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Monitoring the Structural Responses in Shake Table Tests Using Remote Sensing Approach

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ABSTRACT: The most convenient way to simulate the response of the buildings is to conduct full-dynamic tests either using the shake-table in the laboratories or mass-shakers in the field. No matter which test methodology used, the dynamic response of the building must be measured using convenient data acquisition systems (DAQ). As a general approach, accelerometers and LVDT (linear variable differential transformer) are commonly used both laboratory and field tests. However, the practical problems such as mobilization, cabling, data transfer, time-synchronization etc. are the main issues for the engineers to tackle. In this study, the potential of remote sensing approach was studied for monitoring the response of the building models on shake-table. Out of plane response of the building models were prevented by installing wire braces between the stories in order to make sure torsional effects were eliminated. A high-definition CMOS camera on a tripod was placed in the perpendicular of the motion direction and captured the entire tests as part of DAQ and archiving reasons. The color-matched square markers were also placed at the stories of the model buildings in addition to the moving base of the shake table. The recorded scenes were processed in an Optical Motion Tracking (OMT) program, which was developed by the first author. The time-history results of OMT program were compared with the numerical model of the test building results in order to study the potential of Remote Sensing approach in monitoring the structures using low-cost video recording systems.

1 INTRODUCTION

The conventional approaches to measure the dynamic displacement of the test specimens are to install the displacement transducers around and/or accelerometers on the specimens. However, the difficulties during the installation of the high-capacity transducers at optimum distances to the specimen or the data cables from the acceleration sensors to the Data Acquisition Systems (DAQ) are hard to avoid in every dynamic test laboratories.

The motion detection systems using optic video recorders have been widely used in every part of the life ranging from entertainment to the control systems. The scenes captured by the video recorders are analyzed according to the shape and the changes between the frames which is the primeval application of the interferometry for detection of the displacement within the frame The interferometry technique has found a basis for the determination of the deformation and the displacement of the engineering structures (Lee et al. 2007). There are numerous studies in the literature to evaluate the use of the optical image recorders in the dynamic test systems of the structural engineering (Choi et al. 2011). Even though the video recording systems with high resolution and high-frame rate are recommended in the optical image process studies, the cost of procuring these recording systems for the dynamic tests is very high for the projects with limited budget. Therefore, this paper evaluates the validity of low-cost video recording system based remote sensing approach in the structural monitoring.

2 METHODOLOGY

The remote sensing methodology of the study relies on the tracking the pixel of the objects rather than edge detection. The tests were recorded using an ordinary HD webcam (Microsoft Life Cam HD) with 720P resolution and 30Hz sampling rate. The tracked markers on the test model was selected with distinguished color code (here it is blue) with respect to the surrounding. The video record is first converted in to the picture frames. The first frame was used to determine the distribution of the target color code by computing RGB values for each pixel. The masking of the non-target colors was applied to the each frame acquired from the video. The region smoothing was applied to the masked frame with a 5% tolerance limit. Instead of tracking a single pixel on the frame, the centroid point of the smoothed region representing the tracked marker was computed for each single frame. The workflow describe above named as Optical Motion Traction (OTM) was developed as a MATLAB (The MathWorks 2014) program (Loukogeorgaki et al. 2014) and represented in Fig. 1.

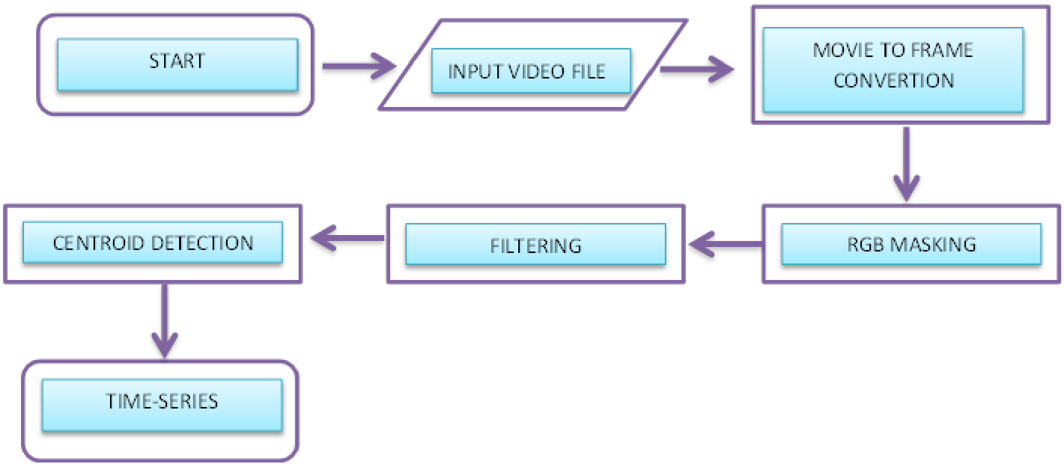


Figure 1. Workflow of the methodology in this study.

