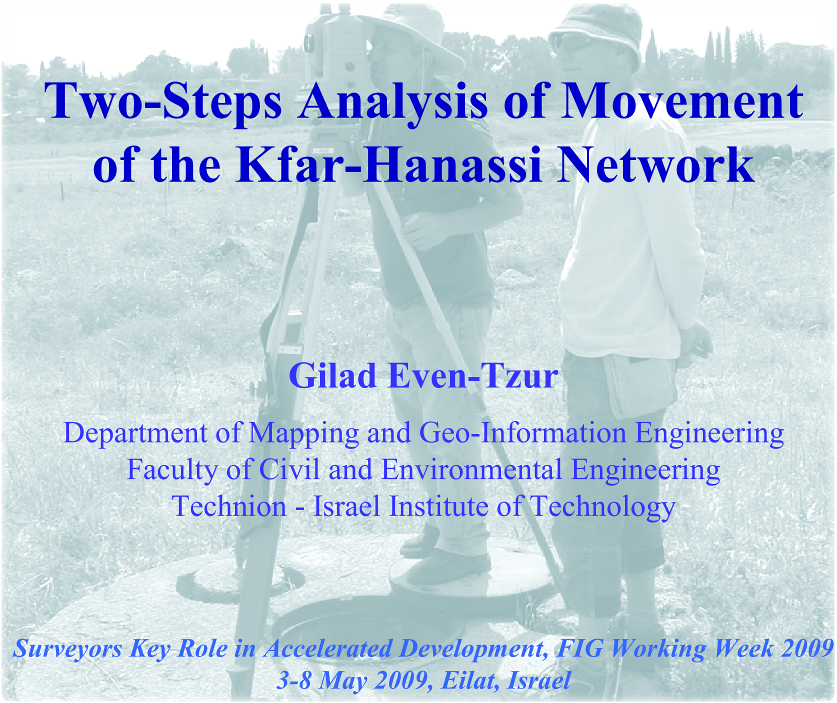


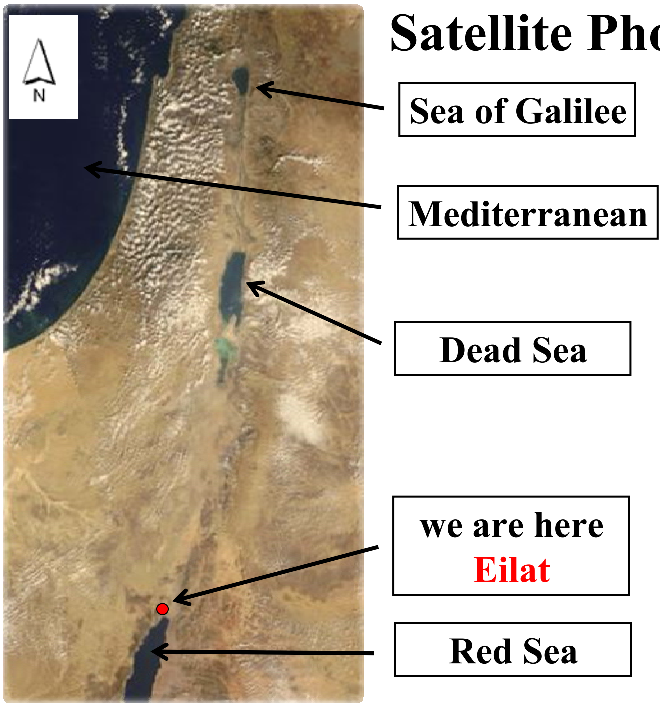
Two-Steps Analysis of Movement of the Kfar-Hanassi Network

