Instrumentation

John Dunnicliff

Introduction

This is the fifth episode of GIN: the start of a second year, so perhaps it's time to reflect on whether the idea of this column makes any sense.

My original purpose *(Geotechnical News, September 1994, page 70)* was:

> *To share useful information relating to geotechnical instrumentation. I intend to focus on performance of instruments. As a practitioner, I know how difficult it is to be confident that such-and-such an instrument will work well, and it seems to me that if we share performance information with each other, we will make this less difficult.*

I still believe in the need to "share", both among users and between manufacturers and users. Some users welcome this column, but some don't like it, believing it to be too shallow. Most responses from manufacturers have been negative, either because one or another claimed I was "favoring the competition," or because there was specific disagreement with something I'd written.

Now to reflect: as the years go by I move away from a "them and us" (manufacturers and users) posture, towards a "we're all in this together" posture. This change colors my approach to continuing education courses, which now include presentations by manufacturers, and to the "sharing" purpose of this column. But the column has created confrontation with some manufacturers, which I regret, very much. Confrontation is the opposite of my purpose. Some years ago Stan Wilson and I discussed how we could encourage cooperation between manufacturers and users, thought about starting a "trade journal," canvassed a few people, but motivation was low and nobody wanted to provide funding. Something like Deep Foundations Institute (an organization to which designers, constructors, materials suppliers and academia all belong, to share common issues) would be an excellent model for our geotechnical instrumentation community, but the community is not nearly big enough for this.

So - where to go from here? I've learned that I need to be flexible about the focus of this column. Constructive exchanges of views are healthy (in the column, in separate articles under the GIN heading, in separate articles for which I don't act as editor, in letters to the editor of GN), but the opposite must be avoided. If I find that these goals can't be achieved, I'll bow to the realities of free enterprise, change the focus, or discontinue the column. Does anybody have better ideas?

Today's Menu

I've solicited two articles for this issue. I asked Arthur Penman to use his established "General Reporter" skills, to write a summary of FMGM 95, not appreciating that this would require him to sit, hour after hour, taking notes on the front row, through three days of presentations. Thank you, Arthur, for enduring, and for showing your skills again. The article by Jim Hall was triggered by a frequently heard observation and question: *"One of the main negatives about automatic data acquisition systems is the concern for damage by lightning. Nobody seems to be able to help me with this. What should I do?"*

Also in this issue of GIN is an article about Slope Indicator Company's electrolevel system.

FMGM 95

Arthur Penman's impressions of FMGM 95 are given later in this episode of GIN. I want to add a few impressions of my own.

Why go to FMGM? This was the first one that I'd attended, thinking "I can read the papers in the proceedings," so there's little reason to go. Wrong! For me, the most striking impressions are:

- The realization that in North America we tend to have an insular view. There's a lot of equipment, and approaches to problem solving, that we don't see in North America. Particularly striking was the technology in Switzerland, Germany and Italy.
- The realization that, in North America, the role of most manufacturers ends when the instruments are shipped to the user, whereas in many other countries the manufacturers also provide major field services. I believe that the North American cut-off relates to avoiding competition with customers and also to avoiding professional liability. However, it seems to me that the end-user (the person who wants good data) may sometimes be better served by a highly-skilled manufacturer/field service organization, such as provided by ISMES in Italy, Solexperts in Switzerland and Interfels in Germany.
- The valuable information to be gained by browsing the exhibits, and talking with exhibitors, in-depth, about applications and problems.
- The luxury of meeting, either for the first or umpteenth time, the "big names" from overseas: Dick Bassett, England; Helmut Bock, Germany; John Burland, England; Elmo DiBiagio, Norway; Michele Jamiolkowski, Italy; Kalman Kovari, Switzerland; Arthur Penman, England; Shun Sakurai, Japan; Arno Thut, Switzerland. How's that for some name dropping?!

Mark your Calendar!

Instrumentation Course
Vancouver, B.C. September 23-24, 1995
See page 39 for a detailed outline

- The outstanding hospitality of our Italian hosts, particularly ISMES, and the people who did all the **real** work: Giorgio Pezzetti and Deirdre O'Neil. A particular thank you to these two.
- The vino.

It was an expensive (except for the vino) experience, but well worth going. Of the 175 attendees, only 12 were from North America (8 representing the manufacturer community and only 4 the user community). Another example of our insularity.

A decision hasn't yet been made on the location of the next FMGM — when I know, I'll tell you.

Instrumentation Seminar in Hong Kong

On May 10, 1995 the Geotechnical Division of the Hong Kong Institution of Engineers organized a seminar "Instrumentation in Geotechnical Engineering." The proceedings are well worth reading, and can be obtained from:
Mr Barry Parkinson, c/o Fugro HK Ltd, 11/F Park Commercial Building, 2-12 Shelter Street, Hong Kong, Tel: +852 2577 9023 Fax: +852 2895 4220
Cost is HK$150 plus postage.

There are twelve papers. Particularly interesting to me are the following five:

- Monitoring the Foundations of the Leaning Tower of Pisa.
  John Burland, Imperial College, London, England
- Electrolevels — A Practical Solution or Numeric Nightmare?
  Chris Spalton, Soil Instruments Ltd, England
- Electrolevels or Servo-accelerometers?
  Cyril Chan, Robert Weeks, Geotechnical Instruments Ltd, Hong Kong and England
- Deformation Measurements using Electrolevel Sensors.
  Chris Rasmussen, Elton Wong, W R Wood, Slope Indicator Co, USA, and Fugro Geotechnical Services Ltd, Hong Kong
- An Automatic Data Acquisition System for the Management of Large Quantities of Geotechnical Monitoring Data.
  Pierre Choquet, Y Desrochers, G Wennerstrom, Roctest Ltd, Canada and Testconsult CEBTP Ltd, Hong Kong

John Burland's paper provides a written version of his fascinating FMGM 95 presentation: there is no paper in the FMGM proceedings. This and the next three all include extensive information on electrolevels (see next heading in this column). The paper by Choquet et al clarified for me the seeming complexity of the various components that make up an automatic data acquisition system.

Electrolevels

The above four papers, that describe performance of electrolevels, include the following views on temperature sensitivity:

- *The results showed conclusively that the electrolevels mounted on beams were much more temperature sensitive than those mounted directly on the walls. It appears that, even in the reasonably stable temperature environment of the instrument room of the [Pisa] Tower, significant thermal flexing of the beams take place. (Burland)*
- *Some original equipment manufacturers choose to use only a very limited central portion of the quoted electrolevel sensor range thereby avoiding the dramatic temperature effects at either side. Whilst the effects will be minimized, the individual nature of the sensors means that they should all be calibrated in a controlled environment to confirm the actual impact of temperature changes on the data generated by a rotational calibration. (Spalton)*
- *In our opinion, it is recommended that the use of commercially available electrolevel-based devices is limited to those applications where temperature changes are virtually non-existent and where access to the devices can be easily maintained in order to adjust them to their null positions. (Chan and Weeks)*
- *Many civil and geotechnical engineers consider electrolevels to be a "black art" obfuscated by jargon and the counterclaims of competing manufacturers. This is understandable particularly in view of the requirements for a fundamental understanding of the sensor behaviour and the need for specially designed signal conditioning electronics to ensure systems provide reliable and stable output over protracted periods of time. The Slope Indicator Co. has committed research and development resources to the issue of sensor excitation methods, temperature effects and the need for sophisticated calibration systems and procedures. This investment in the development of electrolevel technology has been proven by the track record of a large number of successful installations in a variety of different applications and locations. (Rasmussen et al.)*

These, together with other papers describing use of electrolevels (both in GN and elsewhere), have left me with uncertainties when considering use of electrolevels in an environment where there are substantial temperature changes. I believe there is an urgent need for technical papers/articles, authored preferably by knowledgeable users, describing case history experience. If there are doubts about applicability in a particular field situation, I believe that a field trial, with the close participation of the manufacturer, is likely to be appropriate. If anyone "out there" is in a position to do either of these things, please do so, and tell the rest of us what you learned.

