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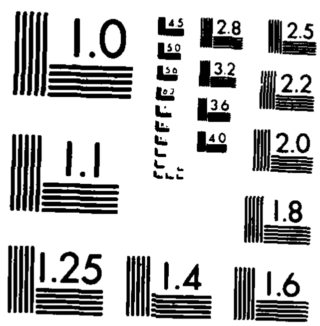
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EXPANDING CLAY SLOPES

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Research Project: CREEP AND SLIDING IN CLAY SLOPES: MUTUAL EFFECTS OF INTERLAYER SWELLING AND ICE JACKING

Principal Investigator: KURT A. CZURDA

Contractor: UNIVERSITY OF INNSBRUCK

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Report Period: DEZEMBER 24TH, 1983 - APRIL 24TH, 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Laboratory tests, partially confirmed by field data, demonstrate that the swelling of freshwater clay exhibits small clay swell expansion (depending upon the initial water content) and additional ice expansion due to ice lense formation. Ice lense formation is enabled only if the freezing process is accompanied by simultaneous water uptake from the bottom. If the natural condition of a sample is almost water saturated, as was the case during sampling in the fall of 1983, the clay represents an already expanded condition..

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## 1. Summary of Research Results up to now

In general, the more advanced laboratory tests from the freezer, the dilatometer and the swell heave apparatus showed excellent trend conformity with the field testing results of the first freezing period: winter 1983/84.

In the laboratory it could be proved that the swelling fresh-water clay exhibits small clay swell expansion (depending on the initial water content) and additional ice expansion due to ice lense formation. Ice lense formation is enabled only if the freezing process is accompanied by simultaneous water uptake (adhesion) from the bottom. If the natural condition of a sample is almost water saturated, as it was the case during sampling in fall 1983, the clay represents already an expanded condition.

The three freezing periods during winter 1983/84 forced the clay in our test section Remigen within the freshwater Molasse of Upper Austria, to form ice lenses during freezing, resulting in an absolute swell heave of roughly 6 cm within the top layer of 10 cm thickness. 10 cm means the maximum of possible frost penetration during the winter period under discussion. The extremely high axial strain - the laboratory results even exceeding - suggests water adhesion from the ground water reservoir through the dried zone immediately below the freezing front. The according thawing periods brought about swell heave within the dried out zone by clay water adsorption.

Fabric rearrangments of the clay flakes show a loosening effect on the clay and probably are responsible for a remaining increased volume and better swelling conditions on further water uptake. Structure collapses are to be expected.

## 2. Results of Field Testing

First results from our field testing equipment is now available and can be evaluated. The following data were obtained in winter 1983/84 between Nov. 7. 1983 and March 3.1984. (Fig. 1)

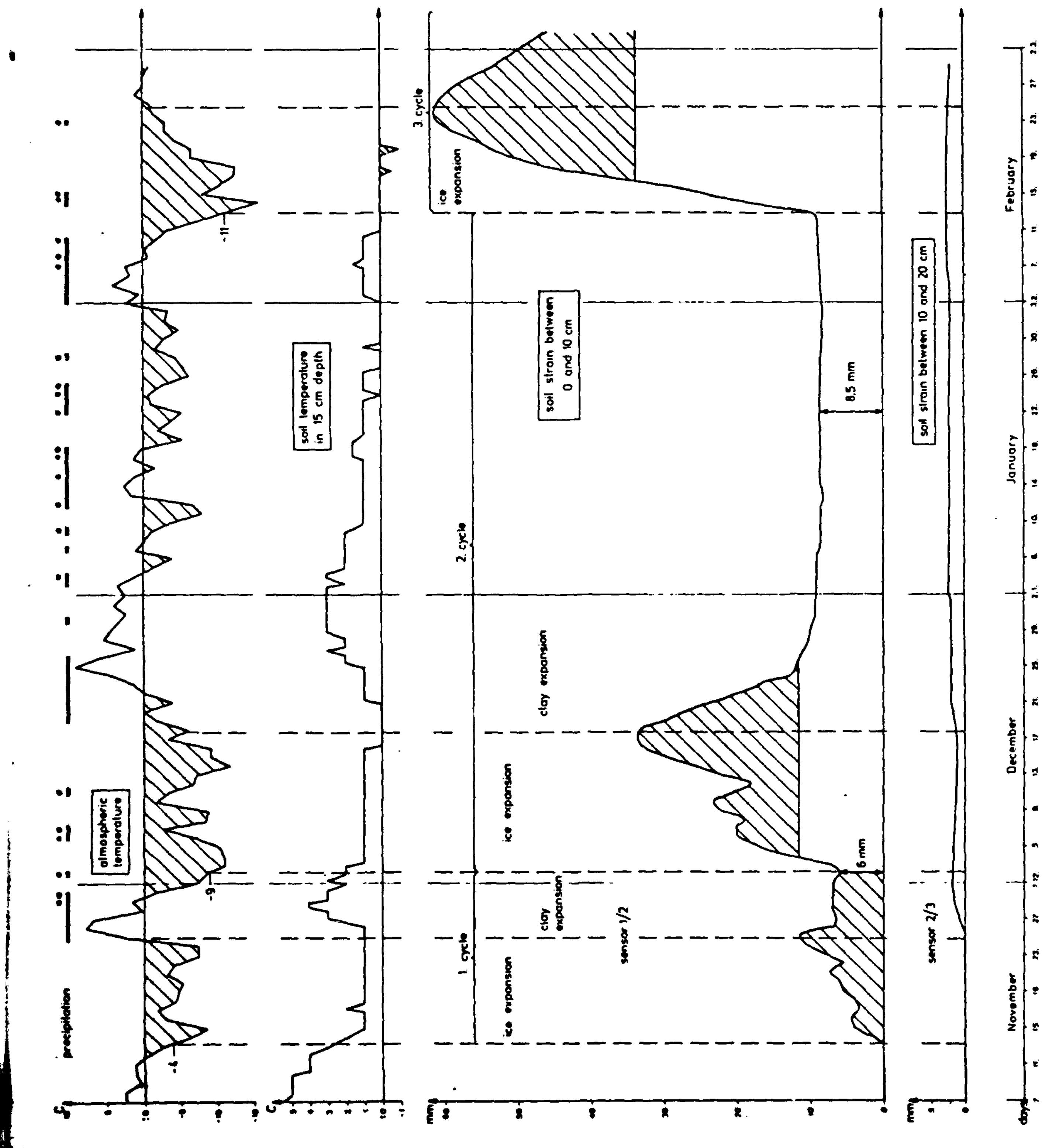
No frost days were registered before the installation of the field testing equipment (soil strain gauges, thermograph) on Nov. 7., thus no frost heave was missed this season.

