POTENTIAL OF CRUSTAL MOVEMENTS AS PRECURSORS FOR EARTHQUAKE PREDICTION IN ASWAN REGION

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ABSTRACT

The principal object of the current study is the elucidation of all minutes details of anomalous earth surface deformation process that take place during the preparation stage of earthquakes in Aswan region to serve as an essential precursor for earthquake prediction. The motivation behind this research is that Aswan region is found to be one of the active seismic zones in Egypt and especially encompassing the vital engineering structure of the High Dam. The stability of the High Dam should be studied to ensure its safety versus earthquakes disasters. In addition, the crustal movements precursory will push the earthquake prediction studies in Aswan region especially and Egypt generally to a wide horizons. The continuous and discontinuous crustal movements techniques and their turns in earthquake mechanism will be discussed here, as well as they are being as precursors for earthquake occurrence. The precursory of geodetic crustal movements of Kalabsha local geodetic network are examined here as examples of the potential of the precursory of crustal movements for earthquake prediction in Aswan region, Egypt. Strong recommendations are made concerning the necessity of studying and monitoring the earthquake precursors around the strategic highly seismo-active area for reducing or minimizing the earthquake disasters.

1. INTRODUCTION

The interest in the systematic study and detection of recent crustal movement has increased nowadays in connection with the prediction of earthquakes. Thus the detection of crustal movements becomes very essential for the safety of man kind as well as his economical achievements. The study of crustal movements means the determination of the direction and the rate of these movements.This study usually comprises three main items: The area of interest, the direction of monitoring the movements and the technique of collecting the essential data.

The area of interest may be global, regional or local. In case of global or continental cases, the area comprises lines of few thousands of kilometers. The regional area includes lines of few hundreds of kilometers such as countries or the boundaries of the earth's plates or few tens of kilometers such as states, provinces and areas surrounding earthquakes zones. The local areas involves lines of few kilometers such as the area of minor faults and the immediate vicinity of the huge engineering constructions (Nassar, 1986). As far as the direction of monitoring, it can be horizontal (computations in the local geodetic system), vertical or spatial (combined horizontal and vertical). For our purpose here of using crustal movements information as earthquake precursors, the emphasis will be oriented towards in both regional and local techniques as one group.

Different methodologies and techniques have been developed for monitoring crustal movements. A comprehensive summary of them is necessary because a successful analysis of crustal movements should have a good knowledge of data acquisition techniques in order to reach correct prediction of earthquakes. The different techniques for such study are classified as continuous and discontinuous techniques, as shown in

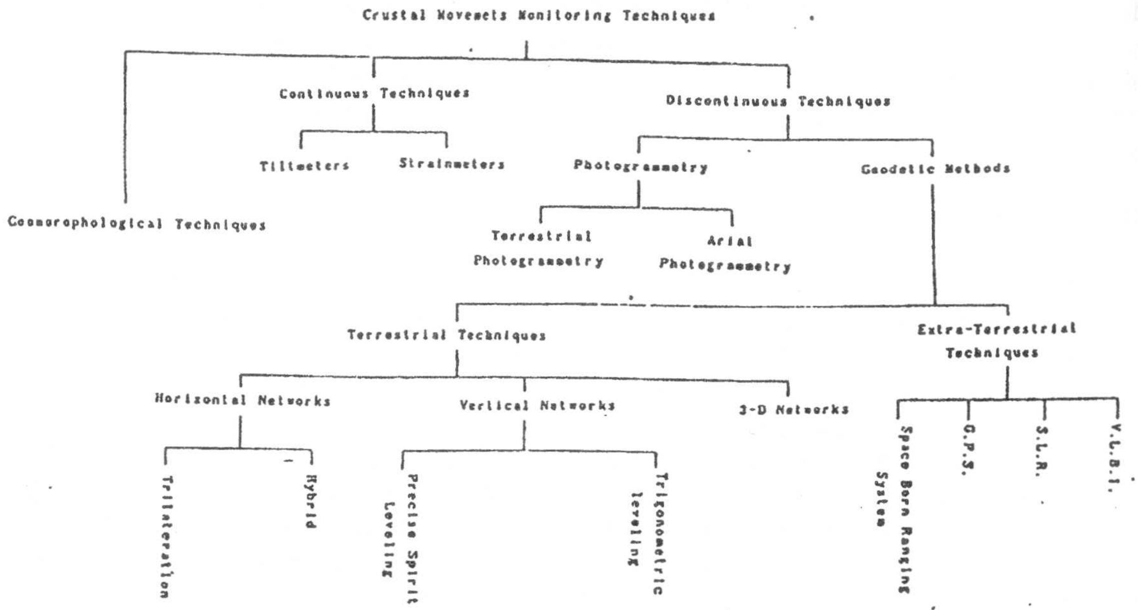
Table (1). Each one of the above two categories will be discussed. However, before digging into that, it may be useful to introduce firstly the interrelationship between earthquake mechanism and associated crustal movement, in order to use information gathered from the latter as precursors for predicting the former.

After November, 1981 earthquake in Aswan region, a joint project program has been effectively initiated for monitoring seismicity, crustal movements activity and underground behavior activity. An exploratory investigation of crustal movements earthquake precursors is performed in the current research through investigating the relationship between the crustal movements, seismicity and earthquake occurrence.

2. EARTHQUAKE MECHANISM AND ASSOCIATED CRUSTAL MOVEMENTS

Reid of the U.S.A. (Benioff, 1964), who developed the elastic rebound theory of earthquake, made what was probably the world's first attempt of earthq prediction using surveys of the earth's movemen analyzed the San Francisco earthquake of (M=8.3) using the results of triangulation sur made between 1851 and 1855 and surveys immediately after the earthquake: these studies res in the elastic rebound theory. This theory main that elastic strain accumulates in the crust due t relative movement of a fault, such as the San A fault. When the strain reaches a critical point, the rebounds, producing seismic waves. Noting tha relative displacement of the during 50-year p before the earthquake was approximately 3.2 m that the greatest amount of slip during the earthq was 6.5 m Reid estimated the San Franc earthquake occurrence cycle to be (6.5 m / 3.2 m) years = 100 years. Although Reid's long earthquake prediction method was somewhat naiv was basically the same as the method as that used which also depends on observation of crustal strai a precursor to predict earthquakes.

Table 1. Classification of crustal movements monitoring techniques.



There is no doubt about the earthquake mechanism described above. This has been proven through the analysis of seismic waves generated by earthquakes and through surveys of crustal movement both before and after earthquakes. The release of strain has been confirmed by both seismic and crustal movem measurements.

The discussion thus far points to the fact that me looking at earthquakes as vibrations of the earth does not provide a comprehensive understanding, but rather looks only at the aftereffect of crustal rupture. Earthquake phenomena must be seen in their totality as a process in which seismic energy accumulated in the form of progressive strain that finally reaches the stage of rupture. From the stand point of earthquake prediction the stages prior to the point of rupture are far more important than the phenomena that occur after the rupture has taken place. The complete rupture process may be visualized to contain the following four stages, namely (Sato, 1981):

Progressive strain that is almost constant;

Arrival of the critical point;

Beginning of the principal rupture; and

Occurrence of principal rupture.