The locations of the centroid of the each marker within the entire frame were taken as time-series for the following each frame till the end of the recording. The number of the time-series from the optical motion detection was equal to the number of the markers placed on the test model. Since the time-series acquired from the masked frame is in pixels it is necessary to convert into the unit with physical meaning. The conversion was utilized by measuring the vertical distance markers as a reference value which is indeed the first frame in the video.

3 TEST SETUP AND TEST PROTOCOL

Two-story simple shear-type model on a small-scale shaking table was used as test structure, Fig. 2. The shaking table in Istanbul Kultur University is capable of moving in one direction up to ±90mm. The out-of-plane motion of the structure was prevented by placing x-braces between the stories. The motion types applied by the table are either Sine wave (for certain amplitude and corresponding frequency) or random motion (representing the earthquake). The background of the shake table and the lighting during the tests were arranged for optimum white color balance and shading, respectively.

Figure 2. Test setup; Shaking Table, test structure and video recording system.

The protocols used in this paper focuses on the respond of the structure to the harmonic motion of the Shaking Table. There are two categories in the test protocol; Quasi-Static and Dynamic (high- and low-amplitude), Table 1. Full-length footage of the tests is available at http://youtu.be/Tvmfs9dUVps.

Table 1. Frequency and amplitude of the shaking table during the tests

Test	Test Type	Frequency (Hz)	Amplitude (mm)	Cycle number	Remark
1	Quasi-Static	0.1	90	10	Successful
2		1	90	10	Successful
3	Frequency Sweep with high amplitude	1	50	10	Successful
4		2	50	10	Successful
5		3	50	10	No clear video frame
6		4	50	10	Successful
7		5	50	10	Successful
8	Frequency Sweep with low amplitude	1	10	10	Successful
9		2	10	10	Successful
10		3	10	10	Resonance
11		4	10	10	Successful
12		5	10	10	Successful

The numerical model of the test structure was created in SAP2000 ((CSI) 2014)in order to compare the measured results with the numeric results, Fig. 3. The first vibration period of the dynamic characteristics of the shake table was calculated as T=0.33s (f=3.00Hz).