### 2.1. Clay Strain

The first frost day was Nov. 12.1983. The first frost heave was registered two days later when the external temperature fell below - 4° C. This is due to the fact that the water surrounding the clay flakes stays in a state of tension and freezes at lower temperatures than ordinary water. The temperature where all the water is frozen depends on three parameters: kind of clay minerals,electrolyte content and extent of water saturation. The freezing point of - 4° C for the clay under investigation fits perfectly with the laboratory results (freezer tests). This first freezing period mentioned continued until Nov. 25. The frost heave, interrupted by two small shrinkage intervals, continued for the same time. It's extent of axial volume increase went up by 11,5 mm. Within the following thaw period shrinkage could be registered with an extent of 5,5 mm within one single day. The remaining 6,0 mm persisted as clay swell heave resp. as volume increase due to newly developed surface parallel microcracks.

A second freezing period started on Nov. 30. Certainly the expansion due to freezing began when the atmospheric temperature fell below - 9° C, which was about the lowest temperature during the second freezing period. During this period an expansion up to 27,5 mm occured, again interrupted by two small shrinkage events.

Fig. 1: Atmospheric temperature, soil temperature and soil strain results from winter 1983/84, test site Remigen. Three freeze-thaw cycles with maximum axial volume increase of about 6 cm during the third frost period in Feb. 1984.



Very low resp. none swelling at all has been recorded by the lower sensors: between 21 and 31 cm resp. 31 and 41 cm (sensors 3/4 and 4/5) a swell heave of 0,5 mm during the first frost period and 0,2 mm during the 2. The lower parts of the test section (below 41 cm = sensors 5 to 8) were not affected by any expansion or shrinkage.

## 2.2. Temperature

The temperature, recorded by a dial thermometer in a depth of 15 cm, shows a similar course like the atmospheric values. By all means it is noticeable that all changes - either freezing or thawing - are shifted by two days. The lowest temperature value which was reached in 15 cm depth was - 1° C during the 3. frostheave period (20.2.84). The temperature at 90 cm depth was lowered down to + 4° C during the same period.

The steady registration by means of three thermosensors in 2, 7 and 12 cm depth was not succesful because these sensors are too sensitive against vibrations. We have to place this equipment at another location, seperated from the other installations, in order to avoid disturbance.

Furthermore, during the coming winter season, the accurate freezing depth has to be measured. This could be achieved most accurately by sampling small drilling cores during frost periods.

## 2.3. Piezometer

The recording of the groundwater level through the especially drilled piezometer hole could be done only sporadically and therefore no measured trend in fluctuation could be gained. During the coming cold period, the groundwater level has to be recorded daily because it is of striking interest, how it influences the expected suction during the ice lense formation within the top clay layers.

A direct connection between precipitation and frost expansion resp. shrinkage could not be observed. The most abundant rainfall in most cases goes with thawing periods.

