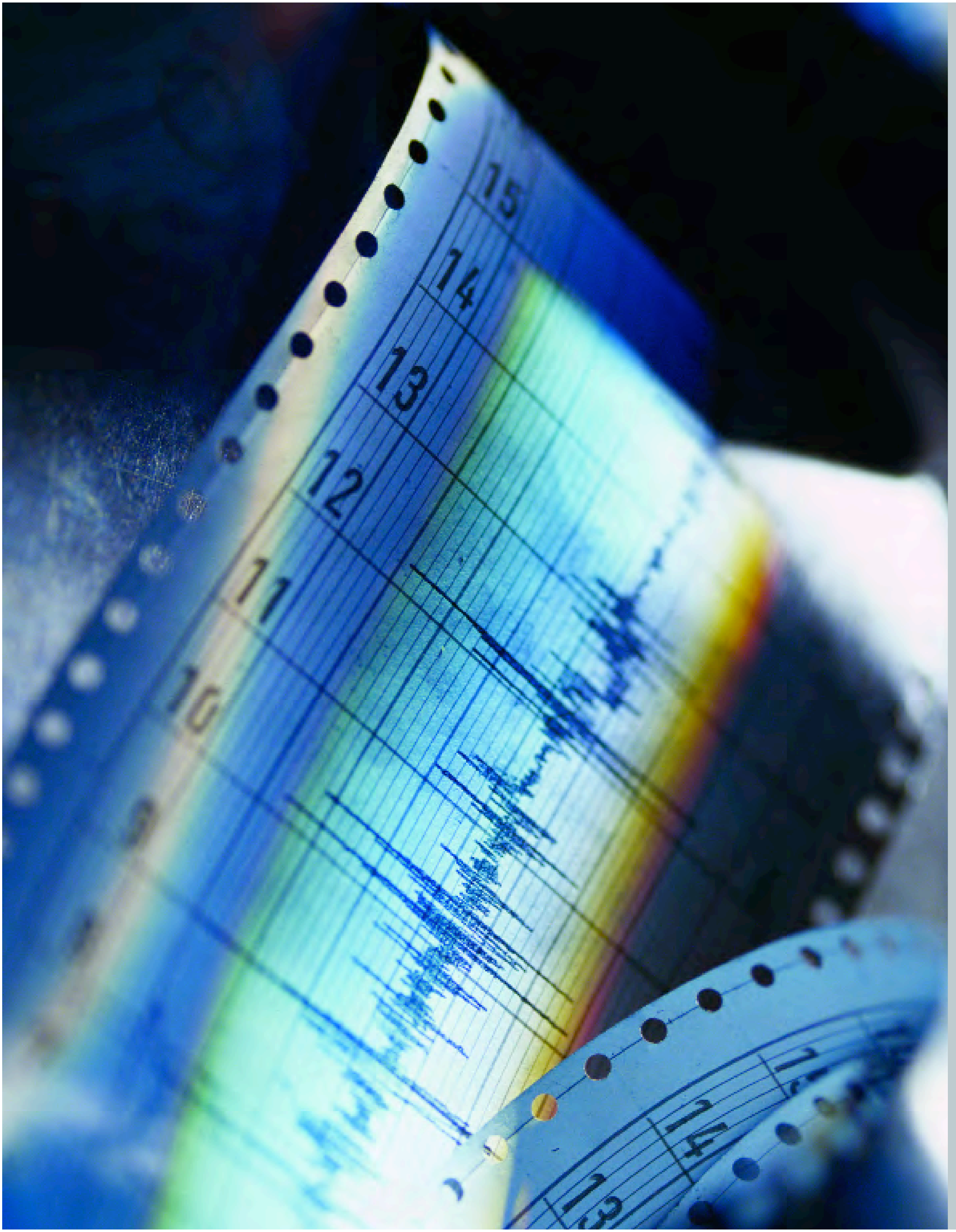
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SEISMIC PROTECTION is spreading across the country and the way it's being done is changing. By **Roland J. Huggins, P.E.**

SPRINKLER shake-up

WHEN IT COMES TO providing seismic protection for sprinkler systems, historically, we have had either a "yes" or "no" statewide requirement. This is no longer the case with the current model building codes. Additionally, there are conflicts caused by the building codes on how to design the seismic protection.

