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JOINT HYPOCENTER DETERMINATION OF THE GULF OF AQABA EARTHQUAKES

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الخلاصة: تناول البحث تحديد مواقع زلازل خليج العقبة بطريقة تحديد مواقع الزلازل المترابط وذلك باستخدام حركة الموجات الابتدائية لزلازل خليج العقبة والمسجلة بواسطة ٧ محطات سيزمية تابعة لشبكة محطات الزلازل الأردنية كما تم عمل تصحيح زمن رحلة الموجات الابتدائية للمحطات السيزمية ومنها ٣ محطات: الحطبة (HIT)، العقبة (AQB) ، المرصد (MRS) لها قيم سالبة وهى –٠,٠٠٣ و–٠,٠٢١ و –٠,٠٠١ (ثانية) بالتتابع ويمكن افتراض ان هذه المحطات تقع فوق مناطق لها تراكيب سرعات عالية والمحطات الأخرى: النقب (NAQ) ، الدراويش، (JDR)، المدورة (MDR) و الهشيم ( ) HSH لها قيم موجبة وهى ٠,٠٠٥ و ٠,٠٠٣ و ٠,٠٠١ و ٠,٠١٤ (ثانية) بالتتابع. ويمكن افتراض أن هذه المحطات تقع فوق مناطق لها تراكيب سرعات منخفضة. والزلازل الموقعة بهذه الطريقة أكثر دقة من التحديد باستخدام برنامج HYPO71PC والتي تستخدم في تحديد مواقع الزلازل فى العمل الروتينى اليومى.

ABSTRACT: *Seven seismic stations at the north-western side of the Gulf of Aqaba belonging to the Jordan Seismic Network were used in the calculation of joint hypocenter determination method. Three stations HIT, AQB and MRS have negative signs in P-wave travel time corrections and their values are -0.003, -0.021, -0.001. It is possible to assume that the underground structure in this area has a particular characteristic of high velocity structure and other stations HSH, MDR, JDR and NAQ have positive signs and their values are 0.014, 0.001, 0.003, 0.005. It is possible to assume that the subsurface structure in this area has a particular characteristic of low velocity structure. The hypocenter locations determined by the joint hypocenter determination method are more precise than those determined by HYPO71PC program. The method simultaneously solves for earthquake location and station corrections. The station corrections reflect not only different crustal conditions in the vicinity of the stations, but also the difference between actual and model seismic velocities along each of the earthquake - station ray paths.*

INTRODUCTION

The Gulf of Aqaba is known to be one of the seismic active area .Earthquake Occurrences are mainly found in both ends of Gulf of Aqaba. Only shallow small-size earthquakes are observed along the Levant - Aqaba Trend. This trend is a continuation of the Levant active fault and extends along the Gulf of Aqaba and southwest in the Red Sea and bisects the clsymic trend at about 27^o N and 34.6^o E (Kebeasy, 1990). The Gulf of Aqaba location map and seismicity map are shown in figures 1 and 2.

The earthquake location is defined as the origin time and coordinates of the focus of the source of elastic radiation, the hypocenter. The epicenter is the point on the earth's surface directly above the hypocenter; therefore the epicenter and the hypocenter coincide for a surface event.

Douglas (1967) introduced a method for joint hypocenter determination for teleseismic events that has been followed by numerous variants and many applications.. This method has been widely used to improve the location of a group earthquakes, by Freedman (1967) Dewey (1972 and 1990) ; Smith (1982); Spencer and Engdahl (1983); Vert et al (1984); Hurukawa, and Imoto (1987); Pujol (1988 and 1992);Consoler et al. (1992) and Shater (1995). The importance of this method in earthquake implication can be summerized in the following: This method should reveal any regional bias in travel times from the same region and then based on this bias characteristic, the nature of velocity in that area could be more understood.

The joint hypocenter determination method was applied for simultaneous determination of hypocenter location, origin time and station travel time correction. This method, in general, is applying merely initial P-wave arrival times.

