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ATTENUATION PROPERTIES OF SEISMIC WAVES AROUND THE GULF OF SUEZ AREA, EGYPT

**Mamdouh A. Morsy and *Mahmoud A. El Hefnawy

** Al Azhar University, Faculty of Science, Geology Dept.*
*** National Research Institute of Astronomy and Geophysics*

دراسة الخصائص الاضمحلالية للموجات السيزمية حول منطقة خليج السويس– مصر

الخلاصة: الغرض من هذه الدراسة هو محاولة فهم الخصائص الاضمحلالية للموجات السيزمية وذلك بحساب معامل التشتت العكسي و قيم الجى ومعامل الاضمحلال فى منطقة الدراسة. ويعبر معامل التشتت العكسي عن مقدار ما تفقده الموجات السيزمية لطاقتها مع المسافة التى تسير فيها. أما قيم الجى فهى تستخدم لاظهار المنطقة النشيطة زلزاليا. وتستخدم قيم معامل موجات الكودا فى تعيين هذه المعاملات وأيضا الخصائص الاضمحلالية التى تحدث نتيجة عمليات التشتت للموجات السيزمية قصيرة المدى فى منطقة الدراسة.

ولحساب معامل الاضمحلال العكسى وقيم الجى ومعامل الاضمحلال لموجات الكودا فى منطقة خليج السويس فقد استخدمت مجموعة من الزلازل المسجلة رقمياً فى محطات الزلازل حول منطقة خليج السويس. وقد قيست قيم السعة الموجية لموجات الكودا عند الترددات ١و ٣و ٦و ١٢و ٢٠ هرتز. وتستخدم قيم السعة الموجية لاستنتاج قيم معامل الاضمحلال وقيم التشتت العكسى وقيم الجى.

ومن نتائج التحليلات وجد أن قيم اضمحلال الموجات تكون منخفضة عند الترددات العالية والعكس بالعكس، وتتراوح هذه القيم بين ٠,٠٠٠٦ الى ٠,٠٠١٤ عند التردد ٢٠ هرتز وتكون بين ٠,٠١٦ الى ٠,٠٥٤ عند التردد ١ هرتز.

القيم المحسوبة للتشتت العكسى تتراوح بين ٠,٠٤ الى ٠,٠٩ عند التردد ٢٠ هرتز وبين ٠,٠٥ الى ٠,٢٢ عند ١ هرتز. وهذه القيم تعنى ان موجات الكودا تفقد ما بين ٤ الى ٢٢ بالمائة من طاقتها الاصلية بالتشتت لكل كيلو متر تقطعه.

أما قيم الجى المحسوبة فتتراوح بين ٠,٩ و ١,٢٨ عند ٢٠ هرتز وتكون بين ٠,٧٣ الى ١,٦ عند ١ هرتز، وهذه القيم تكون مرتفعة فى المناطق النشيطة زلزاليا.

ABSTRACT: *The aim of this study is to understand the attenuation properties of seismic waves by calculating the backscattering coefficient, g-values, and the attenuation factor in the area under study. The backscattering coefficient is a factor, which indicates the loss of the wave energy by scattering per unit travel distance. The g-value factor is used to monitor the seismic active area. Coda waves quality factor is used to determine these factors and the attenuation properties caused by scattering processes of the short period seismic waves in the area under study.*

For calculating the backscattering coefficient, g-values and to estimate the Coda waves quality factor around the Gulf of Suez area, a group of earthquakes in digital form recorded in seismic stations around the study area are utilized. The amplitude of the Coda waves at the central frequencies 1, 3, 6, 12 and 20 Hz is measured. The measured amplitude is used for the estimation of Q^{-1} values, backscattering coefficient and g-value.

From the analysis, the Q^{-1} value is low at high frequency and vice versa. The estimated Q^{-1} values range from 0.0006 to 0.0014 at 20 Hz and from .016 to .054 at 1 Hz.

The calculated backscattering coefficient at 20 Hz ranges between 0.04 and 0.9 and between 0.05 and 0.22 at 1 Hz. Physically, this means that Coda waves lose from 4 to 22 percent of their original energy by scattering for every kilometer traveled.

The calculated g-value at 20 Hz ranges between 0.9 and 1.28 and between 0.73 and 1.60 at 1 Hz. It has higher values in the seismically active localities in the area.

