THE PRODUCTION LINE USED IN THE THIRD PRECISE LEVELLING OF SWEDEN

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The National Land Survey of Sweden (NLS) is deeply involved in the Third Precise Levelling of Sweden since the 1970s. The whole project represents more than 50 000 km double levelling (50 000 benchmarks) and the production work is supposed to be completed about year 2000.

This paper describes the unique production line that is used in the third precise levelling network. Most of the production line is digital and has been so since the start. We have been using the same production line almost throughout the project which mean that we have been trying to treat a specific type of data the same way during the 20 years that the project has been going on. Included in the production line is, besides the actual levelling, also the production of site descriptions, maps as well as storage of data in a suitable archive.

The production line can roughly be divided into five different phases that are synchronised in time. These are

1. *Planning the network*
2. *Establishment of benchmarks*
3. *Storing information about the benchmarks into the archive as well as preparations for the levelling*
4. *Levelling*
5. *Computation, archiving and delivery of results.*

The whole process takes for one region about four years of work to complete.

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INTRODUCTION

Before the actual production work of the third precise levelling network started in 1979, major discussions took part concerning how the production work should be done the best way. It was decided very early that if the network should be of the highest quality, the production work should be done in a homogenous way and that means in the same way throughout the whole project. Therefore, it was necessary to have a production line that was as correct as possible from the beginning. It was also decided that the production work should be done in a digital production line. The manual work should be held to a minimum. We are proud to say that it was almost possible for us to create this production line from the beginning and that we are using the same methods today as we did in the beginning of the project. The 20 year old production line is still working excellent.

The work with the third precise levelling can be described in five different phases that must be synchronised in time. This is graphically described in figure 1 below and in the text in the paper.

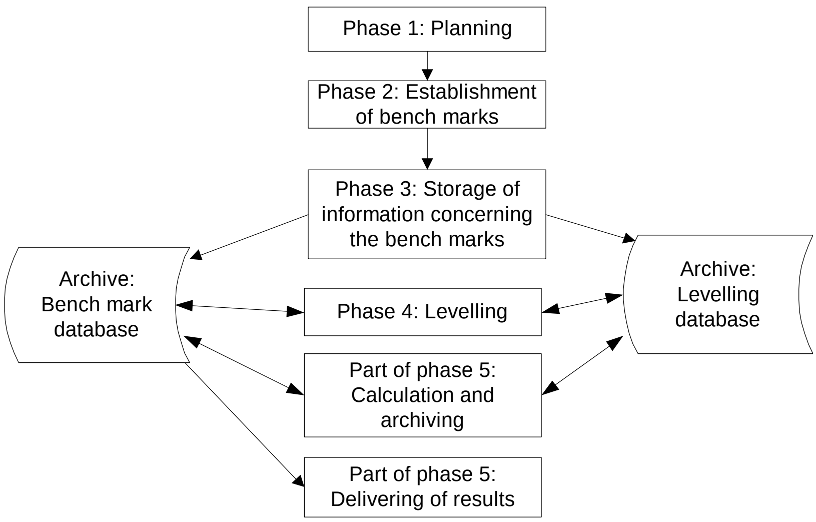

Figure 1. Phases in the third precise levelling project.

The benchmark database contains information about the benchmarks. The information consists of benchmark number, type of monumentation, description of how to find the benchmark etc. The levelling database consists of information about the levelling. All data in this database are stored section by section. The benchmark and the levelling databases are the two major databases in the project but there exists several other databases as well. All the databases have been on a PR1ME computer since the beginning. We are at the moment changing server for the databases and will be using an Oracle database to store all the information. Beside the storage of data in the two databases, all important files in the project are stored.

As mentioned earlier, it is important to do the right thing at the right time. Figure 2 shows the order of the five different phases as well as when these different phases takes place. We can see that the work in a certain region starts during the autumn in year 1 with the planning of the network. The planning stage is done during the winter and must be finished in time for the field work during the spring in year 2. The establishment of benchmarks is done during the summer and all the data from this work are stored in our databases during the winter. We are at this stage also preparing the levelling work that takes place during year 3. The field work is followed by the computations and storage of data during the next winter. The whole process covers almost three years of work spread over four years.

	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											

Figure 2: 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. Establishing 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 data and delivery of results.

PHASE 1: PLANNING OF THE NETWORK

The first phase in the creation of a new height network is a very important one. There is no point in creating a new network if the end-users are not satisfied with the network from the beginning. They who are the users of the network and they need to have good, stable benchmarks with good quality both in the monumentation and the heights. The benchmarks should also be easily reached from roads. These demands can not be taken care of if the planning phase is not properly done and involving the end-users in the specific area.

