REQUIREMENTS ON THE HEIGHT BENCHMARKS IN THE THIRD PRECISE LEVELLING OF SWEDEN.

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ABSTRACT

The development in the field of surveying is very intensive today. The instrumentation as total stations, levelling instruments and GPS-equipment is constantly improved in order to be easier to use and to achieve better accuracy of the measurements. Calculation programmes are also improved for the same reasons.

However, most measurements are related to some kind of reference points in the terrain that should carry the coordinates or the heights calculated from the measurements, so what happens if the benchmarks does not meet the standard of the measurements is that the good measurements performed are loosing a bit of its value. The efforts made to achieve high-class measurements are more or less wasted. Or can we really afford to make those accurate measurements just for the pleasure to see that nice low RMS in the result files from the calculation?

Not only the stability and accessibility of the benchmark is important, but also to be sure that the point used in the field is the right one. To guarantee that, it is necessary to have a reliable identification and documentation of all the points.

The quality of a measurement can easily be judged by calculation, and we can accept the measurement or remeasure, but how can the quality of a benchmark be judged? Unfortunately this can usually not be done until the point is used the next time, perhaps after several years, and then it is too late.

This paper mainly describes the requirements on the benchmarks in the third precise levelling of Sweden and what is done in order to meet those requirements. The actions taken here can however be applied to most kinds of networks.

INTRODUCTION

The third precise levelling of Sweden has been going on since 1979. The network will consist of about 50 000 km double run levelling and about 50 000 benchmarks to represent the measurements in the terrain.

Before the project started the requirement of high quality benchmarks was realized. Earlier levellings in Sweden had suffered from unreliable benchmarks in different ways, and that had essentially decreased the value of those works. Therefore we could not perform a project like this with such an enormous amount of high quality measurements without trying our very best to secure the measurements in the terrain for the users.

This paper describes mainly the actions taken in order to establish reliable and permanent benchmarks in the third precise levelling, but the problems are mostly the same for all kinds of network. Besides, at least in Sweden, vertical movements are the most critical for a benchmark because of the ground frost, so we have to pay special attention to those problems when we deal with a vertical network.

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The paper will give an account for the whole process of benchmarking, from planning the new points to updating and maintenance.

A good benchmark means the right kind of marker applied in the right way in the most stabile kind of foundation at the right place for the users. The point is permanent to destruction, it is distinctly identified and the information connected to the point is updated and relevant.

With the development of the GPS-technique, the need of benchmarks is beginning to be called in question, especially for horizontal networks, but also for vertical networks. It should not be necessary to connect the measurements to benchmarks since we can determine the measuring points on each occasion. We should only need a few reference points in order to connect the measurements. For the vertical component ellipsoidal heights could be used.

For the local users however this arrangement is not a realistic alternative within the foreseeable future, since many local users do not yet have access to the GPS-technique. On the local level many measurements of different kinds are done for many different purposes, and in many cases the GPS-technique is not available or the most suitable. Ellipsoidal heights are for practical reasons impossible to handle for most local users. So classical techniques will still have an important role in this field for many years, and that requires as good benchmarks as possible. Besides, it has always been necessary to connect measurements from different epochs, and then the benchmarks are essential as a carrier of earlier measurements.

REQUIREMENTS ON THE BENCHMARKS

A study group at the NLS worked with the specifications for the new levelling project for several years, often in collaboration with our Nordic colleagues. The importance of high quality benchmarks was stressed in the report presented from the study group in 1976. This is shown in the following extract from the long list of specifications regarding the benchmarks:

