GEODETIC WORKS ON THE CONSTRUCTION OF THE HYDROPOWER PLANT IN KJENSVATN, NORWAY

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ABSTRACT

The construction of the Kjensvatn hydropower plant will lead to modernization and expansion of the Durmålsvatnet network of hydropower plants in the Nordland area of Norway. Annual output of the power plant will amount to 80 GWh and all energy will be drawn solely from renewable resources. The whole set of tunnels is situated in a mountain massif. It includes an entry building, 200 m long access tunnel, the power station and approximately 5000 m of other tunnels.

Geodetic works carried out during the construction of this project are divided into several interconnected activities. A high-quality and densely placed special setting-out network will be constructed and connected to the basic setting-out network (primary network) made by the investor. The other activities include setting-out the direction of excavation, profile and navigation of the drilling rig by means of laser. Furthermore, the actual profile after excavation will be measured by means of cross sections and compared with the theoretical profile. The actual building construction will also be measured and compared with the project.

Estimated date of completion is May 2014, which means that all geodetic works are still in progress.

Keywords: Hydropower plant, tunnel, setting-out network, profile, drill rig, cross sections

KJENSVATN HYDROPOWER PLANT

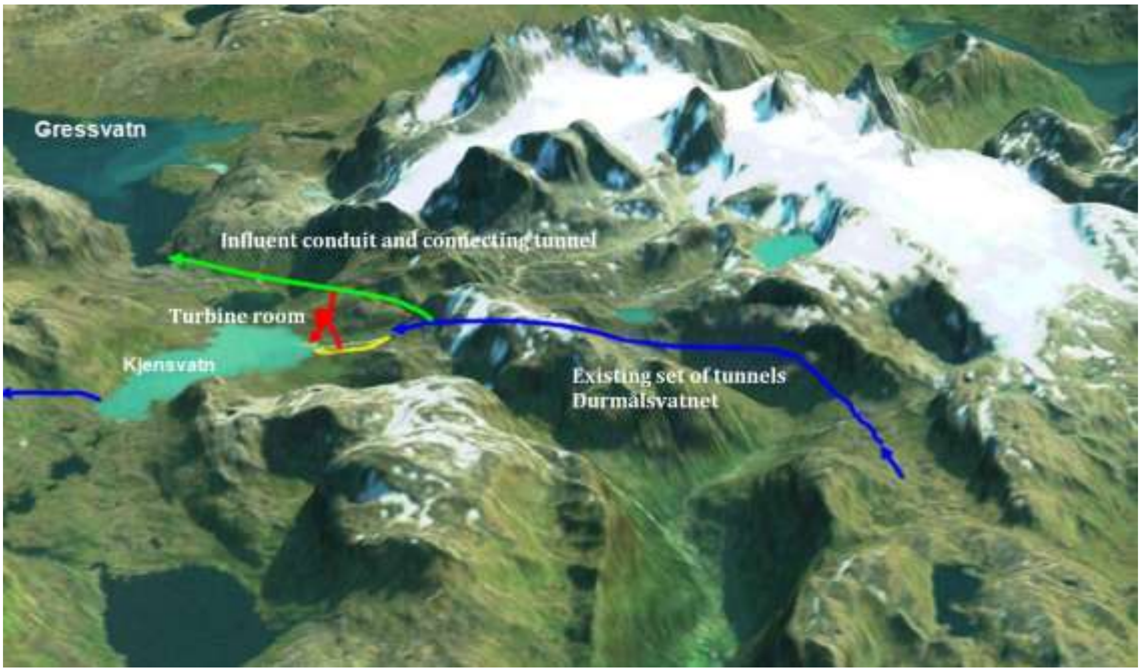
The Kjensvatn hydropower plant, which is currently under construction, is situated near the Hemnes municipality in the Nordland area of Norway. It is a part of modernization and expansion of the Rana, Durmålsvatnet network of hydropower plants; the newly constructed power plant will be connected to the existing set of tunnels between the Gresvatnet and Kjennsvatnet regulation reservoirs. The annual increase in production should amount to ca 80 GWh, which corresponds with power consumption of approximately 3750 households. All the energy will be generated solely from renewable resources [1].

The preparatory work commenced in the spring 2012 and the expected date of completion is May 2014. During the realization of the project the environment is taken into consideration so that the impact on the surrounding landscape and vegetation would remain as small as possible [1].

