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STABILITY OF OPENINGS IN ALLUVIAL PERMAFROST

FINAL REPORT
By
Frank J. Skudrzyk, Professor
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Submitted to:

Faculty Grants Committee
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and

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Stability of Openings in Alluvial Permafrost

Final Report

By

Frank J. Skudrzyk

1. ABSTRACT

Alaska has tremendous auriferous gravel deposits many of which are located in permafrost at depth both economically and environmentally too great to allow conventional surface mining. In recent years, with regulatory pressure and improvements in technology for underground mining of hardrock deposits, the Alaskan placer mining industry has shown much interest in underground mining of frozen placers. This approach eliminates one of the main current environmental issues in Alaska - water pollution caused by excessive discharge of silt into the local water bodies - but at the same time creates new safety, and of a different nature, environmental problems.

The project was designed to collect data from a newly started underground mine on Wilbur Creek in Livengood District on temperature of the underground environment, deformation of pillars, convergence of the openings, and deformation and strength characteristics of the geologic materials encountered in the mine, in order to assess potential instability of the ground and influence of the underground mining on the above surface. Thermistors were used to measure underground temperature of frozen alluvials and air at selected locations in the mine. A broad range of ground temperatures was observed from very close to freezing point on October 24, 1987 when the mine was open after summer shut-down, to near -20°C late in the winter at several locations in the lower part of the mine where natural ventilation during the 87/88 winter brought about significant heat exchange.

Roof falls, large deflections of silt slabs, and extensive convergence of openings was observed after the '87 summer shut down. At one location vertical converge of 60cm of initially 2.77m high opening was observed. As evidenced by observations, the unusually high temperatures and extensive instabilities of the underground mine were caused by inflow of water which took place during the 1987 summer. Because of the unexpectedly low grade of the mined deposit, the mining on Wilbur Creek during the 87/88 season was limited to driving exploratory drifts and thus did not leave behind pillars and did not produce possible caving of the roof. This eliminated from the project, the possibility of measurements of pillar deformations and observations of surface subsidence.

Approximately 500kg of samples of frozen gravel and silt were collected including a cylindrical frozen gravel sample 23cm in diameter and 45cm in height. They were used to determine grain size distribution, ice content, porosity, and strength and deformational properties of both natural and simulated (refrozen after thawing) materials.

In particular, data collected on secondary creep rate as a function of stress level and temperature can be used to predict rate of convergence of underground opening thus serving as guidelines for frozen gravel pillar design.

2. INTRODUCTION AND SCOPE

Alaska has tremendous auriferous alluvial resource (Barker, 1986) much of which is located in continuous permafrost at relatively greater depth (20m and greater). Conventional mining technology, very popular in Alaska, removes the frozen overburden silt by hydraulicking. This technology, though very effective, is often economically and environmentally unacceptable when thick layers of overburden have to be removed. The effluent from such operations cannot be effectively treated for silt removal thus causing severe environmental water pollution problems. Removal of the overburden itself, even in a frozen state, disturbs the surface and requires reclaiming which in turn increases the overall cost of mining.

These problems can be avoided by underground mining of frozen placers. Modern mining technology developed primarily for hardrock deposits can now be easily transferred to effectively mine frozen placers. However, serious consideration has to be given to the stability of underground openings excavated in the ground which is much different from the one encountered in typical hardrock deposits. The Alaskan permafrost, initially already at close to freezing point temperature, may be warmed up in a course of mining. Potential heat sources are:

- powered equipment
- miners working underground
- detonated explosives
- outside air having a temperature above that of the local ground, brought underground through ventilation system
- lights, water brought underground for drilling, etc.

In addition, the excavation of underground opening will ultimately cause subsidence of the earth's surface which may have a detrimental impact on the environment.

The State of Alaska, has recently supported through its DNR and DEC Grant Programs, developments by the local placer mining community of new placer mining technology including underground mining. However, this support fell short of recognizing stability-related hazards of the underground method. In fact, an attempt in 1985 to undercut a frozen overburden in one of the placer mines in the Livengood District caused a major landslide during which some $30,000m^3$ of frozen silt collapsed into a pit (Skudrzyk, et al., 1986).

The problem of stability of openings in frozen ground has been recognized since the beginning of underground placer mining in Alaska, locally it is called drift mining. The U.S. Bureau of Mines in the late 1960's, undertook a limited research which was conducted in the Permafrost Tunnel near Fairbanks (Pettibone, Waddell). However, no attempt was made to simulate actual full size mining underground in which large quantities of potentially warm air would be ventilated though the mine and in which large powered equipment generating much heat would be used. Since that time, the Permafrost Tunnel has been maintained at below the original temperatures and because of that can only provide limited information on the stability of openings in frozen ground.

In recent years procedures for design of pillars in frozen gravels were developed (Skudrzyk, Mukesh, 1984; Mukesh, 1985; Skudrzyk, 1985, Skudrzyk, et al., 1987).

The stability of an underground opening in frozen ground, and frozen pillar in particular, is controlled by several factors, most significant of which are temperature associated with the heat balance of the underground environment and strength and deformational properties of the main geologic constituents (weathered bedrock, gravels, and high ice content overburden silt) in close proximity of the opening. These materials are, in general, site specific and though certain generalizations are possible based on laboratory studies, data from a particular mine are needed to design a layout of its underground openings (to determine size of pillars and spacing between them).

The proposed pillar design formula based on laboratory measurements of strength and deformation rate of artificial samples is (Skudrzyk, et al., 1987):

$$\frac{C_p}{FS \cdot CRF} \geq P_v$$

where $C_p = f_1(v) \cdot f_2(s) \cdot f_3(T) \cdot f_3(IC) \cdot f_5 \cdot C_o$

where C_p = frozen gravel pillar strength, MPa,

$f_1(v)$, $f_2(s)$, $f_3(T)$, $f_4(IC)$ = dimensionless functions which account for pillar volume (size), shape, temperature, and ice content, respectively,

f_5 = dimensionless function accounting for organic matter content, salinity of the frozen gravels, and other impurities content,

C_o = uniaxial compressive strength of the standard frozen gravel sample (for selected size, shape and ice content, tested under specific conditions of temperature and straining rate), MPa,

FS = safety factor which accounts for heterogeneity of the material, scatter of test data, and nonuniformity of the vertical stress distribution in the pillar (dimensionless),

CRF = creep rate factor (dimensionless).

P_v = vertical stress in the pillar, MPa

The creep rate factor can be determined from a formula:

$$CR\ (\frac{C_p}{CRF}) \leq \dot{\varepsilon}_a$$

where

$CR(C_p/CRF)$ = creep rate of a frozen sample at stress level of C_p/CRF, $m\,\varepsilon/h$

$\dot{\varepsilon}_a$ = acceptable closure rate of a pillar, $m\,\varepsilon/h$

$$1m\,\varepsilon/h = 10^{-3}\ \frac{m}{mh}$$

Functions $f_1(v)$, $f_2(s)$, $f_3(T)$ and $f_4(IC)$ and C_o were determined earlier for the Fox gravel (Skudrzyk, et al., 1987). Function f_5 is for now, assumed to have a value of one (in some instances, organic matter content and salinity may play an important role, but its determination would require a separate study). Factor of safety can be no smaller than one. It is standard practice in pillar design in coal mining, to assume a value of two for the factor of safety.

The creep rate factor was a subject of laboratory testing described in this report. It was proceeded by a limited uniaxial compressive testing of artificial samples in a temperature range from -16.5 to -0.8°C in order to determine temperature dependency of the uniaxial compressive strength, C_o. The testing was conducted on Wilbur Creek gravel, a material collected from the Wilbur Creek Mine, Livengood Mining District. This would allow a comparison between laboratory measurements and data on temperature and convergence collected from the mine which were also conducted within this project and are reported here.

2.1 Description of the Wilbur Creek Mine Site.

The Wilbur Creek placer is a bench type deposit along Wilbur Creek, one of the Tolovana River tributaries, in the Livengood area. The bedrock in this area consists of thin well weathered vertical beds of Wilbur Creek unit (Weber et al., 1985) striking northeasterly. The Wilbur Creek Unit consists of shale, conglomerae and graywacke.

The placer gravels derived from the Wilbur Creek unit rocks are 0.3 to 2.4m thick, well sorted with approximately 20% of quartz and less than 11% silt and clay content. Overburden, 20 to 41m thick, consists of wind blown silt and organic material and abundant ground ice as sheets (lenses), wedges, irregular masses and pore ice. The segregated ice constitutes about 20% of the volume of the overburden and ranges from clear with a large quantity of trapped air bubbles, to laminated with silt. Its specific gravity is as low as 0.94. The remaining 80% is frozen silt, sp.gr. 1.52, which contains 40% interstitial ice by weight. Overburden stratification is evident at greater depth with inclusions of organic material and volcanic ash. When removing overburden as it was the case in the past, a 30° stable slope is typical for the overburden material covered with new vegetation.

The auriferous deposit, 2km long and 60m wide, extends approximately in a N-S direction west of the current channel of Wilbur Creek. The high grade paystreak varies in width as evidenced by recent underground mining.

2.2 Mining Activities.

The Wilbur Creek property has been mined since the early years of this century using initially drift mining and later on hydraulicking. It is estimated that the creek produced several thousand ounces of gold (Rybachek, 1986). The current owner, Stan Rybachek has worked this property since 1961 using first hydraulicking and since October 1986, modern underground mining method. The deposit was accessed by a portal in a highwall left behind the previous hydraulicking and the mine was to be a room and pillar operation. However, because of unexpectedly low grade of the accessed deposit, mining was limited to driving of exploratory tunnels. In May 1987, the mine was shut down in preparation for the summer thawing season. The portal, in a form of 4.2m diameter and 9.0m long steel colvert, was strengthened with wooden props, sealed off and insulated using plastic, plywood and baled hay. The mine was open again in October 1987 only to realize that the undertaken measures to isolate the underground were insufficient. A considerable volume of water (some 20 to $40m^3$) from the highwall thaw entered the mine causing a warm-up and subsequent extensive caving, sagging of slabs and convergence of openings. With reestablished circulation of cold outside air, the openings stabilized quickly, hanging blocks of frozen ground were scaled down and hauled out and the mine returned to its regular operation. During the 87/88 winter season the exploratory mining continued as indicated in Fig. 1. without leaving any pillars behind.

3. TESTING PROCEDURES

3.1 In-situ Temperature Measurements

Thermistors with a resolution of 0.05°C calibrated at 0°C were used to measure temperature at selected locations in the mine as shown in Fig. 1.

The thermistors were installed in holes by placing the sensors at the bottom of the holes and filling the holes with water. Thermistor T1 was placed near the portal on November 13, 1986 in the middle of a sidewall (top of gravel) 15cm in a hole. T2 was installed on January 7, 1987 approximately 45m underground in the middle of a sidewall (in gravel close to their contact with bedrock) in a 0.9m hole. T3 was frozen on February 13, 1987 in a hole 2.4m deep located 45m underground in a sidewall along a contact between gravel and bedrock, next to T2. T4 was installed on April 7, 1987 30m underground in a sidewall's hole 0.9m deep. T5 was also installed on April 7, 1987 at the roof's surface next to the portal. All these thermistors were located in the lower part of the mine at elevations below that of the portal's sealing. Thus the lower portion of the mine was in the zone of natural ventilation, allowing extensive exchange of air with the outside atmosphere.

Because of experienced loses of thermistors; a new approach to temperature measurement, was assumed. On December 16, 1987, 2 0.9m holes were drilled in sidewalls in a close proximity to the contact surface between bedrock and gravels. One of them, the T6 hole was located in a side opening 135m from the portal and the other, the T7 hole, 180m from the portal in a newly excavated drift paralleling the paystreak. Additionally, the T8 hole replaced the lost T4 thermistor (30m from the portal). See Fig. 1 for locations. As before, the holes were drilled in a slightly downward direction and subsequently filled with SAE grade 40 oil. They were used for temperature measurements by inserting the thermistors all the way into them and allowing the temperature to stabilize.