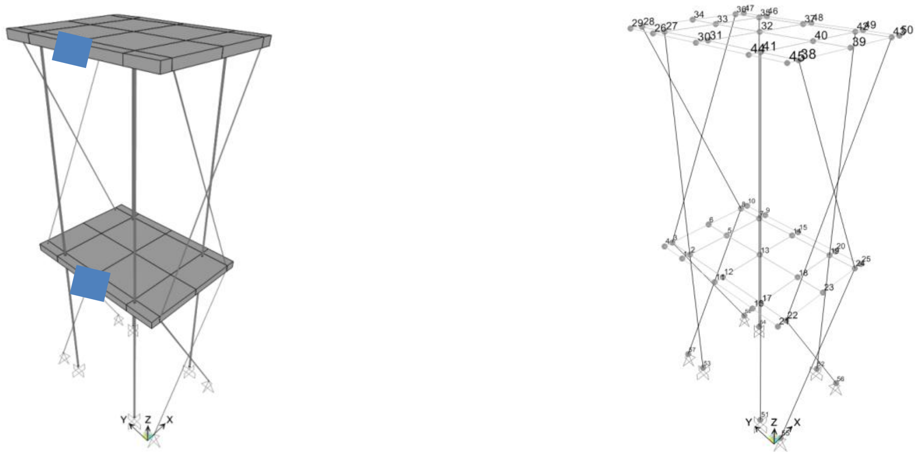
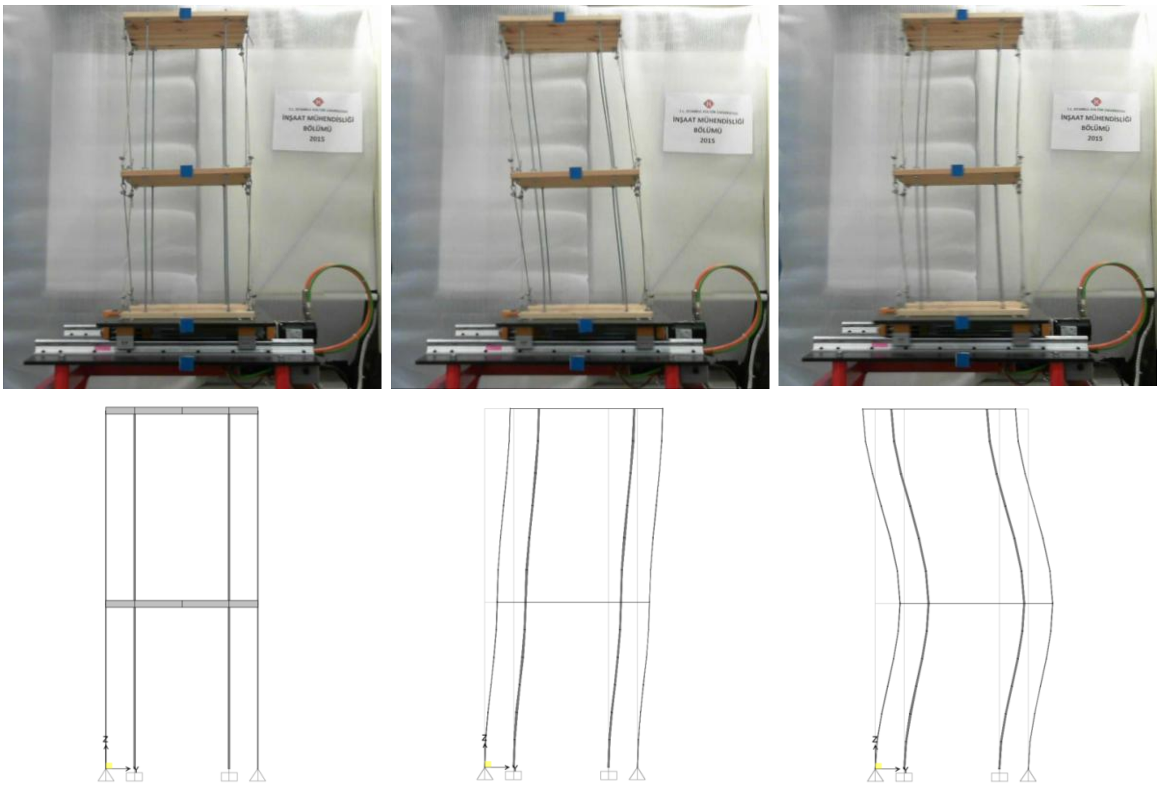


Figure 3. Numerical model of the test structure, markers and corresponding joints on FEM model.

The modal shapes of the test system and the numerical model were compared in order to validate the structure. The model shapes from both systems are consistent with each other, Fig. 4.



1st mode 2nd mode

Figure 4. First two mode shape of the test structure and the numerical model.

4 RESULTS

Quasi-static and dynamic tests were conducted on the test structure and the results from to OTM and the numerical model were compared.

4.1 Quasi-Static

Very slow motion of the Shaking Table (10s and 1speriod with 90mm amplitude) resulted structural response with little phase, Fig. 5. The response of the first story (Story 1 and Joint 11) are in good relation for both QS tests, whereas the top story response (Story 2) was measured a little bit high by OTM compared to the numerical model result (Joint 30). An amplitude differences for the top story between the two results in the first and last cycle are noticeable. However, the free vibration response calculations are almost identical.

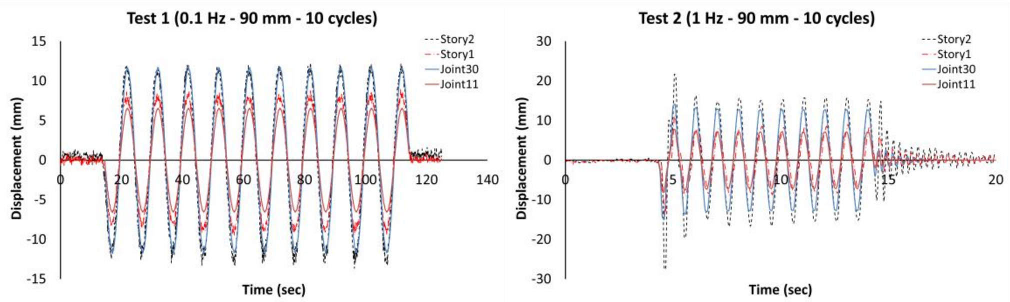


Figure 5. Quasi-static test time-histories

4.2 Dynamic tests with high amplitude

The frequency sweep with constant high-amplitude tests revealed that time-histories between the OTM and numerical analysis were almost same except some cycles, Fig. 6.

