Four Dimensional Monitoring of Ground Subsidence in Kawasaki, Japan, by repeated GPS survey

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Abstract:Repeated GPS survey had been applied for monitoring ground subsidence from early year of GPS. Recent advancement of GPS geodesy, especially improvements in height and geoid determination accuracy, enables us to apply repeated GPS/Leveling for four dimensional monitoring of ground deformation. We applied GPS/Leveling solution by Kostakis and Sideris(1999) in its simplified form for ground subsidence monitoring in　Kawasaki、Japan,　with repeated surveys for every February ~ March of 2003, 2004, and 2005.We performed 24 hours GPS observations at the selected bench marks more than ten inside Kawasaki,Japan and determined horizontal position and ellipsoidal height. Also we applied the GSIGEO2000, a geoid model covering　the whole area of the Japanese Island, and determined the orthometric height. We also performed ordinary precise leveling at the same station of GPS observation. Thus we may compare two kinds of height, leveling orthometric height and GPS orthometric height. Mean difference of these two heights　is ＋6.９mm.This suggest that we can obtain orthometric height with applying－６.９mm of correction.

Temporal change of geoidal height ranges +0.2ｍｍ/ｙafter Ardalan and Grafarend(2001).We can neglect time change of geoidal height difference inside comparatively narrow area such as Kawasaki. Thus time change of　height difference between to bench marks should be coincide each other with respect two height system of leveling and GPS height. Our experiences indicates two height coincide within accuracy of ±15mm／year. Furthermore we can obtain horizontal displacement vector by successive GPS survey. Our conclusions are that it is possible to carry out GPS/leveling　with the accuracy of ±１5mm and deduce displacement vectors with the accuracy of several mm/year.

1.Introduction

Repeated GPS survey had been applied for monitoring ground subsidence since early year of GPS(e.g. Chrzanowsky et al[1], Sharif et al[2], Heus[3]). Furthermore recent advancement of GPS geodesy, especially improvements of accuracy of height determination replace precise leveling by GPS height determination(e.g.,Zikoski[4]), and also development of hybrid geoid model enables us to apply repeated GPS/Leveling for four dimensional monitoring of ground deformation.

Theory of GPS/Geoid Leveling was completed exactly in Osakis and Sedaris[5]. We applied this solution with its simplified form for monitoring ground subsidence in Kawasaki, Japan, by the repeated surveys for every February ~ March of 2003, 2004, and 2005 respectively. GPS solution is three dimensional position determination, so repeated GPS survey provide not only height change but also horizontal position change. Our new system can provide four dimensional monitoring of ground deformation.

2.GPS/Geoid Leveling in its simplified from

We can deduce the following observation equation at i-th station

$$h_i^g = H_i^g + N_i^g + \Delta N_i^g \qquad (1)$$

where

h_i^g ：ellipsoidal height at i-th station obtained from GPS observation

H_i^g ：orthometric height at i -th station obtained from precise levelling

N_i^g ：geoidal height at i -th station caluculated from geoid model

ΔN_i^g ：systematic correction to be applied to geoidal height at i -th station,unkown .

ΔN_i^g should be zero when obtained orthometric height gives completely exact separation between geoidal surface and ground surface where geodetic stations locate and two reference surface for geoidal height and ellipsoidal height are the same one. However, this is not general case. We assume this term is one of the systematic error. Other terms can be deduced from observation or suitable model, so ΔN_i^g is estimable.

We assume that the j -th stations are the one where orthometric height are net yet known. These stations locate inside the area where the precise leveling were already performed. Now following equation hold

$$h_j^u = H_j^u + N_j^u + \Delta N_j^u \qquad (2)$$

where

h_j^u ：ellopsoidal height of the j -th station

H_j^u ：orthometric height at j station

N_j^u ：geoidal height at the j -th station

ΔN_j^u : correction to be applied to the j -th station .

Now we assume that ΔN_i^g is a function of the position of geodetic station. When h_j^u, H_j^u, and N_j^u are known from special observations or application of some model, ΔN_j^u is estimable. We can estimate ΔN_j^u at any point thus H_j^u can be deduced. Least squares collocation is applied as in Kostakis and Sideris(1999). We apply more simple deduction and caluculate ΔN_j^u at any point as follows

$$\Delta N_j^u = \frac{\sum_j \omega_j \Delta N_i^g}{\sum_j \omega_j} \tag{3}$$

Where weight ω_j is given by

$$\omega_j = \frac{1}{S_{ij}}$$

S_{ij} : linear distance connecting two points i and j .

