The Roll of the Geodesy in the Romanian Seismicity Study

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Abstract: *The study of the recent crustal movements could be integrated in the ensemble of the scientific research with a fundamental character at which competes all the geosciences that study the Earth dynamism, understanding the description of all the complex phenomena which are permanently taking place in the Earth's crust and also much deeper. The results obtained by the correlation of the efforts made separately or in the frame of complete interdisciplinar research programs, realised by the geology, geophysics, oceanographyc sciences, with the results from the geodesy determinations, competes to the elucidation of a multitude of issues regarding the evolution of the changes from the internal structure and from the upper side of the Earth crust, at the cognition of actual processes and to the prediction of their future evolution. In this way the mentioned fundamental studies bring very important explanations for the application researches, such as for example, those from the massive constructions area, from the exploitations of the mines, especially regarding their behaviour and stability. The research themes from this area, elaborated in this moment in the most developed countries have this complex structure, which kick off with the clarification of the earth crust mechanics and even of the deep structures till the antiearthquake protection measures, necessary before and even after the generation of this kind of natural phenomena , which could have sometimes a devastating character(WENZEL, 1997)*

Keywords: *crustal movements, geodesy determinations, behaviour and stability, seismicity.*

1. Introduction

The participation of geodesy at the studying programs of the crustal movements was determined and simultaneously developed with the agreement of the global tectonic concept. These studies are realized for the determination of a very important precursor of the earthquake's prediction, especially of the crustal deformations establishment (such as compressions, extensions).

The geodesy provides, more exactly and promptly to the other geosciences, information about the movements of the Earth crust deformations of which it could have been calculated the quantity of the potential accumulated energy between the series of measures made into the determined limits by the hypothesis accepted by the statistical nature.

By involving the geodesy in such studies, deep changes were realized in preparing and activity of the geodesy specialists. Thus, according with the theory of tectonic plates, which confirms the fact that nothing is unflexible in the whole nature, in time or space, it has been enforced as very necessary the introduction of the fourth dimension (time) in processing of repeated geodetic measurements.

In order to be able to respond with the needed capability by the requirements of the other geosciences, the specialists in geodesy must have acknowledges from the areas they are collaborating to (geophysics, geology, constructions) especially in the area of the solid corpse mechanism which could deformate, so as from the repeated geodetic measurements could be determined those physical quantities (movements, deformations, tensions, potential energy) which can be used as precursors of a prospective seismic event.

In the last few decades, new procedures had been developing for the processing of repeated geodetic measurements in order to establish the already mentioned parameters, of which the finite elements method have found numerous adepts. The main theoretical concept used in the finite elements method, is based on the use of variation principle in which intervenes first the solution of diferential equation systems in a particular area which must respect some certain conditions at the limit, by using minimal conditions imposed to functional sizes from that area. The specific of the finite elements method is the fact that these conditions are applied on subareas of the studied object, named finite elements. These are tied between them in some certain points named knots which in the case of geodesy webs are represented by the points of which the web is made up. Therefore, it could be assessed the research’s actuality and the utility of the outcomes, regarding the studies of seismic risk and earthquake’s prediction.

2. The contribution of geodesy in the interdisciplinary studies regarding the earthquake’s prediction.

Throughout the years, the earthquake’s prediction together with the prediction of historical events or extraordinary natural phenomena such as wars, diseases, starvation, floods have constituted remarkable concerns of several politicians, scientists, fortune-tellers or even of so-called prophets. The skepticism that surrounded this kind of preoccupations is on the agenda even nowadays, though the efforts and the meanings are continuously developing.

If we limit ourselves only to the object of this presentation, we can mention that in worldwide acknowledged works (Lyell, 1968) it is analyzed the evolution in time at the capable methods to emphasize the phenomena that appear before the earthquakes in the legitimate attempt to warn the population as fast as possible about an imminent earthquake. Among such as traditional precursors we can mention: the special changes of the climate conditions, the earth movements up and down and also the unnatural behaviours of some animals concluding that the popularity of folkloric myths have often a scientific background. Many scientists have also released the hypothesis of the appearance of such opinions and theories, as psychological reaction of the population, affected by the mentioned disasters and less by scientific proved analysis.