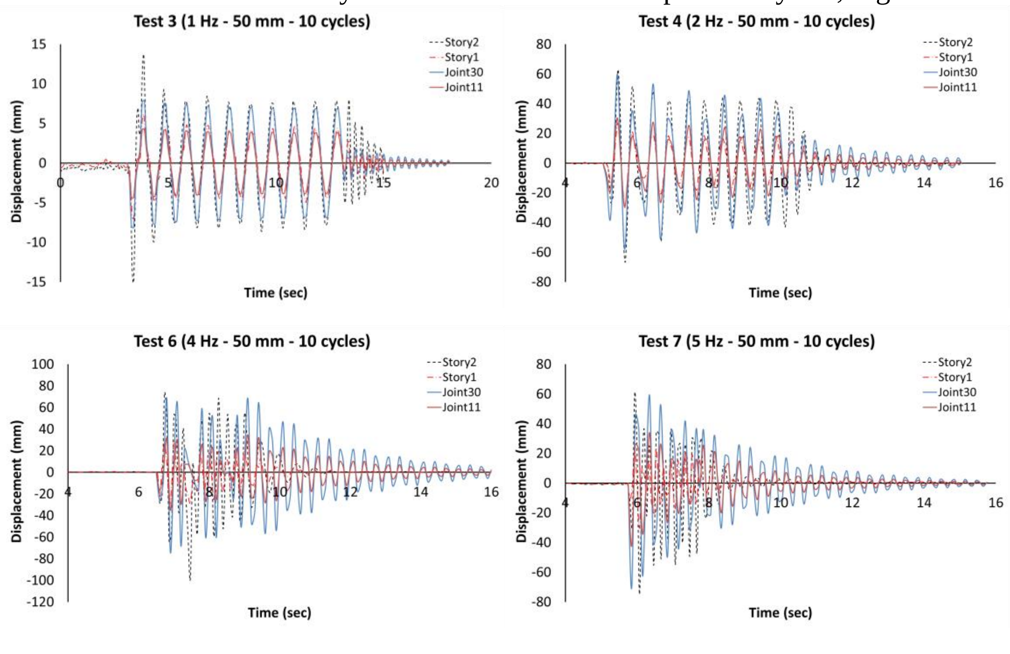


Figure 6. Dynamic test (high-amplitude) time-histories

Once the forcing vibration is higher than the fundamental frequency of the structure, a significant phase delay appears between the results. On the other hand the amplitudes are not close to each other.

4.3 Dynamic tests with low amplitude

Contrary to the high-amplitude dynamic tests, the low-amplitude tests reveal inconsistent time-histories those are difficult to compare in terms of amplitude and the phase, Fig. 7.

