SURVEY COMPARISON USING GNSS AND ME5000 FOR ONE KILOMETER RANGE

S.Matsui, H.Kimura, RIKEN, Kouto, Sayo-cho, Sayo-gun, Hyogo, 679-5148 JAPAN

Abstract

The measurement comparison of distance using Mekometer ME5000 and GNSS were done for 200m up to 760m. The differences were 0.0 to 0.3mm. Moreover the difference was 0.1mm for one kilometer distance. The difference between weather conditions around one kilometer region was negligible although the wavelength is sensitive to the water vapor pressure. Eight survey monuments were made around the SPring-8 storage ring for the construction at sixteen years ago. These monuments were surveyed again using GNSS. The three monuments are shifted. The displacements are 15, 5, and 5mm.

INTRODUCTION

The total satellite number of GPS is already larger than 24 (6 orbits every 4 satellites). The number of GLONASS is increasing up to 24 (3 orbits every 8 satellites), however about 10 now. The number of GALILEO is planed to be 30. New frequency L5 will be added. Moreover the specification of the receiver becomes better by the progress on microwave electronics. Thus the condition for the survey using GNSS (Global Navigation Satellite System) becomes better.

Ten monuments were made for building construction and accelerator alignment at SPring-8. The distance meter ME5000 and theodolite T3000 were used sixteen years ago. [1] However, the network is cut by the building, thus GNSS is planed to measure the shifts of these monuments. The elevation changes can be measured by the normal method for example, N3. But it is difficult to measure the horizontal positions by the optical survey instrument.

STATIC RELATIVE POSITIONING

The survey area is very small for GNSS. The technique is called Static Relative Positioning or Carrier-Phase Differential GPS. One receiver is base station and the other is rover. (Fig.1.) The distance is calculated from the measured phase difference.

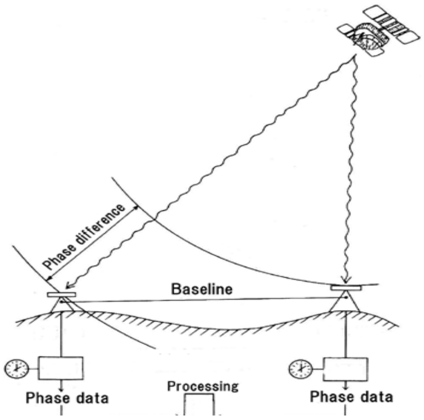

Fig.1. Static relative positioning.

The data is acquired into the memory card in the each receiver. Actually, the phase difference is calculated using two satellites to cancel the clock difference in the two receivers as shown in fig 2. This phase difference is called Double-(phase) difference. When the number of visible satellites is ten, the independent solutions number is nine.

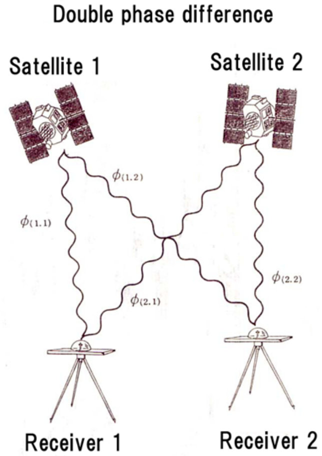

Fig.2. Double phase difference.

Phase measurement

The carrier frequencies of L1 and L2 are mainly used for static relative positioning. The P and C/A code are not used. The diagram of phase measurement is shown in fig3.

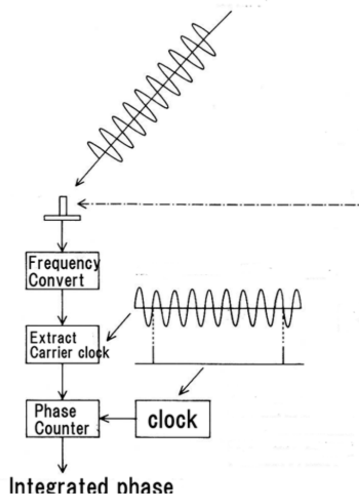

Fig.3. Diagram of phase difference measurement.

