Survey and Alignment of the J-PARC

Kenji Mishima[1] , Naohiro Abe
PASCO, Higashiyama 1-1-2, Meguro-Ku, Tokyo, JAPAN,

Norio Tani, Takatoshi Morishita, Akira Ueno, Shinichiro Meigo, Masahide Harada
JAEA, Tokai-Village, Ibaraki-Ken, JAPAN

Masashi Shirakata, Masanori Ikegami, Masakazu Yoshioka, Takanobu Ishii, Takao Oogoe, Yasunori Takeuchi, Yoshiaki Fujii, Hiroyuki Noumi, Hitoshi Kobayashi
KEK, Oho 1-1, Tsukuba-City, Ibaraki-Ken, JAPAN

1. INTRODUCTION

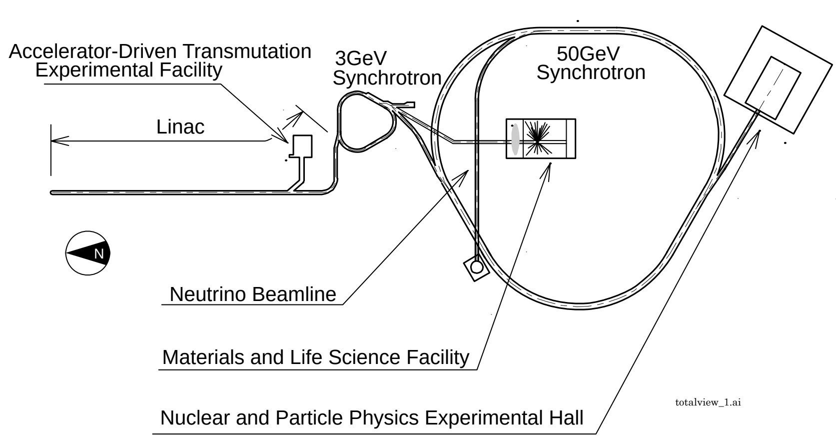

Figure 1 : Schematic View of This Facility

[1] kKenji_mishima@pasco.co.jp

The High Intensity Proton Accelerator Facility, which is refers to as “J-PARC” project (Japan Proton Accelerator Research Complex), is constructing at the Tokai Campus of JAEA, about 130 kilometers northern east of Tokyo in Japan (see Figure 3). This facility is constructed as joint project of the Japan Atomic Energy Agency (JAEA) and the High Energy Accelerator Research Organization (KEK).

This accelerator complex consists of following accelerators (see Figure 1) :

(1) 400 MeV normal conducting Linac,

(2) 600 MeV superconducting Linac to increase the energy from 400 MeV to 600 MeV,

(3) 3 GeV synchrotron ring, which provides proton beams at 333 mA (1MW), and

(4) 50 GeV synchrotron ring, which provides proton beam at 15 mA (0.75 MW).

These accelerators are located on the extensive area about 1000 meters to north and south, and about 500 meters to east and west (see Figure 2).

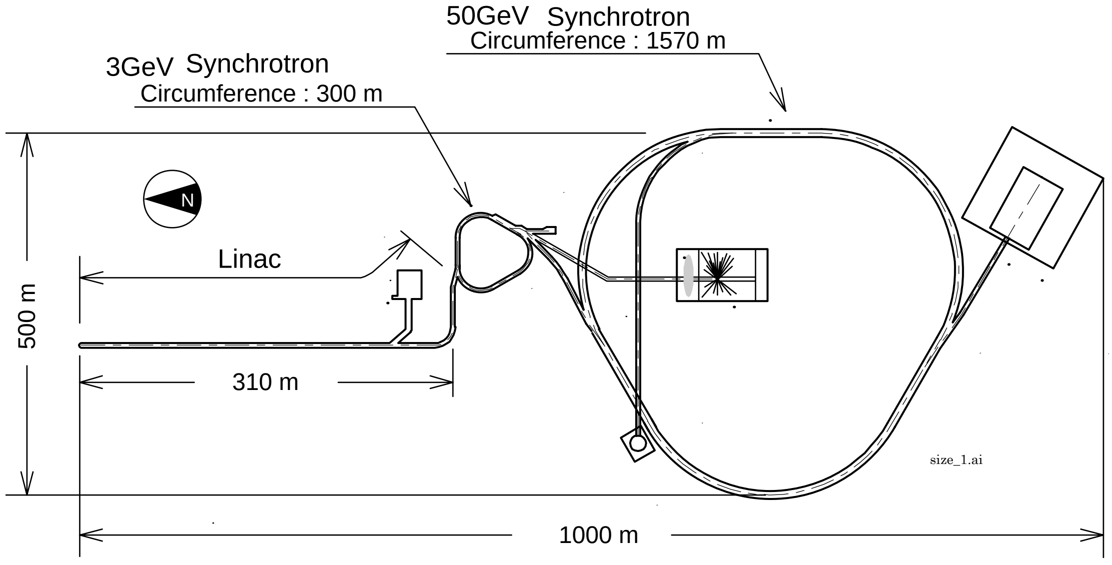

Figure 2 : Approximate dimension of this complex

Especially, one of many experiments on the 50 GeV proton synchrotron is the neutrino oscillation using the Super-Kamiokande as a detector. The distance from this J-PARC to the Super-Kamiokande is 300 kilometers. Therefore, this is a huge machine about 300 kilometers to west and east (see Figure 3 at next page). Consequently, survey work must consider the curvature of the earth.

The status report of survey and alignment at J-PARC has presented on previous work shop, which is IWAA2004 at CERN. The title of the report was “Geodetic Survey Work of High Intensity Proton Accelerator Facility”, and the report presented the result of surveying from year of 2002 to year of 2003. This is a report from year of 2003 to year of 2005, and the continuation of the last report.

2. GEODETIC SURVEY (SURFACE NETWORK)

Final goal of survey is to align components of accelerator according to design orbit within required tolerance. Therefore, the purpose of this geodetic survey is conformation of the agreement of the accelerator machine into the accelerator tunnel, and outside of facility with Super-Kamiokande away to the west at 300 kilometers (see Figure 3 and Figure 4).

