지구물리 제 6 권 제 1 호, p. 1-11 (2003년 3월)

Advantage of Using Free Network Adjustment Technique in the Crustal Movement Monitoring Geodetic Networks

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ABSTRACT

There are numerous adjustment techniques that deal with the adjustment of geodetic networks but the least squares adjustment is the most common one. During the network adjustment procedure two techniques can be used, the free network adjustment technique and the constrained network adjustment technique. In order to determine the optimum technique for adjusting the geodetic networks, which used for the geodynamical purposes, data from two different geodetic networks "Sinai geodetic network, Egypt, and HGN network, South Korea" had been examined. The used networks had a different configuration and located in different areas with different seismic activity. The results show that both techniques have a high accuracy and no remarkable differences in terms of RMS. On the contrary, the resulted coordinates shows that the constrained network adjustment technique not only cause a remarkable distortion in the station final coordinates but also if the fixed points that define the datum parameters are changed different solutions for the coordinates will be determined. This distortion affect not only in the determination of point displacement but also in the estimation of the deformation parameters, which play a significant role in the geodynamical interpretation of results. Comparing the results which obtained from both techniques with the widely known geodynamical models of the area reviles that the free network adjustment technique results are clearly match with these models, while those obtained from the constrained technique didn't match at all. By considering the results it seams to be that the free network adjustment technique is the optimum technique, which can be used for the geodetic network adjustment.

Key words: adjustment, geodetic networks, distortion, least squares adjustment

Ahmed M. Hamdy and Bong Gon Jo, 2003, Advantage of using free network adjustment technique in the crustal movement monitoring geodetic networks. Journal of the Korean Geophysical Society, v. 6, n. 1, p. 1-11

요 약: 측지망 조정에는 여러 가지 기법이 있으나 가장 보편적인 것이 최소자승법이다. 지각 변위 연구 등 지구역학적 연구를 위해 GPS 자료를 처리할 때 일반적으로 두 가지 망조정 기법이 사용되는데 그 중 하나는 자유망 조정법이고 나머지 하나는 제한적망 조정법이다. 이 두가지 기법 중에서 어느 것이 더 지구역학적 목적에 적절한지를 결정하기 위해 두 개의 다른 측지망 즉, "이집트의 시나이 측지망"과 "한국의 HGN 측지망"의 데이터를 사용하여 조사하였다. 사용된 두 개의 망은 서로 모양이 다를 뿐만 아니라 지진학적 활동이 다른 지역에 위치해 있다. 이 연구의 결과는 두 기법이 모두 RMS 입장에서 보면 고정밀성을 가지고 있고 큰 차이가 없음을 보인다. 그러나 좌표값 결과를 볼 때 제한적망 조정법이 자유망 조정법에 비해 더 많은 왜곡을 일으켰을 뿐만 아니라 측지망을 정의하는 고정점이 변하면 좌표값도 다르게 결정되었다. 이러한 왜곡은 측정점의 위치 이동량은 물론 자료처리 결과의 지구역학적 해석에 중요한 역할을 하는 변위요소들의 추정에도 영향을 미친다. 이 연구의 대상 지역에 대해 널리 알려진 지구역학 모델과 두 기법으로부터 얻어진 결과를 비교해 보면, 자유망 조정법의 결과가 이들 모델에 확실히 잘 맞는 반면 제한적망 조정법의 결과는 전혀 맞지 않는 것으로 나타났다. 이런 결과를 종합해 볼 때 자유망 조정법이 지구역학적 목적에 더 부합하는 측지망 조정기법이라고 판단된다.

주요어: 조정, 측지망, 왜곡, 최소자승법

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1. Introduction

Numerous adjustment techniques can be used for geodetic network adjustment, but the least squares adjustment is the most common technique which widely used in geodetic network adjustment (Vaniček and Krakiwsky, 1982). The adjustment of a GPS geodetic network data may be done by one of the following methods, free network adjustment technique or constrained network adjustment technique (Nassar, 1985 and 1986; Bock, 1982 and 1983; Strang and Borre, 1992). The term free network refers to a network whose adjustment is made free from any kind of external constrains. This means that the network can freely translate, rotate or undergo scale change in space. Based on that concept all the network positions will receive some corrections after the adjustment.

While, the basic of constrained network adjustment is to choose some network stations to be fixed or their coordinates are assigned known variances. If the fixed points that define the datum parameters are changed different solutions for the coordinates will be determined (Mousa, 1992).

2. GPS geodetic networks and campaigns

The data, which used in our study, were collected from two different geodetic networks "Sinai geodetic network, Egypt and HGN, South Korea", table (1) represents the campaign's information for the both geodetic networks. Sinai geodetic network, which composed of ten geodetic stations, is mainly constructed to monitor the recent crustal movements in and around the Sinai Peninsula (Hamdy, 2001). Sinai Peninsula is considered to be a seismo active area where it is surrounded by three seismic zones (Fig. 1a), the largest earthquake which occurred in this area took place in Nuweiba city at November 22, 1995, and it has a magnitude of Mw = 7.1 (Kebeasy, 1990; Said, 1990;Tealeb, 1995; Kimata *et al*., 1996; Atiya, 1997; Hamdy, 2001). While, the Honam Geodetic Network " HGN" is apart of KAO geodetic network "Korea Astronomy Observatory" and it is composed of five geodetic stations (Hamdy *et al*., 2002). Generally the Korean peninsula is considered to be having a relatively low seismic activity with respect to the seismic activity in Sinai Peninsula (Figs. 1a and 1b) (KMA, 2001; Hamdy *et al*., 2002). Through out the previous information it is easy to find out that the two networks are differing from each other not only in their location "latitude and longitude" and their configuration but also they differ from each other by the amount of expected movements.