JOINT HYPOCENTER DETERMINATION (JHD) METHOD

The main idea of joint hypocenter determination method in earthquakes application is the delineation of any regional bias in travel times from the same region and the bias characteristics by which the nature of velocity in that area can be better understood. Consequently, if the rough epicenter location, depth, origin times of seismic events are known, the equation of condition for calculating the corrections to these approximate values is:

$$dTij = To - Tc = \frac{\partial \mathrm{Tij}}{\partial \mathrm{xi}} dxi + \frac{\partial \mathrm{Tij}}{\partial \mathrm{yi}} dyi + \frac{\partial \mathrm{Tij}}{\partial \mathrm{zi}} dzi + dti + dsj \quad (1)$$

I= 1........q , j= 1......p

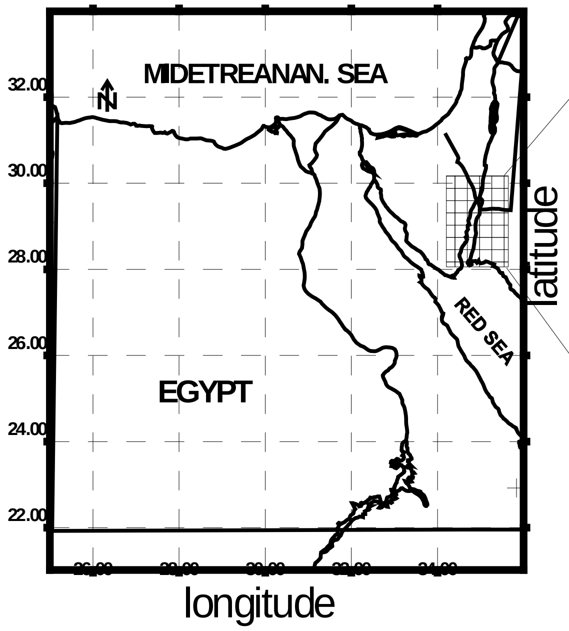

Figure (1): Location map.

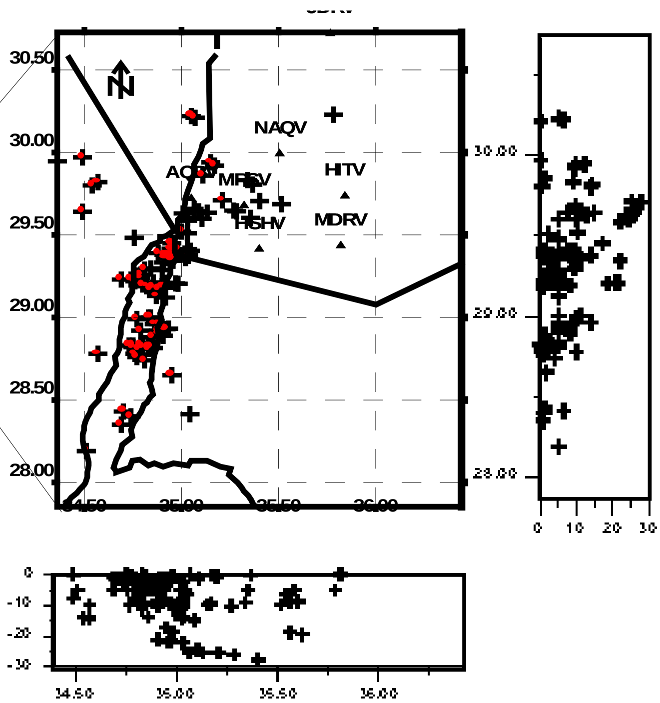

Figure (2): Seismicity map.

where

$dTij = To - Tc$ = The travel time residual for the i-th event at j-th station.

$\frac{\partial Tij}{\partial xi}, \frac{\partial Tij}{\partial yi}, \frac{\partial Tij}{\partial zi}$ = Coefficients obtained from travel time table.

dx, dy, dz = Corrections to the hypocenter in Cartesian coordinate x, y, z.

dt_i = The correction to the initial origin time for the i-th event.

ds_i = The correction to the station travel time.

