Case study of deep learning-based image analysis for vibration measurement in physical model tests

S.J. Han, S.J. Park, S.H. Han and Y.W. Choo*
Kongju National University, Cheonan, Republic of Korea, ywchoo@kongju.ac.kr

S.S. Yoon and J.H. Jeon
Korea University, Seoul, Republic of Korea, susik@korea.ac.kr

ABSTRACT: This study aims to measure dynamic displacement using a deep learning-based algorithm, so call You Only Look Once (YOLO) in three types of experiment: a shaker test, dynamic centrifuge test, and resonant column/torsional shear test. For the shaker test, a plastic block that vibrated vertically under a sinusoidal wave was recorded by a smartphone camera. In the resonant column/torsional shear test, the rotational vibration of the driving plate in the loading system was recorded by the smartphone. In the dynamic centrifuge test, a single degree of freedom structure attached with an accelerometer was excited by the Kobe earthquake. These three applications were analyzed by YOLO and its performance are evaluated under various conditions.

1 INTRODUCTION

Traditionally, the displacements of vibrating structure have been measured by contact or point sensors, such as accelerometers and displacement transducers, which are attached and point to a single spot on the structure for measurement. Recent remarkable advances in camera technologies and image processing algorithms have expanded the applicability of deep learning-based image analysis methods to wider application areas. These techniques enable precise displacement measurements under various conditions (Liu et al., 2024). Nevertheless, previous studies have primarily focused on the static experiments, while dynamic displacement measurement is scarce.

Therefore, in this study, the deep learning based YOLOv11 (You Only Look Once version 11) algorithm was used to measure dynamic displacement in three types of experiment.

2 EXPERIMENT

A shaker test was conducted using a plastic block with black and white pattern (Fig. 1) that vibrated vertically in a form of sinusoidal wave with frequency of 30 Hz, and its displacement was measured by a laser sensor, accelerometer and YOLO algorithm utilizing images that captured by smartphone camera.

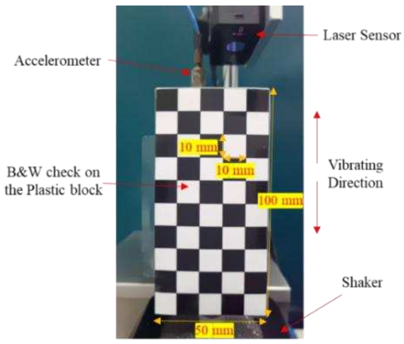

Figure 1. Shaker test setup.

The resonant column/torsional shear test (RC/TS) was performed. Patterns were printed at the corners of drive plate to trace the rotation of the drive plate during the resonant column/torsional shear tests (Figure. 2). The patterns include prohibition sign, square, triangular, and X shape. The input motion was a 1 Hz sine wave.

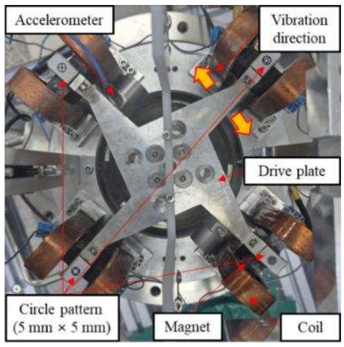

Figure 2. Resonant column/Torsional shear test setup.

A dynamic centrifuge test was performed with a single degree of freedom (SDOF) structure supported by basement installed on sandy ground (Park et al., 2025. The excited input motion was Kobe earthquake (Station: Santa Monica), and the accelerometers were used to measure acceleration attaching to the top mass of the SDOF structure. The high-speed camera was used to record the motion of SDOF structure during excitation, capturing the top view of the testing system.

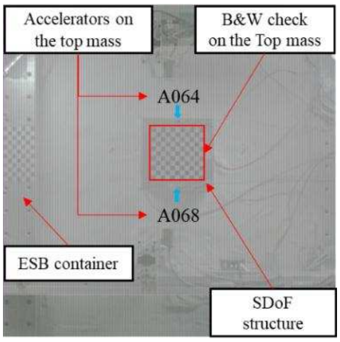

Figure 3. Dynamic centrifuge test setup.

3 RESULTS

The results of each test are compared in Figure. 4 and summarized in Table 1. The performance of YOLO algorithm was evaluated using peak to peak error (P2PE). The P2PEs of the shaker test and the resonant column/torsional shear test were 3.796% and 3.569%, respectively.

In the dynamic centrifuge test, the P2PE was 7.069%. These results seemed to due to the low sampling rate, which provided about 14 data points per wavelength, thereby limiting measurement precision.

$$P2PE(\%) = \left| \frac{y_{peak,\,i} - \hat{y}_{peak,\,i}}{y_{peak,\,i}} \right| \times 100 \quad (1)$$

where, y_i is the actual value, $\hat{y}_i$ is the predicted value.

Table 1. Test setup and results.

Test	P2PE
Shaker	3.796
Centrifuge	7.069
RC/TS	3.569

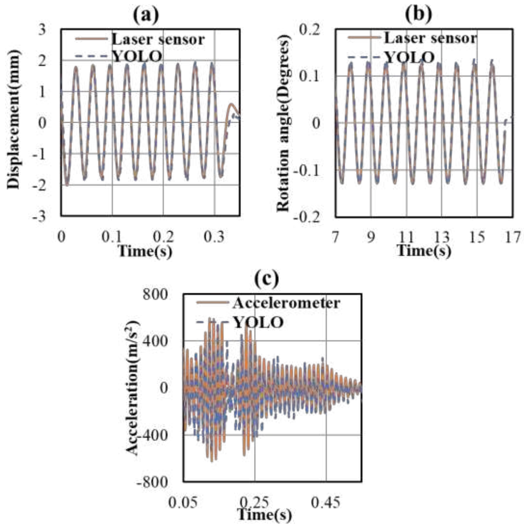

Figure 4. Time history curves according to tests: (a) shaker; (b) RC/TS; (c) dynamic centrifuge.

4 CONCLUSION

This study demonstrates the applicability of the deep learning-based YOLO algorithm for noncontact measurement of dynamic displacement in the three types of experiments (Shaker, Dynamic Centrifuge, and RC/TS test). The performance of YOLO method provides relatively high accuracy when applying to the laboratory experiments, confirming its potential as a reliable alternative to traditional sensors. Although a high error occurred in the dynamic centrifuge test due to resolution and sampling limitations involved in measurement environment, it is expected to be mitigated through noise correction and multi-camera based displacement detection.

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