Structural Sustainability

sustainability and preservation as they pertain to structural engineering

Environmental Impacts of Fire

By Erica C. Fischer, Ph.D., P.E. and Amit H. Varma, Ph.D.

Fire is an extreme loading condition that must be considered in the design of buildings. Upon initial ignition, building fires are typically small, localized and dealt with efficiently by active protection systems, such as sprinklers. In certain situations, where there is adequate fuel, ventilation, and lack (or failure) of active protection systems, the compartment fire may flashover and develop into an extreme fire loading scenario. During such design fire scenarios, the gravity loading on the structure does not change significantly, but the structural properties (elastic modulus, yield strength, and failure strength) of the steel and concrete materials decrease dramatically. In addition, thermal deformations and movements due to the expansion of structural members, and the restraints by the surrounding (cooler) system impose large force demands.

This behavior is different from other natural or man-made disasters where the material properties of the structural elements remain constant while the imposed loading increases. Researchers and engineers in the field of extreme loading on structures (i.e. earthquake, hurricane, tsunami) are developing performance-based design approaches as an alternative to the current prescriptive methodologies. This shift in engineering design allows building owners to specify the additional performance objectives the design team should target. These performance objectives are not only for the structural and non-structural performance of the building, but also include environmental impacts throughout the life of the building. Climate change has made building owners and design team contributors cognizant of the carbon emissions and embodied energy of a typical building. Popular sustainability metrics (i.e. LEED) aim to reduce carbon in buildings through decreasing quantities of material. More recently, LEED developed three pilot credits to incorporate planning for and reducing vulnerabilities towards natural disasters such as earthquakes, tsunami, wildfire, floods, and hurricanes. Structural fire engineering research typically focuses on life safety, property loss, and continuity of business; however, the fire event can have significant impact on the natural environment as well.

In addition to the carbon emission of the fire itself, a fire can have non-carbon contamination of the air, water supply, and soils. The fire plume contains contaminants from the contents of the building. Many new building products are made from synthetic plastics and polymers, which are more flammable than their natural predecessors and release harmful agents during a fire. Contamination of the soil and water can occur from the products of combustion in the fire plume. Lastly, contamination of the water supply in an area can occur as a result of runoff from fire suppression methods (i.e. sprinklers, firefighting techniques) which can contain toxic byproducts of the fire.

Sustainability

Within the sustainability framework, there are two measures for the contribution of buildings to climate change and impacts on the environment. One such measure is life cycle assessment (LCA), which is a standardized methodology for comparing environmental impacts of developing, using, and disposing of a product or a service. Another measure is the cumulative energy demand (CED). The CED is the energy consumed during a product's life cycle. The result of this evaluation is called the "embodied energy" of a product or a service. Commercially available software such as Athena Impact Estimator (Athena Sustainable Materials Institute) includes the embodied energy of a building in the output when the user can input the operating fuel consumption.

The topic of sustainability as it relates to structural fire engineering has two parts: (i) reduction in embodied carbon and energy of a building by optimizing the use of fire protection systems and construction materials to achieve the required fire resistance rating of a building, while minimizing the impact of fire on the building and surrounding area, and (ii) reducing the ecological impact of fires through environmental impact assessment, site planning, and strategic storage of chemicals. Both of these objectives align with the goals and objectives of many sustainable metric programs (i.e. LEED); however, fire is not considered a potential hazard on buildings by these metrics. Buildings around the world require sprinkler systems above certain occupancies and floor area via applicable codes. To improve the fire resistance of a structure, building owners can increase the fire protection of the building. Fire protection comes in two forms: active and passive. Active fire protection is in the form of building sprinklers, and passive fire protection is in the form of fire protection on individual structural members (i.e. spray-applied fire protection, intumescent paint). To increase both the passive and active fire protection in a building, additional material is required, and therefore additional carbon emissions and embodied energy is added to a building. While the upfront carbon may be higher in a building with an increased fire resistance rating, the potential for replacement of components is lower. Therefore, if a fire does occur within a building, there are less elements that would need to be replaced afterwards. This is one potential vantage point

*Erica C. Fischer is a member of the ASCE/SEI Sustainability Committee and Chair of the Disaster Resilience Working Group. She is also an active member of the ASCE/SEI Fire Protection Committee. She works as a Design Engineer at Degenkolb Engineers in Seattle, WA. Dr. Fischer can be reached at **efischer@degenkolb.com**.*

*Amit H. Varma is a Professor and University Faculty Scholar at Purdue University's Lyles School of Civil Engineering. He is a member of the AISC Committee of Specifications and Chair of AISC Task Committee 8 on Fire. He is also the Chair of the SEI/ACI Committee of Composite Construction. Dr. Varma can be reached at **ahvarma@purdue.edu**.*

of addressing sustainability and structural fire engineering – from a material quantity standpoint.