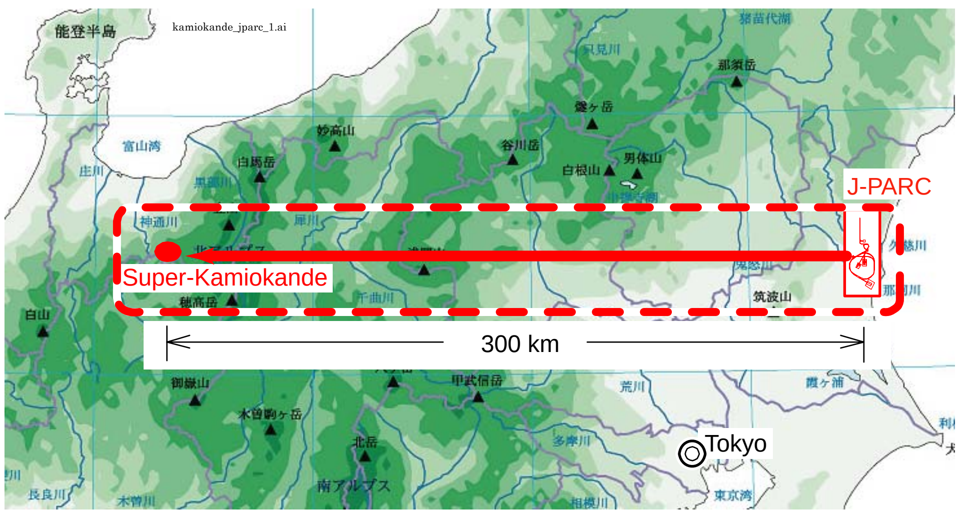

Figure 3 : Schematic view of Super-Kamiokande and J-PARC (1)

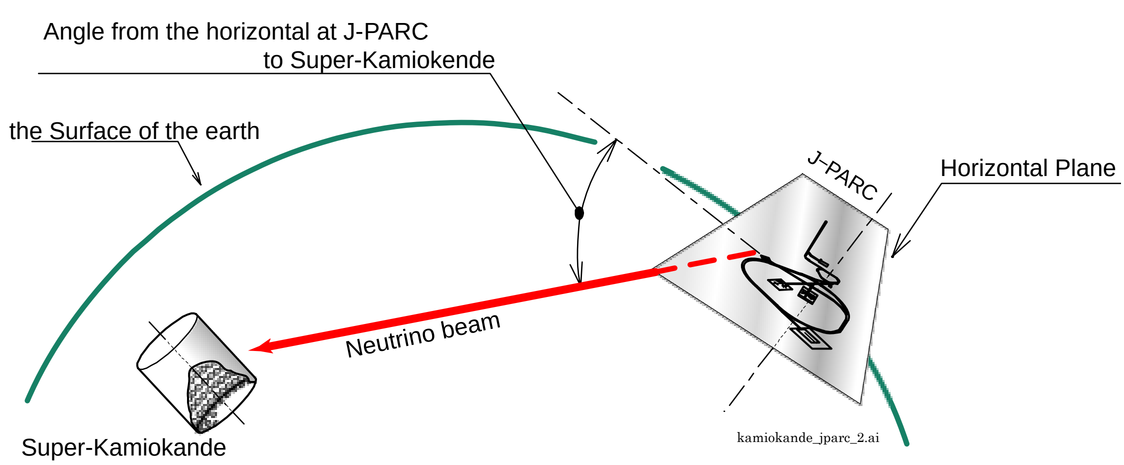

Figure 4 : Schematic view of Super-Kamiokande and J-PARC (2)

2.1. The Result of Surveying from 2003 to 2005

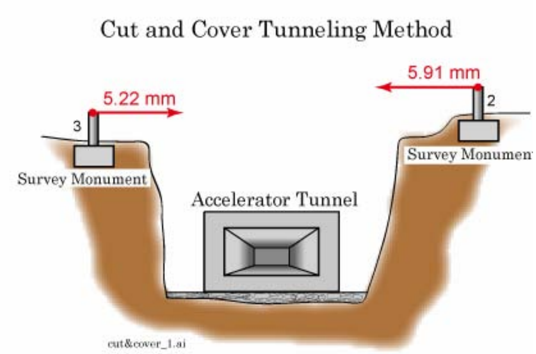

Figure 5 : Typical displacement of monuments

Figure 7 shows the displacement of monuments from February 2003 to February 2005. Because there were a lot of trees and the prospect between monuments for the surveying was bad. So, these had been surveyed by GPS (Global Positioning System), and the survey network is Figure 8.

Most accelerator tunnels are constructed by the open cut method (cut and cover tunneling method). So, the foundation was displaced because of the change in the load and the release of the stress. The monument of №2 and №3 was the most typical displacement, and these have been displaced toward into the trench (see Figure 5).

2.2. The Result of Surveying from 2005 to 2006

Figure 10 shows the displacement of monuments from February 2005 to February 2006. As the construction work became the last stage, the visibility for the surveying has extended along with it. Then, the surveying method was changed from the GPS survey to the traverse survey. It is the reason why the total station which is TDA5005 is more highly accurate than the GPS (see Figure 9 and Figure 11).

Figure 6 : Surveying for surface network by TS

There are big displacements in Figure 10. These are the following causes:

(1) Tunneling works and building constructions were closed to last stage, the foundation of this area was under huge load changing.

(2) The Surveying method has changed from the GPS to the total station.

The surface network had been tied to accelerator tunnel through six survey shafts (finally fourteen survey shafts and see Figure 12). Vectors of displacements in Figure 10 were decided as following process:

(1) Coordinates of monuments were computed by surveying data (angles and distances) with the free network adjustment.

(2) Many cases of vectors were computed by combining referential monuments.

(3) The case of minimum vectors in accelerator tunnels was adopted.