The high frequency is down converted adding local oscillation and amplified. The phase of extracted carrier clock is integrated by the phase counter. The wavelength is 190mm for GPS L1, 244mm for L2, and 190mm for GLONASS L1, 241mm for L2. It is said that the measurement of one degree is easy by the recent electronics. The specification of carrier phase precision is 0.1mm in the case Topcon NET G3. The phase 0.2 degree corresponds to the distance 0.1mm.

Troposphere correction

The refractive index n of microwave in the air is expressed by temperature T[K], air pressure Pd[hPa] (except water vapor pressure), water vapor pressure Pw[hPa], [2,3]

$$n = 1 + (77.6\frac{P_d}{T} + 3.73\times 10^5\frac{P_w}{T^2})\times 10^{-6} \qquad (1)$$

The refractive index of red light (633nm) is expressed by IUGG recommendation, [4,5]

$$n = 1 + (\frac{300.2307793}{0.9+0.003661\times T}\frac{P_d+P_w}{1013.25} - \frac{0.041\times Pw}{0.9+0.003661\times T})\times 10^{-6}$$

$$\ldots = 1 + (\frac{300.2307793}{0.9+0.003661\times T}\frac{P_d}{1013.25} + \frac{0.255\times Pw}{0.9+0.003661\times T})\times 10^{-6} \ldots\ldots(2)$$

If T=300 K, then the deviations of n by the Pw=10 hPa are 41ppm for (1) and 1.3ppm for (2). The influence of water vapor pressure 10hPa is much larger as the case of microwave.

Troposphere layer consists of dry air part and humid one. The thickness is totally 40km and humid layer is 11km. If the troposphere is homogenous the refraction is almost same. (Fig.4). Thus the baseline distance lu equal ld. The correction due to the refraction and water effect is no needed if the baseline distance is small. Small correction is needed owning to the refraction, for example, difference between the angle θ 1 and θ 2. Analysis with Goad-Goodman troposphere model was used.

The influence of ionosphere is neglected because the baseline is small relative to the height of ionosphere.

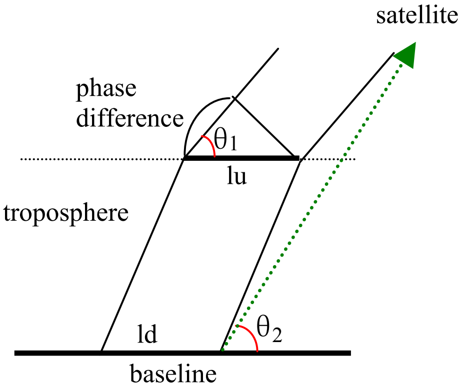

Fig.4. Influence due to troposphere refraction.

MEASUREMENT

Satellites

Figure 5 shows the visible satellites during January 20 to 22 (GST) at SPring8 site. Character "G" represents for GPS and "R" for GLONASS. The number of satellites is about thirty for GPS and ten for GLONASS. These satellites rotate for about 12 hours. But the earth rotates for one day. Thus the period of same situation is not 12 hours but one day. The measurement time was chosen almost 1 day.

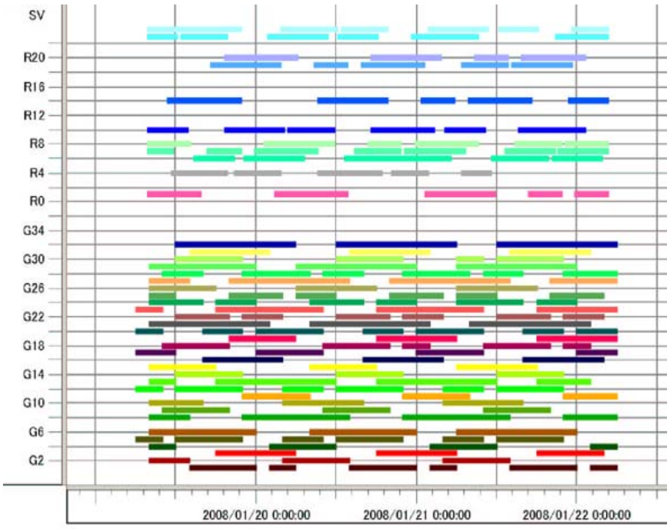

Fig.5. Visible satellites from January 20 to 22.