In order to involve the major end-users we send a map with the planned lines to all the local users, community authorities, road and railroad authorities and others who can possibly be a user of the points in the region. They are all invited to give their opinion of the plan. The views of the users are collected and we can make a final plan. In the plan, we try to combine all the different demands. This is not always easy and we may not be able to fulfil all the different demands on the location of the levelling lines. We also have certain demands of our own on the network configuration in order to create a strong and homogeneous network all over the country. We always have to find the best common solution.

We also collect benchmark maps and descriptions covering the region from the local users that we are in contact with. This is important since we do not want to establish a new benchmark at the same location as a local one. We do however have high demands on the benchmarks, which means that many local points can never be used for the third precise levelling of Sweden. For more details concerning our demands on benchmarks, see Eriksson (1999).

Sometimes a local user is interested in expanding the original plans of the precise levelling in the region to cover his own needs better. We try to meet these demands as much as possible. Of course, the local users will have to pay for the extra levelling work since it is not part of the third precise levelling but more as an extension to suit the local users needs in first place. However, we try to keep the price as low as possible, as we think that these extra works are important. It is important that the local users can connect their networks to the new national height network.

PHASE 2: ESTABLISHMENT OF THE BENCHMARKS

One of the main purposes by establishing a new height network is to give good and solid benchmarks for the users with heights that they can trust. Establishing a new benchmark is therefore an important job and must be done with the greatest skilfulness. The location of the benchmark should be chosen so that the point is well protected and easily reached at the same time. The point should be established on stable ground, preferably on bedrock. To choose and to establish a benchmark is therefore a job that requires personal with experience. Teams of two specially trained persons from the NLS do this work. We are using one to three teams each year depending on the needs of establishing benchmarks and what type of ground that we are working on. One team normally establishes 10 benchmarks a day. However, if there is no bedrock or solid rocks but only soil the work goes much slower. In this case, about three benchmarks are established every day.

This phase uses the plans originated in the first phase. These plans may though be affected by minor amendment to reach the best quality in the net and in the benchmarks. These amendments are made directly out in the field.

When the benchmark is established, a site description is created. The information on the description is e.g. point number (unique one for each point), type of benchmark and how to find it (both verbally and with a drawn sketch). All the information is collected in analogue form in the field and transformed into digital form in the office after the field work.

During the establishment, the location is also marked on a map with the scale 1:50 000 (or 1:100 000). The point is digitised directly using a MapInfo application developed at the National Land Survey. The point is accurate in the horizontal to approx. 50 metres and the digitalisation is merely a cartographic one. The purpose of the digitalisation is twofold; we need to have approximate horizontal co-ordinate of the point for the computation and we need to represent the point on a map. When we have all information in digital form, we use MapInfo to handle the digital geographic data.

PHASE 3: STORING SITE DESCRIPTIONS INTO DATABASES. PREPARATIONS FOR LEVELLING

It is essential to save all raw data throughout the whole project. Therefore a systematically storage is important. It is vital to have the opportunity during and after the project to go back to the actual readings and study these. This means however that we are forced to store a lot of files. Simple calculation concerning the number of raw data files from the levelling work gives at hand that each levelling team produces seven different files each day. For one levelling season covering 100 working days and three levelling teams, this means 2100 files from the levelling field work alone. However, the levelling field work is just one part of the production work. Just as important is all the data describing the point.

It is also important to store the information in an organised way, e.g. in databases. We are using two main databases within the project. These are the benchmark and the levelling databases. Besides these two databases, a number of other databases are used. More information about some of them can be found under phase 4.

The benchmark database is composed by information concerning the benchmark as approx. co-ordinates, benchmark number, type of benchmark etc. The information comes from the field work in phase 2. Most of these information can later be found on a site description, see Appendix 1. Everything but the sketch is in digital form. We have been using a PR1ME computer with the PRIMOS operative language since the beginning of the project. We are now forced to change computer system. Everyone who has been forced to change computer system in the middle of a major project knows about the amount of work that is involved. The new geodetic archive at the National Land Survey will be based on Oracle under Windows NT. Since the new archive is not complete yet, we are forced to use Access as a temporary solution for the levelling project.

The information in the levelling database is built up section by section. The information in the database is e.g. measured height difference, length of section, number of set-ups, observer, instrument nr, rod nr, type of road, type of weather etc. In total, 54 different items is stored for each section.