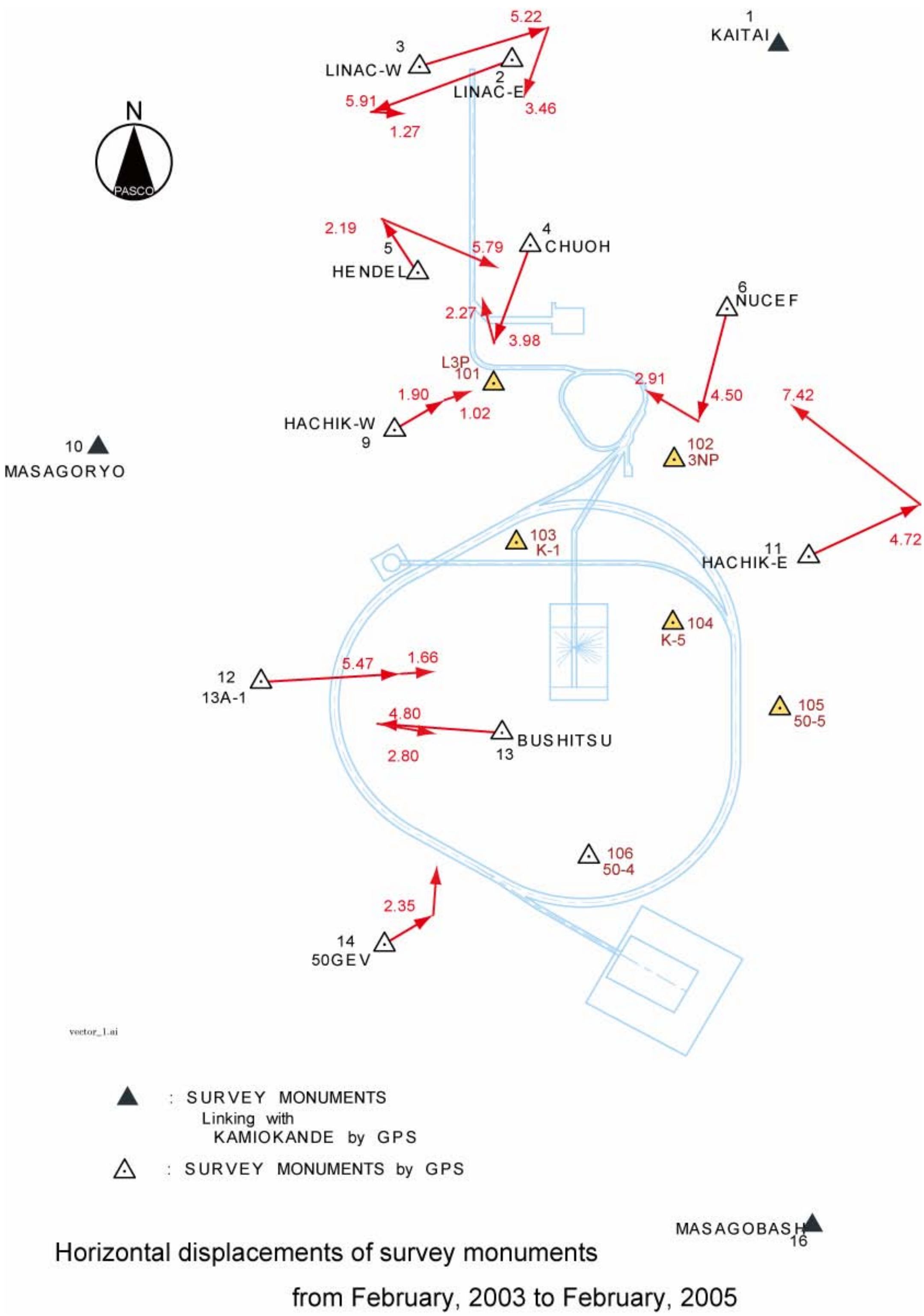

Figure 7 : The hysteresis of displacement vector of monuments from the year of 2003 to 2005