Receiver, Antenna, and Software

Two receivers NET G3 made by Topcon Positioning Systems, Inc. were used. The specifications are as follows:

Tracking GPS L1, L2
GLONASS L1, L2
Accuracy horizontal ±(3mm+0.5ppm×Distance)
vertical ±(5mm+0.5ppm×Distance)
Data output rate 1-10 Hz (20Hz option)
Carrier phase precision 0.1mm

The name of antenna is G3-A1 with Ground Plane. The analysing software is Pinacle made by Topcon. This software works in the personal computer.

Data acquisition

The acquisition condition was sent from PC to receiver. The lengths of one recorded file were infinitive (start and stop by manual) for base station and one hour for rover.

Fluctuation

Two antennas were put on the stage apart from about 0.9m. The directions of them were same firstly. The angle of obstacle is almost less than 10 degree and less than 13 degree due to small cottage. (Fig.6.)

The output rate was 1Hz. The measured time was two days. Figure 7 shows the fluctuation of relative positions.

One point is the horizontal position from one-hour data. The standard deviations were 0.48mm in the NS direction and 0.49 mm in the EW direction.

Fig. 6. Two GNSS antenna on the stage.

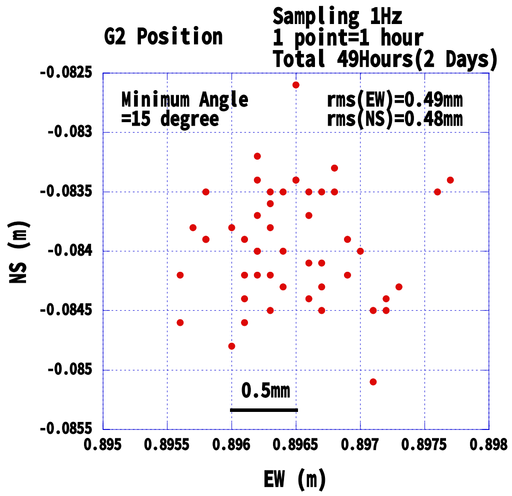

Fig.7. Fluctuation of the GNSS position result for 2 days.

Mask Angle

Figure 8 shows the variation of the rms values of GNSS positions at the place of fig.6 against the elevation mask angle. According to this curve the mask angle was chosen to be 15 degree

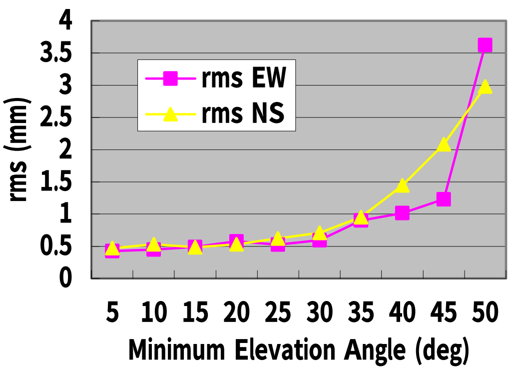

Fig.8. Position rms dependence on mask angle.

Antenna Center

Firstly, antenna G2 was fixed and the other G1 was rotated every 90 degree.(Fig.9.) Secondly, G2 was rotated (Fig.10). According to these results, the offset is less than the fluctuation.

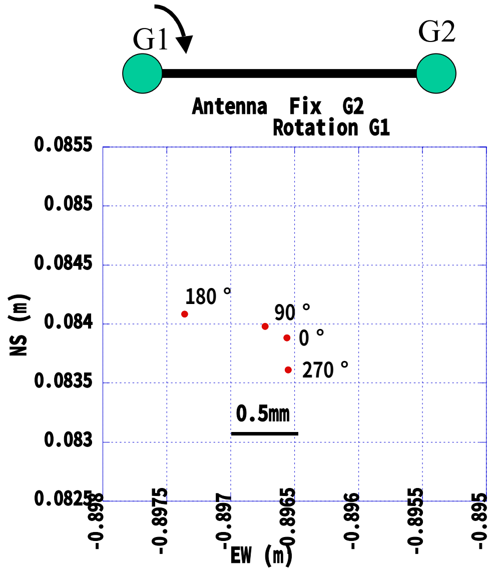

Fig.9. Rotated G1 positions relative to G2.

