DOI: 10.3217/978-3-99161-057-1-081

Re-meshing Method for Finite Element Model Updating based on Extracting Structural Anomalous Information from Point Cloud Data

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ABSTRACT: Finite element analysis (FEA) is widely used to evaluate civil structures' performance. To consider detected structural anomalies due to damage in FEA, it is required to represent the anomalous areas in the original finite element (FE) model and update the mesh configuration. This study proposes an approach for updating the shell-element FE models of thin-walled structures with anomalous areas by the point cloud data (PCD)-based CV method, focusing on surface planar anomalies. In this approach, the Iterative Closest Point (ICP) algorithm was used for the alignment of the point cloud with the FE model. The Density-Based Spatial Clustering of Applications with Noise (DBSCAN) on HSV values of PCD was used to extract points of anomalies. The anomalous region is denoted as its boundary points detected by the Alpha-shape algorithm. Constrained Delaunay Triangulation (CDT) generates the new meshes over a constrained area based on points related to anomalies. An experimental study was conducted for validation using a steel plate structure with various stickers attached to simulate the anomalies. The proposed CV-based FE model updating method was validated by comparing the PCD-based updated model and the manually updated model in terms of geometric and analytical accuracy. Most of the corresponding anomalous regions in the two models show a high degree of consistency, except for some areas affected by the low quality of the PCD, which, however, do not have a significant impact on the FEA results. With the same thickness reduction of anomalies, the analysis results indicate that there is only a minimal error between the two models. The proposed method is feasible as a substitute for manual rebuilding, facilitating the automation of the FE model updating with anomalies.

KEY WORDS: Finite element analysis; Point cloud data; FE model updating; Shell element; Anomalies detection; Registration.

1 INTRODUCTION

Since civil infrastructures, such as buildings, bridges, dams, and tunnels, in many countries have been in service for extended periods, various damage accumulated through aging in these in-service structures seriously threatens their safety. The damage assessment for aging structures is critical, considering the infrastructure's crucial role in supporting the quality of life and the economy.

Residual capacity assessment, based on simulation with finite element analysis (FEA), is one of the most widely used methods for evaluating damage to in-service structures. Computer vision (CV) techniques based on point cloud data (PCD) enable the identification and representation of real structural anomalies in computational models. However, current PCD–based modeling studies primarily focus on geometric reconstruction, while relatively limited attention has been given to their applicability in structural analysis. Moreover, there are far more studies related to mass solid structures such as concrete than shell structures like steel[1], [2], [3], [4], [5].

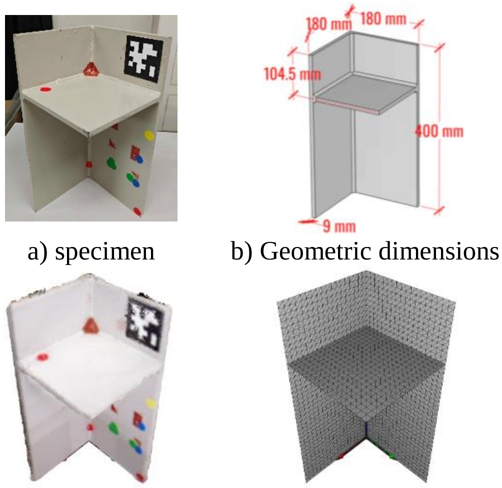
Considering that the PCD-based method of extracting anomalies can greatly facilitate the subsequent damage assessment based on numerical simulation, the purpose of this research is to propose a method for extracting anomalous information from the point cloud and incorporating it into the finite element (FE) model for analysis.

2 EXPERIMENT

This research conducted a full-scale steel structural mock-up test to simulate the actual inspection process of anomalies in steel structures. Shell element FEA was used to assess the structure's performance. The results of the manually built model served as a reference to validate the proposed CV-based modeling method. The specific setup of the specimen and FEA will be elaborated on as follows.

The specimen was set up in this experiment as shown in Figure 1. It is based on a combined structure, consisting of three orthogonal SS400 steel plates welded together, with dimensions of 400 mm in height, 180 mm in length, and 180 mm in width. The thickness of all plates is 9mm.

On the surface of the specimen, stickers of different shapes, sizes, and colors are arranged in various locations to indicate anomalies.



a) specimen b) Geometric dimensions

c) Point Cloud d) Nominal FE Model

Figure 1. Setup and source data of specimen.