Elevation wise, the two new locations for T6 and T7 were above the sealing of the portal, it is in an area where only limited cooling took place during times when the mine fan was forcing the outside cold air underground.

3.2 In-situ Convergence Measurements.

A single convergence monitoring station consisted of 4 anchors installed as shown in Fig. 2. Sidewall and roof anchors were installed in 2.2cm diameter holes by setting them with expandable lead shells which contained threaded steel tubes. The floor anchor of similar design, was set in 15cm diameter steel housing with a cap, in a depression dug in a floor. Upon installation the housing was partially filled with water which after freezing provided additional anchorage.

Initially, convergence stations were installed at four locations (see Fig. 1). E1 on November 13, 1986 (8 days after excavation of this location) 3m from the portal, E2 on January 7, 1987 (23 days after excavation), E3 on Jan 7, 1987 (18 days after excavation), E4 on April 7, 1987 (76 days after excavation). An additional station, E5 was installed on December 16, 1987 (306 days after excavation). All stations except for E5 were installed in the lower part of the mine. Vertical anchor of E1 was lost on December 2, 1987 during scaling, E2 and E4 were lost during summer 1987 warm-up, and one of the horizontal anchors of E3 was lost in February 1987 when the LHD, used in the mine for material haulage, bumped into it. Relative displacements between the pairs of vertical and horizontal anchors were measured using Slope Indicator Co. tape extensometer model 518115 E/M which allows accurate distance measurement with overall accuracy of ±0.15mm over a distance between measuring points up to 20m. Relatively simple anchors installed in shallow holes remained stable and required only defrosting before taking measurements.

3.3 Sample Collection.

Approximately 500kg irregular lumps of frozen gravel and silt were collected from the Wilbur Creek Mine for laboratory testing. All of the irregular lumps were collected from freshly exposed surfaces. The samples were transported to the laboratory in sealed containers to minimize ice sublimation.

An attempt was made to collect a natural cylindrical sample for uniaxial compressive testing. A sizeable block of frozen gravel was carved using a chisel and a hammer to fit a cylindrical mold 22.9cm in diameter and 45.7cm in height. This was quite a painstaking process, though because of very low strength of gravel lumps, which often broke in half under impact, a relatively straight and smooth walled cylinder was produced.

3.4 Sieve Analysis and Ice Content.

Irregular gravel lumps were weighed, dried at 95°C to content weight, weighed again, and separated into fractions using sieves and Ro-Top testing sieve shaker.

The ice content with respect to dry weight and percent of fractions weight were then calculated.

3.5 Porosity and Density.

It is believed that porosity and ice content of gravels (as any other frozen granular material) play an important role in their mechanical behavior. In brief, ice-unsaturated materials will contain voids and will have grains in contact with each other, whereas ice oversaturated frozen granulars will have rock grains somewhat dispersed, in otherwords, the grains will not be fully compacted. Ice-oversaturated frozen alluvials may still show significant porosity (contain voids filled with air).

Natural porosity and density of frozen gravels are somewhat difficult to measure taking into account that in order to perform measurement on representative samples, large volume samples (at least a few liters) are required. In addition, tests have to be performed on frozen samples likely to contain open pores. Temperature dependency of volume measurements is a critical factor to account for. With this in mind, porosity, p, was calculated as:

$$p = \frac{V_p}{V_s} \cdot 100\%$$

where V_p = volume of pores

V_s = original volume of sample

Initial volume of a sample (frozen lump) was determined using large (20l) 'pycnometer' (Fig. 3) filled with water at temperature close to freezing-point. The volume of water displaced by the sample having a temperature of a few degrees below freezing point, was assumed to be the sample volume. The sample was then allowed to thaw and after that the change in volume, as indicated by the pycnometer, was determined. The sample was dried weighed and the ice content calculated. The change in sample volume, corrected for change in volume of samples' ice when thawed was assumed to be the volume of pores. Volumes measured by pycnometer were corrected for pycnometer - water volume change as a function of temperature. This relationship was determined using linear regression, to be 16.2 $cm^3/^oC$.

Density, ρ, was calculated as:

$$\rho = \frac{W_s}{V_s}$$

where W_s = weight of frozen sample.

3.6 Uniaxial Compressive Testing of Natural and Artificial Samples.

The natural large cylindrical sample (approximately 22cm in diameter and 44cm in height) was resurfaced using -6.3mm Wilbur Creek gravel fractions (-6.3mm+4 mesh and -4+8 mesh fractions were making up for the missing coarse fractions) with water content equal to that of the average ice content of the Wilbur Creek gravel. A special slotted cylindrical mold, having 22.9cm diameter and a quarter of the cylindrical surface cut out, was used to bring the side surface of the sample to a surface of a smooth circular cylinder. The end surfaces were recapped with the same material as above, followed by a very thin layer of a mixture of -20 mesh material with natural water content in order to produce very smooth surface. The natural sample (data file WILGR1.DAT) was tested in compression at -4.9°C. The test was run in displacement mode with constant axial contraction rate of 10 $\mu\varepsilon$/s. Load on sample; two axial, and two latteral deformations; and temperature at four points (top and bottom plattens, sample and air) were recorded.

Six artificial samples for compressive testing were prepared in a form of straight circular cylinders having a diameter of 15.2cm and a height of approximately twice larger than the diameter. The grain size distribution of the artificial samples was proportionate to the natural gravels except for the grains having a size greater than 25.4mm. They were replaced with the same quantity of -25.4+12.7mm fraction. The amount of water used was based on the required ice content including correction for volume change when freezing. Water and fractions were mixed and pored into a mold which subsequently was shaken till water appeared at the sample surface. The top surface was then smoothed parallel to the bottom surface and thermally insulated. The mold was placed in a freezer with the bottom surface of the mold in contact with a metal plate. This arrangement allowed progressive freezing of a sample from its bottom to the top with excess water escaping and freezing at the top. It is believed that this procedure produced samples free of residual stresses. It was evidenced by the fact that the mold did not expand after its clamps were released. The ice accumulated at the top surface was then completely chipped away with a chisel and the surface recapped as in the case of the natural sample making described above. The samples were tested at constant axial strain (contraction) rate of 10 $\mu\varepsilon/s$ at temperatures from -16.7 to -0.8°C (see Tab. 1). Load on sample, two axial and two transverse deformations and temperature at four points (top and bottom of a sample, top and bottom plattens) were recorded during each test. A schematic view of a sample and a picture of an actual sample during testing are shown in Fig. 4. Tests were run beyond the ultimate strength point, though the axial strain was not allowed to exceed 0.5%. Two samples one before (right) and one after (left) testing are shown in Fig. 5.

3.7 Creep Test on Artificial Samples.

As indicated earlier, the creep rate factor and creep rate encountered in the secondary stable creep are important components of the pillar design formula. To determine stable creep rates, a creep test was run on 13 artificial samples (having the same composition and shape as in the case of compressive testing) at stress levels and temperatures indicated in Tab. 2. One to four creep tests were run on each sample.

The samples were loaded to desired load (stress) level in 5 min. (arbitrarily selected time) and then constant load was maintained for a time span sufficient to collect data points (usually a minimum of 20 data points at 0.5 min. intervals) for the secondary creep rate determination. The secondary creep was considered unstable (becoming the tertiary creep) when the volumetric strain of a tested sample started to increase. This can be justified as follows. Samples made of continuous materials (pores and fissures are neglected here) when loaded in compression, show decrease in volumetric strain (volume change of an initial unit volume is called volumetric strain) unless latteral expansion is larger than axial contraction. Thus increasing volume in compression indicates that the material (sample) is not any longer continuous, in otherwords, cracks start to develop.

For each of the tested samples, a data file was created including time, load, temperature and two axial and two latteral deformations.

4. RESULTS

4.1 In-situ Measurements and Observations

Data on temperature changes and convergence of openings in the Wilbur Creek Mine at selected locations are shown in Fig. 6 and Fig. 7 and Tab. 3 and Tab. 4, respectively.

As mentioned earlier a significant amount of water (some 20 to 40m^3) seeped to the lower portion of the mine during the 1987 summer. This produced much heat underground. On October 24, 1987, a few days after the mine was reopened, during a short visit to the mine, it was noticed that the floor of the lower part of the mine was still covered with slush. At that time, the temperature in the mine must have been close to the freezing point. A few weeks later on December 16, after the natural ventilation brought cold air underground and after scaling was done, the temperatures around the openings were measured and they already were below -10°C.

Convergence of the openings was difficult to measure because of the extensive deformations which took place during the 1987 summer and shortly afterwards. During the October 24th visit (very short, to limit exposure to unsafe conditions) the mine floor was covered with blocks and slabs. Some of them were still hanging posing a serious hazard. In particular, the upper part of the mine (the curving cross-cut A-B, Fig. 1) was in a poor shape with several areas partially caved-in. At location C (with a shallow pocket) a 20cm smooth slab of silt sagged by over 60cm forming a symmetric 4m long nest as shown in Fig. 8. At several locations, remnants of such slabs hanging from the roof were observed. Usually a slab consisted of frozen silt with a thin layer of ice (ice lens) along the upper surface indicating that the separation between slabs took place along an ice lens.

The floor anchor at Station E1 was covered in October of 1987 with slush and later on, when the temperatures dropped, with ice. Removal of ice, when the mine was cleaned up, allowed an access to the anchor and vertical convergence was measured on December 2, 1987. Subsequently the roof was scaled and the roof anchor at E1 was lost. Several other anchors were lost during cleaning of the mine as indicated in Tab. 4.

4.2 Grain Size Distribution, Ice Content, Porosity and Density of Natural and Artificial Samples.

Grain size distribution based on sieve analysis of 205kg of dry gravel is given in the Tab. below.

Grain Size Distribution Wilbur Creek Gravel

Size			
in./mesh	mm	% weight	cumm. %
above 2 in.	50.8	5.6	100
-2 + 1 in.	25.4	7.7	94.4
-1 + 0.5 in.	12.7	11.0	86.7
-0.5 + 0.25 in.	6.3	25.2	75.7
-0.25in + 4 mesh	4.8	8.9	50.5
-4 + 8 mesh	2.4	17.6	41.6
-8 + 20 mesh	0.84	16.0	24.0
-20 + 35 mesh	0.42	5.9	8.0
-35 + 150 mesh	0.105	1.1	2.1
-150 mesh	0.105	1.0	1.0

Ice content measured on four large natural samples (above 10kg each) was 17.6, 15.7, 14.5 and 18.6% with a weighed average of 16.6%.

Porosity of natural gravels was measured on two large samples with calculated values of 0.5 and 1.6% and an average of 1.1%. Density of natural gravels was determined on two samples with an average value of 2.16 g/cm^3.

Because of the problematic accuracy associated with testing difficulties of the porosity measurements, it was decided not to measure porosity of the artificial samples. However, data on ice content and density for these samples were obtained and are listed in Tab. 1. Ice content of artificial samples varied from 14.4 to 16.5% with changes in density from 2.18 to 2.06g/cm^3 as shown in Fig. 9.

4.3 Uniaxial Compressive Strength of Wilbur Creek Gravel

Uniaxial compressive tests were run at constant strain rate of 10 $\mu\varepsilon$/s at temperatures as shown in Tab 1. The ultimate strength defined as the maximum compressive stress imposed on a sample at the specified strain rate is also shown in Tab. 1. Typical stress-axial strain as well as stress and volumetric strain vs. time curves are shown in Fig. 10A and B, respectively.

