CHAPTER 4

RELIABILITY AND DURABILITY

SECTION 401

RELIABILITY

This chapter addresses the importance of the reliability of individual protection systems and strategies as well as the reliability of the interaction of these systems in achieving the design performance level for a particular building or facility addressed in Chapter 3. Reliability is a function of the many factors discussed below, including redundancy, maintenance, durability of materials, quality of installations, and integrity of design. The discussion is primarily focused on fire safety systems and strategies but is intended to address other aspects of building design such as structural stability, mechanical systems, and plumbing.

Systems reliability

Under prescriptive codes, the typical failure rates of systems are sometimes compensated for by requiring redundancy. One of the perceived advantages of a performance design is that it might allow the designer to minimize redundancy in order to achieve cost efficiency by increasing the reliability of the systems and/or strategies used to implement the design. In other words, increasing the number and effectiveness of the layers of protection provided may not necessarily increase the overall reliability of a design if probabilities of successful operation are not factored in. Therefore, a focus upon reliability should be established. Redundancy is only one, though important, way of achieving reliability. Reliability should be explicitly accounted for in the performance analysis. As part of this analysis it is important that all factors affecting reliability over the life of the building be understood and addressed.

Operational reliability

Operational reliability is defined as the probability that a system or component will function as intended when called upon. A reliability of 100 percent means that the system will always work. Of course, because there is always a slight chance of something going wrong, 100 percent reliability can never be achieved.

Reliability analysis is a science used where the proper functioning of systems is crucial; the military, aircraft industry, and nuclear power plant operators all apply reliability analysis to their systems. The reliability of a system is a composite of the reliability of its component parts, with a reliability of 1 being the same as 100 percent reliable. Mathematically, this can actually be calculated as 1 minus the sum of the probability of the failure rates of the component parts.

However, the failure of certain parts may not result in a failure of the system to perform within its intended range of performance. These are called noncritical parts and should not be included in the reliability calculation. This simplest approach to reliability analysis is called the parts count method.

However, the failure of several noncritical parts could lead to the failure of a critical part, but this mode of failure would not be addressed by a parts count reliability analysis. Therefore, a more detailed analytical method called Failure Modes and Effects Criticality Analysis (FMECA) may be necessary. With FMECA, the failure modes of each component as well as the probability of the occurrence of those failure modes are evaluated as to the effect they will have on other components. For example, an electronic part that fails 75 percent of the time when it is open may have no detrimental effect, but if the electronic part fails 25 percent of the time when it is shorted, it may overstress a critical part and cause it to fail. These failure modes and probabilities are then incorporated into the overall reliability analysis, which can become quite complex, especially for a complex system.

Reliability of fire protection systems

These same concepts can be applied to fire protection systems or other critical safety systems in buildings incorporating a performance design. The greatest obstacle to conducting such an analysis is the lack of failure rate data on certain systems components. The major users of reliability analysis mentioned above have kept detailed failure records on equipment for many years. These data do not exist for most systems found in buildings, although some data exists in surveys and in data kept by insurance inspectors. From these, estimates of systems reliability can be derived or approximated. In the future, manufacturers and service/maintenance companies will need to establish data bases based on testing and field performance.

The most data available for fire protection systems and methods appear to be for sprinkler systems. Experience with commercial (NFPA 13) sprinkler systems indicates a fairly high operational reliability. Further, the data indicate that about half of the operational failures are attributed to some impairment in the water supply. For example, shut valves, clogged pipes, pump failures, or problems with the municipal supply are the more common causes. Depending on where the problem is within the system, this could mean that only a few sprinklers might be affected or that the entire system might be impaired. This important distinction must be taken into account in the performance design analysis.

Data on the operational reliability of fire alarm systems suggest that they may not be as reliable as commercial sprinkler systems. But here, many of the failures appear to occur in individual detectors. Because detectors operate independently in a parallel wiring scheme (the exception being when one fails shorted, which results in a false alarm signal), problems with fire alarm systems tend to be more localized, the remainder of the system continuing to operate normally. Addressable and intelligent technology increases reliability by more specifically targeting detector activation and by providing the ability of detectors to be adjustable for sensitivities to elements such as dust.

Although not often thought of in this way, fire-resistance-rated construction has reliability associated with it as well. Assemblies are furnace tested under ASTM E 119 to assign a fire resistance rating based on exposure to a standard time-temperature curve. The assemblies must be constructed in accordance with the tested design to assure proper performance, although some assemblies are not very sensitive to construction errors. For example, masonry walls seldom crack or come apart to allow the passage of fire and hot gases (one of the E 119 acceptance criteria), but most fail when the temperature on the unexposed side exceeds a specific value (another E 119 acceptance criterion). Thus, errors in construction that do not affect heat transfer through the wall will likely not lead to failure. On the other hand, gypsum walls typically fail when the gypsum wallboard on the exposed side falls off, allowing fire to penetrate to the interior of the wall assembly and quickly through the entire assembly. Constructing one of these walls with too few or the wrong type of fasteners or improperly installed fasteners could lead to a wall that has less than the tested fire resistance.

