Evaluation of High-Rate GNSS-PPP for Monitoring Structural Health and Seismogeodesy Applications

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Outline

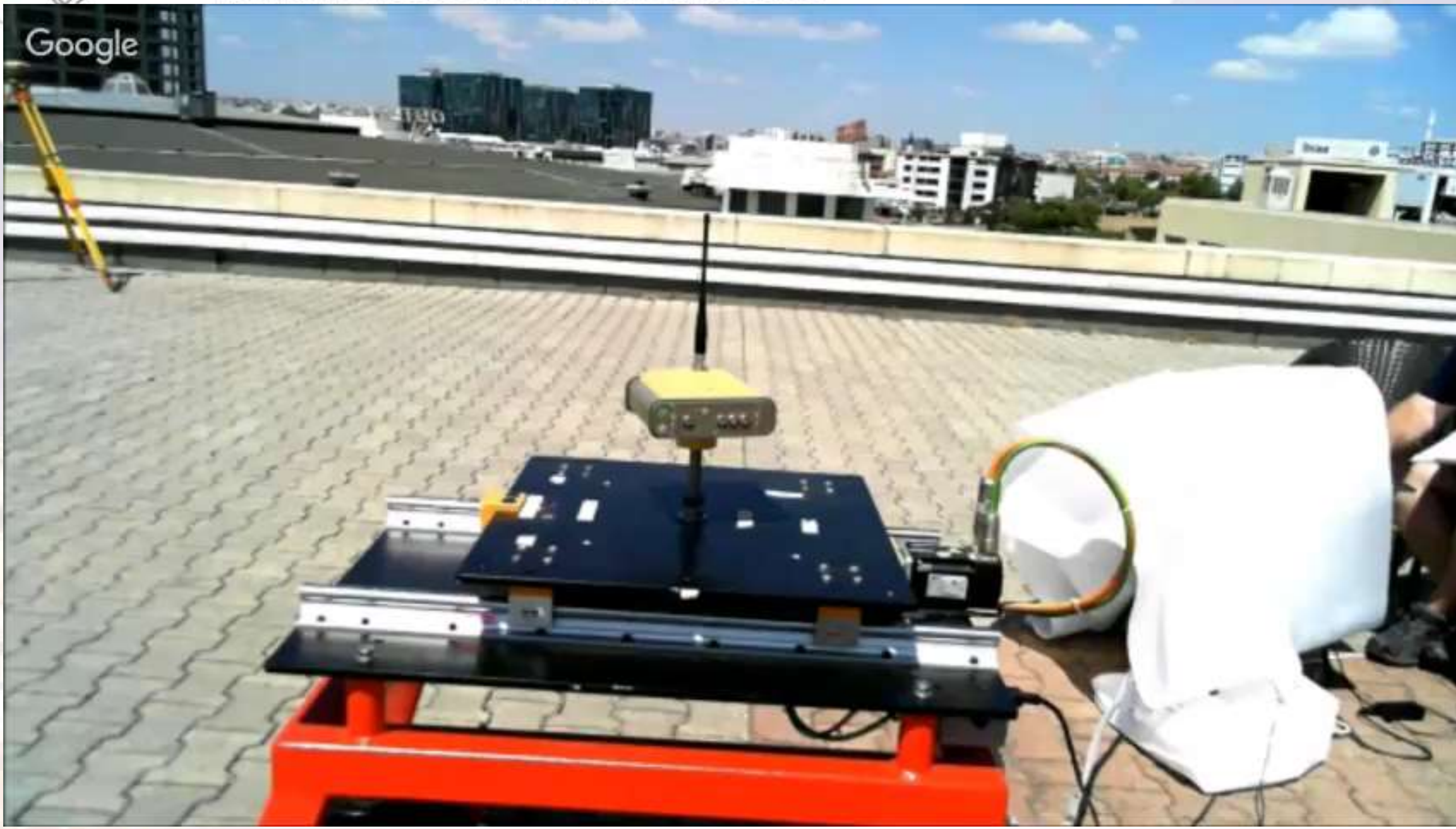
- High Rate GNSS-PPP
- Experimental Setup
- Data Processing
- Results
- Conclusion

High Rate GNSS-PPP

- The Global Positioning System (GPS) has been traditionally used to study long-term earth deformation through the analysis of position time series of daily solutions. The GPS stations were usually operated at 30 s. Recent developments in receiver technology, storage capability and data processing technology have made GPS receiver work as seismometers possibly by increasing the data sampling rate (1-Hz or higher) and by processing the data with a kinematic epoch-wise approach.
- With the advance of GNSS hardware, one can now collect GNSS data at a sampling rate of 1–100 Hz, which has found wide applications in measurement of seismic waves, monitoring of tsunami, volcanoes, landslides and safety diagnostics and monitoring of a variety of man-made structures

High Rate GNSS-PPP

- In the case of large (mega-)earthquakes, there exist no GNSS stations that can serve as reference/datum stations without movement. Kinematic relative positioning will likely fail to produce absolute displacements of GNSS stations in this case, though the absolute displacements are essential to estimate the growth and magnitude of the earthquake for early warning.