An important task in this phase that must not be forgotten is the preparation for the levelling field work that will take place in the next phase. This means that benchmark maps and site descriptions are copied, the equipment as instrument and cars are checked. This is done during the winter/spring before the levelling season starts and by personal at the National Land Survey.

PHASE 4: LEVELLING

This phase takes place during the third year. The data from the field is checked, processed and compiled for computation. For statistics from the production work, see figure 3.

Year	No of team	No of working days	Prod. total	Relev. km	Relev. %	Prod. netto	Netto km/day
		Total	**Km**	**Km Total**	**Ave/team**	**Km**	**Ave/team**
-78	2	284	3016	121	4,0	2895	10,2
-79	3	370	3164	394	12,4	2770	7,5
-80	4	487	4378	226	5,2	4152	8,5
-81	5	552	5491	240	4,4	5251	9,6
-82	5	566	6646	255	3,9	6389	11,3
-83	6	557	6896	295	4,8	6599	11,5
-84	5	397	4636	209	5,8	4429	10,5
-85	5	503	5370	347	6,1	5021	10,0
-86	5	541	6099	418	7,2	5680	10,4
-87	5	453	5326	301	5,9	5026	10,9
-88	4	474	5969	529	8,7	5440	11,5
-89	4	419	5063	451	8,9	4612	11,0
-90	4	462	5505	585	10,7	4919	10,6
-91	3	344	4249	278	6,5	3971	11,5
-92	3	309	3989	257	6,4	3732	12,1
-93	3	333	4180	258	6,2	3938	11,9
-94	3	304	4077	447	11,0	3630	11,9
-95	3	288	3964	425	10,7	3539	12,3
-96	3	306	3815	445	11,7	3369	11,0
-97	3	257	3470	291	8,4	3178	12,4
-98	3	254	3376	285	8,4	3091	12,2
SUM:		8460	98679	7057		91631	

Figure 3: Statistics from the field work

As a summary the daily production varies between 4.5 and 6.5 km double run levelling for a team with an average relevelling frequency of 5 to 8 % for 5.5 hours measuring. One team consists of four persons. The field season production has varied between 1 600 and 3 300 km and up till now almost 46 000 km double run have been levelled, excluding the relevellings.

The levellings started in the south and have now reached the most northern parts, see figure 4. Due to weather conditions, the levelling season becomes shorter and shorter and it started last year in the beginning of June and ended in the beginning of October.

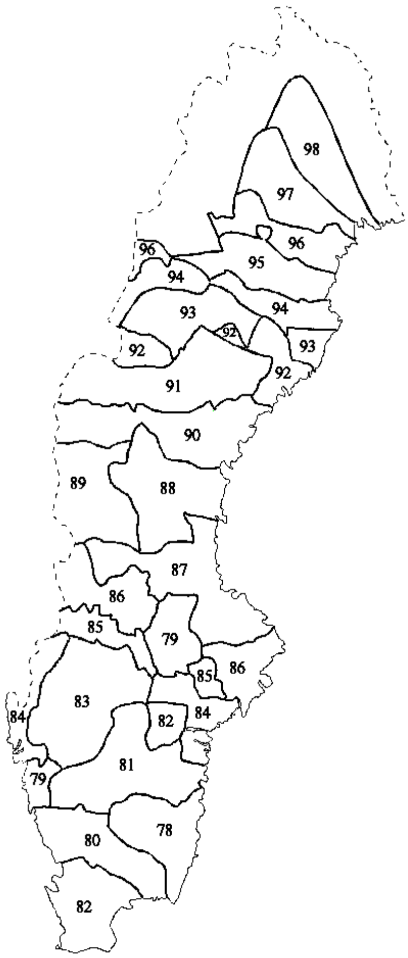

Figure 4. The progress of the third precise levelling of Sweden.

The average time per set up is less than 2 minutes including the moving of the cars. The maximum allowed sight lengths are 50 meters. All operations, except the connection to benchmarks, are done from the vehicles. For this reason working methods have been designed to minimise observing time and optimise the quality of the results.

The instrument used is NI002 from Carl Zeiss Jena. Due to the 360 degree rotational eyepiece, one can say that the instrument is the heart of the motorised levelling technique. This means that the observer can stand at one spot and shoot around the horizon. The system with the turnable pendulum that gives a quasi-absolute horizon is another big advantage of this instrument. The readings are made on the two scales of the rod, one scale in each pendulum site.

