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Comparison between the tectonic movements of Nanga Parbat-Haramosh Massif and Mt. Everest

***Giorgio Poretti[1], Chiara Calligaris[2], Shahina Tariq[3], and Hawas Khan[4]**

[1]*University of Trieste, DMI, Italy*

[2]*University of Trieste, DiGEO, Italy*

[3]*COMSATS University, Pakistan*

[4]*Karakorum International University (KIU), Gilgit–DES*

*(*Email:calligar@units.it)*

ABSTRACT

The initial results obtained by an international research project named 'Monitoring of the horizontal movements of the Nanga Parbat Haramosh Massif', funded by the Italian Ministries of Culture and Foreign Affairs through the Ev-K2-CNR Committee, concerning the Karakoram – Himalaya mountain ranges in the north eastern part of Pakistan. The purpose of the study is to determine the horizontal shift of the Nanga Parbat Massif and to compare it with the results obtained from a permanent GNSS station located at the Ev-K2-CNR Pyramid laboratory near the Mount Everest Base Camp. The determination of plates and arcs movements through surface GNSS systems could be a solid contribution to the structural geologists to confirm or deny some theories on the tectonic movements of the Himalayan mountain ranges. The project started in April 2009 and to obtain reliable quantitative results it should go on for at least 10 years. To arrive at the first measure, the project, in its starting phase, went into three different steps: (1) the choice of the measuring points; (2) the monumenting of the benchmarks; and (3) the first measure in November 2009.

At the present time a first measure has been realized on solid monuments net; in the following years results will be available for future researches.

Keywords: Nanga Parbat Haramosh Massif, GNSS net, Mt. Everest

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INTRODUCTION

If Himalayas are a land of extremes from the topographical, geophysical and geological point of view (Windley 1986), the Karakorum (Fig. 1) is a land of superlatives, having the highest concentration of mountains over 8000 meters, having the longest glaciers other than those at the poles, being the source of one of the longest rivers.

From the geophysical point of view it contains the largest gravity anomalies (Poretti 1998) and thickness of the earth's crust (75 km) (Finetti et al. 1978, 1983) and the highest values of deflection of the vertical.

It contains also the highest relief (7000 meters from the Indus Plains to the summit of Nanga Parbat). It seems also that this area is subject to the highest uplift and to a horizontal shift of the Indian Plate of about 5 cm/y to the north (Windley 1986). This has been mentioned by many authors who have derived the values through indirect methods, but they have not yet been confirmed by accurate direct observations. Lewis Owen reports 0.7 mm/y using fission-track methods (Owen 1989). Other values (2 mm/y) are inferred by several researchers (Zeitler 1985; Seeber et al. 2005; Lyon-Caen et al. 1983). An average value of 6-10 mm/yr was the hypothesis of Zeitler et al. (1985) including uplift and erosion.

