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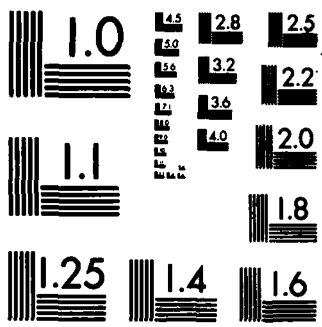


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(3)

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EXPANDING CLAY SLOPES

DAJA 45-83-C-0010



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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5. INTERIM REPORT

Report Period: APRIL 24TH, 1984 - AUGUST 24TH, 1984



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## 1. Summary of Research Results

The expansion-shrinkage behaviour of the swelling Molasse clay of our test site Renigen, province of Upper Austria, was the main task of our field- and laboratory measurements and test series. In this respect, field- and laboratory data are in fairly good accordance.

The first winter field testing-period, 1983/84, is now completed and evaluated. Three freeze-thaw cycles could be observed. They are clearly proved by axial heave- and shrinkage processes. The maximum axial volume increase was measured with 61 mm. Frost penetration could be detected down to 15 cm but frost heave occured only down to 10 cm. This means mainly ice lense formation. Frozen pore water is of minor importance. The ice lense marks the frost penetration front. Ice lenses form under clay specific conditions: the necessary water is not provided from the surface but from the bottom ground water table. The mechanism is adhesion against gravity through the unfrozen and denser water film around the clay flakes.

Ice lense formation means drying of the clay at the freezing front and further adhesion is enabled. This water consuming process only works during freezing. If, after a thawing period,freezing starts again, new ice lenses form only if the temperature achieves lower values than during the previous freezing period. The previously formed - and at least partly preserved - ice lense seals up against water adhesion from below. In the same manner meltwater from top is hindered to penetrate downward. In case the temperature falls below the values of the previous freezing period, deeper down a second ice lense will be formed. That means: minus temperature variations form new ice lenses in ever increasing depth if the previous freezing temperature value is again lowered. This exclusively in clays and conditions of near groundwater tables.

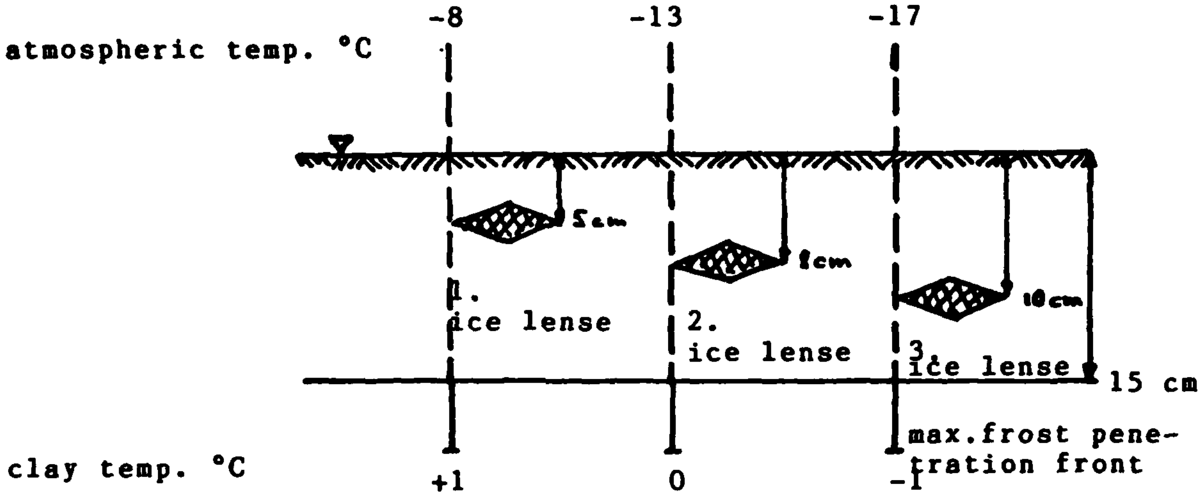


Fig. 1: Diagrammatic sketch of ice lense formation processes during freeze-thaw cycles. Following minus temperatures exceed the previous ones. Maximum frost penetration down to 15 cm but ice lenses not as far. This because of sealing effects of the ice layer against water adhesion from the groundwater.