3. GPS data Analysis

The observed data from both geodetic networks

Table 1. Networks Campaign's Information.

Network	Campaigns	Campaigns length	Remarks
Sinai Network	1994 1996	7days	In 1995 an earthquake with a magnitude 7.1 take place near by Nuweiba city.
HGN Network	2001 2002	5days	

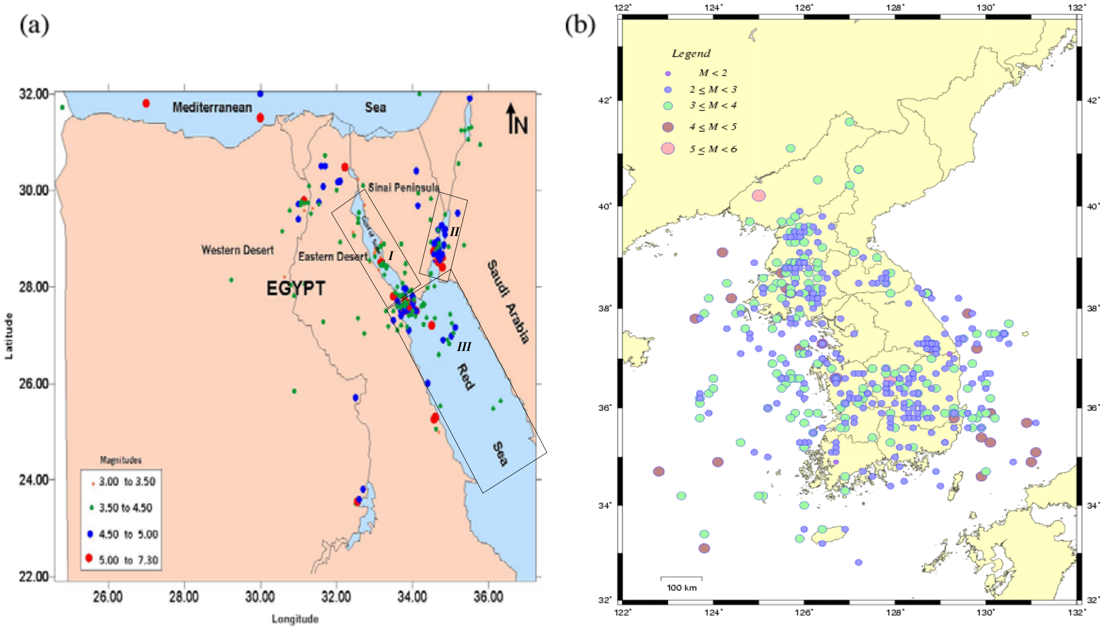


Fig. 1. (a) Seismic map of Sinai Peninsula, (b) Seismic map of the Korean Peninsula.

have been analyzed by using Bernese software version 4.2 (Beutler *et al.*, 2001). The IGS final orbit "Prices ephemeris" had been used in the orbit determination and the quasi- ionosphere free (QIF) strategy was used for the ambiguity resolution. We estimated the baselines with L3 ionosphere free linear combination. In adjustment step for both geodetic network two-adjustment techniques "free network adjustment technique and constrained network adjustment technique" were used in order to compare the results of both techniques.

Regarding to table (1) the considered epochs for Sinai geodetic networks are 1994 and 1996 respectively. During the adjustment step of Sinai geodetic network by using free network adjustment technique the network C.g. "Center of gravity" is considered to be fixed, resulting from that all the network stations coordinates receive some corrections after the adjustment step "from the definition". The resulted coordinates together with their RMS "root mean squares error" are represented in table (2). In case of constrained network adjustment technique "if the station which defined the datum is changed different solutions will be obtained, from the definition" two strategies have been used in order to investigate the stability of this solution. Firstly, station HUR "this station have a moderate longitude with respect to other network stations and lying in the southern part of the network (Fig. 2a)" is considered to be fixed during the network adjustment. Secondly, we fix FAN station, which is considered to be lying in the northwest part of Sinai geodetic network (Fig. 2a). The results, which obtained from the constrained network adjustment technique, are represented in table (2). In order to distinguish the distortion occurred in the network final coordinates figure (3) has been constructed to illustrate the relation shape between the initial coordinates "prior coordinates" and the final coordinates "adjusted coordinates". From figure 3, it is clear that" in case of HUR fixed" all the network stations move to the south direction to ward station HUR. While in the east-west direction some stations move to the east while others move to the west depending on it is location with respect to station HUR. While the resulted distortion from the fixation of FAN station is so clear where all the network stations move toward the fixed station "FAN station" i.e. all the network