The whole set of tunnels is situated in a mountain massif (pic. 1) and is 7 km long. The individual parts of the power plant can be divided into:

- Regulation reservoir for water inflow (Gressvatn)

- Inflow tunnel (influent conduit)
- Power plant (turbine room)
- Outlet tunnel (drainage conduit)
- Connecting tunnel (between the newly constructed power plant and the original Durmålsvatnet powerplant)
- Two access tunnels (Tverrslag and A-tunel)

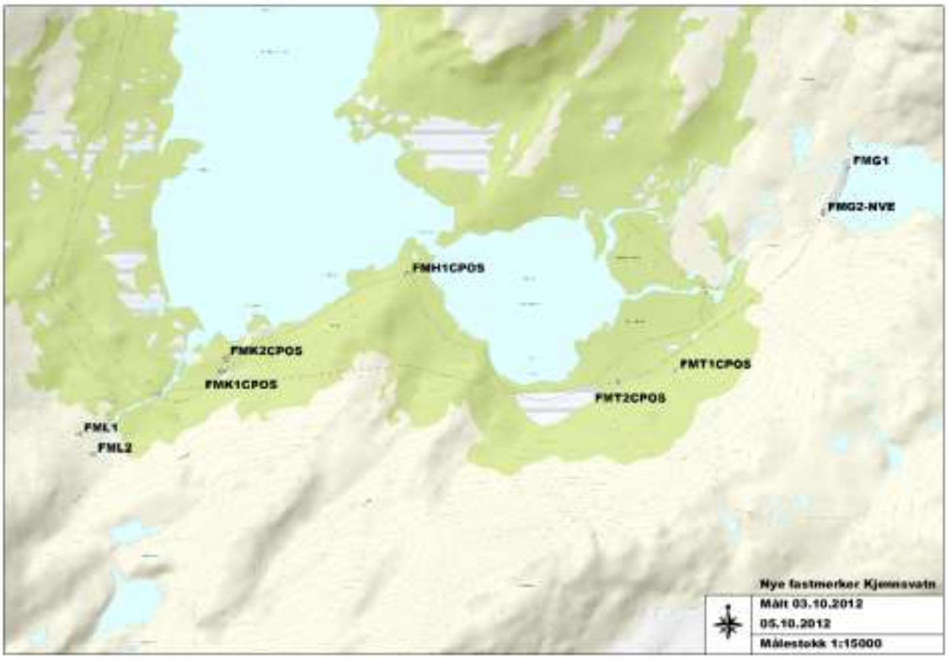


Pic. 1.: Picture of the newly constructed hydropower plant

BASIC SETTING-OUT NETWORK (PRIMARY NETWORK)

Before the initiation of all geodetic works the investor had built a basic setting-out network which consisted of 9 points (pic. 2) placed along the tunnel. The individual points were fitted by means of special bench marks placed in rock blocks (ashlars).

The network was surveyed by means of the GNSS system; the static method was used. Each point was surveyed twice and was checked subsequently. The resulting coordinates were transformed into the Universal Transverse Mercator Coordinate System (UTM), zone 33. The transformation was carried out by means of the 7-parameter Helmert Transformation. The Normal Null 1954 (NN1954) Vertical Datum was used.



Pic. 2.: Distribution of the points of the basic setting-out network along the course of the tunnel

- The mean coordinate error of all the points was defined as $m_{x,y} = 0,010$ m
- The mean error of height of all the points was defined as $m_h = 0,020$ m

With respect to the size of the underground construction (tunnels are being bored simultaneously on several sites using counter-headway), the investor ordered the points of the primary network to be regarded as exact; their inspection will be carried out on bi-monthly basis.

