# A State-of-the-Art National Grid
# Based on the Permanent GPS Stations of Israel

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**Key words:** geodetic control, permanent GPS station, datum, transformation

## SUMMARY

A new coordinate system was adopted officially in Israel in June 1998, after some 5 years of implementing in governmental cadastral projects. This system (called ING, for New Israeli Grid) was the result of a readjustment of classical geodetic observations. The accuracy of the 4th-order control points is estimated to be better than 10cm (s.d.). In the GPS era, this accuracy is not sufficient anymore.

The paper describes the solution the Survey of Israel chose in order to meet the demands and abilities of the new technology. Following more detailed description of the problems, we discuss the options for improving the geodetic control, as well as the considerations for the decisions we took. The Israeli geodetic control network will be based on an array of permanent GPS stations "densified" by Virtual Reference Stations (VRS). The paper suggests the strategy for carrying out this move, which ushers us to a new era in geodesy and surveying.

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## 1. INTRODUCTION

New survey regulations for the State of Israel were prepared by the Survey of Israel (SOI) and issued officially in June 1998. A major item in the new regulations was the replacement of the existing National Israeli Grid, which dates back to 1920, by the New Israeli Grid (NIG). NIG was the result of a readjustment of the available classical geodetic observations (Laplace-azimuths, horizontal angles and distances). A specific geodetic projection named ITM (Israel Transverse Mercator) was developed, which minimizes coordinate-differences between the old and the new grids, to be less than 1 meter in the northern part of Israel (which contains about 95% of the population). In order to achieve this, the unusual scale of 1.000,0067 was adopted and the central meridian is absolutely fictitious (for details see Adler and Papo1984). The readjustment was carried down to fourth-order network for a total of about 24,000 triangulation points. The first-order network has a density of about one point per 600 square kilometers, while at the 4th-order the density is 600 times higher. The accuracy of 4th-order points is estimated to be better than 10 cm. (s.d.), relative to the nearest 1st-order points. The coordinates of the three top orders were released in 1993 and were used mainly for governmental cadastral projects. Since July 1998 every new geodetic project has had to adhere to NIG. The majority of those new projects are executed on the basis of GPS measurements, using at least three control points with NIG coordinates for local datum definition. This datum definition is achieved by adjusting the free local GPS network to those control points using 4- or 7-parameter transformation and the ITM projection equations. The results are obviously dependant on the specific control points used for the project. Due to the low accuracy of the basic control points, we can see inconsistencies in the order of 10-15 cm between neighboring projects which are based on different control points. The ultimate goal of the SOI is to define the cadastral boundaries with accuracy of 5 cm at 95% confidence level (Steinberg 2001). As explained above, the existing horizontal control network is not sufficient for this goal. So, the Survey of Israel had to search for a way to improve the geodetic control.

## 2. OPTIONS FOR IMPROVING THE GEODETIC CONTROL

In 1996 the SOI, together with the Geological Survey of Israel (GSI), established an accurate network of 160 well-based control points for geodynamic research and 1st-order (3D) geodetic control named G1 (see Ostrovsky 2001). 3 GPS Permanent Stations were established at the same time and constitute the forebears of the array of permanent GPS stations GIAN (GPS Israeli Active Network). Because of its nature, access to most of the G1 points is difficult, and they are not convenient for everyday use. There was a plan to establish a 2nd- order 3D geodetic control (G2) as a densification of G1, to about 10 by 10 km network of points with easy access. Such a network of some 300 points could serve as an appropriate substitute to the existing network of about 20,000 points mentioned above, and ascertain the desired accuracy. This plan was carried out only partly, while at the same time some 25,000 new control points in the orders 4 to 7 were measured by GPS as mentioned above. Those points are usually used for densification by traverses and for cadastral and other projects. The SOI is checking and approving all those new control points (about 50,000 altogether) as well as the cadastral projects (about 1,000 per year). It should be noticed that in order to utilize the suggested G2 network, the surveyors must operate at least two GPS receivers and also need to occupy at least two G2 control points. On the other hand, we must be cognizant of the development in GPS technology, which enables the surveyor to use but a single receiver, once we establish an array of permanent GPS stations.

## 3. THE GPS ISRAELI ACTIVE NETWORK (GIAN)

The network of permanent GPS stations in Israel (GIAN) consists of 11 stations (Figure 1). The network provides a reference frame for precise GPS measurements in Israel. It was designed and constructed to serve basic and applied geophysical research. Besides that, it will serve as the major geodetic control network of Israel. Three new stations are planned to be constructed in the near future. RAMO is the official IGS (International GPS Service) station in Israel.

Each station is equipped with geodetic GPS receiver, geodetic antenna, AC power, and emergency backup power. The GPS receivers are connected to a control room equipped with master and backup servers through frame relay connections. The GPS data flows to the server in real time using a 15-second receiver sampling rate. The GPS raw data is gathered into 3-hour interval files and posted on the internet.

