# The Monitoring of Fast Progressive Landslide Movements in Taşkent/Konya via Rapid Static GNSS Techniques

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1/ 28

Introduction
Study Area
Material and Methods
Results
Conclusion

## Outline



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2/ 28

1

2

Deformation measurements and the analysis of movements are an essential task in the field of engineering surveys.





## Introduction

**Problem Definition**

Landslide is one of the most dangerous natural hazards

**Determination of Methods**

Determination and prediction of landslide occurrence.

**Solution of the Problem**

Solution of the problem and taking precaution from landslide hazard.

## Landslides

"Landslide" is a common term defined as a the movement of a mass of rock, earth or debris down a slope.

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## Introduction

Landslide monitoring is required for a wide variety of reasons. These may include; to determine the extent, magnitude and style of landslide movement, for risk and even emergency risk management assessments and/or to assist with the design and implementation of site remedial and/or mitigation works. Landslide disasters occur almost worldwide, from high mountain areas to coastal areas and even in marine geologic units, from very wet or heavy rainfall areas to very dry areas, and from seismic or volcanic areas to tectonically non-active areas

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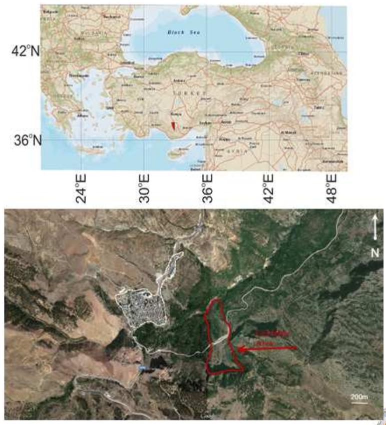
## Study Area

The Taşkent province of Konya city has several landslide hazards in different parts of region. The study area has important play role for transportation between Taşkent province to towns. Landslide has occured many times on the route of the Taşkent and Balcılar road.

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## Material and Methods

Landslide monitoring can be undertaken in many forms. The monitoring may include traditional ground survey techniques repeated over time to determine movements. It may include subsurface investigations with the aid of borehole inclinometers and their periodic manual monitoring and even continuous automated monitoring. Over recent years, automated robotic ground survey using various laser scanning techniques have been shown to be possible to monitoring landslides very fast. However, the most cost effective technique is still GNSS (Global Navigational Satellite Systems) techniques at the present time.

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## GNSS Measurements


Changes in the ground surface are monitored through the periodic measurement of a network of survey stations.

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Introduction
Study Area
Material and Methods
Results
Conclusion

## GNSS Measurements

In relative positioning, two or more receivers make simultaneous phase measurements on the carrier frequencies from four or more satellites

There are several different field techniques for GPS surveying using carrier frequency.

Followoing techniques that are commonly used:

- ❑ Static Surveys,
- ❑ Rapid Static surveys (also Fast Static)
- ❑ Kinematic
- ❑ Pseudo-kinematic (pseudo-static)
- ❑ Real Time Kinematic (RTK) Surveys

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## Reference Network

A geodetic deformation network was established for monitoring soil behavior and detecting landslides movement in respect to the current border of landslide. The network consists of 34 points.

### Reference Network

The reference network consists of four reference points that are all built in stable regions outside the landslide area. These points cover 240*ha* and are 625*m*, 725*m*, 1379*m*, and 2287*m* away from the active landslide area. The GNSS surveys were performed simultaneously with rover GNSS receivers. Reference stations surveyed for eight hours and sampling intervals were set to 10 second and the elevation mask angle was $10^o$

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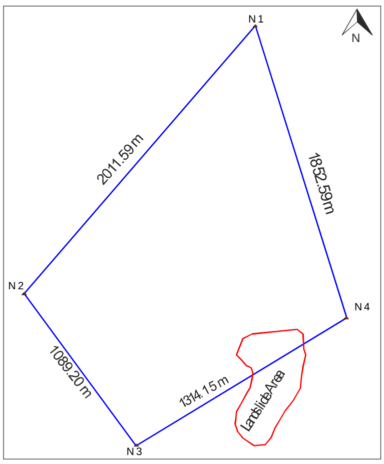


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1. Free Adjustment of the network
   The significance of the deformations depends on the accuracy of the observations and on their assumed normal distribution. If the observables are disturbed by outliers or by systematic effects, those distortions might be interpreted as significant movements. The basic concept of deformation analysis for the detection of movements in control networks are outlined.
2. Statistical analysis of deformations (Testing Deformations)

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## Detection of outlier

Detection of outliers can be applied by data snooping and the tau criterion. In this project, ouliers are detected and removed by tau criterion. Tau statistic value can be computed as

$$\tau_{\alpha/2} = \frac{t_{\alpha/2,r-1}\sqrt{r}}{\sqrt{r-1+t^2_{\alpha/2,r-1}}} \qquad (1)$$

Using the tau criterion, observations are considered for rejection when

$$\frac{|\bar{V}_i|}{S_0} > \tau_{\alpha/2} \qquad (2)$$

t table value
r-1 degrees of freedom
$|\bar{V}_i|$ standardized residuals
$S_0$ standard deviation

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The data snooping and tau criterion are theoretically different. However they have similar results in practice. Statistical tests can be chosen as personal preference.
The rejected observations are reinserted into the adjustment one at a time to determine if they are again detected as blunders. Any observations that are detected as a blunder second time are discarded as blunders.