The first stage is the accumulation of seismic energy, and it progresses rather slowly. At the second stage, conditions -including the progress of the strain- are no longer constant as the critical point approaches. And yet there is still time before the principal rupture stage is actually reached. The length of this period seems to depend on the scale of the principal rupture - or, in short, on the magnitude of the earthquake.

The third stage is the immediate precursory period before the principal rupture. The principal rupture does not occur suddenly, but seems to be preceded for several days (or in some cases, several hours) by precursory phenomena. At this stage the principal rupture has begun in earnest, and there is no turning back. The observations and examples of actual surveys have supported this model. Unfortunately, the mechanism of the second and third stages, which are the most crucial to earthquake prediction, are not yet quite clear. The future development of earthquake prediction techniques hinges on the research that will elucidate this part of the earthquake mechanism.

The first, second and the last stages of rupture process do not involve the vibration phenomenon although they are accompanied by minor and micro earthquakes. The phenomena that take place in these stages are principally changed in crustal strain.

Since the first stage of crustal rupture is thought to be in constant progress over a long period of time, repeated geodetic surveys, constituting the discontinuous methods, are the most effective way of observing it. As these methods cover an extensive area, it is possible to detect the extent of energy accumulation, thus enabling one speculate on the magnitude of future earthquakes.

Once the rupture process reaches the second and third stages, the phenomena, according to recent research, cease to progress constantly in terms of either time or space. If this is the case, then the periodic repetition of surveys may miss some significant information. Therefore, it is vital to continuously observe changes in strain which can be achieved via the continuous methods. Hence, some of the second and third stages that are especially crucial to short-range prediction were detected by the continuous observation of crustal movement or by other, similar, methods. This fact alone points to the indispensability of continuous observation. It may be worth mentioning here that both continuous and discontinuous methods for crustal movements determination will play an important role as a precursory information.

3. THE USED TECHNIQUES FOR DETECTING LAND DEFORMATION

There are different techniques for monitoring crustal movements, and hence land deformation, which can be classified into two board categories, namely: Geodetic and non geodetic. The former techniques are based on periodic comparison of repeated survey measurements to detect changes in horizontal, vertical, or spatial positions of well distributed terrain points. The latter category comprises geomorophologic and continuous techniques. Geomorophological techniques are used in detecting past crustal movement and orienting the detection to be used in predicting preliminary earthquake recurrence interval and estimating the magnitude of earthquakes. Continuous crustal movements techniques utilize continuous observation obtained from special instruments such as tiltmeters, strainmeters and tide gauges.

3.1 *Geomorophological - Crustal Movements Techniques*

A knowledge of the past is necessary in order to predict the future. As it is known, great earthquakes repeat themselves, so the 'past' must be extended and more information extracted from it. The discovery and analysis of ancient documents is one way to do this, but they are not the only records of the past. Land forms and strata-materials that precede human history most contain some imprint of the past. By recognizing the imprints that earthquakes leave and finding and decoding these imprints will be helpful in providing the information needed for earthquake prediction.

When an earthquake fault appears at an earthquake's epicenter it is in fact underground fault that has surfaced, and the movement of the fault is what causes the earthquake. Such a fault is the most direct and significant of all earthquake traces. As earthquake recur, the displacement accumulates and is recorded within the landforms. By studying these landforms one can trace the incidence and nature of prehistoric earthquakes. In the case of shallow earthquakes the size of the "scar" the earthquake leaves (fault length, fault slip, and radial extent deformations)is in direct proportion to the earthquake magnitude. Understanding these relationships quantitatively are very helpful in estimating the size of an earthquake from a past scar.

Examination of the landforms, then, can reveal the direction, amount and velocity of crustal movement during a certain period in the past or from a point of time in the past to the present. If several reference landforms of different ages are available in an area, the locus of the crustal movement over time can be examined. In general, for restoration of the movement, location of the reference landform must be determined at various points of time using landforms as a clue. Therefore, geologic methods such as radio-carbon and radioactive fission track are used to determine the chronological gradations within landforms. In general, old topographic surfaces are severely eroded and have lost their original forms. As a result, restoration of the minute details of crustal movement within ancient landforms is extremely difficult. However, based on geological experience, the age of surface terrace can be assumed (Matsuda, 1982).

3.2 *Continuous Observations Techniques For Crustal Movements*

As indicated previously (sec. 2) that Monitoring of the first stage depends entirely upon repeated surveys; monitoring of the second stage requires that repeated surveys be supplemented with continuous observations. When the process has reached the third stage, continuous observations are again necessary for definite short-range prediction. Hence we can summarize th aims of continuous observations of crustal movemen as following: To fill in the gaps between discontinuo geodetic surveys; and to study the earthqua mechanism through observations of the release of stra that accompanies the principal rupture.

3.2.1. *Tiltmeters Continuous Observations*

Crustal tilt is monitored continuously by tiltmete installed in observatories. Crustal tilt can be defined the varying inclination between the earth's crust an level surface of the earth's gravity field. Measuring tilt using continuously recording tiltmeters, are important source of geophysical information. Tiltmete record crustal tilt as well as the inclination o level-surfaces or deflection of the vertical caused b the tide effect.

Tiltmeters which are used for obtaining informati about the elastic behavior and the mobility of th lithosphere and a constraining factor of earthqua generating models, must be well sealed and protect against the direct influence of atmospheric pressu changes.

Earth - tides are the dominating features on t records. Anomalous tilt amplitudes and phases are du to regional lithosphere conditions, the influence ocean - tides, local geological structures and also cavi effects when the tiltmeters are installed in vaults. The anomalous are separated and analyzed for furth studies of the earth's internal constitution. All the above information about the elastic and plastic behavi of the earth's crust, when obtained in earthqua zones, are very important. Most relevant as t earthquake generating processes are the observations temporal change of tilt amplitudes associated wi stress and strain accumulation. This temporal change the tilt amplitudes seems to be a premonito phenomenon which must be considered serious (Vogel, 1979).

There are many examples of earthquake precurso detected by tilting crustal movement that take pla anywhere (Japan for instance) from several hou before to immediately before the earthquake itself f example (Sato, 1981): Kanto earthquake (1923 Tottori earthquake (1943), Central Gifu earthqua 1969).

