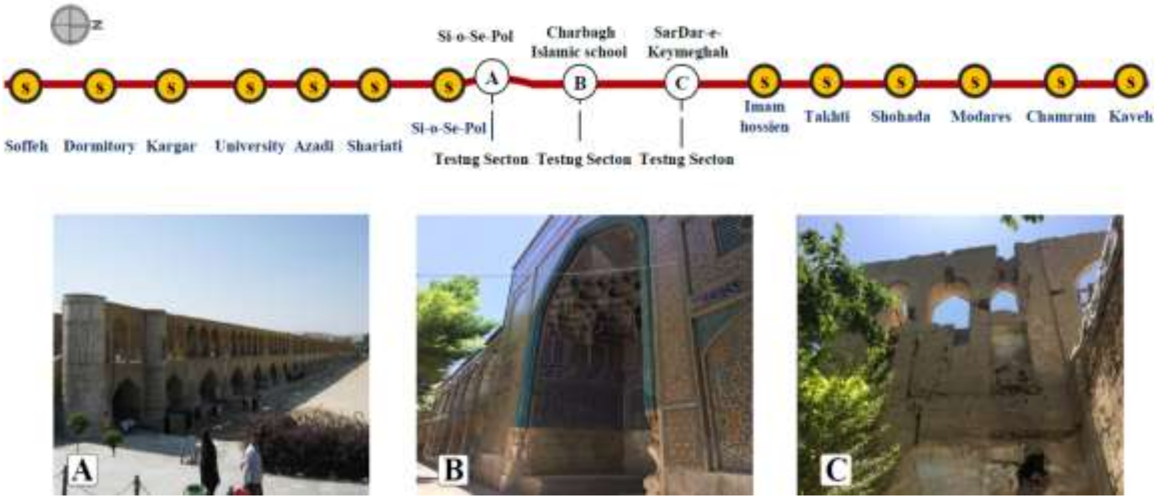
Development of a new seismic monitoring system for historical buildings in IRAN

R-sensors' CME-4211 seismometers and MTSS-1001 geophones and
Geoarmatech's GeoArm-R24 recorders were used



Historical buildings involved in the research, Isfahan, Iran

Background

One of the main concerns in constructing subways in old cities is destructive effects by train-induced vibrations on historical buildings. There is still a danger of damaging historical structures that are close to subways. To protect the human cultural heritage and reduce effects of vibrations, a continuous seismic monitoring is being established in old cities where subway lines are adjacent to historical buildings.

Challenge

Vibrations are usually measured at the source (a railway track) and the FTA (Federal Transportation Association) transfer function is used to derive the amount of vibrations received by the buildings. But due to the changes made inside of the buildings to the surrounding soil media over the time, the accuracy of FTA prediction for continuous monitoring of train-induced vibrations is questionable.

Research Goal

The research goal was to compare the FTA measurement to the measurement at the vibration source. A new seismic monitoring system was to be developed and tested in **Isfahan**, one of the oldest cities of Iran. A 1-year monitoring of vibrations received by several well-known historical buildings was to be established. The vibrations were to be compared to those predicted by the FTA method.

Details

In the past 30 years, continuous monitoring systems have been installed on historical structures to monitor vibrations from various sources including explosion, road traffic and construction machineries. However, most of the above systems have the sensors installed on the *vibration receiver* (i.e. historical buildings) but not on the *vibration source*. Those systems have deficiencies such as complicated data filtering and processing, finding a correct point of placing on a building, a worse view of a building with sensors installed on it. So, there is a need for a system which can monitor buildings at the vibration source. In response to this need, a comprehensive theoretical and experimental research was made. It led to design a system which can monitor by means of measuring vibrations on the railway track.