Gilad Even-Tzur

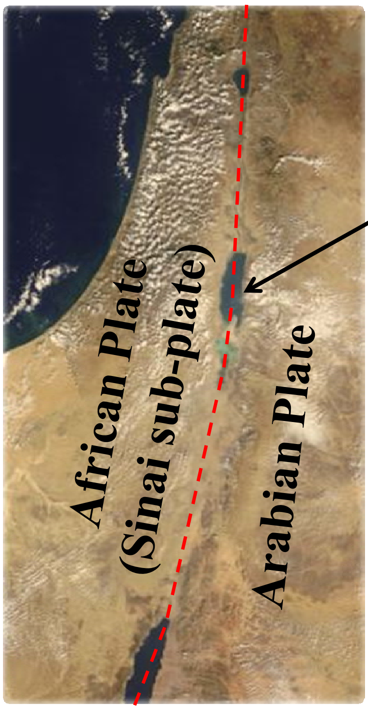
Department of Mapping and Geo-Information Engineering
Faculty of Civil and Environmental Engineering
Technion - Israel Institute of Technology

Surveyors Key Role in Accelerated Development, FIG Working Week 2009
3-8 May 2009, Eilat, Israel

Satellite Photo of Israel



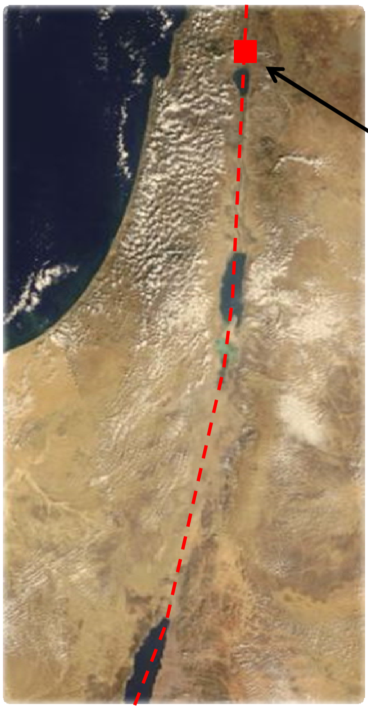
Satellite Photo of Israel



The Dead Sea Rift

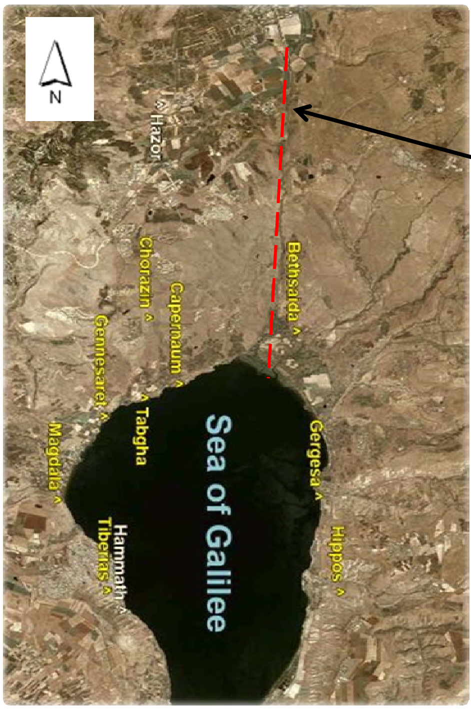
Displacements of several millimeters per year between the Sinai sub-plate and Arabian plate are expected