This equation can be written in a compact matrix as follows:

$\Delta T = A\ \Delta X$ (2)

ΔT = the vector of observed- calculated (o-c) residuals based on approximate solution.

A = coefficient matrix

ΔX = the solution vector containing the aggregate of hypocenters and station time correction.

$$\begin{bmatrix} \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} 1 & & 1 & & \\ : & 0 & & . & \\ \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} 1 & & & & 1 \\ & \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} 1 & 1 & & 1 \\ & : & 0 & . & \\ & \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} \frac{\partial T11}{\partial x1} 1 & & & 1 \\ & & 1 & & 1 \end{bmatrix} \begin{bmatrix} dx1 \\ dy1 \\ dz1 \\ dT1 \\ : \\ dTq \\ ds1 \\ : \end{bmatrix} = \begin{bmatrix} dT11 \\ : \\ : \\ dT1p \\ : \\ : \\ dTq1 \\ : \end{bmatrix} \quad (3)$$

All the solutions of the equations in this study are obtained by means of the iteration of the least square method.

DATA

The available earthquake data in the present study are the events which had been routinely determined by the Jordan Seismic Network in the period from January 1998 to November 1998. Using the initial P-wave reading observed at four or more stations among 7 stations (Table 1). The total number of earthquakes was 64. The P-wave velocity structure model used in this study is the same structure used in the routine work for earthquake location, Table (2).

Table (1): Coordinate of seismic stations.

Station	Latitude (deg)	Longitude (deg)	Elevation (km)
1 HIT	29.743	35.841	1.235
2 HSH	29. 421	35.400	1.100
3 AQB	29.728	35.050	0 .170
4 MDR	29.442	35.520	0.900
5 JDR	30.728	35.766	1.365
6 NAQ	30.000	35.505	1.164
7 MRS	- 29.882	35.322	0.810

Table (2): Crustal structure model.

VELOCITY	DEPTH
3.500	0.000
6.050	1.500
6.320	10.000
6.500	18.000
6.650	20.000
7.380	28.000
8.100	33.500

Table (3): P-wave travel time and distance corrections .

N	STN	PSC	DSC	MEAN	STD	STD^2	NQ
1	HIT	-0.003	0.733	-1.836	1.232	2.463	58
2	HSH	0.014	0.634	-1.552	1.090	2.180	61
3	AQB	-0.021	1.994	0 .275	1.193	2.385	32
4	MDR	0.001	0.871	-2.522	1.264	2.529	61
5	JDR	0.003	0.431	0 .422	1.532	3.065	10
6	NAQ	0.005	0.753	-0.166	1.402	2.804	36
7	MRS	- 0.001	0.708	-0.566	1.156	2.312	57

SUM= 0 .000

Where:

STN = Station name.

PSC = P-wave travel time station correction .

DSC = distance station correction.

STD = standered diviation .

NQ= number of earthquake recorded by station .

Table (4): Earthquake hypocenters and their corrections .