INTRODUCTION

Coda waves have many interesting features such as; they converge to low values at high frequencies, and independent on the current tectonic activity for a variety of areas. Also, the Q^{-1}value around 1 Hz varies from place to place by an order of magnitude. It shows a strong correlation with the intensity of current tectonic activity.

There are basically two approaches for estimating the backscattering coefficient. One is to study the fluctuations of amplitude and phase of the total seismic signals, which are composed of primary and scattered waves. This approach is appropriate for the data obtained near scatters. The other approach is to study the naturally scattered waves isolated from the primary waves. The data for this purpose are the Coda part, after the passage of all the primary waves of local earthquake seismogram recorded at a short distance from the source.

In most of the attenuation studies, either the amplitude spectrum or the amplitude ratio decreases linearly with increasing frequency. From the slope of the regression line, a constant Q-value can be determined, which is valid within the applied frequency range.

The aim of this present work is to estimate the Coda waves quality factor, which represents the attenuation properties of seismic waves. Also, the estimation of the backscattering coefficient, which expresses on the percent loss of the original wave energy and the g-value, which represents the seismic activity around the Gulf of Suez area.

Data Acquisition and Analysis

For the estimation of the Coda waves quality factor, a group of seismic events recorded in seismic stations around the Gulf of Suez area are used. Figure (1) represents the locations of the seismic stations and figure (2) represents the locations of some selected events.

The analysis of short period waves is done through the following procedures. The Coda waves part is selected according to the used model. The starting of Coda waves is twice the S-waves travel time. The end part of Coda waves is selected when the signal to noise ratio is equal to 2. This coda part is divided into seven overlapped parts. The Fast Fourier Transform (FFT) technique is applied to each part separately. The average amplitude at the center frequencies 1, 3, 6, 12 and 20 Hz is measured. These seven average amplitudes are used as input data for the least-squares fitting. A straight line with slope (b) is obtained from the obtained b-values in each central frequency, which the quality factor can be estimated. From the estimated Q-value for each wave type in different central frequencies, the backscattering coefficient and g-value are calculated.

Results

1- Estimation of Coda waves quality factor

1- According to Aki and Chouet (1975), the displacement envelope of Coda waves is given by the following expression:

$$A(\omega, t) = C(\omega)\, t^{-1}\, e^{-\omega t/2Q(\omega)} \quad (1)$$

$$b = \pi_{(\log 10)}\, f/Qc(\omega) \quad (2)$$

where: A is the amplitude of Coda waves
ω is the angular frequency
t is the lapse time
c is represents the source term
Q is the quality factor
f is the central frequency

The Coda source factor C(ω) has been replaced by the constant (C), since it is dependent only on frequency. Coda waves quality factor $Q_c(\omega)$ is determined from the slope (b) by the application of the least squares solution on equation 2.

The average Q^{-1} values obtained in each area are listed in table (1). The quick look on these data indicated that, the estimated Q^{-1} value of Coda waves has low values at low frequency, and vice versa. At 20 Hz, the Q^{-1} value decreases towards the east and increases towards, the western part. At 12 Hz, the Q^{-1} values seem to be almost the same in all the area, but it is increased to the west and decreased to the east. The Q^{-1} values are higher in the southeastern and northeastern parts of the area. It has a lower value in the eastern part. At 6 Hz, the Q^{-1} value increases toward the west and decreases toward the east. The Q^{-1} values are higher and attain the peak value toward the southwestern and northwestern directions At 3 Hz, the Q^{-1} values decrease towards the eastern direction. It increases towards the western direction. The Q^{-1} factor has higher value at the southwestern part of the area, while it has lower value at the southeastern direction. At 1 Hz, the Q^{-1} values almost have the same variation in all the area, but it increases at the southwestern and northeastern parts of the area. It has the lowest value at the eastern part. Examples at 20 and 1 Hz are shown in figures (3 and 4) in three-dimensional presentation.

Comparing the above-mentioned results with the geological map, it is clear that the area, which is covered by the Miocene rocks, has lower Q^{-1} values, while the area, which is covered by the Eocene rocks, has rather lesser Q^{-1} value, and that covered by the Nubia sandstone rocks has higher Q^{-1} value. It could be noticed that, the older rocks have higher estimated Q^{-1} values and vice versa.