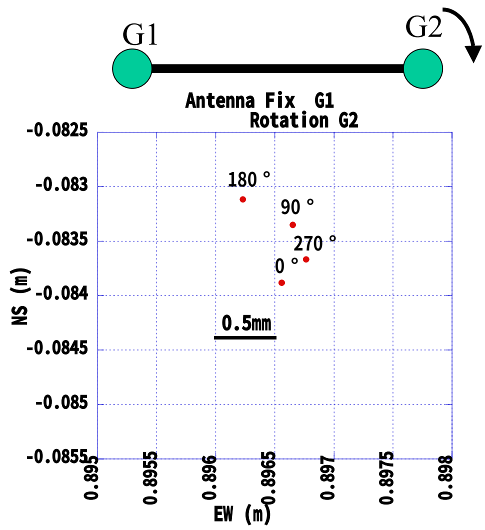

Fig.10. Rotated G2 positions relative to G1.

Distance Comparison

There are five monuments which distance to the next are 100m to measure the ground motion. The distance measurements were done by putting Mekometer ME5000 and GNSS on these monuments. (Fig.11 and Fig.12) The accuracy of ME5000 is 0.2mm±0.2ppm ×distance. The values were corrected owning to air temperature and pressure for ME5000 measurement.

Table 1 shows the distance comparison between by GNSS and by ME5000.

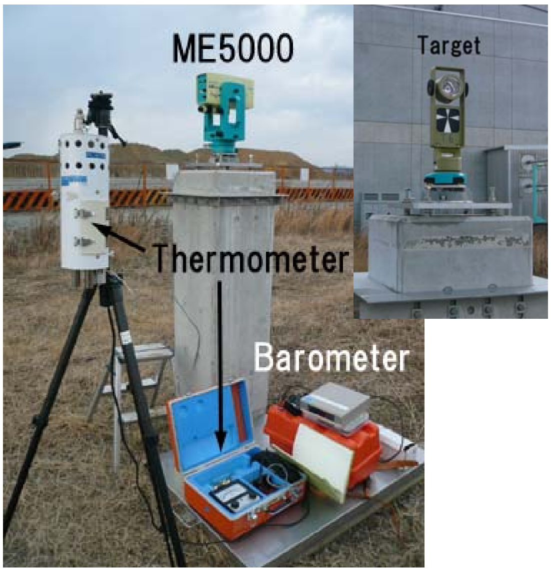

Fig.11. Mekometer, thermometer and barometer.

Fig. 12. GNSS system around the monument.

The error when exchanging ME5000 or target to GPS antenna is estimated within 0.1mm. The time for GNSS was almost one day.

Table 1: Comparison between GNSS and ME5000

Distance(m)	GNSS(m)	ME5000(m)	difference
200	200.0049	200.0049	0.0mm
300	300.0061	300.0060	0.1
400	400.0025	400.0028	-0.3
670	670.8335	670.8337	-0.2

1 km measurement

The area of SPring-8 site is not large. The measurement comparison was done as shown in Fig.13.

Fig.13. One kilometer baseline and GNSS receivers in the SPring-8 site.

Two tripods were used instead of concrete monuments. The angles of obstacle were less than 11 degree at both positions in fig.13.

