APPLICATIONS OF HYDROSTATIC LEVELING IN CIVIL ENGINEERING

D. Martin
European Synchrotron Radiation Facility (ESRF), Grenoble, France

1. INTRODUCTION

The Hydrostatic Leveling System (HLS) was originally developed by the Alignment and Geodesy (ALGE) group at the ESRF for long term monitoring and control of rapid realignment of the Storage Ring machine. By historical accident, it was employed extensively in the monitoring of concrete slab instabilities at the ESRF. Since then it has found its place in a number of civil engineering applications requiring monitoring of long term (several months), medium term (a few days), short term and punctual events. The value of the HLS in this area has led to new developments. It also opens the door for other as yet unidentified applications. This paper will present a synthesis of the work done in this field to date by the ESRF ALGE group.

2. AN HISTORICAL ACCIDENT - A NEW APPLICATION FOR THE HLS IN CIVIL ENGINEERING

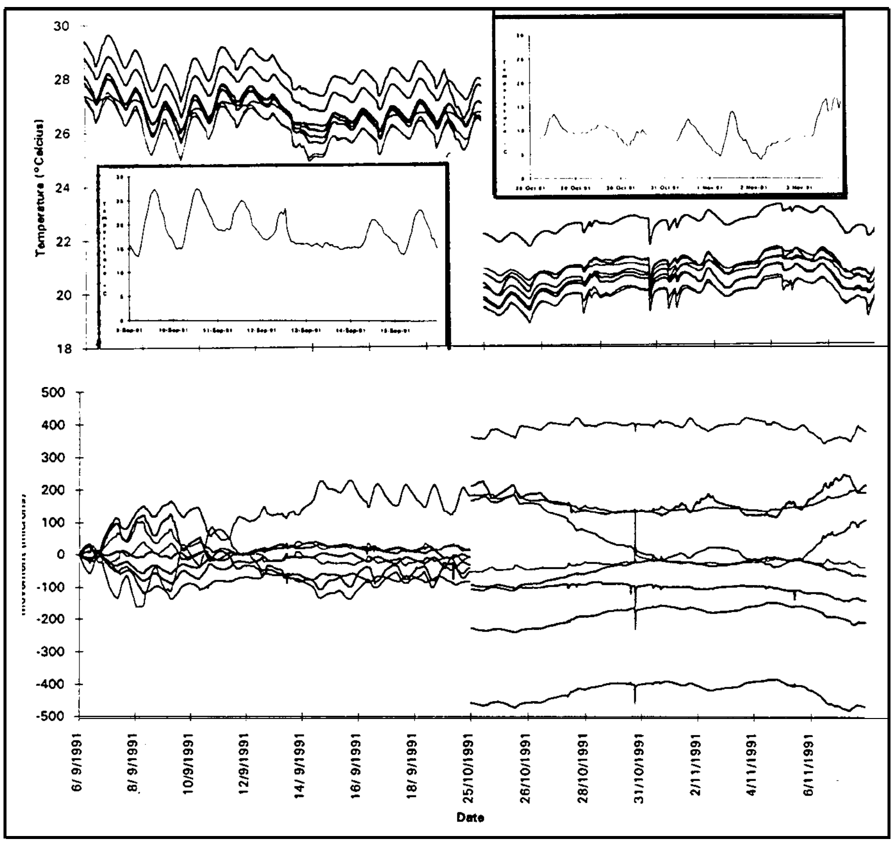


Fig. 1 Movement and temperature recorded on the µSOS test slab over the weeks 6/9/91 to 18/9/91 and 25/10/91 to 7/11/91. External temperatures for 9/9 to 16/9 and 28/10 to 4/11 shown in boxes.

Shortly after the concrete floor of the ESRF experimental hall (EXPH) was poured in 1990 slab instabilities were identified. It was then the ALGE group was asked to begin monitoring the evolution of EXPH floor.

The µSOS experiment was installed in July 1991 on what was to become the future ID21 beam line. It was used to study the behavior of the hall slabs and was instrumental in the characterization of the instabilities. It ran continuously until December 1991.