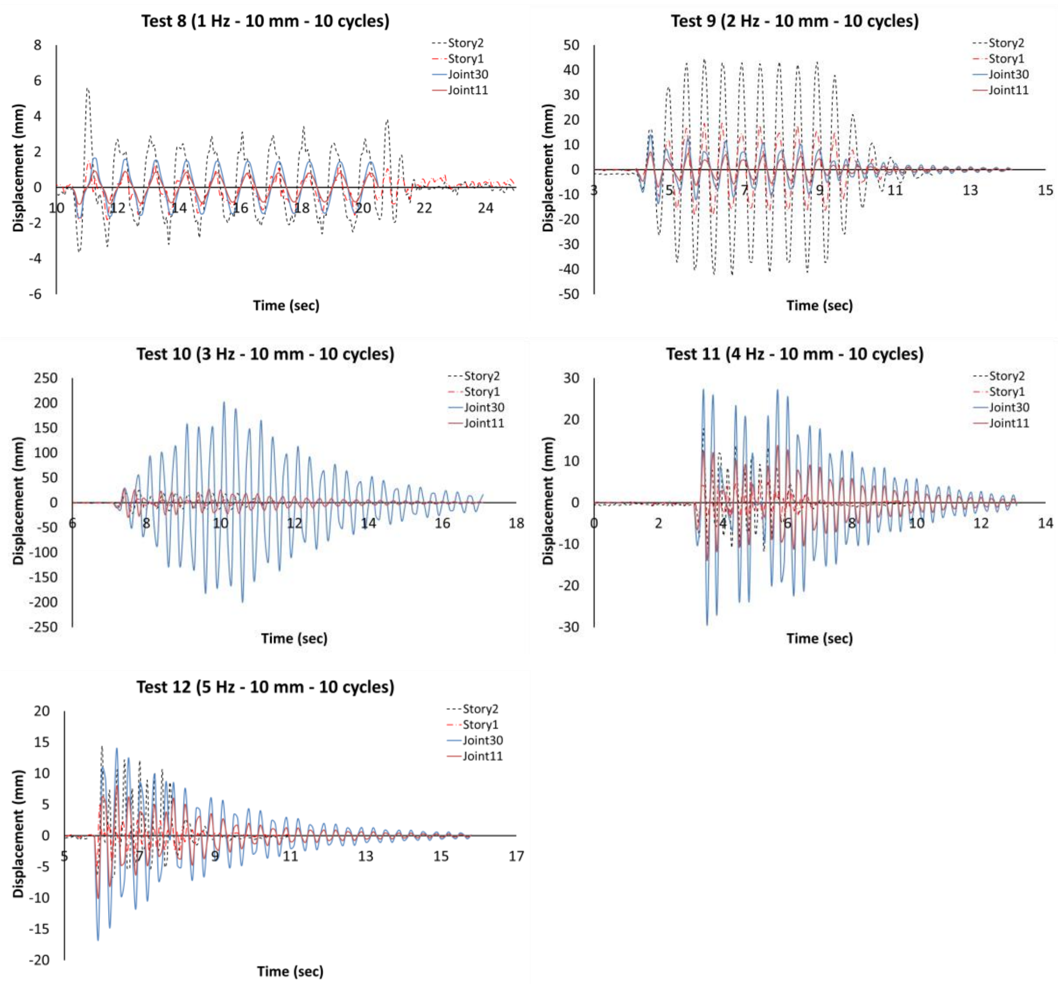


Figure 7. Dynamic test (low-amplitude) time-histories

On the hand, the response of the system at Test 9 revealed a resonance action according to OTM results whereas numeric model is in resonance action, as expected, in Test 10. During the Test 5 and 10, the optic image frames extracted from the video were not in good quality hence the tolerance limit in the smoothing increased more than 50% which drastically reduces the reliability of the methodology.

5 CONCLUSION

This study aims to form a basis for one of the remote sensing techniques Optical Motion Tracking to use in the Shaking Table and Scaled Coastal Structures tests. Three category of the test were conducted in order to scrutinize the response of a two-story simple shear-type building response measured by video recordings and the results were compared with numerical FEM model. The followings are the conclusion of the tests.

- Remote sensing based data acquisition systems in the laboratory test have great advantages since it is practical in the preparation and acquisition period. The conventional methods of using displacement transducers and/or accelerometers require extensive cabling and maintenance efforts before, during and after the tests.
- The comparison of the both results displayed that OTM has high potential to determine the structural response in the quasi-static motions. As come to the dynamic motion, the amplitude and motion frequency has noteworthy influence on the results.
- High-amplitude with lower than structural natural vibration frequency, the OTM results are almost same with the numerical model. In other cases, OTM falls short in the measuring the amplitude in addition to phase lag. Low-amplitude tests, unfortunately the OTM results are not consistent with numerical model results indicating that the measurement error in the little displacement are not satisfactory with respect to the recording system properties (low-cost webcam and low-frame rate).
- Optical Motion Tracking methodology was used in the process of the video recording of the 12 tests. The duration of the tests was 11.38 minutes however the OTM process took 100 minutes. There is a great difference between the data acquisition and the process. However, the process period is entirely related to the computer resource and subjected to the optimization in the future. Using high-level image-process tools, the process time can be reduced down to near-real time.

This study displays the preliminary work in the remote sensing data acquisition and process efforts for the dynamic test systems. The future of the study is to improve the acquisition and process systems.

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