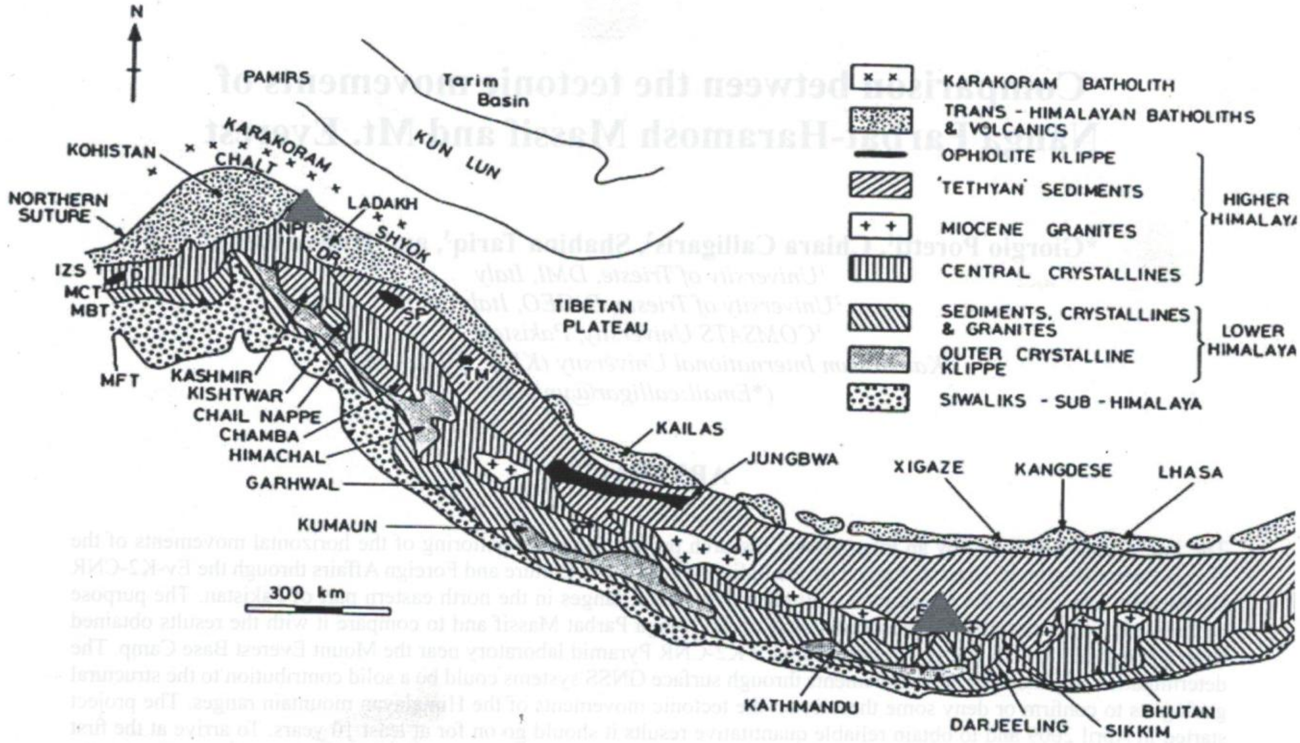

Fig. 1: The Himalayan orogenic belt: red triangles indicate the studied areas (Nanga Parbat Haramosh Massif and Mount Everest) and their approximate location (map from Windley 1986).

The present paper describes the criteria adopted in the selection of the benchmarks for the installation of a GNSS network including two permanent GNSS stations, between Islamabad and Gilgit in the northern areas of Pakistan. Two points were located on the Nanga Parbat – Haramosh Massif.

A permanent GPS station is present near the Ev-K2-CNR Pyramid Laboratory at Lobuche in the Khumbu region, in Nepal, since 1994. This station is providing long records of data during the last 15 years.

The target of the project is to compare data obtained from Everest with the ones from Nanga Parbat in order to evaluate the direction of the movement of the two massifs and, in the long term, their uplift rate.

An eventual difference in the amplitude and direction can suggest a rotation in the movement of the Indian continent that might have also seismological implications.

TECTONIC SETTING AND REGIONAL GEOLOGY

The Nanga Parbat area

The Nanga Parbat-Haramosh syntaxis is one the most striking geological features in North Pakistan. The Himalayan collision system at present day configuration is limited by two major suture zones, the Indus Suture Zone (ISZ) and the Northern Suture in the south and north, respectively (Tahirkheli et al. 1982; Coward et al. 1985; Coward et al. 1987; Coward et al. 1988). This collisional tectonics and mountain-building activity is the result of continent-arc-continent collision. The Kohistan Island Arc is sutured to the Karakoram Block (Shyok Suture) in the north along the MKT (Main Karakoram Thrust) and to the Indian Plate along the Main Mantle Thrust (MMT) in the south (Tahirkheli et al. 1982). The tectonics of Kohistan is related to the collisional tectonics of the Hindu Kush, Karakoram and Himalayan ranges which involve the Indian Plate with the Nanga Parbat-Haramosh Massif, the Karakoram Block and, sandwiched in between, the Kohistan Arc (Bendick et al. 2001) (Fig. 2).