The sight lengths forward and backward are kept equal within 5 to 10% for each set-up. This is done with the help of Digitrips mounted in all the cars.

The observer tells the staff readings to the driver, who enters the readings into a small handheld computer (Micronic). The communication between the driver and the observer is done with a headset and a speaker in the car, because of the traffic noise. The datalogger calculates the difference between the two scales of the rod. If one of the fault limits is exceeded, the driver is told that a new measurement must be done. When the set-up is OK the driver is allowed to proceed. In this way, it is very hard to get a gross error into the measurements.

The same type of datalogger is used in the rod cars. The rod car drivers are storing information about point numbers and time for levelling. Type of weather, type of road surface and temperature of the invar band at an upper and a lower point on the band is stored for each set-up. This way of work leaves minimum of work for the observer and optimised amount of work for the whole team.

Figure 5. Entering reading to the Micronic.

The moving of the vehicles must always be done in the same chronological order and observations must be carried out in a predetermined and systematic order.

As mentioned earlier, each team produces three files each day. These files are transferred to a portable computer after each working day. The three files, called D-files, are checked and if necessary corrected. This work is done in the evening the same day as the levelling is done. Errors can be wrong point number, wrong time of measurement, wrong information of type of road or weather. After correction the result will be three new files called D/R-files and a T-file including information from all three D/R-files, see figure 6.

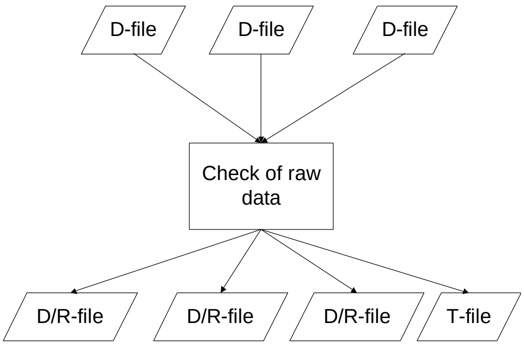

Figure 6: Check of raw data after levelling

All the files are sent home to NLS, where they are stored in a file database, see Appendix B. In the portable PC in the field there is a local copy of the levelling database, where all the measurements are stored during the field season. In this database corrections for earth curvature and temperature can be done. From that local database the measurements can be used to do some control calculations e.g. check of loop misclosures or other faults. That is a way to ensure that no gross errors are made during the field season. Rod corrections cannot be done here, since the rods are calibrated before and after the field season, and the corrections are interpolated from those calibrations. These corrections are done after the autumn calibration as well as the earth tide correction, see figure 7. Then the T-file and all the corrections are stored in the real levelling database.

To be certain to have a good quality of the levelling, all the equipment is checked with a regular basis. For instance, the instruments are checked once every week using a special designed check procedure. All the information from these checks are then stored in a special designed database for this purpose, the instrument database.

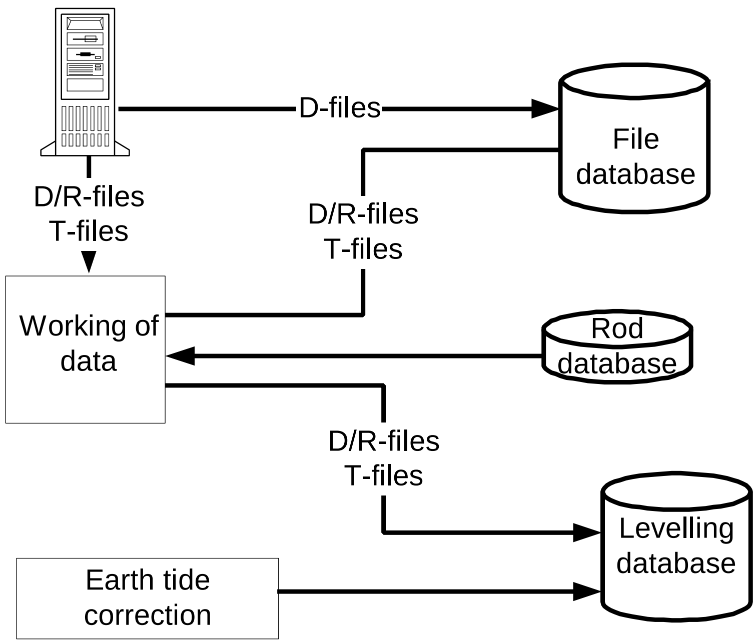

Figure 7. Correction of raw data after the season.