Satellite Photo of Israel



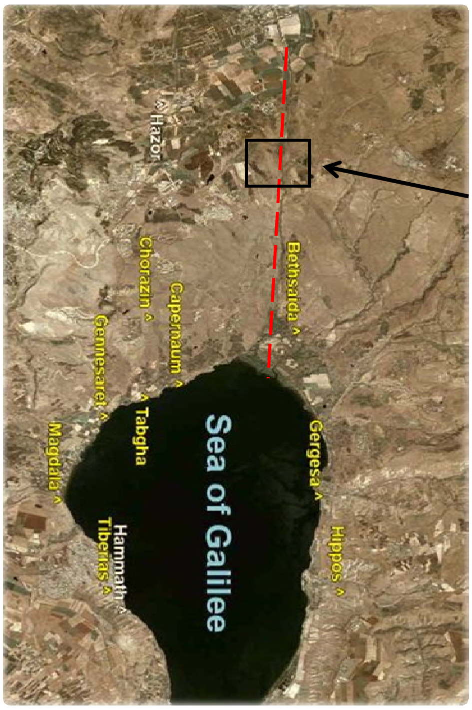
The Kfar-Hanassi Network

Satellite Photo of North of Israel



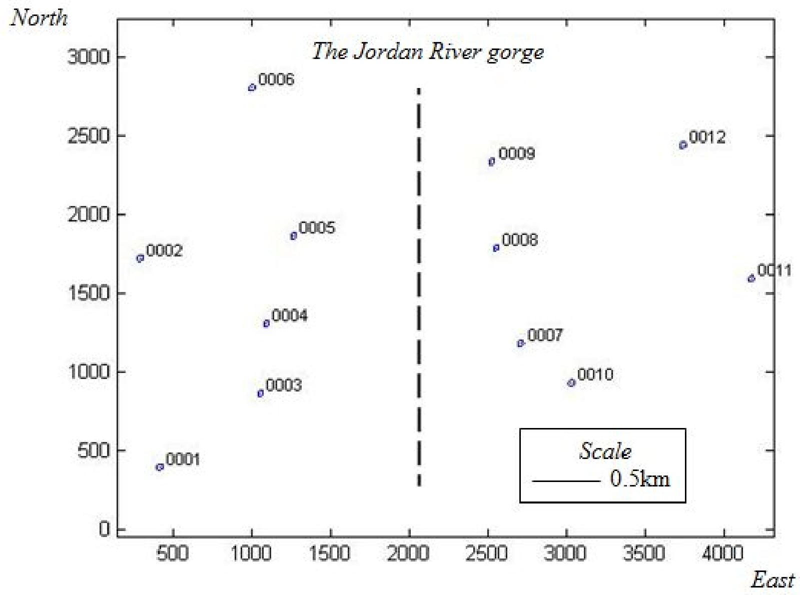
The Jordan River

Satellite Photo of North of Israel



The Kfar-Hanassi Network

The Kfar-Hanassi Network



The Kfar-Hanassi Network

- The network consists of twelve benchmarks, six benchmarks on each side of the Jordan River gorge.
- The network spreads over 2.5×4.0km and was designed for EDM measurements.
- The configuration of the network was mainly affected by the topography of the area and by geomorphological considerations.
- The benchmarks were built according to high technical specifications to ensure their geotechnical stability.

The Benchmarks Specifications

- A borehole, approximately 30cm in diameter, was drilled to a depth of at least 12m.
- The pile consists of concrete reinforcement by steel rods.
- The upper 3m long of the pile is isolated from the ground by a sleeve of asphalt paper.

The Benchmarks Specifications

- Instrument support is provided by three micropiles, 1m deep and 0.2m in diameter with tube sockets for the tripod, driven into the ground around the center pile.

Field Campaigns, 1990-1993

- The network was measured annually during the years 1990-1993 using a Kern Mekometer ME5000.
- 65 distances were measured out of 66.
- Most of the distances were measured twice from each edge of the line.

Field Campaign, 2008

- During the summer of 2008 the network was measured once again using a Leica TC2002.
- Four distances were not measured due to line of sight problems.
- All the distances were measured twice from each edge of the line.

Measurements Procedure

- Precise optical plummets were used throughout the campaigns to set up the instrument and prisms over the benchmarks.
- Meteorological conditions were monitored in detail in the line ends during the measurement process.
- The measured distances for each campaign were corrected for the actual meteorological conditions and were reduced to horizontal distances at sea level.

Two Steps Deformation Analysis

Two types of models are pertinent in deformation analysis:

- Mathematical model -
  representing the geodetic measurements
- Deformation model –
  describe the physical reality

The first step is a rigid adjustment of each campaign to a network of points.

In the second step the variation in network geometry is modeled.

First Step:
Epoch by Epoch Data Processing

- For every measuring campaign the distances were adjusted into a network.
- The variance of the observations was modeled by:

ME5000 → $\sigma_i^2 = (0.5\text{mm})^2 + (d_i \times 1\text{ppm})^2$

TC2002 → $\sigma_i^2 = (1\text{mm})^2 + (d_i \times 1\text{ppm})^2$

where d_i denotes the horizontal distance.

