FINITE ELEMENT MODEL GENERATION OF SHEAR WALL-FRAME SYSTEMS WITH VARYING CONFIGURATIONS USING A COMBINED QUADTREE-OCTREE PARTITIONING

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ABSTRACT

Shear wall-frame systems are lateral force-resisting systems that are widely-used in mid-rise and high-rise structures. The objective of the study is to develop a model generation procedure for these systems using a combined quadtree and octree partitioning. The procedure leads to efficient placement of multiresolution mesh (voxel and tetrahedron) elements, with constraints provided by dimensions and material designation of the structural elements. Two models of a 10-story structure with different arrangement of shear walls and columns were considered as demonstrative example. The results show that the procedure is capable of generating meshed models with high resolution, thereby allowing for modeling the local variations in structure response. The obtained low computation time of mesh generation of million finite elements show the advantage of the developed procedure, which is expected to contribute to improving the computational efficiency of an entire model generation-analysis process.

Keywords: shear wall-frame systems, finite element method, model generation, octree, quadtree

I. INTRODUCTION

With the increasing move to digitalization in the construction industry to support the rapid infrastructure development, the demand for efficient procedures for Computer-Aided Design and Computer Aided-Engineering (CAD-CAE) integration is gaining attention. One of the major bottlenecks in the CAD-CAE process is the model generation stage. As reported in Bazilevs et al. (2010), about 57% of the overall analysis time is consumed by creation of analysis-suitable geometry. This is because finding the optimal geometry for analysis and design is iterative. If the model generation and updating are done manually, the iterations of the overall process equates to significant manhours. Thus, huge savings can be achieved if the model generation process can be improved. The need for efficient procedure is highlighted in the case of shear-wall frame system, which is a type system that consists of a moment-resisting frame combined with shear walls, and is designed to resist the lateral forces due to wind or earthquake. In such systems, the arrangement of the walls has significant effect on the dynamic response of the structure. Depending on the structure geometry, finding the optimal arrangement can lead to multiple iterations, hence, longer model generation-analysis time.

In the field of computational geometry, methods that use the Cartesian grid to partition the space are widely-available. Examples of these methods are quadtree and octree partitioning which are well-suited to domains that are regular (i.e. there are no curved sections) in shape. With recursive partitioning, the resolutions may be controlled and can be used to map information that are localized, such as geometry and material properties. Applications of this partitioning in the Finite Element (FE) Analysis have been shown to provide computation cost reduction (memory and time) without sacrificing the accuracy in meshing complicated geometries (see Ichimura et al. 2009; Fujita et al. 2016, for applications in fault-site ground motion modeling and soil-structure seismic analysis). In this study, the application of this partitioning is extended for FE model generation of shear wall-frame systems.

II. METHODOLOGY

The objective of the study is to develop a model generation procedure for shear wall-frame systems with the inherent advantages of quadtree and octree partitioning. The procedure follows the framework of hybrid-grid FE model generation proposed by Ichimura et al. (2009), with modification by the use of quadtree partitioning. The procedure for mesh generation are as follows: (1) a volume defined by the structure's extreme point coordinates is created; (2) the volume is subdivided into background cells; (3) planes with normal directed along the height of the building, cut the volume at specific elevations corresponding to the ground, and floor levels of the building; (4) grids, which are the result of intersection of the planes and the background cells, are applied with quadtree partitioning, with constraints given by the pre-determined dimensions of columns and shear walls; (5) octree partitioning is applied in the whole volume with constraints determined in the step 4, and the resulting octree leaves provide the template for the placement of mesh elements; (6) finite elements (multiresolution voxels and tetrahedron) are assigned in selected octree levels, thereby finalizing the meshed model.

A key feature in the procedure mentioned is that instead of continuous refinement from unmeshed model to a refined meshed model that is typical in mesh generation softwares, the procedure does the reverse, which is coarsening from the size of background cells to the largest octree partition. This is done to preserve the geometry information of the structural members. In addition, prior to running the procedure mentioned, the geometry and material data of all the parts of the structure must be known. These data can be readily extracted in CAD or BIM files, and thus provides a direct interfacing with the procedure.

III. RESULTS AND DISCUSSIONS

A 10-story structure with 6 and 11 bays, is considered for demonstration of the application of the procedure. Figure 1 shows the base model (without any shear walls) and plan views of two arrangements of shear walls for the base model, named as Model1 (without opening) and Model2 (with opening).

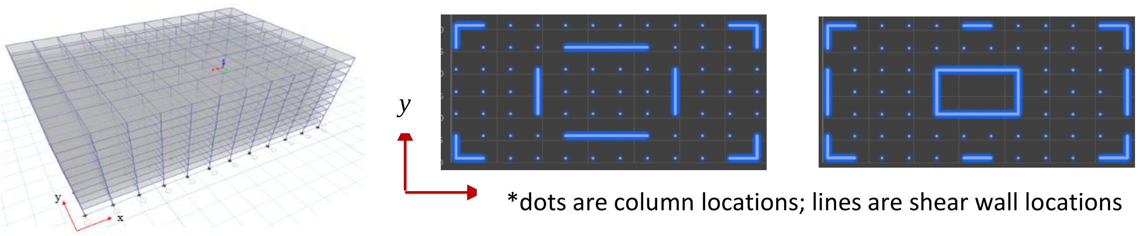

Figure 1. (Left) The base model; (center) Model1 (without opening); (right) Model2 (with opening)

Figures 2 and 3 shows the generated meshed models for Model 1 and Model 2, respectively, and a time snapshot of their deformation response (along the weak axis) to a dynamic load inputted at the bottom.