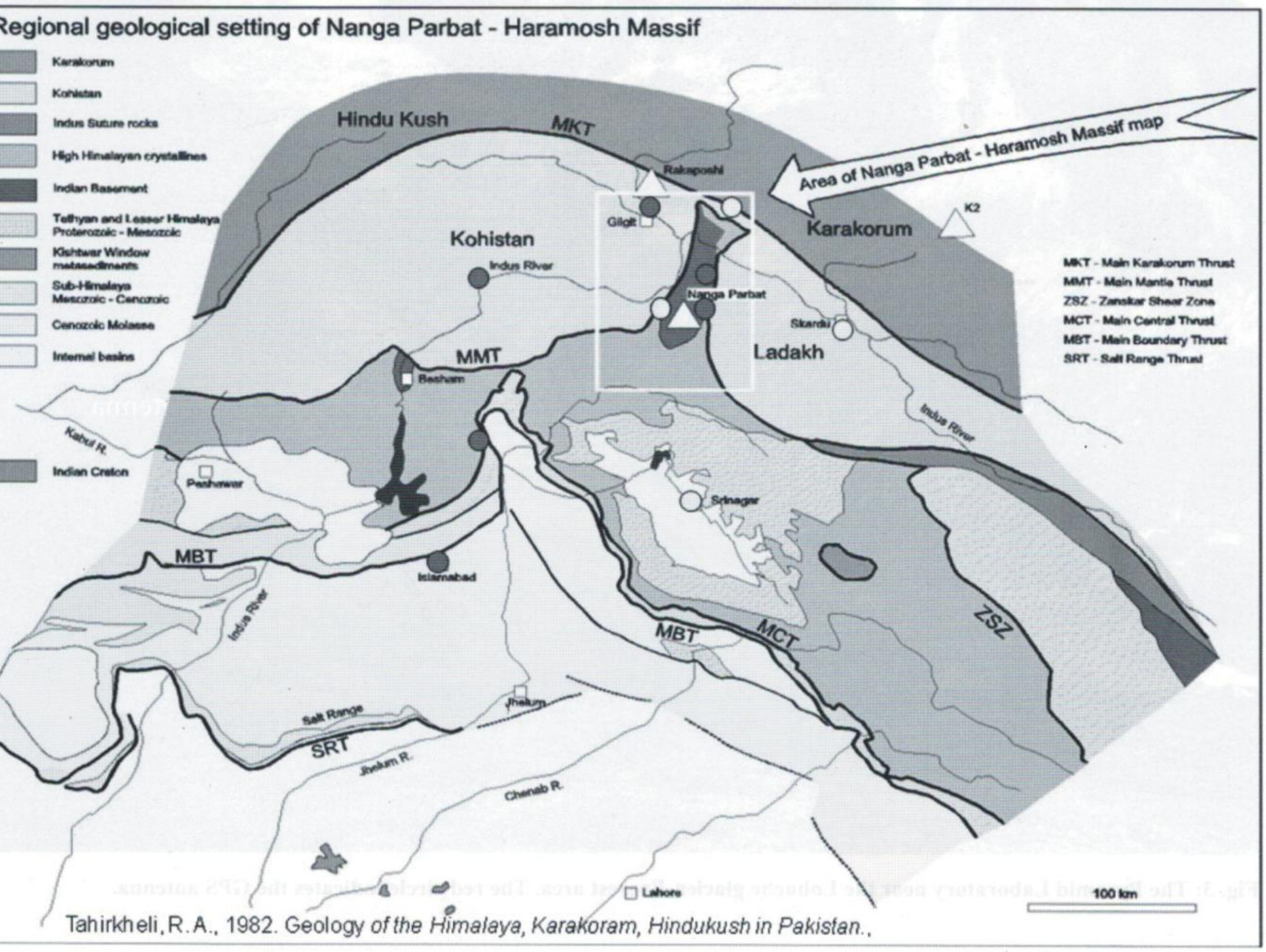

Fig. 2: Regional geological setting of Nanga Parbat. Red circles are the established stations; yellow circles the proposed ones (Tahirkheli 1982).

The Everest area

Mount Everest (Fig. 3) plays an important role in understanding how the Himalayas evolved.

In the last 55 Ma, India has been driven northward subducting beneath Eurasia (Rowley 1996). In this way rocks of the passive margin in northern India have been progressively thrust southwards towards the Indian Plate producing a regional metamorphism, deformation and crustal melting, complicating the geology of the area.