Data points for ultimate strength vs. temperature for artificial samples are shown in Fig. 11 as solid squares together with the best exponential fit:

$$C = 10.4(1-\exp(0.0723T)),\ \text{MPa},\ T \text{ in } {}^{\circ}\text{C}.$$

An astrisk in Fig. 11 indicates the ultimate strength of the natural sample.

4.4 Secondary Creep of Wilbur Creek Gravel.

As mentioned earlier, creep tests were run on artificial samples simulating the Wilbur Creek gravels. A typical plot consisting of two stress levels (3rd at 570 psi attempted), creep curve and volumetric strain curve is shown in Fig. 12. A straight line was fit to approximately linear secondary creep portions of the creep curve (for the first and second cycle of loading) as shown in Fig. 13A and B. This particular test was discontinued after two cycles of loading since the sample showed significant increase in volumetric strain signaling development of cracks as a part of a just started failure process.

All secondary creep rates for stable loading of tested samples are shown in Fig. 14 in a 3D view with horizontal axes being temperature and stress at which a particular creep test was run. These data points were used to find lines of constant secondary creep (at 5, 10, 20, 30 and 50m ε /h) based on linear interpolation between experimental data points, as shown in Fig. 15. As an example, the interpolated data points with linear regression fits for secondary creep rate of 10 and 30m ε/h are shown in Fig. 16A and B.

4.5 Tensile Test Apparatus

An adapter which would allow running a tensile test in a compressive testing machine available in the UAF rock mechanics laboratory was designed and machined together with grip boxes which would allow loading of a frozen silt (gravel) sample in tension. A limited time span of the project did not allow these tests to be run. Based on this circumstance, the tensile test program will have to wait until another project comes along.

5. DISCUSSION OF RESULTS

5.1 In-situ Convergence and Temperature Measurements

Much of the convergence which took place in the Wilbur Creek Mine was of unstable nature - leading to a local collapse of a portion of an opening. This type of convergence can be most conveniently measured with continuously monitoring devices, though under such circumstances a loss of transuders, if not the entire set of monitoring equipment, has to be accepted.

A monitoring program conducted within this project allowed collection of limited data on convergence. It also identified problems associated with convergence measurements conducted in frozen alluvials. Basic philosophy, the simplier the better, employed in this project and pertaining to equipment and procedures proved to be successful. 75mm long anchors proved to be long enough to avoid losening of shells caused by progressive sublimation of ice. The relatively simple mechanical tape extensometer worked well allowing very accurate measurements.

As indicated in Tab. 4 and Fig. 7, relatively small horizontal convergence (as indicated by change in distance between the two horizontal anchors) was observed. This may be at least partially explained by the shape of the openings having larger span than height.

Horizontal convergence at E1 was initially greater than the vertical one. This is different from data for other stations. One explanation which may be offered here is that the station was located close to the foot of the highwall where the vertical stress (associated with the weight of the overburden) was smaller than the initial horizontal stresses in this area. By the time the temperature went up in the 1987 summer, the horizontal stresses were already relaxed due to creep and vertical convergence prevailed. It is also possible that a separation between silt layers above the vertical anchor took place during the 1987 summer which contributed to a larger vertical convergence.

Extremely large vertical convergence (over 0.6m) was observed at station E3. This would indicate a highly unstable situation in any hard rock mine, however in a frozen alluvial mine, this still seems to be safe especially when looking at the convergence after the temperature dropped down in December 1987. It is also possible, that a separation in the roof occurred which, since the roof was not scaled down, may lead in the future to a collapse of the roof. This location needs to be carefully monitored in the future in order to avoid an accident.

Such large deformations may be very difficult to predict using rheological (in particular, linear) models. Data on convergence (strain or creep) rates as a function of temperature and stress level obtained from laboratory studies may be very helpful in predicting whether a particular convergence rate is safe or not.

Because of changes in mining plans, pillars were not excavated and no full size caving of the roof took place. This eliminated from the project measurements of pillar deformation and observations of surface subsidence.

Temperature measurements in the Wilbur Creek Mine, again, despite their very limited and discontinuous nature, offered several interesting observations. Natural ventilation has a pronounced effect on temperature distribution in a horizontally accessed mine. With outside-atmosphere temperatures below those encountered in the mine, a natural movement of air takes place caused by barometric pressure differential which can lead to significant cooling of the underground provided that the outside temperatures are sufficiently low. However, portions of the mine, elevation wise above the highest point of a the portal, were not affected by the natural cooling, to the contrary, the outside warm air, if present, may enter a mine (see temperature measurements at the face in March 1988, Tab. 3). Obviously temperatures of frozen ground approaching the freezing point can cause disaster as evidenced by the 1987 summer warm-up and associated with it extensive cave-ins and deformations.

5.2 Uniaxial Compressive Strength and Secondary Creep of Natural and Artificial Sample

As indicated earlier, only one natural sample was tested in uniaxial compression. The sample itself was "reshaped", after it was carved underground, to bring it into a shape of straight circular cylinder required for uniaxial compressive testing. The ultimate strength of this sample (astrisk in Fig. 11) is smaller than that of artificial samples (solid squares). Several factors such as breaking of a block, from which the sample was carved, proximity to a place where the ground was blasted, carving itself, transportation to the laboratory (though sample was mechanically and thermally insulated) and reshaping might have effected the strength. The collection of this sample from the underground demonstrated however that it can be done and the obtained result suggested that the artificial samples simulated the natural material reasonably well.

Data on uniaxial ultimate strength, ice content and density of artificial samples are given in Tab. 1. The ultimate strength is highly influenced by temperature and is somewhat lower than the strength of Fox gravel determined earlier (Skudrzyk, et al., 1987). This can be explained by high ice content of the Wilbur Creek gravel. The small variations in the ice content and density of artificial samples seem to correlate rather well with each other as can be seen from Fig. 8. They are close to the values obtained for natural material (ice content within 9% and density within 0.9%). The variations in the ice content and density for the tested natural samples were greater (12.6 and 1.3%, respectively).

Creep testing conducted within this project provided much needed data on secondary creep (stable convergence) rates as a function of temperature and stress levels. Both temperature and stress effect secondary creep rate in a very nonlinear fashion. For example at -3.0°C the creep rate increases nonlinearly with, as indicated by Curve #1 in Fig. 15, stress and at 2MPa stress level increases nonlinearly with increase in temperature as shown by curve #2 in Fig. 15.

6. CONCLUSION AND RECOMMENDATIONS:

Data collected from the Wilbur Creek Mine on temperature and convergence provided very useful, though limited, insight into the response of frozen alluvial deposit encountered on Wilbur Creek to excavation of tunnels. At temperatures in the mine below -10°C, the frozen gravel and silt were very stable, whereas at higher temperatures the rate of convergence, as also indicated by laboratory studies, is highly stress-level dependent. At, for example, 2MPa stress level, the critical temperature is slightly above -4°C whereas at 1MPa stress level, this temperature is slightly above -2°C (assuming 20 mε/h as a value at which the secondary creep starts increasing rapidly, see Fig. 15).

Natural ventilation plays a significant role in temperature distribution in a horizontally accessed mine, such as the Wilbur Creek Mine, but only openings having elevations below that of the portal can be cooled by it.

Both the thermistor temperature sensors and tape extensometer and mechanical anchors proved to be suitable tools to measure temperature and convergence in a placer mine located in permafrost. It would be helpful to have a continuous temperature monitoring system available, as the temperature, in particular close to the portal, varied frequently with changes in outside temperature. It was proven in this project that a sample of frozen natural gravel for compressive testing can be collected.

However at least several samples should be tested to prove that the artificial samples produced under laboratory conditions well simulate the real material. In this respect porosity, in addition to ice content, grain size distribution and density, should be considered as important variables. Aging of ice in artificial samples and history of loading should be considered as additional factors in obtaining good agreement between natural and simulated frozen material.

Tensile testing of frozen silt stratified with ice lenses should be undertaken to explain formation of slabs leading to local roof falls. Also, deformation of pillars and surface subsidence should be monitored when full size room and pillar mining will be initiated.

7. ACKNOWLEDGEMENTS

The author is thankful to the University of Alaska Fairbanks Faculty Grant Committee, and to the U.S. Bureau of Mines for providing support for this project. Also, work on this project done by V.K. Mishra and V. Kasakidis, graduate students in Mining Engineering, UAF is acknowledged. Special thanks is directed to Alice Baergen and Lucy Trant for editing of this report.

8. REFERENCES

1. Barker, J.C., 1984, Deep Placer Deposits in Alaska, U.S. Bureau of Mines, AFOC Fairbanks, Unpublished Data.

2. Mukesh, K., 1985, Design of Pillars in Time Dependent Materials, M.S. Thesis, University of Alaska-Fairbanks.

3. Pettibone, H.C., Waddell, G.C., 1969, Stability of an Underground Room in Frozen Gold Bearing Strata, Fairbanks, Alaska. Proc. 75th Annual Northwest Mining Association Convention, Spokane.

4. Rybachek, S.C., 1986, Private communication.

5. Skudrzyk, F.J., Mukesh, K., 1984, Pillar Design for Permafrost

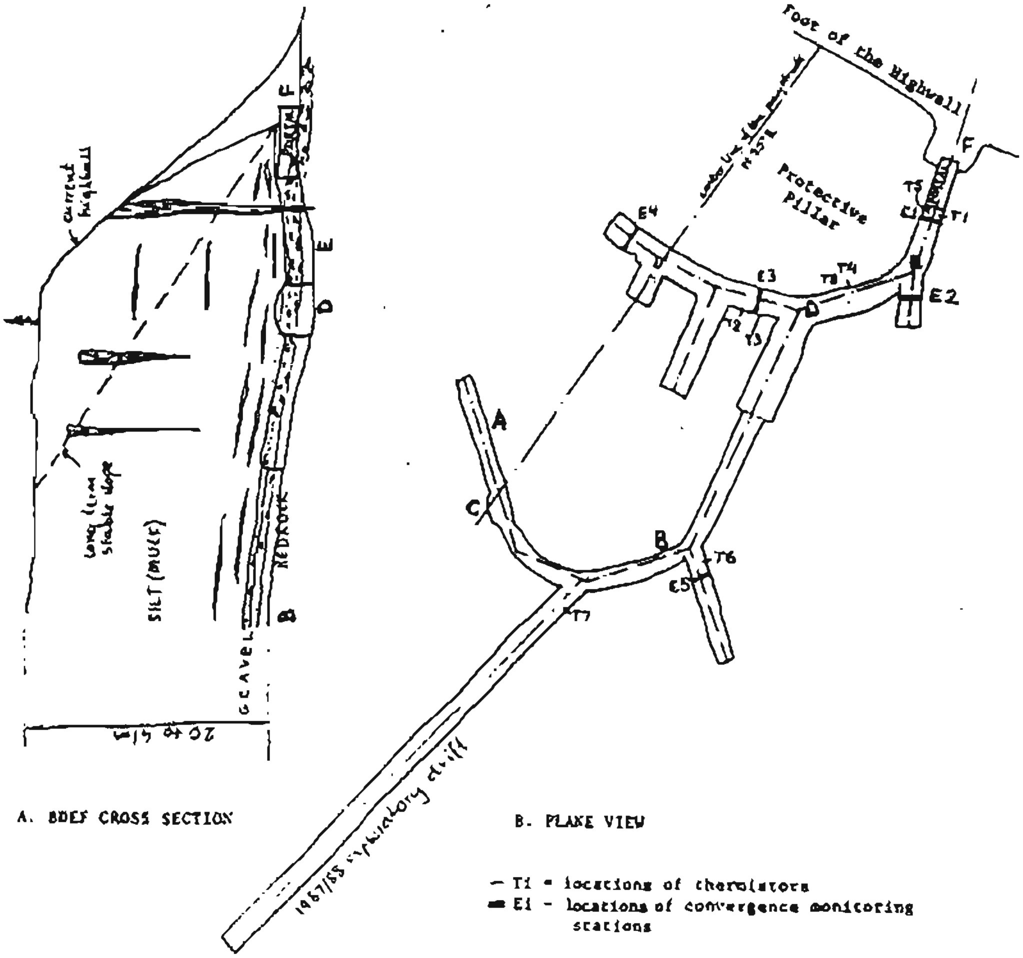
Placer Mine, 2nd Annual Workshop, Proc. Generic Mineral Technology Center, Nov., 12-13.

