Exploring new collapse prevention systems for seismic events.

Still STANDING

BY JOHNN P. JUDD, P.E., PH.D., AND FINLEY A. CHARNEY, P.E., PH.D.

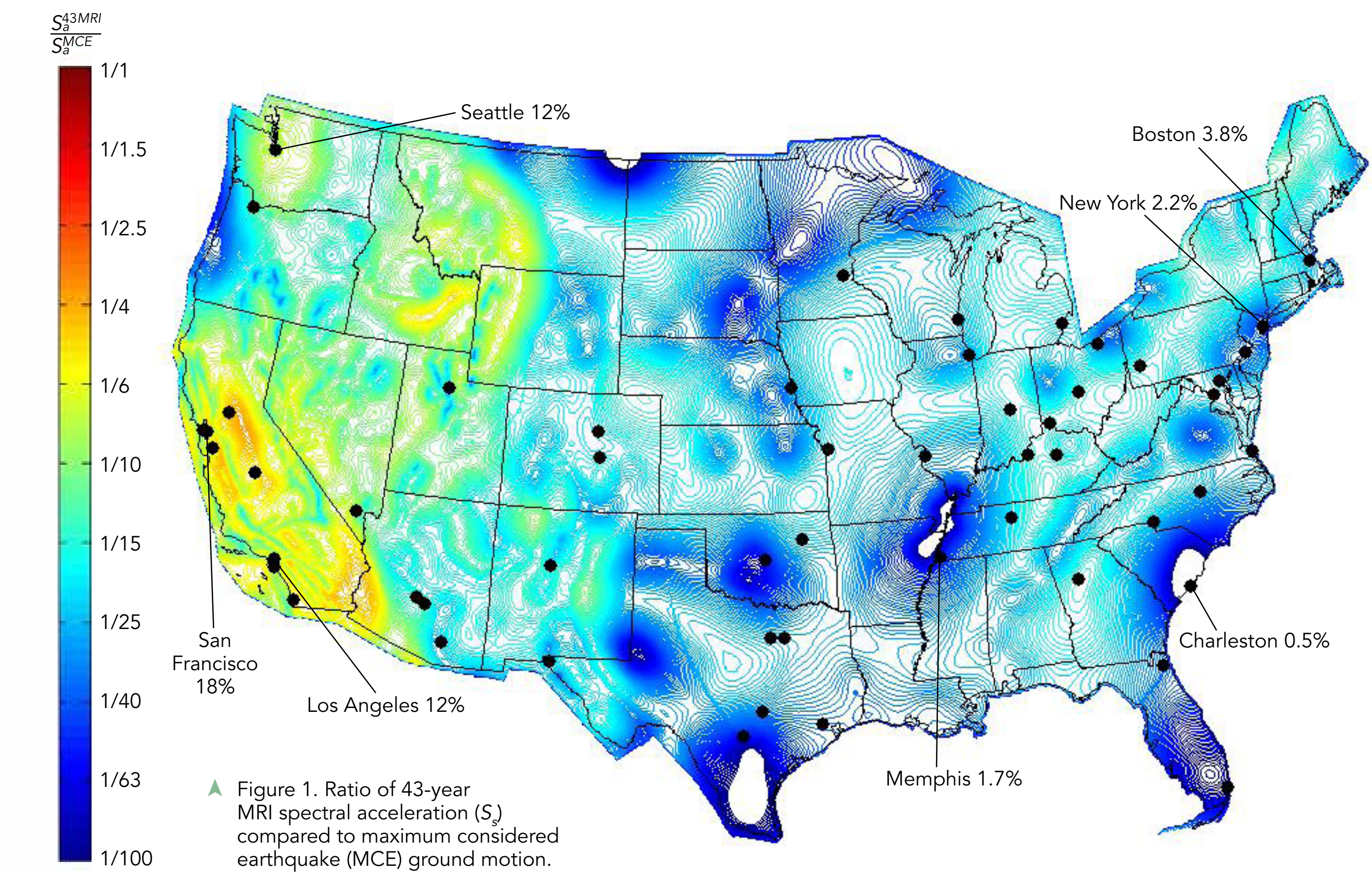

Figure 1. Ratio of 43-year MRI spectral acceleration (S_s) compared to maximum considered earthquake (MCE) ground motion.

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NOT ALL SEISMIC ZONES are created equal.

Ground shaking and spectral acceleration conditions vary significantly between the central and eastern U.S. and the west (see Figure 1 for an example). Yet lateral force resisting systems tend to be designed in essentially the same manner throughout the country.

However, the concept of designing lateral force resisting systems for regional differences in seismic accelerations is gaining some traction. A new kind of seismic force resisting system called a collapse prevention system (CPS) is being developed for implementation in the central and eastern U.S.

