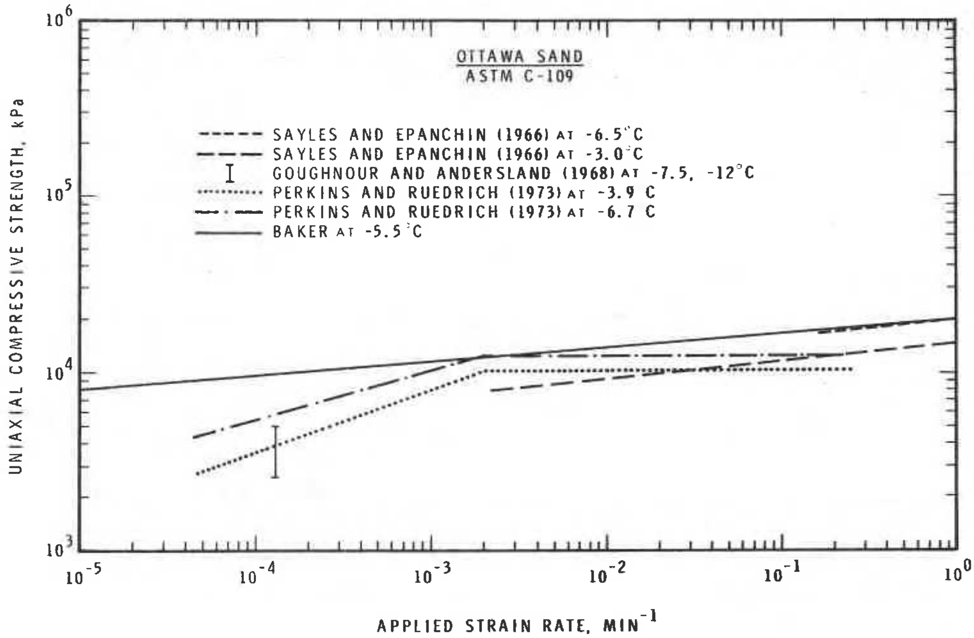

FIGURE 2
EFFECT OF APPLIED STRAIN RATE ON UNIAXIAL COMPRESSIVE STRENGTH OF FROZEN SAND

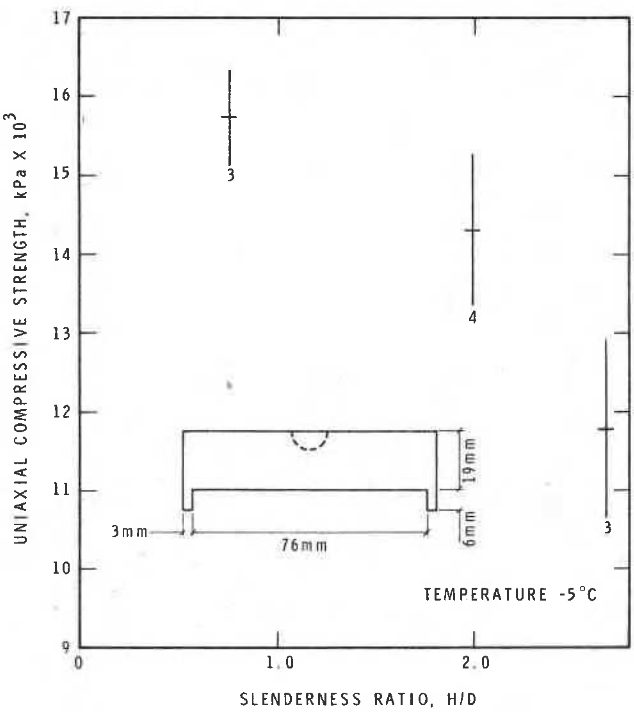

FIGURE 3
ALUMINUM END CAPS

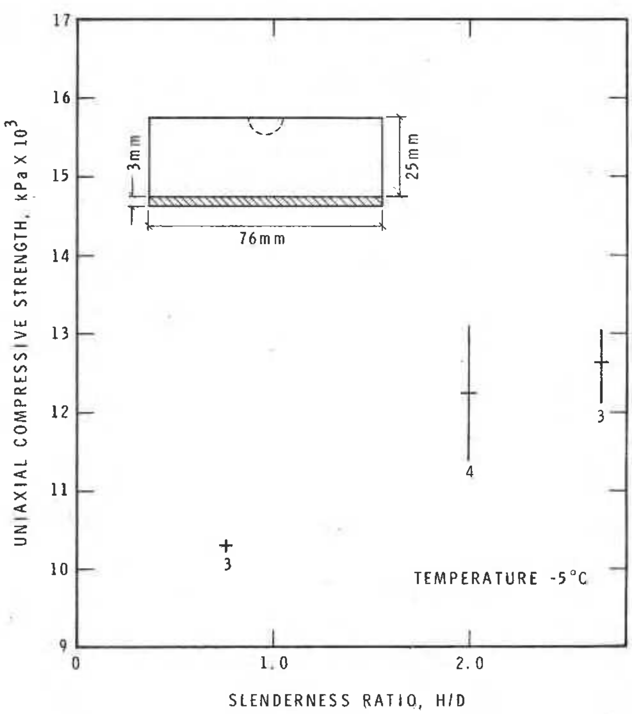

FIGURE 4