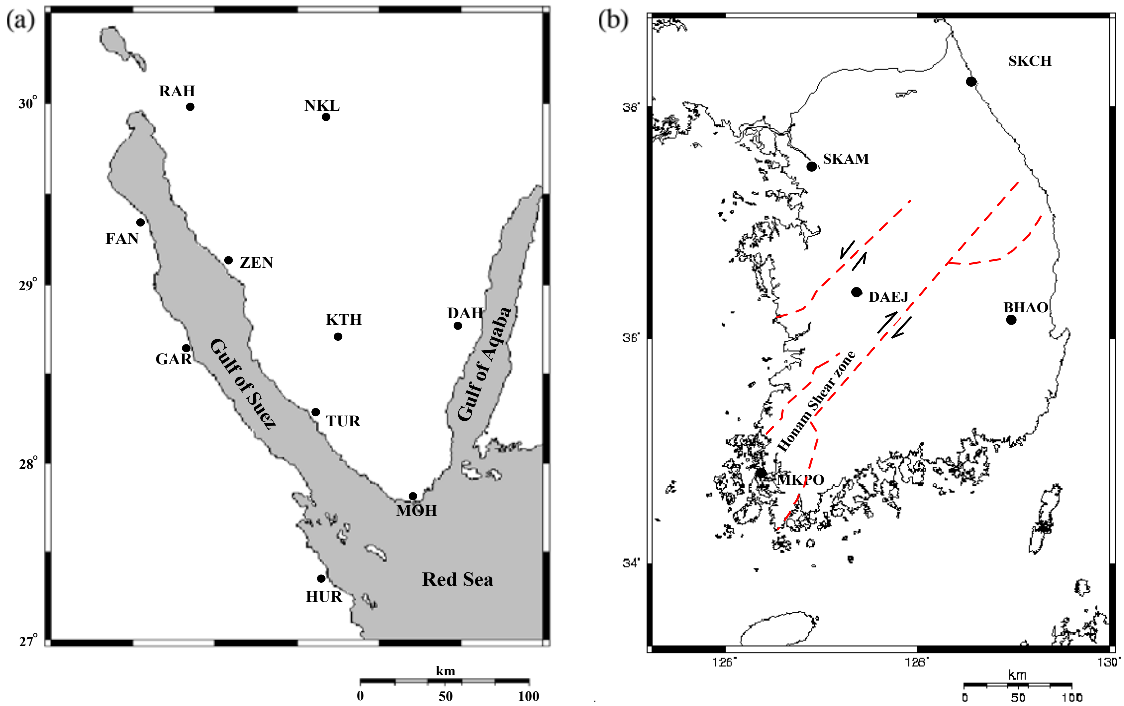


Fig. 2. (a) Sinai geodetic network, (b) HGN geodetic network.

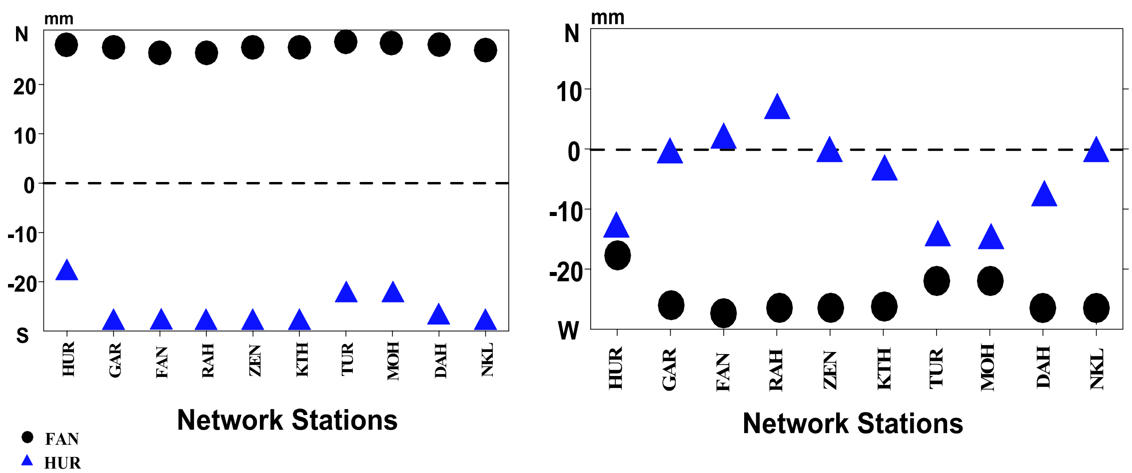


Fig. 3. Distortion in Sinai geodetic network coordinates resulting from the constrained network adjustment technique.

station move to the northwest direction.