PHASE 5: CALCULATION, STORING AND DELIVERY OF DATA

This phase covers the work to be done during the autumn and winter after the levelling season. The computations are done in delimited regions defined by the loops from the second precise levelling. Since we cannot wait for the whole network to be completed before we deliver heights we will have to perform the calculations in the height system based on the second precise levelling, called height system RH70. First the measurements in a region are picked out from the levelling database and then a free adjustment is done. We are using a program developed by our selves for adjustment. Then the heights of the common benchmarks from the second and the third levelling are examined. Then it shows what points from the second precise levelling are of good quality. A number of the old points must be recalculated in each area, depending on e.g. poor benchmarks or errors in the measurements. After that the final calculation is done with the choosen points from the second precise levelling kept fixed. Since the calculation is done with points in height system RH70 fixed the new heights are also in system RH70. To show that these heights comes from the third precise levelling and that they should not be mixed with other heights in system RH70, we call the heights from this measurements RHB70.

Together with the data already stored in the databases the heights are stored in the benchmark database. There is also a register containing information about the calculation. All the heights are connected to an adjustment number. In that way we can always see from what computation the height is calculated. A scheme of the production line for the adjustment can be found in figure 8.

When the whole net is completed in a couple of years, a new adjustment will be performed including the entire network. On that basis, a new national height system will be established. Similar projects are going on in the other Nordic countries. Denmark is working with the implementation of their new height network DNN KMS1990 and Finland have reached as far as Sweden in their third precise levelling. The plans for Norway are unfortunately not quite clear now. The plan is that there will be a common adjustment for the whole Nordic block when we all have finished our levelling projects. To help with the preparation of this work, the Nordic Commission of Geodesy (NKG) has a working group working with height determination questions.

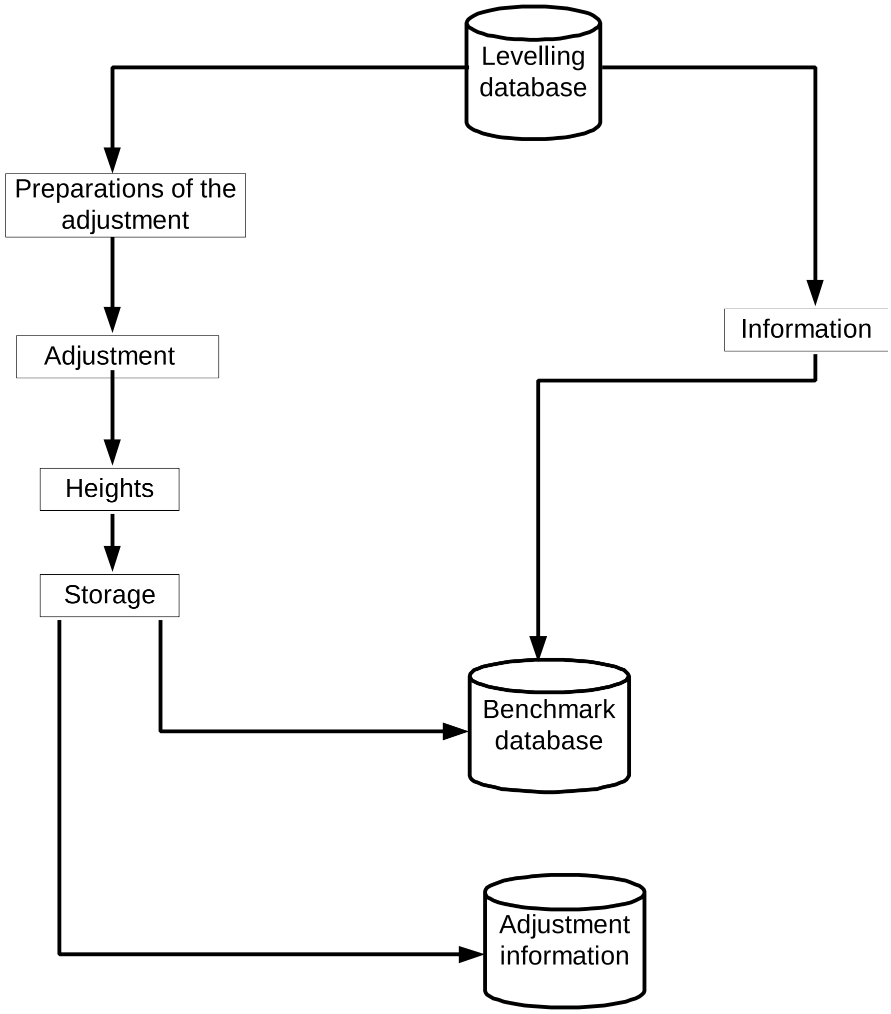

Figure 8: Production line for the adjustment

MAINTENANCE OF THE NEW HEIGHT NETWORK

The maintenance work can be treated as phase 6. The oldest parts of the network will be around 25 years when the new network is finished and the important implementation work starts. Investigations have shown that ½-1 % of the benchmarks are destroyed each year with the lower figure in woodlands. If we want to have a network with benchmarks, maintenance work needs to be done.