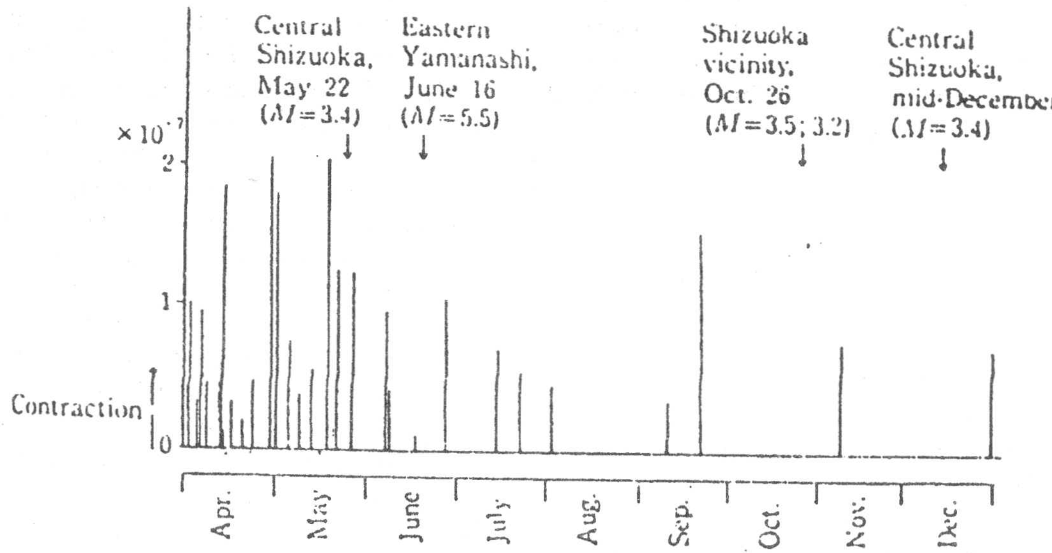


Figure 1. Strain changes in Shizuko, Japan, before a series of earthquake in 1976.

On the other hand, it is not difficult to see that the quality and speed of collecting continuous observations by tiltmeters, as useful information for predicting earthquakes are affected by several practical limitations, namely: spatial distribution, time resolution, sensitivity and recording system of each device.

Continuous observation originally emphasized that static side of the investigation of crustal movements. It takes a long, careful look at the process in order to clarify the nature of the movement itself since understanding the nature of crustal movement itself is very important to be utilized for earthquake prediction. This requires that the network of tiltmeters stations must send their recording observations at once to a central site for immediate analysis and predicting minor earthquakes a few minutes ahead before their occurrence. Unfortunately, this is not the case with the previously used recording system since the records are collected manually and consequently the analysis is delayed and becomes useless for earthquake prediction in many cases. Therefore, it is very essential to revise the present recording system to be meaningful for continuous crustal movement monitoring and hence for earthquake prediction (Rabah, 1992).

3.2.2. Strainmeter Continuous Observations

Strain accumulation and strain releases have been measured preceding and during earthquakes using straimeters. Many classical designs for strainmeters have been commonly utilized for collecting continuous strain data needed for several geophysical applications, for instance, precursors for earthquake prediction. The most common types are invar wire strainmeters, quartz-tube strainmeters and laser interferometric strainmeter (Karianien, 1979).

Crustal strain is monitored continuously by strainmeters installed in seismic zones. Measuring of strain using continuously recording crustal strainmeters are important source of information providing precursors for earthquake prediction. There have been several days after aseismic sudden strain changes occurred in the same area. As an example, the Eastern Yamanashi earthquake (June 16, 1976) occurred after frequent strain changes took place in Shizuok (Japan) as shown in Figure (1).

Should be stated here that such classical strainmeters have similar limitations and problems as has mentioned before, concerning the tiltmeters. Such problems are mainly related to spatial distribution, time resolution, sensitivity, and recording system (Rabah, 1992).

A new version of strainmeter (embedded volume strainmeter) is now available that overcomes most of classical strainmeters problems, in addition a promising tool for spatial measurements of strain which is called Holographic Interferometric Laser Strainmeter.

3.2.3. Tide Gauges Continuous Observations

In seismically active areas with coastlines, as the north and east coasts of Egypt, it seems that networks of sea level records are promising for the measurement of vertical crustal movements. Up lift can be related to mean sea level using tide-gauges, and in some cases, apparent local changes in sea level have been observed prior to earthquakes. Only a very few examples of precursory land uplift or subsidence relative to sea level have been found through modern tide-gauge observations.

The tidal observations give us the continuous information on the crustal deformation which is intermittently revealed by the geodetic leveling. Since the height of sea level is influenced by various environmental elements such as atmospheric pressure, water pressure, wind, ocean currents salinity and so on. So the sea level fluctuates very irregularly, and this fact makes it difficult to interpret the tidal data.

The difficulty of the analysis depends on what the problem need to be solved. When the purpose of the analysis is to get the absolute change of ground, it is very difficult to solve this problem. But when our purpose is only to get the relative change of ground, it is not difficult to analysis the tidal data.

A conventional way of eliminating the noise in tide-gauge observations arising from such oceanographic and meteorological origins is to compare the observed height of sea level between neighboring tide-gauge stations on the assumption that both stations are reflected by the noise to an approximately equal extent is considered. Taking the difference of sea level between two stations, the irregular variation are almost canceled out each other and the relative change of ground is easily obtained. Figure (2) shows the relative changes of sea level, which are considered to be the result of the changes of ground between two stations before and after the destructive earthquakes. The change of sign in the gradient that occurred about one year prior to the earthquake might be premonitory effect (Tsumura, 1964).

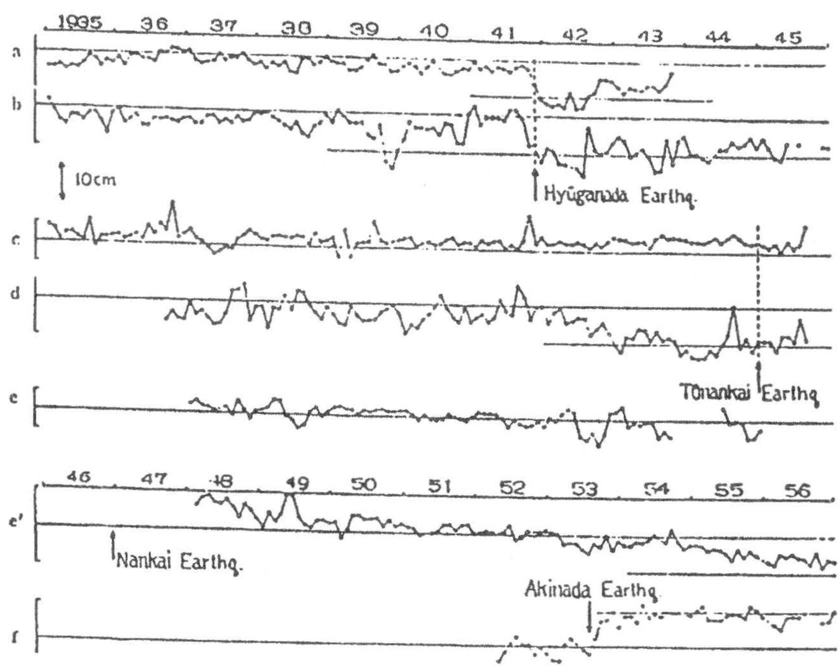


Figure 2. Difference of monthly mean sea-levels between two stations before and after the destructive earthquakes where the remarkable changes shown in the figure is considered to be mainly due to the vertical crustal deformation at the underlined stations. (After Tsumura, 1964).