Continuing Education Courses on Geotechnical Instrumentation

A reminder: the 2-day course in Vancouver will be on September 23 and 24, 1995, immediately preceding the 48th Canadian Geotechnical Society Annual Meeting and Conference. See page 39 for an outline, and call or fax Sandi or Lynn at BiTech for more details. A flyer with a full course description and schedule is now available.

The 3-day course in Florida will be on November 6-8, 1995. Contact *Ole Nelson, Associate Director, DOCE/Conferences, Tel: (904) 392-1701, ext 244, FAX: (904) 392-6950, E-Mail: ole@nervm.nerdc.ufl.edu,* for a course flyer.

Quality Assurance Program

Someone asked me recently for a list of items that should be included in a quality assurance program, to help ensure high-quality instrumentation data:

- Factory calibrations
- Personnel training for all office and field tasks
- Preparation and review of written procedures for all field tasks
- Pre-installation acceptance tests
- Acceptance tests at "hold points" during installation
- Post-installation acceptance tests
- Comprehensive installation records
- Regular maintenance and calibrations of readout units
- Duplicate or triplicate initial readings
- Rapid identification of whether a significant change has been measured
- Ongoing re-evaluation of data collection frequency
- Ongoing verification of the correctness of data processing, presentation and interpretation tasks
- Ongoing correlations among measured parameters, to develop relationships between causes and effects

Does your instrumentation program include these quality assurance steps?

Tomorrow's Menu

The following articles have been promised (to be written when the arms of prospective authors have recovered from twisting) for future issues of GIN:

- Measurements of pore water pressure at the face of driven concrete piles
- Measurements of groundwater pressure while jet grouting
- Modern surveying methods: geotechnical applications
- Why many great opportunities in field instrumentation are squandered in the U.S. construction industry
- Potential of fibre optic sensing in geotechnical applications
- Performance parameters - evolving tool for dam safety

Closure

As said before, please send me discussions, new material, whatever you think may be useful, to 16 Whitridge Road, South Natick, MA 01760, Tel (508) 655-1775, FAX (508) 655-1840. Santé.

[The "toasts" in these closures are by courtesy of Birger Schmidt, who has lent me a Tuborg beer mat which lists toasts in numerous languages. We'll have to see how Lynn at BiTech copes with later toasts in Moroccan, Chinese, Greek and Japanese characters!]

Field Measurements in Geomechanics: 4th International Symposium, Bergamo, Italy (FMGM 95) Some Impressions

A.D.M.Penman

PRIME POINTS

Kobe

The devastation caused in the Japanese city of Kobe by the earthquake on 17th January 1995 was graphically presented by Professor Shunsuke Sakurai of Kobe University. He had organised the 2nd FMGM that was held in Kobe in 1987.

The earthquake occurred at 05.45, during the hours of darkness when most people were in bed, causing a heavy death toll. The epicentre was 14 km deep, directly under the south-west end of the Akashi-Kaikyo suspension bridge which is going to be the world's longest. It will now be even longer: the earthquake has moved the south west anchor 1.4m west, increasing the span from 1990m to 1990.8m. But damage here was minimal and construction is going ahead. Within the city, however, damage was very severe with liquefaction in the harbour, the collapse of many buildings and the interesting feature that the 6th floors of many blocks collapsed: there were many leaning tower blocks -Kobe easily outstripping Pisa as the town of leaning towers!

A particular feature was that the tunnels suffered remarkably little damage...

At ground level the vertical shock had been much greater and of a higher frequency than those in the horizontal directions, although at a depth of 79m, the vertical shock had been much less than at ground level. A particular feature was that tunnels suffered remarkably little damage, adding further confirmation to the findings of Sharma and Judd (1991). A concrete lined tunnel passing under buildings, the bottom floors of which had completely collapsed, was almost undamaged. It passed through a known fault, and during construction the position of the fault had been marked on the tunnel walls. Here the concrete lining had been sheared with a movement of 80mm on one side and 10mm on the other, showing clearly that the fault had moved, but there was virtually no other damage to the tunnel. It could not, of course, be used because of the devastation outside at both ends which blocked access. An even more unexpected case was that of a much bigger, 70 year old railway tunnel on the main railway line, that had the usual flat invert and an arched roof, with a masonry lining of fairly large stones. Buildings above and at both ends were wrecked, but not a single stone had been dislodged inside the tunnel. One would have expected that the old arch structure would have collapsed, but it would seem that one of the safest places to be during an earthquake is inside a tunnel, even an old masonry lined one!

Pisa

The tower of Pisa is leaning towards the south at an angle of 5° 14' 46": an angle that has been steadily increasing since measurements began. The upper surface of the foundation formed a walkway around the tower and the south side had sunk below ground level. In 1838 it was exposed again to the view and delight of the public by excavation: an excavation that increased the tilt by half a degree. An attempt to stabilise the foundation by grouting in 1935-6 increased the tilt by 31 arc seconds, and pumping for water supply from the underlying sand during 1975-80 increased the tilt by a further 41 arc seconds. From 1940 to 1990 there has been a steady acceleration of the tilt to its present 6 seconds a year.

Surveying by level and theodolite was begun in 1911, with numerous points on the walls of the seven-storey tower. In 1934 a pendulum accurate to a tenth of a second of arc, was hung from the 6th floor. At the same time a very accurate spirit level, 4½m long, was provided to measure between points set on the inner ring of the foundations. The present Commission set up by the Italian government to advise on the tower, is chaired by Professor Jamiolkowski of Turin University. The numerous members include Professor Burland of London University who, in going through previous measurements, found that the pendulum had been observed during a complete 24 hour period on 13/14th September 1966. This showed that the tower was describing a daily circular motion, tilting away from the sun, and was likely to be causing cyclic loading on the foundations. To check on any movements transferred to the foundation, he arranged through the British Building Research Establishment for Gerwyn Price to bring and fit electro-levels to the foundation. These were connected through computer to provide continuous monitoring and revealed that the foundation was, in fact, subject to a daily cyclic motion caused by the sun: a motion that virtually ceased when there was cloud cover. This work also showed that electro-levels mounted on the masonry were more stable than those mounted on beams, which showed a lot of thermal effects. By combining the measured foundation movement with the observations of tower position that had been measured by the topographical surveys of 1911-28, it was established that the centre of rotation of the tilting motion was well above ground level so that as the south side of the foundation sank, the north side came up. It was thus seen to be possible to consider loading the north side of the foundation to limit and reduce tower tilt.