3.GPS/Geoid Levelling for monitoring ground subsidence in Kawasaki

For a long time, Kawasaki City,Japan had been suffering from ground subsidence with the order of several cm/year, some times exceeding 20cm/year at the specified bench marks. Extensive precise leveling works had been carried out in order to monitor the subsidence at least once in a year covering whole area of Kawasaki. When GPS survey can provide reliable information of ground subsidence instead of precise leveling, we may save many of the tedious works. Thus application of GPS/Geoid leveling is expected to replace precise leveling, and test observations started since 2003 and continued to 2004,2005.

We performed continuous GPS observations with two 12 hours sessions at the selected bench marks more than ten inside Kawasaki, and determined their horizontal position and ellipsoidal height. The employed dual frequency receivers were Trimmble 4000SSE and sampling interval was 15second with 15 degree of elevation angle. We adopted IGS final ephemerides for analysis the data with BerneseVer.4.2. Also we applied the GSIGEO2000(Kuroishi et al[6]), a hybrid geoid model covering whole area of the Japanese Island, and determined the orthometric height. We also performed ordinary precise levelings at the same stations of test GPS observation. Fig.1 indicates occupied stations for GPS and leveling work in 2003,2004,2005 respectively. The occupied station in 2003 were 8, and successively incleased to be 16 stations in 2004,and finally 20 stations in 2005.

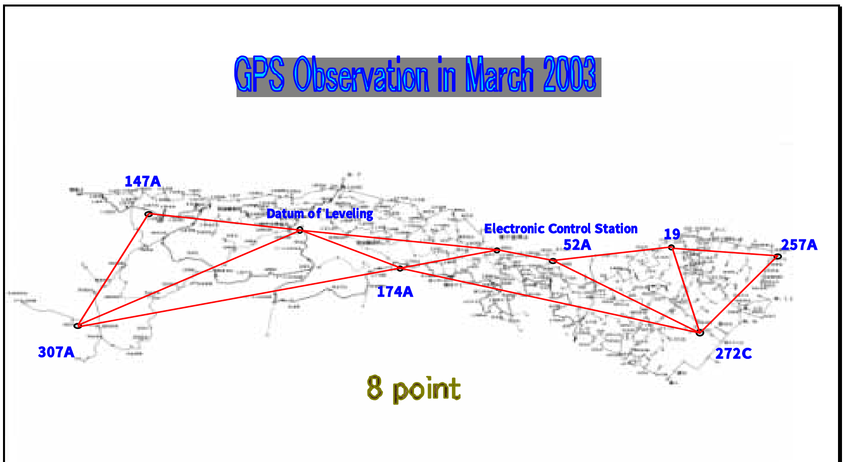

Fig.1 (a)

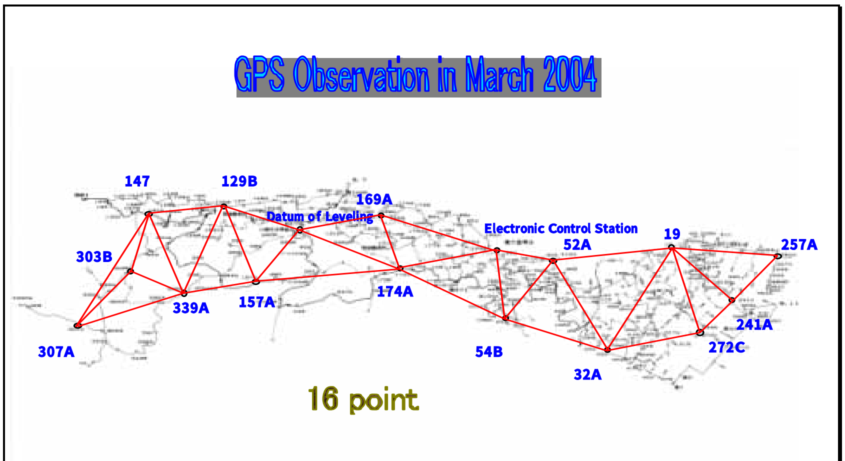

Fig.1 (b)

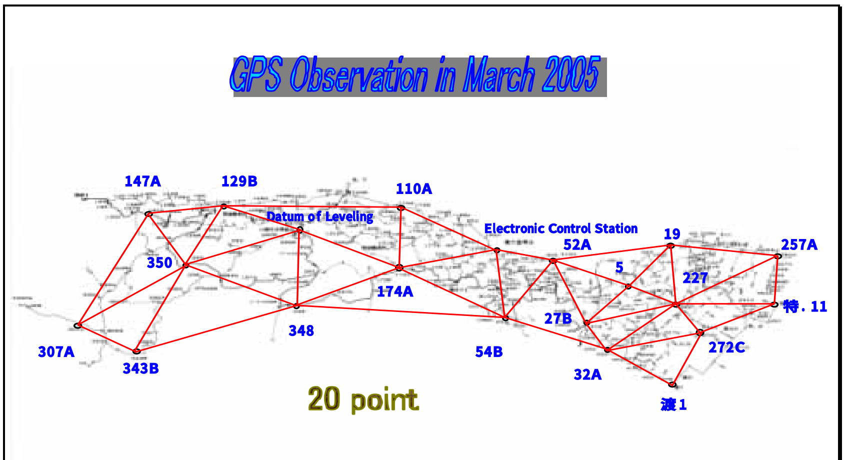

Fig.1 (c)