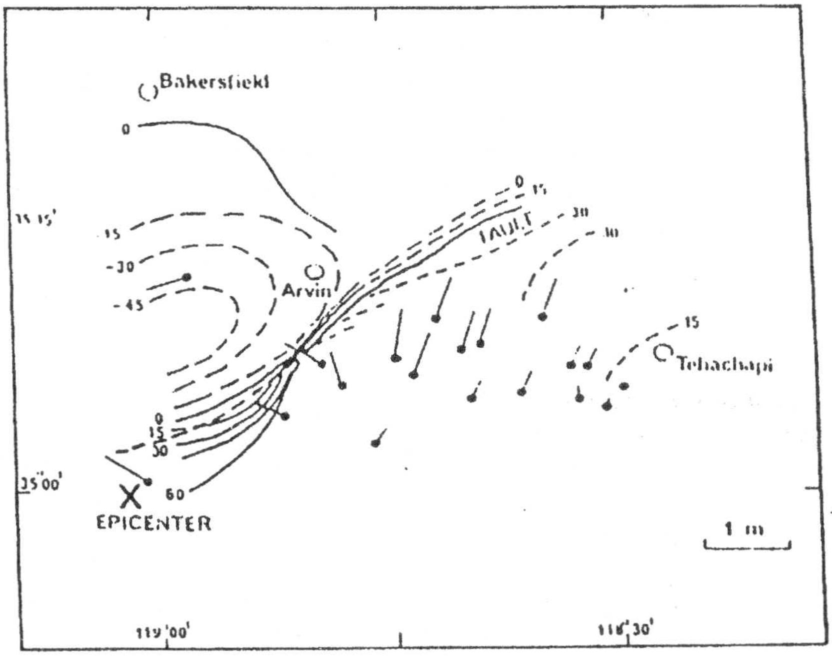


Figure 3. Horizontal displacements of the triangulation stations associated with the Kern earthquake, California. Numerals indicate the vertical displacements in units of cm. The epicenter is indicated by a cross.

3.3 *Discontinuous Crustal Movements Observations Techniques As A Precursory For Earthquake Prediction*

In many countries, remarkable land deformations associated with earthquakes in seismic areas were found by comparing geodetic surveys over these areas carried out before an earthquake to those after it. The land surface movement anomalies that accompany earthquakes are determined by the size, shape and amount of displacement of the faults involved. Consequently, a fault's position, size and displacement can be determined from the deformation of the earth's surface. Since these data are basic earthquake information, a post-earthquake survey of ground movement is of vital importance for earthquake prediction as well as for seismological research.

As in example, Figure (3) represents the horizontal and vertical displacements of the earth's crust associated with the Kern country earthquake (California) of magnitude 7.7 which took place on July 21, 1952. It was fortunate that a triangulation and leveling surveys had been completed several months before the earthquake. Hence the horizontal displacement and the depression of the land mass north of the fault as shown in Figure (3) are deduced from the two surveys respectively carried out in 1951-1952 and 1952-1953 (Rikitaki, 1976). There are three modern geodetic techniques serving for detecting regional crustal movements, which are made by the extra-terrestrial geodetic techniques, photogrammetry techniques and ground surveying techniques.

3.3.1 Extra-terrestrial Geodetic Techniques

The extra-terrestrial techniques involve both interferometric and artificial satellite methods. Such techniques are basically used for regional spatial crustal movements determination, the spatial movement means here the change of the chord distance between any two terrain points in the regional area of interest. On the other hand, such spatial movement can be, if required, resolved into horizontal and vertical movements (El-Maghraby, 1991).

Interferometric Techniques

There are two types based on the principle of interferometry, namely radio interferometry and light interferometry. Both types lead to the measurement of the length and spatial orientation of a very long base line connecting intercontinental stations, which when determined at two different epochs can be used for detecting crustal movements, and usually denoted Very Long Baseline Interferometry (VLBI).

Artificial Satellites

Satellite techniques use artificial earth satellites orbiting the earth to which ranges for example SLR or GPS, directions (photographing), range differences (Doppler) and combinations among them are measured for the purpose of precise determination of the position and coordinates of the observing stations. Two or more terrain stations with intercontinental distances can simultaneously observe the same artificial satellite which yields the precise determination of their relative positions (chord distances) and orientations. When this process is repeated at different epochs (say 5 to 10 years intervals), it can be easily used for detection of the global and regional crustal movements. Some results from the above satellite techniques are given here.

Two methods exist for the accurate determination of crustal movements by using laser ranging, namely, natural moon and to artificial satellites. Lunar laser ranging has been done at the Universities of Texas Hawaii since 1969. Similar observatories are also being constructed in Japan, Australia and in Europe. Satellite laser ranging facilities capable of ranging to Lageos (artificial satellite 6000 km altitude) are in facilities operated by the Smithonnian Astrophysical Observatory.

A spaceborn laser ranging system that can survey a large network of ground reflectors and provide their relative locations to a precision of 1 cm. Such performance is believed reliable for networks covering up to million square kilometers and for only a few days of observations, using ground stations separated from 20-1200 km (Schmitz, 1979).

A geodetic satellite can also carry electronic signaling equipment to produce the Doppler effect which furnishes range-rate information that can be used for geodetic positioning through the observed Dop count. Currently six satellites of the Doppler type in operation. By tracking several satellite positions known orbits at several positions, the positions of ground station is linked to their orbits and in turn the center of the earth, i.e. to the average terres system. Methods for using Doppler electronic data geodetic purposes have been thoroughly tested proven to give a feasible and significant geod accuracies.

As discussed above some of the previous sate techniques do not satisfy all the requirements of re precise geodetic applications, one of which is crustal movements of small rates. Moreover, as it mentioned previously, one of the objectives continuous observation is to fill the gaps in t resulting from repeated survey. But, this objective not been completely achieved since, at present observation sites are not spaced densely enough. E if we cover an extensive area spatially, that wil very costed, moreover, the time resolving powe horizontal vault observation, particularly, is still high enough to meet the objectives of all observa needed. The noise -up till now -can not be control so some discrepancies are still present, which affect quantitative examination that will be necessary in fu for more accurate understanding of earthqu mechanism

There exist, however, another problems, such vault or bore hole creeping and crack movements groundwater changes, which may affect the observa and make it difficult to measure the regional cru deformation quantitatively, Fixed-point GPS base determination network is expected to solve dilemma. By measuring base line lengths every co of hours it will become possible to moni continuously the crustal movement in a wide a (Shimada and Sekiguchi, 1988). Details concern GPS system and its maintaining authorities can found in several literatures (e.g. Nassar et al, 199

A number of proposals have been made to utilize GPS satellites to obtain relative global positions to few centimeters accuracy for use in crustal mot studies. Because of high altitude of satellites, most the involved errors will not be significant even stations separated by hundreds and perhaps thousand kilometers, and hence can be easily eliminated. T will be of course depending on whether predic fitted or spatially computed ephemeries are used.