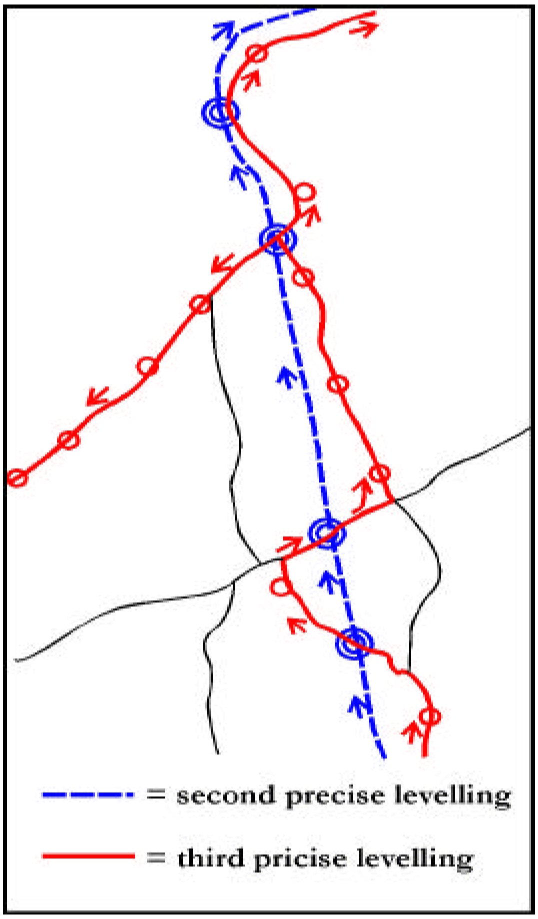
- The net should be shaped so that all polygons have equal circumference all over the country (between 80 and 120 km).
- The net should cover the whole country, which is not done in previous precise levellings.
- When the location of the lines is planned, the local needs and demands should be taken in consideration as far as possible.
- The distance between the benchmarks should be 1 km.
- The choice of location of the points should be done with the greatest care and every possible effort (since those are the fundament of the network and should guarantee the permanency for many years). The prime foundation should be bedrock.
- The marker should be designed with a well-defined highest point so that a rod with a flat bottom can be set up vertically.
- The point should be located so that the risk of destruction is minimised.
- The marker should be equipped with an identification, and a description should be drawn up in such way that no mix up with other points can be done.
- If the distance between points in bedrock is too far, special measures will have to be taken. (Type of benchmark described below).

- The point number system should be based upon the map sheet system in order to generate unique point numbers.
- All information about the points should be stored in a database.
- Maintenance and updating of the new network should be carried out on a regular basis.

Considering that those recommendations were drawn up in 1976, one must say that they were very well thought-out, and they are mostly still up to date. Since those guidelines have been at hand from the very beginning of the work, it is all done in the same shape, which is a big advantage. Let us now see what have been done in order to fulfil the recommendations.

PLANNING THE NETWORK

When we are planning for new measurements we must take into account that different users need the established points for future measurements. Therefore it is important that the points are located so that they are easy accessible in order to minimise future measurements for connections, since those measurements means extra costs every time they are carried out. The distance between the points is about 1 km, and must not exceed 1,5 km. In urban areas the distance is shorter. The points should be located where they are needed.



Fig; 1 Location of new lines along old precise levelling lines

In order to assure that, a map with the planned lines is sent to all the local users, community authorities, road and railroad authorities and others who can possibly be users of the points. They are invited to give their opinion of the plan, and when their view is collected, we can make a final plan, where we try to combine all the different demands. This is not always so easy. Sometimes all the local demands cannot be fulfilled. Different local users can have totally different opinions of the location of a line. We also have certain demands of our own upon the network configuration in order to obtain a strong and homogeneous network all over the country *(see fig.1)*. In those cases we have to find the best common solution together.

This process starts one year before the fieldwork (*see table.1*), but when it is done we know that the established points will be as useful as possible to as many users as possible.

Before the fieldwork starts, we then visit each one of those users to discuss local matters. That could be the location of the lines on a detail level. Benchmark maps and descriptions over the local networks are collected. Perhaps the local user has points of his own that can be used, and in that way have the local network connected to the national network without any extra measurement. In addition to that we can avoid setting out another point at the same place, which could cause mistakes by using the wrong point. That can happen if we do not know the location of the local points.

Local points can be used if they meet all the demands valid for benchmarks in the precise levelling network. Many local officials proudly shows maps and excellent calculations from their measurements at the office, but when the benchmarks are inspected in the field, it turns out far too often that the local points are not possible to use. Since we cannot risk the quality of the precise levelling network by using those points, the local user will have to connect his measurements himself, which means extra costs. In addition to that he has in fact an unreliable network, in spite of the good measurements, and that will cost even more in the long run.

Sometimes a local user wants more points or a denser network than the specifications for the national network. In that case the user will have to pay for that extra densification. Such additional points or lines can be prepared either by the local authorities or the NLS, and can be levelled at the same time as the measurements in the national network. The result from the benchmarking in the national network can be sent to the clients immediately after the fieldwork. Since the benchmarking is performed one year before the levelling, the clients will have time enough to decide on those matters.

There are other reasons to establish the points one year in advance. One is that the points will have time to stabilise and rest over the winter between benchmarking and the levelling. This is important especially for the underground type of benchmark described below.