Accordingly, from 1st May 1993 to 7th March 1994, 600 tons of lead weights were added to the north side in five carefully controlled stages. By then, instrumentation included many new instruments, such as a hydraulic levelometer from the Italian research company, ISMES, electrolytic bi-axial inclinometers supplied by Applied Geomechanics Incorporated and a new plumb line with 'telecoordinometers' at

Pisa tower supported by the Penman girls three levels up the tower which automatically record the wire position, giving continuous monitoring. These instruments, together with the electro-levels, gave a very complete picture of foundation and tower behaviour as the lead weights were added, and showed that the tilt had been reduced by 54 arc seconds.

Critics of the work of this current Commission waited until the lead weights were in place, then produced old records of a tower in Venice during the 16th century, which began tilting. A learned monk proposed a lead weight solution, which was put into effect, but we do not know how much weight was used. Neither do we know the instrumentation of those far off days, but the tower was reported to have stopped tilting. Unfortunately, after a short time, it began tilting the other way and soon collapsed on to the monastery, killing two monks. The critics perhaps hoped that the Pisa lead weights would then be quickly removed, but they had not reckoned on the detailed instrumentation which provided a continuous record of tower movements.

As a more permanent solution, 10 ground anchors taken down through the clay layers to be 10m into the underlying sand stratum, each capable of 1000 kN, will replace the lead weights: work that is expected to be complete before the end of 1995. This arrangement has the advantages that nothing will be visible and will be better than weights during an earthquake. In addition, under-excavation will be carried out with boreholes inclined at 30° to the horizontal, spread out in plan over a 120° arc on the north side of the tower. The anchors will have the advantage over the lead weights of being self compensating, in that when the north side begins to go down due to under-excavation, they will lose tension, applying less restoring moment to the tower and avoiding a Venice type collapse!

There is the comfort about the under-excavation approach in that it has already been used to reduce differential settlements of Mexico City's Metropolitan Cathedral and adjacent Sagrario. This ancient building, begun in 1567, had developed a differential settlement between the main alter and the Cathedral's western tower of 0.80m by 1667. By 1900 this had increased to 1.53m, producing cracks in the vaults and walls, requiring frequent repair. During the 1940s part of the Cathedral was underpinned and during 1975-6 further underpinning was carried out under both the Cathedral and the Sagrario. Despite these efforts, the differential settlement had increased to 2.42m by 1989. Following a study, it was decided to under-excavate below the high points, using the observational method to control excavation. 30 shafts have been put down to a maximum depth of 25m, with radial 100mm diameter horizontal holes 6m long, formed by jacking-in 1m long sample tubes, withdrawing them and disposing of the contained soil. 900 cu.m. of soil have been excavated in this way, causing the 2.42m differential to reduce to 2.0m by March 1995. Work is continuing.

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FEATURES FROM SOME SELECTED PAPERS

Automated Surveying

A bar code system similar to that used at the check-out counters of supermarkets, has been used during the past 5 years for levelling and rough distance measurements. The staff, instead of being marked in numbers that could be read from the level telescope by human eye, is marked with a bar code, read by an automatic level. Bar coded hand held staffs were used in the Mexico City Cathedral. In Switzerland, the levels of the weir pillars of the Eglisau run-of-the-river power plant, built during the 1890s on the Rhine, were checked automatically during refurbishing works by a digital level reading bar coded staffs fixed to the pillars. The level contained two motors: one for focus and the other to swing the telescope on to the target. A searchlight was fitted to it so that the staffs could be read at night. Level accuracy was 0.01mm and distance 10mm.

Stress-strain

We all know that stress is a concept and that it cannot be measured, so it was refreshing to have this aired publicly. We measure deformations and say they are caused by stress changes, but we cannot directly measure either stress or pressure. The irregular behaviour of soil and concrete make the determination of stress from measured deformations most difficult. We also all know the robustness, accuracy, reliability and long life of vibrating wire strain gauges, so it was delightful to hear of a piece of basic research from the Laboratoire Central des Ponts et Chaussées. It is a very detailed study of the behaviour of vibrating wires and should be referred to in the Proceedings of the Symposium.

Tunnels

A number of the papers were about tunnels, with problems of squeezing by the rock; temperature effects; the 1.9km Signayes motorway tunnel in the Alps, with slope stability problems at its northern portal; the condition of old tunnels in Germany where there are 500 more than 100 years old, and problems due to nearby excavations as at the Gare de Lyon in Paris where the concrete lining of twin running tunnels were exposed in the excavation. Traffic on this main underground route could not even be slowed down during the 2 year period of work, and an automated monitoring system of instruments was set up to measure deformations continuously and warn of any developing danger.

Dams

Several dam projects were the subject of papers. Data for dynamic analysis of the 56m high Clocotis arch and the 55m Perti rockfill dams in Romania were obtained from controlled explosions. Three-dimensional crack gauges had been developed in South Africa to measure the behaviour of concrete dams. A dam-type problem involved a 140m high conical stockpile of waste containing abraum salts. It was on weathered Bunter Sandstone and creep plus slope instability were affecting a nearby main road. Movements were measured by inclinometers and topographical surveys. Problems that had been resolved by the use of instrumentation in several fill dams were described as was the near failure of the 43m Fontenelle dam in USA during 1965. Continuing observation up to 1984 caused sufficient concern for a 0.6m thick concrete diaphragm wall to be constructed by slurry trench method as a cut-off through the whole dam. A mystery standpipe piezometer downstream of the new core, fitted with a vibrating wire transducer, shows a pore pressure fluctuation of about 1m head on a 2½ month cycle. It is clearly not connected with the moon and is not related to reservoir fluctuations. As a double check, readings have been taken by dipping, and gave the same mysterious result. If anyone out there can think of a cause, the US Bureau of Reclamation will be pleased to learn.

Slope stability problems were of concern during the construction of the Ravedis gravity dam in a narrow valley in the Alps. Block samples 150mm square were carved out of the rock and tested in situ in compression by applying a vertical load reacting on anchors. Large scale landslide-type slope stability is a risk for an existing hydro plant in the Alps, and studies are being made with piezometers and long wire extensometers laid in 0.3m PVC protective pipes on the slopes, with constantly monitored drum transducers to show slope movements.

Earth Pressures

In order to measure earth pressures against a new harbour wall at Hamburg built by the slurry trench method, special 0.8m diameter gauges were made from 2mm thick steel plates held apart by a spacing ring 20mm thick, and welded together. For installation, the cells were mounted on the reinforcing cages, using a special cranked lever device which, by pulling a rope when the cage was at its correct level, released the cells from an upper clip and pressed them against the earth-side of the trench while concrete was tremmied to form the wall. Automatic monitoring was used to check conditions during various stages of construction and dredging.

Automatic Data Acquisition

A feature running through the whole symposium was automatic data acquisition. Almost everybody had their instruments hooked up to computers which not only read them at required intervals, but also converted the readings to engineering units so that changes and trends could be seen in real time and appropriate action taken. Very many gauges could be read in this way and there appeared to be no firm favourite.

Electro-levels

Currently in Britain, the gauge of the month is the electro-level. It is an instrument that has been available for very many years, but in the early days it appeared to be too sensitive for geotechnical work of the time, and it was very unstable. It was revived 20 years ago at the Building Research Station (now called an Establishment: BRE) to measure deformations around piles, and with new AC circuitry, was much more stable. Its use continued for pile research and steady improvements were made, developing it, with the correct electronics, into a robust, reliable and very accurate gauge ideal for field use. It began to be used to measure the small deformations of buildings that can be the cause of cracking and proved useful to control compensation grouting. Today, with the new tunnelling work going on in London, one has the impression that every building on the line for a tunnel is festooned with electro-levels, all hooked up, of course, to computers that give immediate information about undesirable movements.

