Status of the Maintenance of the NGF, French National Levelling Network, by GPS

Michel KASSER and Paul BONNETAIN, France

Key words: Levelling, GPS, maintenance of levelling network**.**

SUMMARY

The operational maintenance of the NGF using GPS has started early 2002, and the results are presented here. The main points are the cost-effectiveness of this methodology, the possibility to define technical specifications that are much more customer-oriented than the former ones, mostly based on the requirements of the classical direct levelling methods, and the simultaneous production of marginal cost data extremely valuable for a new computation of the national geoidal altimetric correction grid. In 2002, the production amounted *de facto* to 165 base map sheets (82000 km^2) using 3 teams of 2 people 6 months each. Thus it appears as possible to close this phase of heavy maintenance within 6 years for the whole France. The new specifications will be commented and the computation aspects will be discussed.

RESUME

L'entretien opérationnel du NGF avec assistance de GPS a commencé de façon opérationnelle en 2002, et les premiers résultats de production sont présentés ici. Les points principaux sont la rentabilité de cette méthodologie, la possibilité de définir des spécifications techniques qui sont beaucoup mieux adaptées à la demande que celles employées précédemment, qui étaient principalement basées sur les exigences méthodologiques du nivellement direct classique, et la production simultanée de données, à coût marginal très faible, extrêmement précieuses pour un nouveau calcul de la grille de correction geoidale altimétrique nationale. En 2002, la production a été *de facto* de 165 feuilles de la carte de la base (82000 km^2) en utilisant 3 équipes de 2 opérateurs 6 mois chacun. Donc il paraît possible de mener cette phase d'entretien lourd en 6 années pour la France entière. Les nouvelles spécifications sont commentées et les aspects techniques du calcul discutés.

Status of the Maintenance of the NGF, French National Levelling Network, by GPS

Michel KASSER and Paul BONNETAIN, France

1. HISTORICAL ASPECTS OF THE NGF FRENCH NATIONAL LEVELLING NETWORK.

From 1857 to 1970, three networks of primordial levelling have been observed in France.

- The NGF-Bourdalouë network (NGF = Nivellement Général de la France) established by Paul-Adrien Bourdalouë in the years 1857-1864. With 15000 km in length, its standard kilometric deviation is around one cm.

- The NGF-Lallemand network established by Charles Lallemand, Director of the Service of the NGF, from 1884 to 1892. With a length of 11723 km, partially taking the Bourdalouë itineraries, its kilometric error is 1,7 mm. It covered 12715 km in 1931 with the 1st order of Alsace-Lorraine and Corsica.

- The " NGF-IGN1969 " network, established by the IGN from 1962 to 1969. With a length of 13754 km its standard deviation is 2 mm / km½.
  2. THE PRESENT NGF-IGN1969

2. THE PRESENT NGF-IGN 1969

In 1962, the IGN reobserved the primordial network. Was added a few 200 000 km of networks of 2nd, 3rd and 4th order during the years 1900-1960. The IGN decided in 1962 the resumption of the primordial network, that ended in 1969, and, according to the recommendation of the AIG, the altitudes were expressed in the normal mode.

In parallel to the reobservations of the primordial network and up to 1994, the IGN maintained and densified the 2nd, 3rd, and 4th order. Since 1982 was used the geometric motorized levelling for the 2nd and 3rd order, and then the trigonometric motorized levelling was invented and used for itineraries of 4th order. At the end of 1987, altitudes of all levelling benchmarks were published in normal altitude in the system NGF-IGN1969. Since 1995, following recommendations of the CNIG (Interministerial Counsel for Geographic Information), the IGN has continued its efforts only on the maintenance of networks of 1st, 2nd and 3rd order. Because of their dangerous access and the new situation due to the TGV high speed trains, all itineraries situated on rail tracks have been transferred on the road network while preserving at best the old benchmarks. Besides, the method of the geometric motorized levelling is always used as it offers a better cost-efficiency and the highest precision.