Seismic events, or earthquakes, are common occurrences throughout the world. The Richter scale is one way to measure the size or magnitude of an earthquake. The Richter scale is a logarithmic base scale whereby an increase in one whole number represents a ten-fold increase in measured amplitude and a release of 31 times more energy. For instance, a 7.0 represents the discharge of 31 times more energy than a 6.0.

Magnitude is not the only variable dictating the ability to cause damage. The depth of the hypocenter (where the actual facture occurs verses epicenter, which is a vertical projection to the surface) also influences the surface motion. The shallower the event, the smaller the affected area, resulting in a greater potential surface motion.

The consequences of an earthquake are naturally tied to the construction features within the area. Criteria for the protection of the sprinkler system first appeared in NFPA 13, *Installation of Sprinkler Systems*, in the 1940s. As expected, changes to it have been made after the evaluation of facilities following major earthquakes. These evaluations have also shown that systems can be adequately protected but omission of only a few components can result in pipe damage. So, when in doubt, more is better.

Another event that has imposed recent significant change on NFPA 13 is realizing the need for better alignment with the National Earthquake Hazard Reduction Program (NEHRP) and the criteria of the American Society of Civil Engineers (ASCE) 7, *Minimum Design Loads for Buildings and Other Structures*. This is reflected by TIA 13: 02-1 published in 2003. It made extensive changes, particularly for the allowed loads on fasteners, and can be downloaded from www.nfpa.org.

The criteria of NFPA 13 define only how to protect a system. The local building code dictates when that protection is required. In the past, most areas with statewide codes would decide based upon the acceleration depicted by the Seismic Zone Maps, see Figure 1.

As shown, the intensity varies across the country and within individual states. At what level to require protection was left up to the individual state. Most of the country, though, being less than a zone 3 didn't require seismic protection. With the adoption of NFPA 5000™, *Building Construction and Safety Code*™, or the IBC, even relatively low accelerations such as Zone 1 can no longer be casually ignored.

PHOTOGRAPH: CORBIS

When Protected

NFPA 5000 states under Section 35.10 Earthquake Loads that all building, and portions thereof, shall be designed to resist the effects of earthquake motions. The IBC has the same requirement.

You then have exceptions when protection isn't required for the building or just the system therein. As such, you have to prove whether protection is allowed to be excluded for each building. If the acceleration is very low, (less than 0.15 g for the short period) it is a simple yes/no issue. Otherwise, there are multiple site-specific variables that influence the evaluation. This leads to the possibility that two adjacent buildings of the same construction type can differ with only one of them requiring protection. It's also possible within a building being protected, that one mechanical system requires protection whereas another may not.

The determination on whether protection is required is the responsibility of the A/E team designing the building.This is clearly identified by NFPA 5000: 35.4.2.5 - Earthquake Design Data, which states that the following eight items shall be shown regardless of whether seismic loads govern the lateral design.The IBC similarly calls for 10 items in Section 1603.1.5.

The eight items in NFPA 5000 are:

1) Mapped maximum spectral response acceleration,
2) Site class,
3) Design spectral response acceleration,
4) Seismic use group and occupancy category,
5) Seismic importance factor,
6) Seismic design category,
7) Seismic force resisting system, and
8) Analysis procedure.

In addressing items 7 and 8, simply referencing the codes in defining how protection is to be provided is inadequate as discussed hereafter. This information is needed by the building official to review the building plans and for the contractors to bid the job and develop shop drawings. Contractors also need to know these requirements since the building plans often don't have the data or needed guidance and the contractors inherit the responsibility.

The process of determining if protection is required is handled well by both model codes. They're consistent since both model codes reference ASCE 7. NFPA 5000 shows this information in less than half a page by identifying each of the above eight items with their applicable sections of ASCE 7. The IBC (2000 edition) covers these items by extracting 25 pages of information.