The comparison of sought accuracy as obtained from the different satellite techniques indicated that GPS is the most accurate one, and hence, will be the most promising satellite techniques for crustal movement studies especially for the purpose of earthquake prediction. Therefore, some interested organizations and research institutes all over the world have already started planning their specific regional crustal movement projects through the implementation of the new technology of GPS. One of such project, for instance, Japanese project is nowadays underway (Shimada and Sekiguchi, 1988).

3.3.2.2. Photogrammetric Techniques

Photogrammetry techniques include remote sensing for global areas and both aerial and terrestrial photogrammetric for both regional and local areas. Although, some of these photogrammetry techniques provide less accurate results, they can supplement non geodetic technique with rapid and useful information concerning preliminary crustal movement analysis, in addition, photogrammetry techniques are capable of providing information about horizontal and vertical crustal movements simultaneously.

Remote Sensing

One method of gaining information pertaining to crustal movements is by using remote sensing techniques. These give excellent synoptic coverage of an area showing all its details clearly. Also, when the remote sensing data is added to geophysical, geochemical and geological data, it will enhance the interpretability of these traditional techniques. The use of satellite imagery, with all its various forms, can give cost-effective regional tectonic evaluation.

The continental-wide coverage of satellite mapping is admirably suited to the broad scale processes of crustal movements. Areas of economic interest can be defined for further study, and continuing imagery can be used to monitor the small changes in the earth's crust for our comprehension of recent crustal motion (Boud, 1984).

Aerial Photogrammetry

Aerial photogrammetry is a modern tool of map making and geodetic positioning from a series of overlapping photos taken by special cameras from air craft. Stereoscopic pictures can be formed from the overlapping adjacent photos, using special stereoscopic instruments, and used for several purposes. For the purpose of geodetic positioning (the method of detecting horizontal and vertical crustal movements) identifiable control points must be established on the ground and marked clearly in the corresponding photos. These control points enable us to obtain the coordinates of all points of interest from the photos and then fitted properly into the geodetic coordinate system of the known ground control, and hence, make the point positioning using the photogrammetric technique meaningful reality (El-maghraby, 1982).

Ultimately, in place of just map making, we should be able to use photogrammetric point positioning for the densification of lower order geodetic control network since it is more rapid and economical compared to ordinary terrestrial ground survey. Of course photographing the same regional area twice at two different epochs will enable the detection of regional horizontal or vertical crustal movements to a certain level. By this method we can get standard deviation of 2 cm for difference between coordinates of order of 5 cm.

Terrestrial Photogrammetry

This method has been extensively used in the determination of deformation of large structures and ground subsidence on local bases (Nassar, 1986). In general,the advantages of photogrammetry monitoring methods are: Simultaneous determination of the deformation of any point in the deformed area; provision of complete and instantaneous information in the three - dimensional space; reduction of field work to minimum; and a special model of the deformable area can be recovered at any time.

In addition , the precision of photogrammetric point determination has been much improved in the past few years, which make it attractive for high precision deformation measurements. The main reason for this development is the successful refinement of the mathematical models by using self - calibration techniques (Chen, 1983). This development includes checks to guarantee the reliability of the results. The precision reaches standard deviations of 2 - 3 mm in the image coordinates ,i.e. in the order of 10^{-5} of object camera distance (Schneider, 1982).

3.3.3. Ground Surveying Techniques

Ground surveying techniques are usually based on establishing a network of geodetic points that should be will distributed within the seismic area of interest or around faults under investigation for the purpose of horizontal crustal movements. Similarly, the same networks points or a separate network of points (Bench Marks) can be observed periodically for the purpose of vertical crustal movements determination. In fact, since geodetic stations used for horizontal movement detection are situated on the top of hills, for satisfying the intervisibility requirements, they are not in most cases suitable for vertical movement studies. Instead, a network of bench marks are erected and observed periodically for vertical crustal movements determination.

Horizontal Geodetic Networks

The horizontal crustal movement in any desired direction can be obtained if we perform our computations of the involved geometric quantities in the local geodetic system. This method is generally used for detection of horizontal crustal movements near and acrossing the active faults displacement. such networks may be treated as triangulation, trilateration or hybrid networks.

Generally , geodetic monitoring networks are divided into relative and reference networks. The former provides the change in relative positions of the points. Meanwhile, the latter serves as a reference to which the displacements of the object points are referred. A confirmation of the stability of reference points is the only aim of the measurements in the reference network (Chrzanowski et al, 1982).

In reality, horizontal triangulation monitoring networks have been gradually replaced by trilateration or hybrid networks. This is simply because the precision of angle measurements remained from 0.5″ to 1″ for the first - order observation scheme , while the precision of distance measurements has been much improved (Nassar, 1986). It can reach 0.1 p.p.m w the use of multiple wavelength distance - measur equipments (Chen, 1983).

On the other hand, when sitting up a geode network to monitor earth movements, one must assu that such network will not have internal inconsisten equal or greater than the anticipated earth moveme Seismical and geological data are very important preanalysis of the shape, size, number and accuracy the observations of the survey to help us to de movements much larger than survey errors. T analysis, in addition to the configuration of t network, formulates the practical basis for opti design of geodetic network established f monitoring crustal movements (Mousa, 1992).

The above method has been widely used monitoring crustal movements for a long time. T reasons for that can be summarized as follows: T supply the overall status of the area un consideration; they contain the scheme of self check of the results and are capable of evaluating measuring precision globally; they provide versati and suitability to any environmental and operat situations.

However, in opposition to these undeniable meri some drawbacks can be stated as: Complexity measurement requires the presence of many operat for several days; the intervesibility between t stations is not always possible while it is essential this method; it is difficult and expensive to adopt t geodetic methods for continuous monitoring (nea impossible). Thus, this method provi measurements of deformation at discrete epochs time, only at a finite number of points (Schneid 1982).

Vertical Geodetic Networks

Spirit leveling is the most accurate method f determining the height differences. Till now it is t only method which can be used for leveling of hi precision needed for detecting vertical crus movement. There are different techniques of usi precise leveling for this purpose depending on cert circumstances which are releveling on single poin releveling considering pairs of points and releveli several points.

Table 2. Land deformation precursor as derived from the geodetic analysis of Kalabsha network in the specified area of Aswan.