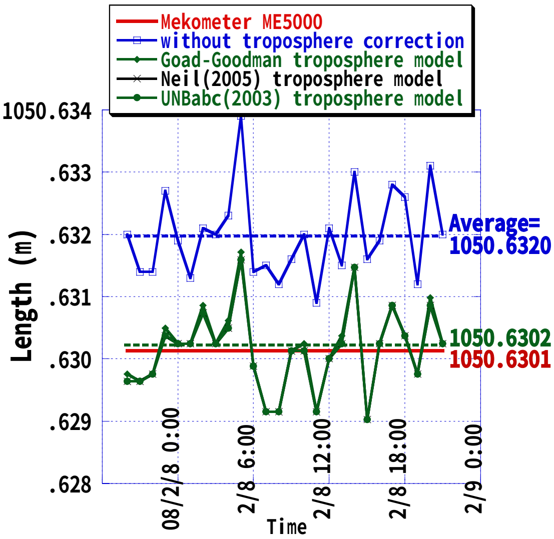

Fig.14. Distance comparison of one kilometer baseline between ME5000 and GNSS.

The results is shown as Fig.14. Red line represents the distance by Mekometer ME5000. The difference between ME5000 and GNSS without troposphere correction is 2 ppm. However these two distances agrees within 0.1mm after troposphere correction. These distances were not horizontal but measured total length. The height difference was about 3.9m.

Influence of Rain

The influence of water vapor pressure is small. However the influence of rain did not seem to be small. Figure 15 shows the distance variation with humidity and rain. The fluctuation of distance is large during rain though the distance is only 100m.

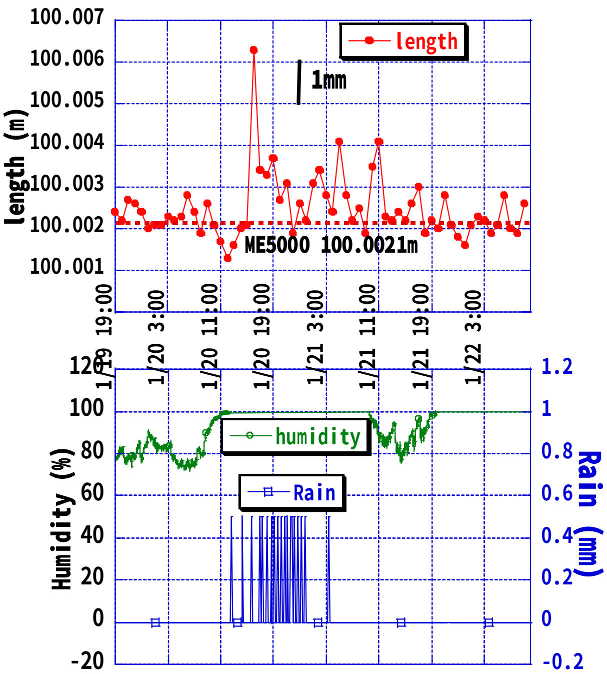

Fig.15. Distance and the influence of rain.

SHIFT OF SURVEY MONUMENTS

Old Survey of SPring-8 Storage Ring

The survey was carried out using ME5000 and theodolite T3000 before building construction in 1992-1993.(Fig.16.) [1] The position of a survey monument is the center of plus mark on the circular brass attached to the rectangular as shown in fig.17. Figure 18 shows the cross section of survey monument. The rectangular is isolated from the surface ground.

The error ellipses of survey results were less than 1mm shown in fig.19.

Fig. 16. Old survey using optical instruments.

Fig. 17. 2nd class survey monument of Japanese style.

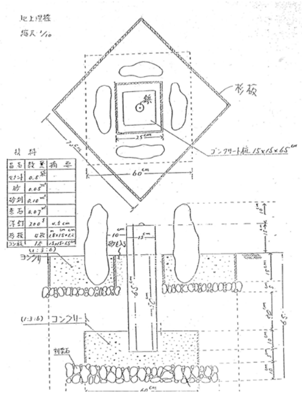

Fig.18. Cross section of Japanese 2nd class survey monument.