NM	Y M Da H Mn	SEC	Δ T	LAT	Δ LAT	LON	Δ LON	DEP	ΔDEP	MAG
1	98 01 02 1925	10.62	0.02	29.51	0.27	35.03	0.29	2.27	0.17	2.3
2	98 01 05 2016	13.37	0.02	29.37	0.37	34.93	0.31	1.01	-0.09	3.2
3	98 01 07 1545	53.55	0.39	29.38	1.86	34.93	5.16	0.09	-1.2	2.7
4	98 01 07 1105	12.91	-0.06	29.36	1.21	34.93	2.32	3.51	-0.09	3.2
5	98 01 08 1955	29.51	0	29.17	2.63	34.85	4.00	0.9	0.3	2.3
6	98 01 09 0402	36.31	2.1	29.17	3.62	34.86	5.56	0	-5	2.4
7	98 01 09 1930	10.49	-0.04	29.38	0.40	34.96	0.41	1.21	0.01	2.8
8	98 01 10 0818	37.66	-0.57	29.23	3.07	34.71	6.75	6.96	2	2.6
9	98 01 10 1216	55.38	0.97	29.34	7.40	34.93	9.99	0.18	-3.3	2.3
10	98 01 13 1637	23.61	0.01	29.36	1.26	34.94	2.24	4.84	-0.16	2.5
11	98 01 14 0701	0.06	0.03	29.92	0.29	35.17	0.32	9.3	-0.1	2.5
12	98 01 14 0943	54.8	-0.04	29.38	0.58	34.94	0.54	1.1	0	3.2
13	98 01 18 1131	36.78	0.1	28.99	4.74	34.83	5.20	0.99	-0.21	3.3
14	98 01 20 0440	40.87	-0.85	28.84	5.08	34.78	4.92	2.83	2.8	3.2
15	98 01 20 1311	37.5	-0.3	28.74	5.67	34.82	4.71	4.61	0.81	3.1
16	98 01 24 1440	28.38	-0.38	29.18	2.08	34.9	2.70	3.33	3.3	2.4
17	98 01 25 1717	50.64	0.05	28.96	3.06	34.89	3.16	3.57	-1.4	2.4
18	98 01 25 1845	22.05	-0.64	28.94	2.93	34.91	2.79	2.9	0.9	2.8
19	98 01 25 2215	9.45	-0.48	28.92	3.00	34.9	2.81	3.33	0.33	2.9
20	98 02 01 2202	46.85	-0.87	28.84	2.27	34.83	6.16	2.17	2.9	3
21	98 02 13 0105	2.08	-0.77	29.18	2.59	34.92	3.42	0.52	5.5	2.8
22	98 02 13 0446	47.82	-0.81	28.83	6.08	34.81	5.54	2.58	1.9	3.1
23	98 02 14 0335	22.99	-0.62	28.77	5.38	34.79	4.74	2.51	1.9	3.1
24	98 02 20 0344	18.19	-0.41	28.92	1.47	34.8	12.43	9.39	1.4	2.9
25	98 02 26 0006	54.52	0.08	29.52	0.35	35	0.80	12.11	1.9	2.9
26	98 02 27 0747	38.67	2	28.37	3.01	34.67	1.76	0	-1.3	3.5
27	98 02 27 1847	49.58	-0.41	28.67	3.85	34.97	2.62	1.44	-0.06	2.9
28	98 03 02 2319	16.92	-0.56	28.84	3.10	34.86	2.72	2.42	1	3.1
29	98 03 04 1736	10.98	0.04	29.23	1.03	34.79	1.40	4.87	-0.13	3.1
30	98 03 04 1806	35.54	0.64	29.27	6.68	34.78	14.82	5.67	0.67	2.3
31	98 03 06 1942	16.82	-0.16	29.71	0.24	35.22	1.21	24.75	-0.55	2.5
32	98 03 07 1117	0.11	1.7	29.99	4.72	34.44	1.98	0	-0.1	3
33	98 03 11 0909	6.17	-0.71	29.23	5.49	34.79	0.61	2.54	1.4	3.1
34	98 03 22 1603	58.18	-51	28.77	0.86	34.58	.0. 87	9.99	8.3	4
35	98 04 07 1332	2.33	56	28.21	0.38	34.54	1.89	1.47	-8.4	4

Table (4): Continued.