In case of HGN geodetic network we also use both adjustment techniques "free network adjustment technique and constrained network adjustment technique" in the network adjustment step. The free network adjustment technique had been applied to the HGN network data and the resulted final coordinates and their RMS are represented in table (3). In constrained network adjustment technique we also use two different solution strategies "by using two different fixed stations". In the first solution strategy we fix station DAEJ while in the second

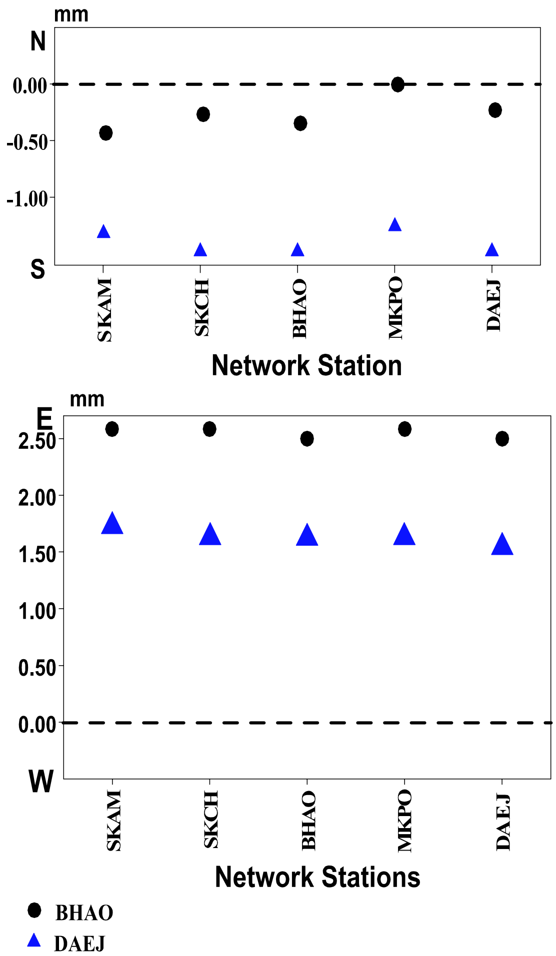


Fig. 4. Distortion in HGN geodetic network coordinates resulting from the constrained network adjustment technique.

strategy we fix station BHAO (Table 3 and Fig.2b). Moreover the changes that occurred in the network stations final coordinates, which resulted from constrained network adjustment technique, are represented in figure (4). In case of fixing DAEJ station most of the network stations move toward it but this movement is not so clear as that in case of HUR and FAN stations in Sinai geodetic network "maybe because DAEJ station is near by the HGN C.g.". In case of BHAO station all the network stations move to the south and to the west directions, which is clear from figure (4), i.e. all the network stations move towards BHAO station.

4. Discussion

The obtained results from Sinai geodetic network computation reveals that the RMS in cases of free network adjustment technique is less than 1.2mm while in case of constrained network adjustment technique the resulted RMS are not greater than 1.7mm (Table 2). For HGN geodetic network and through out table 3 it is clear that the RMS in case of free network adjustment technique are less than 0.6mm and in case of constrained network adjustment technique it is less than 1.0 mm. Generally, by examining the RMS of both techniques the RMS that resulted from the free network adjustment technique shows a slightly higher accuracy (tables 2 and 3).

Since the displacement is considered to be the only required input data when we are calculating the deformation tensor (Grant, 1990), we also examine the results to investigate the effect of different solution on the resulted displacements. The results, which obtained from Sinai geodetic network was used to calculate the displacement in Sinai peninsula by considering epoch 1994 as a reference epoch for 1996. Firstly the displacement was calculated using the coordinates which resulted from the free network adjustment technique (Fig. 5a and Table4). Secondly the displacement was calculated using the resulted coordinates which obtained from constrained network adjustment technique (Figs. 5b and 5c and Table4). Through out these figures and table it is recognized that there is a remarkable change in the displacement components "d_n and d_e" not only between the free network adjustment technique and the constrained network adjustment technique but also when we use different strategies in constrained network adjustment technique different displacement components are obtained. In case of HGN geodetic network displacement computation we use the epoch 2001 as a reference epoch for the epoch 2002 and by comparing the results, it is found that there is a remarkable differences not only in the station displacement components but also in their corresponding azimuth (Figs.6a, 6b, 6c and Table 5). Finally, we compare the obtained displacement

Table 2. The Stations final coordinates in WGS 84 reference frame system, resulting from using different adjustment techniques for Sinai geodetic network.