Yet of the 62 papers, only one relates to electro-levels, and that is concerned with British work. Ingenious devices have been developed (Price and Wardle 1992) to measure vertical and horizontal deformations of buildings or inside tunnels, with understandable results given in real time by computer. The apparatus has been fitted to running tunnels on the London underground system, enabling the deformations caused by adjacent works to be monitored throughout the 24 hours, even though the trains only stop running for 5 hours.

Deformations of the concrete face slab of the 150m high Xingo concrete faced rockfill dam on the Rio Santiago in Brazil were measured by electro-levels during reservoir first impounding and subsequent operation. 10 watertight units were fixed at intervals up the 1 on

> **The electro-level . . . has been available for very many years, but in the early days it appeared to be too sensitive for geotechnical work**

1.4 sloping slab and the measured rotations analyzed by use of a 6 degree polynomial, integrated to give deflected shape at various levels of the rising water. With the reservoir full, the crest deflection, measured by topographical survey, showed 16cm, while that given by the electro-levels, assuming that the heavily anchored concrete plinth did not move, was 15cm, thereby confirming the accuracy of the method. The information was given as verbal contribution to the Symposium by Professor Rocha Filho of the new Universidade Estadual do Norte Fluminense in Rio State, who has close connections with BRS. It does not appear as a paper, but an account is being published (Rocha Fihlo 1995).

Procurement

Instruments can confirm design assumptions and give answers when there is a problem. They should only be used to provide wanted information, not just distributed to look nice on a drawing. But reliable answers do not come from low bids. It is unfortunate that so often controlling accountants insist that the lowest bid must be accepted, while in practice it may be the most expensive instrument that is the cheapest because the cost of the instrument itself is minor compared with the cost of installation, reading and analyzing. Failure or misleading readings that result in damaging deformations of the works, can prove extremely expensive. Quality data do not come from low bids and the recommendation was made that `professional service' contract methods should be used.

Satellites

The world is now surrounded by satellites, giving us the international network of telephone and fax that we have so quickly taken for granted and could no longer do without. But there is much more than that. They can see everything that is going on on earth: give vast amounts of information about every aspect of our lives. It is a whole new field, much bigger than instrumentation and all of geotechnics. We were fortunate in having Alan Belward, Sveere Holte and Vincenzo Lanza to give us special lectures on remote sensing, satellite communication and the global positioning system (GPS).

Alan Belward gave a fascinating lecture. The first view we ever had of the whole world was from a photograph taken out of the window of the first manned space rocket more than 3 decades ago. By 1972 we had Meteosat to look at the weather and by 1985 resolution was so good, an aeroplane could be seen landing at Heathrow. The vast amount of material given by the satellites can be interpreted to give information on areas of land, crops being grown, condition of ripening and expected yield, felling of forests, landslide mapping with their rates of movement, positions of ships and icebergs, hurricanes with their path of destruction; everything that you could want to know. Radar interferometry gives even better detail, with theoretical resolution of 1cm, and we already have ERS-1, a radar satellite giving all-weather day and night imagery and during April 1995 the even better ERS-2 is to be launched.

SCORE (Signal Communication by Orbiting Relay Equipment) launched on 18th December 1958 was the first satellite communication experiment. It was followed by Courier, launched on 4th October 1960, then Telstar on 10th July 1962. Dr Holte described a geostationary satellite as a mirror in space for electronic signals. Syncom II, launched by NASA on 26th July 1963, was the first of these satellites, put into its orbit 36,000km above the earth's surface, so as to make one orbit every 23hrs 56mins and thus remain static in relation to the earth. Now we have Intelsat focusing on Europe, Insat 2C on India, Hispasat on Spain and the Canaries and four satellites Inmarsat covering USA. Individual organisations can have their own system and use Telemetry and data transfer via SATellite: TSAT 2000 was the first world-wide. Your own hub costs 25,000$US and remote stations cost 7,000$US, plus 3,000$US a year for as many remotes as you like. Hydro power projects in the north of Norway, where access in the winter is impossible, use 8 stations to measure reservoir levels, operate gates etc.

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GPS is of great value for fixing positions and the Real Time Kinematics (RTK) system can be used to measure the volumes of stockpiles, position manholes in the road and can be used for the automatic control of machines for crop spraying, positioning of containers etc. Portable apparatus was used during the Gulf war that gave vehicles their own positions, accurate to ±10m, but with fixed equipment and a reference point accuracies of ±3mm are claimed.

Background of FMGM

In 1973 a symposium organised by the British Geotechnical Society entitled `Field Instrumentation in Geotechnical Engineering' was held in London. In 1977 an instrumentation symposium related to rock mechanics was organised by Professor Kovari in Zurich, Switzerland. In 1983 he organised another, called `Field Measurements in Geomechanics' held in Zurich and advertised as international. This has become known as the 1st FMGM. A second, organised by Professor Sakurai, was held in his native Kobe, Japan, in 1987. The 3rd, organised by Norwegian Geotechnical Institute, was held in Oslo, Norway, in 1991, so establishing the four-year interval. This one, in Bergamo, Italy, organised by ISMES, is the 4th, held as it has been, between the 9th and 13th April 1995. A 5th should be held in 1999.

The 557 page Proceedings contains 62 papers plus a valuable author index, and was given to delegates when they registered in Bergamo on 9th April. The quality of printing and reproduction of drawings and photographs is excellent. From the 62 papers, 31 were selected for presentation during the Symposium and the authors given 10 minutes each. Copies of the Proceedings can be obtained at a cost of 45$US plus shipping, from the Publishers, S.G.E., 3 via LAGRANGE, 35143 PADOVA (BG); fax +39 49 62 03 19.

Future For FMGM

Dr Elmo DiBiagio gave a brilliant lecture `What will be discussed at FMGM in 2005'. Wired up for sound and holding a mouse in one hand and a laser pointer in the other, he launched into a high speed overview, illustrated by a continuous succession of computer-generated colour slides. 2005 just meant the 21st century: if FMGM continues to be held every 4 years there will not be one in that year! After a quick summary of past symposia, he turned to the present, representing it as a five part puzzle consisting of: 1)Sensor sequence, 2) Data acquisition, 3) People, 4) Processing and presentation, 5) Interpretation and reporting. Each piece, he said, was a puzzle itself and each one included people. He then looked at each part and split it into considerations of Status, Problems, Trends and Needs. As an example, Table 1 shows the part of the puzzle for data acquisition.

Table 2 shows possible arrangements for FMGM 2005.

And as for the format for the 2005 Symposium, we could either 1) hold it in the traditional way, or 2) use the new technology and hold the meeting at home, with us all linked up through the international super highway. Since part of the purpose of these Symposia is to meet colleagues from all around the world, sense body language etc., it was thought most would prefer option 1).

References

Price, G. and Wardle, I. F.(1992). BRE Monitoring Systems. Geotechnical & Structural. Building Research Establishment, Garston, Watford, WD2 7JR, UK.

Rocha, Filho P. (1995). Slab deflection of a CFRD. Dam Engineering, (in press).