Date	M	Epicenter	Amount $x10^{-5}$	precursor time (days)	Epicentral Distance (km)
2.7.1986	3.40	23.66N, 32. 69E	15	139	26
28.2.1987	3.10	23.66N, 32. 70E	20	44	28
18.6.1987	3.30	23.65N, 32. 70E	20	138	21
19.6.1987	3.40	23.57N, 32. 68E	20	139	21
19.6.1987	3.00	23.57N, 32. 68E	20	139	21
19.6.1987	3.30	23.57N, 32. 69E	20	139	21
7.10.1987	3.10	23.55N, 32. 58E	25	22	10
19.4.19887	3.26	23.52N, 32. 58E	25	93	8
8.7.1989	3.90	23.55N, 32. 55E	35	159	6
2.12.1989	3.70	23.52N, 32. 51E	35	306	2
20.7.1989	3.60	23.64N, 32. 71E	20	171	25
2.8.1990	3.35	23.52N, 32. 51E	25	183	4

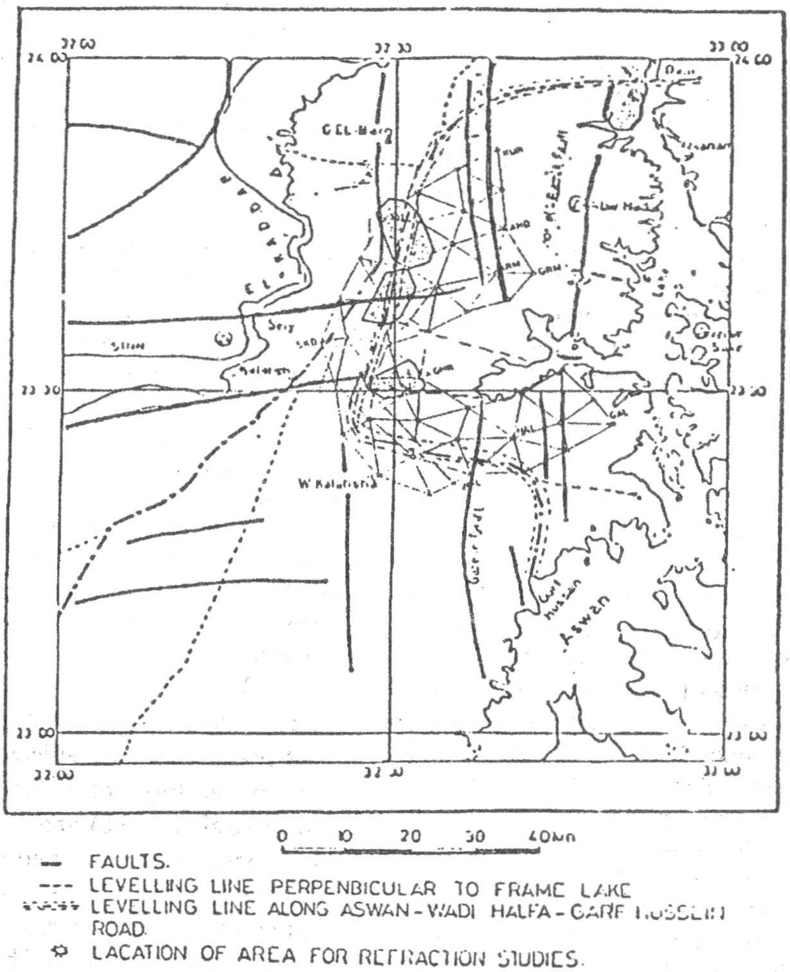


Figure 4. Local and subregional geodetic networks established for monitoring regional crustal movements in Aswan region.

In the first case occasionally the distribution of original and repeated leveling is almost ideal for a small area. Two levelings covering the study area, each accomplished within a short time period and adequately separated from each other in time, may be adjusted independently. After the adjustments, vertical movements are calculated by comparing the two sets of adjusted heights. This method is generally used in almost all the trials made for detecting the vertical crustal movements all over the world. For example in the USA, a rate of 35 mm/year was experienced (Chen, 1983).

The second case is more applicable for vertical crustal movement determination than the single point technique because data requirements are less restrictive. The original repeated observations existing in an area will generally not be separated by a constant time interval. By forming velocity difference observations from repeated leveling, the data are effectively made homogeneous. We can get the change of height of any point by using linear interpolation on the velocity rate of any two points.

The last case is generally based on fitting a velocity surface for the vertical crustal movements over the entire area of interest. The main advantage of this method is that it minimizes the number of unknowns in the solution and we can get the vertical crustal movements of any point at any time by using the surface of vertical crustal movements of this area. This technique was applies by Vanicek et al. 1979 in several places in Canada and USA, where a contour maps of velocity surface was produced, indicating rates of vertical crustal movements ranging from 0-10 mm/year (Nassar, 1986).

4. INVESTIGATION OF GEODETIC CRUSTAL MOVEMENTS AS EARTHQUAKE PRECURSORS IN ASWAN REGION

In order to monitor the crustal deformation associated with the earthquake activities, a system of local geodetic networks were established around parts of active faults at the northwestern part of High Dam Lake as shown in Figure (4). The first local geodetic network, of Kalabsha networks was established around an active part of Kalabsha fault in 1983. It consisted firstly of 16 geodetic points for horizontal measurements and two leveling lines crossing the Kalabsha fault for vertical crustal Movements. Three geodetic points for horizontal measurements were added in 1988 for improving the sensitivity of this network to satisfy its objective (Nassar et al., 1990a). The initial horizontal geodetic measurements were carried out in December 1984. The measurements were repeated with a rate twice per year.

Each one of the Kalabsha geodetic observations s has been processed by the responsible personnel of t Dept. of Geodesy and Geophysics of NRIAG institu using a software called GEODET which was provid through a joint cooperation with the Internatio Center On Recent Crustal Movements, of Pragu Czechoslovakia (Vyscocil et al, 1992). The da processing includes:

1- The separate adjustment of the horizon measurements of each epoch as a free network.
2- The transformation of the coordinates of t different epochs into the system of coordinates the initial measurements using Helmert transformation.
3- The evaluation of the results of adjustment a transformation using the error criteria as well a error ellipse.
4- Computations of the displacement vectors of t network stations from the coordinate changes each current epoch after being transformed relati to the initial epoch. Then the deformation vecto are used to construct the deformation tensor of t network, from which the essential parameters ca be deduced.

As shown in Figure (5), zones of relative hi tension were prevailed to the south of Kalabsh network during the epoch from December 1984 t February 1986. This provide a picture of surfa deformation during the process of preparation a occurrence of earthquake of magnitude 3.4 at t epicentral distance 26 km from the center of highe strained region as indicated in Table (2). In additio it is interesting to note that the area of maximu accumulated strain in Figure (5) (February, 1986) h experienced no strain accumulation in Figure ((January, 1987) which clearly indicates the occurren of an earthquake at or near this location characteriz by the release of the maximum strain. Simil comments hold true for all earthquake events a illustrated in Table (2).

From Table (2), it can be seen that the accumulat strain changes from event to event according to t event magnitude, the epicentral distance (the distan from the earthquake epicenter to the center of t highest strained area) and the precursor time (the tim from observed the network to the earthqua occurrence time). It is easy to conclude that t accumulation strain increase with the increase of t magnitude and decrease of both the precursor time a epicentral distance.