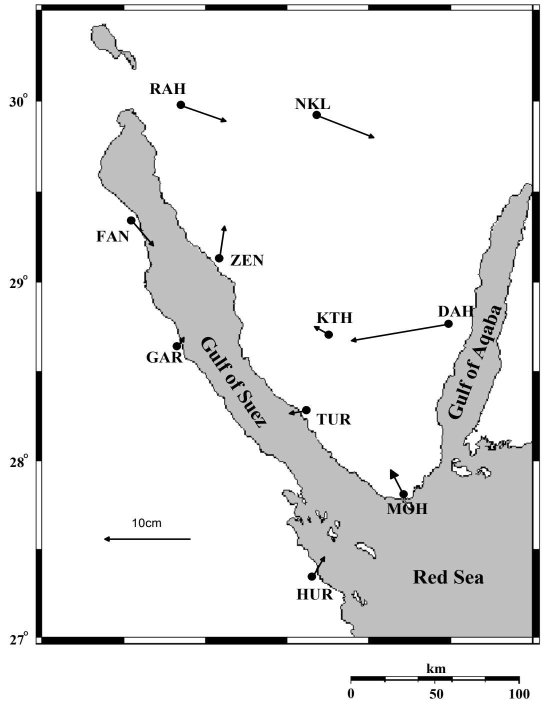
Year	1994						1996					
Station	X	RMS X	Y	RMS Y	Z	RMS Z	X	RMS X	Y	RMS Y	Z	RMS Z
HUR*	4719518.2919	0.0008	3138837.0651	0.0005	2915115.8445	0.0005	4719518.2668	0.0015	3138837.0663	0.0010	2915115.8601	0.0010
GAR*	4705289.2190	0.0006	3034782.9436	0.0004	3044479.4424	0.0004	4705289.2136	0.0015	3034782.9436	0.0010	3044479.4588	0.0010
FAN*	4687850.8120	0.0008	2994041.2460	0.0006	3110554.6495	0.0006	4687850.8228	0.0012	2994041.2803	0.0008	3110554.6699	0.0008
RAH*	4643927.5962	0.0010	3000769.1439	0.0007	3169580.6647	0.0007	4643927.5866	0.0012	3000769.1983	0.0008	3169580.6859	0.0008
ZEN*	4670465.8399	0.0007	3044908.3133	0.0005	3087652.1872	0.0005	4670465.8063	0.0008	3044908.2997	0.0005	3087652.1820	0.0005
KTH*	4652796.2331	0.0006	3113620.7406	0.0004	3047399.8611	0.0004	4652796.2292	0.0010	3113620.7260	0.0007	3047399.8497	0.0007
TUR*	4682682.1719	0.0006	3110728.4507	0.0004	3002886.4845	0.0004	4682682.1809	0.0009	3110728.4358	0.0006	3002886.4936	0.0006
MOH*	4668877.2562	0.0006	3171025.0784	0.0004	2961578.6486	0.0004	4668877.2412	0.0011	3171025.0522	0.0007	2961578.6392	0.0007
DAH*	4614302.4850	0.0012	3167434.6264	0.0009	3049704.7707	0.0008	4614302.5647	0.0015	3167434.5296	0.0010	3049704.6891	0.0010
NKL*	4598942.7208	0.0012	3072099.8381	0.0009	3167150.7723	0.0009	4598942.7147	0.0011	3072099.9143	0.0008	3167150.7991	0.0008
HUR#	4719518.2919	0.0000	3138837.0651	0.0000	2915115.8445	0.0000	4719518.2919	0.0000	3138837.0651	0.0000	2915115.8445	0.0000
GAR#	4705289.2189	0.0007	3034782.9437	0.0005	3044479.4425	0.0005	4705289.2417	0.0023	3034782.9450	0.0016	3044479.4454	0.0015
FAN#	4687850.8117	0.0011	2994041.2459	0.0008	3110554.6495	0.0007	4687850.8524	0.0022	2994041.2827	0.0015	3110554.6574	0.0015
RAH#	4643927.5953	0.0015	3000769.1435	0.0011	3169580.6643	0.0010	4643927.6164	0.0023	3000769.2010	0.0015	3169580.6734	0.0015
ZEN#	4670465.8397	0.0010	3044908.3132	0.0007	3087652.1872	0.0007	4670465.8349	0.0019	3044908.3014	0.0013	3087652.1687	0.0013
KTH#	4652796.2329	0.0011	3113620.7407	0.0008	3047399.8612	0.0007	4652796.2578	0.0022	3113620.7276	0.0015	3047399.8364	0.0014
TUR#	4682682.1719	0.0008	3110728.4508	0.0006	3002886.4846	0.0005	4682682.2080	0.0016	3110728.4361	0.0011	3002886.4795	0.0010
MOH#	4668877.2563	0.0009	3171025.0786	0.0006	2961578.6488	0.0006	4668877.2677	0.0016	3171025.0521	0.0011	2961578.6246	0.0010
DAH#	4614302.4848	0.0016	3167434.6265	0.0012	3049704.7709	0.0011	4614302.5927	0.0025	3167434.5306	0.0017	3049704.6754	0.0016
NKL#	4598942.7199	0.0017	3072099.8377	0.0012	3167150.7720	0.0012	4598942.7437	0.0022	3072099.9163	0.0015	3167150.7859	0.0015
HUR^	4719518.2931	0.0011	3138837.0661	0.0008	2915115.8453	0.0008	4719518.2523	0.0022	3138837.0295	0.0015	2915115.8371	0.0015
GAR^	4705289.2199	0.0009	3034782.9444	0.0007	3044479.4431	0.0006	4705289.2017	0.0020	3034782.9087	0.0013	3044479.4377	0.0014
FAN^	4687850.8120	0.0000	2994041.2460	0.0000	3110554.6495	0.0000	4687850.8120	0.0000	2994041.2460	0.0000	3110554.6495	0.0000
RAH^	4643927.5961	0.0014	3000769.1441	0.0011	3169580.6648	0.0010	4643927.5762	0.0015	3000769.1645	0.0010	3169580.6659	0.0010
ZEN^	4670465.8404	0.0009	3044908.3138	0.0007	3087652.1877	0.0006	4670465.7947	0.0013	3044908.2651	0.0009	3087652.1611	0.0009
KTH^	4652796.2337	0.0011	3113620.7413	0.0008	3047399.8617	0.0008	4652796.2176	0.0017	3113620.6914	0.0012	3047399.8287	0.0012
TUR^	4682682.1728	0.0009	3110728.4515	0.0007	3002886.4852	0.0006	4682682.1680	0.0016	3110728.4001	0.0011	3002886.4718	0.0011
MOH^	4668877.2572	0.0010	3171025.0793	0.0008	2961578.6494	0.0007	4668877.2277	0.0018	3171025.0162	0.0013	2961578.6169	0.0013
DAH^	4614302.4857	0.0017	3167434.6272	0.0012	3049704.7714	0.0011	4614302.5524	0.0022	3167434.4946	0.0015	3049704.6677	0.0015
NKL^	4598942.7207	0.0017	3072099.8383	0.0013	3167150.7725	0.0012	4598942.7035	0.0018	3072099.8801	0.0012	3167150.7785	0.0012