By silver-thiourea exchange the main interlayer cations and the cation exchange capacity (CEC) was determined. CEC ranges between 24.9 and 58.5 meq/100g. As main interlayer cation appears $Ca^{++}$, followed by $Mg^{++}$, $K^{+}$ and $Na^{+}$.

Freezing- and shear strength behaviour are influenced by the cation balance.

Shear strength, a major sliding parameter, depends strongly on the moisture content of the clay. Vane shear tests have been performed in the laboratory. Frozen clay gains considerable higher shear strength but thawing periods raise the water content and linearly lower the shear strength.

## 2. Results of Field Testing

The first winter field testing - period 1983/84-is now completed and evaluated. See Fig. 2. As already mentioned in the 4. interim report the beginning of a first frost expansion period was registered on Nov. 14. 1983. During the following weeks we could distinguish between three freeze-thaw cycles with maximum axial volume increase of 61 mm during the third freeze cycle on Feb. 24.1984. From this time on a continous shrinkage could be registered. This is due to the thawing process, interrupted by two small freeze-swell cycles.The thaw-shrinkage cycle was finished on March 28.1984 and a resulting heave of 11 mm remained (compared to the beginning condition before the frost period).

This amount of resulting heave is certainly due to a loosening of the clay flakes and a microfabric rearrangement during the freezing process by ice lense intercalation. We expect further microfabric rearrangements especially during rain periods and a further decrease of volume before the next frost period begins. For this reason sporadic measurements are done during this summer.

The temperature in a depth of 15 cm went down to its lowest value, that is -1 °C, on Feb. 20.1984. So the 0°C level penetrated deeper than 15 cm but the ice heave