Since we are setting out about 2 000 points/year we will need some time to prepare the levelling. Each levelling team must be equipped with all the descriptions and maps they will need during the field season before they go out into the field.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Year 1									1			
Year 2	1			2						3		
Year 3	3			4						5		
Year 4	5											

Table 1: Time schedule for the process

1: Planning of the network. Planning for the location of the lines in collaboration with the local users.
2: Field work. Setting out the benchmarks. Discussions on detail level with the local users.
3: Storing benchmark descriptions into databases. Preparations for levelling.
4: Field work. Levelling.
5: Calculation. Storing levelling data and results into databases. Delivery of data to the users.

FIELD WORK

Location of the benchmarks

When a network is established, disregarding what kind of network, it is desirable that the "lifetime" of the points is as long as possible. A point like this turns out to be quite valuable when we sum up all the costs for benchmarking, levelling, and calculation. All that money is in fact invested in the very benchmark, and if the benchmark is destroyed after a short time, the investment does not pay off. Today we are also very interested to connect the points from the first precise levelling from 1886 – 1905, and the second one from 1951 – 1967, in order to establish the relation between former height systems and the new one to be. In the Nordic countries there is land uplift that can be calculated if we know those relations. This is an important task of the project, and that would be impossible if there should be too few or no old points left to connect. Therefore there are always lines located to the same route as the lines from the previous precise levellings.

In Sweden the law protects benchmarks established by NLS or a local user. It is not allowed to deliberately destroy a benchmark without permission from the owner. This law is very hard to practice, since a person who removes a benchmark can always say that he was not aware of the benchmark when he destroyed it. Road constructors are the people who destroy the largest number of benchmarks. That is quite natural since most points are located along roads. Therefore the road planning authorities are always asked about their long-term plans for bigger projects of road constructions. There are always small projects that can not possibly be foreseen, but many points can be saved by those interviews.

This means that we should try to locate the new points so that they are well protected from destruction. At the same time we want the points to be accessible. If we add the requirement for stabile foundation of the benchmark, we can easily see that we can have a problem. Where can we locate a point that fulfils all these demands? We will often have to compromise between the different demands. If we have to choose, the most important demand probably is to have a stabile point. Second choice is the permanency of the point and the third is the accessibility. It is no use to have an accessible point if the coordinates or the height given are not valid or if the point is destroyed shortly after the establishment.

All those considerations have to be done by the personnel who shall set out the benchmarks, and that really takes a lot of experience in ground analyse as well as in surveying. A great deal of patience and common sense is also valuable. Not anybody should be trusted to do this work, because the responsibility of the total quality of a network is really in the hands of the people who are doing this work. Unfortunately this responsibility is not seldom handed over to the youngest or latest employed assistant, who is sent out to set out the points. If the guidelines for the work are poor in addition, the whole network is more or less ruined even before any measurements have been done.

Foundation

In Sweden and the other Nordic countries we have ground frost, that in Sweden can be up to 2.0 m below the ground in certain types of soil, or even more when there is no snow in the winter. The ground frost can lift even a big boulder or a steel pipe that is used as a benchmark. This is a problem where we cannot use bedrock for the benchmarks, and in large areas of the country there is no bedrock. The depth of the ground frost of course is dependent of the temperature, but it also varies with the type of soil. The ground frost is deeper in soil that contains more water. Therefore clay and some types of moraine are more dangerous to use as foundation for a benchmark than sand or other well-drained types of soil.

The best kind of foundation is the bedrock, which is normally very stabile in Sweden. It is important that the bedrock has no cracks on the surface or right under the surface. If it is cracked the frost can burst the bedrock. This can easily be detected if we knock on the bedrock with a hammer. However bedrock is not available in all parts of the country.

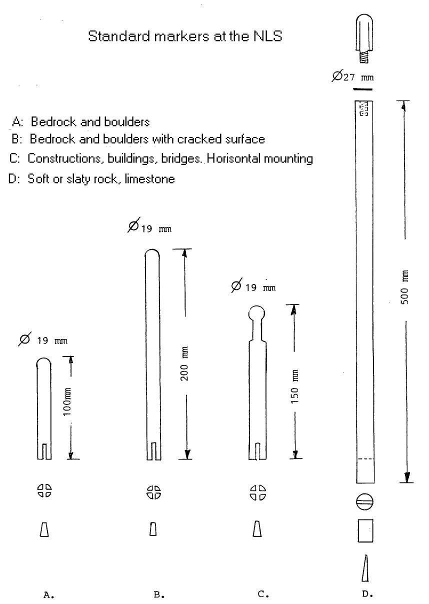
Therefore boulders or blocks of stone are also used as foundation if they are properly embedded in the ground. This is the most common type of foundation for height benchmarks in Sweden *(see table 2)*. If there are no blocks available, buildings, bridges or other constructions can be used, if they are founded well enough. Since points located in constructions are often horizontally mounted, it is important to assure that we really can set up the rod vertically on the point. Too often there is a leaning wall, a roof that is too low or some other obstacle that makes the points impossible to use.

