ESTABLISHMENT OF KURICHHU HYDROPOWER DAM DEFORMATION MONITORING BASIS USING GLOBAL POSITIONING SYSTEM

Ugyen Thinley
Sr. Survey Engineer, Kheychok GeoInfosys, Post Box: 662, Olakha, Thimphu, Bhutan; Tel: +975 17916468 and +975 77371659; Email: ugeh_t@hotmail.com

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ABSTRACT: Dams are very large and critical structures and demands an application of precise monitoring surveying at regular intervals, which requires timely detection of any behavior that could deteriorate the dam structure. Kurichhu dam has suffered from cracks and displacements due to the tremors from the successive earthquakes in 2009 and the impact from 2004 Tshatichhu floods. This exercise was first of its kind carried in Bhutan initiated by the government eventhough hydro projects are the first and highest revenue producer of the country.
The main purpose was to establish the basic data using space-based GPS technology, which can serve as basis for the future monitoring studies. The GPS derived information will help to assess the amount of deformations for further change analysis both horizontally and as well as vertically and predict the trend in long run.
Dual frequency Leica GPS (Global Positioning System) device with static observation technique was deployed for positioning and heighting. Three dimensional coordinates of the points were defined accurately using the dual frequency geodetic GPS technique.
Four reference points were established surrounding the dam area on stable ground and connected to the existing zero order station and high precision leveling benchmark. The 28 object/deformation points were established on the dam embankment consisting of various blocks that are suppose to undergo deformations. The accuracy of network adjustment for the reference stations varied between millimeter to 2 centimeter level for absolute observation residuals and about 3 cm for heights respectively. However, for the deformation points, the standard deviation values were generally in millimeter level.
Recommendations and proposals to integrate the other inputs like digital or precision leveling and the re-observation strategies in future were also mentioned.

1.0 BACKGROUND

The Kurichhu Hydropower Plant officials have requested to conduct a survey to establish a base line for monitoring of deformations in the Dam structure. Discussions were thus held to assess the needs and to conduct such a high precision requirement task.

It was decided that that GPS could be used to establish the base line to monitor deformations in the horizontal plane and leave the height factor to be carried out in future.

2.0 IMPORTANCE OF DEFORMATION MONITORING

Monitoring of engineering structures has become importance particularly after the possibility of destructive natural catastrophes has increased (Azar. R.S. and Shafri, H.Z.M., 2009). For the hydroelectric projects, the mission of the water structures is controlling of water and producing energy. Due to increasing energy requirement, higher dams are built where, this situation have also brought great risks to public safety living near and downstream to the dam in case of natural hazards. Therefore, in order to provide safety, well planned geodetic monitoring is very essential for such engineering structures.
Deformation measurements have an important status among various engineering surveying. Results of deformations directly concern with the human life and safety (Kalkan *et al*, 2010). Deformations can exist both on dam and near area. Structure of dam, weight of dam and reservoir, water pressure, temperature change, crustal movements and natural hazards are the reasons of deformations. These factors can cause geometric changes by the way of horizontal and vertical small structural displacements and physical changes. These geometric and physical changes have to be monitored and defined whether significant or not. Thus, safety, efficiency and life of the structure can be increased.

In addition, geodetic method is the only way often used for monitoring the deformations as it can detect the small structural changes. Shown in the figure is the Kurichhu dam in eastern Bhutan.

Figure 1: 60 MW Kurichhu dam in Eastern Bhutan.

3.0 OBJECTIVES

The main purpose for carrying out the GPS surveying is to establish and determine the basic deformation data, which can serve as basis for the future monitoring studies of dam structures. Therefore, the present GPS observations will help to set the base line for future comparison and analysis of deformations both horizontally and as well as vertically and predict the trend in long run. The objectives can be specifically written as:

3.1 To monitor the displacement of the dam structure relative to the reference stations established near the dam.
3.2 To detect the changes amongst the deformation points in the different blocks of the dam.

