D5 Fire Dynamic Simulation — Assessing Structural Damage and Suppression Potential of a Church Fire

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After attending this presentation, attendees will better understand the use of fire dynamic simulations to determine the extent of structural damage and suppression potential during the progression of a fire.

This presentation will impact the forensic science community by demonstrating analytical tools to determine culpability in the protection of a historical structure.

This case study details an investigation of a fire at a historical church in Provo, UT. The church's construction dated to the 1880s and included much of the original framing. The attic contained a plywood deck that was installed in the 1980s, at which time smoke detectors were installed within this space. In late 2010, the church was holding an annual Christmas play. Alterations to the lighting system were made temporarily for the play. The changes included removal of the existing light fixtures in order to descend a decorative lighting truss through the ceiling. The contractor performing this work placed one of the fixtures on the plywood deck; however, he failed to turn off the light, which eventually led to a smoldering fire. Although some witnesses smelled smoke during the play, no one had been in the attic since the lighting system was placed in operation. Some time after the end of the play, burning embers breached the perimeter of the fixture and developed into a full-scale fire. This fire progressed through the attic and eventually consumed much of the roof, which led to a partial collapse of the structure.

The cause of the fire, while accidental, resulted in action against the lighting contractor; however, pertinent issues of suppression potential and a failure to recognize the fire were raised. The fire was not discovered until several hours after the end of the play. Past false alarms in the smoke detection system confused the security detail during the initial alarms. This confusion resulted in a 90-minute delay in responding to the fire, at which time the fire began to breach through the attic floor and into the ceiling of the church. In order to assist in a determination of the effects of this time delay on the condition of the structure and suppression potential, representatives with the church commissioned a fire dynamics simulation of this event.

The investigation began by reviewing the findings of the fire marshal, who was intimately involved in fighting the fire and in determining its cause. Modeling the fire required detailed knowledge of the dimensions of the church and materials used in the construction, especially within the attic. The shell of the structure was still in place at the time of the site visit; however, considerable efforts were underway to salvage the original brick walls and to expand the depth of the foundation. These efforts, as well as the extensive gutting of the church following the fire, limited the information available for use in the model. Information based on the as-built diagrams, plans devised during past remodeling, and the photographic record assisted in reconstructing the roof frame and the contents of the attic.

Fire Dynamic Simulation (FDS) and Smokeview software was used to perform the analysis. This software was developed by the National Institute of Standards (NIST) and has been widely used in both design of fire safety equipment and the reconstruction of fire events. FDS is a computational fluid dynamics model of fire-driven fluid flow. Smokeview is a visualization program for the results of the simulation. Input variables and output files are written into Fortran code and solved within the FDS program. Computing these results for a large-scale fire over a long period of time proved challenging for both the analysts and hardware.

Modeling the fire involved setting global boundaries, defining cell sizes, assigning materials (i.e., wood and metal) to the solid items within the attic, and setting the geometry for these items. Ventilation at the ridge and gable ends was also included in the model. In order to limit computational time to periods of days rather than weeks, the cell sizes were selected toward the maximum limit recommended by the program developers. The large cell sizes limited assessment of the progression of the fire within the interstitial spaces of the ceiling frame. Additionally, the program requires sloped and curved objects to be modeled in Cartesian coordinates, which creates vortices at the resultant corners that limited the ability to complete some simulations. This problem was alleviated by a modification to the software code; however, these changes limited the amount of information gleaned by the analysis.

The results of the analysis were consistent with the time frame developed by the original fire investigators. Output data included burning rates, gauge heat flux, soot mass fraction, as well as surface and air temperatures. Soot levels indicated that the smoke detectors would have been activated within a few minutes after the smoldering fire breached the perimeter of the light fixture shield. Testing performed by the fire marshal indicated that the smoldering fire would develop into open flames once air was introduced into the fuel mixture. The duration of this test is consistent with witness observations during the play and the timing of the smoke alarms. Thus, the delay in responding to the fire was no greater than 90 minutes.

Still, this represents a considerable time for open flames to spread throughout a large, open attic. The fact that the roof frame was composed of wood that had dried for more than a century in a desert environment likely increased the rate of consumption. The results of the analysis confirmed the decision by the fire chief to avoid entering the attic after the fire was ultimately discovered. The extent of damage to the framing members and temperatures within the attic precluded an interior attack. The limitation of the suppression efforts to a defensive approach prevented any successful salvaging of the structural elements. The actions of the security company were assessed, namely their failure to recognize the signs of a fire and respond to the alarms; however, a few conditions that were out of the security company's control factored into these failures.

Fluid, Soot, Burning Rate