Type of foundation	**Nr of benchmarks**	**% of the total number**
Benchmarks in bedrock	16 768	36 %
Benchmarks in stone blocks	25 360	54 %
Benchmarks in constructions	2 674	6 %
Underground benchmarks	1 851	4 %

Table 2; The table shows the distribution among the different types of foundation in the Third precise levelling of Sweden up to 1997. The total number is 46 686.

When new measurements are connected it is important that the connection points are reliable. Otherwise we have to spend money on connection measurements, which should be unnecessary. In order not to get too many weak points in a row on the lines, in the third precise levelling of Sweden we say that at least in the urban areas every fourth point should be founded in bedrock. Since this cannot be fulfilled, we have another method to establish reliable points. This method is described below.

Choice of type of marker



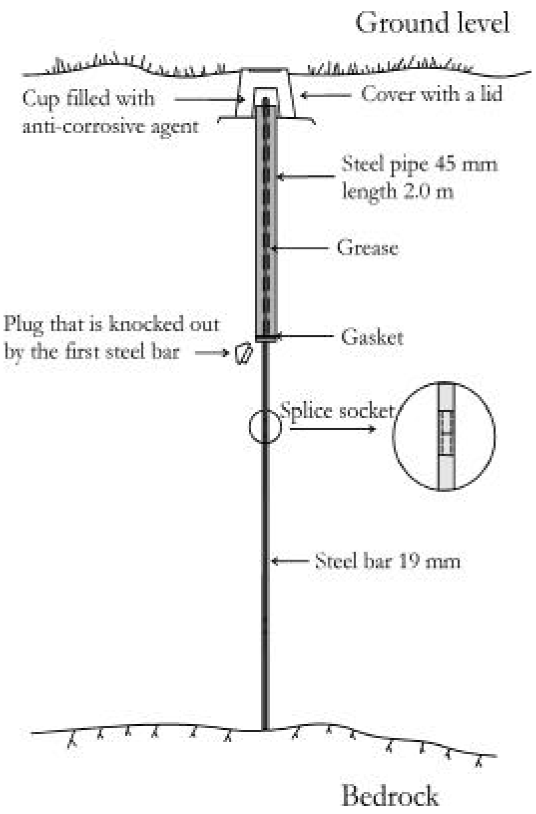
Fig;2 Common types of markers in the third precise levelling of Sweden. All types are made of stainless steel.

The quality of a benchmark is not only dependent of the foundation. We also have to use a suitable type of marker for each type of foundation and for each type of measurement. In various exhibitions we can see many different types of markers, each one intended for a special kind of foundation and measurement.

. For levelling we want to have a type of marker with a distinct highest point. Therefore this kind of marker should have a spherical upper surface. In that way the bottom of the rod always stays on the highest point of the marker. For horizontal installation these markers can be shaped like a ball or a cylinder. The safest way to anchor the marker into the foundation is to have a wedge, flat or conical, that is expanding the bottom of the marker when the marker is hammered down into the borehole. In constructions other types of expanders are used *(see fig.2)*.

Not only the ground frost can be a problem. When expanding a marker into a borehole we must prevent water from coming down into the hole. Otherwise the water stays on the bottom of the hole and when it is freezing in the winter it can lift the marker in the hole, even if it is fastened with an expander. This can easily be avoided by putting some waterproof silicone in the hole before driving the marker down.

