# Structural Health Monitoring of Monuments in Itchan Kala in Khiva (Uzbekistan): Subsequent Laser Scans Combined with Ambient Studies

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## Abstract

This paper highlights the main objectives and some results of an extensive structural health monitoring (SHM) project, which has started in Khiva, Uzbekistan. According to archaeological data, the city of Khiva was established around 1500 years ago. The research team consists of experts from the University of California – Berkeley (Berkeley, USA) and Urgench State University (Urgench, Uzbekstan). The project started from Itchan Kala as a representative example of the ancient monuments of Khiva city. Itchan Kala was the first site in Uzbekistan to be inscribed in the World Heritage List (1990). The continuous structural health monitoring has become essential to ensure its preservation for the mankind. The SHM became the main objective of the ongoing extensive project, some results of which are presented herein. The structural health monitoring consisted of three majors components. First, a frequent monitoring of the monument by accelerometers, which were strategically placed throughout the monument. They were used to study the resonant frequencies due the ambient vibrations. Second, subsequent laser scanning was deployed to monitor anomalies of the monument's geometry in 3D. The monument's geometry was captured as a collection of points, which is called a "point cloud". The laser scanning was conducted several times a year to capture global movements of the monument due to change of elevation of the underground water table in rainy and dry seasons. Third, a finite-element (FE) model based on the as-found geometry of the point clouds was generated. It was calibrated based on the collected data to ensure acceptable correlations with the results of the measurements. The FE model was generated for future restoration efforts to evaluate the performance and efficiency (if any) of the proposed restoration measures. Based on the results of numerical simulations and health monitoring results, preventive measures were developed. In addition, the recommendations on further preservation of the historic monument were developed.

**Keywords:** *Structural Health Monitoring, Seismic Assessment, Laser Scanning, Accelerometers, Real-time monitoring, Khiva, Great Silk Road.*