5.0 GPS RESOURCES AND SURVEYING METHODOLOGY

Global Positioning System (GPS) technology is used many engineering applications efficiently today (Kalkan *et al*, 2010). It can be used for measuring the surface deformations associated with earthquakes, steady flow of huge masses of ice, in weather forecasting, measuring the slow and rapid deformations of the Earth's crust. GPS provides a valuable tool for monitoring geospatial deformations, and thereby aids in understanding the complex structural and tectonic mechanisms related to the interaction of the water reservoir and the body of the dam (Gikas *et al.*, 2005).
The Leica receiver system 1200 and Leica antenna AX1202 GG tripod have been used for data capture in the field. The simultaneous static GPS observation with the carrier phase measurement, which is the most accurate positioning technique, was used (Thinley, 2009). The reason accredited to change in satellite geometry and observation over long time will increase the number of common satellites whereby the precision will improve too. Dual frequency receivers with application of precise ephemeris that yielded good results were used. The campaign involved simultaneous static GPS observation with six GPS sets, which occupied six separate stations for 5 days consisting of sessions varying from 2 hours for deformation points to more than 4 to 10 hours for reference stations. The logging interval of 1 second and elevation mask of 10° throughout the campaign was maintained. In order to get precise antenna heights, measurements were performed carefully up to third decimal places.

5.1 Reference Stations

Deformation networks include reference points and deformation points usually. Reference points were established on the areas, which expected no deformation whereas deformation points were established on dam embankment and surroundings undergoing deformation or where deformation is expected relative to the reference points. Four reference stations were established on the surrounding area of the dam and connected to the Zero order station (Jivall, 2004). in Aerong, which is on Bhutanese datum, DRUKREF 03. In addition, the reference stations were connected to the existing leveling Type-B benchmark (1988) of Yadi for the height control.

5.2 Deformation Points

Deformation network with 28 GPS points, embedded with bolted iron pegs on the dam top of different blocks were designed for monitoring dam deformations later in future. Figure 2 indicates the detail view of the locations of the reference stations with deformation points on the dam embankment of Kurichhu hydropower project. These reference stations were established on a stable location where the team felt that there would be no interference from developmental activities and other disturbances. The construction of reference stations have been already done by project authorities.