Order	Standard deviation mm/(km)½	Length (km)	Number of benchmarks	Mean year of completion
1	2	14221	22617	1981
2	2,3	18992	28727	1983
3	3	49840	71134	1982
4	3,6	172676	251617	1965
River Profiles	around 4	42911	54728	1920-1930

Situation of the NGF-IGN 1969 network at the 1er January 2001

So in the year 2000 it exists a 256000 km levelling network, with a quality considered as satisfactory in precision and extremely useful, but only one quarter was maintained since 1994, 387000 benchmarks being accessible by service Minitel-fax, and since 2001 free of charge on the Internet site of the IGN. The NIVAG method (GPS Assisted Levelling) allows now, with constant financial means, to maintain the totality of the NGF. For that, new specifications of result has been discussed and adopted (Kasser 2002), and following numerous applied researches the production have begun in 2002. This method can function correctly only because :

- The French Network of permanent GPS stations is dense and operational enough (more than 35 stations at the end of 2002),
- The geoidal correction grid RAF 98 is precise enough on all the France.
- Operations of visit of geodesy and levelling networks have been made recently ; they give a status permitting to know exactly where must be made the interventions of maintenance by NIVAG.

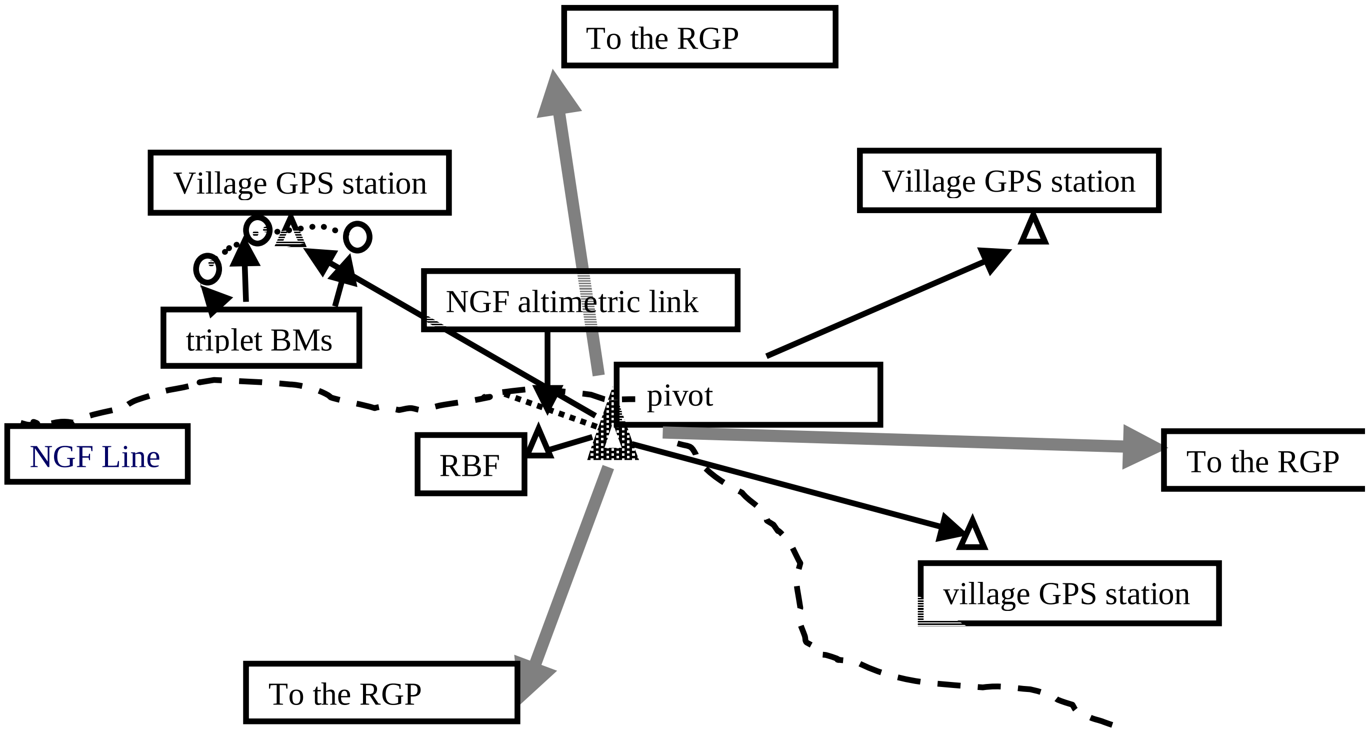
3. PRACTICAL ORGANISATION OF THE WORK

3.1 Choice of Sites for Maintenance

This schematic drawing shows the different types of measurements performed within one base map sheet, in a typical case where the RBF site is in the centre of the sheet.

At the end of the visit, zones of intervention are defined. With the GIS software Geoconcept, on a background of scanned maps at 1/100000, are integrated levelling benchmarks of the Geodetic Data Base as well as points of the RBF (modern marked geodetic network, base of the RGF 93 official reference).

Then, two circles are defined. The first of a 0,5 km radius is centered on the centroïd (in general the town hall) of agglomerations following the specification criteria (more than 200 inhabitants, a triplet of benchmarks, etc). It serves as centre for the second circle of 5 km radius. Then are known the zones non-covered by these circles, inside which one considers that the NGF is sufficiently accessible.



3.2 Equipment Used

Independently of the usual equipment (bi-frequency GPS receptor, choke ring antenna, digital level, heavy tripod, etc), we have designed specifically :

- A new model of benchmark. It is a variant of the model usually used but permitting a very fast and mechanically immediate very resistant fixing.