Sharma, S. and Judd, W.R. (1991). Underground opening damage from earthquakes. Engineering Geology, vol 30, pp 263-276.

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Table 1. Puzzle for Data Acquisition (Anything from Pencil to Computer)

Part of Puzzle	Suggestions
Status	Anything is possible. Communication links puts the user in the field.
Problems	Highly trained people are required. Errors are not always obvious.
Trends	Highly integrated multimedia systems. Everything is possible.
Needs	Data quality verification procedures.

Table 2. Possible Arrangements for FMGM 2005

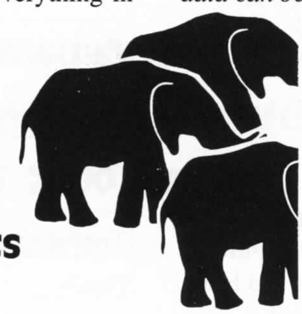
Topic	Possible Arrangements
Attendance	Anyone interested in instrumentation. Contractors and owners should attend. New people: lawyers (bit undesirable, but a trend).
Programme	Case histories: the way we learn. Site investigation: more geophysical methods. Construction control: instruments in work. Performance monitoring. Large scale tests.
Fundamentals	Fibre optic sensor. Laser and optics. Better materials. Industrial standard for v.w. sensors. Overvoltage protection. Fallacy of low bid approach.
Data Acquisition	Use of telephone lines, satellites. Remote monitoring by cellular phones. Low power micro loggers. Methods of implementing data acquisition.
Data Processing	Image processing. Effective use of data bases. Expert systems. Data quality control. Processing tools available in international data highway.

Transient Protection for Automatic Data Acquisition Systems

James Hall

Electronic data acquisition systems may lose data or be damaged from transients introduced into monitoring equipment and instruments from lightning, power lines, telephone lines, electromagnetic radiation or interference (EMR and EMI), grounding systems, miswiring to ancillary equipment or mains power, and other sources. Each application must be evaluated for potential problems and appropriate transient protection solutions implemented. As important as it is, transient protection is just one part of an overall instrumentation strategy needed to provide adequate and reliable data. Strategies for protecting systems and meeting data requirements in an urban high-rise basement may be quite different from those at a remote wilderness dam site.

You know it wasn't quite right when the elephants are gone



Just as there is no single or typical transient, there is no single, complete solution that will save everything. In a contest of brute strength, nature always wins and data are lost. Knowing the potential effectiveness of a particular transient suppression scheme is a little like tethering elephants. You know it wasn't quite right when the elephants are gone.

1. Possible Transient Protection Strategies

Large or complex jobs: If your monitoring system is large or complex, or has limited opportunity for success, do a system design analysis to determine how transient protection fits into your requirements. Transient protection must be part of a more comprehensive strategy of test and monitoring design (and risk assessment if appropriate). Issues to be considered include an evaluation of client expectations and legal or contractual issues, data requirements, instrumentation system design, data monitoring equipment selection, wiring and cabling design, site conditions, maintenance, and incremental implementation costs.

Small jobs: Detailed analysis and design efforts may not be useful and comprehensive protection of everything in the system following conventional guidelines will probably be the most effective and economical.

All jobs: Each piece of equipment must be protected. Sometimes grouped equipment can share protection (e.g. mains power conditioning for an entire data monitoring shack). Usually this is not the case. Exposed instrument cable runs longer than 3 to 4 meters can be dangerous and some form of protection should be provided at the instrument as well as the monitoring equipment inputs. Radio antennas, radio modems, shared grounds, mains power, on-site voice communication systems, telephone systems, motor controllers, switching power supplies, and other related sources can all introduce their own transient signals, large and small, that can finally compromise the data.

2. Some Transient Protection Issues

Transient protection con be expensive: Simple, low energy content protection designs (single stage small MOVs, polymer fuses, PTC thermistors, fuses, R-C filters, zener diodes and transorbs) will usually be sufficient. For systems where expected transients are not severe, these methods may be adequate (and quite inexpensive). They would be best applied to protect inexpensive, easily replaceable equipment or heavily redundant systems where some data loss is acceptable.

Replacing damaged equipment or data can be expensive: When protected equipment is expensive, difficult or impossible to replace, the system has little redundancy, or the data is not easily replaced more heroic protection measures may be needed (multistage protectors including a gas discharge tube, large MOVs, special grounding considerations, multiple point protection at both ends of cables, and network designs that include fiber optic cables).

Damaged equipment may cause vital data to be lost: If there is concern that the selected protection scheme may not prevent damage, and that this would result in loss of vital data, other system design issues should be considered including:

- duplicate electrical instruments, periodically read by hand, and never connected to the automatic monitoring system
- mechanical instruments that can be used to duplicate measurements from electrical instruments as needed
- measurements made with replaceable instruments that allow missing data to be calculated, estimated, or inferred indirectly

Cables may need protection at both ends: Transients can take the form of very short, highly energetic pulses that travel toward the near and far end of a cable. Transient protection at one end of the cable may not protect equipment at the other end from reflected energy. How long can the cable be before protection is needed? There is no simple answer. Start to worry if the cable is exposed and the run is greater than 3 to 4 meters. Lightning transients can be induced into underground cables within a meter of the surface by huge (10,000s of amps) natural discharge currents flowing parallel to the surface. These currents are usually associated with lightning and can also result from "silent" (no lightning) discharges. Cables routed down a borehole or shaft perpendicular to the ground surface are relatively uncoupled from these transients. Cables running along the surface or in shallow trenches are susceptible, however. Routing the cables in metal conduit must be done knowledgeably to attenuate the transients. The general recommendation is to locate instrument transient protection at the borehole collar and at the monitoring equipment to suppress transients induced in the cable. All transient protection must be installed in a manner that allows access for replacement of damaged or suspect transient protectors.

Mains power can create problems: Conducted power line transients can damage equipment directly, and can also cause non-destructive data corruption and performance problems that are difficult to track to a specific cause. Although not a transient, line power failures can sometimes cause monitoring systems to behave badly, resulting in data corruption. Detailed analysis is not useful in this case, and the best approach is an appropriate application of brute force transient suppressors, filtering, and, if needed, an uninterruptible power supply (UPS).

Commercial modular surge suppressor

Maintenance is critical: Transient protection, like all other parts of the data monitoring system, must be maintained to be continuously effective. Damaged or burned-out transient protection must be identified and replaced to maintain data integrity. Some surge protectors fail open (no data) and others fail closed (no surge protection). Both failure modes are unacceptable. An open failure is particularly bothersome since in may go undetected, and a subsequent transient may do further system damage. Even worse, the open failure may not be a perfect open and effect the data adversely. Even apparently undamaged (assumed good and not tested) transient protection is always suspect after an 'event'. Testing to verify each transient protector is the only way to verify proper operation. This testing should be included in periodic instrument calibration activities.

At worst: Troublesome automatic data monitoring installations may simply be abandoned as not worth the effort and expense. Inadequate attention to transient protection can lead this result and even with our best efforts, sometimes the worst just happens.

3. Some Solutions: Transient Protection Equipment to Use

Readily available transient suppression equipment, and expert application help have made this once obscure and mysterious concept a relatively straight forward part of current data monitoring systems.