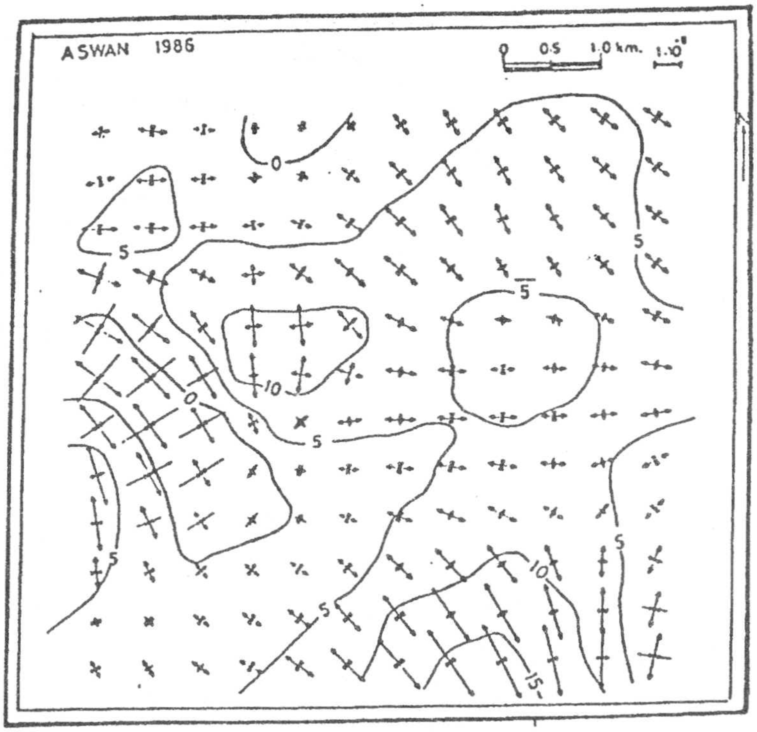


Figure 5. Zones of horizontal deformation fields of Kalabsha network during the epoch from December 1984 to February 1986.

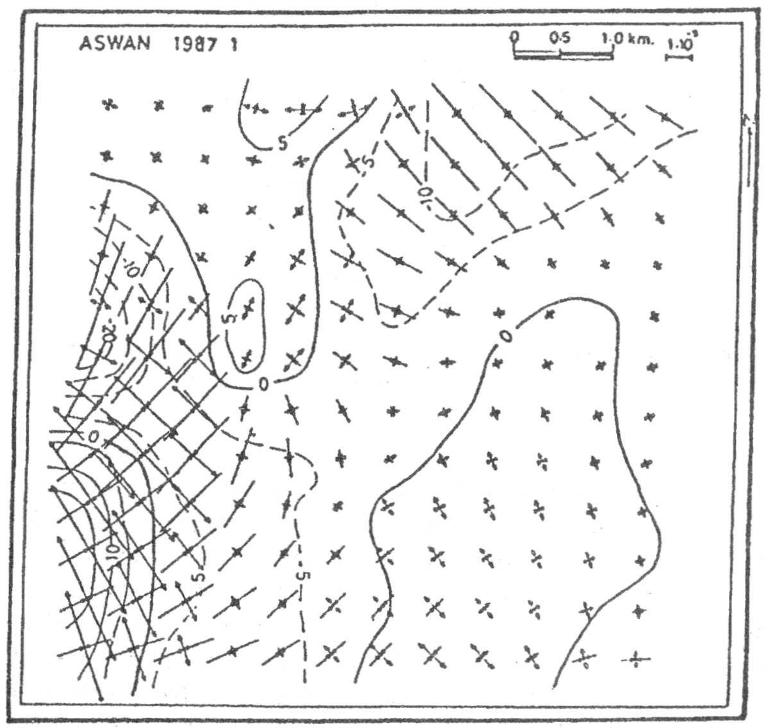


Figure 6. Zones of horizontal deformation fields of Kalabsha network during the epoch from December 1984 to January 1987.

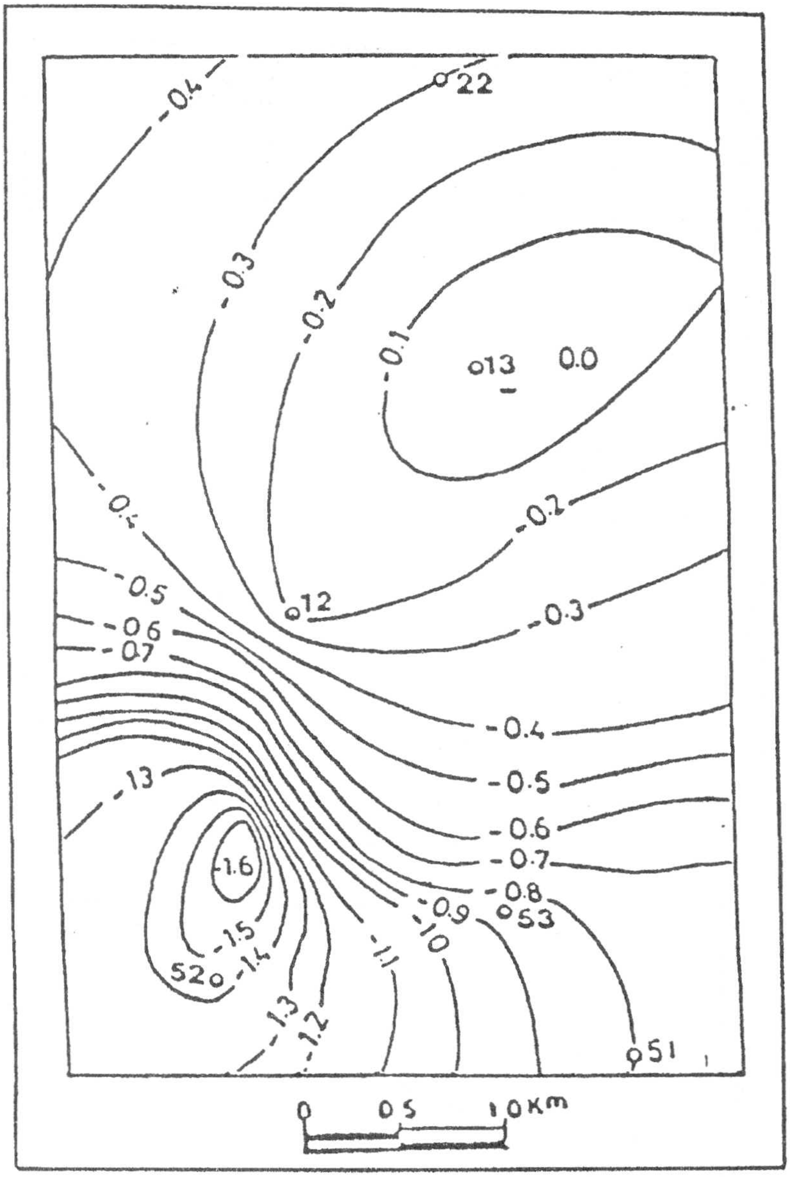


Figure 7. Rates of elevation changes in mm/y in the area of the kalabsha network during the period from January 1986 to January 1988.