At the start of the experiment, air conditioning in the hall was not operational. Daily external temperature fluctuations were as much as 10 to 15 °C. In the hall itself, diurnal fluctuations were in the order of ±4 °C. These large temperature fluctuations were responsible for diurnal height difference (dH) fluctuations of up to 100 µm. Over a period of 20 weeks maximum long term dH movement was in the order of ±0.8 mm. This translates to an mean long term movement from one day to the next of 2.7 µm/day. It was very clear at this early date that the overwhelmingly predominant disturbing factor on the unrepaired slabs were the diurnal and long term temperature fluctuations. This dependence was later confirmed by the ANL - APS slab stability experiment. A new experiment (ID21) was already envisaged to study more carefully the EXPH slabs.

2.1. ID21 (&-Establishment Of µSOS) Long Term Slab Stability Studies

A much denser HLS network was installed on the ID21 beam line in May 1992 after grout had been injected to fiIl the voids which had developed under the floor slabs. It was these voids that were responsible for the instabilities. The experiment ran nearly one year until March 1993.

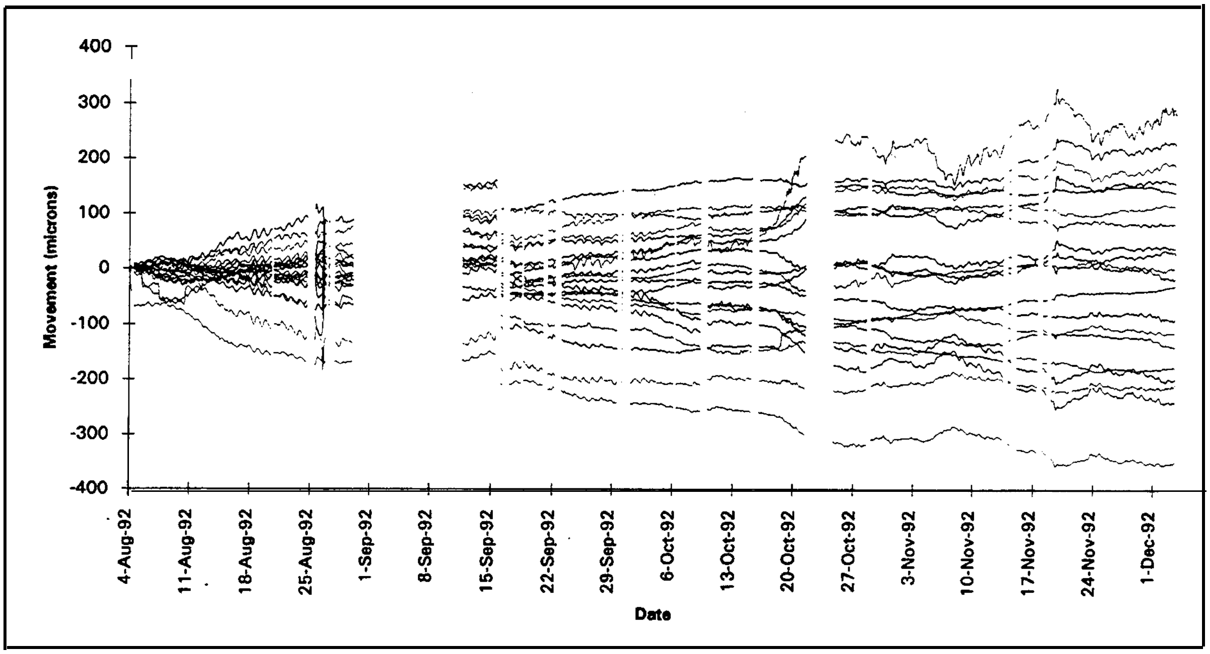


Fig. 2 Long term (4 month) evolution of 24 captors installed on the ID21 experiment.

Table 1 Summary Of Three Slab Studies

Installation	Standard Deviation (µm)	Maximum (µm)	Minimum (µm)	Average*** Movement Per Day (µm)	Number Of Captors In Installation	Number Of Days
µSOS*	218.54	426.13	-482.25	2.679	9	62
ID21**	162.51	297.65	-354.17	1.148	24	121
CERN TT2A	104.11	121.35	-186.68	1.194	8	87

* Measures taken before grout injection under slabs.
** Measures taken after grout injection under slabs.
*** Movement from one day to the next over the long term

The ID21 (formally μSOS) slabs showed a remarkable improvement after grout injection. What is particularly impressive is the more than two times improvement in average daily movement. (see Table 1) However there were persistent though small diurnal movements even though the hall temperature remained stable.