The Kfar-Hanassi network adjustment

Monitoring Epoch	**Instrument**	**Distances rejected**	**Degrees of freedom**	**Mean positional error** (1 sigma)	$\hat{\mathbf{m}}_0$
1990.417	ME5000	1-3, 2-6 3-10	41	0.58mm	0.74
1991.417	ME5000	-	44	0.46mm	0.64
1992.417	ME5000	-	44	0.47mm	0.64
1993.500	ME5000	9-12	43	0.54mm	0.73
2008.667	TC2002	5-8	40	0.61mm	0.69

- The inner accuracy of the measurements is better than the one that was modeled.
- The network accuracy of the campaigns measured with the ME5000 is just slightly better than the one measured with the TC2002.

Second Step:
Movements Analysis

A linear model of movements was tested to describe the plane position of the network benchmarks:

$$x_i = x_0 + \dot{x}\Delta t$$

x_i - Position of a point in time t
t_0 - Reference epoch
$\dot{x}$ - Linear velocity
x_0 - Position at reference epoch
$\Delta t = t - t_0$

Datum Definition

- Distances can be assumed to have scale, the size of the datum defect is 3, since the definition of origin and rotation is missing.
- For the first step we may use the datum parameters that are contained in the distance measurements for estimating the coordinates of the points, but not for estimating the velocities in the deformation analysis.
- Velocities are estimated based on a time series of monitoring campaigns. Therefore, when calculating velocities we should not reduce the datum defects to 3 due to the distances measurements but rather assume a datum defect of 4 parameters.

Statistical Tests of Hypothesis

Statistical tests are applied for estimating the global and partial congruency of the motion model and the significance of its parameters.

$$H_0: \hat{x} = 0 \text{ Accepted if: } w < F_{r,h,\alpha}$$

$$H_1: \hat{x} \neq 0 \text{ Accepted if: } w > F_{r,h,\alpha}$$

$$w = \frac{\hat{x}^T Q_{\hat{x}}^{+} \hat{x}}{r\hat{m}_0^2} \sim F_{r,h}$$

r- degrees of freedom, h- rank of Q, α- significance level

Results - degrees of freedom

The redundancy of the first step provided 212 degrees of freedom.

The second step provided 72 degrees of freedom,

$$((12\text{points} \times 2) \times 5\,campaigns - (12\text{points} \times 2) \times 2)$$

In total 284 degrees of freedom

Results - global congruency test

$$H_0 : \hat{x} = 0$$

$$H_1 : \hat{x} \neq 0$$

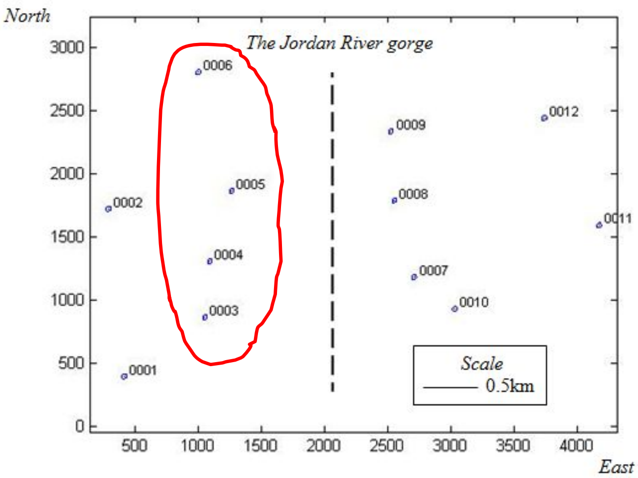
α=5%, d=4, h=20, r=284 then $F(5,20,284) = 1.61$

$$w = 9.62$$

Since $w > F$ the null hypothesis is rejected, indicating that movements occurred during the campaigns.

Results – stable points

4 stable benchmarks 3, 4, 5 and 6, in the west bank of the Jordan River gorge were selected to define the datum.



Results – stable points

α =5%, d=4, h=4, r=284 then $F(5,4,284) = 2.40$

$$w = 1.21$$

Since $w < F$ the null hypothesis is accepted, verifying that the four datum benchmarks were stable.

