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**Finite Elements Method and its Space Application in the Study
of Movements of GNSS BULiPOS Reference Stations in
Bulgaria**

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Finite Elements Method and its Space Application in the Study of Movements of GNSS BULiPOS Reference Stations in Bulgaria

- INTRODUCTION
- FINITE ELEMENTS METHOD FOR THE SPACE
- GPS DATA PROCESSING OF BULIPOS REFERENCE NETWORK
- FEM APPLICATION FOR THE BULIPOS REFERENCE NETWORK
- CONCLUSION



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INTRODUCTION

- The territory of Bulgaria characterizes with active tectonics and seismotectonics.
- A number of geological, geophysical and geodetic investigations demonstrate the recent activity of the region and try to give a reasonable and adequate interpretation of the obtained results.
- The advanced GNSS have been recently used for geodetic determination of the earth crust movements from estimated velocity vectors of located GNSS stations in millimetre level.
- This work is an attempt to contribute to the geokinematics of the territory of Bulgaria by means of Finite Elements Model (FEM) using estimated GNSS station coordinates in different time periods.



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FINITE ELEMENTS METHOD FOR THE SPACE

- Finite Elements Models recently are successfully used in the analysis of movements of stations from GNSS data processing in order to be obtained strain tensors and strain accumulation [1], [2], [6], [9].
- In this work the FEM is developed and applied for deformation analysis in the space - determination of linear deformations of baselines between GNSS stations.
- Deformation analysis based on GNSS data for large territories - proposed a FE model for the space where the baseline vectors between stations in space are projected onto the ellipsoid used.



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- The estimated space positions of investigated stations obtained from GNSS data processing are first projected onto the WGS84 ellipsoid and then the finite elements are configured by using ellipsoidal chords (baselines on the ellipsoid) between projected station positions.
 - Determination of vectors of displacements at the apexes of the triangles (finite elements) and deformations of triangle sides
- Coordinate components of the vectors of displacement are obtained as follows:

$$dx = X - X'; \quad dy = Y - Y'; \quad dz = Z - Z'.$$

(X, Y, Z) and (X', Y', Z') are the coordinates of triangle apexes (i, j, k) in the observational epochs t and t' .



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- Linear deformations of triangle sides are obtained from the following relationships

$$m_{i,j} = \frac{S'_{i,j}}{S_{i,j}} - 1, \quad m_{i,k} = \frac{S'_{i,k}}{S_{i,k}} - 1, \quad m_{j,k} = \frac{S'_{j,k}}{S_{j,k}} - 1,$$

$m_{i,j}$, $m_{i,k}$, $m_{j,k}$ - relative linear triangle side deformations, S and S' are the lengths of triangle sides in the observational epochs t and t' .

The proposed approach is appropriate for study of geodynamical phenomena of large territories where the finite elements are with long baselines.

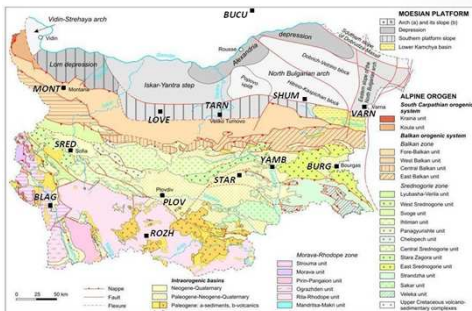


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GPS DATA PROCESSING OF BULiPOS REFERENCE NETWORK



The BULiPOS GNSS reference network [15], [16], [18] covering evenly the territory of Bulgaria (Figure 1) has been used for demonstration the proposed Finite Elements Model in space for large territories.

Fig. 1. BULiPOS GNSS reference network coverage (tectonic map after Dabovski, Zagorchev, 2009)





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- One week GPS data from each of the five years 2009 - 2013 of BULiPOS network stations have been processed with Bernese software, version 5.0. Ten IGS stations have been involved in the processing. By reason of consistency the same IGS stations have been used for datum definition in each of the five years and for each year their quality has been tested by Helmert transformation.
- The estimated Cartesian coordinates of the stations in two time frames have been transformed in ETRF2000 by applying ETRF components.
- These relative to the Eurasia stable plate station coordinates have been used in the finite elements model.



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FEM APPLICATION FOR THE BULIPOS REFERENCE NETWORK

The finite elements have been configured using all BULiPOS stations and the nearest three IGS stations – BUCU, ISTA, ORID from all together 10 IGS stations, as it is shown in figure 2.