Google

Experimental Setup

a. Shake Table

- The uniaxial movement = ± 95 mm
- The total stroke of the table= 190 mm
- The maximum velocity= 400 mm/s

Experimental Setup

b. GNSS Data Collection

Experimental Setup

b. GNSS Data Collection

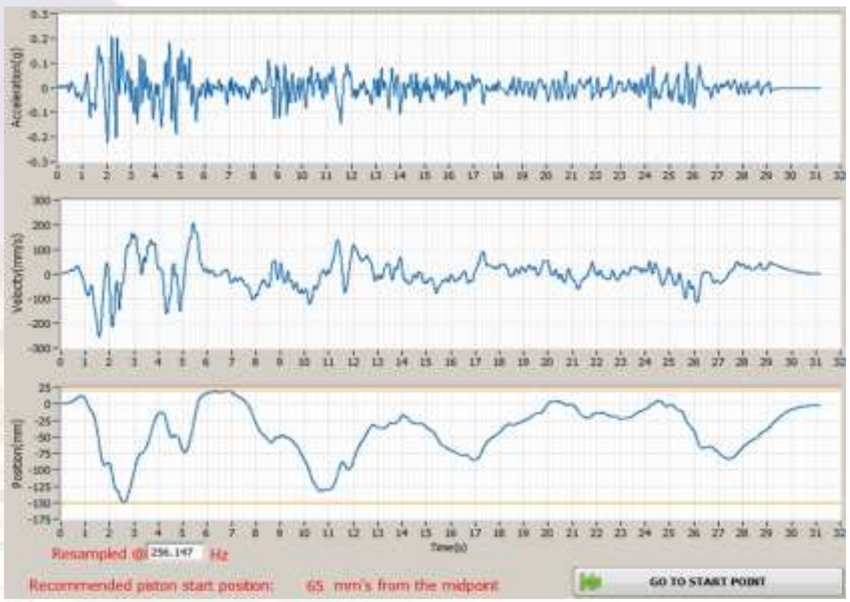
Harmonic Oscillation Tests

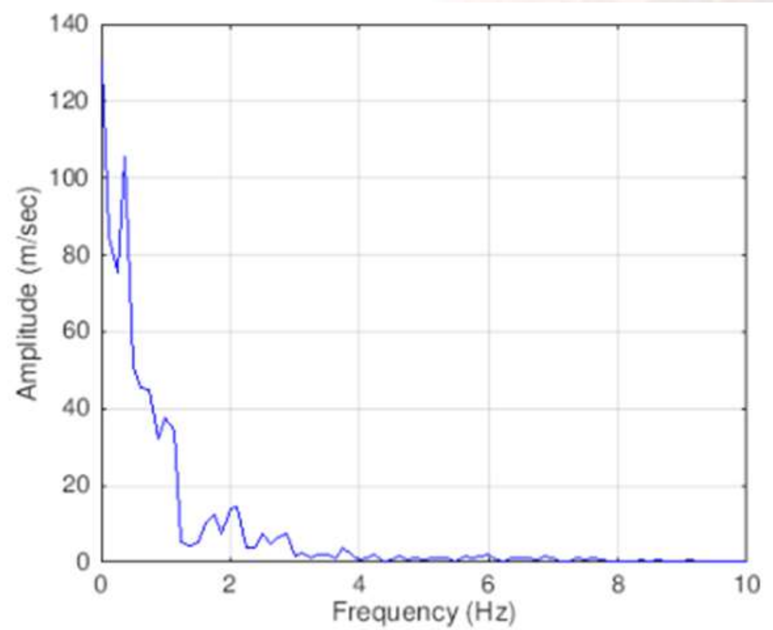
		Oscillation Amplitude			
		5 mm	**10 mm**	**15 mm**	**20 mm**
Oscillation Frequency	**0.2 Hz**	Event 1	Event 2	Event 3	Event 4
	0.5 Hz	Event 5	Event 6	Event 7	Event 8
	1.0 Hz	Event 9	Event 10	Event 11	Event 12
	1.5 Hz	Event 13	Event 14	Event 15	Event 16
	2.0 Hz	Event 17	Event 18	Event 19	Event 20
	2.5 Hz	Event 21	Event 22	Event 23	Event 24