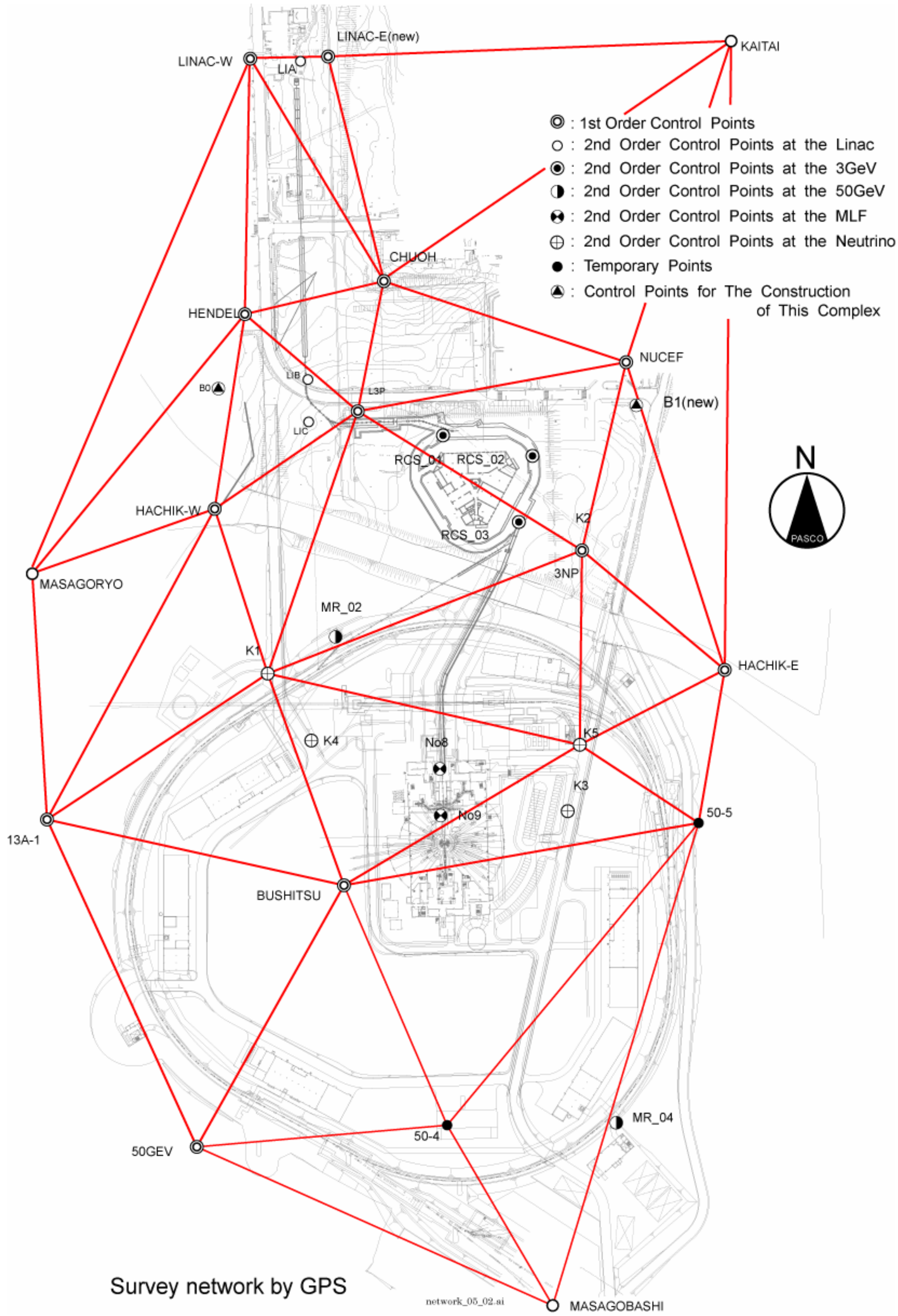

Figure 8 : The survey network by GPS from the year of 2003 to 2005

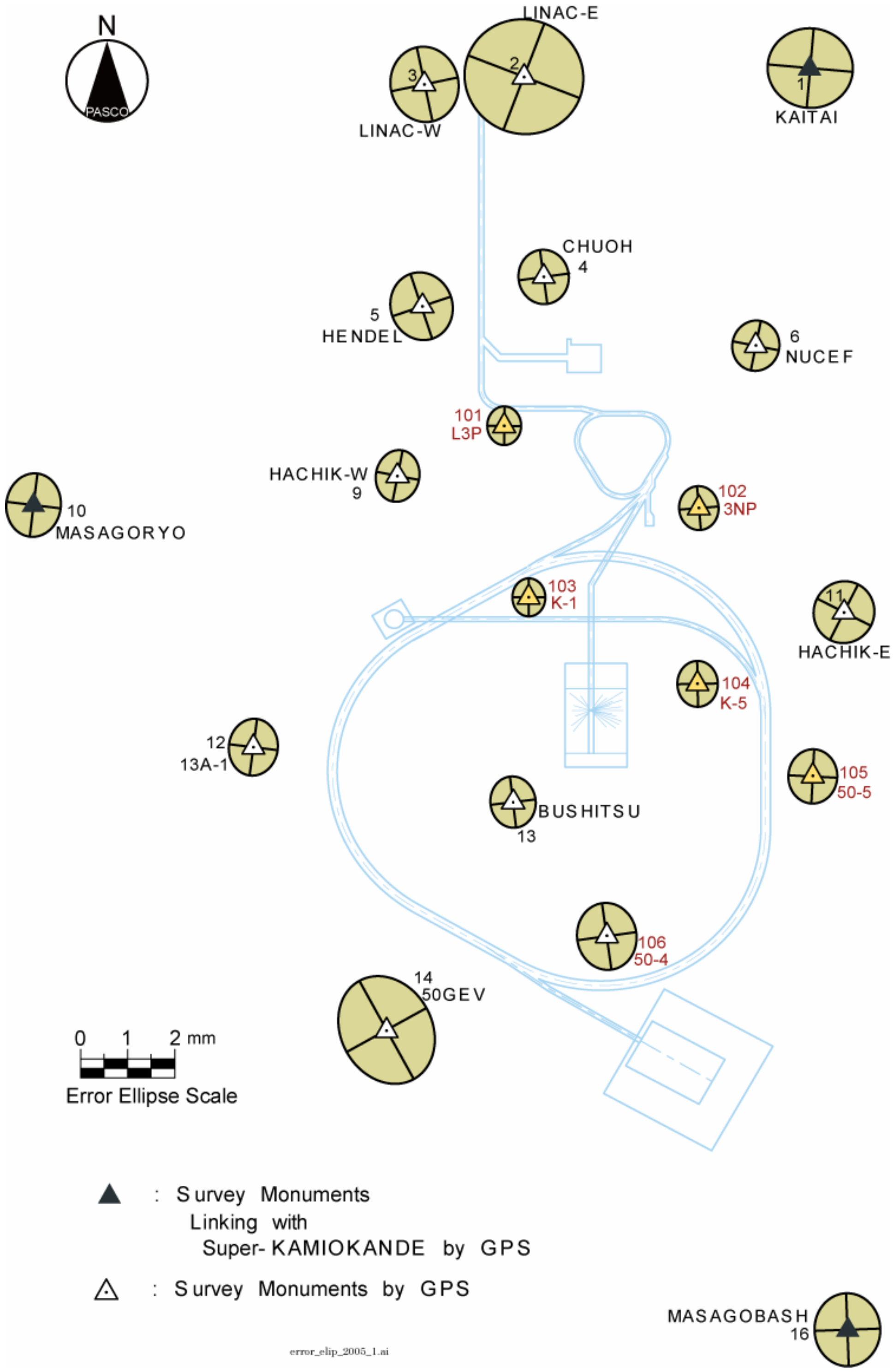

Figure 9 : Error ellipse by GPS at the year of 2005

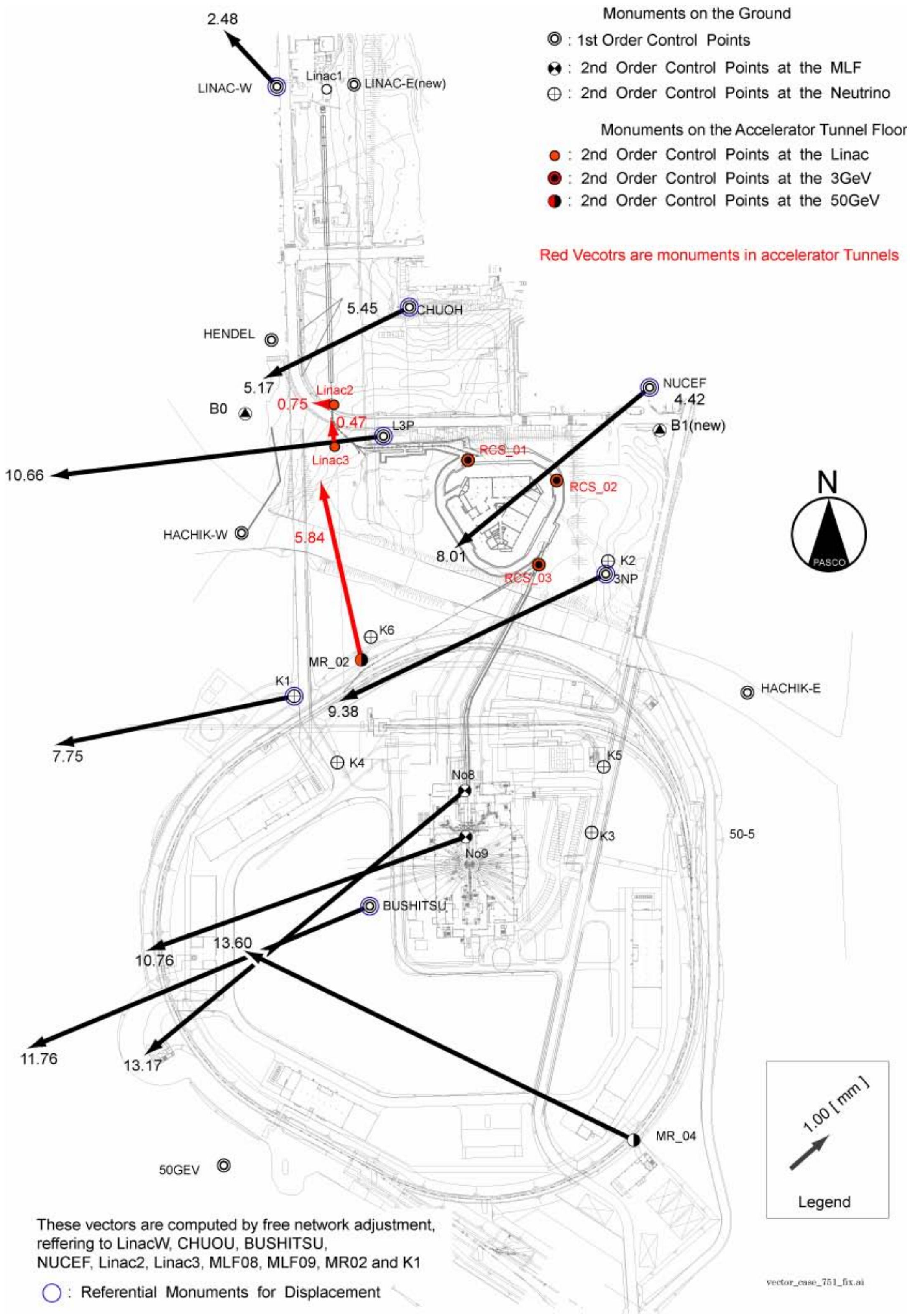

Figure 10 : Displacement vector of monuments from year of 2005 to 2006

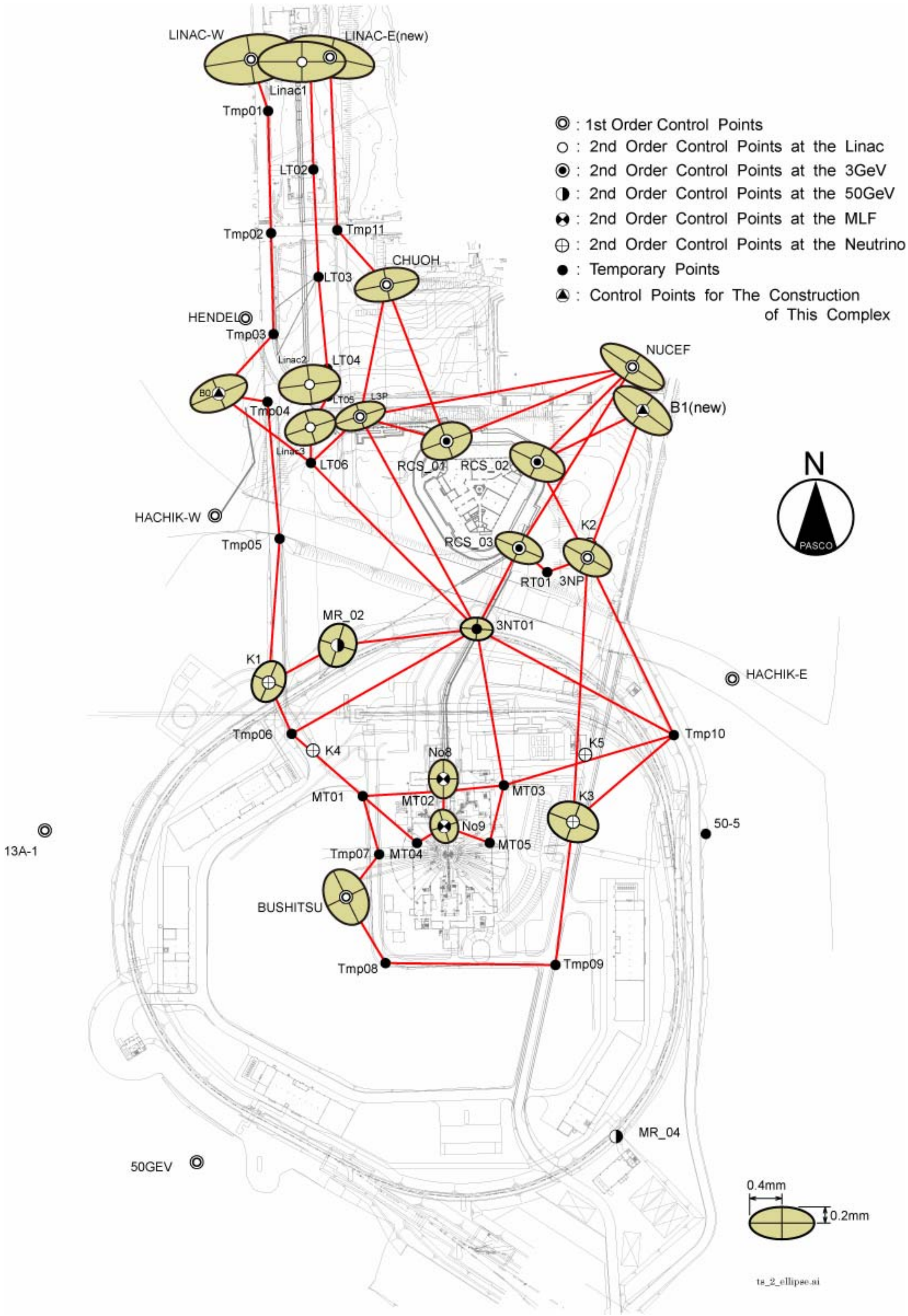

Figure 11 : The survey network and error ellipses at February, 2006