Most data logging equipment manufactures offer optional built-in transient protection, or as an external add-on for their equipment. By all means use them. Apply and install transient protectors according to the manufacturer's recommendations and instructions. Try to understand the fundamentals of the protection gear you are using (grounding, proper wiring methods, equipment location and interconnections), not the advertising hype or industry buzz words. Many modular electronic equipment manufacturers now offer complete lines of transient protection (from low to high effectiveness and cost; and application engineering assistance). Specialty transient protection manufacturers can be helpful, however avoid the "single concept" product and evangelist engineering that sell the single best solution to all problems. Very good transient suppressors and isolation transformers are readily available. For power mains filtering, many manufacturers combine all of the desirable features in one unit (isolator or UPS) and offer expert application assistance. When selecting one of these units be sure to check out several manufacturers. Ask for and check out manufacturer supplied references to other users with similar applications to yours. In this case there will be a definite cost/performance relationship (the best units are very heavy and expensive), however, beware of expensive (and heavy) junk.

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Electrolytic Sensors: Problems Identified and Resolved

Chris Rasmussen & Rick Monroe

Abstract

Electrolytic sensors, when properly engineered and calibrated, are robust, reliable, and stable, making them ideal for monitoring deformation in structures. This paper presents data from both laboratory tests and field installations of Slope Indicator's EL-series sensors to demonstrate that potential problems have been addressed with success or have proved, in practice, to be insignificant. The problems include temperature effects, instrument drift, vibration, cable length, and calibration procedures.

The Problem of Temperature

The temperature sensitivity of an electrolytic sensor varies with the type and shape of vial used, the chemical content of the electrolyte, the properties of the packaging material around the vial, and other factors, such as the angle at which the vial is tilted. Temperature effects can be minimized by the design of the vial and its packaging, by using the sensor over a limited tilt range, and by applying temperature corrections.

Slope Indicator's EL beam sensor (an electrolytic tilt sensor mounted on a rigid beam) is generally not supplied with temperature correction factors since it exhibits very small temperature effects over its specified range. This claim is supported by laboratory tests as well as by field data. Both are presented below.

Temperature Test in a Laboratory

The temperature test was performed at the Fredericks Company laboratory, where unpackaged, non-insulated EL-series vials were subjected to rapid changes in temperature between short periods of extremely low and high stable temperatures. In one hour, the temperature in the test chamber was cycled from +23°C, down to -20 °C, up to +50 °C, and then down to +23 °C to allow retrieval of the vials. Temperature was held stable for approximately 10 minutes at -20 °C and later at +50 °C. Changes in temperature, including the 70°C change from -20 °C to +50 °C occurred over a period of 15 minutes. (See figure 1.)

Results show that rapid temperature changes caused the EL-series vials to produce errors, as one would expect, since nearly any type of sensor will produce errors when subjected to temperature changes of 4.7 °C per minute. However, even during the rapid changes, the maximum error never exceeds 16 arc seconds (equivalent to an apparent movement of 0.15 mm per meter).

Furthermore, the errors nearly disappear when the temperature stabilizes, even at extreme temperatures. The largest difference between readings at -20°C

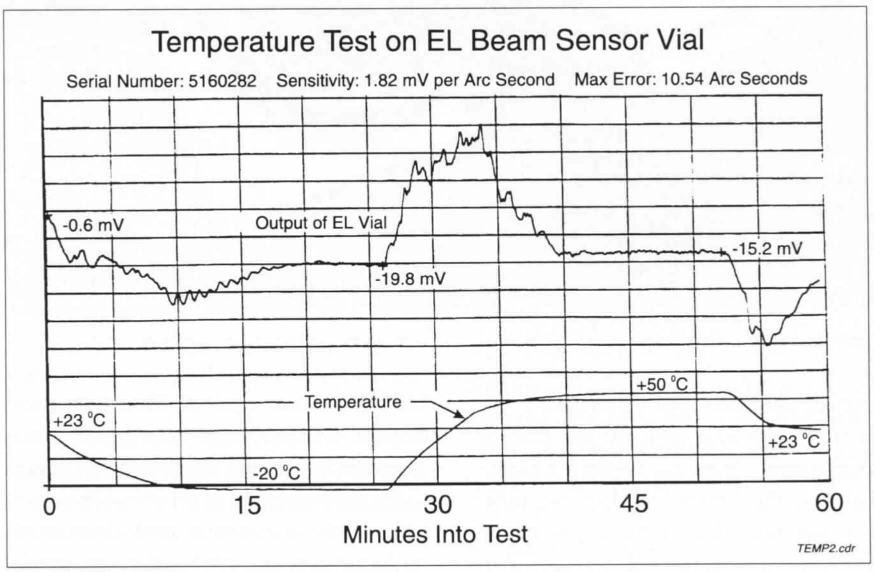


Figure 1

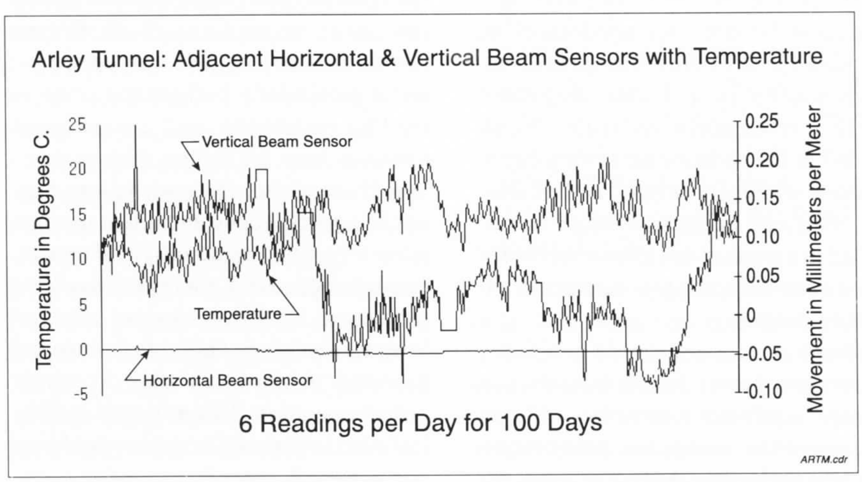


Figure 2

and those at +50ºC is only 2.5 arc seconds (0.01 mm of displacement over a 1-meter beam).

The worst-case stable temperature error over the entire 70 °C range occurred at -20 °C. This error of 11 arc seconds is equivalent to 0.05 mm displacement per meter.

Temperature Effects at Arley Tunnel

216 pairs of beam sensors were installed to monitor deformation during the refurbishment of Arley Tunnel. In each pair, one sensor was mounted on a vertical beam to monitor convergence. The adjacent sensor was mounted on a horizontal beam to monitor settlement. The two beams shown in figure 2 were installed one meter from the data logger, which measured temperature. During the 100 days shown on the graph, the temperature varied over a range of 15 °C. The presence of men and heavy equipment added to the natural changes in temperature.

The data show that temperature fluctuations do not have a significant effect on EL beam sensors. The vertical sensor shows significant movement, but the horizontal sensor does not, though both were subject to the same temperature changes. In fact, the tunnel walls were moving with temperature and the vertical sensor was simply recording this movement.

The Problem of Longevity and Drift

A mismatch between the excitation level and the electrolyte and electrodes in the vial can cause unwanted electrochemical effects that appear as drift in the sensor reading. However, when these elements are in balance, electrochemical effects are greatly retarded, and longevity and drift appear to be eliminated as issues for concern.