Simultaneously with the appearance and the development of adequate instruments and technologies which have been used in numerous seismic areas on the whole globe, in our country also, this has been followed by filling out the list of earthquake’s precursor phenomena with new components of whose inducements gets an emphasized scientific character and to whom it is given more and more the necessary credibility.

3. The main precursors of earthquakes

One of the research directions in the last years, which maintained the hope for the reduction of the losses and faults produced by earthquakes is represented by the revealing of new technologies capable to realize their prediction, by the study of physical measured precursors which happen before the earthquake in general. In the specialized literature (Rikitake, Vogel, Scholtz) they are presented several classifications of earthquakes precursors.

Among more than 20 precursors (Rikitake) taken into consideration at the production of Japanese earthquake's prediction Japanese program, an important position is granted to the recently crust movements study.

The vertical movements, as the horizontal or tridimensional movements also, as specific measurable deformations could be considered real disciplines in this area.

3.1. Geodetic technics and gravitation measurements

In the same time with the appearance of tectonic plates, a new dimension was attached to geodetic measurements time. The geodesy was requested together with the other geosciences : geophysics, geology, geomorphology, oceanography to bring their contribution into confirm or fulfillment of the hypothesis which were found at the basement of this theory. In this context, the modern geodesy is characterized by a systematic approach of the dynamic phenomena which modifies the shape and the gravitational field of the Earth as a whole or only in limited areas. Being a continuously developing science, the geodesy brings important contributions at the mentioned agenda, while other more developed technologies appear and especially with enlargement areas bigger and bigger, getting close to the covering of the whole globe.

- Vertical geodesic webs;
- Horizontal geodesic webs;
- Repeated measurement of gravity;
- Space-related geodesic technics.

The classification of geodetic determinations of the Earth's crust recent movements

The geodesy has an important role in earthquake's prediction studies, which have a strong interdisciplinary character, being the only geoscience which can offer geometrical information more and more precise, regarding the Earth's crust deformations. The results obtained by correlation of the observation and studies realized by geology, geophysics, geomorphology, oceanography with those obtained by geodesic findings , competes to the solving attempt of issues regarding the evolution of Earth surface and profound structure, to the acknowledgement of present processes which integrate in crust dynamic and the attempt of predicting their future manifestation way.

The spotting of the movements (including the deformations) of the upper side of Earth's crust which are happening before, during or after the earthquakes, by geodetic methods, give them a fundamental research character, and also a practical one competing to the determination of stability degree of the ground in the populated areas or in the areas where big industrial or edilitar objectives are about to be placed.

Classification regarding the reference system taken into consideration:

- the absolute determinations
- the relative determinations of vertical, horizontal, and tridimensional movements.

Classification regarding the amplitude of the recent movements determinations of the Earth's crust:

- global determinations
- regional determinations
- local determinations.

Classification regarding the geodetic determination precision

Classification regarding the results obtained by processing

Classification regarding the final product realized upon the process of repeated geodetic measurements

- the vertical movements map
- the horizontal gradients of vertical movements

Classification regarding the processing methods of repeated geodetic measurements

- processing models in a status concept
- processing models in quasi-status, quasi-cinematic concept
- the determination of movements and of mobile entirely deformations.

4. The geodesy contribution in earthquake's prediction

The earthquakes prediction has as a final goal the reduction of huge damages produced by then, as well as human loss. Approximately 3 decades ago, they use to consider that the prediction of the earthquake couldn't have been considered a real scientific research. However, in the 60's, research programs of earthquake's prediction have appeared in Japan and USA, which have denied the previous hypothesis. The strongest earthquakes which brought human losses and also material losses, which can be considered catastrophic and which took place in the last years in several areas (for example the one that occurred in our country at March 4th, 1977) prove the necessity of the approach and step by step solving of the extremely complex issue which is the earthquake's forecasts.

In the earthquake's prediction we can underline the following basic aspects (Dambara, 1980)

- the area's prone to have strong earth earthquakes with bigger probability
- observing the measurable changes in sight of this areas amongst the precursors of earthquakes, for the calculation of the moment when the earthquake will strike
- the development of display patterns of the earthquakes source in order to realize a proper interpretation of the phenomena evolution and the research outcomes.