NM	Y M Da H Mn	SEC	Δ T	LAT	Δ LAT	LON	Δ LON	DEP	ΔDEP	MAG
36	98 04 10 1036	41.33	-37	28.95	4.52	34.86	4.52	13.71	8.7	2.8
37	98 04 13 0704	49.1	-7.6	29	1.29	34.85	1.09	3.88	-9.9	3
38	98 04 13 0746	16.18	33	28.95	2.62	34.95	2.41	5.96	0.96	2.6
39	98 04 13 0925	15.5	-0.05	28.82	1.87	34.75	1.50	1.24	-3.8	4.1
40	98 04 17 0320	52.74	-37	29.45	0.44	34.95	0.62)	17.22	16	2.8
41	98 05 091049	36.93	16	28.83	3.66	34.86	3.40	0.7	-16	2.8
42	98 05 040118	0.89	35	28.99	1.13	34.78	1.02	10.12	10	3.7
43	98 05 100939	11.21	13	29.82	0.44	34.59	1.51	1.39	5.7	3
44	98 05 211120	0.23	0.56	30.22	0.20	35.05	0.25	2.66	-3.2	3.2
45	98 05 022345	47.71	-37	28.37	7.42	34.73	12.50	3.66	-11	3.6
46	98 05 241859	29.32	-29	30.21	0.16	35.07	0.42	0.12	-6.3	3.3
47	98 05 310410	53.68	-7	29.36	1.41	35.02	2.67	11.9	11	2.1
48	98 05 311325	18.94	10	29.25	1.15	34.79	1.55	3.66	3.6	2.8
49	98 06 020340	4.81	49	29.2	1.62	34.81	1.80	0.48	-10	3.7
50	98 06 041021	50.51	-31	29.13	3.32	34.88	4.34	1.16	3.2	2.8
51	98 06 042102	26.01	-21	29.17	1.58	34.88	1.53	0.59	9.7	2.4
52	98 06 050713	20.13	30	29.86	0.35	35.11	1.04	1.48	-3.5	2.4
53	98 06 050837	9.55	16	29.41	1.32	34.97	3.65	6.13	1.1	2.2
54	98 06 071912	42.01	-22	29.41	0.41	34.98	0.44	0.62	-0.68	2.3
55	98 06 121906	44.83	-35	29.41	0.50	34.95	0.49	1.47	-7.9	2.1
56	98 06 121955	4.87	37	28.39	3.81	34.75	1.89	0.26	-0.34	3.5
57	98 06 122011	16.16	29	28.82	4.06	34.79	2.40	3.74	2.3	3
58	98 09 030051	8.13	-3.2	29.8	0.29	34.55	1.02	4.75	14	3.2
59	98 09 272225	49.06	-17	28.77	2.47	34.77	1.87	0.03	-1.4	3.5
60	98 09 272228	26.23	-9.8	29.19	1.55	34.83	1.99	2.17	3.2	3.5
61	98 10 031625	8.06	-0.15	28.89	3.14	34.87	2.96	3.46	-10	3.2
62	98 10 091939	27.47	22	29.63	0.54	34.39	8.32	0	-0.5	4.1
63	98 11 060202	42.73	-17	28.82	1.55	34.84	1.13	3.21	-4.8	2.9
64	98 11 062014	37.72	-30	31.33	2.83	35.6	0.37	2.36	6.2	3.3

where:

NM =Number .
Y = Year .
M = Month.
Da = Day .
H = Hour .
Mn = Minute .
SEC = Seconde .
LAT = Latitude .
LON = Longitude
DEP = Depth .
Δ T = correction in origin time .
Δ LAT = correction in latitiude .
Δ LON = correction in longitude.
MAG = Magnitude .

RESULTS AND CONCLUSION

The hypocenter location determined by the joint hypocenter determination method is more precise than those determined by HYPO71PC program (Lee and Lahr 1975). Seven seismic stations at the western side of the Gulf of Aqaba which belonging to the Jordan Seismic Network were used in the calculation of joint hypocenter determination method. Three stations HIT, AQB and MRS have negative signs in P-wave travel time corrections and their values are -0.003, -0.021, -0.001. This can be understood in the assumption of underground structure in this area which has a particular characteristic of high velocity structure. The other stations HSH, MDR, JDR and NAQ have positive sign and their values are 0.014, 0.001,0.003, 0.005. This means that seismic signal from the hypocenter takes a bit more time to reach the station, then to make correction in travel time, we should subtract these values before computation. It is possible to assume that underground structure in this area has particular characteristic of low velocity structure as shown in table (3) . The method simultaneously solves for earthquake location and station corrections. The station corrections reflect not only different crustal condition in the vicinity of the stations, but also the difference between actual and model seismic velocities along each of the earthquake - station ray paths. Figure (3) and table (4) show the relocated earthquake hypocenters.