6. Skudrzyk, F.J., 1985, Pillar Design for Frozen Placers, Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, S.D. 26-28 June, pp. 97-110.

7. Skudrzyk, F.J., Bandopadhyay, S., Rybachek, S.C., 1986, Mining-Induced Landslide in Permafrost, Proc. of the International Symp. on Geotechnical Stability in Surface Mining, Calgary, 6-7 November, pp. 169-177.

8. Skudrzyk, F.J., Bandopadhyay, S., Mukesh, K., 1987, Design of Natural and Artificial Pillars for Placer Deposits in Permafrost, Proc. 13th World Mining Contress, Stockholm, Sweden, May 31, pp. 915-935.

9. Weber, R.F., Smith, T.E., Hall, M.H., Forbes, R.B., 1985, Geologic Guide to the Fairbanks-Livengood Area, East-Central Alaska, Alaska Geological Society, Anchorage, AK.



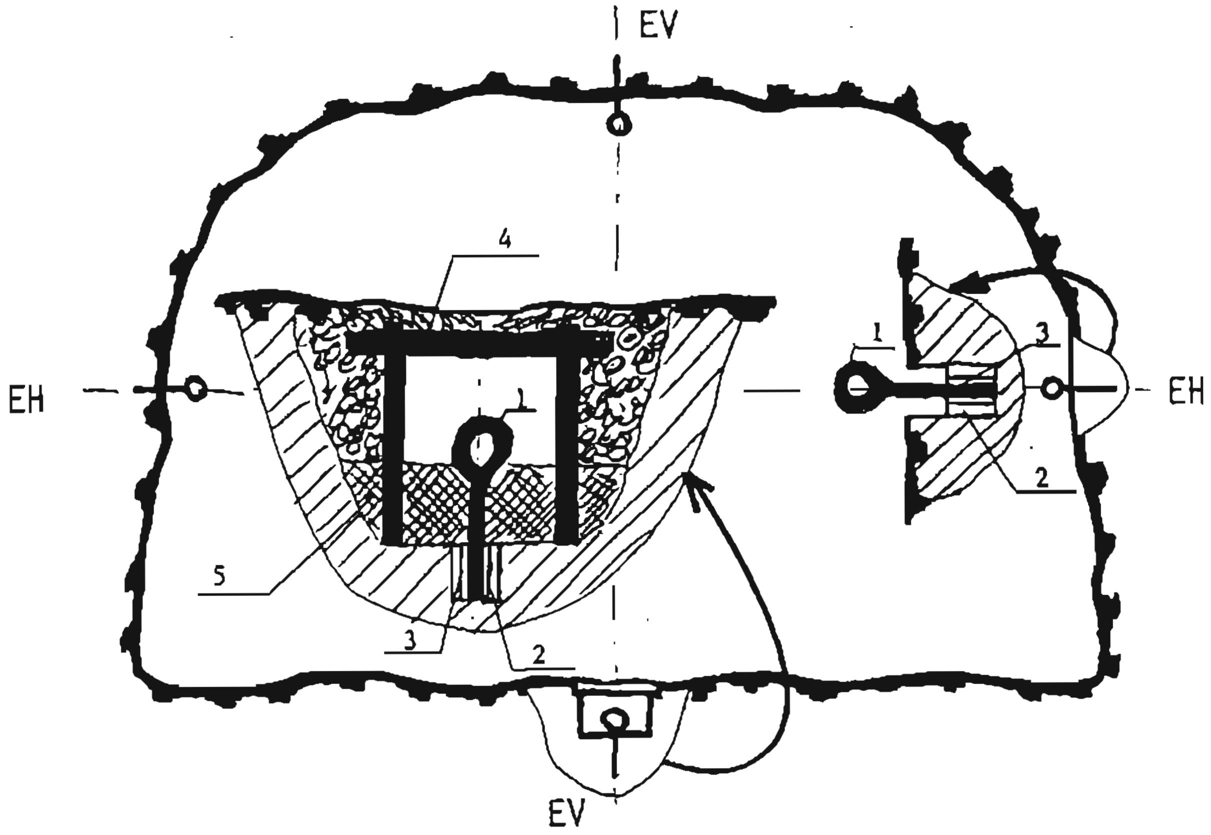
A. BDEF CROSS SECTION

B. PLANE VIEW

— T1 = locations of thermistors
▬ E1 - locations of convergence monitoring stations

NOT TO SCALE

FIG. 1: WILBUR CREEK MINE - GENERAL OUTLINE OF THE MINE AND LOCATIONS OF MONITORING STATIONS.



1 = eyebolt
2 = lead expandable shell
3 = threaded steel tube
4 = protective lid
5 = refrozen ground

EH = horizontal anchors
EV = vertical anchors

FIG. 2: CONVERGENCE MONITORING ANCHORS

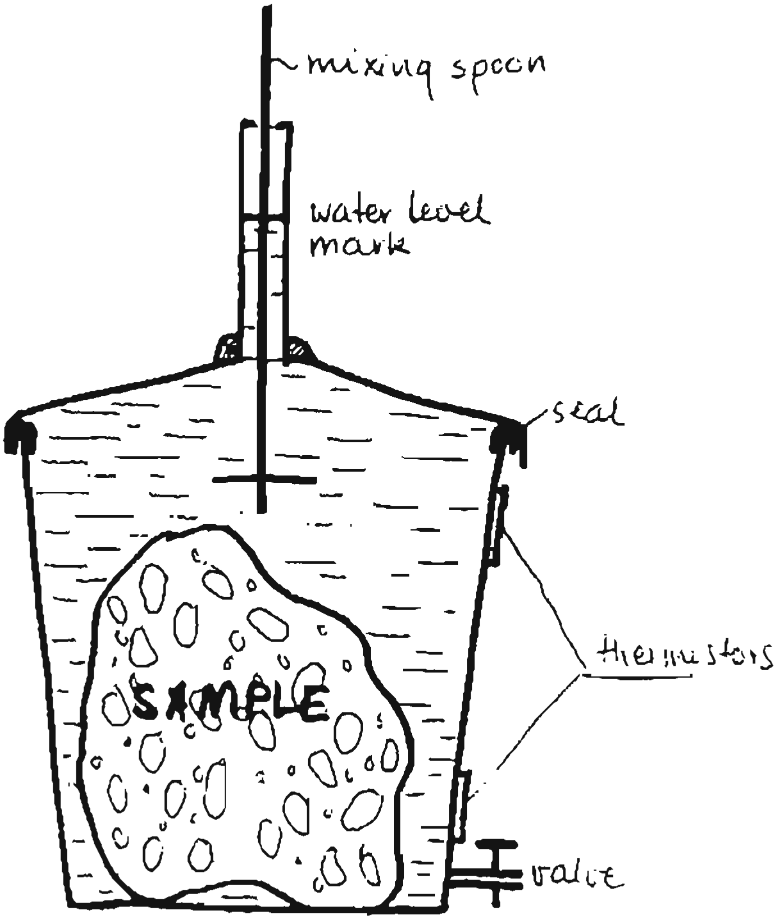
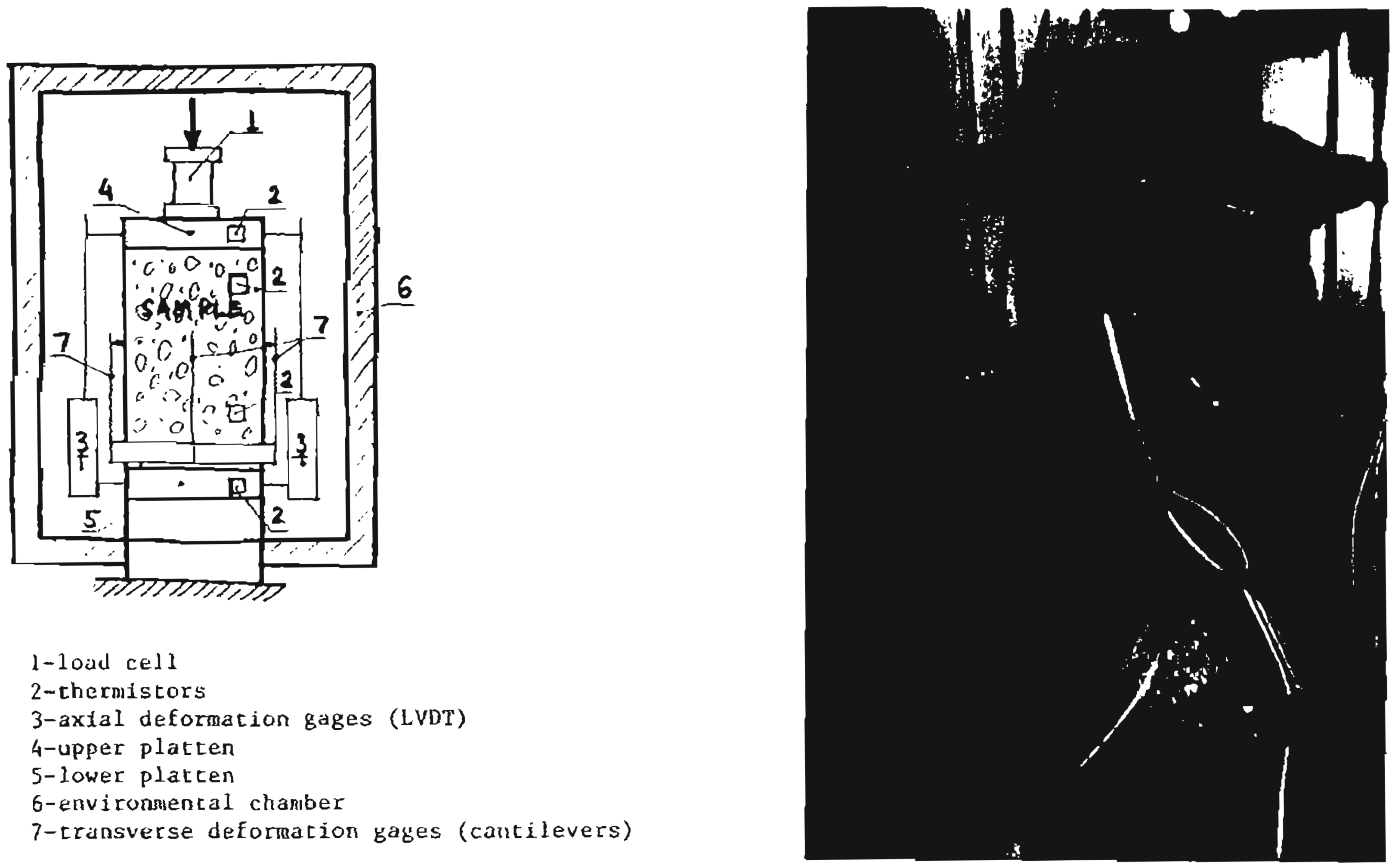


FIG. 3: PYCNOMETER



1-load cell
2-thermistors
3-axial deformation gages (LVDT)
4-upper platten
5-lower platten
6-environmental chamber
7-transverse deformation gages (cantilevers)

A. SCHEMATIC VIEW

B. SAMPLE DURING TESTING

FIG. 4: ARTIFICIAL SAMPLE IN COMPRESSION

FIG. 5: SAMPLE BEFORE (RIGHT)
AND AFTER (LEFT) TESTING.