In this paper. A standard static analysis was conducted on the model using the commercial FEA software Abaqus. The reference model is manually imprinted with the outline lines of

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anomalous regions in the geometric model, and the mesh generator tool included with the software is used to generate shell element (S3) meshes. Meanwhile, the test model is automatically remeshed based on the existing nominal FE model. The re-meshing is only executed within the local region specified by the proposed method. To introduce an observable amount of load capacity reduction, a uniform shell thickness of 3 mm is used in the anomalous regions for both models, representing a corrosion depth of 6 mm.

3 METHOD

We propose a PCD-based, CV-driven approach for updating the shell finite element model with anomalous information on the structure. This approach comprises three tiers.

The Perception Tier extracts geometry, features, and anomalous information from structures using point cloud data and establishes correlations between this information. The PCD of the steel structure was registered to the mesh through two steps: coarse (PCA) and fine (ICP) alignment. A clustering method that combines the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm and the Support Vector Machine (SVM) was implemented to extract anomaly-related points based on the color information of points.

The Anomaly Description Tier processes anomalous information in the point cloud, extracting features to represent the anomalous area. We utilize the Alpha-shape algorithm for boundary detection. For a single anomalous area that may distribute across multiple planes, the points are further separated into corresponding planes by joint lines, allowing boundary detection to be conducted on each subset.

The Re-meshing Tier performs local mesh regeneration of the target area based on the feature extracted by the previous tier. The Constrained Delaunay Triangulation (CDT) algorithm is used to generate new meshes within the original edge lines of the remeshing region.

4 RESULTS

The original model, manually updated model, and PCD-updated model are shown in Figure 2.

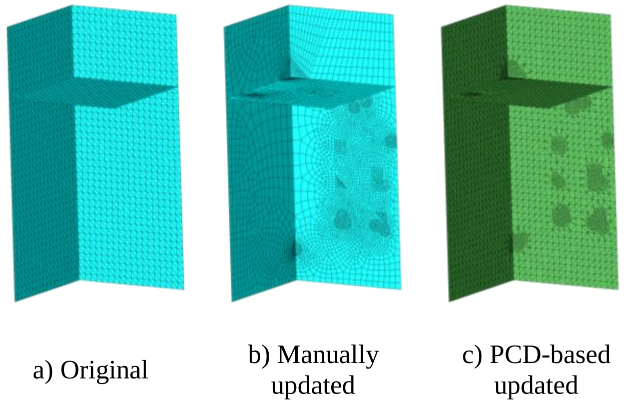

Figure 2. Results of the updated FE model

The locations of anomalous regions in the PCD-based updated model are generally consistent with those in the manually updated model.

Figure 3 present the load-displacement curves at the loading point for the three models during the loading process.

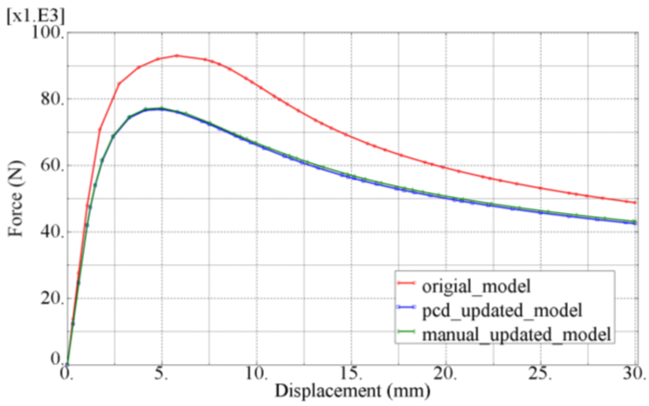

Figure 3. Load-displacement curve

5 CONCLUSION

This study proposed a method that utilizes PCD-based CV techniques to extract anomalous information from the structure and update it into an existing FE model. This paper focuses on surface anomalies commonly encountered in structures modeled by shell elements. The meshes corresponding to anomaly are locally updated based on geometric and color information contained in the point cloud.

The PCD-updated FE model was validated at the analytical level using a manually updated model created according to the design as the criterion. The following conclusions were drawn:

1. The PCD-updated model accurately captures the changes in the global distribution of stress and reduction in ultimate load capacity caused by anomalies in nonlinear analysis. Its results are in good agreement with those of the manually updated model, with a difference of less than 1% in the ultimate strength reduction.

2. The local stress distribution in the anomalous areas of the PCD-updated model is highly consistent with that of the manually updated model. However, due to limited detail in the extracted boundaries of anomalous regions, its local stress concentration effects do not perfectly match those of the manually updated model. Nevertheless, the level of accuracy is sufficient for evaluating structural load-bearing capacity.

ACKNOWLEDGMENTS

This work was supported by JST SPRING, Grant Number JPMJSP2124.

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