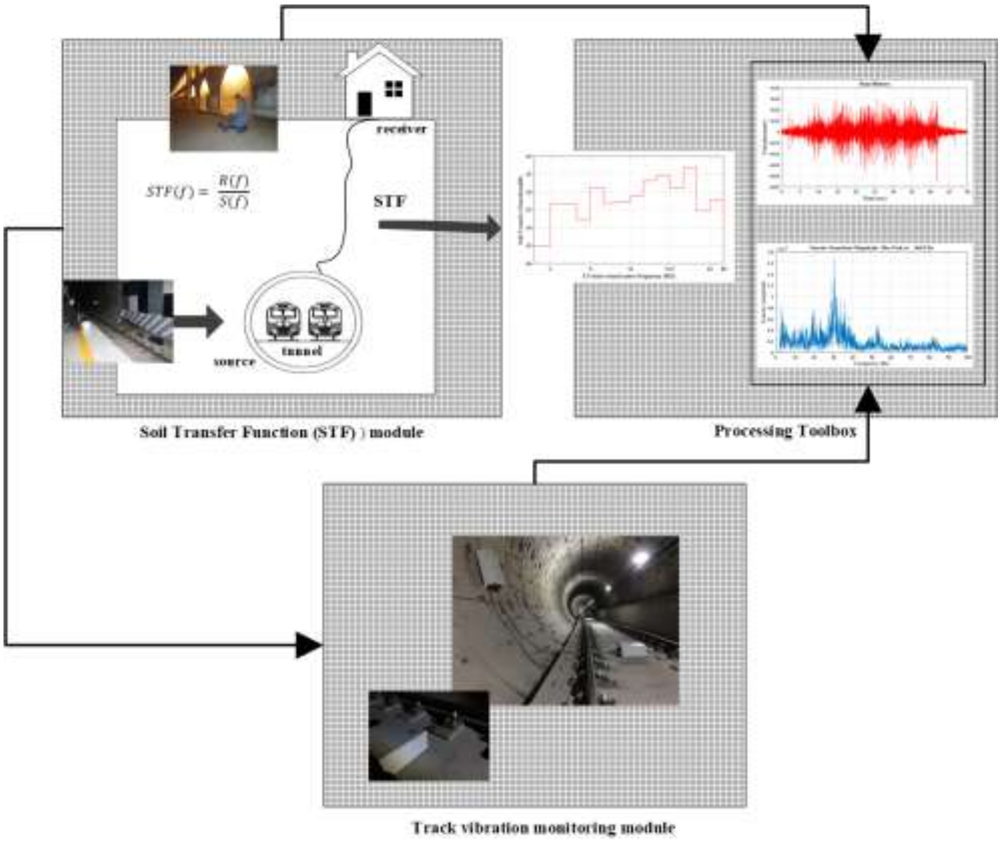


Fig. 1. Layout of Monitoring System modules: soil transfer function module, track vibration monitoring module (R-sensors), processing toolbox (Geoarmatech)

The first monitoring system design based on vibration measurements on the source has been developed **(Fig. 1)**. The system consists of 3 modules: a soil transfer function (STF) module, a track vibration monitoring module, a processing toolbox. The STF is calculated by dividing the ground response to the track vibrations in the frequency domain. The track vibrations are measured using a set of sensor networks installed on the track. The signals are then processed in the signal processing toolbox. That is how the vibration at the ground level is being monitored.

The proposed system's structure was installed in Isfahan's subway network at the 3 locations. The system was validated through comprehensive field measurements. The field measurements included the STF measurement method and the tests procedure (i.e. tests setting, instrumentations and method of data acquisition and train passing speed). The tests were carried out between the 2 stations **(Fig. 2)**.