Having this data within the code is preferable but it is covered in different sections and requires a lot of jumping around. One should have ASCE 7 on-hand since it's extensively referenced. In the IBC (2003 edition), the material was condensed and replaced with references to sections of ASCE 7. The application of protection to systems within the building is cleaner in the IBC since it directly addresses it in Section 1621. NFPA 5000 also addresses systems in Section 35.10.1 by stating all buildings "and portions thereof" and a general reference to Section 9 of ACSE 7. Within Section 9, there are criteria for systems.

The required level of seismic protection is assigned based upon the seismic design category of the building. The possible categories are A through F, with A being the least demanding. There are several steps required to determine the design category. Actually, there are two evaluations based on duration. One is the short period response for 0.2 seconds (designated by a lower case "s" such as Ss for spectral response, short) and the other is the 1.0-second period (designated by a "1"). You determine separate design categories, following the same steps for both durations, then use the more demanding category. To simplify matters, only the short duration is discussed in this article.

Design Process

The first step in determining the design category is to determine the mapped maximum considered earthquake spectral response acceleration (Ss) for the building site. You can use the figures in ASCE 7 (which resemble the NFPA 13 zone maps but show the acceleration contour boundaries across the country) but in areas with close boundaries, it's hard to accurately identify the applicable acceleration. You can also use software developed by the United States Geological Survey that identifies acceleration by zip code.

The unit of measurement for acceleration is "g," such as 0.15 g. It's a percentage of the acceleration caused by gravity, which is 32.2 ft/s2 so a difference of 0.2 g is much larger than it sounds. The second step is to determine the Site Class, which is a function of the type of soil and how it is expected to fare during an earthquake. It is also assigned letters, using A through F with A (hard rock) being the least affected and F (such as peats or very high plasticity clays) being the most vulnerable to potential failure or collapse. If no information is available, you default (with approval of the building official) to a class D (a relatively stiff soil profile).

The third step is to determine the Site Coefficients (Fa). It is a number between 0.8 and 2.5 and is picked from a table based on site class and spectral acceleration. For instance a site class A at Ss < 0.25 has a coefficient of 0.8 but at a site class E, the same Ss will result in a coefficient of 2.5. This coefficient is then used for the fourth step of determining the Design Spectral Response Accelerations (SD) = Ss x Fa x 2/3. Site class significantly affects whether or not one must provide protection. For instance, with the same Ss, the SD is 0.133 for site class A and 0.417 for site class E.

The fifth step is to determine the Seismic Use Group.