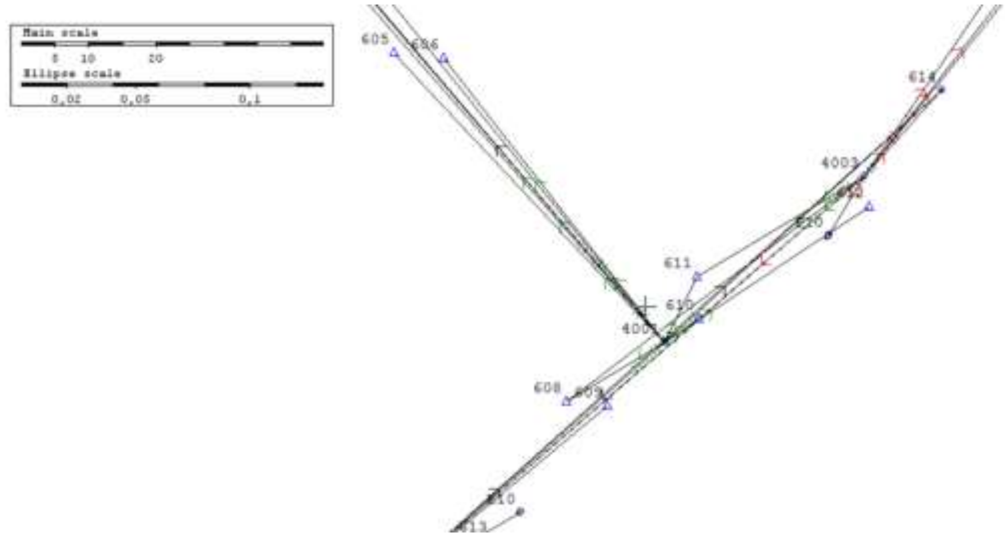
SETTING-OUT NETWORK

The setting-out network is connected to the basic setting-out network. The individual points are monumented in the walls of the tunnels by means of steel anchors or fittings for mounting the tripod with prism (NCC system).

The setting-out network was constructed by combining linear and planar networks. The points in the individual tunnels were first positioned by means of free traverse; on every station several orientations were surveyed and, subsequently, the individual polygonal traverses were connected into a linear network tied with the primary planar network. The points were positioned multiple times as new monumentations were occurring during the course of the construction [2].

To measure the polygonal traverses a set for the three tripod system, a set of surveying prisms Leica Mini and Leica Circ and a total station Leica TCR 1203+ were used. Adjustment of the coordinate net was carried out in the Geo Professional software by means of the least square method (pic. 3). In total 91 points were positioned and monumented.

Because the project is still under construction the breakthrough has not been carried out yet. Therefore the real deviation of the direction traverse to the drift and the deviation of stationing were not determined. During the adjustment of the network, the mean coordinate errors for the individual points (m_x, m_y, m_z) were calculated and the ellipses of errors were determined. The maximum values of mean errors can be found at the terminal points of the network and range between m_x, m_y = 4 to 6 mm and in height m_z = 2 to 3 mm.



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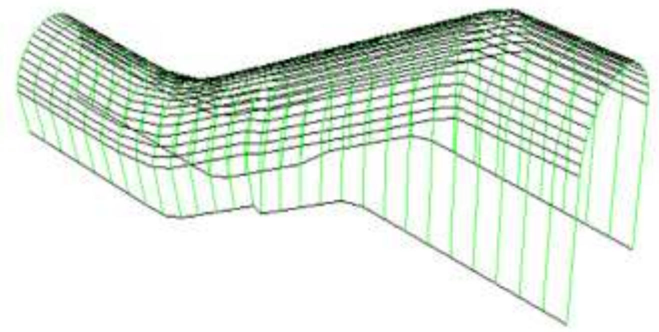
	Point	X Coord	Y Coord	sX	sY	sXY	a-axis	b-axis	Angle
1	4001	7 326 554,708	468 722,989	0,000	0,000	6,05e-8	0,000	0,000	55,8873
2	4003	7 326 579,317	468 752,457	0,001	0,001	7,49e-8	0,001	0,001	48,1772
3	5001	7 326 517,333	468 680,947	0,000	0,000	1,21e-8	0,000	0,000	91,2119
4	614	7 326 592,083	468 764,014	0,001	0,001	1,03e-7	0,001	0,001	41,8280
5	615	7 326 494,678	468 646,971	0,001	0,001	6,18e-7	0,002	0,001	65,9226
6	616	7 326 498,706	468 643,542	0,001	0,002	5,18e-7	0,002	0,001	74,1667
7	617	7 326 478,303	468 620,198	0,001	0,002	4,34e-7	0,002	0,001	70,0208
8	618	7 326 482,157	468 616,823	0,001	0,002	3,84e-7	0,002	0,001	74,9251
9	619	7 326 634,629	468 796,922	0,002	0,002	2,08e-7	0,002	0,002	29,7401
10	620	7 326 639,759	468 794,153	0,002	0,002	1,50e-7	0,002	0,002	21,2168
11	E10	7 326 529,504	468 701,623	0,001	0,001	7,77e-7	0,002	0,001	66,3088
12	E20	7 326 457,790	468 585,209	0,001	0,002	1,08e-7	0,002	0,001	85,5917
13	E21	7 326 457,794	468 585,210	0,001	0,002	1,08e-7	0,002	0,001	85,5907
14	F10	7 326 570,455	468 747,168	0,001	0,001	8,34e-7	0,002	0,001	36,1893
15	F20	7 326 669,145	468 821,958	0,002	0,002	-5,07e-7	0,002	0,002	153,6101
16									