Building fires have environmental impacts that effect the air, water, and soil quality of a region. Current sustainable design methodologies aim to reduce the CO_2 emissions of buildings by reducing material quantity and embodied carbon of the materials themselves through strategic construction choices. However, during a fire, this reduction in carbon may be negated due to the additional carbon emitted into the environment through combustion of building contents. Environmental impact assessment (EIA) of a fire to the surrounding area must be considered during an LCA evaluation. Typically, this assessment is performed for a project without the consideration of a disaster. Similar to an LCA evaluation, evaluating the impact of a structure on the surrounding environment during a potential hazard is critical to understanding the impact of the structure and its contents on the built and natural environment. In the case of a fire, this means identifying potential hazards in the environment that could result from an unexpected fire event.


Sandoz chemical warehouse fire.

Previous Fires and Their Impacts

Fires have a large impact on the environment due to the transmission of harmful chemicals through combustion of the contents of a building. Previous fires highlight the significant impact fires have on the environment or the impact fire-fighting techniques can have to surrounding areas. Other countries (i.e. New Zealand) have developed agencies to plan and manage ecological disasters resulting from fire-water runoff. For brevity, only a few fire events be discussed within this article: (1) Sandoz chemical warehouse fire in Basel, Switzerland (1986), and (2) Sherwin Williams paint factory in Ohio, USA (1987).

Sandoz Chemical Warehouse in Basel, Switzerland – November 1986

The Sandoz chemical warehouse in Basel, Switzerland stored insecticides, fungicides, and chemical dyes. The fire was too large to extinguish with foam; therefore, water was used from the Rhine river. Fire fighters used approximately 105 gallons (400L) per second of water to extinguish the fire over several hours. Residents of the area were instructed to keep windows and doors closed due to the smell of the burning building's contents and potential for air pollution. The water used to extinguish the Sandoz chemical warehouse fire resulted in large quantities of storm water drainage into the Rhine river. The quantity of fire-water runoff into the Rhine river was not exceptionally large; however, due to the nature of the toxins burning within the building, all aquatic life was destroyed in the vicinity as well as several miles downriver (125 miles or 200km). The aquatic life in the Rhine river was affected for over ten years after the fire.

The lasting effect of toxic chemicals in the Rhine river surrounding the Basel area was not only due to the individual toxic chemicals (1351 metric tons of chemicals, 987 of which were agrichemicals), but also due to the harmful effect of the combination of chemicals, more harmful than the individual chemicals themselves. Long-term effects of the fire-water runoff included contamination of the ground water 46 feet (14 meters) below grade due to seepage of chemicals into the soil. Air contamination was minimal despite a smell in the town due to the Sulphur-based chemicals burning.

The resulting ecological damage caused by the Sandoz chemical fire was the product of poor placement of a chemical facility, and poor emergency planning when considering potential hazards. A facility with ecologically hazardous materials was located near a major water-way, highly reactive and incompatible chemicals were stored close to one another, the sprinkler systems were inadequate for controlling a fire, and no methodologies were developed to control potential water runoff in the case of a fire.

Sherwin Williams Paint Factory in Ohio, USA – June 1987

The Sherwin Williams paint factory in Ohio stored approximately 1.5 million gallons of paint. The paint factory was constructed on top of aquifers that provided water to wells for over 130,000 people in the area. During the fire, the fire department considered the effects of extinguishing the fire with water that would then seep into the ground and potentially contaminate the aquifer versus the potential air contamination from the combustion of the contents of the factory. The resulting ecological damage from the Sandoz chemical fire was taken into consideration when the firefighters were making their decision.

The Sherwin Williams paint factory had a working sprinkler system with a diesel fire pump. The fire pump was located in a separate building and had a capacity of 2,500 gallons per minute (gpm). The pump had fire department connections for additional capacity. These connections were located on the warehouse side of the detached building. The sprinklers were activated by the fire, and triggered the call for the fire department. The fire chief made a decision for the fire fighters not to hook up to the fire pump due to concerns for the safety of the fire fighters and exposure to high heat and potentially dangerous conditions. The sprinkler system controlled the fire in the office area of the building; however, this had little impact on the remainder of the building fire due to the wide spread burning and height of the flames. Early on, the fire department saw the water runoff due to the sprinkler system activation and a broken sprinkler pipe.

Because of the fire chief's concern for water runoff entering into the city's water supply, the fire fighters were directed to only apply water in areas where runoff could be monitored on paved areas. Local water experts, and state air and water pollution experts, were on the scene during the first day of the fire. The consultation they provided to the fire department considered the tradeoff between air pollution and water pollution. The fire was contained within 12 hours of starting. There was a small amount of fire-water runoff contamination in the Miami river; however, it was addressed quickly and effectively.

The management of the Sherwin Williams paint factory fire showed how careful and strategic risk management can be effective. Considerations were made regarding the characteristics of the chemicals and contents burning, proximity to water supply sources, air versus water pollution, ability to control run-off, and short term versus long term hazards due to the fire. These considerations resulted in a successful hazard mitigation procedure for the fire.