The main principle of earthquake's prediction is rather simple but not always easy to accomplish and can be presented in this way: any parameter which can be taken into consideration as a earthquake precursor, which shows big changes reporting to the normal data can be used for the earthquake prediction, if the possibility of its measurements in time exists.

In what concerns the geodetic determinations, the main recently mentioned could be in such way applied: the big and sudden changes in geodetic points position could often be associated with a future earthquake. These changes can be without any doubts strongly influenced by the marking system of the named points.

This has to be in such way accomplished lest should the moments of the superficial stratum influence the conclusions regarding the position of the signs.

The conducted studies have to underline those movements of the geodetic signs which come as a consequence of the sudden released of tensions who have been accumulated, to the break up limit of the active tectonic forces.

Also, a real proficiency can be achieved only with a high rate of the repeated geodetic measurements and as well with an adequate coverage with geodetic points of the researched area. An earthquake's prediction must provide the following main elements: the rupture zone, the magnitude and the moment of the phenomena happening.

4.1. The rupture zone prediction or the epicenter area represents one of the compulsory elements of a complete telluric prediction.

After the earthquake stroke, the rupture zone could be identified by the area that includes the epicenter of the pre-shocks or the size of the surface with crust deformations pre-seismic and co-seismic.

For the crust deformation finding out of an unidentified seismic region must be conducted repeated geodetic measurements, researches which could be considerated having a fundamental character.

Because the interval between the fundamental successive researches cannot be extremely a brief one, due to the expenses and the extremely wide human effort, their frequency could be rather important just in few areas, where the probability of an earthquake strike in the immediate future is obvious, regarding the seism precursors and the previous seismic activity. Therefore, in such regions, geodynamic polygons are created, in which not only geodetic measurements are executed but also other kind of measurements which are repeating at proper time intervals.

4.2. The magnitude prediction

The tensions that could accumulate in a volume unit of Earth's crust, are more or less uniform depending generally on the area's geology and the internal structure of lytosphera. Thus, it is accepted that powerful seismic phenomenon involves large areas with crustal deformations associated with the earthquake .

Such a relation between the earthquake's magnitude and the crustal deformation's area was obtained by Dambara in 1966 and subsequently corrected in 1981:

$$M = 1.91\ \lg r + 4.43 \qquad (1)$$

where M is the earthquake's magnitude and r is the medium rate of the crustal deformations area expressed in km. The relation between lgr and M is graphically presented in fig. 2 for a 34 set of earthquakes that toke place in Japan. The crustal deformations have been detected by geodetic measurements.

The standard deviation for a M value, inferred with the relation (1) is ± 0.3. Even if the relation (1) is obtained from crustal deformations data wich have accompanied an earthquake, the same relation is presumed to remain valid also for the precursor movements. The respective equation can deliver a limit for the estimation of the observation stations density (respectively of geodetic guide marks), for the earthquakes' prediction with different magnitudes. For example the rays of crustal deformations anomalies for different magnitudes can be formulated like this:

M	8	7	6
r	65km	20km	6km

In order to mak a difference between an abnormal area and a normal one it is necessary that there appear abnormal movements in more points (grouped). Therefore, if there is persued the achievement of a prediction of a M=7 magnitude earthquake, it is indiquated to use a triangulation net with maximum 10 km sides. If the next expected earthquake, wich can be predicted, would have the minimum magnitude situated among M=6 value, the distance between geodetic guide marks must be shorter, under 3 km, else, the anomaly can not be detected at the necessay precision, even if this one would take place.

4.3. The prediction of the earthquake's generation moment

The establishment of some dependence relations between the magnitude of the M earthquake and T period of time where it take place crustal movements, has preoccupied several authors (Tsubokawa, 1969, 1973, Scholz a.o.; 1973) resulting different readingsd, whence the more customary is:

$$\lg T = 0.65\ M - 1.2 \qquad (2)$$

where T is the time forerunner measured in years.