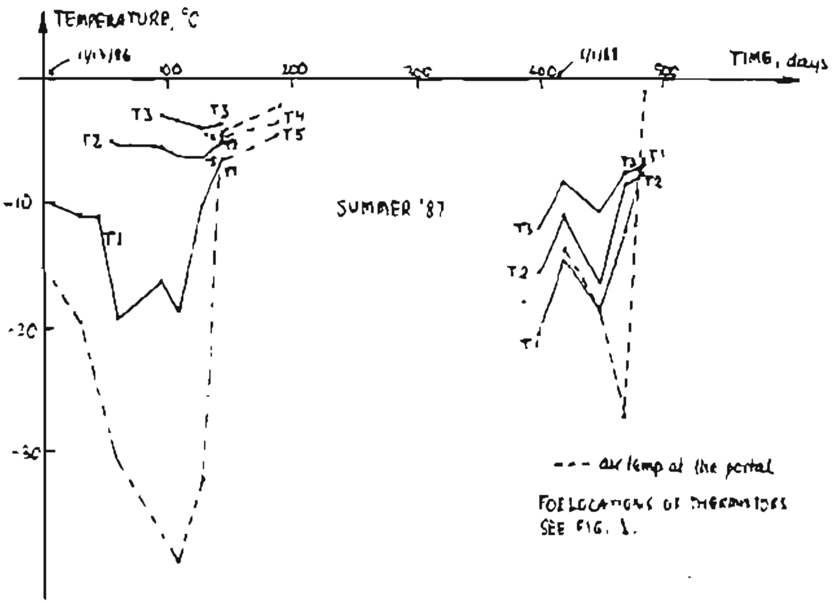


FIG. 6: TEMPERATURE DISTRIBUTION IN THE WILBUR CREEK MINE FROM 11/13/86 THROUGH 03/11/88

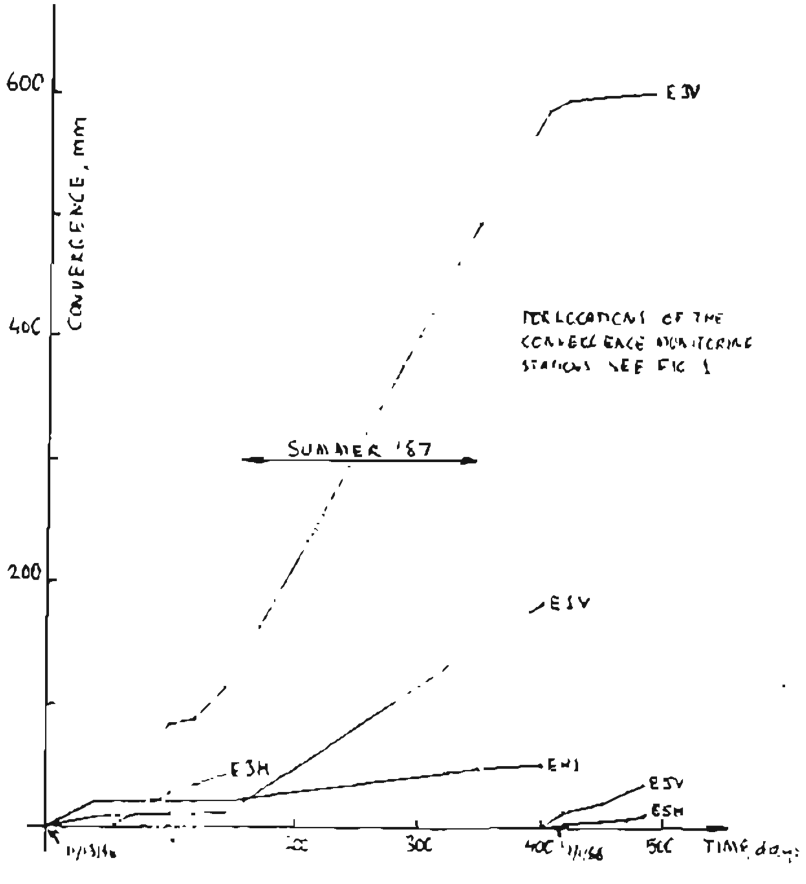
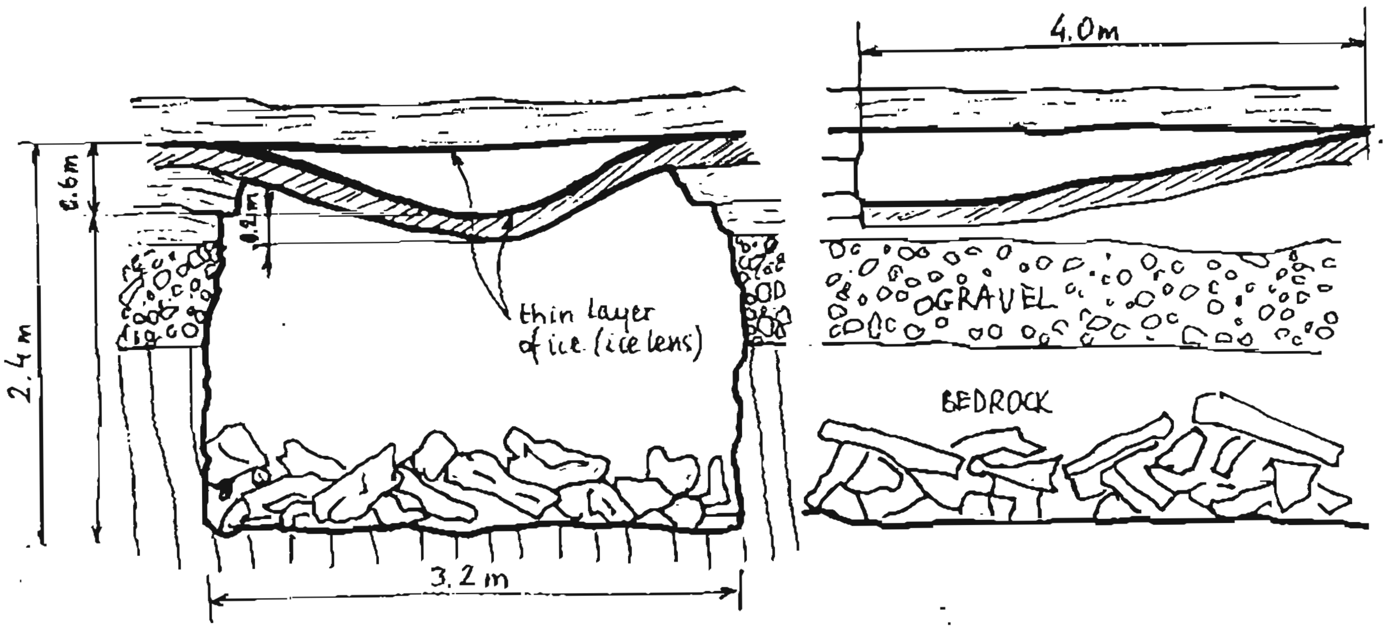


FIG. 7: CONVERGENCE IN THE WILBUR CREEK MINE FROM 11/13/86 THROUGH 03/11/88



A. Cross View B. Longitudinal View

FIG. 8: SILT SLAB SAGGING AFTER THE '87 SUMMER WARM-UP.