In old papers (Heim and Gansser 1939; Gansser 1964) the Himalayas have been divided into four tectonostratigraphic zones: Tibetan Himalaya, Greater Himalaya, Lesser Himalaya and Sub Himalaya.

Mount Everest is located at the top of the Greater Himalayan Slab; a 5-20 km thick assemblage of late Proterozoic to early Palaeozoic metasediments and metaigneous rocks bound to the south by the Main Central Thrust, and to the north by the South Tibetan Detachment (Schelling 1992; Vannay and Hodges 1996).

Fig. 3: The Pyramid Laboratory near the Lobuche glacier, Everest area. The red circle indicates the GPS antenna.

GNSS MONITORING STATIONS

The Nanga Parbat project started with the selection, monumentation and surveying of 11 benchmarks to be measured with GPS instruments (Poretti et al. 2009). The locations of the benchmarks have been decided according to the tectonic lineaments of the area. Their monumentation has been performed on concrete pillars on bedrock (when possible) in order to guarantee the repetition of the subsequent measurements in the same conditions in future years (Figs. 4 and 5).

The points for the permanent stations have been located in Islamabad (BAH0), south of the Main Boundary Thrust and in Gilgit (KIU), between the Main Mantle Thrust (Indus Zangbo Suture) and the Main Karakorum Thrust. The permanent GNSS stations were equipped with Leica GNSS 1200+ receivers with Internet connections that allow the stations to be monitored also from Italy (since November 2010). Two points were chosen on the Nanga Parbat massif and one in Muzaffarabad (AJKU) along the Main Boundary Thrust, close to the epicentre of the October 2005 earthquake.

Six benchmarks were monumented along the Indus River in the area of the construction of the Basha Dam (Fig. 5).

The operational phase of the project started in April 2009 and was carried out in Pakistan with three different expeditions by Italian researchers in the months of May, August and November 2009.

All the proposed targets were reached with the involvement of the local researchers in the project: the study of the area and the selection of the most suitable points for monitoring. The project was presented to the WAPDA (Water and Power Development Authority), the company in charge of the building of the Diamer Basha dam (Fig, 5).

By the end of 2009 the 11 benchmarks were monumented and measured for the first time.

Fifteen years of observations (unfortunately not continuous) are available for the Mt. Everest area, with a permanent GPS station at the Ev-K2-CNR Pyramid Laboratory (Poretti 2008). These data allow the determination of the direction of the tectonic movement of Mt. Everest.

Fig. 4: Pillar and antennas at Bahria University (Islamabad) and at Karakorum International University - KIU (Gilgit)

DATA PROCESSING AND FIRST RESULTS

Nanga Parbat-Haramosh Massif results

A very important phase of the project is certainly represented by the processing of the data, which should provide results that can be compared with those that will be obtained during future surveys, ensuring a fair repeatability.

The first step was the link of the permanent stations to the nearest IGNSS (International GPS Network). This has been possible for the long series of data obtained from the permanent stations BAH0 and KIU. The permanent IGNSS stations were in Polygan (POL2), Chumish (CHUM) and Kitab (KIT3). The rather long distances (more than 700 Km) that do not allow the ambiguities to be solved, can be compensated by the length of the simultaneous recordings (about two months for the first processing). The calculated coordinates are presented in Tables 1a and 1b.

The coordinates of Islamabad (BU) and Gilgit (KIU) linked to the Polygan IGS (POL2) and Chumish stations following 215 hrs of recording (17-26 Novembrer 2009) resulted to be (Table 1a). A much longer session (1383 hours from the 11th of August to the 25th October 2010) was recorded by the receivers of the permanent stations, giving the following results (Table 1b).