RMS is represented in meter. * Free network solution. # HUR station considered to be fixed. ^ FAN station considered to be fixed.

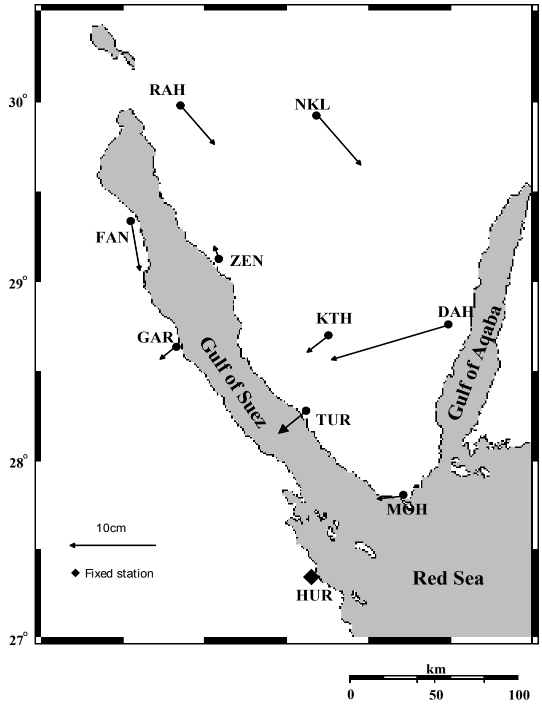
Table 3. The Stations final coordinates in WGS 84 reference frame system, resulting from using different adjustment techniques for HGN network.

Year	2001						2002					
Station	X	RMS X	Y	RMS Y	Z	RMS Z	X	RMS X	Y	RMS Y	Z	RMS Z
SKMA*	-3043536.8299	0.0004	4050958.9427	0.0003	3861031.6215	0.0006	-3043536.8300	0.0003	4050958.9425	0.0004	3861031.6201	0.0004
SKCH*	-3126511.1997	0.0004	3921458.1462	0.0004	3927386.0419	0.0005	-3126511.1994	0.0004	3921458.1438	0.0005	3927386.0421	0.0005
BHAO*	-3243254.5340	0.0005	4008470.7323	0.0004	3743543.6834	0.0005	-3243254.5327	0.0005	4008470.7347	0.0006	3743543.6871	0.0005
MKPO*	-3109396.4416	0.0005	4220348.6338	0.0006	3621241.1409	0.0004	-3109396.4430	0.0003	4220348.6361	0.0005	3621241.1394	0.0004
DAEJ*	-3120042.2237	0.0004	4084614.8118	0.0003	3764026.7873	0.0006	-3120042.2238	0.0003	4084614.8095	0.0004	3764026.7862	0.0004
SKMA#	-3043536.8297	0.0006	4050958.9426	0.0008	3861031.6216	0.0007	-3043536.8298	0.0005	4050958.9448	0.0007	3861031.6210	0.0006
SKCH#	-3126511.1998	0.0004	3921458.1460	0.0006	3927386.0420	0.0006	-3126511.1993	0.0005	3921458.1461	0.0007	3927386.0430	0.0007
BHAO#	-3243254.5346	0.0006	4008470.7329	0.0007	3743543.6842	0.0007	-3243254.5326	0.0006	4008470.7370	0.0008	3743543.6880	0.0007
MKPO#	-3109396.4416	0.0004	4220348.6339	0.0006	3621241.1407	0.0005	-3109396.4428	0.0005	4220348.6383	0.0007	3621241.1400	0.0006
DAEJ#	-3120042.2237	0.0000	4084614.8118	0.0000	3764026.7873	0.0000	-3120042.2237	0.0000	4084614.8118	0.0000	3764026.7870	0.0000
SKMA^	-3043536.8290	0.0008	4050958.9418	0.0010	3861031.6209	0.0009	-3043536.8311	0.0007	4050958.9399	0.0008	3861031.6163	0.0008
SKCH^	-3126511.1991	0.0007	3921458.1449	0.0009	3927386.0408	0.0008	-3126511.2005	0.0007	3921458.1413	0.0009	3927386.0385	0.0009
BHAO^	-3243254.5340	0.0000	4008470.7323	0.0000	3743543.6834	0.0000	-3243254.5340	0.0000	4008470.7323	0.0000	3743543.6834	0.0000
MKPO^	-3109396.4409	0.0007	4220348.6331	0.0009	3621241.1404	0.0008	-3109396.4441	0.0007	4220348.6335	0.0009	3621241.1355	0.0008
DAEJ^	-3120042.2231	0.0007	4084614.8111	0.0008	3764026.7868	0.0008	-3120042.2249	0.0007	4084614.8070	0.0008	3764026.7824	0.0007