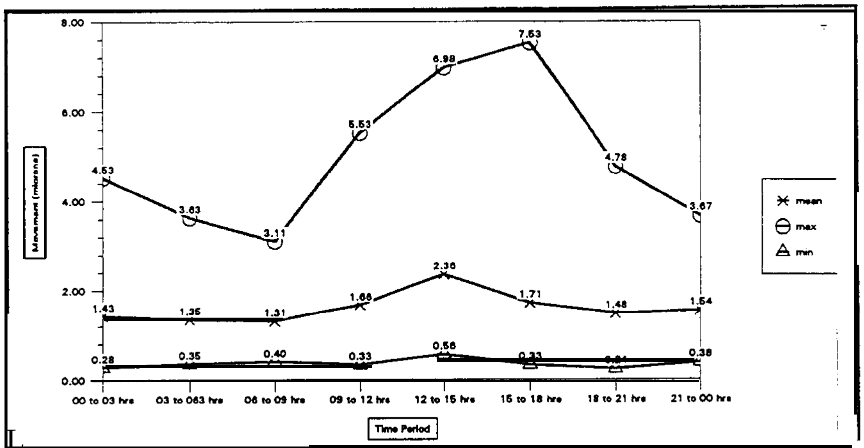
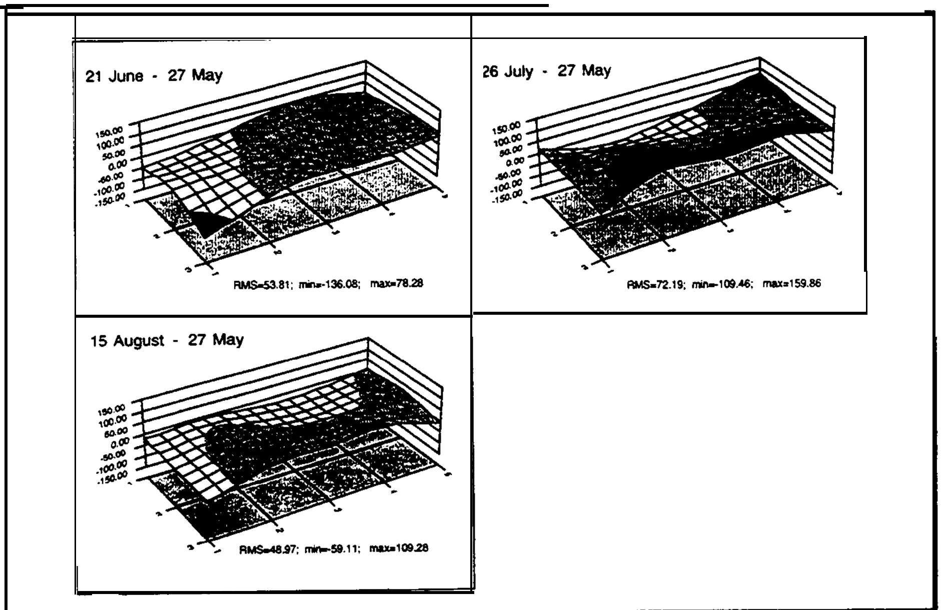


Fig. 3 (left)
Average diurnal movements over 4 months recorded on the ID21 slabs. (left)

Fig. 4 (below)
Long term evolution of ID21 slab 2.



There was particular interest at the ESRF in the long term evolution in the form of the slabs. One slab had 15 HLS sensors installed on it specifically for this purpose. Figure 4 shows this evolution.

Apart from the long term stability studies, several short term charge studies were made. Two interesting studies were the deflection effects of moving a charged overhead crane through the study area. and of placing a 2.4 T charge directly on the slab over one of the HLS sensors.