Table (1) The estimated Q^{-1} values around the Gulf of Suez area

Station	20 Hz	12 H	6 Hz	3 Hz	1 Hz
HAMM	0.0008	0.0017	0.0025	0.006	0.022
ATOT	0.0008	0.0010	0.0021	0.006	0.020
MAZR	0.0008	0.0016	0.0022	0.005	0.019
SHRM	0.0007	0.0025	0.0019	0.009	0.016
SHDW	0.0006	0.0010	0.0018	0.004	0.013
ZEIT	0.0009	0.0019	0.0035	0.009	0.030
ABSH	0.0010	0.0011	0.0040	0.015	0.029
UMDL	0.0011	0.0013	0.0045	0.013	0.027
GHAR	0.0009	0.0020	0.0054	0.011	0.028

Moreover, it can be realized that the attenuation appears to be stronger in the direction perpendicular to the structural trend and weaker in the parallel direction. since structural boundaries and faults may be more effective in scattering waves, which are propagating perpendicular to their planes.

2- Estimation of backscattering coefficient

The estimation of backscattering coefficient has received careful treatment in some of the most recent

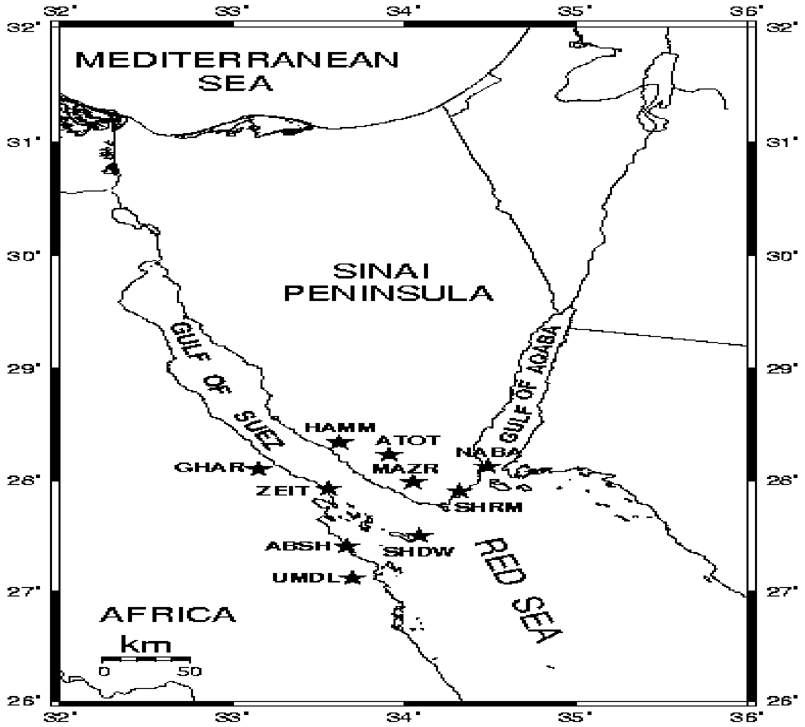

Fig (1) Locations of seismic events and seismic station around The Gulf of Suez area, Egypt