Table 1a: The WGS84 Coordinates of the Permanent GNSS Stations recorded (2009)

Point no.	Location	Latitude	Longitude	Ellipsoidal Height
1	Islamabad (BU)	35° 42' 54.10195" N	73° 01'.42.10047" E	521.358
3	Gilgit (KIU)	35° 55' 29.1135" N	74° 22' 01.7676" E	1444.666

Table 1b: The WGS84 Coordinates of the Permanent GNSS Stations recorded (2010)

Point no.	Location	Latitude	Longitude	Ellipsoidal Height
1	Islamabad (BU)	35° 42' 54.111295" N	73° 01' 42.1277" E	520.513
3	Gilgit (KIU)	35° 55' 29.1039" N	74° 22' 01.7680" E	1444.614

The second step of the processing was the computation of the coordinates of the points in Harchu and Rama with reference to the permanent station of Gilgit. The distance of the stations was of about 65 km but the length of the recordings performed in November 2009 was sufficient for the resolution of the ambiguities (Table 2).

calculation of the shift of the point that was computed t o be of 5.1 cm/year but the movement direction to the North-East presents an azimuth of approximately 38° slightly smaller than the one previously calculated (Poretti et al. 2006).

Table 2: The WGS84 coordinates of the Nanga Parbat Benchmarks

Point no.	Location	Latitude	Longitude	Ellipsoidal Height
3	Gilgit (KIU)	35° 55' 29.1853" N	74° 22' 01.7933" E	1444.666
4	Hospital of Harchu (Gilgit Baltistan)	35° 26' 59.1838" N	74° 47' 40.0972" E	2066.480
5	Rama Bungalow – Astor (Baltistan)	35° 21' 25.4359" N	74° 48' 35.2953" E	3137.731
6	Basha Dam VI	35° 31' 39.5109" N	73° 43' 55.9044" E	1042.201
2	Muzaffarabad (AJKU)	34° 23' 03.3383" N	73° 28' 08.0119" E	667.596

This was not possible for the station of Muzaffarabad for which longer recordings are planned.

The Mt. Everest Pyramid Laboratory

Fifteen years of observations with a permanent GPS station at the Ev-K2-CNR Pyramid Laboratory (Fig. 3) allow the determination of the direction of the tectonic movement of the Mt. Everest area. Taking into account several time intervals linking the Pyramid Laboratory to the permanent GNSS station in Lhasa, the coordinates of Point G can be followed in Table 4.

The coordinates of point G were measured in 1992 with reference to the point III7 of the Chinese triangulation network of the National Bureau of Surveying and Mapping. From 2003 to 2007 the reference point was the IGS station in Lhasa. The Rinex data and the precise ephemeris were downloaded from the IGNSS website.

Several time intervals linking the Pyramid Laboratory to the permanent Lhasa station in Lhasa permitted the

More precise values can be expected from a new calculation taking into account the daily and weekly averages of the recorded data. The constant flow of data from the permanent GPS stations in Gilgit and Islamabad will allow in the future calculating also the amount and direction of their movement.

The topographic network in the Diamer Basha Dam area

On the western side of the NPHM a site of particular interest is located: the Basha dam site where the Pakistani government is planning to construct an electric power plant with a large concrete dam on the Indus River. During the research on the monitoring of the Nanga Parbat massif, six points were monumented, three on each side of the Indus River (Table 3, Fig. 5).

A topographic survey was performed among these benchmarks (Fig. 6) measuring the distances from each point to those on the opposite bank with a total station Leica GRX30. The results are presented in Table 5 and reflect the scheme reported in Fig. 5 with the averages of the

Table 3: The WGS84 Coordinates of the Basha Dam Topographic Network Points obtained through GPS measurements.

Point no.	Location	Latitude	Longitude	Ellipsoidal Height
6	Basha Dam VI	35° 31' 39.5648" N	73° 43' 55.9212" E	1035.0046
7	Basha Dam VII	35° 31' 26.1513" N	73° 44' 06.5654" E	1046.9131
8	Basha Dam VIII	35° 31' 04.3448" N	73° 44' 16.0915" E	1037.0538
9	Basha Dam IX	35° 31' 55.9420" N	73° 44' 08.7840" E	1056.6011
10	Basha Dam X	35° 31' 45.6925" N	73° 44' 18.0360" E	1035.254
11	Basha Dam XI	35° 31' 28.9258" N	73° 44' 31.7999" E	1075.1151