Fig.1 Occupied stations for GPS/ leveling work in 2003,2004,2005 respectively

We may compare two kinds of height stytem, leveling orthometric height and GPS orthometric height. Fig.2 indicates the results of comparison with respect to GPS orthometric height and Precise leveling height in 2003, 2004, and 2005. Mean difference of these height comparison is +6.9mm.This suggest that we can obtain orthometric height after applying－６.９mm of correction to leveled height.

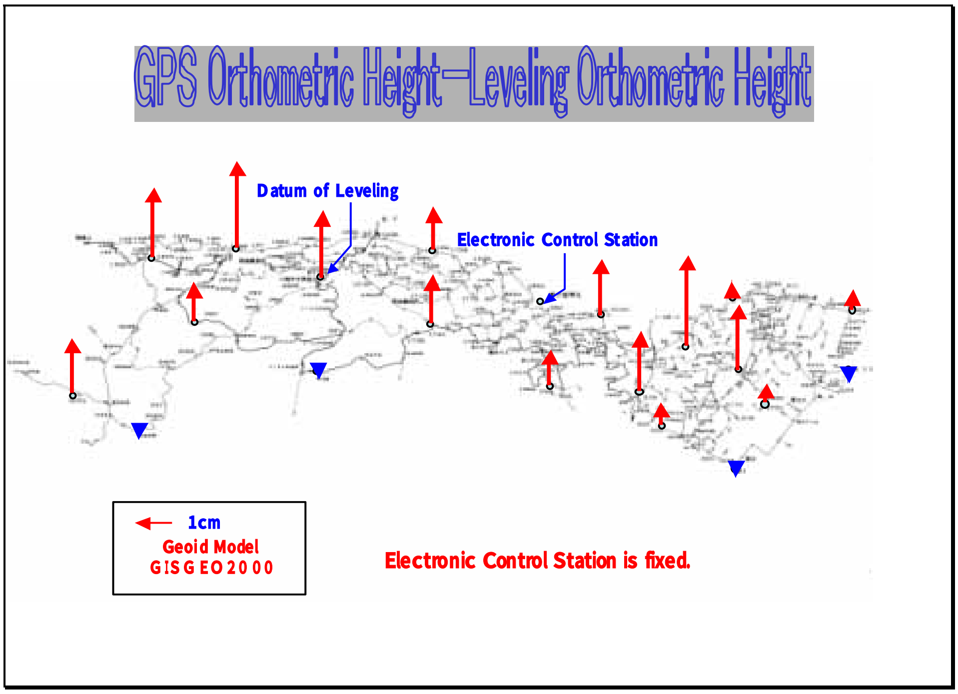

Fig.2 Results of comparison with respect to GPS orthometric height and precise leveling height in 2003, 2004, and 2005.

Temporal change of geoidal height ranges +0.2mm/year after Ardalan and Grafarend[7]. So we may neglect geoidal height change inside comparatively narrow area such as Kawasaki. Thus time change of height difference between to bench marks should be coincide with each other withrespect two height systems of leveling and GPS height. Fig.3 indicates the results of comparison with respect to GPS orthometric height change and precise leveling height change in 2003, 2004, and 2005. No remarkable changes are detected. This may due to effect of recent regulation of pumping out of groundwater by law. Our experiences indicates two height coincide within accuracy of ±15mm／year.