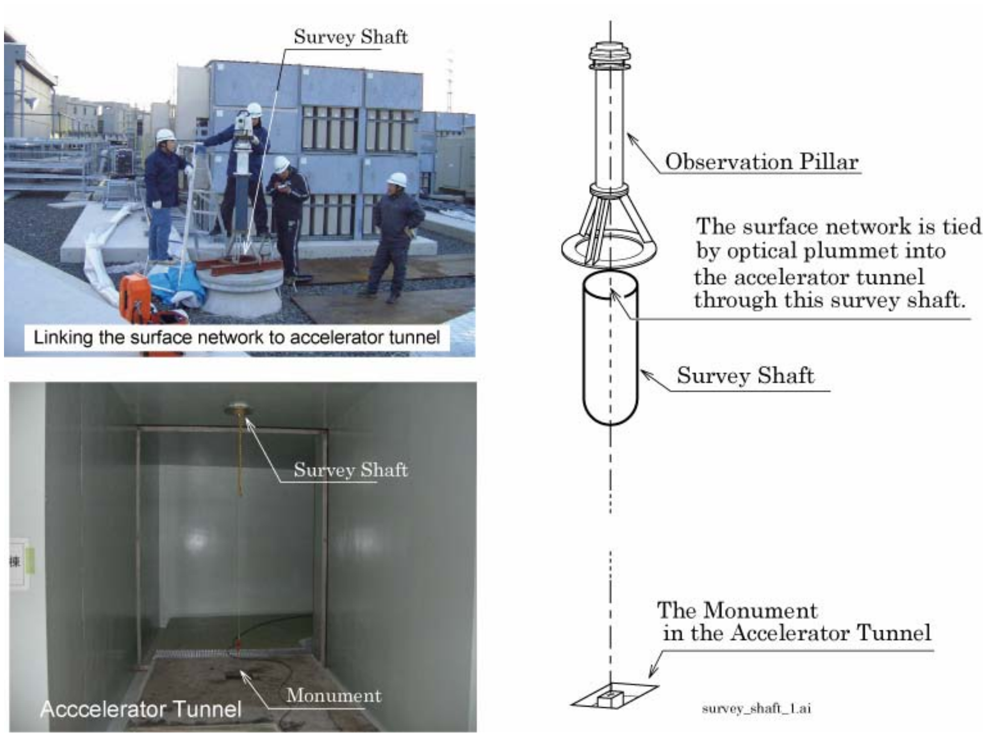

Figure 12 : The survey shaft

Figure 13 : Floor monuments in accelerator tunnels

3. SURVEY AND ALIGNMENT (TUNNEL NETWORK)

Phase 1: Blue line survey on the accelerator tunnel floor.
Phase 2: Installing of components in the accelerator tunnel
Phase 3: Pre-alignment of components
Phase 4: Fine alignment of components
Phase 5: Smoothing

Phased alignment has started in each facility toward final alignment.