## 2.4. Conclusions

The frost heave rates are surprisingly high. With certainty it can be said that the frost penetration face did not exceed deeper than 11 cm. Assuming that it was at roughly 10 cm, then this means an expansion of 60% - and in case the frost penetration did not exceed that far, this value would increase even more. Compared with the laboratory results (29 - 52%) the field values are slightly higher. A small part of this expansion is certainly due to pure swelling by water uptake within and arround the clay flakes, especially the swelling phases. At any rate this amounts only up to 1-3%. This because the natural moisture content of the clay was measured between 28 and 34%, which means about water saturation. As we know from the laboratory experiments, the clay in this state of moisture content is expanded already.

The clay below the frost penetration line, between lo and 40 cm dcpht, experienced a slight shrinkage during the freezing periods, possibly due to suction of moisture out of this area into the freezing region. A complete drying out is not to be assumed because the extent of shrinkage was not high enough as we know from our laboratory tests. The swelling during the thaw periods are to be attributed to clay expansion by water adsorption because melt water is now diffusing downward and is saturating the dry lower layers. The measured swell heave of 2-3% is adequate to the laboratory results.

It was metnioned and explained already that freezing only starts below - $4^{\circ}$ C. The fact that frost swelling just starts when the lowest temperature of the previous frost period is attained (-9 resp. $-10^{\circ}$ C) is not fully explained yet and has to be checked by laboratory experiments.

## 3. Results of Laboratory Testing

Fig. 2 shows the test results for about water saturated samples - which means natural conditions. Whereas non saturated samples show no volume change at all, the water saturated condition enables at least a week clay swell expansion ( ① ) followed by a week ice expansion ( ② ), resulting in about 4,5% axial strain. The thawing- and drying out phase ( ③ ) forces the sample to shrink below the initial volume.

Fig. 3 contains the expansion diagram for the simultaneous water uptake freezing tests. In the case of freezing with simultaneous water uptake through the bottom filter stone, a total maximum heave of up to 45% on average could be observed. This is due to mainly ice lense formation ( ② ) and a minor part to clay swell heave ( ① ). The shrinkage upon thawing and drying out extents down to the initial volume in an air dried state ( ③ ).

Up to know, the obvious fabric rearrangements during freezing could not bring about remaining volume changes after thawing but because of the small data base of only 8 tests for the above mentioned diagrams (fig. 2 and 3), this is not proved and explained yet.

## 4. Research Plans for the Coming Research Period

In the laboratory much more freezing experiments have to be carried out. This by means of the freezer, containing 6 samples (dimension of cylindrical samples: Ø 5 cm, lenght 5 - 8 cm) and the dilatometer (dimension of cylindrical samples: Ø 8 mm, lenght 30 - 50 mm). Further, swell heave tests without freezing have to be performed in the expansion apparatus. The influence of different electrolyte solutions on swelling and freezing will be studied as well. The influence of cation saturation as a result of the primary

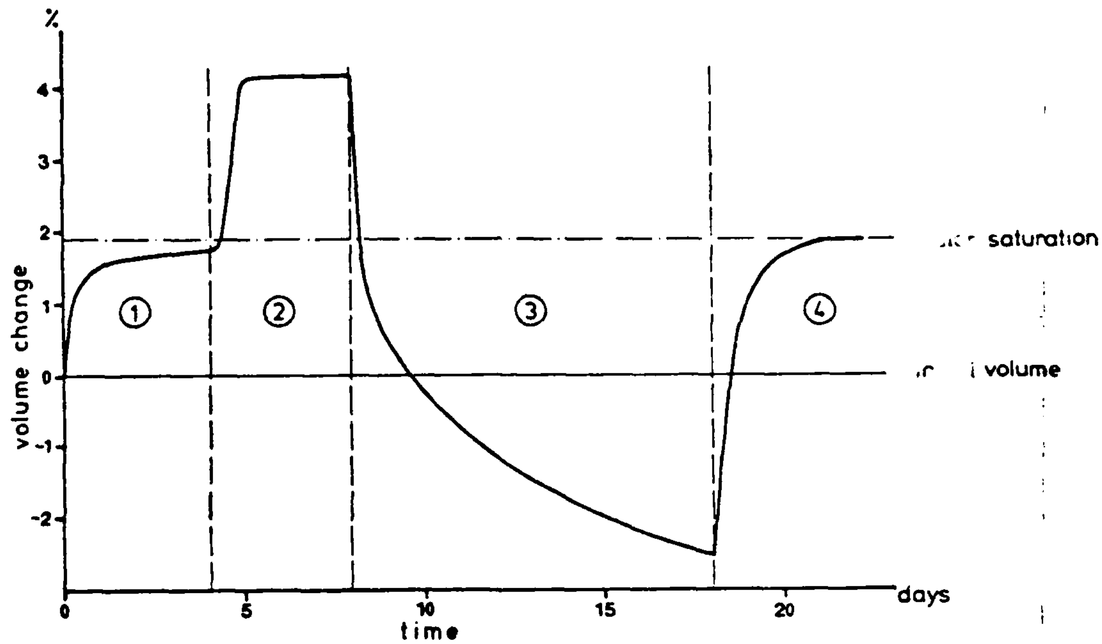



Fig.2: Freezing Test Diagram: samples with natural water content without water uptake during experiment