- To permit the altimetric link of the antenna (pivot, village point) to benchmarks, a device permits to equip the GPS antenna with a 1 m bar-code staff whose zero is at the level the surface of reference of the antenna and so to avoid mistakes of measure in the height of antenna.
- A new organization of one of the two vehicles used, consisting notably in a mobile office allowing the operator to process nearly in real time the tasks usually done in resting place in the evening (data transfer, description of new benchmarks, etc).
- The other vehicle is of the same type that the one used for the motorized levelling, allowing an extremely fast installation of the GPS receiver and its antenna for the observation of the village points.

3.3 Operative Methods

GPS

The pivot is at a maximal distance of 5 km from the RBF. The antenna, centred on a ground temporary benchmark, is fixed on a heavy tripod to assure a perfect stability, implanted with the GPS receiver in a sure place. The proper centring of the antenna is controlled daily. The duration of measurements is a minimum of 48 hours in continuous.

RBF benchmark : the observations link with the pivot last for 3 hours in continuous.

Station GPS village pivot : the distance from the pivot is a maximum of 15 km, the observations link with the pivot last for 3 hours in continuous.

Altimetric link by levelling
The pivot is connected to the nearest levelling line in geometric levelling (only one sighting, only one staff support, with a digital level type DiNi10 or NA 3000) to each of the three benchmarks forming the normal triplet. The observation is pursued toward another benchmark if the discrepancy between them is superior to: 0,7 (1+n½) mm, n being the number of intermediate level stations.

GPS Village Station

The (one or two) existing old benchmarks, the new benchmarks and the GPS antenna on the site are linked by geometric levelling, only one sighting, only one staff support, with a digital level (type DiNi10 or NA 3000).

Calculation of the altitude of the pivot
The process of calculation uses the Bernese software for GPS process and the observations of the French GPS network permanent (RGP). It covers all steps since the check of the raw observations during the field mission and the recuperation of files from the RGP up to the creation of a file of Cartesian coordinates of points observed in the national system RGF93. In complement of the processing software and its own automatic devices of GPS calculations (BPE, Bernese Processing Engine), complementary tools based on the utilization of the interpreted language "Perl" have been created in order to reduce the manual interventions.