3.1. Case of 3 GeV Ring

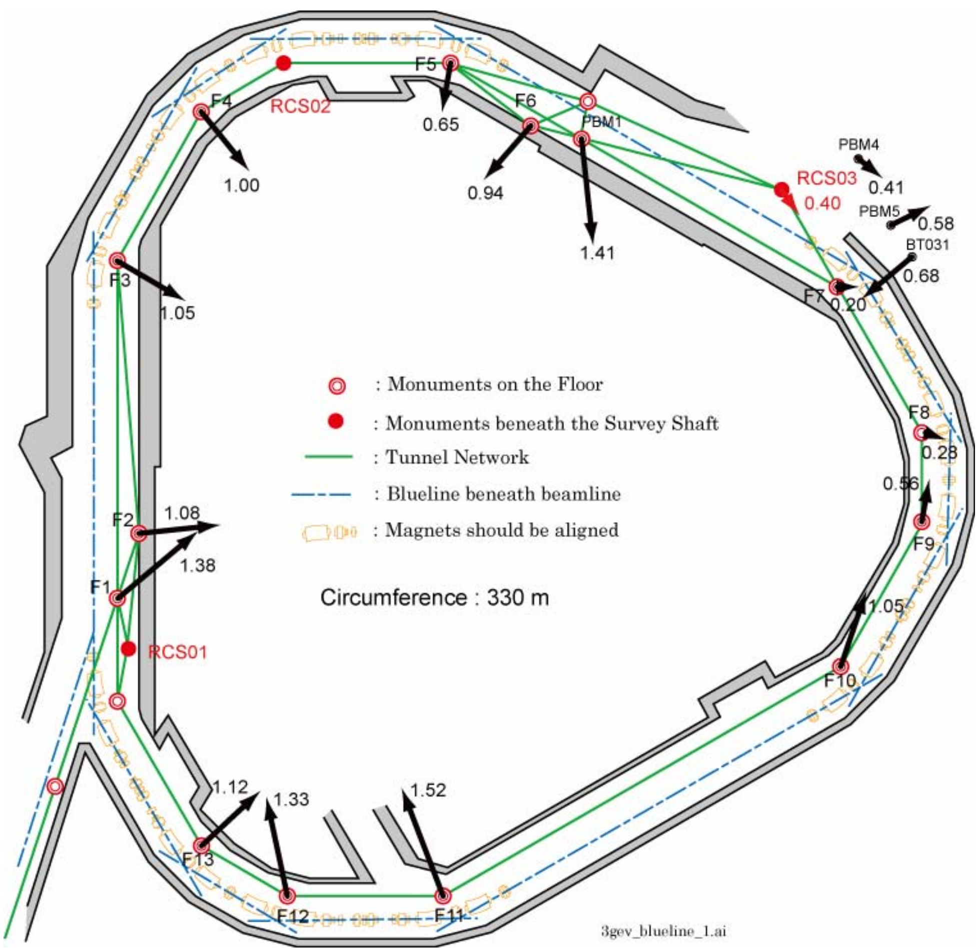

Figure 14 : Displacements of floor monuments in 3GeV Ring

Figure 14 shows displacements of floor monuments in 3GeV Synchrotron ring from August 2005 to February 2006. It seems that it influences by the heat contraction because most vectors for the center of this synchrotron ring. The purpose of this survey is performed to lay out the anchor bolt positions. Therefore, The blue line survey had been executed as it was.

In addition, pre-alignment has been started since beginning of this month.

3.2. Another Accelerators

The status of alignment in each accelerators and facilities are shown in Table 1.

Table 1 : Status of survey and alignment

Accelerators and Facilities	Status of Phase
Liniac	Fine alignment and Smoothing
3 GeV Synchrotron	Pre-alignment
50GeV Synchrotron	Blue line survey, Installing and Pre-alignment
Material and Life Science Facility	Blue line survey, Installing, Pre and Fine alignment
Nuclear and Particle Physics Experimental Hall	Blue line survey, Installing and Pre-alignment
Neutrino Facility	Under Constructing

4. CURVATURE CORRECTION FOR BEAM HEIGHT

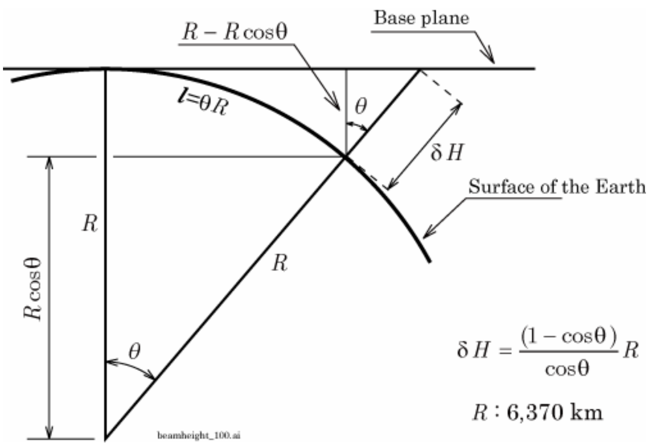

Figure 15 : The influence of curvature of the earth on the base plane

Table 2 : The influence of curvature of the earth on the beam height

l [m]	δH [mm]
50	0.20
100	0.78
200	3.14
300	7.06
400	12.56
500	19.62
1000	78.49

It is general that the height of components of accelerator is aligned along a horizontal plane. However, this straight line is a parallel straight line to curvature of the earth, and no straight line for the beam (see Figure 15 and Table 2).

The radius of curvature in meridian, prime vertical and vertical cut are different according to latitude and the longitude. Therefore, it is necessary to set the tangential plane by the latitude and the longitude.

4.1. Base Plane of each accelerators

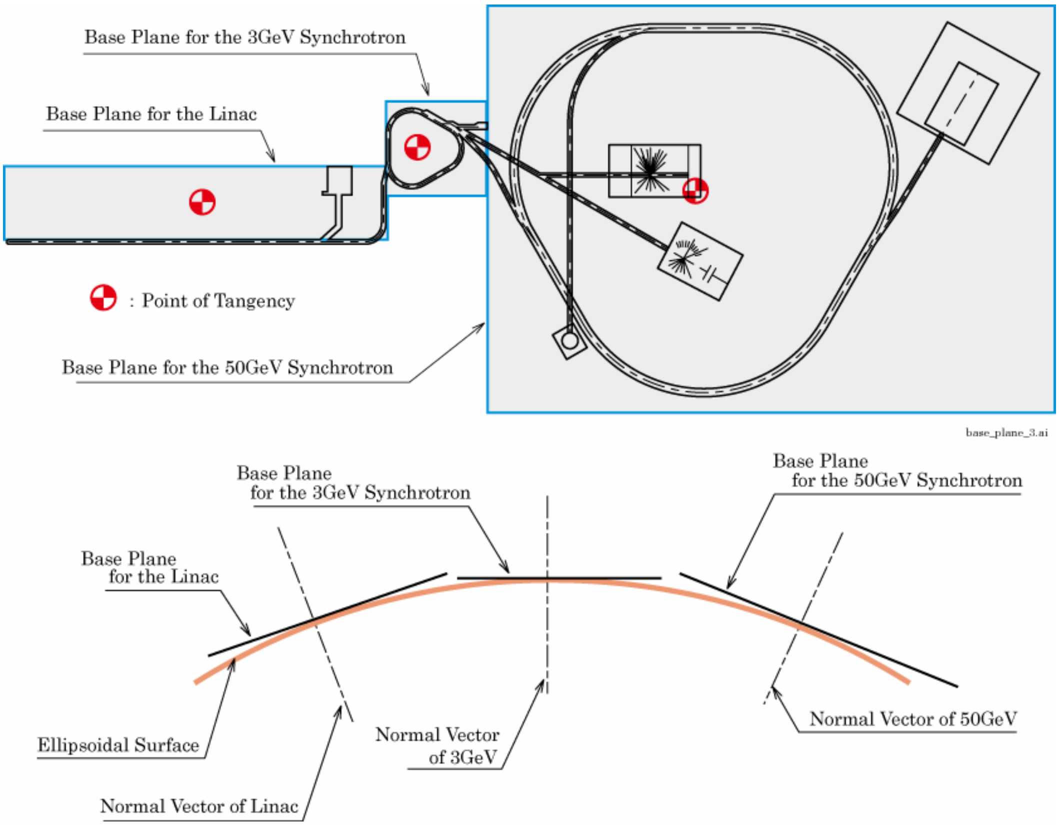

Figure 16 : Base planes for correction for beam height

Figure 16 shows base planes in the J-PARC. Each base plane is skewed (see Figure 17).