## Deformation Analysis

A static model was used to determine the landslide movements in deformation network which is measured through multi-temporal GNSS surveys. Least squares method was implemented for solving the model observation of each period. Coordinate vectors of survey points $x_1$ *and* $x_2$, variance- covarience matrices and standard deviations were used to compute the difference between surveys. Computations were performed as follows,

$$d^i = x_2^i - x_1^i \quad (3)$$

$i = 1, 2, 3..n$ (n) points in network.

The covariance matrix:

$$Q_{dd} = Q^1_{xx} + Q^2_{xx} \quad (4)$$

The null hypothesis established as there are no deformation in network

$$H_0 : d = x^i_2 - x^i_1 = 0 \quad (5)$$





$\theta^2$ is the criteria to test null hypothesis,

$$\theta^2 = d^T Q^+ d \quad (6)$$

$$F = \frac{\theta^2}{m} \approx F_{n,Dof,\alpha} \quad (7)$$

- $Q^+$ inverse of Q
- $d^T$ transpose of coordinate difference

If the test value is greater than the F-distribution table value, the null hypothesis is rejected and point positions probably change. To determine moving points, ($\theta^2$) values are separately computed for each point. If it is decided that a point having a max ($\theta^2$) value has moved, this point is removed and the process is carried out iteratively. As a result, moving points and movements are computed.



Introduction
Study Area
Material and Methods
Results
Conclusion

If the F computed quantity fits the F distribution, there is no reason to null hypothesis not rejected.On the other hand, if there is a significant deviation from the theoretical distribution, the existence of displacements must be accepted.
The next step will be the localization of monitoring points.

To do localization of deformations, a partitioning of the variables and the variance-covariance matrix into two subsystems must take place.

In this partitioning, the variables to be isolated (index I, as "isolated") belong to the one system, and the remaining variables belong to the other (index *R,* as "remaining").





In order to determine only the effect of the isolated variables, it is necessary to divide the mean discrepancy into two independent terms of a sum, so that one term of sum just contains this effect.
The advantage of the local test versus the global test is its sensitivity. This is true because smaller local deviations are obscured by the global test due to the effect of the other variables that are included in the test. It can therefore happen that, using the global test, the null hypothesis is accepted for a total network, whereas using local tests, it is rejected for single variables.

Datum changes may be obtained by S-transformations without having performed adjustments relating to the new computational base.

Choosing the datum with a minimum number of fixed variables, in this way, additional information can be included into the analysis, taking into account the status or the stability of the variables. As an example, the computational base might be selected with respect to a group of stable points. Further analysis could then take place by, e.g., testing for single point or group movements of remaining points with respect to the computational base.

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## Coordinate Transformation

Defining the deformation vector between two periodic measurements in the global coordinate system (Cartesian coordinates) by $X_{ij} = X_j - X_i$, this vector is defined in the local level system (i.e. ITRF) referenced to the tangent plane at $P_i$ point.

$$n_i = \begin{bmatrix} -\sin\phi_i\cos\lambda_i \\ -sin\phi_i sin\lambda_i \\ \cos\phi_i \end{bmatrix} \quad (8)$$

$$e_i = \begin{bmatrix} -\sin\lambda_i \\ \cos\lambda_i \\ 0 \end{bmatrix} \quad (9)$$

$$u_i = \begin{bmatrix} \cos\phi_i\cos\lambda_i \\ \cos\phi_i\sin\lambda_i \\ \sin\phi_i \end{bmatrix} \quad (10)$$

$n_i, e_i, u_i$ axes of the local coordinate system at $P_i$ point the north, east and up direction.

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Deformation vector $X_{ij}$ analytically, is achived by inner products. Assembling the vectors of the local coordinate system as columns in a matrix $D_i$,

$$D_i = \begin{bmatrix} -\sin\phi_i\cos\lambda_i & -\sin\lambda_i & \cos\phi_i\cos\lambda_i \\ -\sin\phi_i\sin\lambda_i & \cos\lambda_i & \cos\phi_i\sin\lambda_i \\ \cos\phi_i & 0 & \sin\phi_i \end{bmatrix} \quad (11)$$