To establish reliable levelling points where we have no bedrock, there is another method *(see fig.3 and 4.)*. It is done with a hydraulic hammer running along a portable rig. First we dig a small hole about 60 x 60 cm and 40 cm deep. Then the rig is set up in the hole and a 2.0-m



Fig; 3. Sketch of a benchmark where we have no bedrock

Fig: 4. An underground benchmark is set out.

long steel pipe with the diameter of 45 mm is driven down into the ground. In the bottom of the pipe there is a loose conical plug to prevent the soil to get into the pipe. The first steel bar later pushes out the plug. The pipe is filled with grease to prevent water from getting into the pipe. Inside the pipe a 3 -m long steel bar is driven down through a gasket in the bottom of the pipe so that the grease does not go out with the bar. When the bar is knocked down another one is spliced and then the joined bars are driven down until they stop. Hopefully we reach the bedrock, but even if we do not, the depth is enough to give a very stabile point. The medium depth of those points is about 15 m, but the variations are very big. The last steel bar is cut off above the top of the pipe and the top is shaped to a sphere, which makes the benchmark. The benchmark is protected with a cover with a lid on the ground level With this method we get a benchmark that is protected from the ground frost by the steel pipe. The frost can lift the pipe, but the steel bar inside is not affected since it has no contact with the pipe.

The grease in the pipe stops the water from coming in and freeze between the pipe and the bar.

This kind of points is considered almost as reliable as a point located in bedrock. They are quite expensive to establish though, since they take between two hours and half a day to produce, sometimes even more, depending on the type of soil and the depth. It also requires some equipment, and the material is quite expensive compared to a standard marker. However compared to the costs for future unnecessary control measurements, this is a good investment.

For horizontal measurements it is important to have a distinct point so that we can set up the instrument exactly over the same point each time the point is used. Often we want to set up a target of some kind over such a point. Therefore those markers mostly consists of some kind of pipe, where a stick with a prism or a signal can be set up. Sometimes it can be sufficient to drive a steel pipe 0.4 – 2.0 m down into the ground, depending on the risk of ground frost. In buildings a plate can be mounted on the wall, and then a special device is attached to the plate every time when measurements shall take place. That gives good protection to the points, but you must be equipped with that special device in order to be able to use the points.

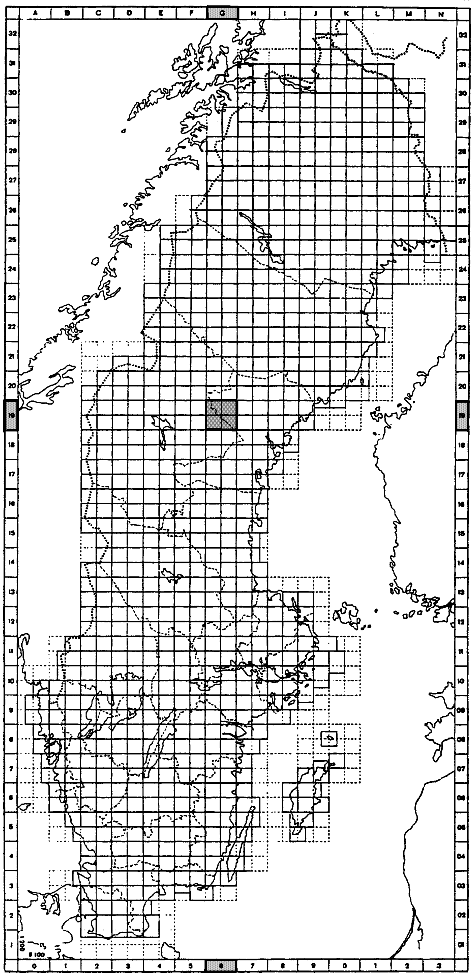


Fig:5. Map showing the mapsheet system and the point number system. Sheet N:r 19G =196 is marked.

For all kinds of markers, it is a good idea to have a mark on the benchmark that tells who is the owner of the point. This can be done by having the name of the organisation punched on to the marker. Then a user will know who can give information about the point.

There are also markers for combined measurements. However they are often more suitable for either horizontal or vertical measurements, and seldom perfect for both purposes.

IDENTIFICATION

Benchmark numbers

We also must have a “waterproof” system for identification of the points, and descriptions containing all information required, not making mistakes when we shall use the points. A point number system that gives unique point numbers is of course essential.

The point number system in Sweden is built up by the map sheet system (*see fig 5)*, where the sheets in the scale 1:100 000 contains 10 x 10 maps in scale 1:10 000.

Those sheets are numbered within each 1:100 000 map. To identify the area of such a map we use 3 digits to identify the 1:100 000-map sheet and two more to identify each 5 x 5-km area. For each of those areas we finally add two digits for consecutive numbers. This system allows us to have 99 points in a 5 x 5-km area. The most crowded squares contains about 30 points. There are points more than 100 years old in the system, so it will probably last another 100 years. In addition to that we have for practical reasons codes for different types of points included in the point numbers. So when a new point shall be established, we must always look at the archive map to check what is the lowest available number in each square.