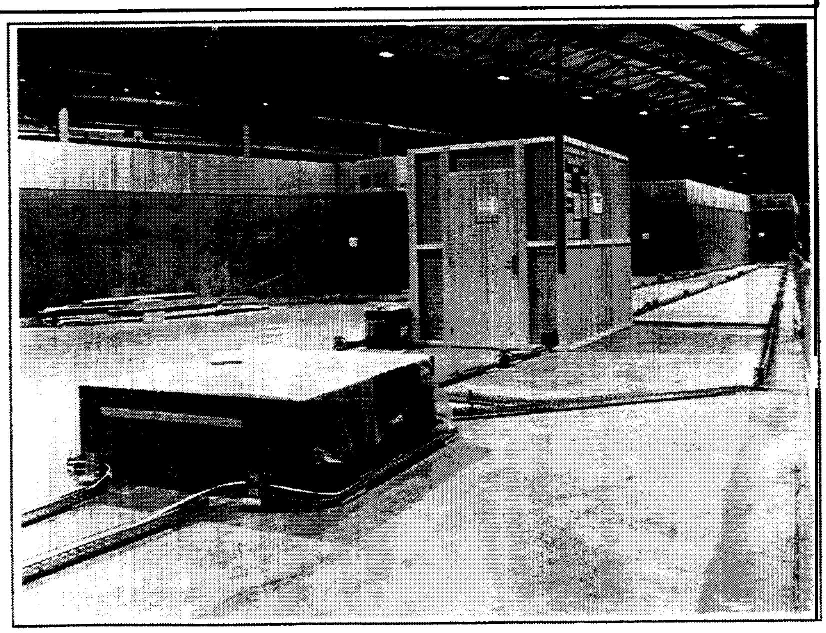


Fig. 5 (right)
Photograph showing the general layout of the ID21 experiment.