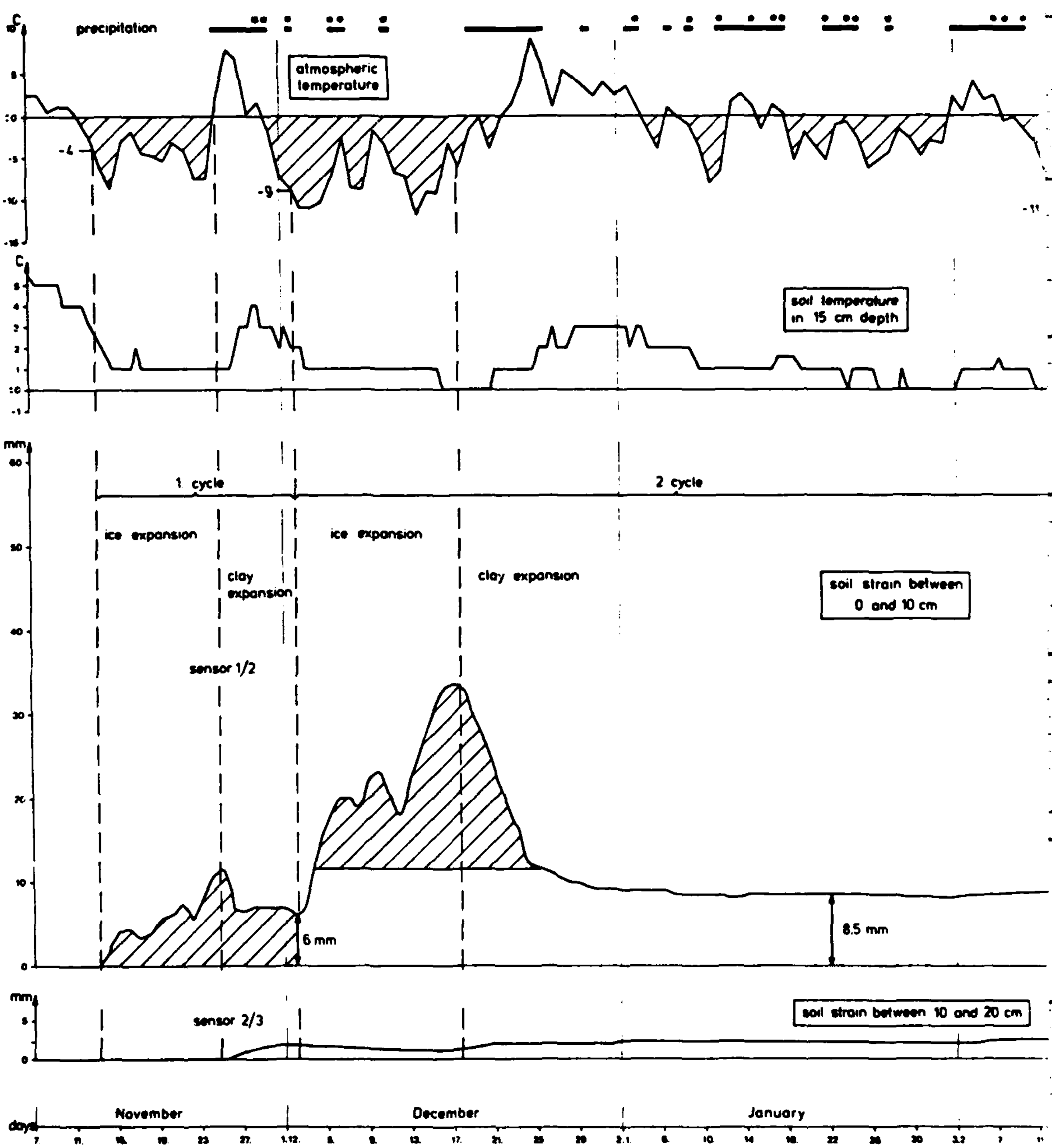


Fig. 2a: The progress of the three freeze-thaw cycles of the first winter observation period (1983/84) in accordance with the atmospheric temperature and soil temperature, measured by Bison soil strain gages. Maximum axial volume increase of 61 mm during the third frost period on Feb. 24.1984.