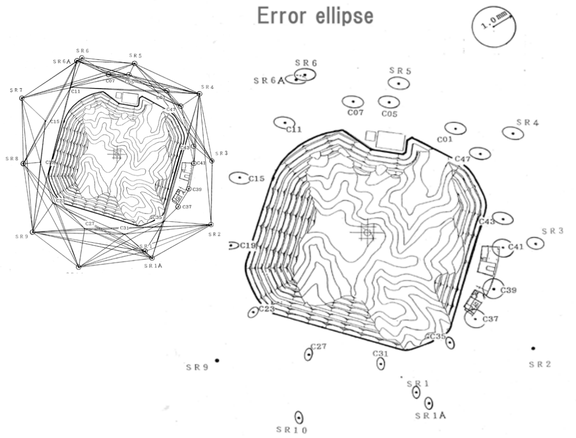

Fig.19. Survey network and error ellipses.

Survey using GNSS

The survey monuments were measured by GNSS (Fig.20.) Base station was put on SR9. The rover was moved to the next monument after the one-day measurement. The lengths of one data file were infinite for base station and one hour for rover. Output rate was 1 Hz. The power of the receiver was from car battery or seal battery.

Fig.20. GNSS base station on the survey monument SR9.

Fig.21. Rover on the survey monument SR4.

Shift for sixteen years

The old survey did not have north direction. Thus old positions were rotated so that the differences became smaller as the fixed point SR9. When the coordinates were rotated SR1, SR4 and SR6 were treated exceptionally because the shifts of these positions seemed to exceed the measurement error. The results are summarized in Table2 and illustrated in Fig.22. The red arrows show the direction and length of the shifts.

Table2: Shifts of survey monuments for fifteen years.

monument	EW(mm)	NS(mm)	shift(mm)
SR1	6.7	-12.9	14.5
SR2	0.9	0.0	0.9
SR3	0.7	0.3	0.8
SR4	4.4	0.9	4.5
SR6	2.1	-4.2	4.7
SR7	1.4	1.1	1.8
SR9	0.0	0.0	0.0
SR10	0.6	-1.2	1.3

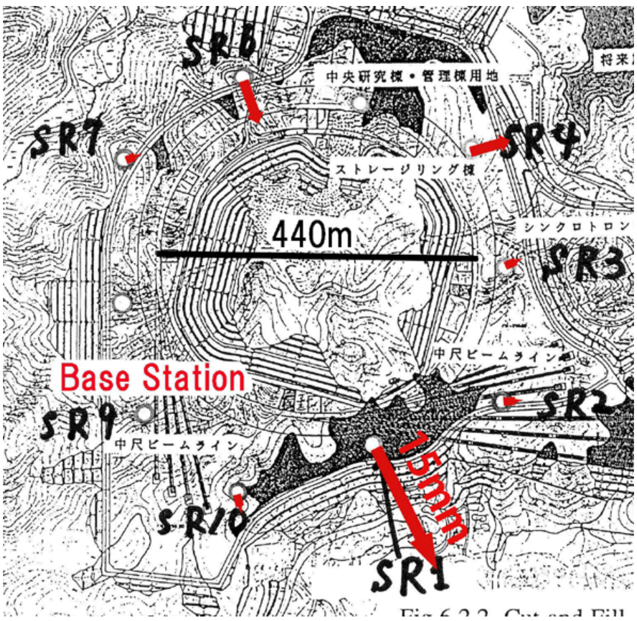

Fig.22. Shifts of survey monuments for sixteen years.

SR1 is not on the rock but on the filled soul. Thus it is easy to move. SR4 is on the ground which tilts to the east direction. The arrow at SR4 is perpendicular to the next road. SR6 is on the unstable place. There was deep trench between SR6 and storage ring at ground improvement.

CONCLUDING REMARK

The measured difference between GNSS and ME5000 were within 0.3mm for the distance range from 200 to 1000 m. The influence of water vapor pressure was negligible for one kilometer measurement. Only the measured fluctuation becomes large during the rain. The statistical error becomes small using high sampling rate. The rate 20 Hz is possible by a recent receiver.

It is clear that the three survey monuments among eight ones are shifted for sixteen years. The shifts of five monuments are less than 2 mm and the other three larger than 5mm.

The relative static positioning by GNSS is very useful though the area is the order of one kilometer if the view from the receiver is good.

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