Pic. 3.: Part of the setting-out network and adjustment of the coordinate net

SETTING-OUT OF THE DRIFT (DIRECTION OF BORING)

It represents a substantial part of the project. Before the first positioning, a mathematical model of the tunnel was constructed based on the project documentation [3]. The mathematical model was defined by the axis of the tunnel (both for the direction of boring and height) and by its shape (profile and position of the axis). The resulting model was transferred into the Geo Professional (pic. 4) and Microstation V8 software and served as the basis for setting-out and measurements.



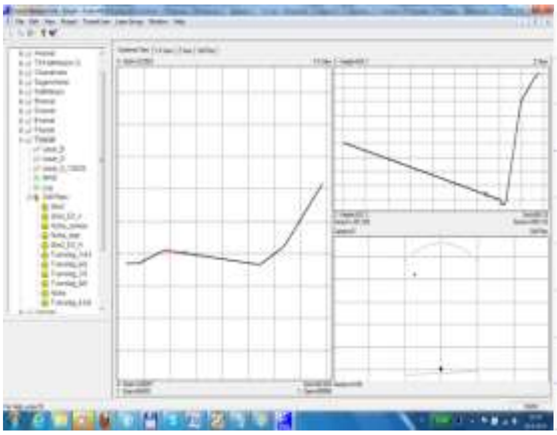
Pic. 4.: Example of the mathematical model of the tunnel – 3D model

During the setting-out, a theoretical profile was marked off (values of stationing, perpendicular and height) on the portal wall. The drill rig was subsequently navigated by means of theoretical laser which went through the axis of the tunnel and was vertically displaced by 1 meter (pic. 5). It consisted in setting-out of central crosslines, direction and left and right wall.

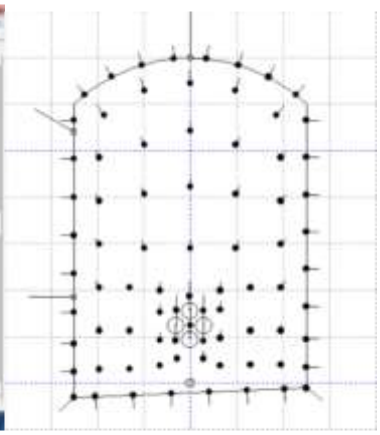
This method was employed during the boring of the beginning of each tunnel – ca first 30 m. Then the drill rig was navigated by means of laser. The laser was monumented in the walls of the tunnels so as to prevent any damage during blasting or operation of construction machinery. There are usually three points positioned on the laser beam: the initial point on the laser lens, the terminal point on the face and one intermediate point for verification.

Pic. 5.: Setting out of the theoretical laser for the navigation of the drill rig

The Atlas Copco – Tunnel Manager Lite software was used to design the drill plans and to import the individual tunnel lines and laser coordinates. The tunnel lines (pic. 6) were adopted from the mathematical model and from the project documentation. The drill plans (pic. 7) were elaborated on the basis of the geological survey and were consulted with the main blaster (explosives expert). The resulting data were imported into the drill rig. The operator alone can navigate the rig by using the linear laser and the known stationing.



Pic. 6.: Creating the tunnel line

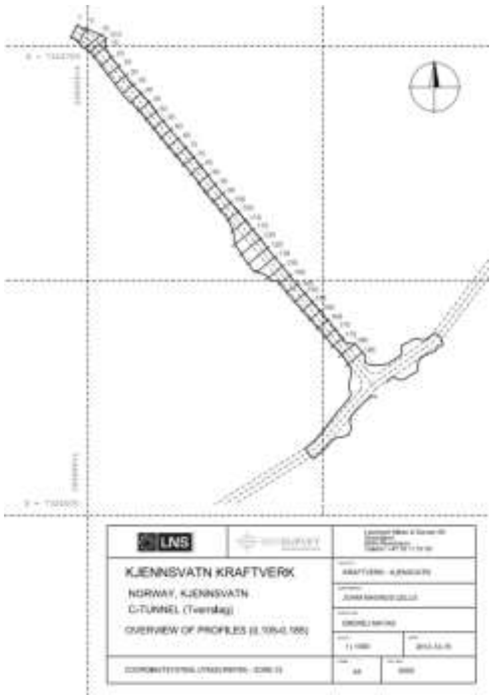


Pic. 7.: A sample of the drilling plan

The whole set of tunnels is being bored by means of the new Austrian method of full face tunnel boring (NATM). Subsequently, the excavation is secured by steel anchors (bolts) and by a layer of sprayed concrete so as to create a statically contributing rock arch around the excavation.