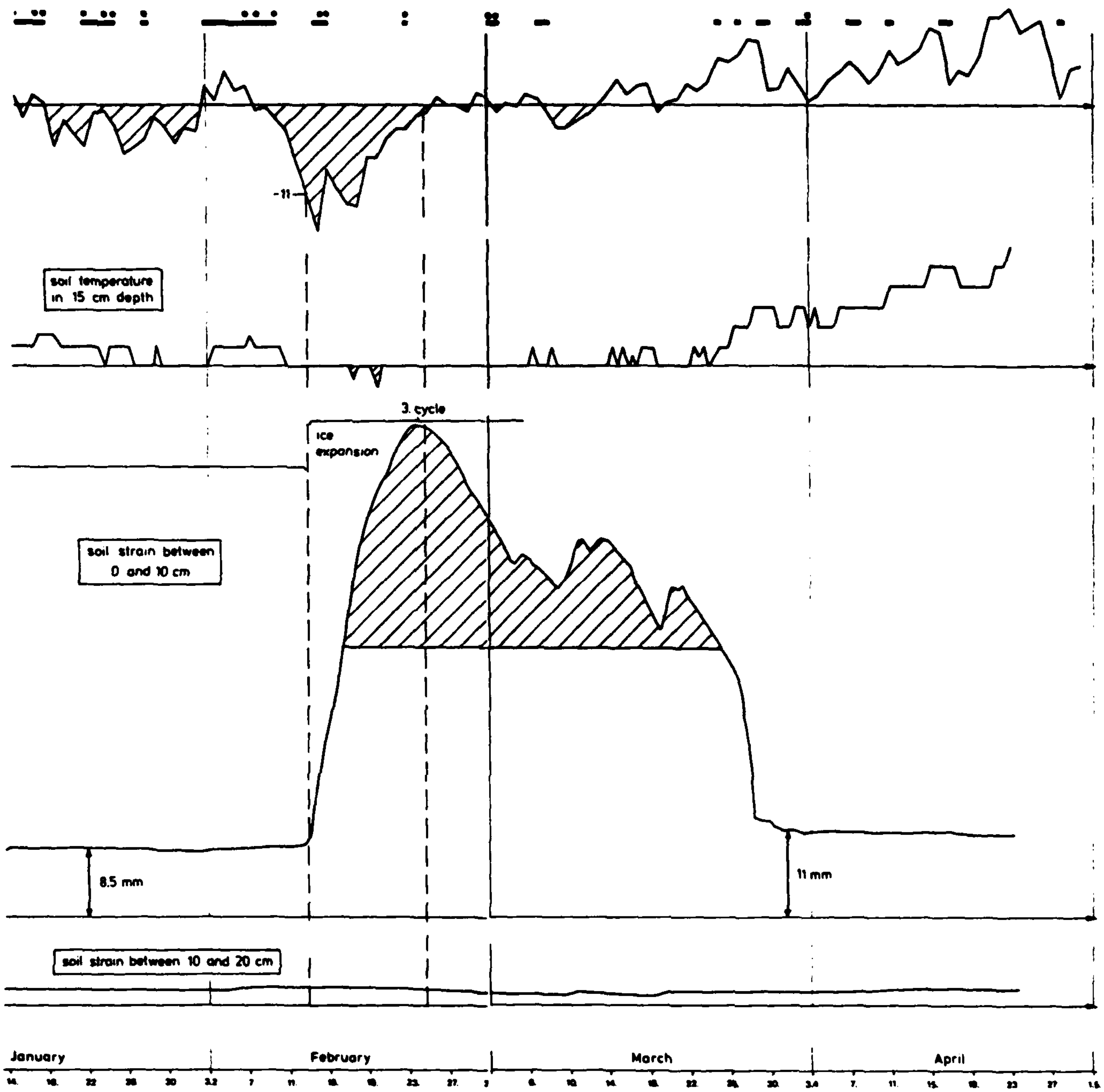
-11
soil temperature in 15 cm depth
3. cycle
ice expansion
soil strain between 0 and 10 cm
8.5 mm
11 mm
soil strain between 10 and 20 cm
January
February
March
April

Fig. 2b:

did not undergo 10 cm, because ice heave in clays only occurs when the temperature is below - 4°C (see 4. interim report).

## 3. Results of Laboratory Testing

### 3.1. Clay Identification

As reported in the 2nd interim report the analyzed smectite clay mineral is of the Ca-type. By a more adequate determination of the interlayer cations by exchange with a 0.1 N silver-thiourea solution this was confirmed, but the new values are slightly lower. See table 1.

Table 1: CEC AND MAIN INTERLAYER CATIONS OF 8 SAMPLES FROM TEST SITE RENIGEN

| | | |
|---|---|---|
| $Ca^{++}$ : | 25.9 - 46.0 | meq/100 g |
| $Mg^{++}$ : | 3.2 - 4.9 | " |
| $K^{+}$ : | 0.4 - 1.2 | " |
| $Na^{+}$ : | 0.2 - 1,4 | " |
| Total: | 31.9 - 51.2 | " |
| CEC : | 24.9 - 58.5 | " |

Some of the Ca may be due to leaching of the carbonate concretions (note the high Ca-value compared to the CEC-value), but nevertheless Ca appears as the main interlayer cation of the smectite. Another more detailed identification of the smectite is done by differential thermal analysis (DTA). This identification is not yet completed and up to now we can only estimate that we have to deal with a montmorillonite, say an Al-Mg-smectite with Ca as the main interlayer cation. The investigations with the DTA also showed a relatively high content of limonite (goethite) for some samples, mainly in combination with the carbonate concretions. But it is to be expected that this is of minor importance for the freezing behaviour.