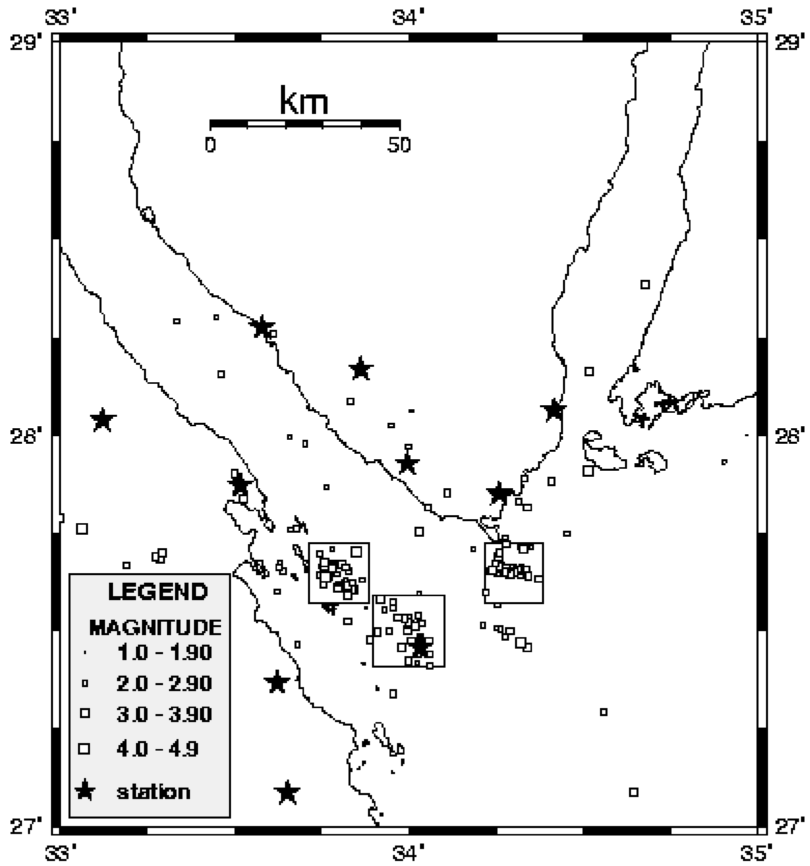

Figure (2) Locations of seismic events and seismic zones

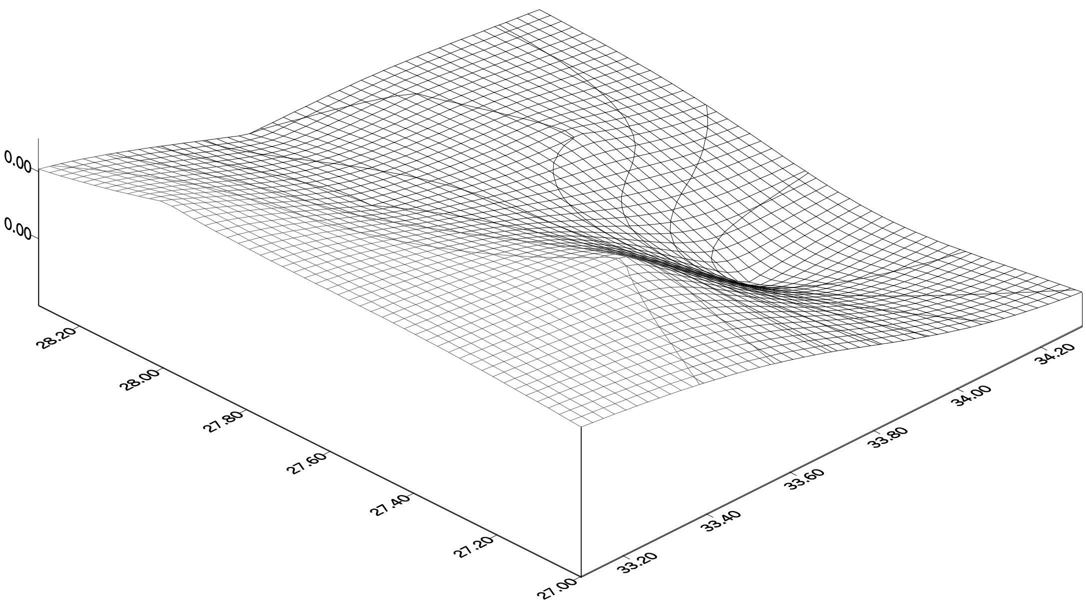

Figure (3): 3-D Distribution of the attenuation shape in Suez Gulf area at 20 Hz

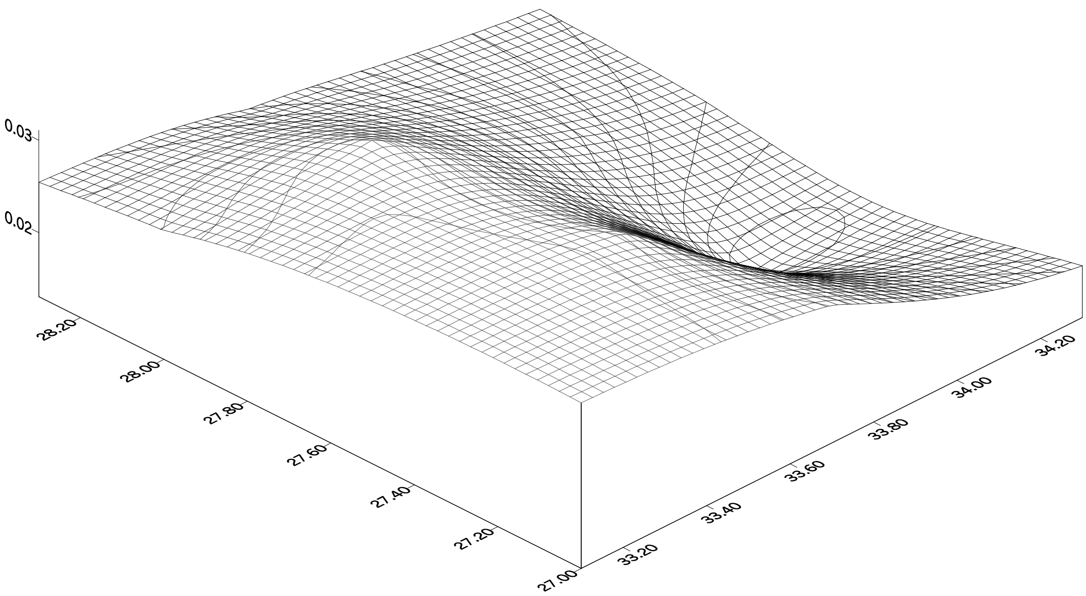

Figure (4): 3-D Distribution of the attenuation shape in Suez Gulf area at 1Hz studies (Sato, 1977a, 1977b and 1982 and Wu and Aki, 1985). The heterogeneity is usually estimated by the backscattering coefficient, which measures the intensity of scattering.

The following equation is used to represent the loss of energy from Coda waves by scattering (Aki, 1980):

$$e^{a} = \frac{SQR(\Delta f)\ \beta\tau o}{2\ SQR\ (\beta g\pi)}\ e^{(\omega\tau o\ /2Qc)} \quad (3)$$

where: ω is the angular frequency

β is the velocity of shear waves

g is the backscattering coefficient

The backscattering coefficient obtained in each area is listed in table (2). The backscattering coefficient values range between 0.04 and 0.09 at 20 Hz; and between 0.05 and 0.22 at 1 Hz. This means that, Coda waves lose from 4 to 22 percent of their original energy by scattering for every kilometer traveled.

Table (2) The estimated backscattering coefficient around the Gulf of Suez area

Station	20 Hz	12 Hz	6 Hz	3 Hz	1 Hz
HAMM	0.05	0.11	0.20	0.23	0.09
ATOT	0.04	0.10	0.21	0.30	0.08
MAZR	0.05	0.10	0.21	0.27	0.07
SHRM	0.04	0.11	0.16	0.27	0.06
SHDW	0.03	0.10	0.14	0.22	0.05
ZEIT	0.06	0.12	0.24	0.44	0.10
ABSH	0.09	0.14	0.26	0.43	0.17
UMDL	0.08	0.18	0.29	0.58	0.20
GHAR	0.07	0.12	0.30	0.44	0.22

The spatial distribution of the obtained backscattering coefficient values in each selected central frequency is studied. It is clear that, many peaks representing the backscattering coefficient in each locality characterize the area.

At 20 Hz, the backscattering coefficient increases towards the western direction of the area and decreases towards the eastern direction. The backscattering coefficient in the southern part of the area has lower value. At 12 Hz, the backscattering coefficient increases towards the western direction of the area and decreases towards the eastern direction, but this change is not so much. The backscattering coefficient has higher values in the western portion of the area, while it has lower values in the eastern part.