Slope Indicator has started an accelerated test of longevity and drift on EL beam sensors. The beam sensors are mounted outdoors and are exposed to weather and direct sunlight. A Campbell CR10 reads the sensors 100 times per second, computes and holds the average

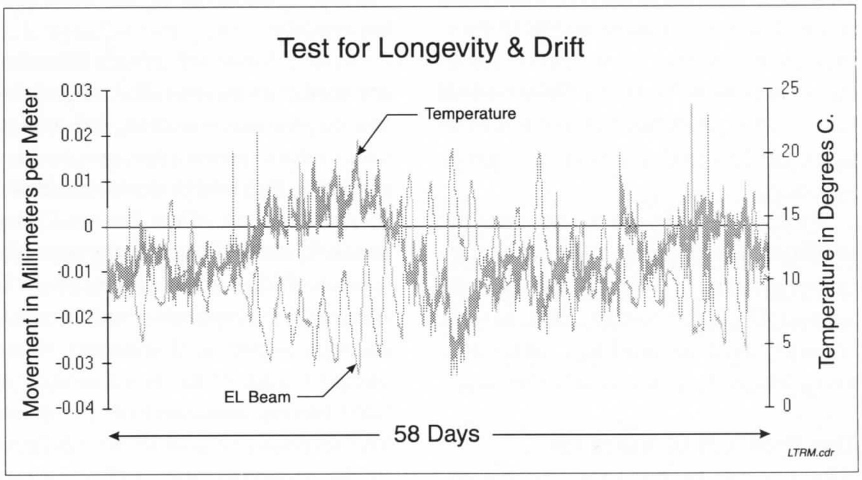


Figure 3

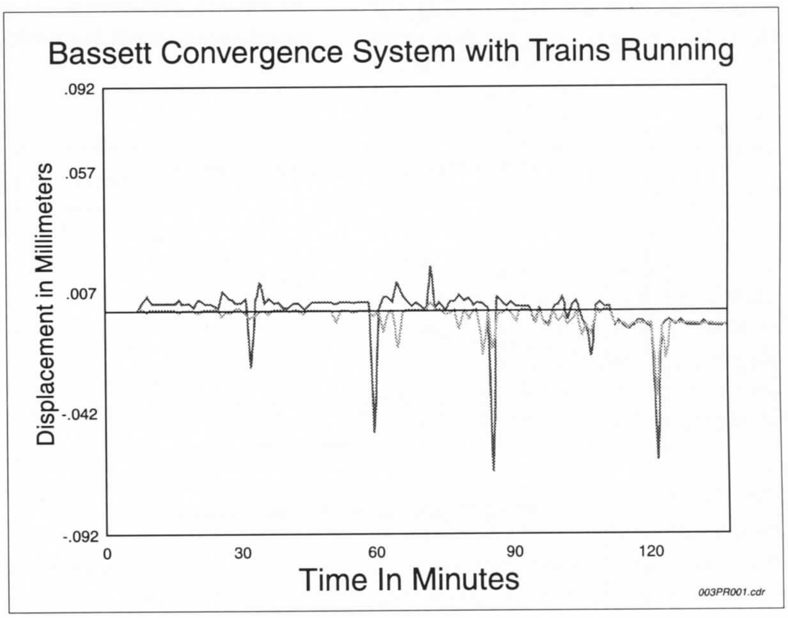


Figure 4

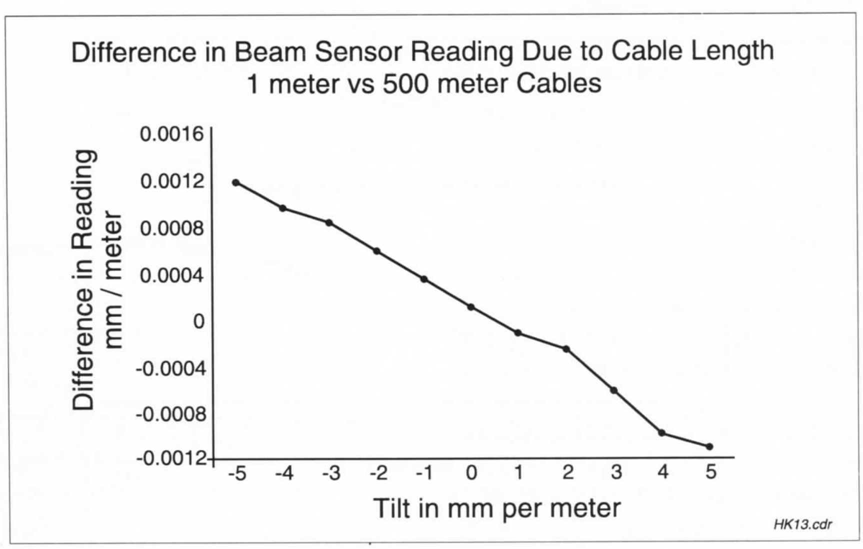


Figure5

for one second, and then stores the most recent 1-second average every 15 minutes. In the 58 days shown in the graph, the sensors have been read 501 million times. This represents at least several years of data under a normal logging schedule.

Readings (see figure 3) show that the structure moves with the diurnal change in temperature. Except for this change, no overall trend is visible. Drift has not occurred because readings taken at a given temperature are nearly identical.

The Problem of Vibration

Vibration has been claimed to be a potential source of error with electrolytic sensors because the vial is filled with fluid. It is easy to imagine that severe vibration would result in wildly unstable readings.

In fact, Slope Indicator's EL sensors are nearly always installed on structures that experience vibration: rail and subway tunnels, parking garages, construction sites, and bridge decks and towers.

A recent test, of the Bassett Convergence System, illustrates the typical response of EL sensors to vibration. The Bassett System provides automatic, unattended surveys of a tunnel section, using a system of reference pins, articulated linking arms, and EL tilt sensors. The reference pins were bolted directly to the cast-iron liner and transmitted vibration from the liner directly to the tilt sensors. The sensors were also subjected to air blasts from passing trains which ran through the tunnel with very little clearance.

The Bassett System was configured to obtain 10-point surveys of the tunnel section at 10-second intervals. Figure 4 shows the displacement of one of these points over a period of two hours and 15 minutes and indicates that the EL tilt sensor is not overly sensitive to vibration. The data show a response to the passage of each of four trains and an immediate return to quiescent levels. Notice that the largest movement recorded during a passage was 0.07 mm.

The Problem of Cable Length

Cable length does not appear to be a problem at all. The calibration curve for an EL beam sensor changes very little with cable length, and good quality cable keeps cable effects to a minimum. Figure 5 shows the difference between two sets of calibration readings, one obtained with a one-meter cable and the other obtained with a 500-meter cable. The differences are small and can be corrected, if necessary, by applying an offset value.

The Problem of Calibration

There has been some question over the number of calibration points required to characterize the performance of a sensor. The three graphs (figure 6) show the calibration curves for five beam sensors using 15, 29, and 113-point calibrations. Since the curves are remarkably similar, Slope Indicator has decided to use the 15-point calibration. Calibration procedures used for EL beam sensors and EL biaxial sensors are described in the appendix.