The system consists of a collapse prevention mechanism working in tandem with the primary steel moment frame and engages the steel gravity framing system to delay or prevent collapse. Where enhanced performance is needed, the collapse prevention mechanism may be augmented with energy dissipation devices.

A Seismic "Airbag"

The idea of the CPS is to satisfy strength requirements for gravity and wind loads independent of seismic effects, and then provide an auxiliary system to prevent collapse if an extremely rare earthquake were to occur. A good analogy is the airbag in a car. The airbag is almost never needed and is completely benign until a severe crash occurs. In the event of a severe crash, the automobile will generally be written off as a complete loss, but the occupants of the vehicle survive. To provide an equivalent level of safety in an automobile without an airbag, a much heavier frame with energy-dissipating crumple zones is required, producing a less fuel-efficient, less sustainable automobile.

The CPS relies on both a primary lateral force resisting system and reserve lateral strength in the gravity framing beams and columns. Shear tab beam-to-column connections with a steel deck and concrete slab system are partially restrained and inherently have lateral stiffness and strength (Liu and Astaneh-Asl, 2000). In new construction, using slab steel can be a cost-effective way to increase strength, stiffness and robustness. The lateral strength in a typical shear tab connection is small compared to an equivalent fully restrained connection (on the order of 10% to 30%, for example), but it can be significant in the aggregate, depending on quantity of gravity connections in the building (Judd and Charney, 2015). The effect of gravity columns is also important. Continuous columns and columns with moment-resisting splice connections, for example, considerably reduce drift concentrations in steel moment frame buildings (Flores and Charney, 2014).

A variety of designs can be considered for the collapse prevention mechanism. The simplest mechanism consists of a pair of slack cables or loose linkages (Figure 2a) that provide no significant increase in stiffness or resistance until the main building system deformation reaches some limit—e.g., 2% inter-story drift. At that point, the cable or linkage becomes taut and engages with the reserve strength in lateral and gravity framing to prevent or delay collapse.

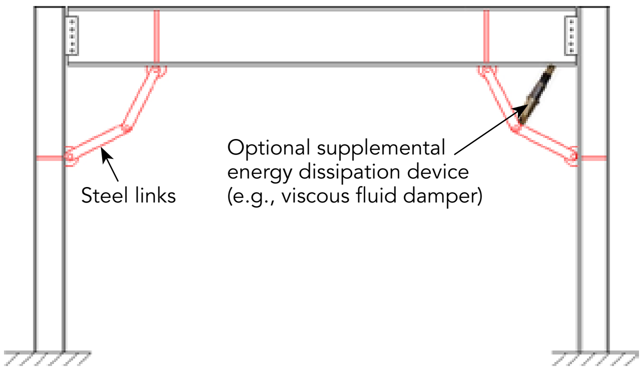
An important aspect of theses mechanisms is their size. The mechanism can be configured to be compact and unobtrusive and, in some cases, they could reasonably fit in the ceiling space. Since the compactness of the mechanisms limits their capacity, they would likely be distributed throughout the building.

A more complex collapse prevention mechanism can be formed using a telescoping brace (Figure 2b). In this mechanism, two steel tubes telescope over each other and can elongate without resistance until a "stop" mechanism causes the brace to go into tension. The brace cannot carry compression. This type of telescoping brace is an adaptation of the hybrid passive energy dissipation device described in Marshall and Charney (2012). Of course, compared to the quantity of slack cables and loose linkages, fewer telescoping braces would be deployed in a building.

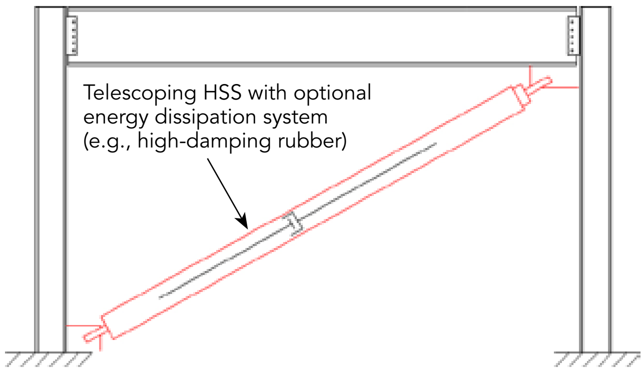
Strength on Reserve

We've put the system to the test (Judd and Charney, 2014), and preliminary results indicate that reserve lateral strength provided by the gravity framing is a significant factor in the success of the collapse prevention system. In most of the buildings we studied, the reserve lateral strength significantly reduced the probability of collapse. For example, CPS with half of the connections for gravity (shear tab) and half

Figure 2. Loose linkage and telescoping brace the collapse prevention mechanisms.