3.2. Freeze - Thaw - Behaviour

In addition to the tests reported previously, a series of further freezing tests has been performed in the laboratory freezer. Most of the samples showed ice heave values as described in the 1st technical report, that means values between 29 and 52%, but we did never attain a value of 60% or more, the value measured in the field experiment. In our opinion this is due to the fact that freezing is going on more steady in the field, that means slower, as it is the case with our laboratory freezing. In the laboratory we cool down our sample from room temperature to the experimental temperature (that can be chosen between -10° and -30°C) in a few hours, which is very rapid. According to the freezer installations, slower cooling rates cannot be achieved at the moment. So micro-ice lense-formation is suppressed in the upper part of the cylindrical sample, and only a thick ice layer forms in a certain depth. Some of the samples even showed heave amounts below 20%. This is probably due to the different grain size distribution of these samples, that means up to 30% sand fraction, and those samples with the lowest ice heave amount did in addition contain coal components. The fact that the field observation shows the ice heave only starting when the lowest temperature of the precedings freeze cycle is undergone (see 4. interim report) may be explained as follows. During the thawing process, the clay starts thawing from top and a frozen layer still remains in the deeper part. Therefore, when during a new freeze cycle the temperature is lowered to -4°C no ice heave takes place, because the suction of water from the depth is suppressed and a new ice heave does only occur when the freezing front has gone deeper than this still frozen part; that means, when the atmospheric temperature has reached the lowest value of the preceding cycle, additional frost heave is to be expected. Some tests have been performed in the laboratory to prove this hypothesis, but until now we have not succeeded.

### 3.3. Sliding Parameters

As described in the 3rd interim report we hade made some shear strength determination with a vane shear tester. This testing showed that shear strength does abruptely decrease with an increase in moisture content. For example table 2.

Table 2: MOISTURE DEPENDENT SHEAR STRENGTH

| moisture content,% | shear strength,k Pa |
|---|---|
| 25 | 60 |
| 33 | 30 |
| 45 | 10 |
| 50 | 5 |

As reported in the 2nd interim report the moisture content in the frozen clay sample is about 80% and higher.

The fact that this high moisture content is present at the moment of thawing, the shear strength must be negligable small ( see phenomena of solifluction). We tried to prove this in the laboratory by vane shear tests. We introduced the vane into the unfrozen sample and installedit in the freezer. In the frozen state the shear strength exceeds by far 130 k Pa (= upper limit of shear vane).

During the thawing process (after about 10 hours) we sheared off, and got still a very high value of 108 k Pa. This is explained by the fact that the upper part of the sample had dried out and the ice heave was only due to an approximately 2 cm thick ice layer in the middle of the sample. As the vane is that broad it was situated mainly in the dried part and therefore the high shear strength value.

For the following tests we have to lower the temperature more steady or at least in several steps, so that the ice lenses can develop regularly over the whole sample.

## 4. Research Plans for the Coming Research Period

The process of water adhesion from the groundwat( during freezing periods is still not proofed. A po( water pressure device should be installed in order to check this process during the coming winter. We are not sure if this will be possible in the course of the present project for up to now our attempts in this respect failed and more financial and time consuming efforts have to be done. Nevertheless we keep track of this problem.

In the freezer the succeeding ice lense formation during freeze-thaw cycles resp. minus temperature levels have to be simulated in order to check our field test results. We further will perform freezing tests in our dilatometer apparatus.

Further vane shear tests, especially with different cation fixation, are intended for gaining parameters of soil creep. Direct shear tests with frozen, unfrozen and cation-different samples are planned but in the long run. We are still convinced that microfabric rearrangements of the clay flakes after freezing take place and are of striking influence on creep- or landslide processes. Frozen and thawed swelling clay samples of our test site show even without magnification bedding parallelism of the loosened clay aggregates. Scanning microfotografs and possibly x-ray diagrams have to proof this arrangement process.

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

Report describes the results of tests conducted during the winter of 1983-84. Frozen pore water is of minor importance in heaving. Relations among freezing processes, ice lense formation, and source water are briefly described.

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