Proof of Calibration

A simple proof of calibration is easily obtained by installing sensors and then applying a given tilt to the beam. The reading delivered by the sensor should match the applied tilt. Slope Indicator performed a carefully controlled version of such a test using a calibration table and a digital micrometer. Tilts were applied during five separate trials. Two calibrations were tested: the wide-range 5th order polynomial calibration and the narrow-range linear calibration. The results (see figure 7) show consis-

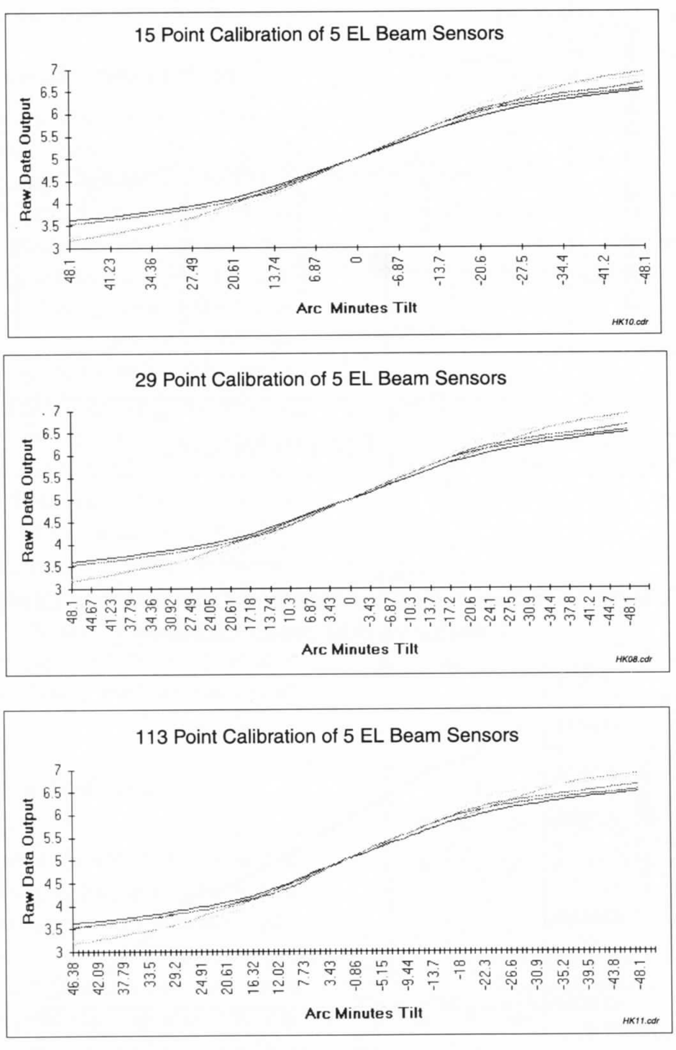


Figure 6

tent performance of both sensor and calibration.

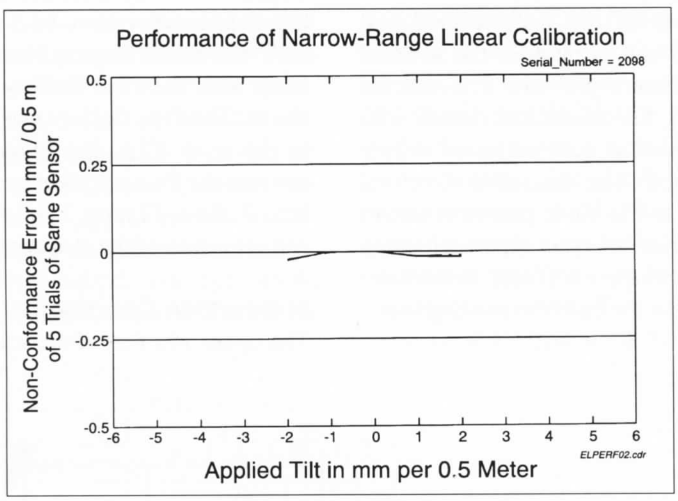
APPENDIX

Calibration of Beam Sensors

EL Tilt Sensors, the sensing devices used in EL beams and EL tiltmeters, are calibrated at the ambient temperature of the test room. The fully assembled sensors are mounted on a sine bar calibration beam, whose half-meter gauge length is NIST traceable. Each sensor is wired to a Campbell Scientific CR10 data logger, which is slaved to a desktop computer.

The calibration test starts with one end of the beam raised 7 mm, as measured by a NIST traceable Mitutoyo digital micrometer. The end of the beam is then lowered in 1 mm steps until it is 14 mm below the starting point. This procedure causes the sensors to be rotated through a range of 96 arc seconds, from 48 arc seconds above horizontal to 48 arc seconds below horizontal. Rotation is performed in only one direction to avoid introducing error from backlash and hysterisis in the test equipment.

Fifteen data points are collected for each sensor during the rotation procedure. The data are then processed by custom software that generates two sets of calibration factors, a narrow-range, linear calibration and a wide-range, fifth-order polynomial calibration. The program also generates a nonconformance table, which flags any sensors that do not meet specifications. Such sensors are discarded.



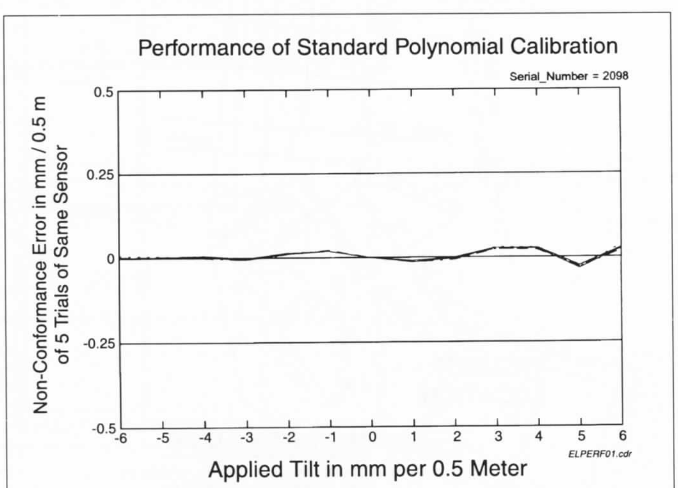


Figure 7

Calibration of EL In-Place Inclinometer Sensors

EL In-Place Inclinometer sensors undergo an automated calibration procedure inside a temperature-controlled chamber that was designed and built specifically for calibration of these sensors. The chamber is isolated from background vibrations by a massive, independent concrete foundation and by vibration-damping pads. Coolant from a rubber-mounted compressor pump two meters away is transmitted through rubber hoses to a rubber-mounted heat exchange coil within the chamber.

Sensors are assembled and installed in their housings for the calibration test. In the standard calibration, the sensors are tested at five tilt angles (-10°, -5°, 0°, +5°, and +10° from vertical) and at three temperatures (1, 6, and 13°C).

Tilt changes are controlled by a precision stepper motor that is NIST traceable to 2 arc second repeatability and are referenced to a temperature-compensated servo-accelerometer sensor mounted on the test platform inside the chamber.

Temperatures are held within 0.06°C as verified by two temperature sensors. Air in the chamber is circulated to minimize thermal gradients. When the temperature in the chamber is changed, there is a delay of approximately three hours before the next set of readings is recorded to ensure that all components are stabilized at the new temperature.

Data are recorded with a Campbell Scientific CR10 data logger, transmitted to a desktop computer, and processed by custom software that generates calibration factors and temperature coefficients. Both sets of factors are then applied to data from the sensor to check for conformance to specifications. Any sensor that fails to conform is discarded.

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