STEEL TUBE INSTITUTE

HSS

ARTICLE

FIRE PROTECTION OF HSS

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HSS members have inherent advantages over other shapes. Structural engineers like them because of their high capacity-to-weight ratio and excellent torsion resistance, and architects like them for their clean look, including smooth surfaces and rounded corners. However, adding external fire protection can negate those aesthetic advantages. There are different types of fire protection that may be employed and some are unique to an HSS member.

ASTM E119, titled "Standard Test Methods for Fire Tests of Building Construction and Materials," is the current industry standard for fire protection. It includes a definition of a "standard fire." This fire heats up very quickly and continues to increase in temperature indefinitely. In reality, most fires burn until they begin to use up all the combustible material in the area, after which they enter a decay phase and begin to cool. When steel is exposed to the high temperature of a fire, it loses both strength (yield strength, F_y) and stiffness (modulus of elasticity, E). If the temperature of the steel does not exceed 1300 degrees F for over 20 minutes, the strength and stiffness reductions have been found to be temporary.

There are three general ways to improve fire safety: prevention (elimination or isolation of potential ignition sources), suppression (such as a sprinkler system), and resistance (how long steel can withstand a fire). Steel, on its own, does not have great fire resistance, but we can insulate it in order to increase its resistance. This insulation falls into two major categories: external insulation and internal insulation. There are also proprietary fire-protected column assemblies in the U.S. marketplace.

For external insulation, there are products such as gypsum insulating boards, spray-applied fire resistive materials (SFRM) and intumescent coatings. These increase fire resistance by forming an insulating layer between the steel and the fire, either with expansive material or by the heating of entrapped water. However, one issue with external insulation is that it changes the look of the structure, negating the aesthetic advantages. Intumescent coatings usually look just like painted steel, but they tend to be more expensive than other types of external insulation.

Internal insulation might take a little more thought beforehand, but does not change the look of the HSS. One option is to fill the HSS with a cementitious material. The relatively large mass of the concrete or grout absorbs heat much more slowly than the thin-walled HSS, allowing the concrete to retain its strength much longer than the steel. HSS members can also be filled with water. If columns are connected to a water reservoir, they can be filled with the water either permanently or only when a fire breaks out. If the water can be constantly circulated and renewed, fire resistance is essentially unlimited.

There is an equation to calculate the fire resistance of a concrete-filled HSS column that comes from ASCE 29, "Calculation Methods for Structural Fire Prevention," and is shown in AISC Design Guide 19, "Fire Resistance of Structural Steel Framing." The fire resistance depends on the effective length of the column, the outside dimension of the column (either the diameter of a round column or the full outside dimension of a rectangular column), the compressive strength of the concrete fill and the unfactored total compressive load on the column. The resistance also depends on whether the column is round or rectangular and what kind of aggregate is in the concrete fill. Since this equation is based on lab testing, there are many constraints to which the column geometry must adhere to in order to ensure that the column in question meets the conditions that were actually tested. For instance, the effective length of the column must be from 6'-6" to 13'-0", and the concrete strength must be between 2900 and 5800 psi. This equation shows that we can increase our fire resistance by increasing the concrete strength, decreasing the length of the column, increasing the size of the column or decreasing the load-to-capacity ratio of the column.

As an alternative to prescriptive lab tests, research has been performed on computer simulations of filled steel columns in fires and the simulations have yielded results very close to those obtained from lab tests. Once it was determined that the computer simulation was giving the expected results, the research moved onto other column configurations that hadn't been tested and maybe don't even fit into the test furnace. This research has found that reinforcing in the concrete significantly increases the fire resistance of the member. Whether the reinforcing is bars or fibers, it holds the concrete together after the steel has lost strength, and therefore allows the concrete to hold its strength longer. Other things such as fire intensity (testing fires other than just the ASTM standard fire), column length, load-to-capacity ratio and cross section size affect the fire resistance as well.

Another item to note is that there are different definitions of "failure." ASTM E119 defines failure as the time when the cross section reaches a temperature of 1000 degrees F, or when any point on the steel reaches 1200 degrees F. Another option would be to define failure as when the column can no longer remain stable. This is an important point because a stable column can allow occupants to exit the building or firefighters access to fight the fire. Research has found that the temperature criterion doesn't accurately account for the contribution of the concrete core in a filled column. As an example, an HSS10.75 filled with plain concrete was found to reach the 1000/1200 degree F failure point after 38 minutes, but in lab testing this member retained its stability for 143 minutes. This is a significant difference of almost two hours.

Much of the work that has been done in fire protection, and many of the items that have been discussed in this article, is prescriptive, that is, a set of criteria and conditions has been put forth and applied to different conditions and situations. It is, therefore, a simplistic, "one size fits all" method. As more research is conducted and fire protection gets more advanced, it is moving toward a performance-based design. The Society of Fire Protection Engineers defines this as a design-based on agreed-upon fire safety goals and probabilistic analysis of fire conditions. In other words, instead of designing for a "standard fire," we now might look at the use of a specific building and what intensity of fire we can reasonably expect to see there. This can result in a more efficient design that has less chance of being overly conservative. In this scenario, the responsibilities of the structural engineer are to determine which are the critical members to check and to provide sufficient load path for redistribution to prevent progressive collapse. At that point, the actual fire design would be performed by a fire protection engineer. It is important to have someone with specialized knowledge of real fire exposures as the design gets more involved and complicated.

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