At 6 Hz, the backscattering coefficient increases towards the western direction and decreases towards the eastern direction. The backscattering coefficient has lower values in the eastern part and has higher values in the western part of the area. At 3 Hz, the backscattering coefficient decreases from the southern part of the area towards the eastern direction. It increases towards the western direction. At 1 Hz, the backscattering coefficient has almost the same value through out all the area. It is relatively lower toward the southeast rather than the southwest. The lowest value is noticed in the northeastern part of the area. Examples at 20 and 1 Hz are shown in figures (5 and 6) in three-dimensional show.

The backscattering coefficient coincides with the estimated Q^{-1} value and the distribution of both parameters values has the opposite trend at varying central frequencies in the area. It can be concluded that, there is a relation between the rock age (as indication to the compaction) and the backscattering coefficient. The older (more compacted) the rocks the higher the loss of energy of seismic waves through backscattering coefficient.

The wave scattering can explain the attenuation of the seismic waves, in which the uncertainty in the estimated parameters does not allow estimating the difference between the total attenuation and the scattering loses. This is the contribution of intrinsic attenuation.

3- Estimation of the g-value

The active areas are characterized by a Q^{-1} value peak at frequencies around 0.5 to 1 Hz. The difference between stable and active areas disappears at about 20 Hz (Aki, 1981). The proportional coefficient (g) of the Coda waves and their frequency are obtained by the following equation:

$$g = \log\ (Q^{-1}/Q_o^{-1})/\ \log\ (f_o\ /\ f) \quad (4)$$

The average g-values obtained in each area are listed in table (3). The spatial distribution of the obtained g-values in each selected central frequency is estimated. It is clear that, many peaks representing the distribution of the g-value characterize the area.