Until recently, the GIAN network was mainly used for geodetic and geophysical research. It was used less for surveying, mainly because of the relatively short observation time span and OTF (On-The-Fly) ambiguity resolution that are being used, which put a limit on the distance to a reference station. Economically and practically, there is no need to increase the number of permanent GPS stations in the north and central part of Israel much above the current number. Additional permanent sites may be needed in the southern part of Israel. In order to enable GPS surveying over the entire state of Israel with direct connection to the permanent GPS network, VRS (Virtual Reference Station) technology is applied. GPS data for a non-existent reference station is computed from all the permanent GPS stations in Israel. The user can select a virtual station close to his project, which allows him short observation time span or the use of a single-frequency receiver. In the near future an RTK (Real Time Kinematic) option will be added to the GIAN network.

Direct connection to the GIAN network or using the VRS together with datum transformations should yield ITM coordinates of any new control point accurate to the level of a few centimeters.

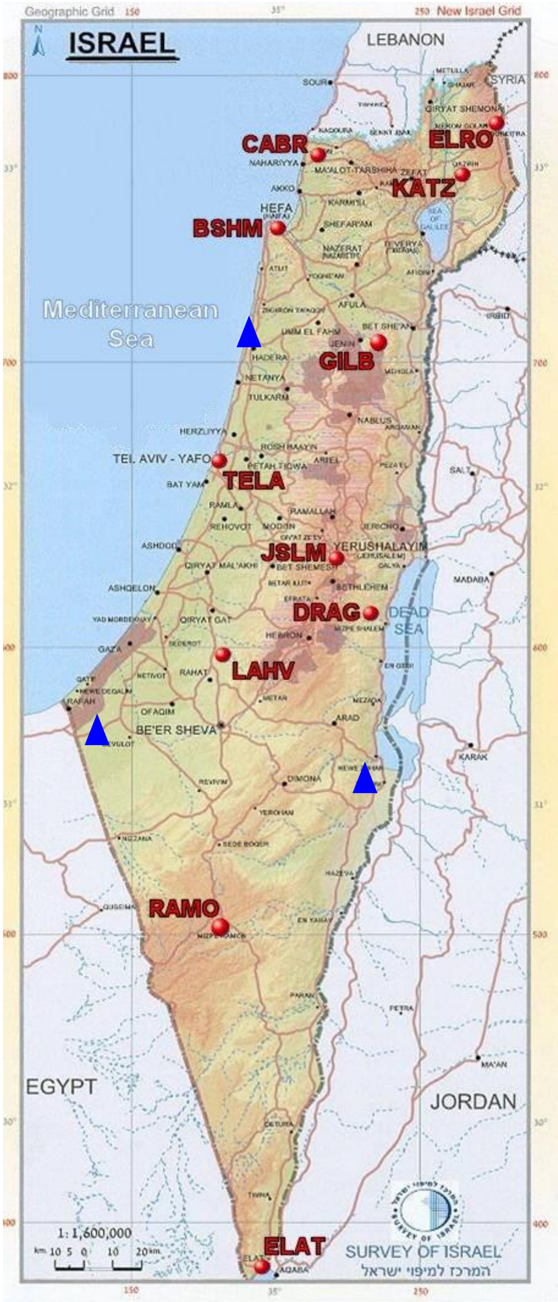


Figure 1 – Location of the permanent GPS stations in Israel.
red circle – existent site, blue triangle – to be established

## 4. DATUM DEFINITION AND DATUM TRANSFORMATION

Geodetic datum is a set of parameters and control points used to mathematically define the size and shape of the earth and the origin and orientation of the coordinate systems used to map the earth. Modern geodetic datums range from flat-earth models used for plane surveying to complex models used for international applications, which completely describe the size, shape, orientation, gravity field, and angular velocity of the earth. The datum is the basis for a plane-coordinate system. The diversity of datums in use today and the technological advancements that made possible global positioning measurements accurate to

a few decimeters requires careful datum selections and conversions between coordinates in different datums.
If the Global Positioning System is used, GPS positions and vectors are referenced in the WGS-84 datum developed by the US Defense Mapping Agency. The reference ellipsoid of this datum is practically equivalent to the reference ellipsoid defined by GRS-80, which is the reference ellipsoid of NIG.