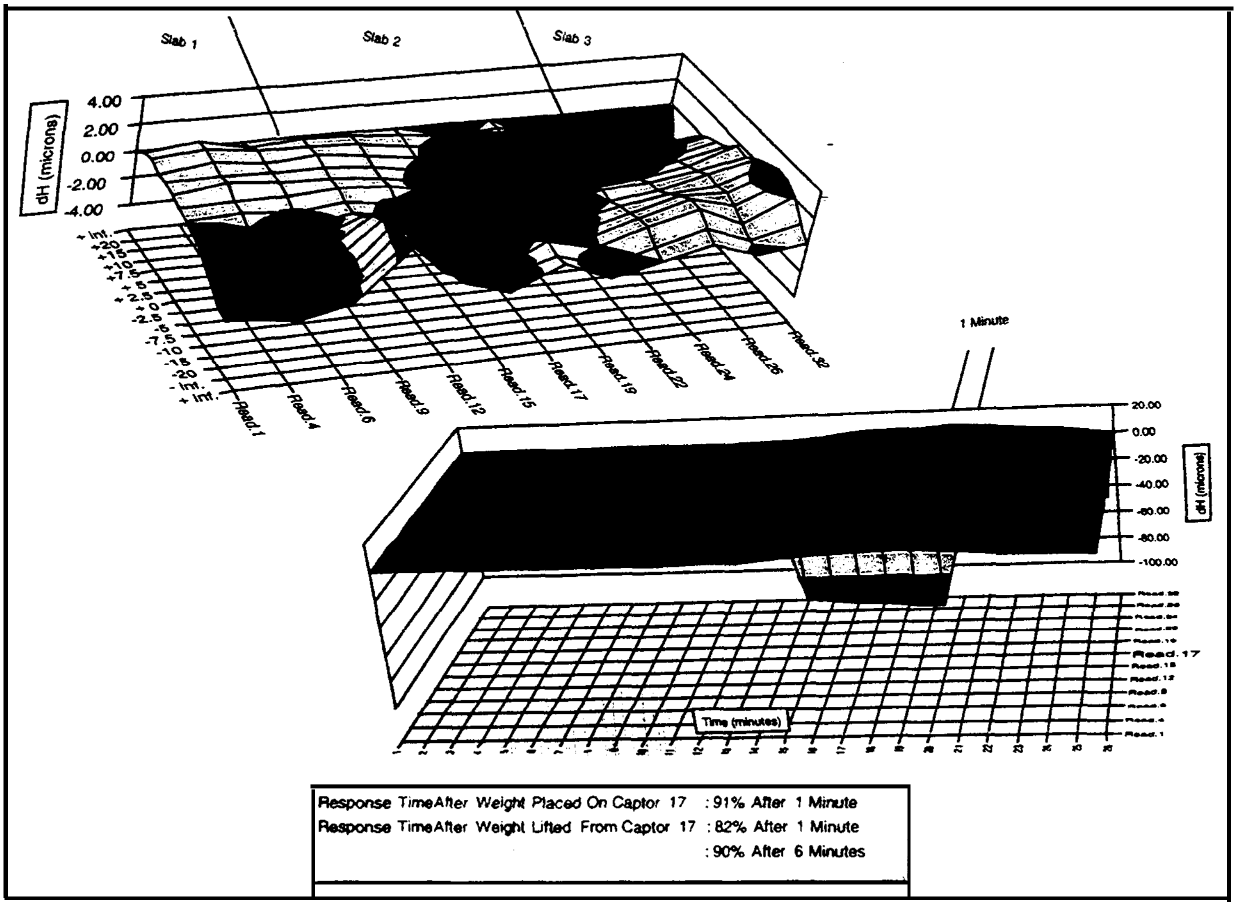


Fig. 6 Effect of crane with 2.4 T charge passing over ID21 installation (upper left). Deflection caused by placing 2.4 T charge directly in the center of slab 2 (lower right)

2.2. ESRF Storage Ring Slabs

After the success of the ID21 monitoring experiment, questions were asked concerning possible movements of the ESRF Storage Ring slabs. Curiously enough, there was a diurnal movement recorded at the slab joints. This is shown in Fig. 5. This movement translated to a rocking motion of the slabs as a function of time of day.

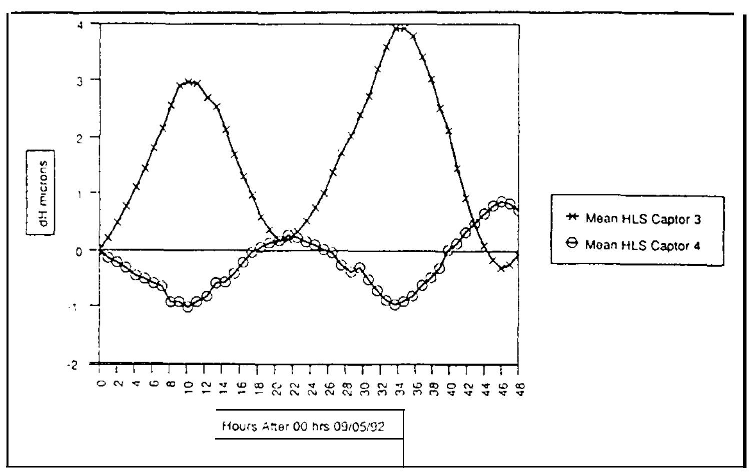


Fig. 7 Diurnal "rocking" motion of ESRF Storage Ring Slabs as a function of time of day. Captors 3 and 4 are located on either side of the joint.

3. CERN - A MODEL SLAB

After experiences at the ESRF, an experiment was established in one of the old transfer line tunnels at CERN (TT2A) to identify the behavior of a "model slab". After an initial start-up period, this slab was seen to be extremely stable. In fact so much so that the greatest perturbation in the installation came from the tidal effect of the moon on the water in the pipework.

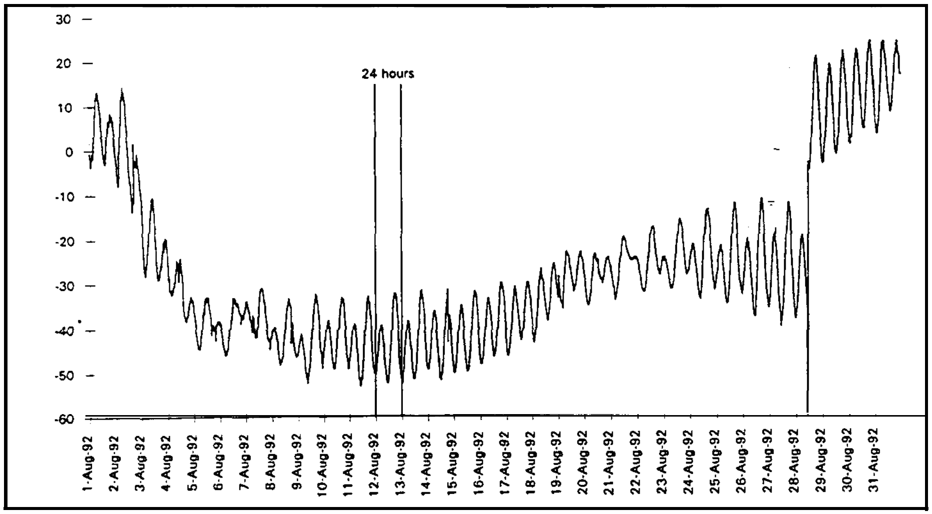


Fig. 8
Tidal effect in the CERN HLS installation pipework.