① Swell heave of a clay sample with natural water content

② Ice swelling of the water saturated sample without water uptake

③ Thawing and drying out with shrinking effect

④ 2nd swell heave until water saturation

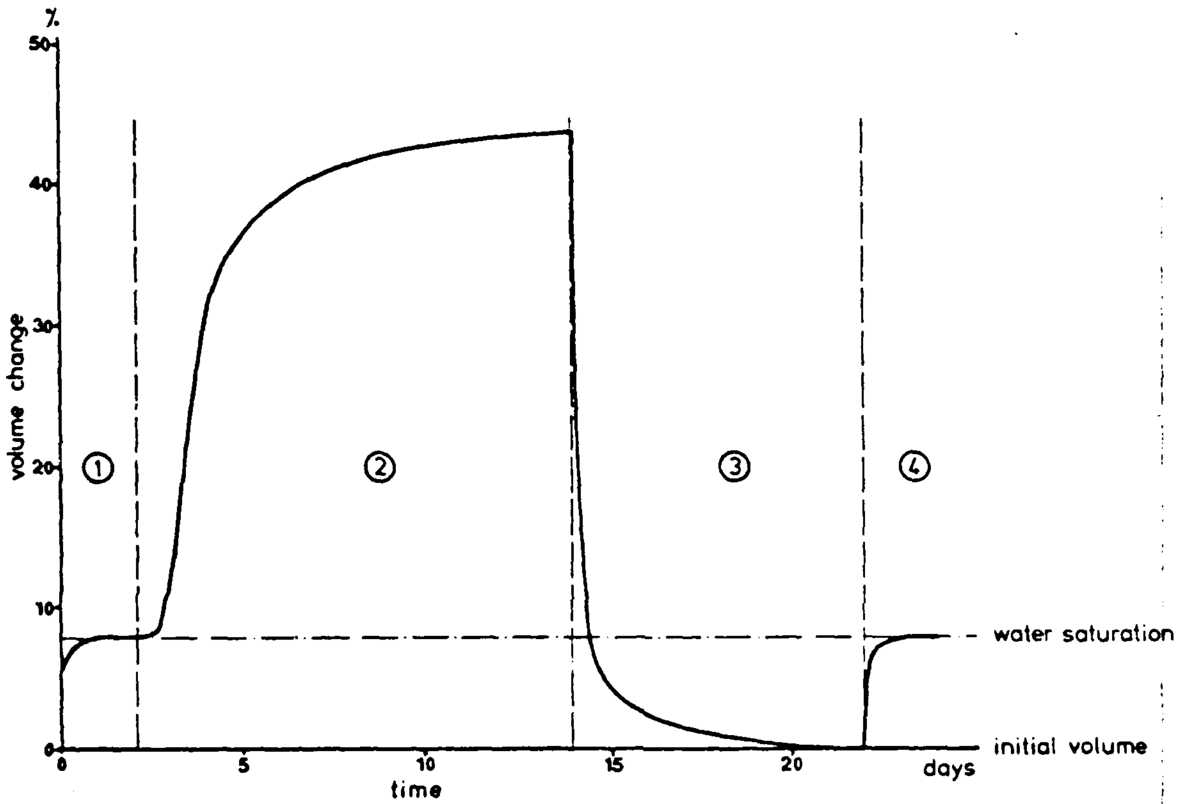



Fig. 3: Freezing Test Diagram: samples in natural condition (almost water saturated) with water uptake during freezing

① Swell heave of a clay sample with natural water content (almost saturated)

② Ice swelling of the water saturated sample: steady water uptake from the bottom and simultaneous ice lense formation within the upper part

③ Thawing and partly drying out with shrinking effect

④ 2nd swell heave on water uptake until water saturation electrolyte composition and diagenetic resp. weathering solution (porewater) circulation controls the shear strength and therefore is of striking influence on the slope creep behaviour. It will be checked by vane shear - and direct shear tests.

In the field, some shrinkage and swelling is to be expected because during summer time there will be very dry periods with low groundwater level, resulting probably in clay shrinkage, and heavy rainfalls with rising groundwater level and extensive surface wetting. The soil strain gages remain installed and will be checked regularly. It is intended as well to make efforts in recording the pore water pressure- if there is any at all. There is of course a gravitational porewater seeping during rainfall periods but an adhesive moisture migration against gravitation from the groundwater level upward may act as well.