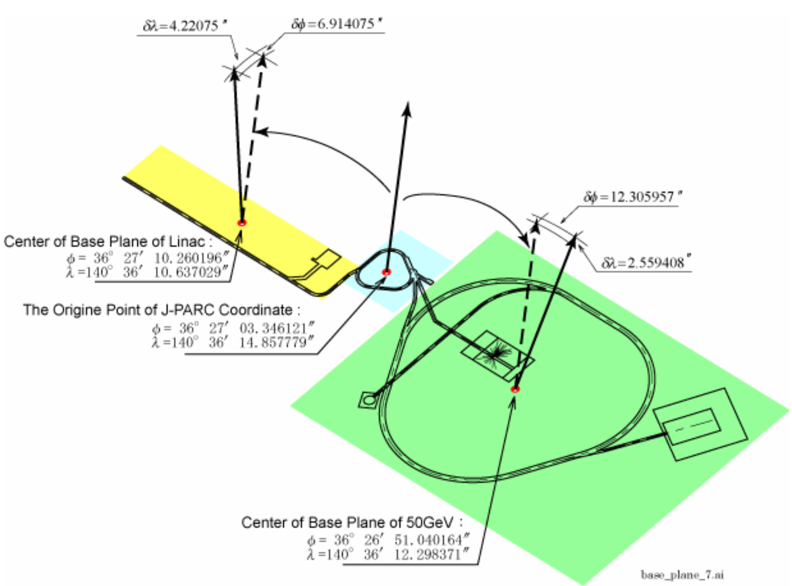

Figure 17 : Relation of each base plane

4.2. Method of the Correction for Beam Height by Curvature of the Earth

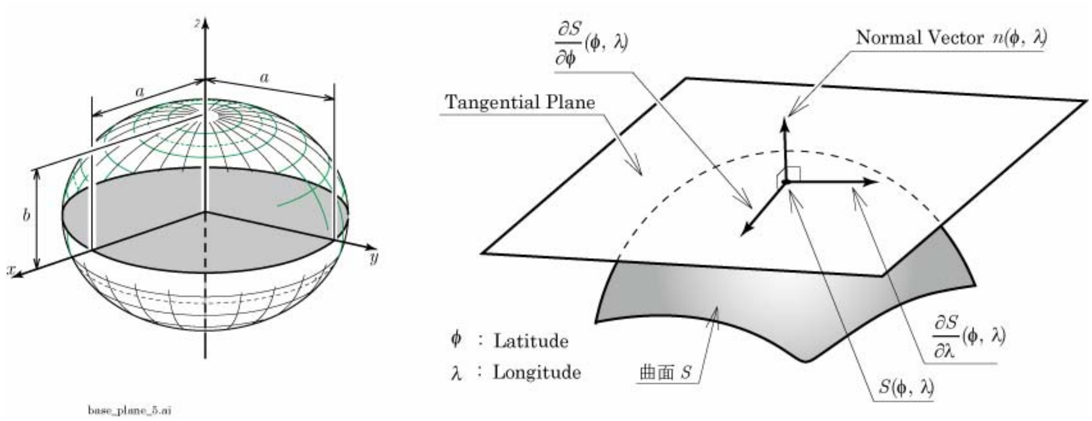

Figure 18 : schematic view of the ellipsoid and the normal vector on the surface

The position of the earth can be represented as equation (1) in geocentric 3D coordinate by latitude ϕ, longitude λ and the radius of curvature in prime vertical Q on GRS 80 ellipsoid.

$$S(\phi,\lambda) \quad : \quad \begin{cases} x = Q\cos\phi\cos\lambda \\ y = Q\cos\phi\sin\lambda \\ z = \dfrac{b^2}{a^2}Q\sin\phi \end{cases} \qquad (1).$$

The derivative of the equation (1) with latitude ϕ and longitude λ gives their tangent lines. The result is shown in (2).

$$\begin{aligned} \frac{\partial S}{\partial \phi} &= \left(\frac{\partial x}{\partial \phi}, \frac{\partial y}{\partial \phi}, \frac{\partial z}{\partial \phi}\right) = \left(-Q\sin\phi\cos\lambda\,,\ -Q\sin\phi\sin\lambda\,,\ \frac{b^2}{a^2}Q\cos\phi\right) \\ \frac{\partial S}{\partial \lambda} &= \left(\frac{\partial x}{\partial \lambda}, \frac{\partial y}{\partial \lambda}, \frac{\partial z}{\partial \lambda}\right) = \left(-Q\cos\phi\sin\lambda\,,\ Q\cos\phi\cos\lambda\,,\ 0\right) \end{aligned} \qquad (2).$$

Then the normal vector is represented as equation (3).

$$n(\phi,\lambda) = \frac{\dfrac{\partial S}{\partial \lambda}\times\dfrac{\partial S}{\partial \phi}}{\left\|\dfrac{\partial S}{\partial \lambda}\times\dfrac{\partial S}{\partial \phi}\right\|} = \frac{\left(\dfrac{b^2}{a^2}\cos\phi\cos\lambda\ ,\ \dfrac{b^2}{a^2}\cos\phi\sin\lambda\ ,\ \sin\phi\right)}{\sqrt{\left(\dfrac{b^2}{a^2}\right)^2\cos^2\phi+\sin^2\phi}} \qquad (3).$$

The normal vector is substituted with $n_0(\phi,\lambda) = (\alpha_0, \beta_0, \gamma_0)$. The equation of the base plane which contains the point on the surface of the earth $P_0(x_0, y_0, z_0)$ is

$$\alpha_0(x-x_0)+\beta_0(y-y_0)+\gamma_0(z-z_0)=0 \qquad (4).$$

Coordinates of fiducial Points on each component are calculated by its latitude and its longitude. The correction value for the beam height is the distance from these coordinates to this base plane.