Experimental Setup

b. GNSS Data Collection

Earthquake Simulation Test





Data Processing

Kinematic Relative Positioning

- Leica Geo Office (LGO) 3.0
- L1+L2
- Hopfield tropospheric model
- GNSS integer ambiguity-fixed solution
- Navigation ephemeris data

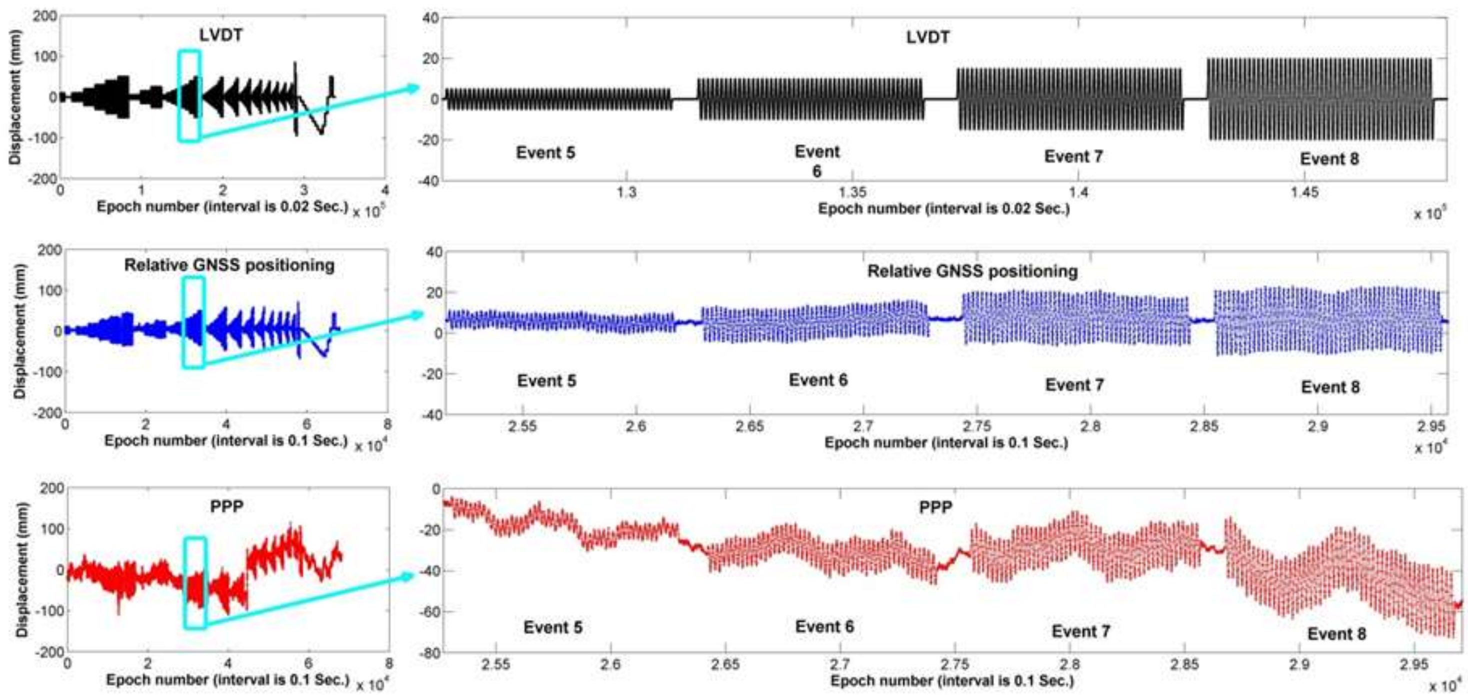
Data Processing

2.Kinematic GNSS-PPP

Mode	Kinematic
GNSS Type	GPS+GLONASS
Observation processed	Code&Phase
Frequency observed	L1, L2
Satellite orbits	Precise (EMU-Ultra rapid)
Satellite product input	CLK-RINEX
Ionospheric model	L1&L2
Tropospheric models	-Davis(GPT) for Hydrostatic delay -Hopf (GPT) for wet delay -GMF for mapping functions
Troposphere zenith delay (TZD)	Estimated
Clock interpolation	Yes
Parameter smoothing	Yes
Reference frame	ITRF