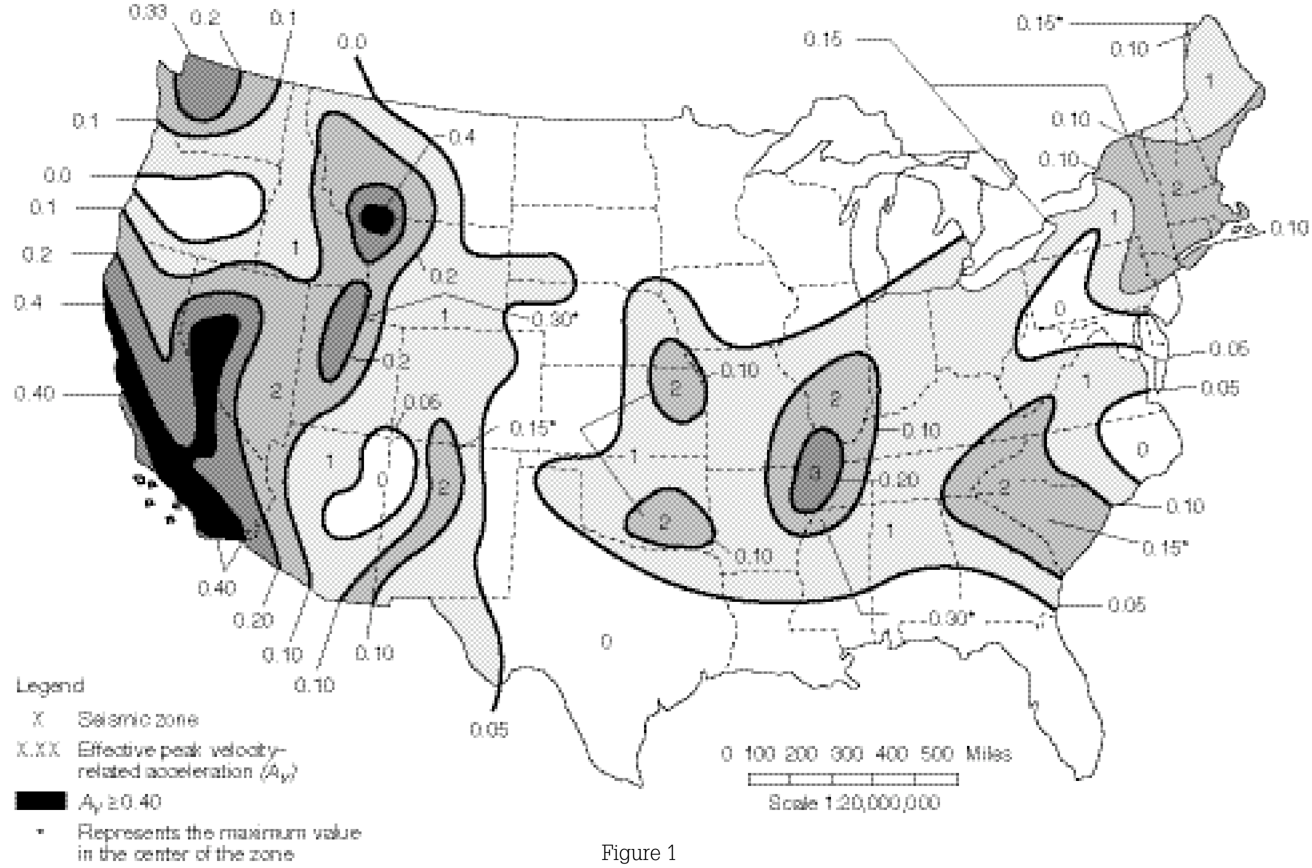

Figure 1

This category focuses on whether the facility could either present a hazard or provide needed services to the community following an earthquake. It's designated as category I, II or III. The IBC has four Use Group categories for other loads such as wind but ASCE 7 combines categories I and II creating just three seismic categories. You are now able do the sixth step and define the seismic design category. It is selected from a table and is based upon the SD (presented as four ranges of acceleration) and the seismic use group. For instance, a Use Group I at an SDs of 0.16g is an A while the same facility at an acceleration of 0.51g is a D.

The seventh and final step is to determine if protection is required for the sprinkler system. ASCE 7, thus NFPA 5000 and IBC, provides two exceptions. The first one is for a very low mapped maximum considered earthquake spectral response acceleration. When Ss is no more than 0.15g (0.04g for S1), no protection is required. The second one is a low design category of A or B. A third exception is offered by IBC when there is a low design acceleration not exceeding 0.167g for SDs or 0.067g for SD1. This exception allows a higher mapped acceleration than the 0.15g exception with site class D equaling an Ss of 0.157g and site class A an Ss of 0.313g.

As an example of the process, a hospital in Monroe, Louisiana, being in Zone 1 and very close to the Zone 0 boundary, would normally not be considered for protection. It's a seismic use group III (being important to the recovery activities) and has a short duration mapped maximum acceleration of 0.189g. This exceeds the exemption value so continue the evaluation.

Let's say it was determined by the civil engineer to be a site class C resulting in a design acceleration of 0.1512g.

This value is less than the SDs exemption threshold of 0.167g; therefore, seismic protection is not required. But, if the site class had simply been assigned the default value of D, the resulting design acceleration would be 0.2016g exceeding the exemption limit. This site class would also have resulted in a Seismic Design Category of C and protection would be required.

Application Problem

So, you have to provide protection and intend to apply NFPA 13, which we've always done. Unfortunately, it's no longer so simple. The problem is that although NFPA 5000 and IBC (2000 edition) via the ASCE 7 Section 9.6.3.11.2 allow the use of NFPA 13, it requires you to verify that the force and displacement exceeds that of the code. Actually, 2000 edition of the IBC requires the force calculated by NFPA 13 to be at least 1.4 that calculated by the IBC. The1.4 multiplier was deleted in the 2003 edition.