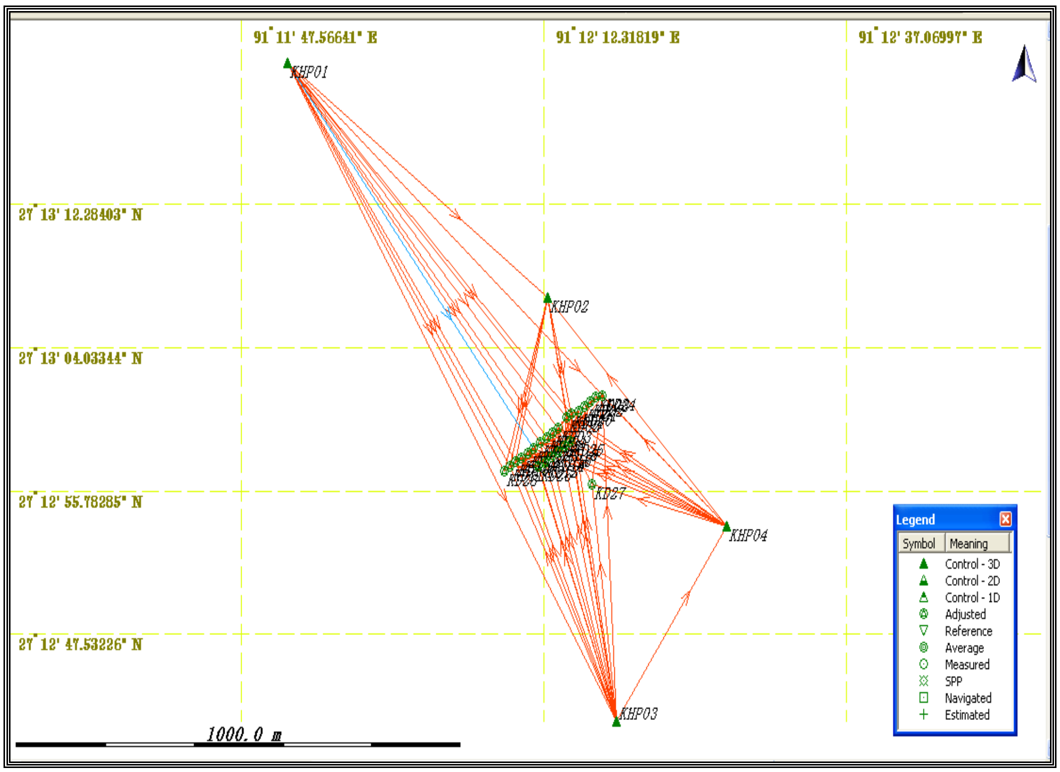

Figure 2: Four reference stations established nearby Kurichhu dam.

Figure 3 indicates the enlarged view of the locations of deformation points on various blocks of the dam embankment. These are the points, which can help assess the deformation of the whole dam structure due to various factors and as well as to further assess the deformation even within these points of different blocks.

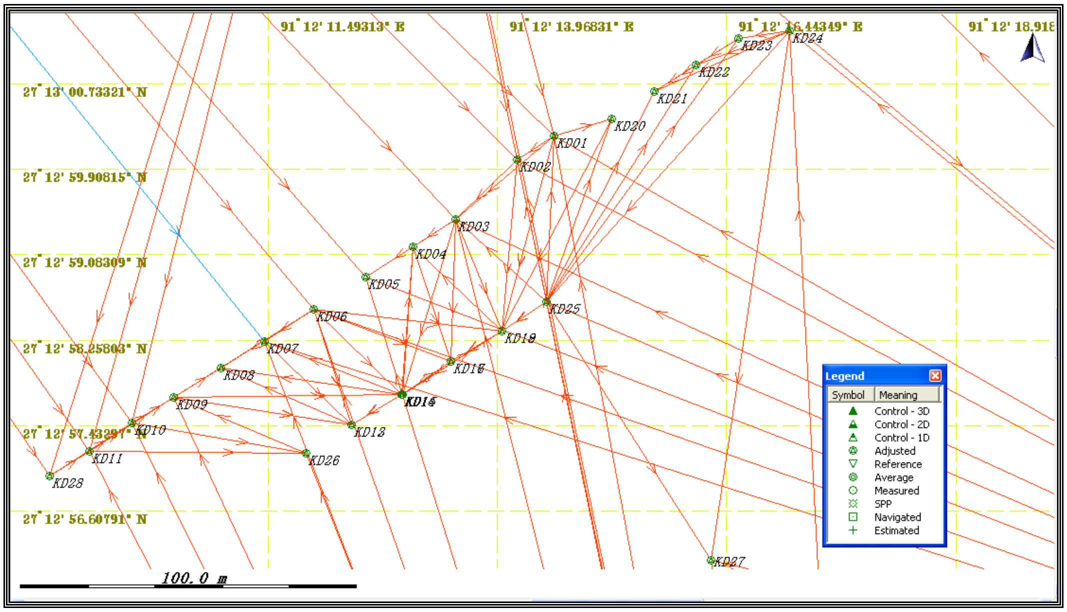

Figure 3: 28 deformation points established on the dam embankment.

6.0 POST PROCESSING

The field GPS raw data that was stored in CF card was downloaded using the card reader into a computer. The post processing has been carried using Leica Geo Office Combined ver.7.0. The precise ephemeris data published in the net after every 10 to 13 days after observation were downloaded from www.ngs.noaa.gov/orbits/ in sp3 format and applied.

7.0 ACCURACY OF REFERENCE AND OBJECT POINTS

The accuracy of network adjustment results for the reference stations varied between millimeter to about 2 centimeter level absolute observations' residuals and about 3 cm for heights respectively. However for the adjustment results of the local coordinates of the deformation points of the dam embankment, the standard deviation of absolute observations and baseline vector residuals were generally in millimeter level accurate. The coordinates are as shown in Table 1.

Table 1: Coordinates of the control, reference and deformation points.