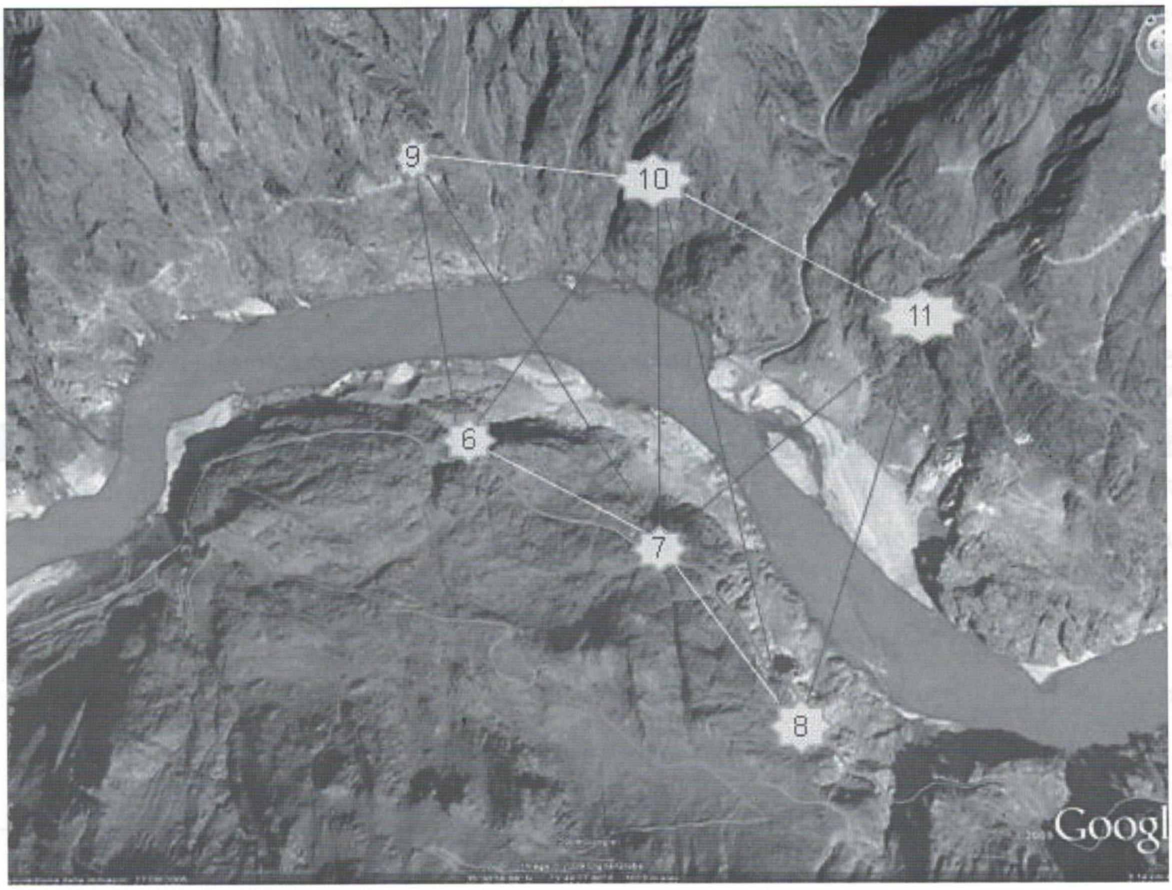

Fig. 5: The surveying network around the Basha dam location

measurements performed in both directions. The standard deviations (in average lower than 5 mm) of the distances show the global accuracy of the measurement and therefore can be repeated. The distances between the points were calculated also from the GPS data.

Analysis of the surveyed data at the dam site

The topographic measurements performed with the total stations required, and will require in future, more attention in the determination of the instrumental heights of the target and of the distance meter (Table 5). These were determined as 8.5 cm for the target and as 25.5 cm for the center of emission of the laser of the distance meter. In the determination of the distances of the different points of the local network a reduction depending on the relative elevation was computed which resulted in a sub millimeter value. Also the temperatures and barometric pressures at the benchmarks were taken into account, but their contribution proved to be negligible since the points did not have large elevation differences.

The distances between the points on the two banks have also been computed with the coordinates provided by the GPS receivers located on the benchmarks. The values obtained in this way differ from those acquired by the distance-meter because of the diferent accuracy of the GPS with respect to it.

