Activities of the IGN Special Works Department

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During 2003 the IGN Special Works Department undertook a number of studies on co-location sites in the field. It has become clear that an overview of the work carried out by this Department would be useful to provide a better understanding of the scope of activities provided by this Department.

The Department:

- 13 permanent staff: 2 engineers, 8 surveyors, 3 assistant surveyors
- Up-to-date equipment: Leica SR530 GPS receivers, Leica TDA5005 and TCA2003 total stations, etc with a range of accessories
- Support from personnel in the Geodetic and Levelling Service (about 70 persons) for major ad hoc missions.

The Department was created at the start of the 1960s, at a time when major infrastructure works were being undertaken, for example by the RATP (extension of metro lines) and the AEC (start of construction of nuclear power stations).

The geodetic surveyors very quickly adapted large scale triangulation methods and implemented them at these smaller sites that required a higher level of precision.

This ability to adapt standard methods and carry out special developments enabled these techniques to be used for various types of site:

- - monitoring civil engineering constructions
- - high precision measurement in laboratories or particular sites
- - monitoring unstable areas

in fact, all types of work requiring precision and uniformity.

This adaptability has played a significant role in the development of the Department, and is perhaps even more important now, at a time when many different technical fields are converging: the world of topography is now merging with the world of graphics.

The following projects illustrate the current range of methods that have been implemented as well as presenting the potential for future projects.

This document outlines projects carried out by the Department (including monitoring movement, laboratory work and sundry measurements).

Note: the term "geodetic metrology" describes the use of geodetic techniques to measure objects with clearly defined shapes (ranging from a few metres to a few kilometres) while providing a precision characteristic of metrology (from a tenth of a millimetre to a few centimetres, depending on the size of the object).

1 Geodetic metrology

1.1 Monitoring movement

The term “monitoring movement” covers several types of work:

- Monitoring civil engineering constructions
- Ground movement
- Safety monitoring

A representative example of each of these categories is described below.

1.1.1 Monitoring civil engineering construction

Objects, such as a bridge, are expected to change with time and thus their shape will alter. Measurements are taken to quantify these changes and ensure that the movement, displacement or deformation measured are in accordance with the behaviour models associated with the object being monitored. Measurement campaigns are usually undertaken at regular intervals (every 6 months, every year, or every 5 years).

There are two main measurement methods:

- - static measurements made using standard surveying methods
- - dynamic measurements using systems that take measurements over a given period of time, typically 24 hours.

In the following example both methods are used.

Study at Charléty Stadium

Sébastien Charléty stadium in Paris is used for many sports events and is, therefore, monitored very closely. Apart from regular visual inspections and measurements provided by individual sensors, an annual inspection is carried out by surveying the building.

The first phase of this inspection is to use various traverses for levelling. These measurements provide information about the behaviour of the lower part of the building (close to the plinth and foundations) to detect any subsidence in the structure.

Figure 1: Sébastien Charléty stadium in Paris

These measurements are made relative to control stations outside the building. Once the control stations have been checked for movement, the absolute movement of the stadium, including overall subsidence, can be measured.

The second stage of this inspection involves standard coordinates measurements:

- - several control stations at intervals around the field are used to determine the coordinates of prisms attached to the upper part of the structure, in particular on the roof framework.
- - the measurements are made with reference to control stations, the height of which has been determined by levelling.

The third part of the inspection uses a motorised surveying system in the centre of the field to track a certain number of the prisms used in the previous phase as well as points on the aerial parts of the construction (lighting masts, roof limits). This system is set up for a period of 24 hours and is used to quantify the movement of selected points (the movement of the lighting masts, for example, is directly linked to their orientation with respect to the sun). A meteorological station is also set up for the period during which the measurements are being taken.

The first two phases are carried out using the principle of a sufficient redundancy of measurements to provide high quality results using least squares. The last phase, however, as implemented on this site does not provide sufficient redundancy, mainly for cost reasons. However, it would be possible to use a second system to duplicate the measurements and thus have sufficient redundancy.

All these measurements are used to provide the sets of coordinates for each of the measurement campaigns and graphs showing the movement measured. We do not analyse this information: this is the task of building construction experts.

1.1.2 Ground movement

A significant part of the Department's work involves checking the stability of natural areas. Some industries, such as salt mines, for example, extract significant quantities of material from the ground. This may cause surface movement, which must be surveyed.

The aim of the survey is, therefore, similar to that for civil engineering works. However, in this case usually only the heights need to be compared on successive dates.

Study at Poligny (Jura)

This site has been mined for many years. Current regulations require the operator to provide the authorities with certain information in order to be able to continue mining.

This submission requires levelling measurements to be carried out.The measurements are made using a standard procedure.

- closed loop measurements or back and forth measurements, depending on the degree of precision and reliability required
- association of all the measurements with one or more control stations, which are themselves checked during the study.

The results are calculated using least squares to provide an indication of the precision actually obtained during the measurements. The site management is then responsible for explaining to the authorities the reasons for any movement that may have been detected.

Figure 2: Poligny (Jura), this site has been mined for many years.

1.1.3 Safety monitoring

Monitoring civil engineering constructions and ground movement could be considered to be safety monitoring. The distinction that is drawn here is related to the general context for setting up monitoring as well as the period over which measurements are taken. We define safety monitoring as:

- - implementing automated techniques
- - continuous or long-term measurement
- - automated processing, often setting up alarm systems

All the techniques used - theodolites, total stations or GPS receivers - can be automated. After a teaching period, each of these methods (associated with a

Figure 3: Safety monitoring in Amsterdam

computer) can operate autonomously and send information to a central processing unit.