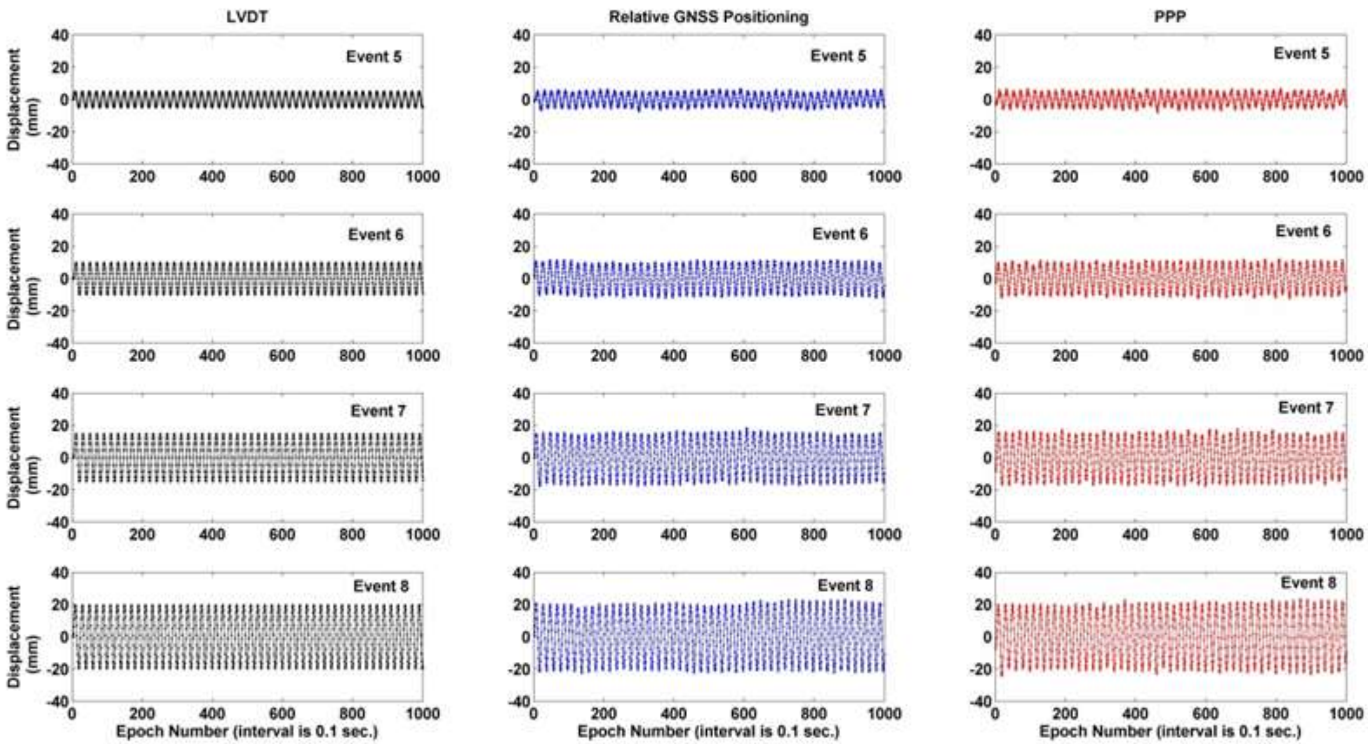
Results

- **Overall LVDT (top panel), Relative GNSS positioning (middle panel) and PPP (bottom panel)-derived displacement (left) and zoom in for event 5 to event 8 (right). Note that relative and PPP-derived displacement is shown for the east component.**