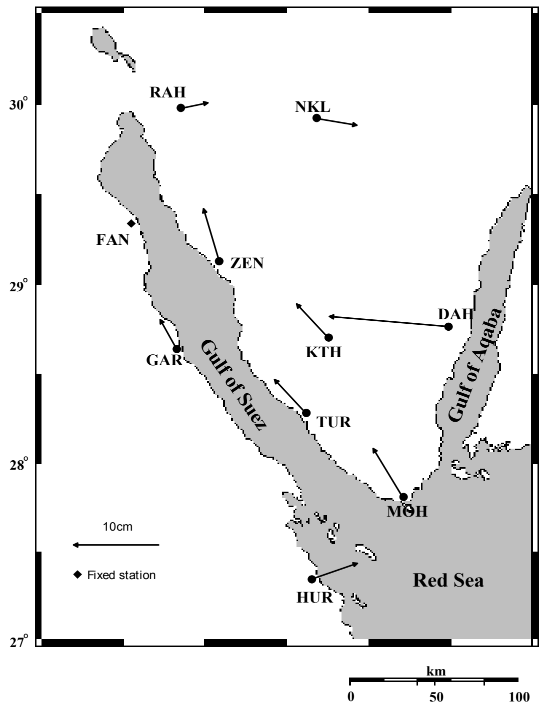
RMS is represented in meter. * Free network solution. # DAEJ station considered to be fixed. ^ BHAO station considered to be fixed.



a. Free network solution

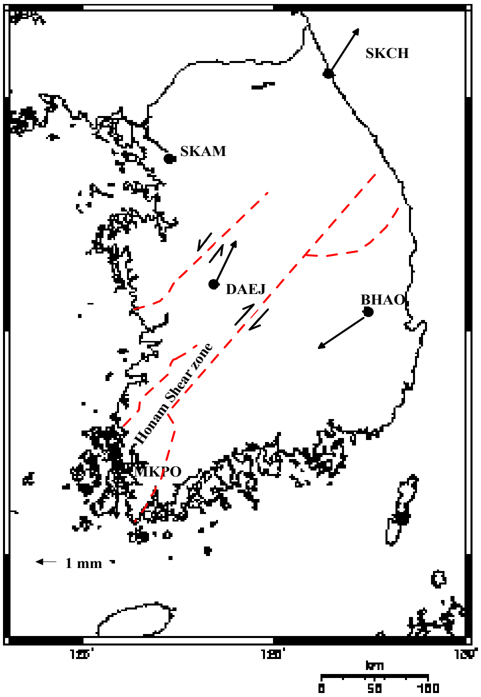


b. Constrained network solution
(HUR is fixed)

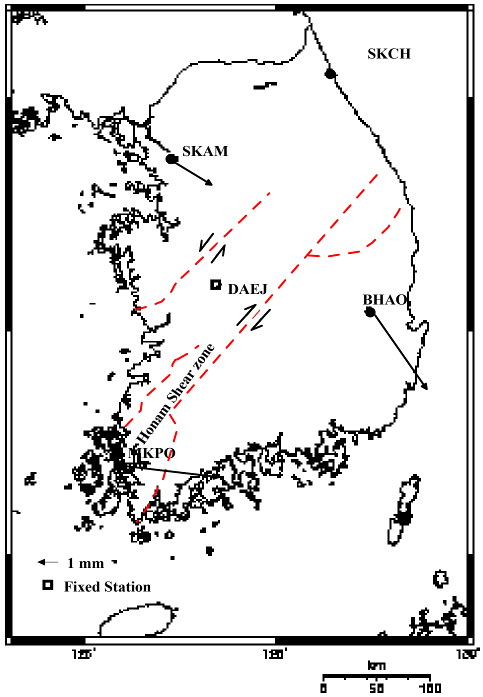


c. Constrained network solution
(FAN is fixed)