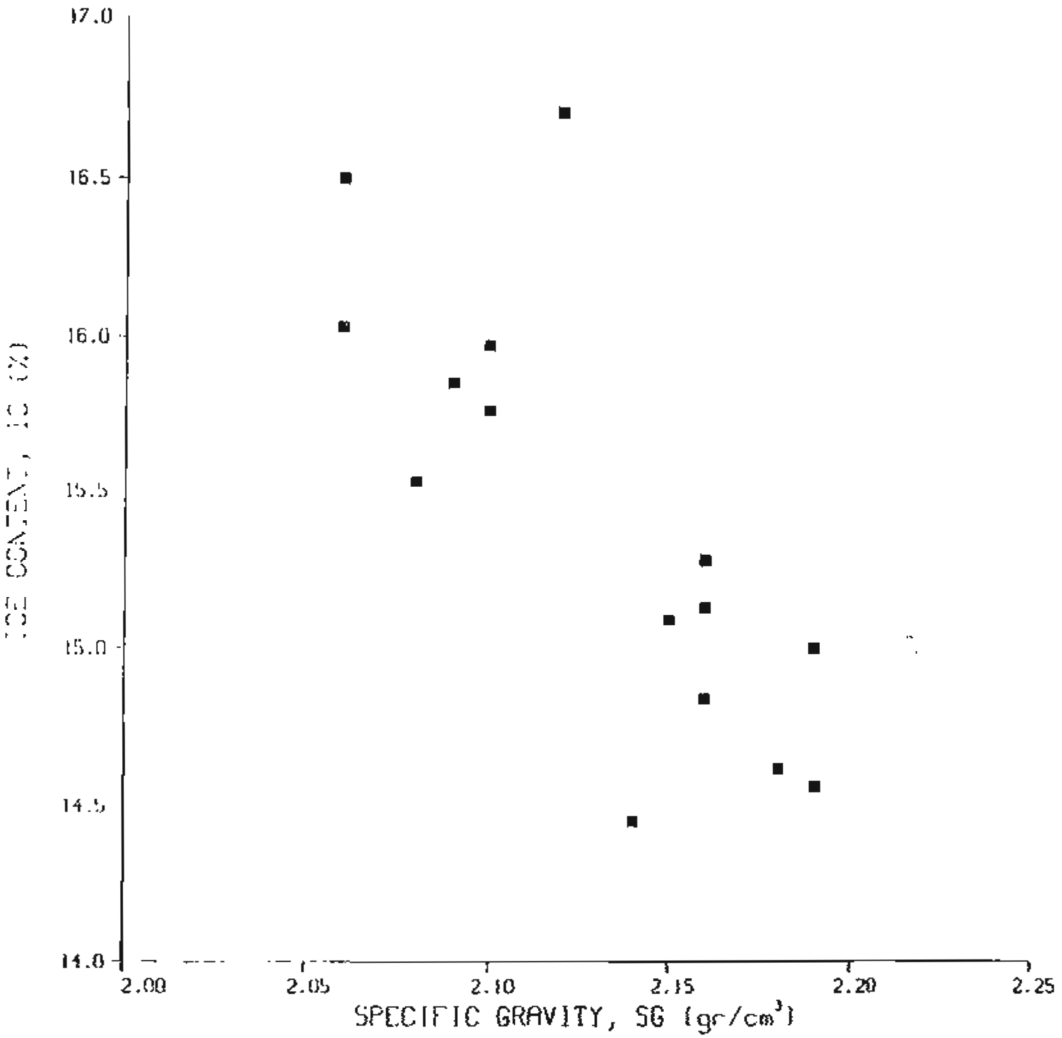
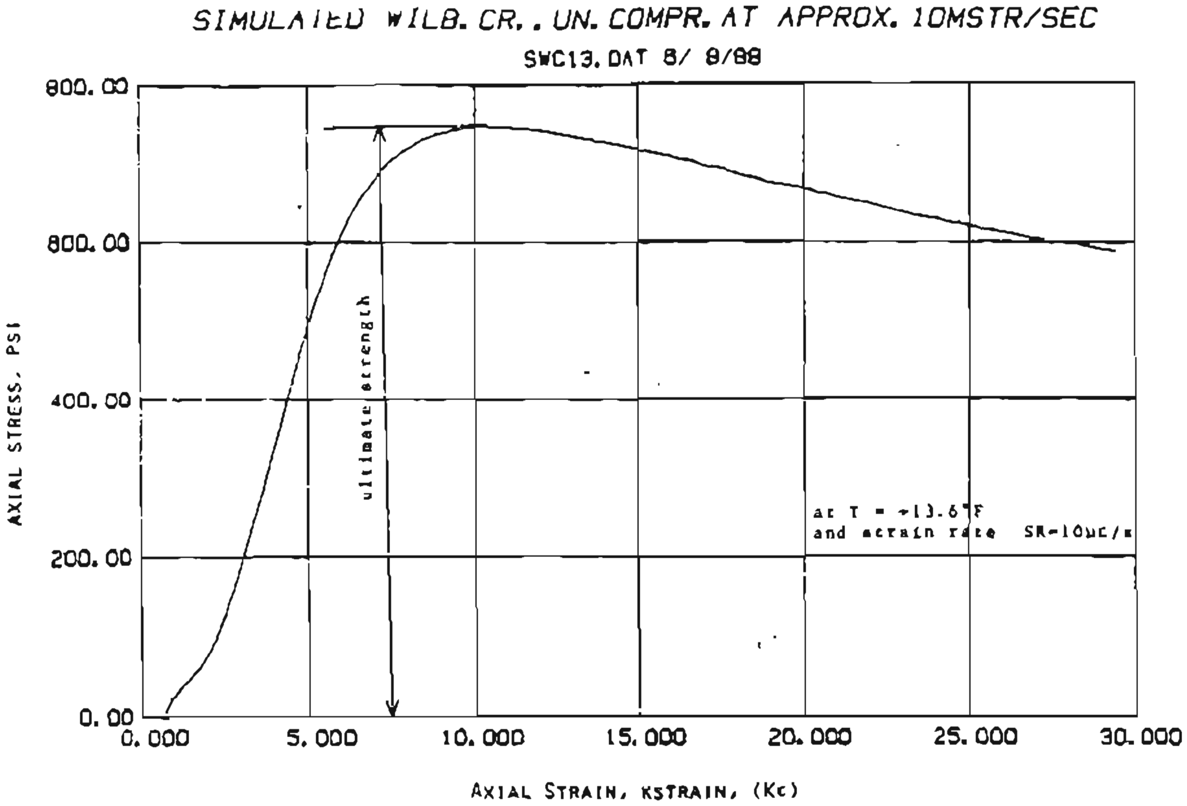
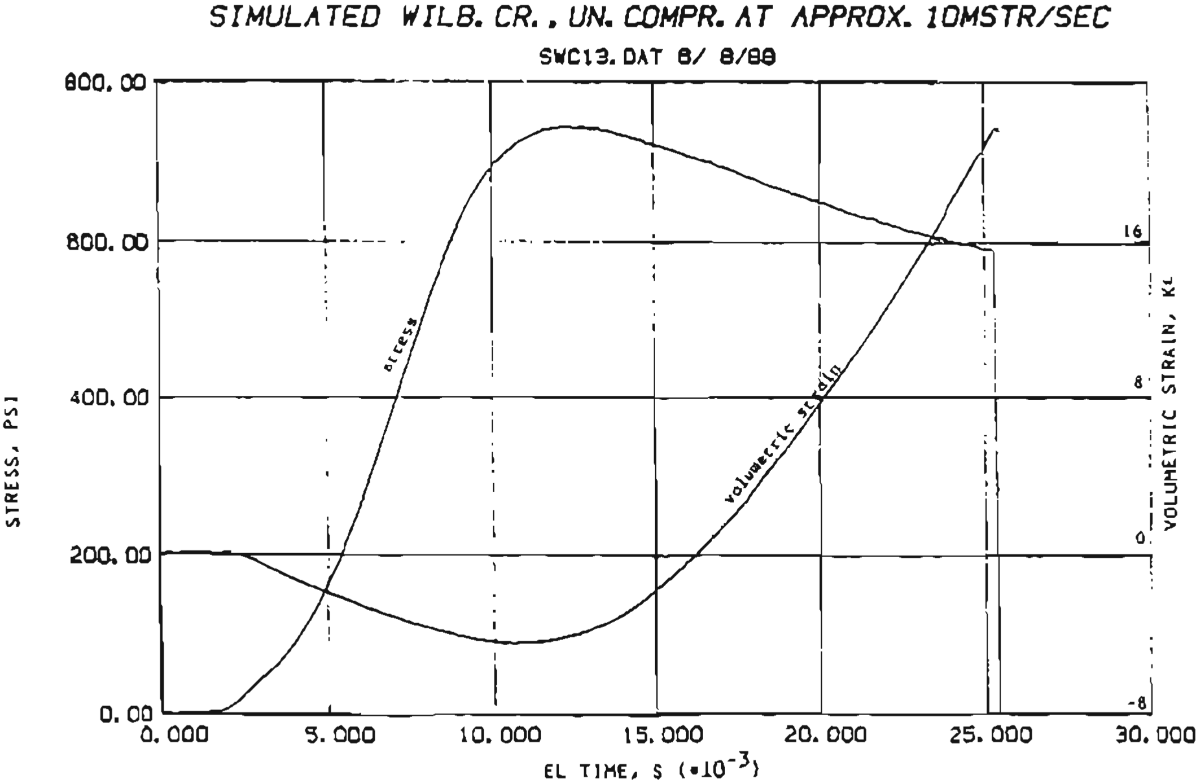


FIG. 9: SCATTER OF SPECIFIC GRAVITY AND ICE CONTENT OF ARTIFICIAL SAMPLES.



A. Axial stress vs. axial strain.



B. Stress and volumetric strain as function of time.

FIG. 10: UNIAXIAL COMPRESSIVE TEST FOR THE WILBUR CREEK GRAVEL.