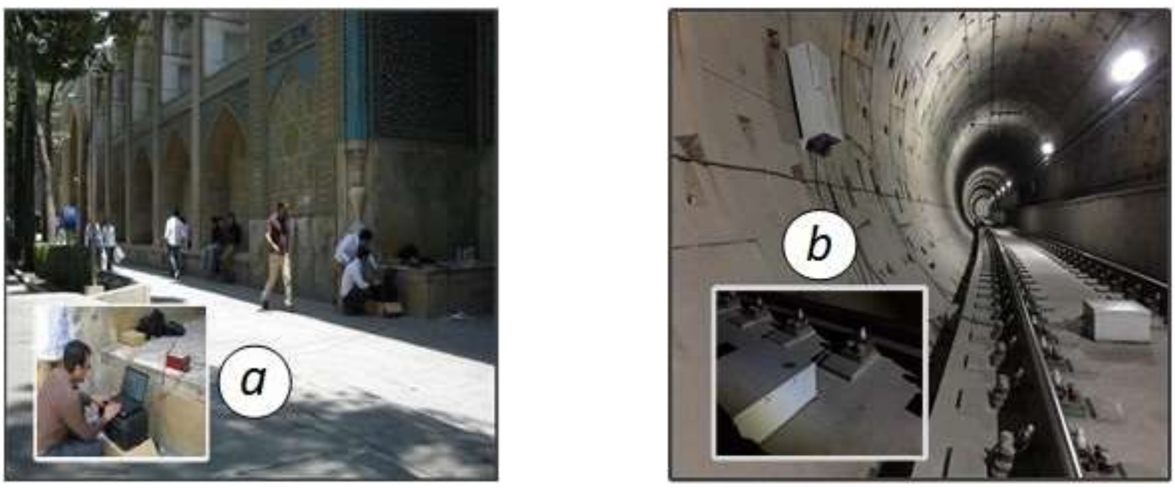


Fig. 2. Field measurements at the locations: a) close to the track; b) at the ground level.

Seismic Instruments

2 types of seismic **molecular-electronic instruments by R-sensors**, Russia, were used:

- 3-component compact molecular-electronic *seismometers* (CME-4211, 30 sec – 100 Hz) were used to measure the vibrations in three directions on the ground;
- 1-component compact molecular-electronic *seismic velocity sensors* (MTSS-1001, 1 – 300 Hz) were used to measure vibrations in different directions in 8 points.

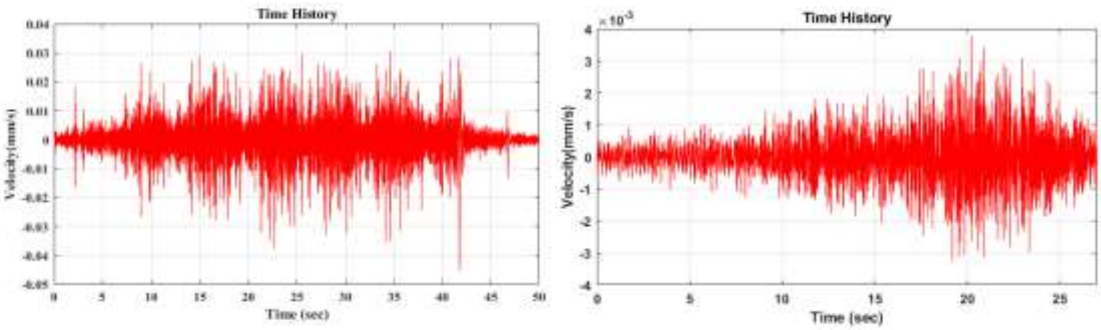
The above instruments are capable of operating within 15° tilt relative to the vertical axis in order to eliminate the local ground inclinations. The sensitivity range of the sensors is up to 250 V/m/s for MTSS-1001 and 2000 V/m/s for CME-4211, with the maximum input signal of ± 30 mm/s and the frequency range of 1 – 300 Hz that cover the interested ranges of railway environmental vibrations. It was shown that these sensors are capable of measuring ground low frequency micro-vibrations. Due to the existence of 4 kV transmission lines along the railways, conventional electromagnetic seismometers cannot be used because of a high magnetic field effect of the above transmission ways. So, the best option was to use molecular-electronic instruments, manufactured by R-sensors, which were not affected by existing electromagnetic fields and their signal output was not impaired by the project.