Rikitake (1979, 1994), who analysed the available forerunner data, that are of a larger class than the former study, has obtained the next equation:

$$\lg T = 0.60\ M - 1.01 \qquad (3)$$

We can notice that there are small differences between the results of those 2 equations for M<7 magnitudes, differences that become greater when there are M>7 magnitudes. There were considered, for example, data from this seismic area (Dambara, 1981).

In geodetic measurements time forerunner can be sued on the diagram presented in 1st fig. and described this way:

(α) – crustal movements extended on a long period of time in wich take place accumulation anomaly movements of the elastic tensions.

(β_1) – anomaly movements extended on a long period of time, for some years, before an earthquake happens. In this period there take place expansion processes.

(β_2) – anomaly movements that take place little while before another earthquake's production.

(γ^1) – in this short stage it takes place an equalization of the tensions that go before the production of the main shock (the γ^2 period) and the liberation of the tensions (the γ^3 period). Here occur big and sudden deformations.

(δ) – this stage represents a sequence with casual movements that happen right after the shock.

After the mentioned stages, restarts the accumulation cycle of the tensions.

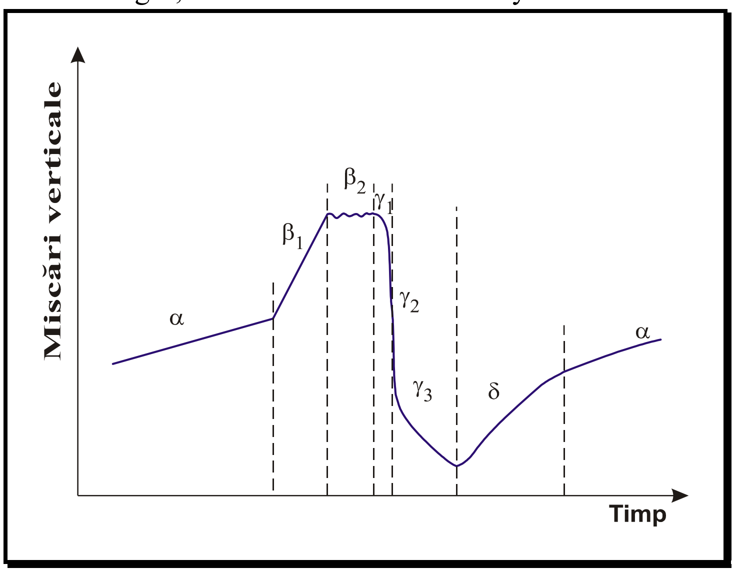

Fig.1 The typical qualitative analysis of the vertical crustal movements in active seismic area (after Dambara, 1981)

5. The principle of the finite elements' method

In order to retrospectively analyse the development of the finite elements' method wich we will name MELFIN (in the anglo – saxon specialized literature, this method was known under the name of the Finite Element Methods – FEM), it has been ascertained that the first trials of using this method has been made about 50 years ago (Olariu & Bratianu, 1986). Thus, Hrenikoff proposed in 1941 the frames method used in elasticity, whereby the analysed body is replaced by a bar ensemble, thus giving the possibility to represent a continuous elastic environment, with an endless freedom degrees, through a bar ensemble with a finite number of elements and freedom degrees.

In 1943, Courant developed the method introducing for the first time estimation functions similar to the one used in the present to define triangular finite elements.

The basic principle wich stands for the formulation of finite elements method, is the correlation between a part and the whole. (Zienkiewicz, 1977, Schearz, 1980 Pascariu, 1985, Serediuc, 1996). According to the dialect conception, the whole is expressed as an unitary totality, being instituted of an ensemble of constitutive parts wich are organically integrated and subordinated.

Unlike the mechanical conception, wich considers the whole as a sum of tha parts, each one maintaining its individuale properties, the dialect conception admits the existence of some interdependence relations between the part and the whole. The finite element considered apart, out of the body, as a result of its relative independence manifestation, has individual properties entirely different from the interaction properties that it has when is being correlated with the other finite elements, components of the body and integrated in it, as a structure element.

Mutually, the whole body expresses its relative interdependence according to the fact that at the action of the external forces the quality of the given answer does not depend on the number of finite elements in wich the body is underdivided nor these one, separately taken, qualitative specific character.

The state changes of the finite elements inside the whole as well as the modification of the correlation interactions' type between the finite elements changes the qualitative behaviour of the considered body.