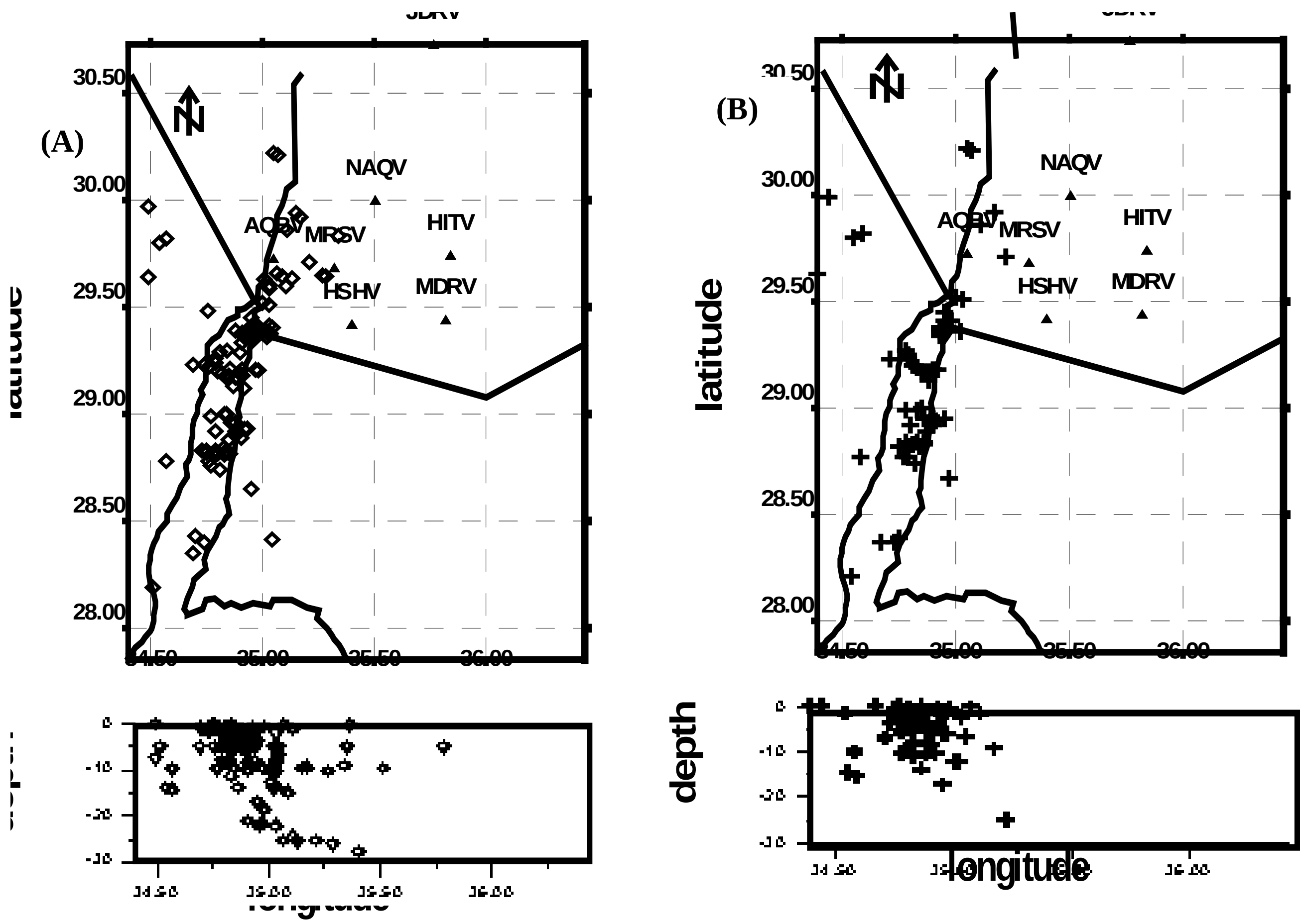

Figure (3): (A) Earthquake hypcenters used in this study.

(B) Relocated Earthquake hypcenters.

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