Control/Reference/ Deformation points	**Coordinate Systems National grid**		**Height**		**Geoidal Separation**
Control stations:	**Northing**	**Easting**	**HAE**	**MSL**	**N**
AERONG	2977577.531	399348.588	1299.911	1344.690	-44.778
KD2 (Tongla)	3004576.650	373590.696	898.860	940.415	-41.555
YADI_BM	3020081.640	385904.592	1458.083	1497.743	-39.660
Reference stations:					
KHP01	3012834.387	368639.433	541.977	582.579	-40.603
KHP02	3012423.382	369226.917	495.705	536.343	-40.638
KHP03	3011675.106	369389.162	520.739	561.458	-40.719
KHP04	3012023.302	369634.278	638.826	679.503	-40.677
Deformation points:					

KD01	3012218.327	369283.011	494.611	535.272	-40.660
KD02	3012211.253	369272.095	494.625	535.286	-40.661
KD03	3012193.352	369254.200	494.621	535.284	-40.663
KD04	3012185.130	369241.540	494.613	535.277	-40.664
KD05	3012175.992	369227.436	494.620	535.286	-40.666
KD06	3012166.185	369212.312	494.615	535.282	-40.667
KD07	3012156.643	369197.576	494.617	535.285	-40.668
KD08	3012148.450	369184.942	494.623	535.292	-40.669
KD09	3012139.862	369170.971	494.849	535.520	-40.670
KD10	3012131.925	369158.676	494.861	535.532	-40.672
KD11	3012123.481	369145.857	494.873	535.545	-40.673
KD12	3012132.058	369223.637	484.186	524.856	-40.671
KD13	3012132.159	369223.802	484.184	524.854	-40.671
KD14	3012141.227	369238.580	484.224	524.894	-40.669
KD15	3012141.345	369238.755	484.223	524.892	-40.669
KD16	3012151.092	369252.976	484.232	524.900	-40.668
KD17	3012151.204	369253.143	484.230	524.898	-40.668
KD18	3012160.224	369268.051	484.294	524.961	-40.667
KD19	3012160.323	369268.218	484.292	524.959	-40.667
KD20	3012223.512	369300.106	494.868	535.527	-40.659
KD21	3012231.767	369312.813	494.862	535.521	-40.658
KD22	3012239.727	369325.143	494.866	535.524	-40.657
KD23	3012247.871	369337.697	494.866	535.522	-40.656
KD24	3012250.190	369352.627	494.883	535.539	-40.656
KD25	3012169.295	369281.185	484.270	524.935	-40.666
KD26	3012123.586	369210.475	484.298	524.970	-40.672
KD27	3012093.012	369330.996	479.027	519.700	-40.673
KD28	3012115.990	369134.159	494.870	535.543	-40.674

8.0 DISCUSSIONS AND RECOMMENDATIONS

For obtaining more accurate height information for these reference and deformation points, digital or precision leveling is recommended to be done in future. It is recommended that the use of only dual frequency geodetic instruments can be of help while assessing results requiring sub-centimeter level accuracy. Now with availability of GNSS, it is highly recommended to carry out the observation with integration of GPS and GLONAS satellites, which would definitely increase the accuracy. Also, it is to be noted that there are so many machines and equipment available in market particularly designed for monitoring deformations. In future, it is recommended to have a good session planning before the real observation as to avoid duplications of baselines actually required for the computation. For the deformation points and reference stations, a minimum of 2 hours and 4 hours observations are required respectively for achieving good results. However, the observation strategy would be to start the observations of deformation points from at least 2 of the known reference stations and closed from the other known reference stations. The reference points and deformation points should be protected and preserved to ensure that they are not lost.

The dam deformation surveys can be performed on a periodic basis (which can be half yearly, annual basis, etc) and during emergency times as required. Thereby, a trend of deformation can be assessed and prediction too can be made in long run using the time-series data.
It is also highly recommeneded that such initiatives are to be continued by the concerned authorities like DGPC (Druk Green Power Coporation) in Bhutan as there are so many existing and as well as ongoing power projects.

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