The method of finite elements presents, by comparison with other numerical methods, certain possibilities more particular, whence we mention the most important ones:

- the modelation of some irregular shapes, using finite elements with different sizes and shapes, adequate for the geometrical configuration of the studied body;
- the treatement, with no major difficulties, of some problems in wich vary the body's physical properties;
- the adaptation of finite elements' dimensions at the main characteristics of the tackled problem, as for instance the size of the studied function's gradient.

The analysis of the effort state with finite elements

As a finite lement for the division of the plane structure (earthly surface) will be considered the triangle (2th figure). Every knot of such finite element has two liberty degrees (crucial shifting), therefore every triangular finite element owns in all six liberty degrees.

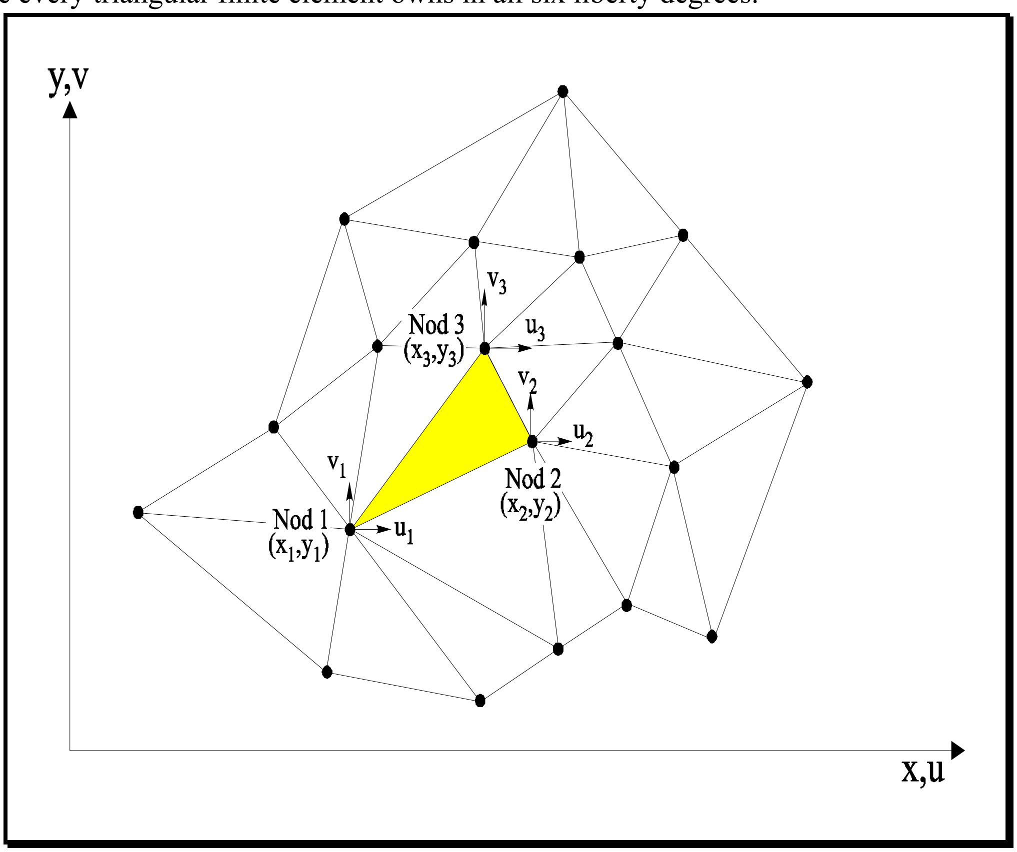

Fig. 2. Disparagement in finite elements (after Mocanu, 1977)

6. The geometry of bidimensional deformations

Some publications, for the deformation concept, are introduced (for a complete clearing up) other clearing up possibilities such as: unitary deformation and respectively un-unitary deformation.

In the unitary deformation, all parallel lines in an undeformed stage, stay parallel in a deformed stage. In exchange, in the undeformed stage it is accepted that at least certain initial straight lines of a body become some curves in the final shape.