Such problems appear to be rare because data from insurance inspections indicate a very high operational reliability for fire-resistance-rated construction comparable to that of commercial sprinklers. Clearly, the weak link in fire-resistive barriers is with intentional openings installed in rated assemblies to accommodate doors, windows, and utility penetrations. The same insurance sources estimate that there is a 50-percent likelihood that a fire door in a rated wall opening will be blocked open or otherwise impaired and therefore negate the rating fire resistance performance of the entire wall assembly. The reliability of both an individual construction assembly and the overall system of compartmentation are important but difficult to measure.

Design and installation

The design and installation of fire protection features and systems and other building systems such as refrigeration systems must be conducted properly, or such features and systems will not be reliable. Especially with active systems such as fire alarm, sprinkler, and smoke management, the devices selected must be appropriate to the hazards, and the installation must be correct. Many systems require a commissioning process that tests the full range of operation and sometimes includes third-party oversight, resulting in a certification. In some cases there are national bodies that certify competence, and many manufacturers offer training programs on the proper installation of their equipment.

Testing and maintenance

Testing and maintenance have a significant effect on the reliability of components and systems. Maintenance prevents failures by reducing wear and stopping problems before they start. Testing does not prevent failures but rather identifies failed components so they can be repaired before the system is needed. Testing must be done more frequently than the time between incidents, and repairs must be done promptly so that the system is working when it is needed. Maintenance must be done properly and at the required intervals so that detrimental effects are avoided. If not, the reliability of the system can be reduced significantly.

There are recognized standards for the testing methods and intervals for active fire protection features such as fire alarm systems (NFPA 72, Chapter 7) and fire sprinklers (NFPA 25). Maintenance required of components and systems is more individualized and is specified by the manufacturer. It is crucial to reliability that the maintenance and testing be performed as required by qualified personnel in order to avoid the introduction of problems by the very process used to avoid problems. Technicians performing testing and maintenance should be certified or at least working under the supervision of someone certified to work on the systems.

SECTION 402

DURABILITY

The objective of this section is to ensure that the building materials selected for a structure or facility are sufficiently durable or are repaired or replaced in a timely manner so that the performance objectives of this code are achieved and maintained throughout the life of the facility. The durability of a specific material, component, or system should be appropriate for its use within the structure or facility and also consistent with its purpose in contributing to the desired level of building performance. The current codes indirectly address this issue by requiring certain types of materials. The durability of building elements, components, and systems contributes to the overall reliability of the entire building as a system.

The selection of building materials and the protection, preservation, and functionality of those materials should be such that the building will continue to satisfy the objectives of the code throughout its life. This may mean that in order to comply with the durability requirements, regular maintenance or replacement must occur. Performance objectives may impact the life-cycle cost of regular maintenance. Event magnitudes selected to meet tolerable impact limitations may influence the useful life of components and systems. For example, the design-performance objective for expansive soils might state a moderate level of tolerable damage to the foundation. But the performance objective for structural stability and means of egress might specify that only mild levels of damage can be tolerated. The design team needs to consider how various event scenarios influence or impact other performance objectives and tolerable limits of damage and how they in turn impact the durability of building components and systems. A design allowing for differential settlements might be well within the limits of moderate impact for the foundation; however, architectural components, HVAC equipment, and floor surfaces could be rendered inoperable or unusable while their durability is adversely affected, negating their contribution to other performance objectives.

The performance of a building is dependent on the materials used in construction and the maintenance of those materials throughout the life of the building. It is anticipated that some materials, such as roofs, will need to be replaced, whereas other materials need only be maintained, such as the paint on an exterior wall. Use and exposure to physical stresses and environmental conditions also impact durability. These factors should be considered within the context of how materials are to be used in or on a building in conjunction with their intended function and their overall contribution to the building's performance.

The determination of whether a material for a specific element must last for the entire anticipated life of the building or can be one that is maintained, repaired, or replaced as appropriate may well be dependent on the accessibility of the element for inspection and maintenance and the importance of the element's contribution to the structural and fire- and life-safety performance of the building. For example, the paint on the exterior bearing wall of a building is easily inspected and maintained and also has a minimal effect on the structural and fire- and life-safety performance objectives during a fire event, but the fire protection encasing a steel column that is located within a framed wall is not as easy to inspect or maintain and is also essential to the structural integrity and fire- and life-safety of the structure during a fire event. Therefore, the paint could be durable for any length of time acceptable to the owner, but the fireproofing material must be durable for a much longer period of time.

The designer must include in the construction documents not only a description of the specific materials being used but also a description of the durability of each material ("a 20-year built-up composition roof, manufactured by the ABC Roofing Company," for example) or must specify the maintenance interval for each material (such as "exterior wood wall shall be painted every 10 years with an exterior grade, weather-resistant paint").

The replacement and maintenance schedules for building materials that are unusual may be required to be documented in the office of the authority having jurisdiction or in an affidavit signed by the owner and recorded so that future owners will be aware of the need for maintenance or replacement.