Calculations are performed in 3 steps :

- Independent daily solution calculations : For these calculations, three strategies have been identified according to the distance of the RBF point and the village points from the pivot.

- Evaluation of a global solution (altogether RGP - Pivot - Village Points - RBF) by daily solution combination with only one RGP point constrained to its coordinates in the ITRF system.

- RGF93 Referencing of the global solution while fixing the RBF point to its published coordinates in RGF93.

At the end of the GPS calculations, the Cartesian coordinates RGF93 of observed points are transformed with the software " CIRCÉ France " and the altitudes determined with the help of the geoidal grid RAF98. The altitude of the pivot so calculated is compared to the one observed on the field by direct levelling : if this discrepancy is compliant with the precision of altitude determination within the RAF98 grid, it is then reported on the whole set of village points observed from the pivot. But in any ways it is the NGF altitude that prevails.

3.4 Calculation of the Benchmark Altitude

At the end of the intervention on site, one has thus 1, 2 or 3 references of altitude, *a priori* no entirely compatible, one is owed to the GPS measures, and one or possibly two bound to the old existing benchmarks. One recomputes systematically, in any case, the altimetric reference according to the new measures, including GPS.

We note :
Alt_F final reference of altitude used for the 3 benchmarks that one lets once on the site the mission is performed.
Alt_G is the reference due to GPS measures only,
Alt_N (N = 1 or N = 2) the one that is due to the existing NGF altitudes on the N old benchmarks.

- Case where no old benchmark is available.

It doesn't exist any NGF benchmark. The system of altitude for the three new benchmarks is necessarily only due to the GPS measures.

- Case where two old benchmarks are available.

One will consider that the precision of a NGF altitude is better than 2 mms (direct levelling between the next points), and that its accuracy, bound to the formation of the French reference (result of several levels of successive orders), cannot be considered better than 5 mm. And in the present state of our means of measure and calculations (including shortcomings of the RAF98), the accuracy of *AltG* will be valued by a standard deviation of 1 cm, as far as the GPS measures respect a duration of 3 hours and are done in the best conditions. Otherwise, when two old benchmarks are present, their altitudes will be reputed the more reliable as their discrepancy will be weak, thus it is necessary to make intervene this discrepancy (*Alt1* - *Alt2*) in the weighting used for the calculation of altitudes.

We then have 3 sets of altitudes, *AltG*, *Alt1* and Alt_2. The optimal weight, to the statistical sense of a gaussian errors, is the one using weights inversely proportional to variances. In this case :

$$Alt_F = \frac{\dfrac{Alt_1 + Alt_2}{(|Alt_1 - Alt_2| + 2)^2} + \dfrac{Alt_G}{10^2}}{\dfrac{2}{(|Alt_1 - Alt_2| + 2)^2} + \dfrac{1}{10^2}}$$

(Alt_F , Alt_G , Alt_1 and Alt_2 expressed in mm)

- Case where only one old benchmark is available :

We do a weighted average between Alt_1 and Alt_G, the first with a weight of 5 mm and the second of 1 cm:

$$Alt_F = \frac{4 . Alt_1 + Alt_G}{5}$$

It is necessary to also define the acceptable limits beyond which measures should be rejected, requiring new GPS measures, or a research of stability on the benchmarks beyond the old benchmarks of the considered triplet.

These limits are deduced from the evoked above precisions and a tolerance of 4 times these values, this tolerance being homogeneous with those used in the new legal texts in France on the tolerances of large-scale surveys.

Therefore between two old benchmarks, the maximal acceptable discrepancy will be 2 x 1,414 x 4 = *11 mm*

In the same way, with an old benchmark and a GPS altitude, the maximal acceptable discrepancy will be of $(10^2 + 2^2)^{1/2}$ x 4 = *40 mm*

It is necessary to notice that, in the case of only one old benchmark, the discrepancy between GPS altitude and benchmark altitude is impossible to impute precisely to the instability of the benchmark, or to the imprecision of the GPS measures, or them both.