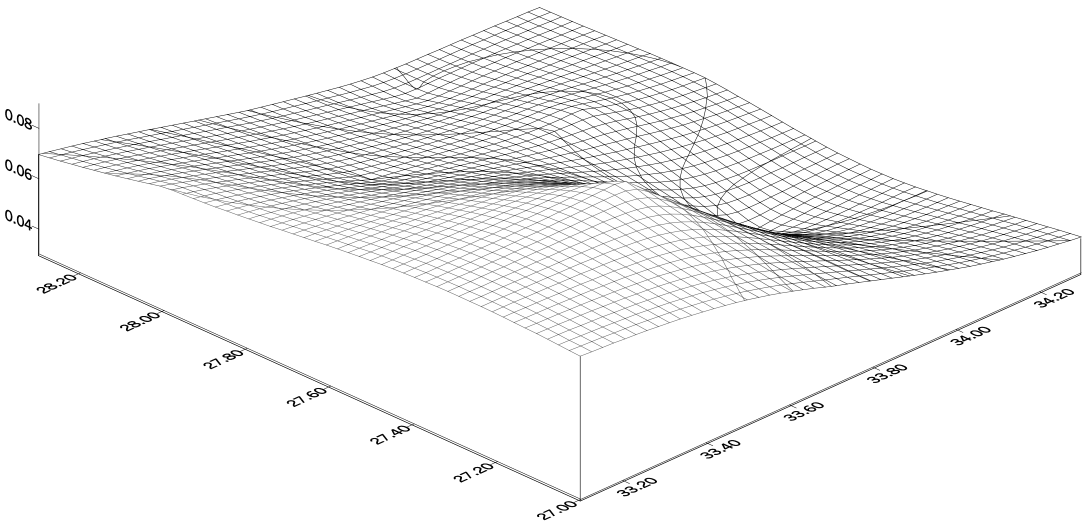

Figure (5): 3-D Distribution of backscattering coefficient in Suez Gulf area at 20 Hz

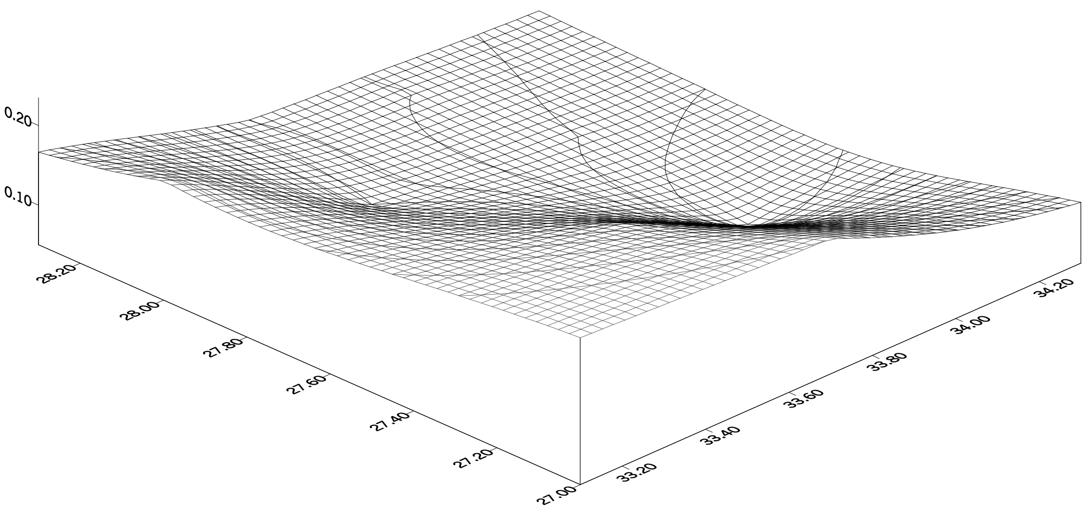

Figure (6): 3-D Distribution of backscattering coefficient in Suez Gulf area at 1 Hz

At 20 Hz, the g-values is not changed so much, but it increases towards the eastern direction and decreases towards the western direction. At 12 Hz, the g-values increase in the eastern part of the area and decrease towards the western direction. The southern parts of the area are characterized by higher values.