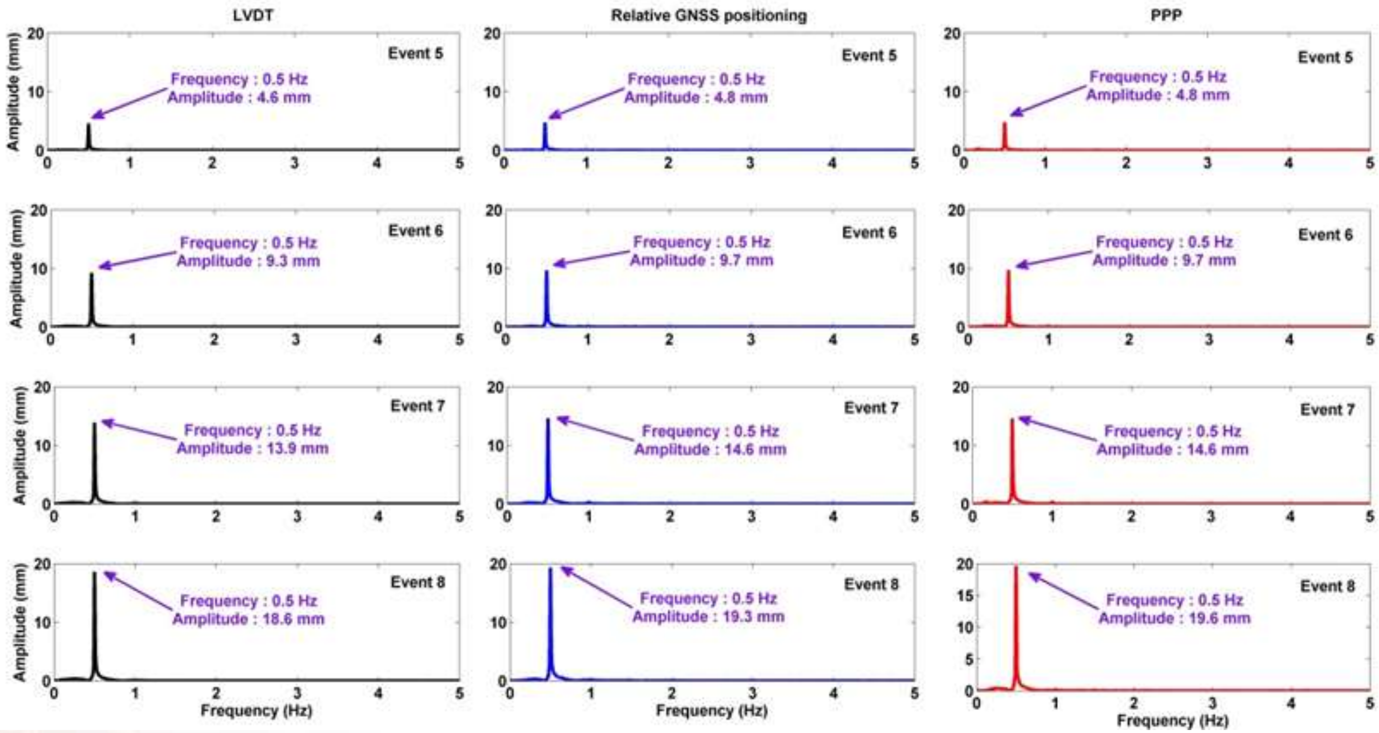
Results

- Time series of Event 5 to Event 8. Note that LVDT data are down-sampled to 10 Hz and PPP-derived time series is filtered
    - Butterworth high-pass filter
    - Cut off frequency: 0.15 Hz