The teaching period consists of defining the points that must be observed and the intervals at which measurements are taken (continuously, once an hour, etc).

The information may be sent by cable, radio, etc, and the measurement can also be processed using a least squares method configured to suit the type of equipment used. Finally, depending on the type of site, alarm systems are often set up to warn of any movement detected. The following example is typical of this type of monitoring and is of special interest as it is currently the largest project of its type.

Safety monitoring in Amsterdam

As part of the construction of a new metro line, Amsterdam wished to set up a very comprehensive system for monitoring buildings liable to be affected by the digging of the tunnel.

Apart from a network of individual sensors and a standard levelling campaign, a system using 74 automatic tacheometers was set up.

This system has been in operation 24 hours a day since the start of 2000 and is intended to remain in operation until the end of the project, which is currently scheduled for completion in 2008.

The system was installed in three steps:

- about 5500 prisms were set up
- 74 tacheometers were set up
- the tacheometers were configured

After setting up the radio transmission equipment, the tacheometers were grouped into networks depending on the geometric shape of the observation areas. The results from each group are automatically calculated using least squares.

This system has already shown that its sizing meets the initial requirements of the customer to detect vertical movements of more than 0.9 mm and horizontal movements of more than 4 mm.

The examples described above represent the main work of the Department.

The following paragraphs describe the diversity of the subjects covered, using surveying techniques and related to the profession of surveying.

1.2 Laboratories, industrial trials

This aspect of the activities of the Department only represents a small part of the work load. However, projects undertaken in laboratories usually require a very high level of precision and some of these methods can sometimes be used for larger sites.

This type of work generally involves:

- angle measurements
- inclination measurements

as well as high precision GPS measurements and, occasionally, gravitational measurements.

IGN has a GAK1 gyro attachment for measuring angles. This can be used for relatively accurate measurements (the typical precision of this type of work is better than 10 seconds) that are usually sufficient to meet the requirements defined by the customer.

Inclination measurements use various types of inclinometer with varying degrees of precision, again designed to meet the customer's requirements.

1.3 Sundry measurements and positions

In addition to these special types of measurement, work is also carried out using GPS.

This is an important part of the Department's activities. It covers all the projects that use GPS in various ways mainly depending on the calculation methods used.

The first category of work consists in determining points, that may be individual or in a network, using static measurements, the aim being to provide the most precise coordinates possible for a given system. This type of activity provides customers with one or more perfectly defined control stations (including the associated precision) for future measurements that will use these control stations.

Another activity related to the GPS consists of ground trajectography. Vehicles were equipped with GPS systems for trajectography to meet the rather unusual requirements related to the end of mining operations. The aim was to provide an economic solution to quantify the potential subsidence in certain areas by going along roads and tracks at regular intervals and comparing the trajectories to infer the extent of the movement with time.

Another experiment using trajectography was carried out in West Africa (between Tangiers and Abidjan) to provide NASA with data for assessing the SRTM Space Shuttle mission.

Finally, GPS techniques are also used to set up procedures for monitoring moving objects in real time.

The first major application was on the Verrières Viaduct (north of Millau Viaduct) where the deck laying was monitored using both standard surveying techniques and standard real time GPS.

The results of this test were conclusive but nevertheless revealed certain limitations of conventional real time procedures. After this test, a monitoring programme on behalf of the Millau Viaduct Construction Inspection Agency (representing the French government) was set up. This was based on a process of transmitting measurements in real time and using a more powerful calculation program, making it possible to use measurements taken by several fixed measurement units. The results obtained therefore had a precision indicator that was more reliable than for more standard processes.

2 Expertise, consultancy

All the activities presented up to now have been projects carried out by Department personnel from the design phase through to the final report stage. Sometimes the Department does not follow a complete project through as in the case of requests for assessment or consultancy.

- Consultancy. The Department carries out simulations to predict the expected results using a virtual implementation based on information provided by the customer.
- Assessment. The Department carries out a verification using its expertise to identify significant elements in a service carried out by a third party.

Figure 4: Verrières Viaduct (north of Millau Viaduct)

A typical example of simulation is the Amsterdam study. Before even knowing which company would be responsible for setting up the safety monitoring system, the whole site was the subject of several simulations enabling us to establish the precision that we considered realistic. Various geometric configurations associated with various types of equipment were tested to provide the most objective assessment of the number of measurement devices that would be required.

Assessments may take various forms, such as

- - angular measurements during tunnelling or checking existing networks
- - criteria for evaluating innovative methods for surveying
- - requests for assessing results as representatives of the courts

As this work is confidential it will not be described in further detail.

3 Research and development

The Department also undertakes various development projects.

Like surveying projects, development projects can also be divided into an acquisition phase, a processing phase and a report phase.

We are working on improving the use of the measuring equipment and on incorporating laser scanning techniques into our work. We are also considering the use of photogrammetry. Assembling images, laser scans and the localisation of these looks to offer promising prospects for some of our fields of activity.

A project investigating the accuracy of deformation tensors is under way with the aim of providing results that are more meaningful for the analysts who use them.

Finally, there is a project investigating the publication of results in the form of a dynamic representation using a 3D GIS incorporating all the information obtained for each measurement campaign relating to a given site.