4.3. The Result of Correction value for the beam height

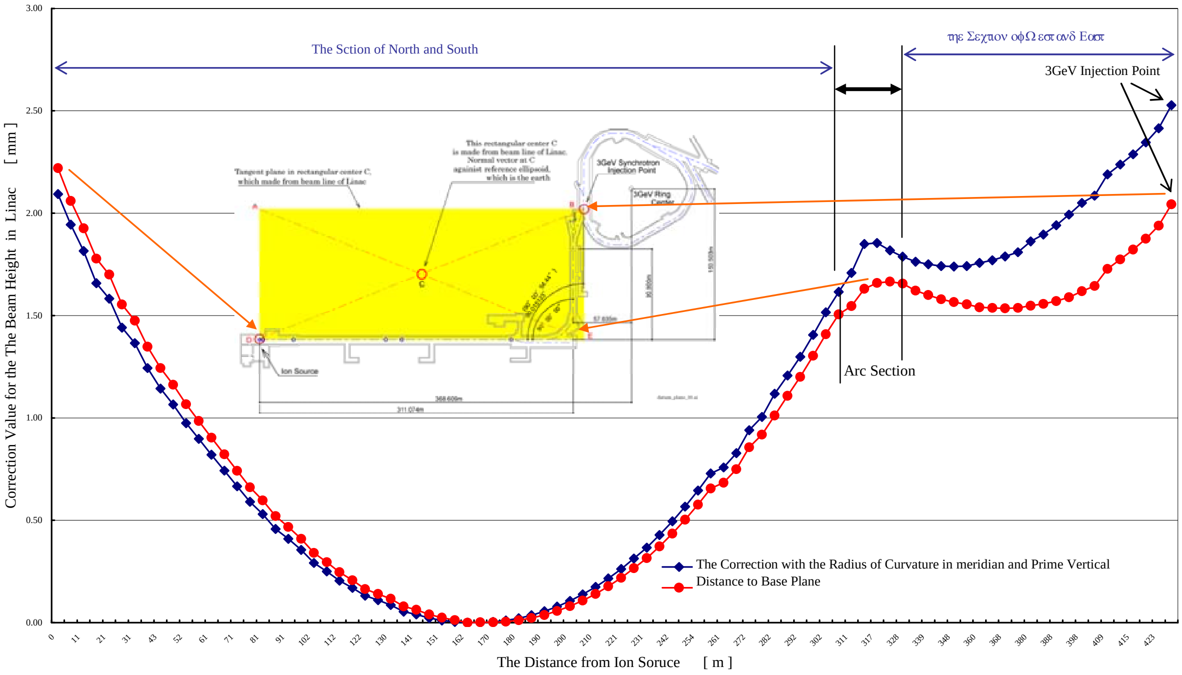

Figure 19 : Distances from magnets to base plane in the Linac

Figure 19 shows distances from components to the base line in the Linac. Components of the Linac are located in north and south at upstream and in west and east at downstream. The beam heights of components are affected by radius of curvature in meridian at upstream in Linac, by radius of curvature in prime cut at down stream in Linac. Blue plots in Figure 19 are calculated by both radius of curvature. The ion source and the injection point in 3GeV Synchrotron should be equal in the height. These correction values by both radiuses of curvature do not have correspondence because the joint of the arc section is difficult. Red plots in Figure 19 are calculated by distances to base plane in the Linac. The ion source and the injection point in 3GeV Synchrotron are equal in the height. Therefore, the correction by the base plane is better for the beam height.

Figure 20 shows distances from components in the Linac and 3GeV synchrotron to base plane of 3GeV. Correction value at the end of Linac is 12.5 millimeters. Therefore, It is right to have set three base planes.

Figure 21 shows the case of 50GeV Synchrotron Ring. The maximum of distance to base plane in 50GeV synchrotron is about 1.25 millimeters even though its circumference is 1,540 meters. The reason for this is that three straight sections are about 120 meters. Therefore, it is not necessary to correct curvature of the earth if there is no straight section.

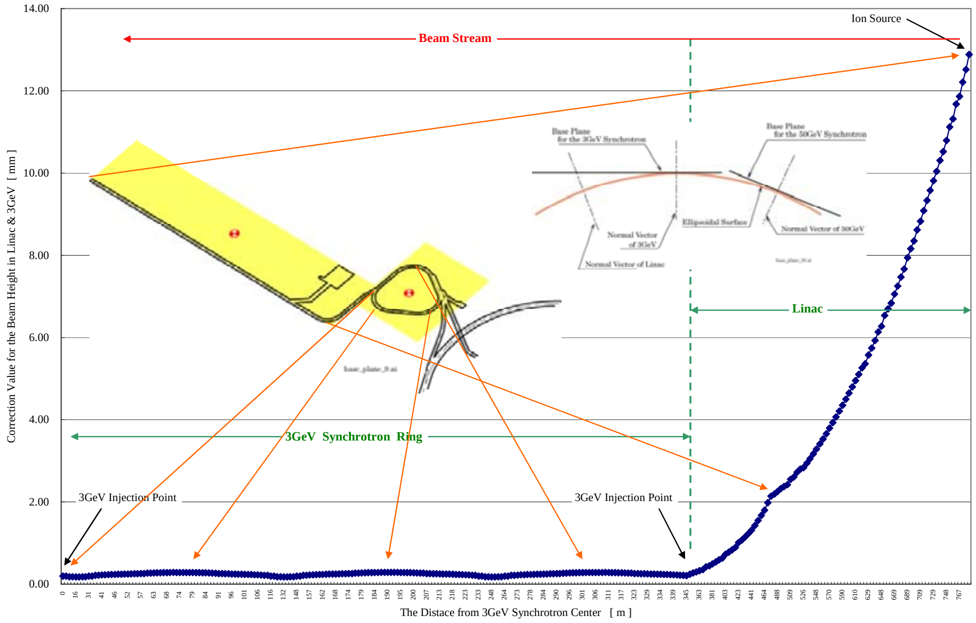

Figure 20 : Distances from magnets in 3GeV Ring and Linac to base plane of the 3GeV Synchrotron

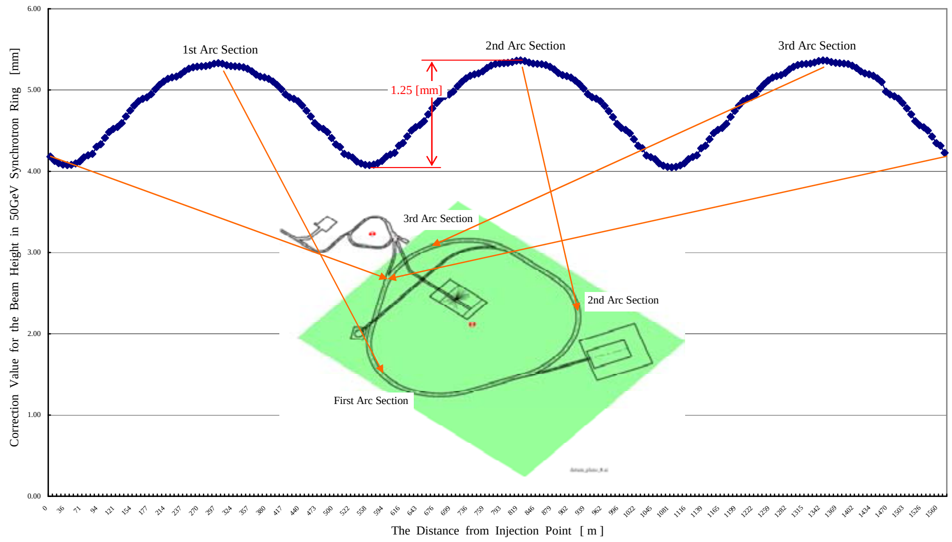

Figure 21 : Distances from magnets to base plane in the Linac

References

[1] Kenji Mishima, Others, “Geodetic Survey Work of High Intensity Proton Accelerator Facility”, IWAA’04, CERN, September 2004.

[2] R.Ruland, “HANDBOOK of ACCELERATOR PHYSICS and ENGIEERING”, .