Transformation parameters describe the relations between two different datum systems. A typical transformation contains seven parameters: three translations, three rotation angles and one scale parameter. Three points, at least, which have coordinate values in both datum systems, allow calculating the seven parameters. It is expected that classical networks will differ from modern GPS-based networks, due to the methods of measurement and computation. Between these two systems there may be accumulated errors, local and regional systematic errors and dynamic deformations.
The set of transformation parameters is determined by a least-squares solution, which minimizes the sum of the squares of the residuals at the common points. The residuals can be used as a measure of fit between the two systems, depending on the quality of both datums.
Each point from the GIAN network was connected by GPS observations to the nearest 1st order control points. A local datum transformation was made in order to assign ITM coordinates to each permanent GPS station. In that way, a set of ITM coordinates to the GIAN network points was produced. A global seven parameters transformation between the GPS datum and the NIG datum based on 11 permanent stations shows residuals at the level of a few centimeters.

A permanent GPS-based network is typically more accurate, reliable and homogenous than a classical network. Therefore, a coordinates-set valid for a certain time in the ITRF2000 coordinate system disseminated by IGS, for instance, can be used as fixed coordinates of the permanent GPS stations. This set of coordinates can be updated periodically, corresponding to the dynamic deformation. A set of ITM coordinates was determined for these permanent GPS stations, based on seven parameters calculated so that it supplied practically zero residuals in the least-squares process. Using seven parameters like these with the fixed ITRF2000 coordinates in any GPS-based project, insures receiving the same ITM coordinates of any GPS-measured point independent on the permanent GPS station that the GPS project was connected to.

## 5. ISRAEL 2005 GRID: THE IMPROVED PLANE-COORDINATE SYSTEM

As mentioned in the introduction, the SOI replaced the Israeli coordinate system to NIG six years ago. The readjustment of the old network was essential, due to large mistakes and inconsistencies in the old computations, which included many additional observations that were adjusted locally. The decision to change the coordinate system (at the kilometer level) was mainly in order to distinguish between the old and the new values. The change was drastic: a shift of 50 km in Y and 500 km in X. At the meter level, a non-regular change of some decimeters in the northern part of Israel, as well as up to some meters in the southern part, is present. Although a change was introduced to a modern projection (Transverse Mercator instead of Cassini–Soldner spheroidal coordinates), the selected scale factor seems odd. Also the central meridian that in the old system passed through an existent major triangulation point near Jerusalem, was shifted to some arbitrary (and not a round number) longitude – to affect a needed rotation. The minimization of coordinate-differences between the old and new grids was important mainly in order to keep the grid lines unchanged on large-scale maps. It is also helpful wherever an accuracy of 1 meter is sufficient.

Now we faced some dilemmas: on the one hand, we are establishing a state-of-the-art grid and in that context it is the proper time to "fix" the odd scale and to choose the central meridian to be, say, $35^0$ – which would suit the shape of Israel very well. On the other hand, that choice might cause a big change of coordinates at the decimeter-meter level, with all its disadvantages. A new shift of the grid at the kilometer level is out of the question, due to the very short time that passed since the last move to the NIG (it has not yet been fully assimilated). A big change of coordinates at the meter level might help to distinguish between the coordinate systems; but it may cause real harm in the case of undetected mistakes (i.e., wrong identification of the grid that the point belongs to).

It is important to notice that in the case of big differences between the coordinate systems, the SOI would have to transform all the cadastral boundary coordinates to the new system, before starting using it. On the other hand, the existing situation is tolerable for the meantime - although it dose not reach the ultimate goal. Considering those issues, the SOI decided to stay with the existing projection and mapping equations.

## 6. TRANSITION TO THE NEW ERA

From January 2005 every new control point will be based on the Permanent GPS stations GIAN, either directly (with the aid of VRS when needed) or by hierarchical measurements.

The superior control points in this hierarchy will be measured by GPS only, at least up to the 4th-order (distances of about 1 km between neighboring points). The coordinates of all the old triangulation points will be canceled, unless measured by GPS in the new system.

The treatment of the control points (about 50,000, as mentioned above) that were measured by GPS in the last decade, and their densification, will be as follows: The first layer of old control points that were used for local datum definitions in each GPS densification project, will be re-measured directly, relative to GIAN. The new (improved) coordinates will replace those which were used for the local datum definition. There are less than 1000 points of that kind. The further computation will consist of the 4- or 7-parameter transformations of the free GPS networks mentioned in the introduction, followed by traverse computations where further EDM densification was done. A great help for this process will be the establishment of a new geodetic dada-base which will include the measurement-connections between the points. At the final stage, for each cadastral project, we will compute some average shift in Y and X, based on the coordinate differences of its control points. The accuracy of those shift values is estimated to fulfill the desired ultimate goal of the Survey of Israel.

## 7. CONCLUSION

The surveyors' work in Israel is under revolution: very soon it will be possible to measure control points, cadastral boundaries, points for topographic mapping and other engineering surveys, within a few seconds, with one GPS receiver, in real time. The survey of Israel is already working to update the survey regulations and instructions, in order to prepare the surveyors, and to be prepared by itself, to the new geodetic era.

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## BIOGRAPHICAL NOTES

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**Societies**

Israel's delegate to commission 5 of FIG.
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