Fig. 6: Surveying the Basha dam network; on the background a large old rotational landslide

These results reflect the scheme reported in Fig. 5 with the averages of the measurements performed in both direction. The standard deviations (in average lower than 5 mm) of the distances show the global accuracy of the measurement and therefore can be repeated. The distances between the points were calculated also from the GPS data (Table 3). The

Table 4: Coordinates of Point G at the Everest Pyramid Laboratory

Point G	Recording time	Latitude	Longitude	Elevation
September 1992	12 hours	27° 57' 33.25863" N	86° 48' 47.11253" E	4992.713
June 2003	10 days	27° 57' 33.2684" N	86° 48' 47.12047" E	4993.295
May 2004	95 hours	27° 57' 33.27333" N	86° 48' 47.12309" E	4992.750
January 2006	45 hours	27° 57' 33.27742" N	86° 48' 47.12708" E	4993.419

Table 5: Angles and distances between the 6 benchmarks of the network installed on the banks of the Indus River (Diamer Basha dam area)

Line	Hz	V	D	SQM
(6-7)	132°55'5.6"	88°48'9.7"	490.997	0.0039
(6-9)	18°38'07.5"	88°05'35.7"	599.830	0.0046
(6-10)	57°05'04.2"	90°03'50.9"	588.684	0.0011
(7-10)	323°49'56.5"	90°56'04.2"	668.007	0.0039
(7-8)	98°29'18.5"	91°03'08.3"	714.230	0.0028
(7-11)	20°34'41.3"	87°41'41.5"	642.627	0.0000
(8-10)	112°32'56.3"	89°53'29.1"	1275.478	0.0007

coincidence is not very close, mostly because of the error in elevation of the satellite measurements that need longer surveying sessions.

For temporary stations of Hartchu and Rama an average recording time of 5/6 hours has been adopted.

For the points located at the Basha dam site, a recording time of 45/60 minutes was used. At an average distance of 700 metres, it was not necessary to extend the recording time for longer intervals since their purpose was only to give them a proper location and to verify the distances determined with the total station across the Indus River.

An initial processing of the GPS data was carried out with the Leica Geo Office program shortly after the return to Italy at the end of the surveying campaign, for the validation of the recorded data. They were repeated afterwards with the precise Ephemerides tables downloaded from the web site of IGS (International GPS Survey).

Table 1a and 1b display the coordinates of the benchmarks obtained from the data recorded in November 2009 and in October 2010 by the permanent GNSS stations.

The results of the observations made at the dam site, if repeated in the future, will be of great importance to the local authorities involved in the construction of the dam.

CONCLUSIONS

The aim of the project is to evaluate the variation in direction of the Nanga Parbat massif and to compare these results with those obtained from Everest in order to understand if their movements can be correlated in amount and direction. After only one year it seems that the movement of the Nanga Parbat area tends more to the East, but it is still too early to draw conclusions that are not within the margin of error of the instruments employed. More reliable results should be obtained from the data of the permanent GPS stations and from subsequent observations on the Massif in future years.

An improvement of the project would be to insert one more permanent station in Skardu and two more monitoring points on the NPH massif, one at Fairy Meadows and one on the northern part of the Haramosh Massif. Particularly interesting will also be gravity and deflection measurements (Ebblin et al. 1983) on all points of the network, both the distant ones and those closer to the dam, in order to point out eventual correlations during the filling of the lake. The network of points installed could possibly be a real laboratory for the study of the effects on the geophysical parameters of the area during the construction of the dam.

As mentioned earlier, this research has also a particular interest due to the planned construction of an electric power plant, with a large concrete dam on the Indus River. The results of the observations made, and those to be repeated in the future, will be of great importance to the local authorities involved in the construction of the dam.

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This paper presents the initial results obtained by an international research project named "Monitoring of the horizontal movements of the Nanga Parbat Haramosh Massif" funded by the Italian Ministries of Culture and Foreign Affairs through the EV-K2-CNR Committee, concerning the Karakoram-Himalaya mountain ranges in the North Eastern part of Pakistan. The realization of this project has been possible for the kind collaboration of the Rector of the Bohria University (Islamabad) and the Vice Chancellor of the Karakoram International University (Gilgit-Baltistam). The authors are thankful to A. Pecher and A. G. Webb for their fruitful comments and suggestion to improve this manuscript.

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