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Environmental Impact of Fire

There are short term and long term environmental impacts of fire. The short term impacts are experienced by the affected community immediately following the fire event; however, the affected and neighboring communities may not be aware of the pending long term impacts of fires. There are a large variety of hazardous agents that are released during a fire. These hazards include: general pollutants/indicators, metals, particulates, polycyclic aromatic hydrocarbons (PAHs), chlorinate dioxins and furans, brominated dioxins and furans, polychlorinated biphenyls and polyfluorinated compounds. In order to perform an EIA and understand the short and long term effects these hazards have on the environment, engineers and researchers must understand the origin of these hazards (what building components or products release these hazards during combustion) and how these hazards impact the water, air, and soils in the area of a fire. The exposure duration (i.e. duration of fire) will have an effect on the impact these hazards will have on the environment.

Short term fire effects include the impact to the local environment within the fire plume zone and the water runoff zone. The short term effects are concentrated in the local area/vicinity of the fire and immediate surrounding areas. Short term hazards can include nitrogen oxides, sulphur oxides, some metals, halogenated acids (HX) and particulates. These short term effects may be easier to mitigate and prevent escalation of. The long term effects of fires are impacts that are not immediately felt or recognized. These effects are more likely to impact the water supply and soils in the area of the fire. The list of hazards that result from long term effects can be extensive.

The smoke plume created from the fire is the largest contributor to potential air contamination. Emissions include inorganic gases, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and dioxins. The quantity of these emissions is not necessarily in a harmful quantity to the average population; however, it can be quite dangerous for the at-risk population. Firefighters and automatic sprinklers use water and other extinguishing agents to prevent the fire from spreading. Run-off resulting from the large quantities of water used should be treated prior to the water entering and disrupting nearby water ways. PAHs, VOCs, hydrocarbons, dioxins, metals, ammonia, and other suspended solids can be expected to be in the run-off. In addition, any products on-site in a building or warehouse will be present in the fire effluent. During the Sandoz chemical fire, chemicals in the factory were present in the runoff that entered the Rhine river. Effects on soil occur much later after the fire than the effects on the air and water supplies. In addition to any products on-site in a building or warehouse, the long-term exposure impacts on the soils are PAHs, dioxins, furans, and metals. The dioxins emissions from a fire are about the same as the dioxins emissions from traffic or municipal waste combustion.

Fire-LCA

A comprehensive fire LCA tool developed by the SP Fire Testing Laboratory in Sweden is available for commercial use. Fire-LCA is similar to typical LCA tools used by the industry (i.e. Athena). The difference is that there are modules to account for the effect of a fire during the life-time of a structure. These modules recognize the extent of the damaged area, the fire extinguishment and replacement of damaged components.

While Fire-LCA is a comprehensive evaluation of the life cycle assessment of a building and the environmental impacts the building would have with a potential fire, the program can be difficult to use. Fire-LCA considers the potential for each material to combust, which requires the consideration of a number of different input fires. This program requires the cooperation of industry providers of building materials to evaluate the post-fire impact on the surrounding environment. In Europe, manufacturers are required to release the information containing the composition of the materials; however, in the United States, the LCA evaluation results include a large range of impacts due in most part to the proprietary nature of building material composition. The commercially available software in the U.S. makes it easier to use Fire-LCA; however, it is still a very complicated and involved process.

Conclusion and Future Work

Hazard mitigation and sustainable design have developed independent of one another. As such, popular sustainable design metrics provide large benefits to the reduction of materials without consideration of the impacts those reductions have on the disaster resilience of structures. These metrics also place large emphasis on the reduction of CO_2 emissions and embodied energy in the selection of building materials. However, previous fires have shown that the effluents released during a fire can negate the reductions in carbon and energy used in the planning and construction process. LEED recently release three new pilot credits which incorporate planning for, designing for, and considering the after math of disasters such as tsunamis, hurricanes, floods, earthquakes, and wildfires. However, building fires were not included in these credits.

The case studies referenced in this article demonstrate that building fires should be considered in an initial hazards assessment of a building site. Emergency planning for a potential fire, especially for buildings containing toxic chemicals, can decrease the potential impact on the ecological and environmental surroundings of a building. Structural engineers have the ability to design buildings for enhanced resiliency to fires through consideration of building-specific fires rather than prescriptive fire protection design. Consideration of the contents of a building is critical when determining the fire resistance rating of the structure. This approach aligns with a performance-based design for fire.

Sustainability and hazard mitigation of fires must be approached from both the material quantity and reduction in emissions standpoints. Excluding one or the other is neglecting to evaluate the full life cycle impacts of a structure that is subjected to a fire within its life time. Researchers have summarized the work to date on the environmental impact reduction of fires. Future work in this field should include continuing to develop an LCA tool that allows for the environmental impacts of a fire to be evaluated both on a local and global scale. To develop this tool, detailed information regarding the composition of building materials must be available. A commercially available, simplistic approach to performing a fire LCA in conjunction with a performance-based design guideline for fire would provide structural engineers with the tools to consider fire as a potential hazard that can fit into a sustainability metric.■

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