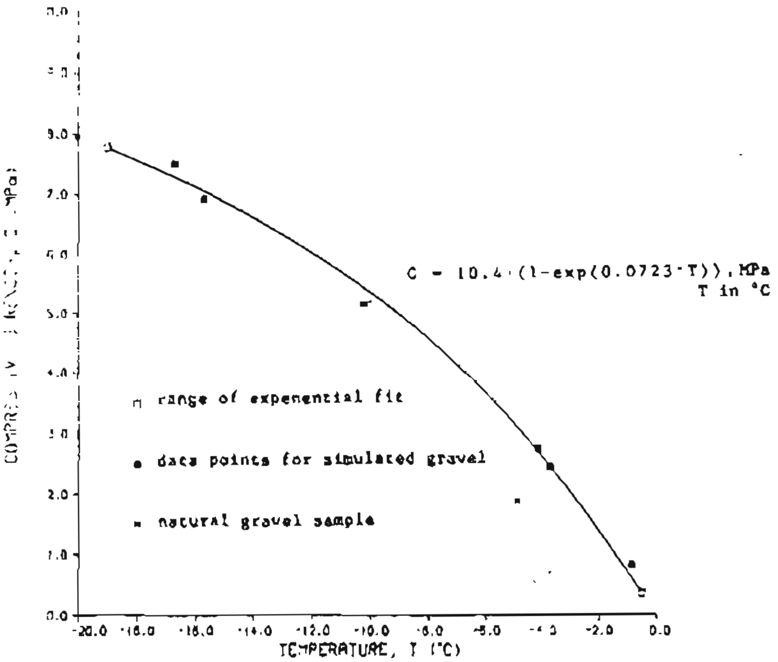


FIG. 11: UNIAXIAL COMPRESSIVE STRENGTH OF THE WILBUR CREEK GRAVEL AS FUNCTION OF TEMPERATURE

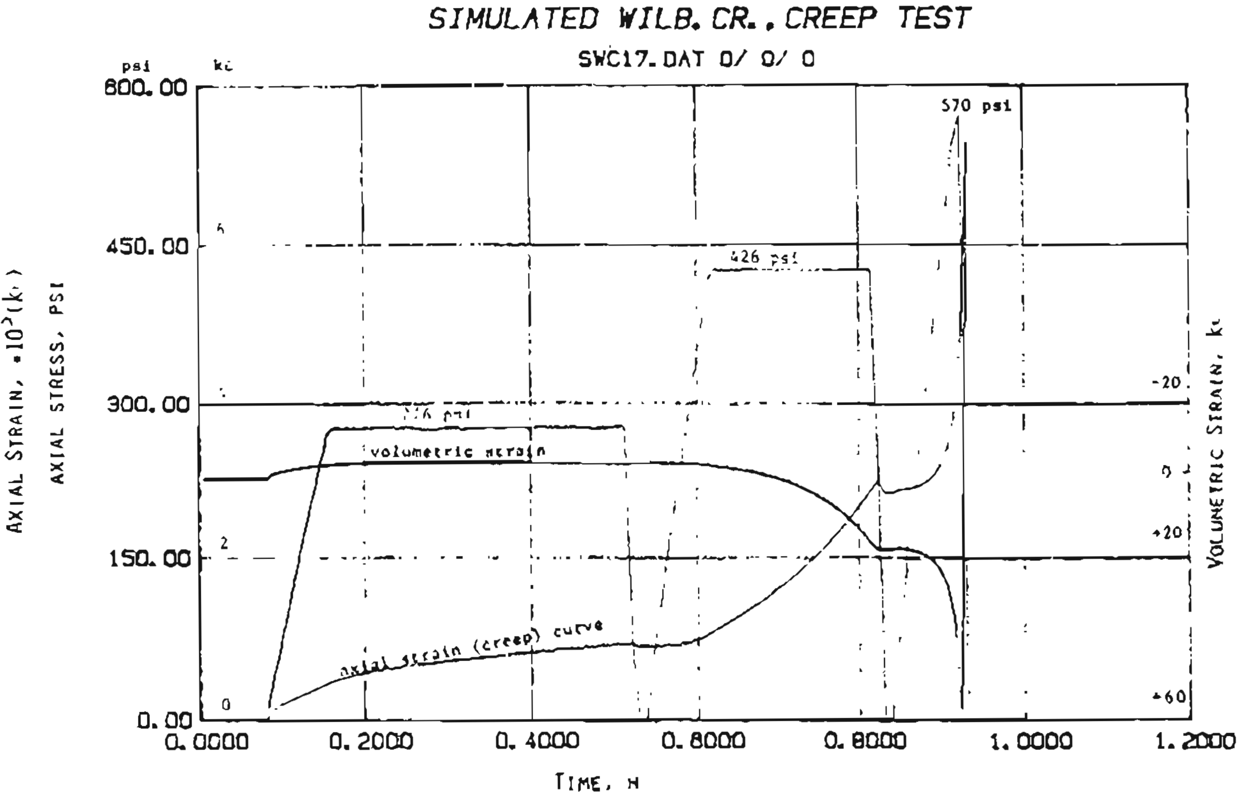
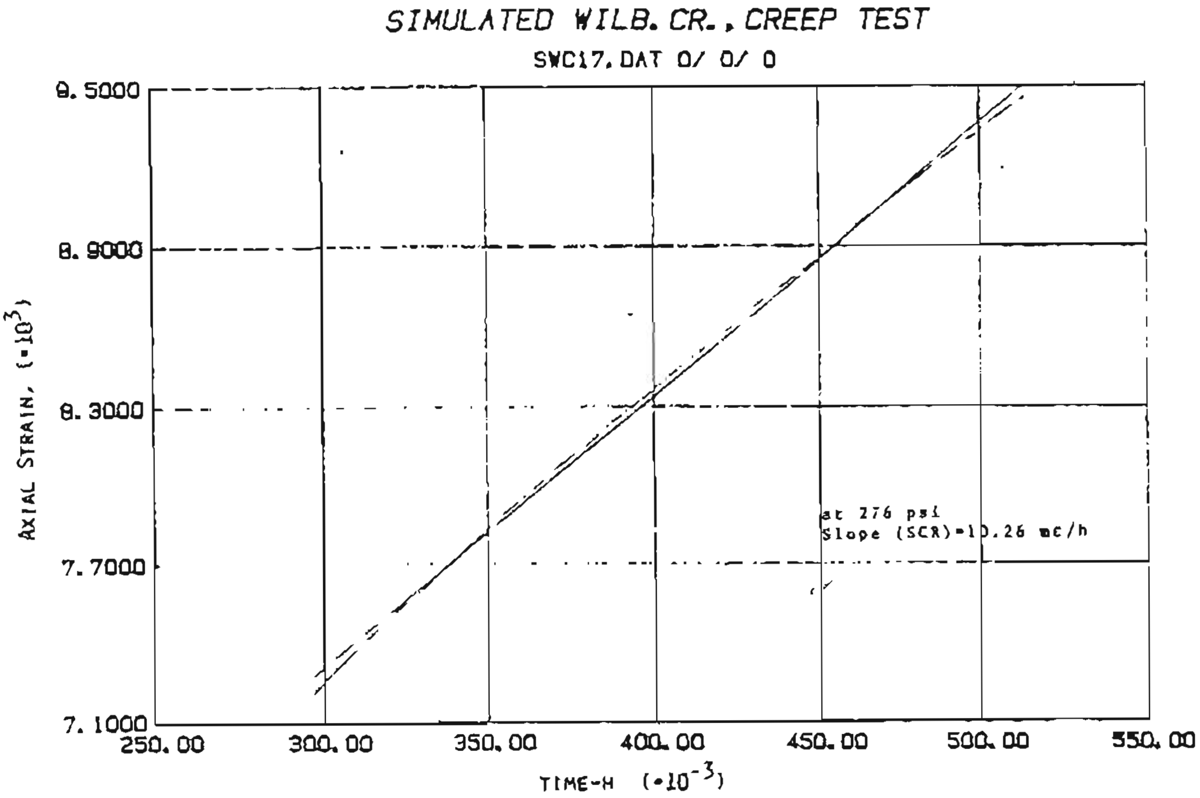
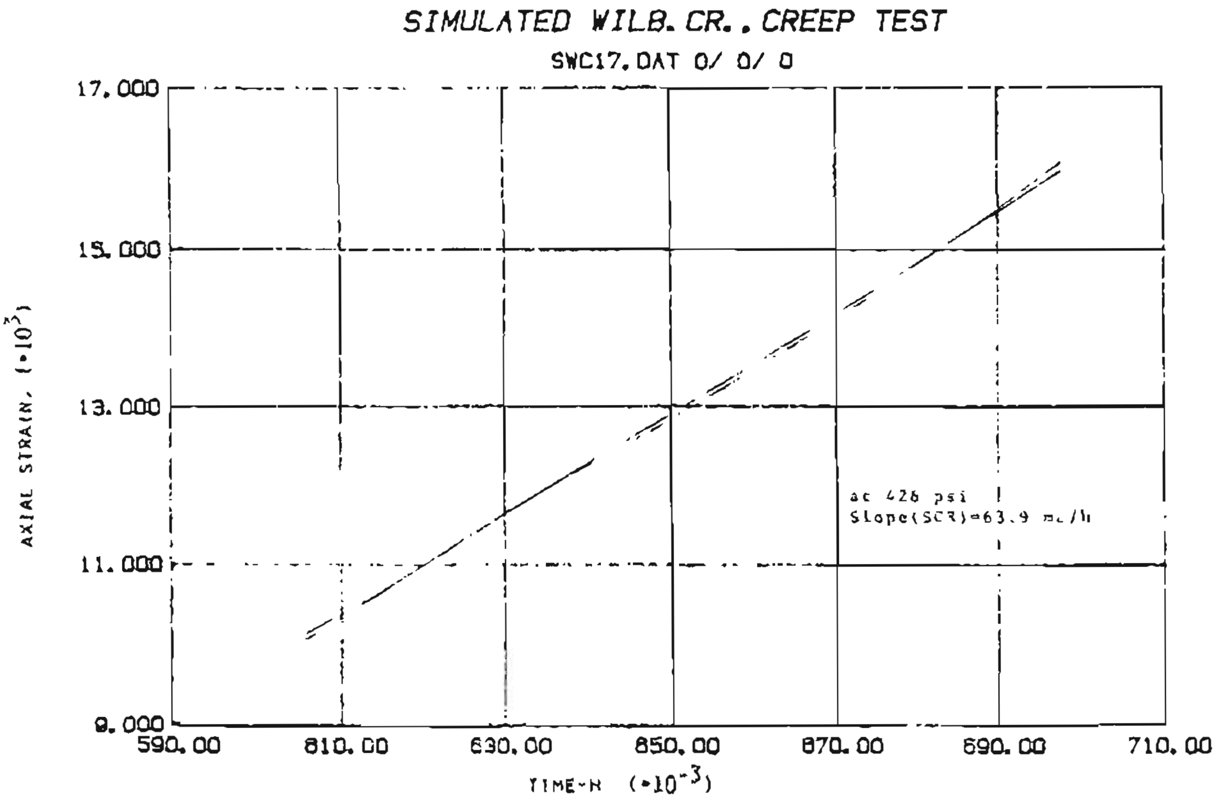


FIG. 12: CREEP TEST ON SAMPLE #17



A. First cycle at 276 psi (1.90 MPa)



B. Second cycle at 426 psi (2.94 MPa)

FIG. 13: SECONDARY CREEP RATE (SCR) DETERMINATION FROM CREEP TEST OF SAMPLE #17.

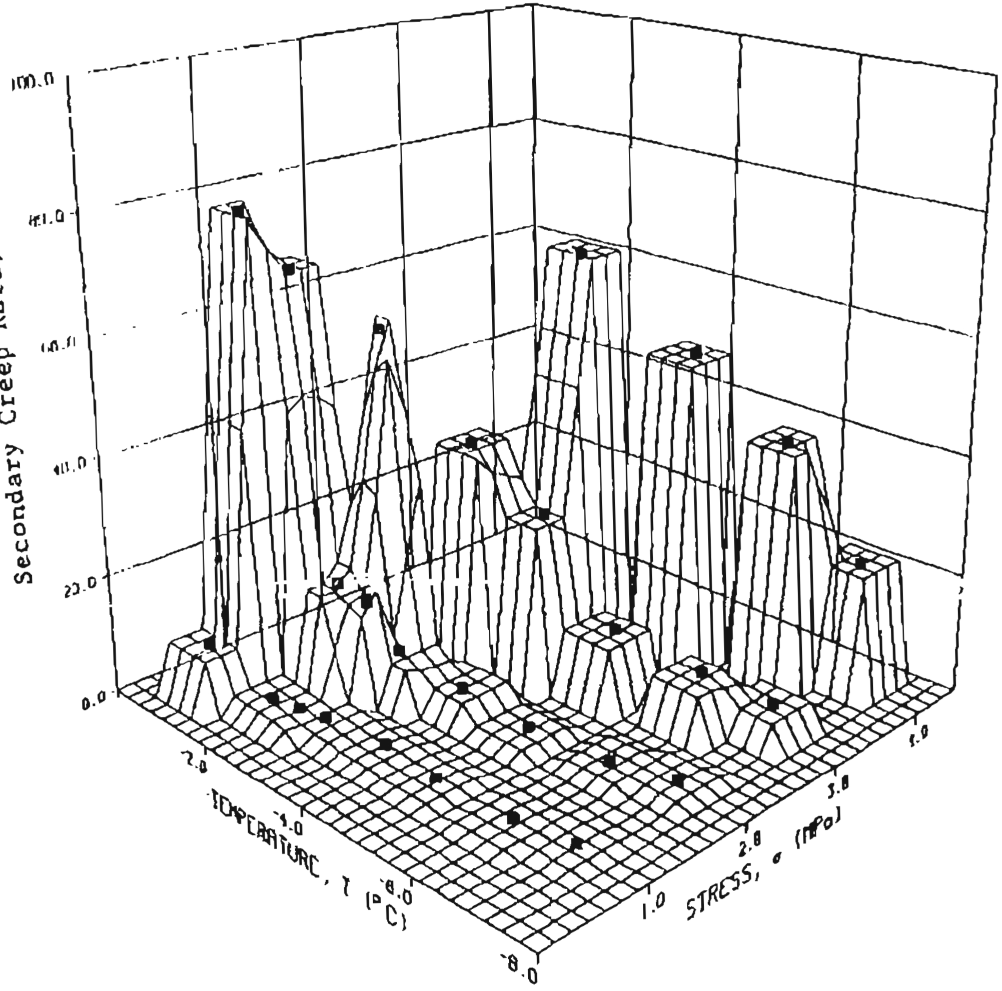


FIG. 14: SECONDARY CREEP RATE, SCR, AS A FUNCTION OF TEMPERATURE AND STRESS FOR THE WILBUR CREEK GRAVEL.