4. LONG TERM SLAB THERMAL STUDY

A study was established to model the behavior of a 30 cm thick strongly re-enforced concrete slab. This slab was considered a possible replacement for the problematic ESRF EXPH slabs. Although the study was unable to provide conclusive information regarding long term stability, several interesting conclusions about thermally inspired slab deformations were made.

The ANL - APS site was not heated when the HLS study line was installed. In order to avoid freezing the water, a heated, insulated housing was built around the system. Although the temperature in the protective housing remained relatively constant, the external temperature fluctuated very dramatically. This led to large movements in the slab being studied.

A very simple model was employed to characterize the slab deformations witnessed on this study. It was assumed that a change in temperature from one day to the next would induce a relative height difference between dH sensors. The most satisfactory model found for this relations was :

$$d(dH_i - dH_1)_{\text{day } j - \text{day } (j-1)} = A_0\,(dT_{\text{external day } j - \text{day } (j-1)} - 0.6 * dT_{\text{external day } (j-1) - \text{day } (j-2)}) + A_1$$

This model indicates a dependence on temperature over a three day period. The correlation coefficients of this relation for the 8 captors involved in the experiment range between 0.79 and 0.90. Eighty to ninety percent of the movements seen on this slab can be attributed to external temperature changes. There was no correlation between the temperature changes measured inside of the housing and the slab movements. The results of this study show that the HLS can be effectively used in the control and modeling of thermally inspired deformations of materials. This study also inspired another development in the HLS.

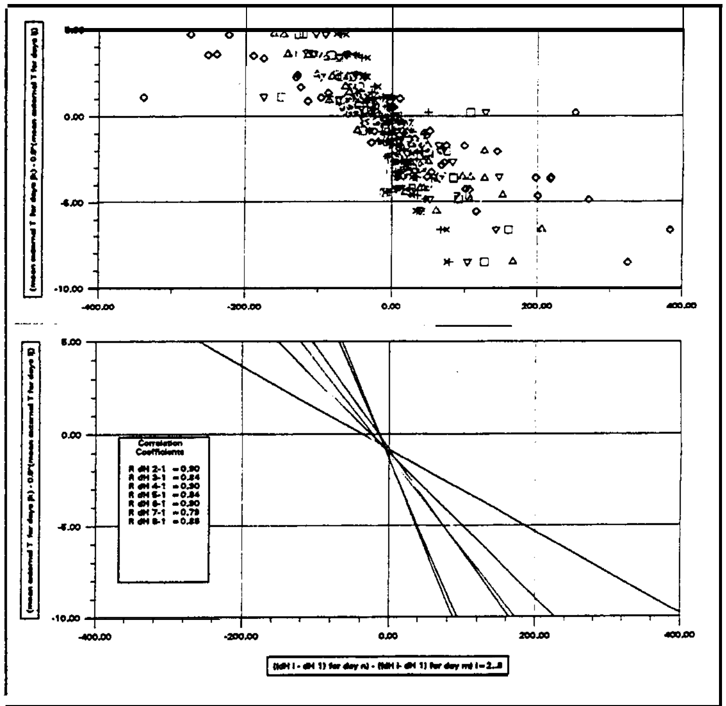


Fig. 9 (left)
Temperature model developed for the ANL -APS slab study. External temperature fluctuations were responsible for between 80 and 90% of the movements seen on this slab.

5. ESRF LONG BEAM LINE ID19 - LOW TEMPERATURE APPLICATION

It was very clear with the ANL - APS study that an alternative to water had to be found for certain applications where temperatures descended well below zero degrees Celsius. The alternative selected was the 40 % glycol and water mixture 'Cool Elf' developed by the French petroleum company Elf The mixture of 'Cool Elf' supplied to the ESRF was very carefully studied to determine the exact percentage (to better than 1 %) of glycol present. It was also studied to determine its specific mass as a function of temperature. This product can be used to -30 °C. In order to characterize the behavior of this fluid with respect to water, a study line was installed on one of the ESRF long beam line tunnels (ID19).