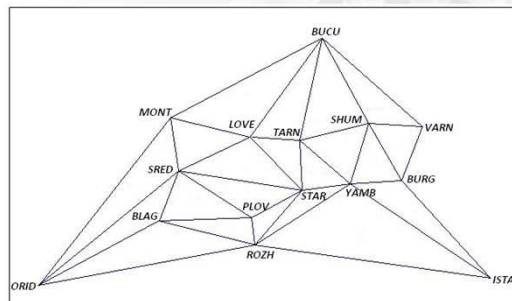


Fig. 2. Configured finite elements



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- All together 21 finite elements (triangles) have been formed. The ETRF2000 coordinates X, Y, Z of all stations in each year have been transformed into ellipsoidal coordinates φ, λ, h .
- The obtained ellipsoidal coordinates φ, λ, h of the stations have been transformed into Cartesian three-dimensional coordinates X_0, Y_0, Z_0 onto the ellipsoid.
- Determination the ellipsoidal chords (baselines between stations on the ellipsoid), which are actually triangle sides of every finite element in each year.
- Linear deformations (extensions or compressions) of all triangle sides have been determined using obtained lengths of triangle sides from all five years in all combinations between five year's results.



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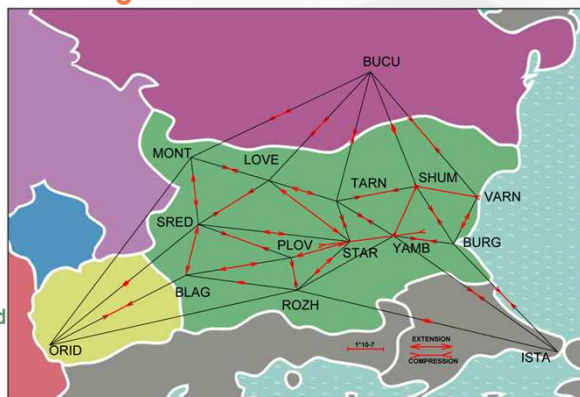
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Deformations of compression and extension of triangle sides are shown in red colour in figures 3 for the longest time period of four years 2009-2013.

Fig. 3. Deformations of compression and extension of finite element sides for time span of four years



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- The smallest relative movements are obtained between station BUCU-TARN, TARN-STAR, ORID-ROZH, ORID-MONT and ROZH-YAMB, which are between $0,005 \div 0,015 \cdot 10^{-7}$ and that corresponds to the extension of $0,1 \div 0,2$ mm for all the mention sides except BUCU-TARN, which is compressed.
- Considering the obtained results for the west part of Bulgaria where they show an extension in direction north-south it can be concluded that there is a good agreement with the directions of estimated GPS velocities of movement from other studies.
- The results confirm the belonging of west-south Bulgaria to the Aegean extensional zone.



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- The largest relative movements are obtained between stations STAR and LOVE – extension of amount of $1,031 \cdot 10^{-7}$ and between stations STAR and YAMB – compression of amount of $1,316 \cdot 10^{-7}$. In fact these are 9,6mm, respectively - 11,3 mm linear deformations.
- For most of the finite element's sides there is no disagreement of the obtained deformations in all time spans studied except a few of them.
- From previous investigations [19], [20] the station VARN shows a strange behaviour. The horizontal station velocity vectors obtained from different time spans have different directions and it is suggested that the station belongs to very local microplate with some rotation [21].
- For the other stations the obtained discrepancy cannot be explained and more detail study should be done



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- Considering the tectonic setting of Bulgaria (Figure 1), baseline BUCU-VARN falls in the areas between two longitudinal and one cross faults.
- Baseline BUCU-SHUM passes through the Alexandria depression and crosses the fault between two blocks (Hitrini-Kaspichan and Dobrich-Vetrino).
- We suggest that the location of this finite element within the longitudinal and cross faults could be a reason for this discrepancy.
- The largest difference of obtained results between four and two years and three and two years time span is obtained for side SHUM-VARN. It is probably a consequence from the discrepancy of sides BUCU-SHUM and BUCU-VARN.
- The comparison of linear deformations of the other sides of finite elements between different time spans shows a good agreement.



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CONCLUSION

On the base of the obtained results, their analysis and comparison it could be generalized and suggested that in northern Bulgaria (Moesia platform) there is compression, in west Bulgaria – extension with direction north-south, in central Bulgaria (Maritsa basin) – extension and in east-south Bulgaria – compression.

These are the first results obtained by the developed Finite Elements Model for the territory of Bulgaria. A denser network of stations will contribute to more precise and reliable results and validation of the obtained results from this study.



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