SURVEYING OF THE REALIZATION OF THE CONSTRUCTION

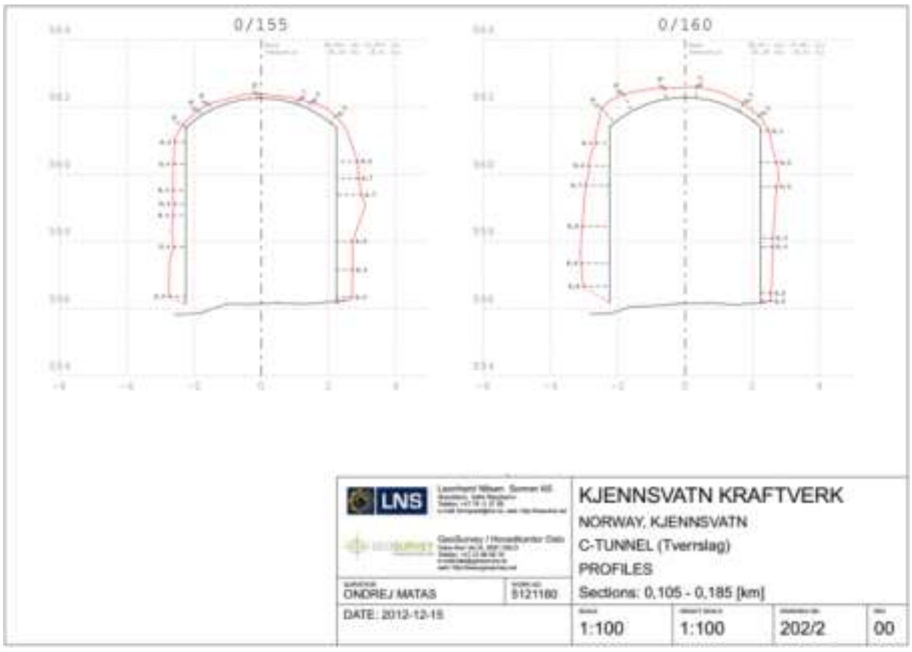
After mucking and securing of the underground construction the shape of the excavation is inspected. The initial basis was provided by the theoretical model of the tunnel where the measured values were compared including deviations from the project values. The surveying was carried out by means of cross sections in the plane normal to the pre-set course [4].



Pic. 8.: Overview of positioned profiles

After consulting the investor, the density of the profiles in the tunnel was set to every five meters (pic. 8). In places where the requirements concerning the real course of the tunnel were higher the density of profiles was increased to one a meter. The output consists of the individual profiles for the given stationing and of a survey of profiles with marked advance of heading (pic. 9). These results also serve to calculate cubic capacity and areas and as the basis for minor adjustments of the profile (in case it is necessary).

All the parts of the tunnel are inspected this way. The transformer station which required greater accuracy (it concerned mainly the inspection of sub-excavation) was surveyed by means of laser scanning using the grid of 5x5 cm. The scanned point cloud was adjusted and cleaned.



Pic. 9.: Example of the individual profiles

The output consisted of a 3D model of the transformer station and a scanned developed surface of the transformer station. The deviations from the project values were marked by colours. Elaboration of cross sections was also a part of the documentation.

CONCLUSION

The role of a geodesist and geodetic works are an integral part of the whole project. They include a wide range of activities from creating a high-quality geodetic control, setting-out of portal gates, setting-out and inspection of profiles, navigation of the drill rig to the positioning of the actual realization of the excavation and elaboration of the project documentation.

In consideration of the level of sophistication of this construction a high degree of accuracy was required. It was achieved through continuous analyses of the interconnected individual operations. An extreme attention was given also to the verification of the project documentation which consisted in its conversion into a 3D system and in elaboration of all the outputs [3].

All the outputs concerning the actual realization of the underground construction are placed on file and given to the investor for the subsequent approval of construction work.