a. Loose linkages



b. Telescoping brace

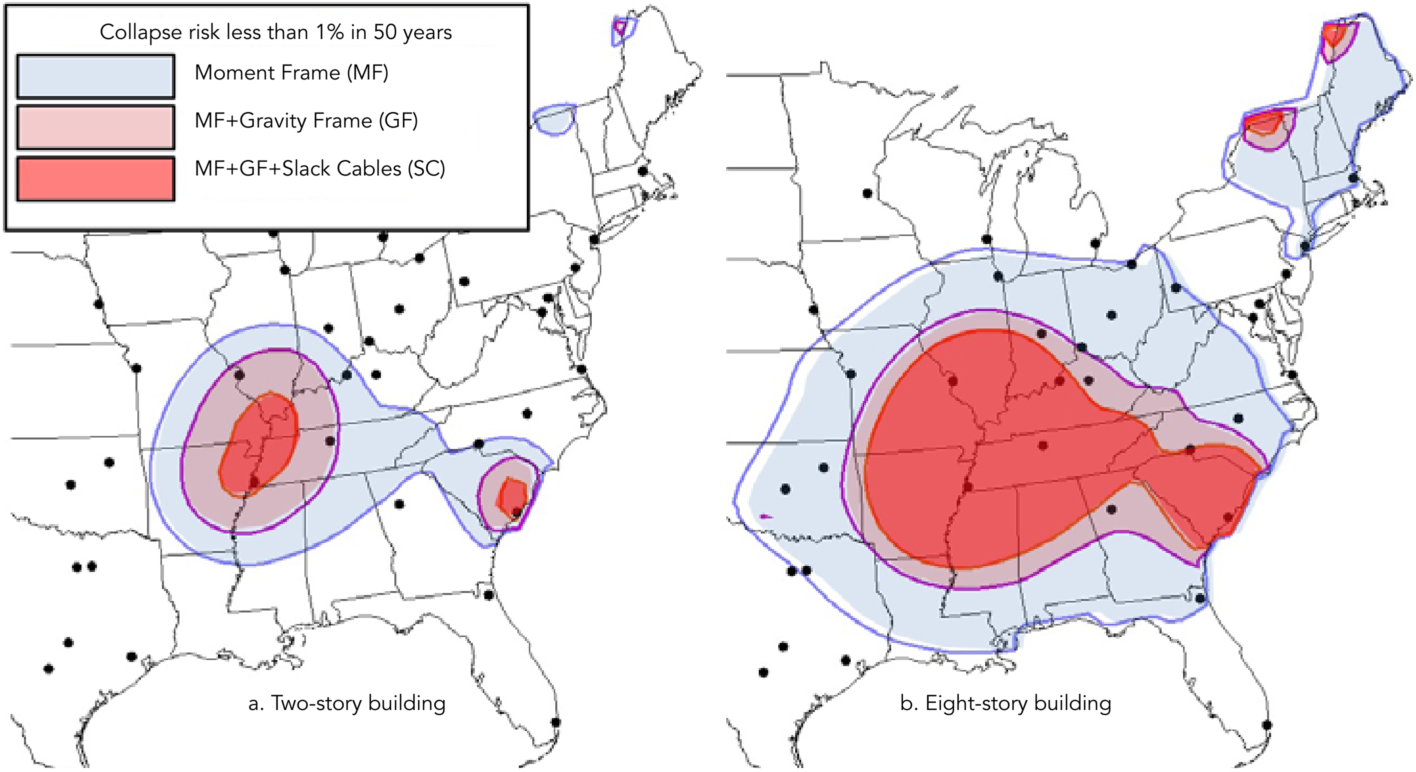


Figure 3. Collapse safety of a steel moment-frame building employing collapse prevention system.

for lateral (directly welded flange steel moment frames not specifically detailed for seismic resistance, or R=3) passed the FEMA P-695 criteria (probability of collapse less than 10% given MCE ground motions) up to the minimum of Seismic Design Category (SDC) D. CPS using steel moment frames were adequate for many regions in the central and eastern U.S. (Figure 3), and improved collapse safety was predicted for CPS using special steel moment frames.

The CPS concept is equally relevant—and perhaps more attractive—for repairing and retrofitting existing buildings. An important advantage in using CPS for rehabilitation (compared to a traditional retrofit) is that collapse prevention mechanisms can be deployed into the gravity system and don't need to be part of the main lateral load resisting system. A related advantage is that the CPS concept has less reliance on added deformation capacity, a key factor in older construction.

Research is still in the early stages, and essential aspects related to the design and behavior of CPS need to be addressed before implementation. Looking forward to the next stage of our research, we are planning to flesh out the details on the proposed collapse prevention mechanisms and their connecting elements. We'll investigate the demands imposed on the gravity framing (such as increased base shear forces) as well as conduct experimental testing of collapse prevention mechanisms.

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