The above results as obtained from the deformation analysis of horizontal control networks can be verified through more or less analogous analysis of vertical control networks (or lines) of precise leveling. Figures (7) and (8) represent two examples of the isolines plots of the rates of elevation changes (in mm/year) for the two epochs of January 1988 and November 1989 relative to initial epoch of January 1986 for vertical control observations across the Kalabsha fault.

From Figure (7) [January, 1988], an increase of the rate of subsidence can be noticed towards the south Kalabsha area (-1.6 mm/year), which confirms with maximum accumulated horizontal strain in the sa direction. On the other hand, Figure (8) (Novemb 1989) indicates a decrease in the subsidence rate the same location (-0.8 mm/year), which means occurrence of some earthquake events between Janu 1988 and November 1989. This conclusion is actu assured by the released strain associated w September 1988 and July 1989 earthquake occurren

(Table 2). From the practical point of view, this analysis recommended that the final decision about earthquake prediction analysis should be manipulated on the bases of integrated information from both horizontal and vertical deformation networks repeated observations at the same epoch. Considering the crustal movement or earth deformation in both horizontal and vertical as precursors.

5. SUMMARY AND RECOMMENDATIONS

An earthquake is a rupture that take place in the rocks within the earth's surface layer, by detecting precursory phenomena preceding the main rupture, it is possible to predict the probable location, size and time of earthquake. The improvements in and discoveries concerning sensitive seismic instruments, crustal movements techniques allows us to watch the earthquake progressive. A series of crustal deformation during preseismic, coseismic and post seismic are associated with earthquake evolution. The discontinuous crustal movements have the ability to monitor the pre and post seismic stages, while the continuous techniques have the capability of monitoring the coseismic stage.

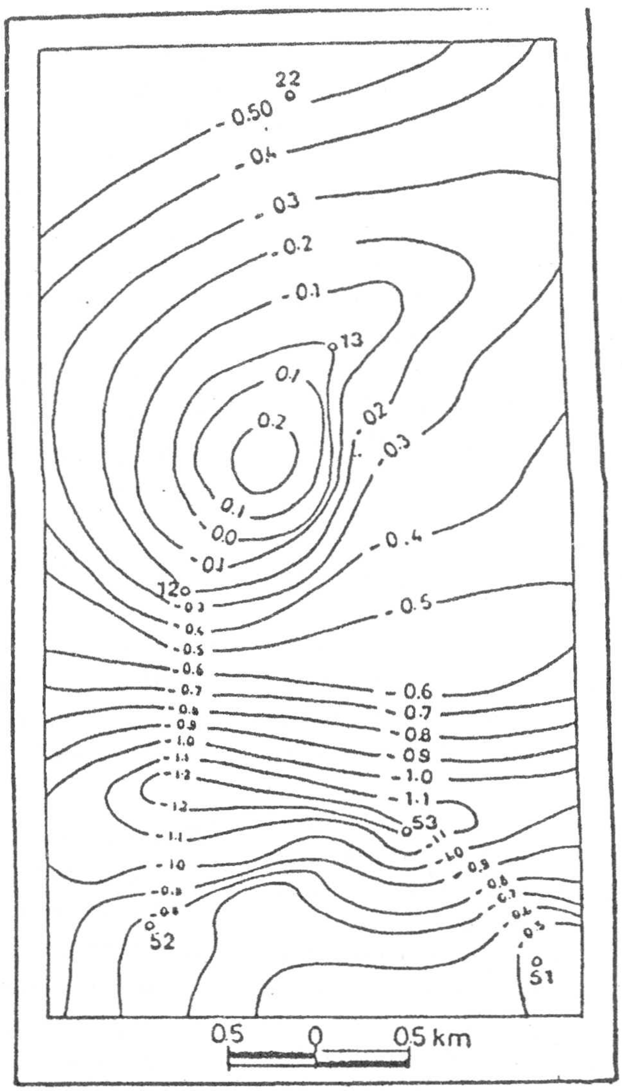


Figure 8. Rates of elevation changes in mm/y in the area of the kalabsha network during the period from January 1986 to November 1989.

When the repeated geodetic observations of Kalabsha local network are carried out before the occurrence of an earthquake, stored energy during the preséismic period are able to be calculated under suitable assumptions. This estimated accumulation of strain energy serves to be an indicator of possibility of earthquake occurrence, i.e. precursor for earthquake events.

The rate of accumulated strain at the area of Kalabsha geodetic network increases with the increase of earthquake magnitude and the decrease of both precursor time and epicentral distance as it is shown in Table (2). This result verifies the strain accumulation principle accompanying earthquake occurrence and the practical feasibility of crustal movements geodetic techniques as earthquake precursors. Therefore, we have to pay the attention towards the geodetic crustal movements techniques generally and up spatial crustal movements techniques especially.

Covering the whole country by seismic network for monitoring seismic activities in Egypt and its surrounding vicinity and establishing the seismic data collection centers and supporting them by the required software which grant sound analysis and reliable results will be helpful in determining accurately the boundaries of highly seismic zones as well as the discovery of latent active faults from detailed earthquakes distribution.

Detailed survey of active faults. That's because as it is known, the faults which have been active repeatedly in the recent geological past are considered likely to repeat their activity in the future and when a part of an extensive fault system becomes active, it sometimes seems to trigger other sections of the fault system. Thus a detailed survey of active faults will be helpful in determining the areas which may be hit by great earthquakes in the future.

To study the crustal deformation in a regional scale and its relationship with the local activities and earthquake occurrences. The local geodetic networks have to be connected together with appropriate regional geodetic network. Then the regional geodetic networks are connected together in a national zero order network covering the whole country for studying the regional crustal movements and tectonics of Egypt and its surrounding vicinity. These networks can be observed periodically (or continuously) by the high precision extraterrestrial techniques like GPS. Also, the design of these network must be satisfied all the need preanalysis and optimal conditions of monitori regional crustal movements networks.

Since geodetic measurements are intermitted, t the continuous observations of crustal movements a at: To fill in the gaps in geodetic surveys w continuous observations of crustal movements and study the earthquake mechanism through observati of the release of strain that accompanies the princi rupture. Therefore, a densely distributed teleme network of embedded volume strainmeter is situate and around the highly seismic zones for obtai continuous observations of crustal deformation.

Construction of an integrated system of d collection, analysis and diagnostic judgment should promoted for the area under investigation. This c be achieved through the establishment of the d bank and the data processing centers and suppor them by tele-communication networks for the differ types of observations which will serve for quick d processing and on-line results.

Egyptian geologists, geophysicts and geodists m be encouraged to form a working team or gr supervising research projects connected with t detection of the different types of earthqu precursors around the strategic highly seismo-ac areas beside the underlying crustal movem precursors.

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