The work is done very much like the actual levelling project. The main differences are that the first phase concerns an investigation on how many of the original benchmarks are still useful and that new ones replace destroyed ones. Site descriptions are updated. We are working with digital sketches on the site descriptions within the maintenance work. The old sketches are scanned and minor changes are done using different types of drawing programs. When there are major changes, new sketches are drawn and scanned. The maps are updated as well.

The levelling work is done with the same technique and the same equipment as the ordinary work within the third precise levelling. We have developed a special levelling methodology to make sure that the quality of new levelling is the same as the original one.

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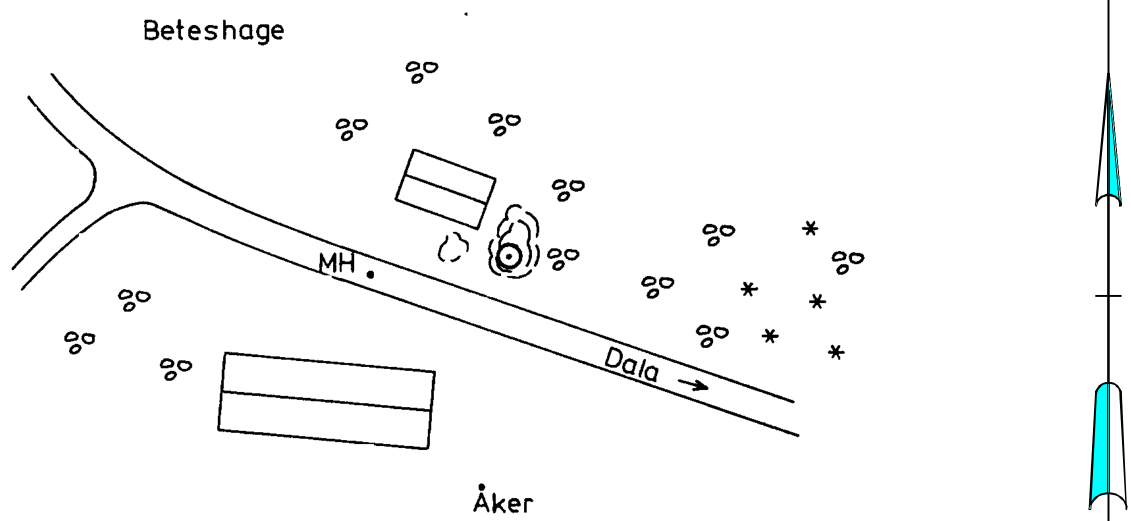
PUNKTBESKRIVNING
Höjdfix

LANTMÄTERIVERKET

Punkt nr	Punktbeteckning
064 RA 0110	6 E 0b:10

Beskrivning med skiss

Hisinge.
Vid vägen Broby - Dala, 1.0 km NV om avtagsväg från vägen Vrigstad - Värnamo, vid den sydligaste gården i byn Hisinge.
Ståldubb i högsta delen av ett delvis övervuxet bergparti, 16.2 m NNO om NO hörnet på en ladugård, 8.7 m NNO om vägmitt och 4.9 m OSO om SO hörnet på ett uthus.



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Typ av markering	Avstånd (m) Fix-Höjdpunkt
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Anm (identitet m m)
Ersatt med 064 0113.

Län	Jönköping
Kommun	Värnamo
Kod	0683
Topografiskt kartblad	6 E Nässjö SV
Avvägd år	1977
Anmäld återfunnen år	
Anmäld ej återfunnen år	
Anmäld förstörd år	1997
Flygbilds nr	75 Eb 059 03

Koordinatsystem i plan	Koordinater (m) X	Y

Beräkningshandl.	Beräkningsår	Höjd (m)	Höjdsystem

Punkten upprättad	Beskrivningen reviderad

	1977-07-28	

Production line from levelling to storage of data