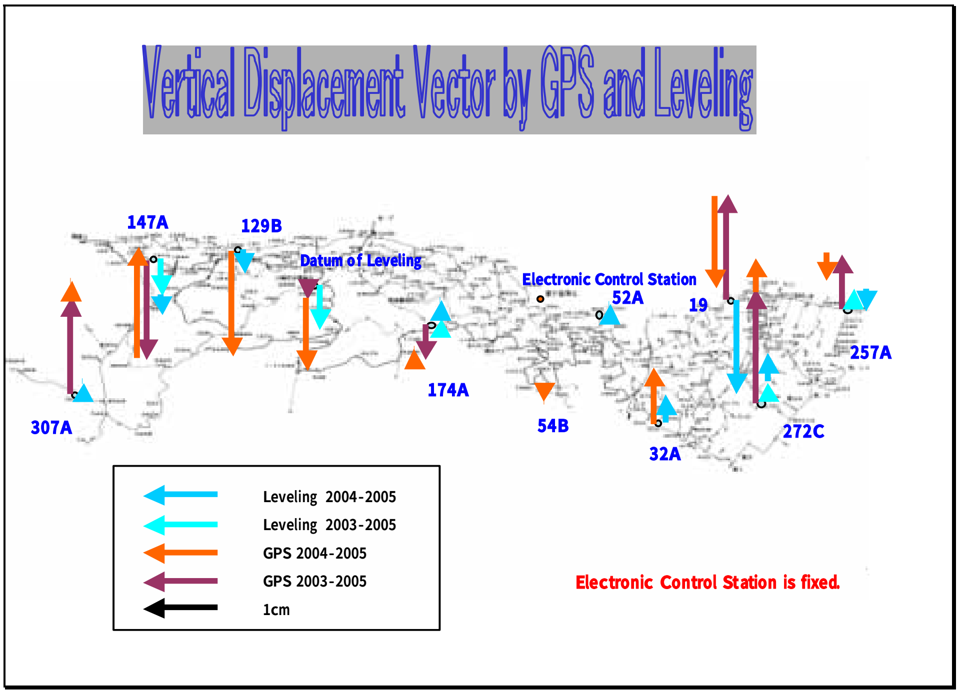

Fig.3 Results of comparison with respect to GPS orthometric height change and precise leveling height change in 2003, 2004, and 2005.

Furthermore we can obtain horizontal displacement vector. Fig.4 indicates successive displacement vectors, from 2003 to 2004 and from 2004 to 2005. The displacement vector at

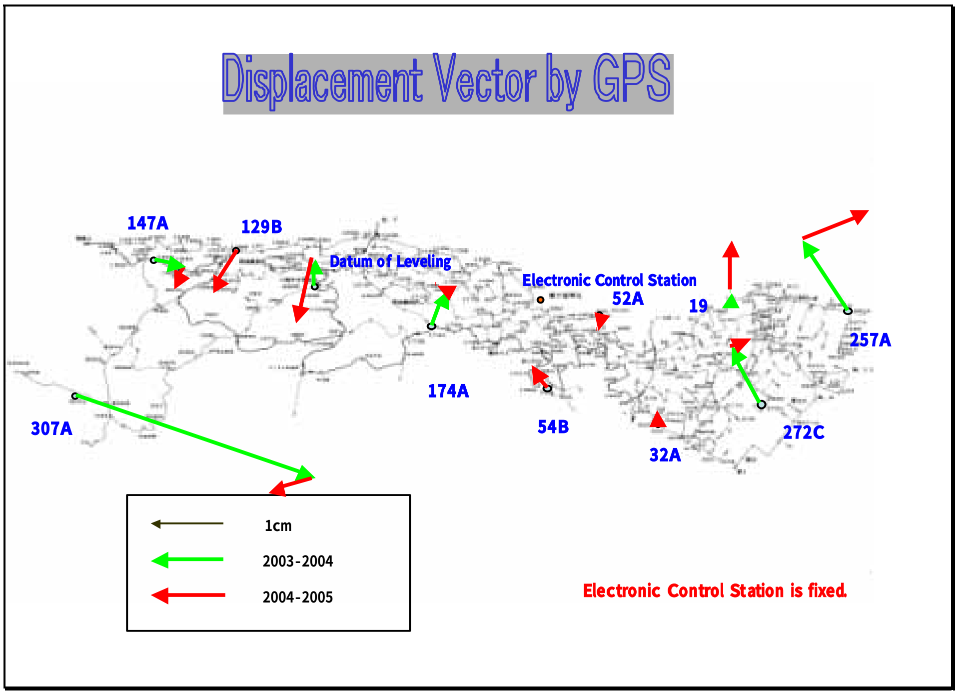

Fig.4 Succesive displacement vector in Kawasaki from 2003 to 2004 and from 2004 to 2005.

307A benchmark indicates some irregular movement and this may due to unknown accident. Neglecting this benchmark, we estimate standard deviation of yeary rate of horizontal movement is several mm/year, and conclude that successive displacement vector at 275A and 272C are significant. Both vectors direct to the north that correspond to the mouth of the Tamagawa River.

4.Conclusions

We may compare two kinds of height, leveling orthometric height and GPS orthometric height. Mean difference of these two heights is ＋6.９mm.This suggest that we can obtain orthometric height with applying－６.９mm of correction. Our conclusions are that it is possible to carry out GPS/leveling within the accuracy of ±１5mm.As for time change of height difference between to bench marks, our experiences indicates two height coincide within accuracy of ±15mm／year. Furthermore we can obtain horizontal displacement vector with the accuracy of several mm/year.

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