Table (3) Estimated g-value around Suez Gulf area

Station	20 Hz	12 Hz	6 Hz	3 Hz
HAMM	1.14	1.10	1.31	1.33
ATOT	1.23	1.03	1.24	1.53
MAZR	1.05	1.09	1.07	1.38
SHRM	1.28	1.23	1.34	1.54
SHDW	1.33	1.33	1.44	1.60
ZEIT	0.94	0.96	0.93	0.90
ABSH	0.83	0.87	0.94	0.88
UMDL	1.00	0.90	0.92	1.00
GHAR	0.91	0.95	0.88	1.05

At 6 Hz, the g-values increase in the eastern part of the area and decrease towards the western direction. The g-value around SHDW station has extremely higher value. At 3 Hz, the g-value has a peak in the eastern and southern parts of the area. It increases in the southern part of the area. From the central part fainting to the eastern direction; it has high value. Examples at 20 and 1 Hz are shown in figures (7 and 8) in three-dimensional presentation.

As mentioned before, the g-value is higher in the eastern part of the area and gently decreases towards the western direction. It has lower value at the southern part of the area.

As is well known, the site in Shadwan and Sinai Peninsula has a noticeable seismic activity than the other neighboring parts. From the quick look on the g-values in figures (7 and 8), it can be concluded that, the estimated g-value has good coincidence with the seismic activity. It has high value in the active area and vice versa.

Summary and Conclusion

The backscattering coefficient represents the loss of the wave energy by scattering per unit travel distance. The estimation of the Coda waves quality factor is used as an indicator of the attenuation, caused by scattering processes of the short period seismic waves.

From the analysis it is found that, the Q^{-1} value is low at high frequency and vice versa. The estimated Q^{-1} values range from 0.0014 to 0.006 at 20 Hz and from .016 to 0.54 at 1 Hz. Comparing the above-mentioned results with the geological map it is clear that, the area covered by Miocene rocks is high Q^{-1} values and .the area covered by Eocene rocks has less Q^{-1} values. Also, the area covered by Nubian sandstone rocks has lower Q^{-1} values. It could be noticed that, older rocks have low value of the estimated Q^{-1} value and vice versa. The attenuation of seismic waves appears to be strongest in the direction perpendicular to the structural trends and weaker in the parallel direction, since structural boundaries and faults act effectively in scattering the waves propagating perpendicular to their planes.

The calculated backscattering coefficient at 20 Hz ranges between 0.04 and 0.9 and between 0.05 and 0.22 at .1 Hz. Physically, this means that Coda waves lose from 4 to 22 percent of their original energy by scattering for every Kilometer travel. The backscattering coefficient coincides with the estimated Q-value, where the distribution of both values has the same trend at varying central frequencies in the area under study. It can be concluded that, there is a relation between the rock age and the backscattering coefficient. The older the rocks the lower the loss of energy of seismic waves or backscattering coefficient.

The calculated g-values at 20 Hz range between 0.83 and 1.33 and between 0.88 and 1.6 at .3 Hz. It has higher value in the seismically active localities at the area. As discussed before it is clear that, the g-value is higher in the eastern part of the area and is lower in the western part of the area. It has higher value at the southern part of the area. As known before, the Gulf area has noticeable seismic activity than the other localities. It is possible to conclude that, the estimated g-values have good coincidence with the seismic activity. It attains high values in the active areas and vice versa.