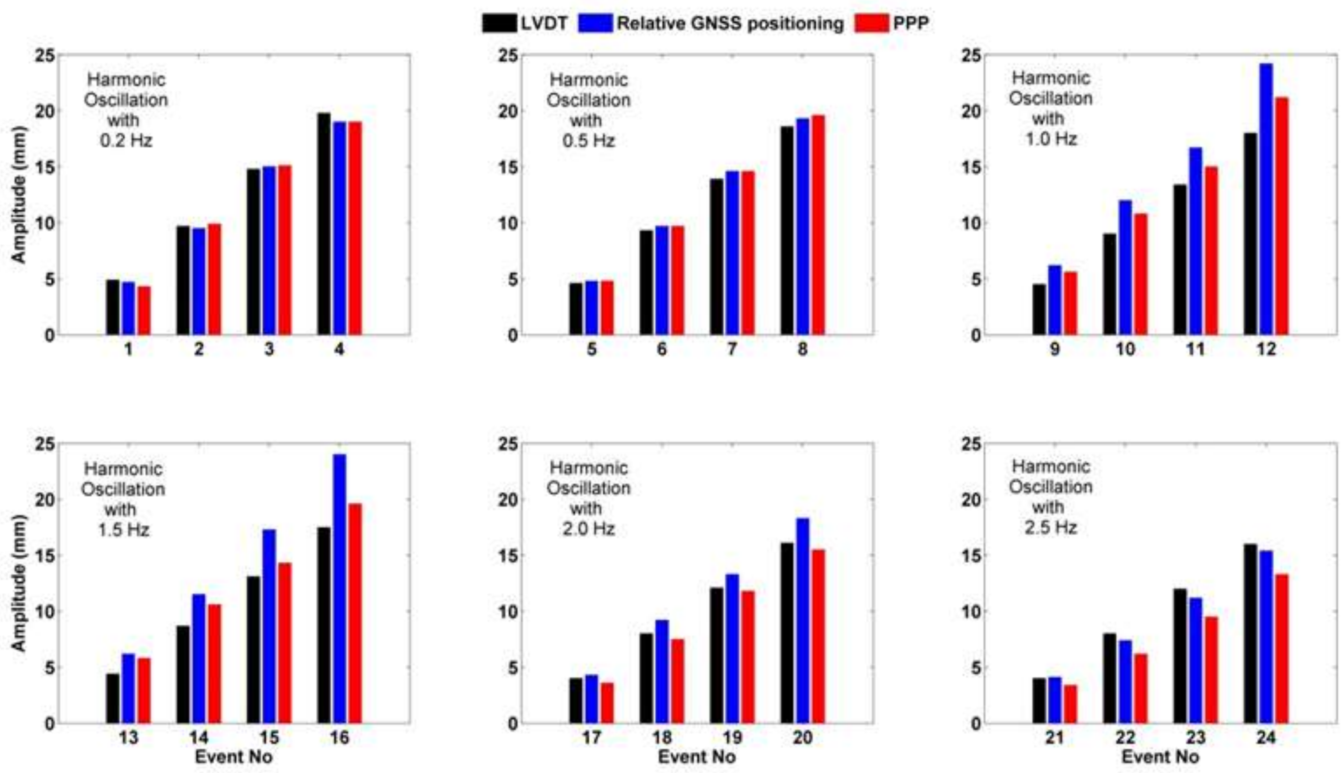
Results

- FFT results of filtered time series for Event 5 to Event 8 for LVDT (left), Relative GNSS positioning (middle), and PPP (right).



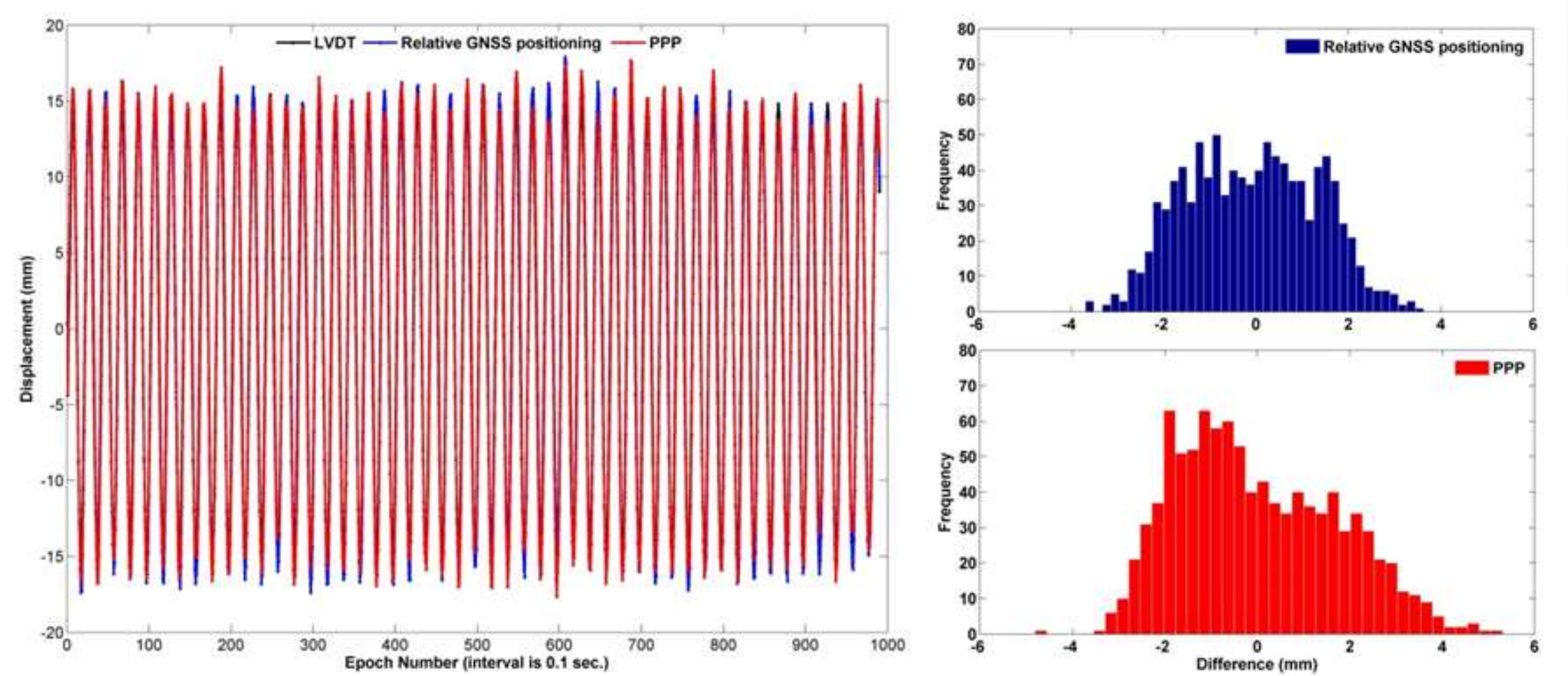
Results

- Amplitude of peak frequency for all events for LVDT (left), Relative GNSS positioning (middle), and PPP (right).