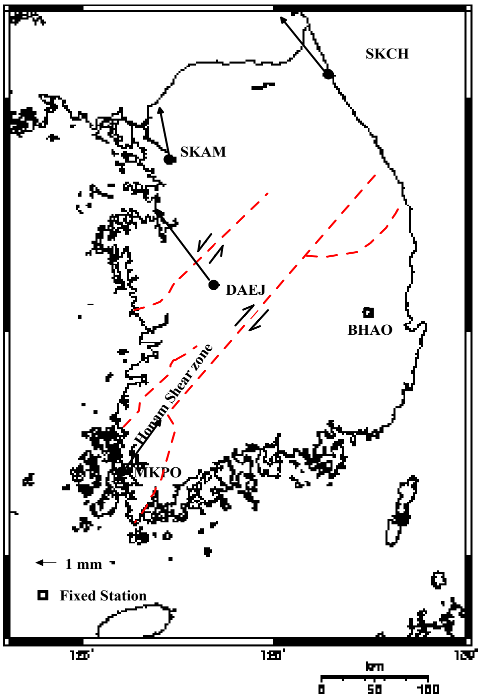
Fig. 5. Displacement in Sinai geodetic network.



a. Free network solution



b. Constrained network solution
(DAEJ is fixed)



c. Constrained network solution
(BHAO is fixed)

Fig. 6. Displacement in HGN geodetic network.

Table 4. Displacement in Sinai geodetic network resulted from different adjustment technique.

Station	Solution Type											
	Free Net work				Constrained net work adjustment							
					Station HUR fixed				Station FAN Fixed			
	d_n	d_e	azimuth	Dis.	d_n	d_e	azimuth	Dis.	d_n	d_e	azimuth	Dis.
HUR	0.0039	-0.0248	30	0.0251	0	0	0	0	0.0347	0.0424	70	0.0548
GAR	0.0008	-0.0053	30	0.0054	-0.018	-0.018	230	0.0228	0.0214	-0.0339	332	0.0401
FAN	-0.0071	0.0352	140	0.036	0.0515	0.0515	170	0.0549	0	0	0	0
RAH	-0.0552	-0.0024	110	0.0552	-0.0121	-0.0121	140	0.0612	-0.0244	0.0146	78	0.0285
ZEN	-0.0053	0.0359	8	0.0362	0.0122	0.0122	339	0.0127	-0.0003	-0.0668	344	0.0668
KTH	-0.0003	-0.0151	300	0.0151	0.025	0.025	232	0.0281	-0.0401	-0.0337	318	0.0524
TUR	-0.0127	0.0119	260	0.0174	-0.0307	-0.0307	230	0.039	-0.0395	-0.0332	318	0.0516
MOH	0.0165	0.0253	334	0.0302	0.0287	0.0287	264	0.0288	-0.069	-0.0092	330	0.0697
DAH	-0.0916	0.0857	260	0.1254	-0.0147	-0.0147	253	0.1444	0.0164	-0.1475	275	0.1484
NKL	0.0349	-0.068	112	0.0764	-0.0162	-0.0162	140	0.0821	0.039	-0.0229	100	0.0452

Azimuth measured clockwise and the displacements are in meter and d_n and d_e are the displacements components.

Table 5. Displacement in HGN geodetic network resulted from different adjustment technique.

Station	Solution Type											
	Free Net work				Constrained net work adjustment							
					Station DAEJ fixed				Station BHAO Fixed			
	d_n	d_e	azimuth	Dis.	d_n	d_e	azimuth	Dis.	d_n	d_e	azimuth	Dis.
SKMA	0.00018	9.4E-05	55	0.0002	-0.0011	0.0019	121	0.0022	0.0027	-0.0005	349	0.00275
SKCH	-0.0021	0.0012	32	0.0024	-4E-05	-0.0003	210	0.00025	0.00304	-0.0023	322	0.00381
BHAO	-0.0004	-0.0027	235	0.0027	-0.0037	0.00255	146	0.00449	0	0	0	0
MKPO	-0.0006	0.00252	182	0.0026	0	0.0045	97	0.0045	0.0026	0.00189	36	0.00321
DAEJ	-0.0007	0.00217	25	0.0023	0	0	0	0	0.0036	-0.0026	324	0.00444

Azimuth measured clockwise and the displacements are in M and d_n and d_e are the displacements components.

for both geodetic networks with the widely known geodynamical models for both areas e.g., (Badawy and Horvath, 1999; Hamdy 2001 "for Sinai", Chough *et al.*, 2000; Hamdy *et al.*, 2002 "for HGN") and it is found that the results obtained from free net work adjustment technique is concede with these models.

5. Conclusions

The previous discussion reveals that both geodetic network adjustment techniques give high accuracy but the free network adjustment technique shows slightly high accuracy than the constrained network adjustment technique. The distortion occurred in the network station coordinates resulting from using the constrained network adjustment technique affect not only the displacement calculation but also in its azimuth, which affect on the deformation parameters estimation. Comparing the resulted displacement from both techniques with the widely known geodynamical models of both areas show that the free network adjustment result is totally concede with these models. The free network adjustment technique is the optimum adjustment technique, which can be used in the adjustment of the geodetic network for the geodynamical applications.

Acknowledgment

This study was supported by KOSEF. We appreciate the supporting given by the Seismological Lab members in the Department of Earth Environmental Sciences Chonbuk National University, South Korea. We also thank KAO for sharing their data. We so appreciated for two anonymous reviewers for their critical reviews and comments, which improve the quality of the Paper.

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2003년 1월 6일 원고접수
2003년 3월 24일 원고채택