Solomon R. Guggenheim Museum Restoration: Correlating Projected and Actual Movement of Thin Shell Concrete Walls

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Summary

The Solomon R. Guggenheim Museum in New York City by the architect Frank Lloyd Wright is a recognized international icon of Modern Architecture. The architecture and structure are completely integrated to define the organic architecture of the building. A rehabilitation of the building exterior was undertaken by the museum to address cracks and deterioration of the coating. A comprehensive structural assessment of the building was done to determine the source of cracking, evaluate the global structural stability and determine if structural repairs were required to improve the performance of the walls. To evaluate the structural performance of the building, a finite element model was created from a laser scan. The model was correlated to the actual performance of the building by comparison with monitoring data and with crack patterns in the concrete substrate. This paper presents the process and challenges faced in creating a model that reflected the as-built, real world performance of the building.

Keywords: concrete; laser scan; monitoring; finite element analysis

1. Introduction

Robert Silman Associates was retained by the Solomon R. Guggenheim Foundation to conduct a comprehensive structural assessment of the museum focusing on the Main Rotunda. See Fig 1. This paper focuses on the most critical aspect of the structural investigation, creating a finite element model of the Main Rotunda that reflects the as-built geometry, existing material properties, actual reinforcing configuration, and building movements. The model was used to analyze the structure under dead loads, live loads, wind loads, temperature loads and the current code required load combinations.

Fig. 1: Solomon R. Guggenheim Museum
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The complex geometry of the building is an expression of the reinforced concrete structural elements. The structure is comprised of both cast-in-place concrete and sprayed gunite concrete. The coating was removed so that the cracking in the concrete substrate could be observed and documented. Additionally several types of monitors were installed around the building to evaluate the global and local movement of structural elements. For correlation of the finite element model, the primary monitors used were radial monitors at the top of the wall. Non-destructive testing and probes were conducted to verify the existing reinforcing. Material testing was completed to verify the structural properties of the different materials used on the building.

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2. 3D Finite Element Model

Often finite element models reflect an idealized building; geometry is based on the original drawings and limited field measurement; reinforcement configuration is based on modern construction standards; typical material properties are used. Accurate finite element modeling involves understanding the relationships between the physical world and the numerical simulation. The project goal was to remove as many assumptions as possible.

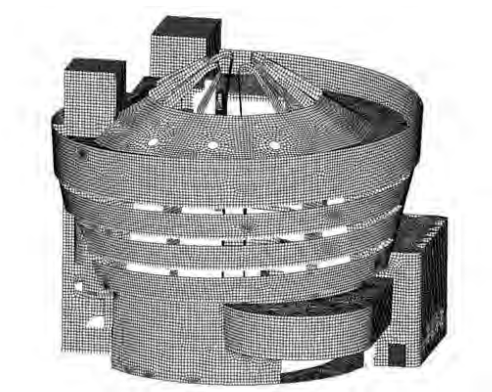

Fig. 7: 3D Finite Element Model of Main Rotunda
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To provide the most accurate analysis possible, the model for this assessment needed to be based upon the as-built geometry. It was determined the best way to obtain the accurate as-built geometry was to base the model on data from a laser scan. This is cutting edge use of laser scanning and was rather complex.

Shell elements were selected to model the primary concrete elements since the majority of structural members in the building are thin slab elements.

Once the model was meshed and connectivity issues were resolved, thickness and material properties were assigned to the elements. See Fig. 2 for image of the finite element model.

Globally the model and monitoring indicated the primary structural elements were stable. At the exterior gunite walls, both the model and the monitoring data indicated movement under temperature loading. The model was revised to reflect the actual movements and the results were compared to the stress contours. The model was then used to evaluate repair methods and select the appropriate repair.

3. Conclusions

Creating a finite element model that correlated to the actual performance of the building was critical to the evaluation and restoration of the Solomon R. Guggenheim Museum. It was a process that required combining the as-built geometry, actual movements, existing reinforcing, and comparison with cracking. All these real world conditions had to be incorporated and were equally important to an accurate structural evaluation of this complex and iconic building.