Such unitary deformations as well as the un-unitary ones arise in the dynamics' study and rely on the division of the crustal layer in vertical prism with triangular section. Knowing the g gravity, the crust's density in the ρ study area, the S section area, the width of the H prism and the modification of its ΔH widht, the modification of the potential energy is calculated using the relation: (Fujii, 1991):

$$\Delta\phi = g\rho SH\Delta H / 2 \qquad (4)$$

The ΔW slate energy is inferred by μ rigidity, γ_{max} maximum slate deformation and Δ dilatation on the Earth surface (Fujii, 1991):

where the specific deformation in the relation is presumed to be:

$$\varepsilon_{33} = -\Delta H/H. \qquad (5)$$

This means that the modification of the prism widht is uniform in the lenght of every finite element's vertical axis. In addition, as we often act in the Theory of elasticity, it is presumed that both the specific deformations, of the two axis that involve horizontal slate deformations, are null ($\varepsilon13 = \varepsilon23 = 0$), and the equality of the two Lamé canstants (also named slate modulus, $\lambda = \mu$). It is necessary to underline the difference between Lamé constants, wich will be applied to the tensions deduction and the ones applied to the slate energy's deduction. In the first situation, Lamé constants, had specific values of the used finite element and of the measurements' type involved in the deformations' calculus. Thus, in a triangle finite element's case, with equal and correlated weight observations (isotrophic geodetic net), Lamé constants are (Grafarend, 1977):

- for the directions' observations:

$$\lambda = -3/4 \qquad \mu = -3/4$$

- for distances observations

$$\lambda = -3/4 \qquad \mu = -3/4$$

- for angular observations: (6)

$$\lambda = -9/4 \qquad \mu = -9/4$$

- for the distance differences observations

$$\lambda = -9/4 \qquad \mu = -9/4$$

In the second case, the one of the deformation energy's calculus, these constants represent the Earth's rigidity inferred by geophisics works.

By totaling the two energies (the potential one and the slate one), it results the E total energy (measured in ergi*), inferred by crustal deformations, wich, introduced in Gutenberg – Richter formula :

$$\log\Omega(erg) = 11.8 + 1.5M, \qquad (7)$$

allows the deduction of M magnitude according to the accumulated energy.

7. Conclusions

The results of the repeated geodetic measurements, sensibly enclosed in the scientific activities that are effected in the domain of interdiscipplinary activity, known as the Theory of the tectonic plates, represent the best accurate data, offered to the other geosciences for the final purpose of the determination of tridimensional shifting vectors of plates and microplates composing the whole earthly Globe, or on limited parts, very interesting . Geodetic methods are more and more frequently used in the investigation of the earthly crust's dynamics in the studies of a continuous pursuit of this phenomenon in very important areas for the national economies and, of course, for the population, or in certain periods of time, in larger dimensions areas and with a reduced instalment of these shiftings.

One of the directions of scientific research particulary present, lies in the determination of some technologies capable to realize earthquakes' prediction, in general, and the ones marked especially through the study of measurable physic forerunners. Within this framework, an important part is given to the study of recent crustal movements. The geodesy, through the earthly technologies, as well as the spatial ones, offers data concerning the modifications of unitary efforts and specific deformations in the earthly crust.

The method of finite elements, apllied in the remarkings of repeated geodetic measurements' results, represents a new element introduced in such remarkings, as a result obtaining geodinamic parameters useful to the geophysic interpretations of recent crustal movements. The basic principle of this method is suited very well to the geodetic nets, meaning that these ones respect the conditions imposed by this method: the correlation between the whole and the part, the division of the analysis' domain, the the constitution of the finite elements' equation as well as the assembling of these equations. the estimated functions, their properties, the dimensions and the number of finite elements, the typical configurations of finite elements are adapted to the geodetic nets, so that this method can be efficiently and easily applied to the repeated geodetic measurements' results.

These studies and conclusions, that derive from repeated geodetic measurements, are particularly useful for the geophysic specialists in general, for seismologists specialists in particular, because through the interpretation and the correlation with the conclusions in one's own studies, there can be made estimations or even predictions concerning the main characteristics of a possible seismic event, (the position of the epicentre, the moment of the production and the dimensions of the magnitude).

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