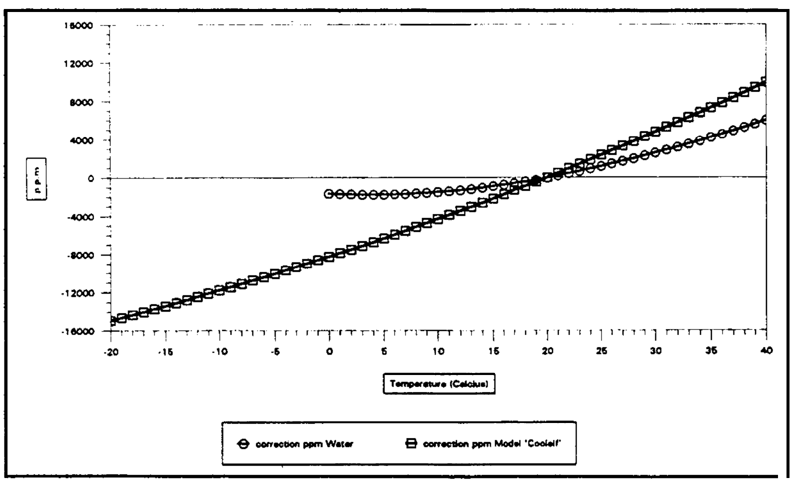


Fig. 10 P.P.M. corrections for the 40% glycol water mixture ‘Cool Elf’ and water

This fluid behaves in the same manner as water with the notable exception of its application at low temperatures and its viscosity. The standard ‘filling test’ used with the HLS to determine if an installation is operating correctly, gave a peak to peak stability of ±10 µm after 1 hour. The stabilization period of water using the same pipe diameter (8 mm interior) is approximately 10 to 15 minutes.

One interesting experiment that was performed on this study line was the truck charge test. A truck with two different loads (26 T and 38 T) and axle configurations was parked on the road passing over one of the captors to determine the deflection of the ground. The deflection was in the order of 40 µm.

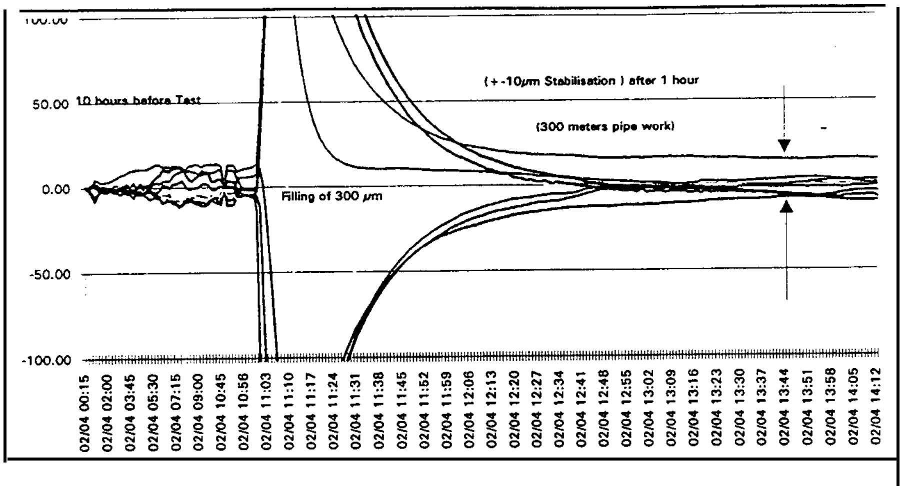
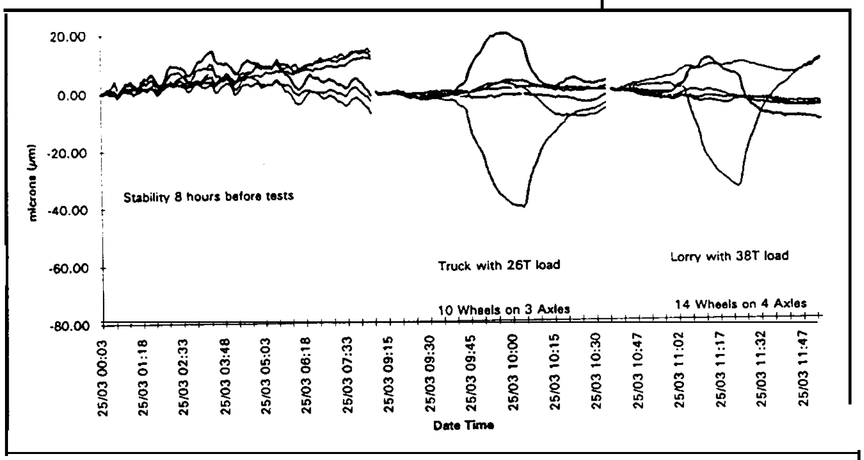