Results – the weight-constraint solution

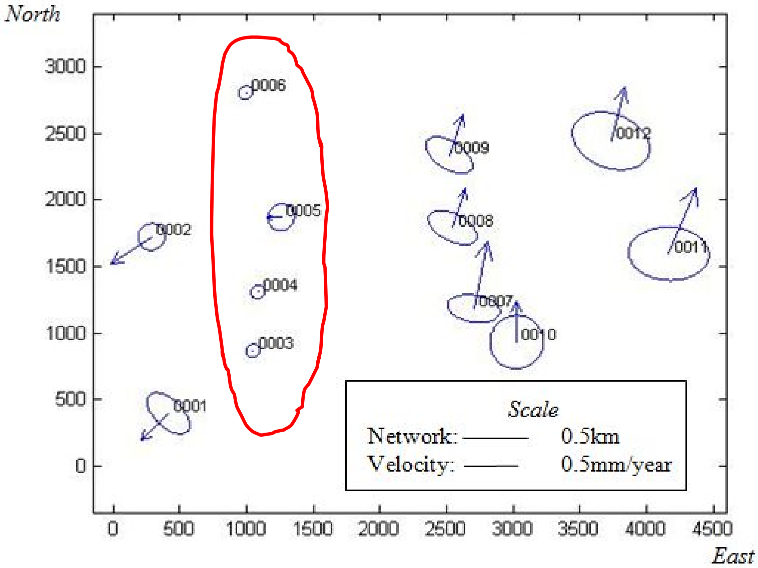
BM name	$\dot{x}_{east}$ [mm/year]	$\sigma_{\dot{x}_{east}}$ [mm/year]	$\dot{x}_{north}$ [mm/year]	$\sigma_{\dot{x}_{north}}$ [mm/year]
0001	-0.22	0.05	-0.21	0.04
0002	-0.29	0.03	-0.23	0.04
0003	0.04	0.04	0.01	0.07
0004	0.00	0.03	0.00	0.04
0005	-0.06	0.04	-0.03	0.04
0006	0.03	0.05	0.02	0.09
0007	0.07	0.03	0.47	0.04
0008	0.09	0.04	0.34	0.04
0009	0.12	0.03	0.27	0.04
0010	-0.01	0.04	0.26	0.05
0011	0.16	0.04	0.55	0.06
0012	0.12	0.04	0.42	0.05

Results – the single point tests

BM name	h	r	F(α,h,r)	w	Significant
0001	2	284	3.03	18.14	**yes**
0002	2	284	3.03	22.52	**yes**
0007	2	284	3.03	17.81	**yes**
0008	2	284	3.03	13.50	**yes**
0009	2	284	3.03	9.91	**yes**
0010	2	284	3.03	3.93	**yes**
0011	2	284	3.03	7.79	**yes**
0012	2	284	3.03	7.18	**yes**

All benchmarks were found to have significantly moved relative to the reference benchmarks.

Results – the velocity filed of the Kfar-Hanassi network



Discussion and Conclusions

- Based on the first four campaigns (between 1990 and 1993) no significant movement along the DSR or deformation were detected.
- The large time interval between the four campaigns measured between 1990 and 1993 and the one measured in 2008 dramatically increased the ability of the Kfar-Hanassi network to detect movements.
- Five distance measurement campaigns along a period of 18 years provide us with a very accurate description of current crustal movements in the Kfar-Hanassi region.

Discussion and Conclusions

- The mean velocity of the benchmarks located on the east bank of the Jordan River gorge relative to the datum points, located on the west bank of the river, is **0.38**mm/year in the north direction and **0.09**mm/year in the east direction.
- Benchmarks 1 and 2 which are located on the east bank (as the datum points) move at a rate of **0.22**mm/year in the south-east direction.
- The results indicate a consistent trend of left-lateral motion along the DSR.

Discussion and Conclusions

- The results may indicate that the DSR behaves as a locked fault.
- Additionally to the linear motion model, the locked fault model can be used to describe the plane position of the network benchmarks.