Benchmark descriptions

In order to find the points and to secure that the used points are the right ones, we need a benchmark description. The description tells where the points are located and contains at least two distinct measures to permanent details in the terrain. A sketch shows the location of the benchmark in relation to other objects in the surroundings. The description should also tell if the point is identical with an older one, a local point etc, or if there is such a point in the neighbourhood, that can cause a mix up between the points. The description also tells when a point has been established and used and what measurements it has been involved in.

The benchmark descriptions are drawn up at the same time as the points are set out. The heights are not given on the description though. They are printed out on separate lists. All the information is stored in databases, including the sketch. That makes it easy to update the descriptions. This work is done during the winter after the fieldwork. We want to induce the users to get the information on the points from our archive every time he wants to use them. In that way he can be sure to have the most actual information.

Benchmark maps

To complete the information about the benchmarks we need a benchmark map that shows all the benchmarks on a mapsheet and their point numbers. Different types of points are drawn with different symbols. The point numbers are determined from the archive map according to the system mentioned above. The archive map is stored in a portable PC, and the new points are digitised on the screen of that PC. Every new point must be inserted on the same copy of that archive map so that everyone working can see which point numbers are occupied. If there are more than one team working, they use the same copy of the database stored on a PCMCIA-card. That card is shifted between the computers in order to avoid errors with the numbers.

This work is done in the evening after each working day. Mistakes with numbering of the points will be detected during the process, but it is easier to correct the errors the sooner they are detected. Built in control functions in the digitising programme helps to avoid some mistakes. So when the fieldwork is finished for the season, we store the data from the computers into the original database, and then we can print out the maps at once. The maps are sent to the local users so that they can see the locations of the new points and decide if they need additional points.

MAINTENANCE

Building a network like the third precise levelling in Sweden can be seen like a gigantic investment that is calculated to pay off over a very long time. In spite of all the measures taken in order to preserve the network when it is built, things happens that in different ways is causing damage to the network. To protect the investment we must therefore maintain the work that is done. This is often an underestimated problem. Benchmarks are destroyed or damaged. The location of the points is changing and makes it hard or impossible to find the points. This process is going on all the time, and if nothing is done the value of the investment is decreasing very fast. What good is it to have accurate benchmark descriptions and exact heights if you cannot find the points or if there are no points left in the terrain? In 1992 an investigation was made that showed that about 1% of the points from the third precise levelling are destroyed every year in the urban areas, and 0,5% in the woodlands. The oldest parts of the network were at that time 13 years.

After that discovery a programme started in order to systematically update the network, even though the network is not completed yet. The ambition is to keep the network at the same standard as it was originally, so there is no extra points or lines established in this work. The local users are involved in this work in the same way as in the establishment of the network. We are now updating the urban areas 13 – 15 years after the establishment, and that means that 10 – 15 % of the points are gone in each area. All the points are visited. The destroyed or damaged points are replaced by new ones or local points, and all the benchmark descriptions are checked and updated, the text information as well as the sketch. All the changes are stored in the databases. To separate those new points from the original ones, the new points are given a special type in the benchmark number. They also have a special symbol on the benchmark maps to point out to the users that something has happened. If the new point is located close to the destroyed one, a user can make a mistake if he is not aware of the replacement.

Conclusions

When a measurement is performed we always need to connect it to other measurements in some way. For that purpose we need benchmarks that have preserved the quality of those former measurements. This will be the case also for the foreseeable future. Since measurements today gets more accurate, the requirements on the benchmarks must also increase. Otherwise the accurate measurements can not be utilised, especially in the long run.

For economic reasons we must plan the network so that the points are as useful as possible to as many users as possible. Measurements for connections and control measurements cost as much as ordinary measurements, and should be unnecessary if the points are reliable and located at the right place. The type of marker used should be suitable for the type of measurement that should be performed. The possibility to safely identify a point is essential. Descriptions should be distinct and contain all the necessary information. In order to protect the investment made in the network, updating must be done on a regular basis.

Unfortunately there are no formulas that can help us to judge the result from the benchmarking like we can when it comes to measurements. That is why we must trust the common sense by the personnel who is dealing with these matters. The more experienced people we use here, the better result we will get.

Taking these factors in account when networks are built and when the benchmarks are set out, the points will be a little more expensive to establish. Compared to the costs for just one extra km double run precise levelling for connection or control measurement, at one occasion, this extra cost is earned several times.

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