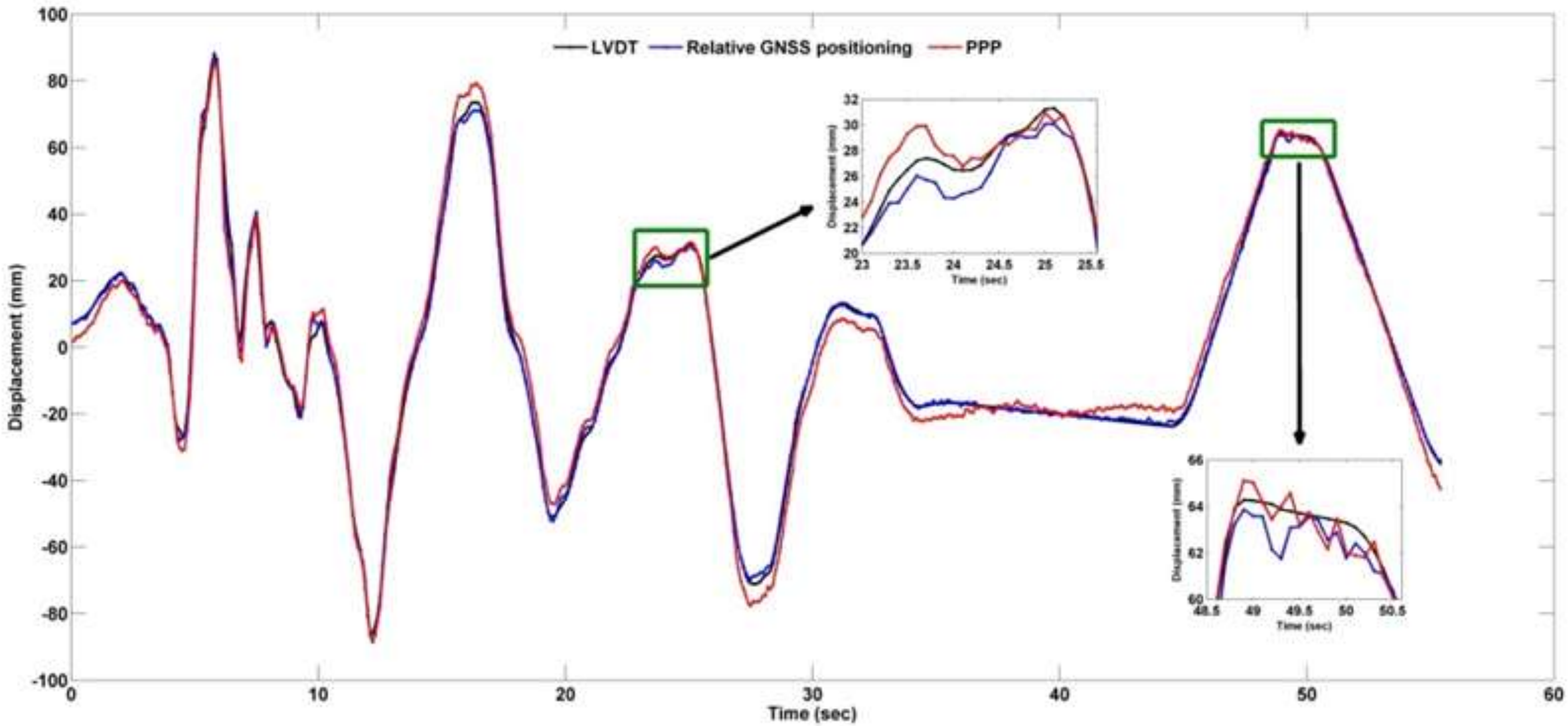
Results

- Comparison of PPP, relative GNSS positioning and LVDT-derived displacement at Event 7 (left). LVDT data are down-sampled to 10 Hz. Histograms of the differences between relative-GNSS and LVDT (top right) and between PPP and LVDT (bottom-right).