ALUMINUM DISK PLATEN WITH A RUBBER INSERT

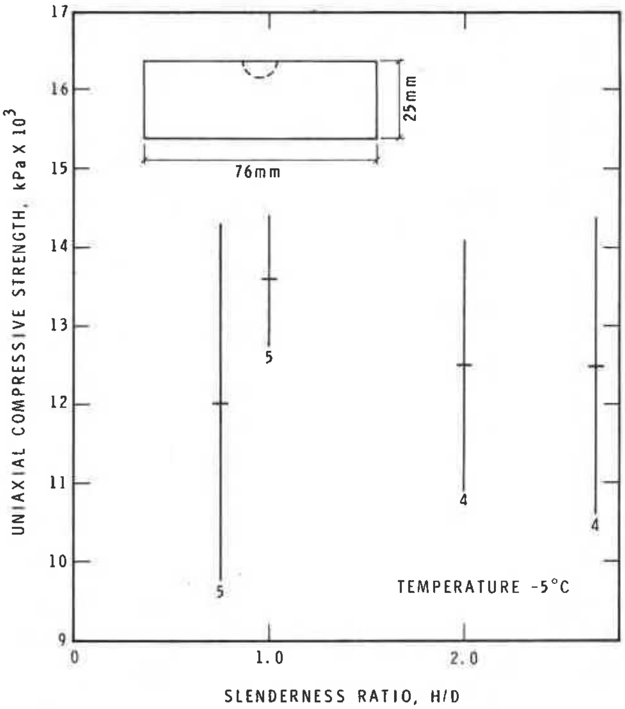

FIGURE 5
ALUMINUM DISK PLATEN

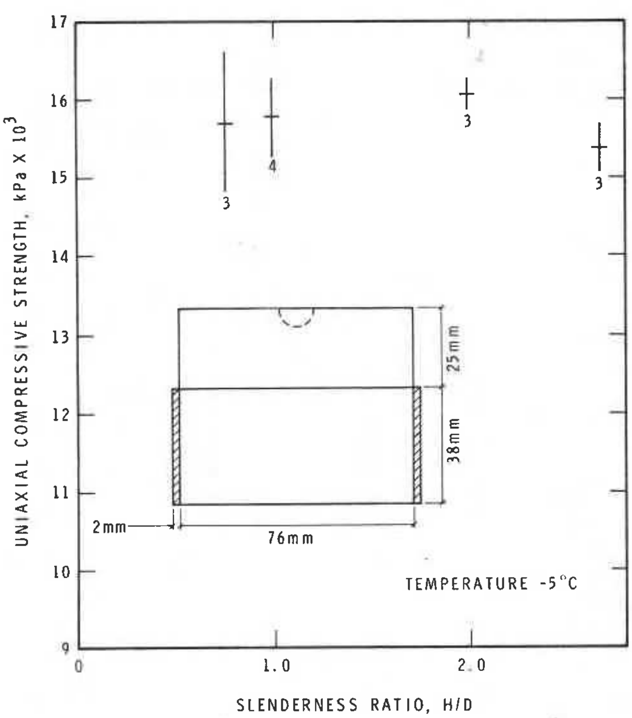

FIGURE 6
MARASET COMPLIANT PLATEN

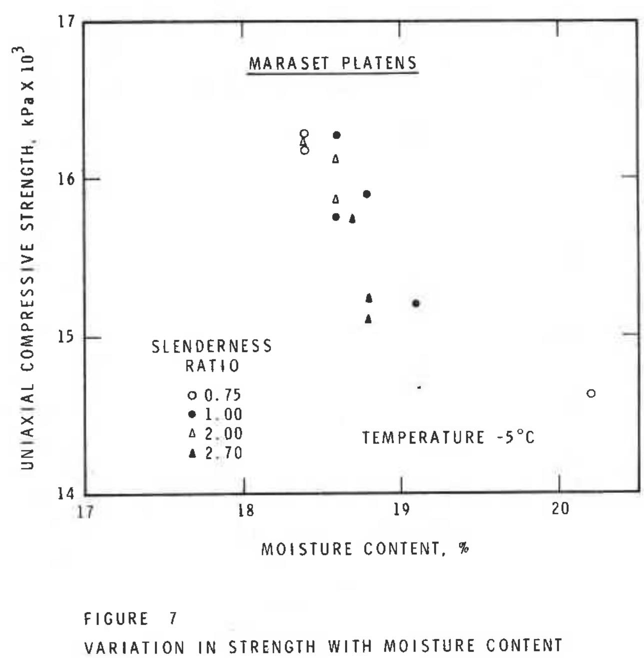

FIGURE 7
VARIATION IN STRENGTH WITH MOISTURE CONTENT