Fig. 11 (left) Filling test using 40% glycol mixture 'Cool Elf'

Fig. 12 (right) Truck test on the ID19 beam line.



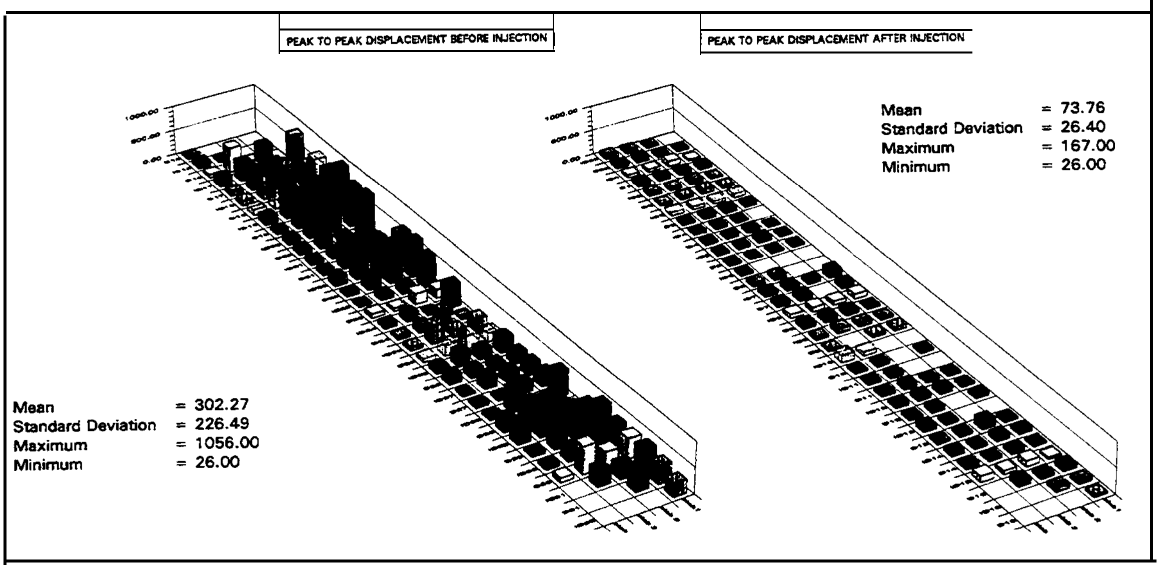


Fig. 13 Results before grout injection (left) and after grout injection (right) of the ESRF EXPH slabs. This work represents the first industrial campaign of measures made with the HLS.

6. INDUSTRIAL CAMPAIGN OF SLAB REPAIR VERIFICATION

The decision to inject grout under the existing ESRF EXPH slabs required the ALGE group to systematically control the results of this intervention. This operation takes one team of surveyors (3 people) one day to control 8 slabs. The slabs are controlled before and after injection of grout. The improvement in the stability of the slabs is impressive. The mean deflection before and after injection is 302 µm and 74 µm respectively. It is also impressive that the HLS can be used in such a systematic fashion.

7. CONCLUSION

Several examples of applications in civil engineering have been presented. Many other applications can be imagined. What has been discussed and demonstrated here is that the role of the Hydrostatic Leveling System in civil engineering is clear and undisputed.

Fig. 14 Photograph showing the general setup used in the industrial measurement campaign of the ESRF EXPH slabs.

8. REFERENCES

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9. ACKNOWLEDGMENTS

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