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3 epoch GNSS analysed and the results of landslide can be seen on table

| Point Id | 2nd-1st Differences (cm) | | | 3rd-2nd Differences (cm) | | | 3rd-1st Differences (cm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | North | East | Up | North | East | Up | North | East | Up |
| 1001 | 16.52 | 15.61 | 6.64 | 13.01 | 5.61 | -11.87 | 17.34 | 26.97 | -3.03 |
| 1002 | 15.80 | 14.07 | -5.46 | 15.84 | 6.83 | -4.7 | 43.45 | 16.46 | -12.61 |
| 1003 | 16.17 | 14.00 | -9.78 | 17.04 | 4.44 | -6.28 | 26.47 | 22.90 | -14.46 |
| 1004 | 219.28 | 96.86 | -99.72 | 61.68 | 31.09 | -39.65 | 280.95 | 127.96 | -139.37 |
| 1005 | 186.20 | 95.35 | -92.70 | 56.03 | 35.77 | -37.44 | 242.23 | 131.12 | -130.14 |
| 1006 | -0.68 | 0.39 | 0.53 | 0.79 | -0.11 | -0.17 | 0.00 | 0.00 | 0.00 |
| 1007 | 0.00 | 0.00 | 0.00 | -18.28 | 1.66 | 6.78 | -0.54 | -0.44 | 1.04 |
| 1008 | 108.68 | 12.61 | -16.08 | 36.93 | 4.64 | -9.2 | 143.26 | 14.09 | -25.86 |
| 1009 | 116.82 | 68.12 | -1.57 | 44.67 | 29.8 | -0.44 | 168.01 | 98.08 | -3.39 |
| 10010 | 0.86 | 0.24 | -0.33 | -0.87 | -0.1 | -0.06 | 0.00 | 0.00 | 0.00 |
| 10011 | 33.59 | 13.94 | -15.82 | 15.95 | 11.2 | -9.45 | 49.54 | 25.15 | -25.26 |
| 10012 | 32.23 | 8.75 | -10.84 | 18 | 4.94 | -7.35 | 49.61 | 14.72 | -18.25 |
| 10013 | 27.20 | 6.85 | -13.28 | 18.03 | 1.98 | -10.68 | 43.23 | 9.51 | -23.64 |
| 10014 | 32.30 | 9.14 | -8.25 | 12.2 | 5.75 | -3.65 | 46.64 | 16.74 | -13.26 |
| 10015 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | -0.48 | -0.19 | -0.50 |
| 10016 | 26.56 | -0.41 | -8.41 | 20.83 | -2.36 | -5.7 | 42.72 | -0.52 | -12.88 |
| 10017 | 30.58 | 0.35 | -10.31 | 21.83 | -0.61 | -7.53 | 47.03 | 1.21 | -16.51 |
| 10018 | 1.15 | -0.70 | -2.04 | 0.39 | -0.75 | -1.23 | 1.73 | -1.50 | -3.25 |
| 10019 | 23.06 | -9.99 | -7.63 | 20.55 | -13.4 | -4.3 | 55.34 | -27.46 | -15.80 |
| 10020 | 22.31 | -7.47 | -6.33 | 20.79 | -7.7 | -4.88 | 48.48 | -13.08 | -11.78 |
| 10021 | 30.00 | -5.43 | -9.13 | 23.72 | -5.7 | -6.03 | 48.35 | -9.50 | -13.45 |
| 10022 | 23.01 | -7.73 | -4.77 | 15.24 | -7.07 | -3.67 | 41.43 | -14.00 | -9.63 |
| 10023 | 22.77 | -5.41 | -11.05 | 20.50 | -6.74 | -6.39 | 49.80 | -10.43 | -18.50 |
| 10024 | 27.38 | -5.28 | 1.61 | 19.03 | -4.68 | -0.86 | 45.89 | -6.43 | 0.92 |
| 10025 | 25.03 | -16.43 | -4.96 | 11.80 | -14.99 | 0.08 | 39.89 | -29.80 | -5.76 |
| 10026 | 28.79 | -17.53 | -8.06 | 14.59 | -16.23 | -4.97 | 52.08 | -36.10 | -15.14 |
| 10027 | 27.59 | -18.47 | -1.78 | 17.66 | -14.97 | 0.12 | 31.03 | -25.79 | 1.62 |
| 10028 | 23.59 | -12.09 | -6.80 | 14.49 | -11.05 | -4.15 | 47.34 | -27.45 | -13.41 |
| 10029 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10030 | -0.04 | 1.28 | -0.10 | -0.56 | -0.43 | -1.88 | -0.46 | 0.87 | -2.23 |
| 10005 | -0.71 | 0.14 | 0.83 | -0.80 | -0.26 | -1.52 | -1.39 | -0.26 | -0.97 |
| 1111 | 0.00 | 0.00 | 0.00 | 0.63 | -0.53 | 0.23 | 0.80 | -0.57 | 0.07 |
| 1113 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1114 | 0.00 | 0.00 | 0.00 | -17.36 | 1.81 | 6.14 | -0.03 | -0.53 | 0.59 |

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## Conclusion

- For the survey of landslide, GNSS offers the advantage of delivering a 3D positioning with sub-centimeter accuracy for half an hour sessions.
- The static deformation model achieved understanding of landslide size by means of GNSS surveys.
- The implemented statistical method shows us that statistical tests are very useful for the detection of landslides.
- This method makes it easy to understand deformation in landslide areas.
- Not only to understand them, but to also tell us a size of movements.
- The results of this study, experienced with measurements of Taşkent landslide, are thought to be very important remarks for deformation analysis studies using GPS measurements.

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