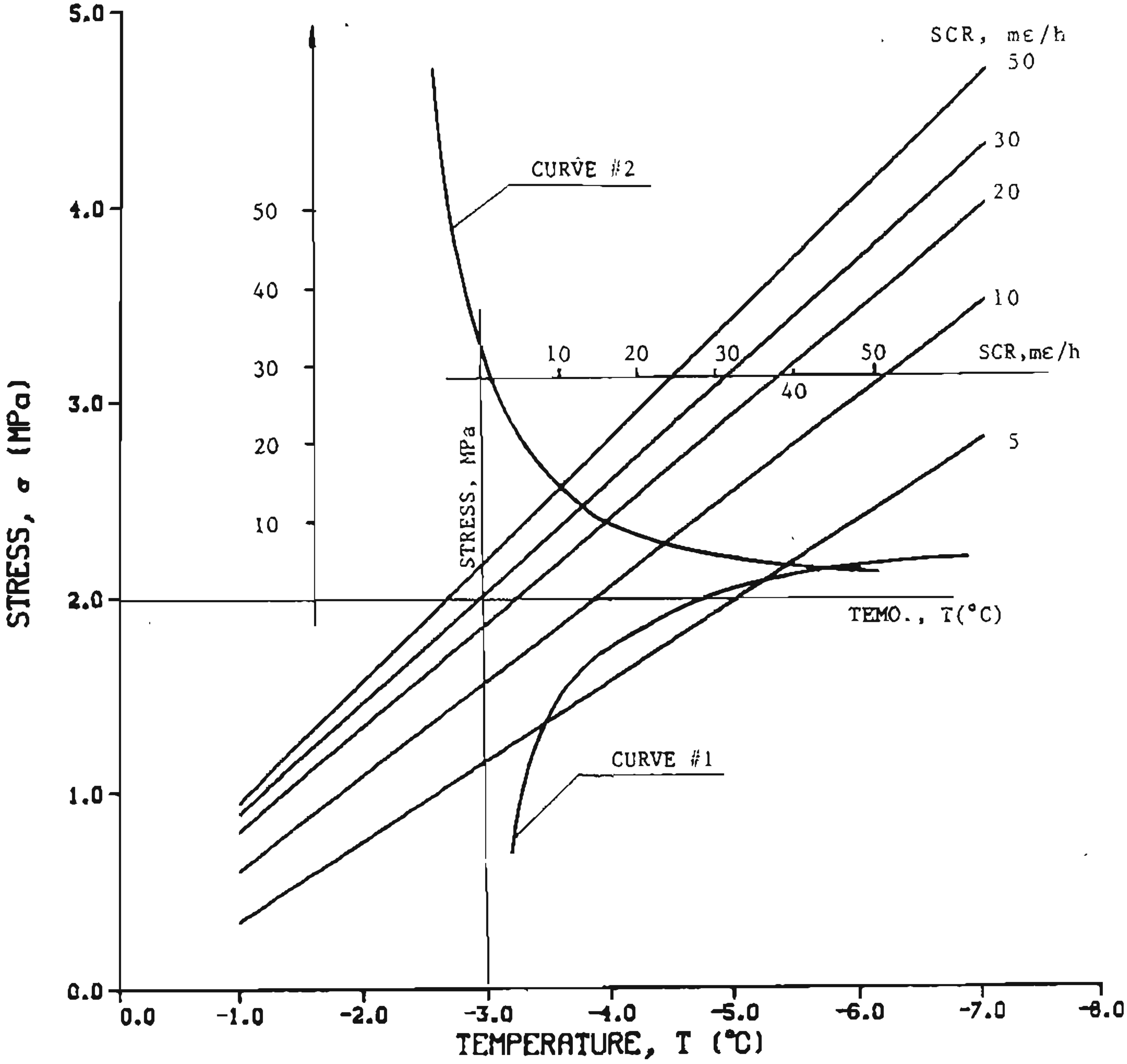
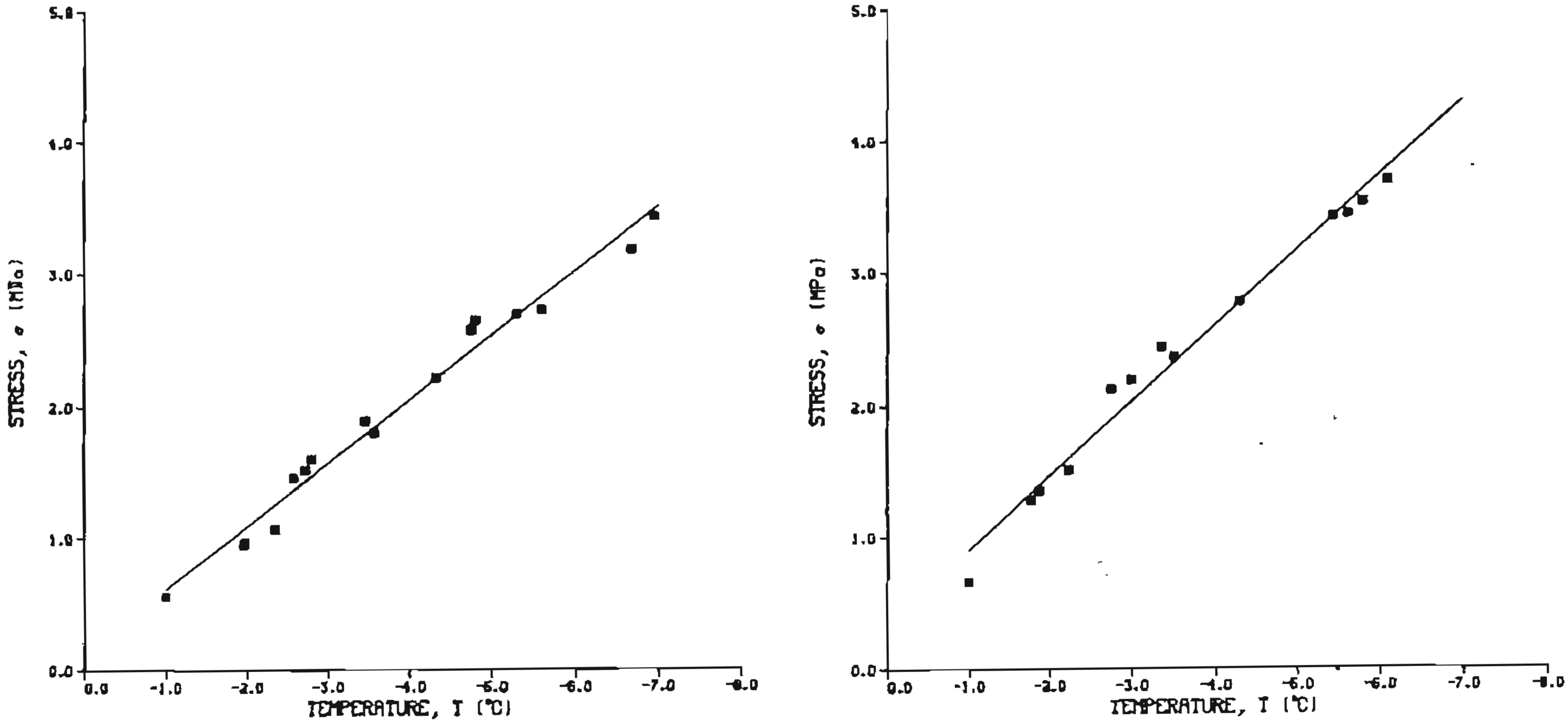


FIG. 15: STRESS VS. TEMPERATURE AT CONSTANT SECONDARY CREEP RATES (SCR) FOR THE WILBUR CREEK GRAVEL.



A. at 10 mε/h

B. at 30 mε/h

FIG. 16: EXAMPLES OF STRESS-TEMPERATURE RELATIONSHIP FOR CONSTANT SECONDARY CREEP RATE.

TABLE 1. WILBUR CREEK GRAVEL
DENSITY, ICE CONTENT AND
UNIAXIAL COMPRESSIVE STRENGTH OF ARTIFICAL SAMPLES

Sample #	Comments D/L,(in.)	Temperature (°F)	(°C)	Compr. Strength (psi)	(MPa)	Density g/cm^3	lb/ft^3	Ice Content %
WILGRL. DAT	Natural D = 8.875 L = 18.5	23.2	-4.9	273	1.88			
SWC2	D = 6.042 L = 11.375	24.5	-4.3	397.5	2.74	2.06	128.5	16.5
SWC10	D = 6.08 L = 9.81	30.5	-0.8	119	0.82	2.15	134.2	15.1
SWC11	D = 6.061 L = 9.875	25.3	-3.7	356	2.45	2.14	133.5	14.4
SWC13	D = 6.065 L = 9.94	13.6	-10.2	745	5.14	2.16	134.8	15.1
SWC14	D = 6.04 L = 10.250	3.7	-15.7	1003	6.92	2.16	134.8	14.8
SWC15	D = 6.09 L = 10.00	1.9	-16.7	1089	7.51	2.18	136.7	14.6
					Average	2.14		15.1

D = diameter

L = length

TABLE 4.

WILBUR CREEK MINE CONVERGENCE (MM)

Station Excavation Date,	DATES 11/13/86	12/23/86	1/7/87	2/23/87	3/11/87	4/7/87	10/24/87	12/16/87	1/8/88	2/5/88	2/27/88	3/11/88
E1V	2617.15	2608.15	2607.15	2605.2	2604.9	2604.9	covered with ice	2432.0	lost	-	-	-
E1H	4288.8	4267.7	4267.5	4267.4	4267.5	4266.45	4239.7	4238.1	4236.6	4235.9	4235.5	4235.05
E1V	0	9.0	10.0	11.95	12.25	12.25	-	185.11	-	-	-	-
E1H	0	21.1	21.3	21.4	21.3	22.35	49.1	50.7	52.2	52.9	53.3	53.75
Nov.5, 1986												
E2V			3119.3	3091.2	3085.7	3078.2	lost					
E2H			7322.8	lost	-	-						
E2V			0	28.1	33.6	41.1						
E2H			0	-	-	-						
Dec.15,1986												
E3V			2771.95	2687.4	2675.0	2658.4	2278.05	2187.0	2178.5	2175.4	2173.5	2171.1
E3H			9271.3	lost	-	-	-	-	-	-	-	-
E3V			0	84.55	96.95	113.55	493.9	584.95	593.45	596.55	598.45	600.85
E3H			0									
Dec.20,1986												
E4V						3146.75	lost					
E4H						11252.4	lost					
E4V						0						
E4H						0						
Jan.21,1987												
E5V								2250.1	2262.3	2270.4	2281.3	2290.0
E5H								3449.3	3452.0	3455.2	3457.3	3460.1
E5V								0	12.2	20.3	31.2	33.9
E5H								0	2.7	5.9	8.0	10.8
Feb.15,1987												
Days	0	40	55	102	118	145	345	398	421	449	471	484

TABLE 3. WILBUR CREEK MINE TEMPERATURE (^{o}C)

Station depth,	Dates 11/13/86	12/23/86	1/7/87	1/13/87	2/16/87	3/2/87	3/20/87	4/17/87	5/22/87	12/16/87	1/8/88	2/5/88	2/27/88	3/11/88
T1 6 in.	-9.8	-11.2	-11.0	-19.2	-16.2	-18.6	-10.0	-6.3	-	-20.3	-14.2	-18.3	-12.1	-6.4
T2 3 ft.			-5.0	-5.3	-5.7	-6.2	-6.3	-5.0	-	-15.3	-10.8	-16.2	- 8.4	-7.6
T3 8 ft.					-2.9	-3.3	-4.0	-3.6	-	-11.8	- 8.2	-10.5	- 7.6	-6.8
T4 3 ft.								-4.3	-3.6					
T5 6 in.								-6.5	-4.5					
T6 3 ft. oil since 12/16/87										-	-5.2	-3.5	- 4.2	-3.9
T7 3 ft. oil since 12/16/87										-	-4.8	-4.0	- 3.5	-3.2
T8 3 ft. oil since 12/16/87										- 16.8	-12.1	-16.8	-11.8	-7.1
air/ location														-1.4 face
air temp at the portal floor	-15.2	-19.4	-12.2	-30.6	-	-38.9	-32.2	-4.2	- 2.1	-	-13.5	-18.5	-27.2	-1.2
days	0	40	55	61	95	109	127	145	190	398	421	449	471	484

TABLE 2. WILBUR CREEK GRAVEL
CREEP TESTS ON ARTIFICIAL SAMPLES

Sample #	Comments	Temperature °F (°C)			Temperature of°C			Temperature			Temperature			Spec. Grav., SG		Ice Cont., IC
			Stress psi(MPa)	Strain/Time mϵ/h		Stress psi(MPa)	Strain/Time mϵ/h		Stress psi(MPa)	Strain/Time mϵ/h		Stress psi(MPa)	Strain/Time mϵ/h	g/cm^3	lb/ft^3	%
3		27.1(-2.72)	116(0.8)	1.434	27.1(-2.72)	222(1.53)	7.159	27.1(-2.72)	334(2.30)	37.858	———	———	———	2.12	132.29	16.7
4		19.6(-6.89)	143(0.99)	0.399	19.6(-6.89)	292(2.01)	0.91	19.6(-6.89)	446(3.08)	4.39	19.6(-6.89)	593(4.09)	20.64	2.08	129.79	15.53
5		23.5(-4.72)	126.5(0.87)	0.569	23.5(-4.72)	255(1.76)	1.389	23.5(-4.72)	390(2.69)	10.744				2.10	131.04	15.97
6		28.4(-2.0)	92.5(0.64)	2.716	28.4(-2.0)	184(1.27)	17.709							2.06	128.54	16.03
7		29.7(-1.28)	182.(1.26)	68.413										2.10	131.04	15.76
8	Length 4"	24.0(-4.44)	122(0.84)	6.146	24.0(-4.44)	252.5(1.74)	9.99	24.0(-4.44)	384(2.65)	34.69				2.09	130.42	15.85
9		30.3(-0.94)	72(0.5)	8.572	30.3(-0.94)	143.5(0.99)	78.30							2.16	134.78	15.28
12	Reversed loading cycle	28.1(-2.17)	327(2.26)	99.58	28.1(-2.17)	104(0.72)	1.168							2.19	136.66	14.56
16		21.8(-567)	127(0.876)	1.024	21.8(-5.67)	257(1.77)	2.765	21.8(-5.67)	390(2.69)	9.607	21.8(-5.67)	519(3.58)	34.614	2.19	136.69	15.00
17	Failure No Record of IC & SG	25.7(-3.5)	276(1.90)	10.259	25.7(-3.5)	426(2.94)	63.894		FAILURE AT 570 psi (3.93MPa)							
18		29.0(-1.67)	107.5(0.74)	4.658	29.3(-1.5)	218(1.50)	55.258							2.17	135.41	15.15
19	2.5 min. loading time	26.5 (-3.05)	217.5(1.5)													