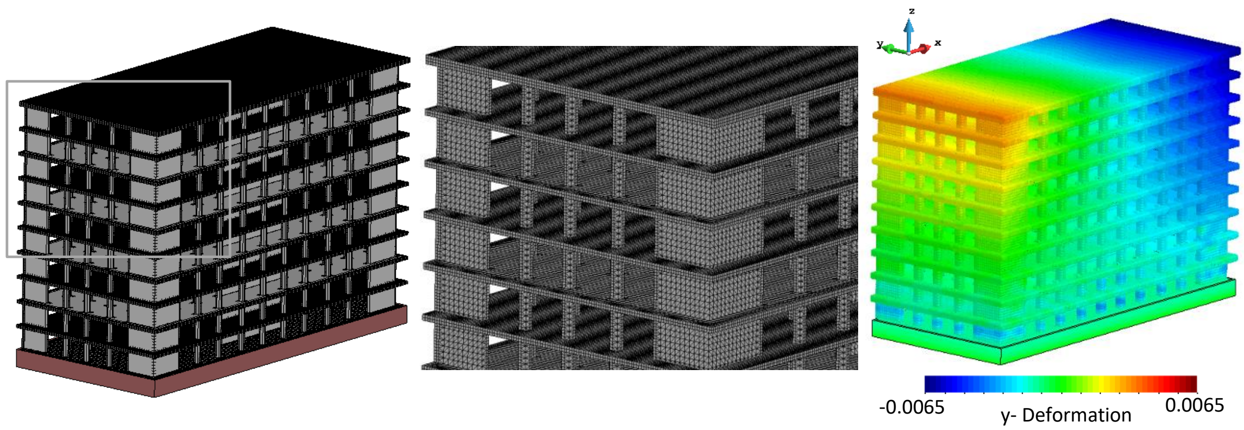

Figure 2. (Left) Generated FE model of Model1 (without opening); (center) magnification showing the multiresolution mesh; (right) time snapshot of amplitude of deformation along the y-axis

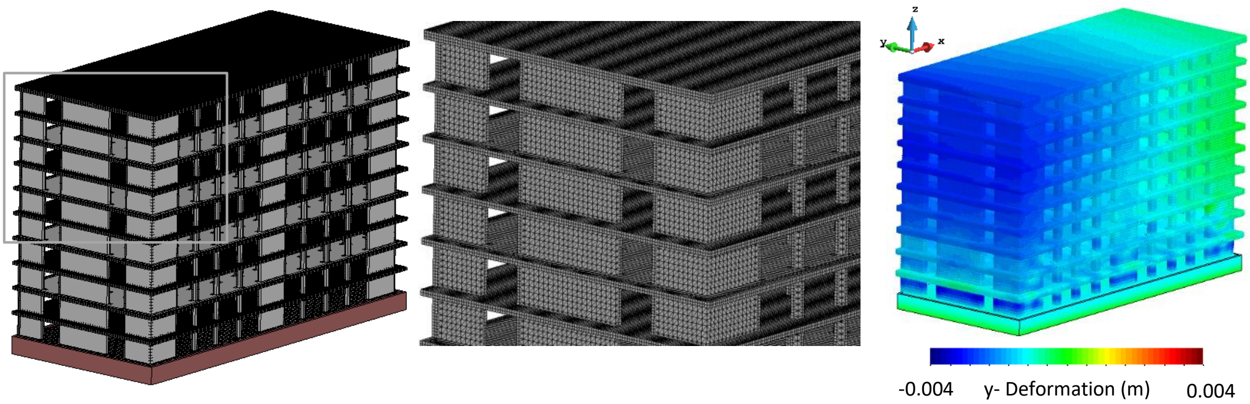

Figure 3. (Left) Generated FE model of Model2 (with opening); (center) magnification showing the multiresolution mesh; (right) time snapshot of amplitude of deformation along the y-axis

The difference in the obtained deformation of the two Models is attributed to the difference in geometry. The fine resolution allowed for modeling the variation of deformation at the local (i.e. within the structural element) level. Table 1 gives the computation cost of these models. The additional shear wall areas in Model2 resulted to larger number of elements compared to Model1. Nevertheless, the additional computation time is not significantly increased, and the overall time is still far lower than in the case of conventional model generation procedure which normally takes hours to complete.

Model	**Number of mesh elements**	**Mesh generation time**
Model1	1,193,746 (612772 voxel + 580974 tetrahedron)	4 min 28 sec
Model2	1,253,886 (665427 voxel +588459 tetrahedron)	4 min 46 sec

Table 1. Computation costs of model generation of Model1 and Model2; computation time is based on running the developed code for the procedure in DOST-ASTI CoARE HPC resources

IV. CONCLUSIONS

An FE model generation procedure for shear wall-frame systems using combined quadtree and octree partitioning has been developed. The procedure leads to efficient placement of multiresolution mesh elements, with constraints provided by dimensions and material designation of the structural elements. Application to two models with different shear wall arrangements showed that the procedure is capable of generating high resolution mesh models (with million finite elements) but with low computation cost.

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