In order to receive the output signals from the above instruments and due to the special conditions of the equipment installation inside of the subway tunnels, it was necessary to use a suitable seismic recorder. But the existing recorders were not optimized for this purpose. **Arman Fanavaran Zamin (Geoarmatech)**, Iran, has a vast experience of designing and manufacturing **seismic recorders**. One of their products is GeoArm-R24 – that recorder was redesigned and optimized for application in this project. That 24-bit seismic recorder with a sampling rate of 200 sps was connected to the sensors to convert analog signals into digital signals.

In order to evaluate the accuracy of the entire monitoring system, the vibration at the ground was measured separately and compared with the system's predictions. To research the long term accuracy of the system, the ground vibrations was being measured for over 1 year in 3 locations.

Comparison Results

The effect of 5 passing train carriages at 40 km/h is showed at **Fig. 3**. It is also illustrated that the ground vibrations of passing carriages are not as clear as the track vibrations of passing carriages.



(a) (b)

Fig. 3. Samples of vibration time histories measured close to the track and at the ground level: a) close to the track b) at the ground level

Overall Results

The ground vibrations were measured for over 12 months at 3 monitoring locations. The results are summarized below.

Comparison of the monitoring system predictions of vibrations directly measured at the ground level at 3 locations is given at **Fig. 4**. As shown, the system signals are clearer than those of direct measurements. The direct vibration measurements contain multiple sources of vibrations in addition to train vibrations, while the system only registers the track vibrations. Much effort has to be made to split all other sources from the track vibrations. Thus, it could be concluded that the monitoring system predictions are *more reliable* compared to those of direct measurements, basically due to multiple sources of the ground level vibrations.

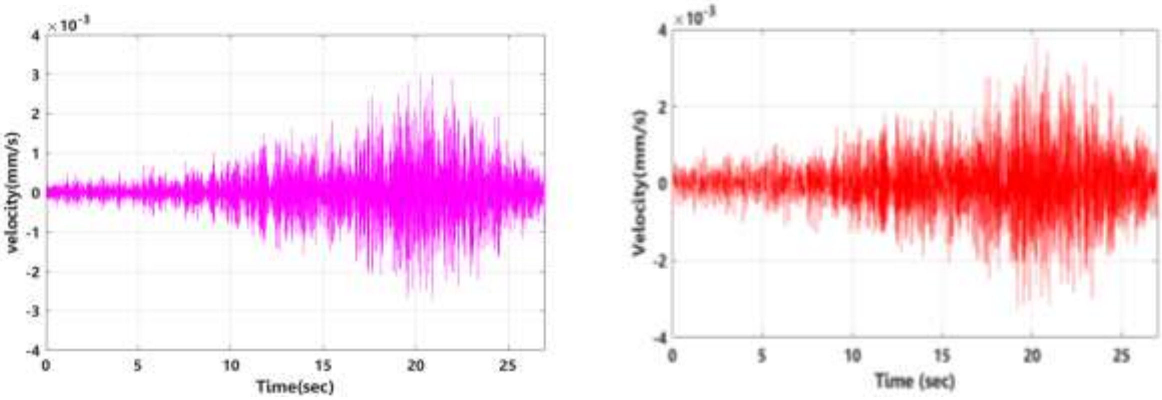


Fig. 4. Comparison of the system predictions of vibrations to direct measurements:
Left: system prediction Right: direct measurements

The main changes in the soil were caused by the depth of the water table. The 3 test locations were close to a seasonal river which largely affected the water table. For over 1 year of the research, the water table changed from 1 to 10 meters that made the vibration levels fluctuate.

The results have shown that the changes in the water table level have a considerable impact on vibrations and significantly influence the accuracy of the FTA predictions. Using the results obtained, a new approach has been developed to improve the FTA predation method for continuous seismic monitoring of train-induced vibrations received by historical buildings adjacent to subway lines.

The instruments used in the seismic monitoring system:

1) seismometers CME-4211, R-sensors, Russia

2) geophones MTSS-1001, R-sensors, Russia

3) recorders GeoArm-R24, Geoarmatech, Iran

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