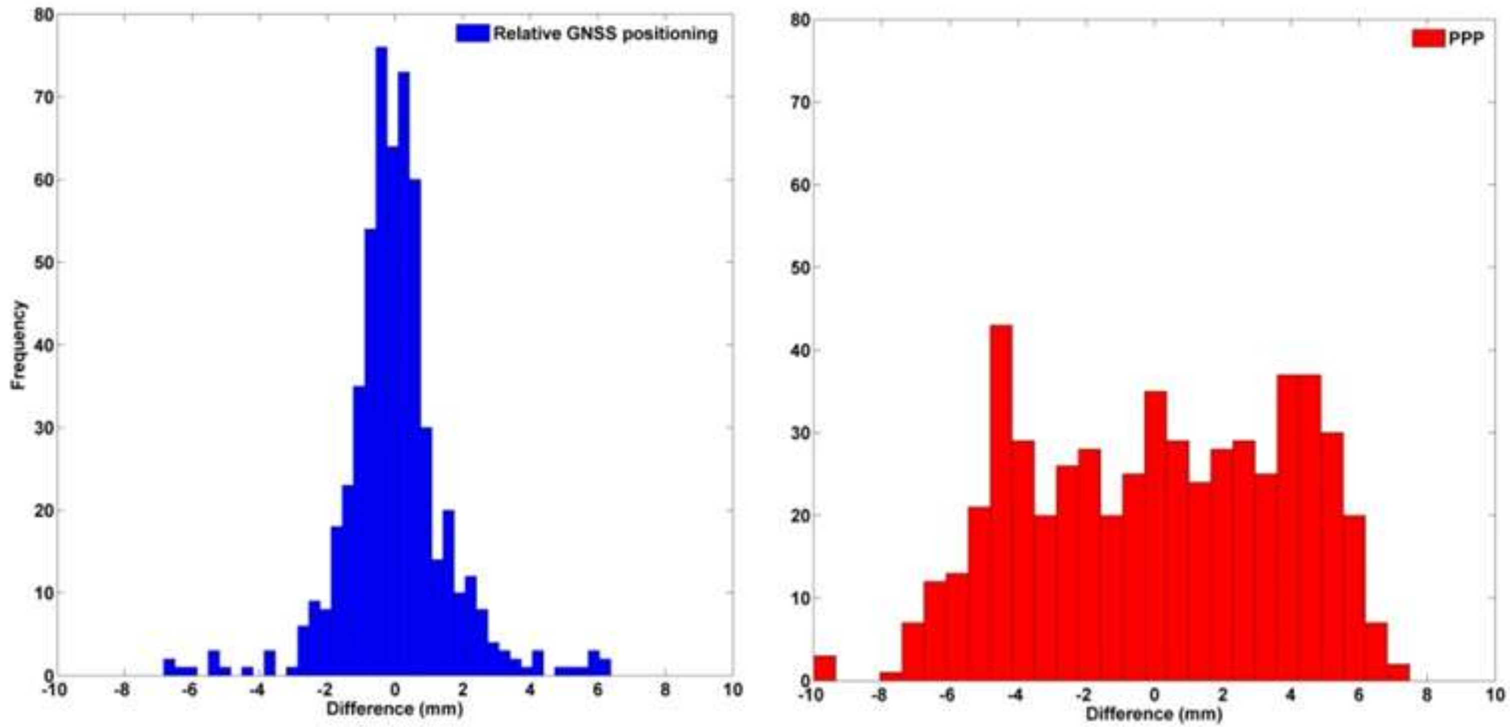
Results

• Comparison of PPP, relative GNSS positioning and LVDT-derived displacement at El-Centro Earthquake simulation. LVDT data are down-sampled to 10 Hz.



Results

- **Histograms of the differences between relative GNSS positioning and LVDT displacement, and between PPP and LVDT-derived displacement for the El-Centro earthquake simulation**



Conclusıon

- The shake table experiment demonstrated good agreement between LVDT, the relative GNSS positioning and PPP-derived spectrum

- In general, the displacement waveforms estimated from PPP and LVDT are largely consistent in the dynamic component within a few millimeters.

Conclusıon

- The results of the experiments show that the PPP method is very efficient and can satisfy structural health monitoring (SHM) and seismogeodesy applications as well as relative positioning method in terms of extracting dynamic oscillation frequencies after removing lower frequency component from PPP-derived time series.

- In conclusion, the PPP method are potentially an ideal method in determining the natural frequencies of engineering structures, if the reference GNSS station data is unavailable or unreliable, and earth surface wave motion caused by large earthquake.


Thank you
for listening