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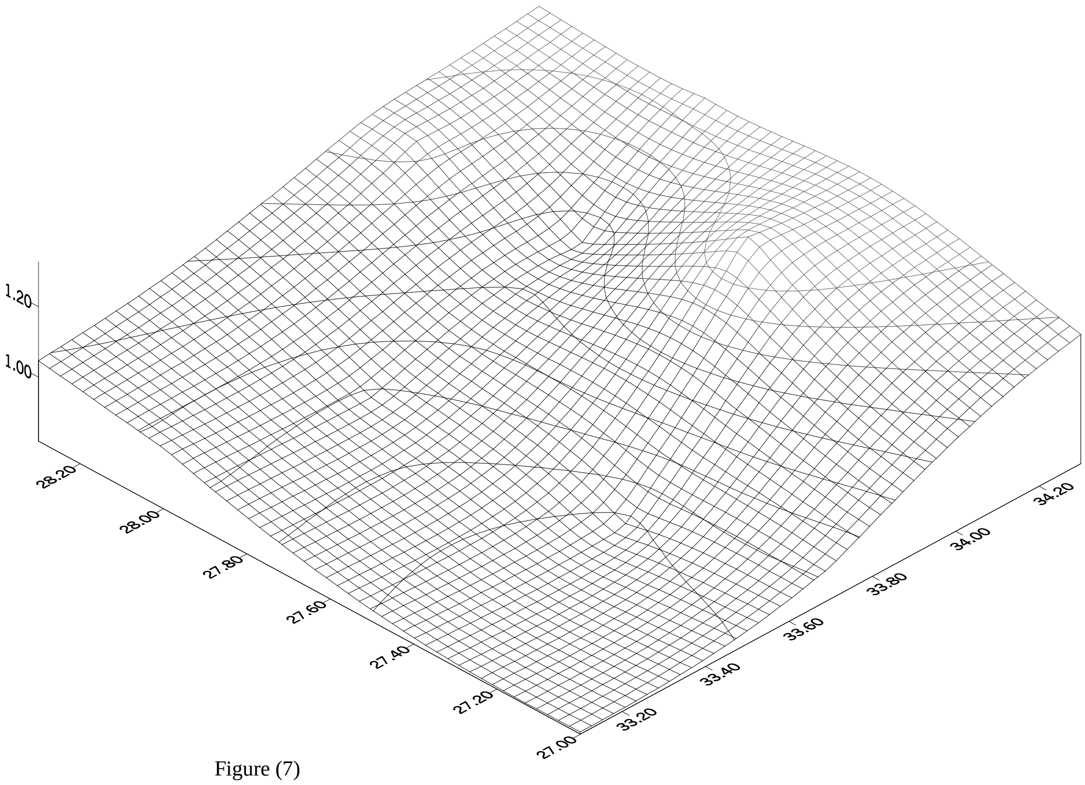

Figure (7)

3-D Distribution of g-value in Suez Gulf area at 20 Hz

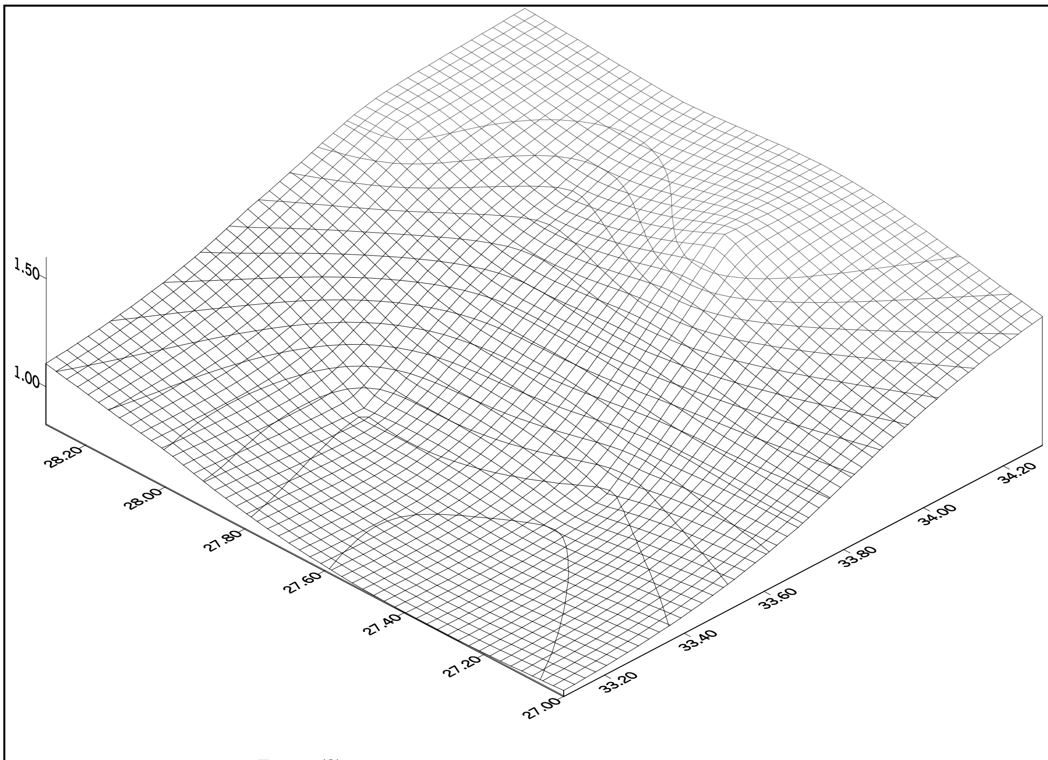

Figure (8): 3-D Distribution of g-value at suez gulf area at 3 Hz

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