ILLUSTRATION: NFPA

Comparing the two forces is straightforward, but how do you prove equivalent deflection when this issue is not explicitly defined in the code or discussed in any NFPA 13 criteria?

One would hope it would get better with the newer editions but in the IBC, it got worse. The 2003 edition now states that sprinkler protection must meet the requirements of Section 9.6 of ASCE 7 EXCLUDING Section 9.6.3.11.2. This excluded section is the one that allows the use of NFPA 13.

The reason we can't ignore NFPA 13 is because it provides all the information about what pipes to brace and where to provide flexibility, what pipes to group together in determining the applicable weight, what's the allowed load capacity for different brace components, and where restraint is required to avoid damage. The building code only provides an exact equation for calculating force (with no indication of what to group together to determine weight) and part of an equation for deflection. Therefore, this leaves us with applying NFPA 13 but needing to determine whether to use its calculated force with a standard force factor of 0.5, assigning a higher force factor or using the force calculated by the codes.

There's also the issue of deflection. We are simply told the seismic relative displacement is equal to the deflection at level A as determined by elastic analysis minus the deflection at level B as determined by elastic analysis. So, that leaves us comparing something for the code provided by others with something not explicitly discussed in NFPA 13. In most worlds, using this as a basis for determining equivalency will not produce a favorable outcome. Keep in mind if conducting a comparison between levels A and B, one is looking at a vertical difference. NFPA 13 addresses deflection between vertical locations by requiring flexible couplings. For example, each floor penetration requires two flexible couplings. With each of them providing 1.5 degrees of deflection, a significant amount of movement can occur without damaging the pipe. It's worth noting that there is nothing in the codes restricting movement on the same horizontal plane but it is addressed by NFPA 13.

Resolving these issues is the responsibility of the A/E in defining the Seismic Force Resisting System and the Analysis Procedure required by the codes. As discussed, a simple statement of providing protection in accordance with the building code provides no guidance. The only reasonable resolution is to apply NFPA 13 criteria but the conflicts with the code's reference to NFPA 13 must first be addressed and what process for determining the applied force must be identified. Applying the force determined by the codes is reasonable.

The force is calculated by equation:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right)$$

Although there are several variables, this equation is straightforward. The variables that are constants and obtained from tables in the code are: ap = component amplification factor, Rp= component response modification factor, and Ip = component importance factor. The h is height of the building and z is the height of the location of interest. The SDs was already calculated in determining if protection is required or obtained from the structural engineer. The two most outstanding differences from NFPA 13 are that the exact acceleration is applied, instead of using a general force factor, and the height within the building affects the force, instead of using a constant throughout the building. It's worth saying that the equation accounts for height if one elects to perform separate calculations for every floor. My question is why wouldn't the designer take a conservative maximum for the whole building and reduce not only their workload but, more importantly, the chance for error. This would be similar to following the industry's practice of using a single remote area for the hydraulic calculations unless there's a reason for a second calculation. For seismic, it would be a significant change in weight or elevation. Otherwise, using a single calculated force would present little difference in construction cost.

There is a third difference in that the building codes also dictate that the calculated force shall not be less than a separately calculated minimum force nor required to exceed a separately calculated maximum force. These equations, based on some of the variables from the base equation for force but with different constants, are:

Fp min $F_p = 0.3 S_{DS} I_p W_p$ *and* **Fp max** $F_p = 1.6 S_{DS} I_p W_p$

In conclusion, why hasn't this conflict been a problem? I suspect it's because the building codes are used only by the building officials while reviewing building plans. These plans typically just say sprinklers to be provided. The sprinkler shop drawings are then later reviewed by the authority having jurisdiction (AHJ) typically applying only NFPA 13. Both have been happy with their individual criteria and the conflict has not really been noticed. So why would a representative for contractors be highlighting this issue? Because, until the conflicts of the building codes and ASCE 7 with NFPA 13 are resolved, contractors need to be aware before bidding on a project whether the A/E teams have addressed these issues and AHJs need to be aware of them in order to define reasonable solutions for their communities. The bottom line is that after the sprinkler system is installed is a very ugly time for a contractor to be retroactively addressing seismic protection.

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