4. PRODUCTION

In 2002, 3 teams of 2 technicians, in a total of 16 months x team, equipped 141 base map sheets (1/50 000), i. e. 78000 km^2.

Number of pivots	Number of villages	Villages for each pivot	Village without BM	Village with 1 BM	Village with 2 BM	Village with >2 BM	Day/man in the field/ pivot	Day/man in the field/ village
92	333	3,6	13%	22%	51%	14%	7,3	2

While operating on these 141 base map sheets, 24 other were found as not requesting any intervention after the visit, in consideration to the new specifications. The figure of 14% for villages with >2 old benchmarks were due to errors during the visit, where one BM had mistakenly been considered as destroyed and was found again.

These times are complete times, they take in account the setting up of the mission, journey between resting place and work site, formation, office work, etc.

Number of map sheets	Number of RBF	Number of pivots	Number of villages	Pivot by map sheet	Village by map sheet	Days/man/field work by map sheet
141	92	92	333	0,7	2,4	4,8

The time of GPS calculation by pivot is evaluated currently to half a day.

Distribution of discrepancies.
Currently (15-2-2003), 14 pivots have been calculated and have been under analysis, or even of recomputation : adjustment of the parameters of the GPS calculation, number of benchmarks on the site, age of the former levelling, etc.

However, even very partial and temporary, the following picture is presented, established from the discrepancies for the meantime noted on 36 sites villages: discrepancy = altitude from the Bernese calculation - altitude of the NGF, using the RAF98 geoidal correction grid.

Total	Discrepancy value (cm)						
	± 1	± 2	± 3	± 4	± 5	± 6	± 7
36	13	10	3	2	3	3	2
100 %	36 %	18 %	8 %	6 %	8 %	8 %	6 %

We have checked whether the discrepancies were related to the distance between the pivot point and the village. Clearly, there is no such apparent dependence. But most of the larger discrepancies are spatially correlated, which suggests that the RAF98 grid may be a large contributor to this figure. Other correlations are investigated, the dependence with the denivelation, quite probable with GPS process but in fact not very alarming, as in hilly areas the absolute quality of the vertical reference is not as necessary as in flat areas.

REFERENCE

Progress Of The Maintenance Of The French National Levelling Network (NGF) Using GPS. *Michel KASSER, FIG XXII International Congress, Washington, 19-26 April 2002*

BIOGRAPHICAL NOTES

Michel Kasser, born in 1953 in Lausanne (Switzerland). Two engineer degrees, from Ecole Polytechnique (Paris, 1972-1975) and Ecole Nationale des Sciences Géographiques (ENSG, 1975-1977). In 1977-1991, with IGN-France as manager, first of the Levelling Department (in charge of the French High Precision Levelling Network), then in 1984 of LOEMI instrumentation laboratory, and then in 1988-1991 of the Commercial Department. In parallel, geophysical geodetic operations in many active areas of the world. Since 1991, appointed as University Professor, Director of the Ecole Supérieure des Géomètres et Topographes (main French technical university in Surveying and Geomatics). Since 1999, he is the head of the Geodetic and Levelling Department, and Director of the LAREG (Laboratoire de Recherches en Géodésie) at IGN-France. He is President of the Association Française de Topographie since 2002, and was the main author with Yves EGELS of the book “Digital Photogrammetry” (Taylor & Francis, London 2001) edited also in French (“Photogrammétrie Numérique”, Hermès Sciences, Paris, 2001). He is delegate for Commission 5 of FIG since 1988 and has chaired several WG within commission 5.

Paul Bonnetain is Senior Engineer in Geodesy. He is the head of the Levelling Section at the Geodetic and Levelling Department, IGN-France.

CONTACTS

Prof. Michel Kasser
IGN-SGN
2 Av. Pasteur
94 165 Saint-Mandé Cedex
FRANCE
Tel. + 33 1 4298 8331
Fax + 33 1 4398 8450
E-mail **:** michel.kasser@ign.fr