SUMMARY: GREATER STRENGTH AND STIFFNESS PRODUCE BIG BENEFITS BUT COST LITTLE

One simple approach to making new buildings more seismically resilient—less likely to be damaged and more likely be usable after an earthquake—is to design them to be stronger and stiffer than the building code requires for life safety. A stronger building is less likely to collapse or be red- or yellow-tagged. A stiffer building is less likely to suffer costly nonstructural damage (cracks in partition walls, broken windows, etc.) that could render the building nonfunctional. (Stiffness can aggravate damage to poorly installed equipment on upper floors, but proper anchorage and bracing prevents most of that.) Some U.S. buildings are already built 50% stronger and stiffer than their neighbors to better ensure that they remain functional after an earthquake. On average, greater strength and stiffness costs surprisingly little, about 1% more construction cost (which translates to about ½ % increase when one adds land value to purchase price) for 50% greater strength and stiffness. How do we know that?

The part of a new building that resists earthquake forces only accounts for about $2 of every $100 of construction cost. Thus, a 50% increase in that $2 part only adds about $1 per $100. The 1% figure is supported by studies for the National Institute of Standards and Technology and for the CUREE-Caltech Woodframe Project. It also agrees with the judgment of leading earthquake engineers. The small incremental cost also makes sense when we realize that the seismic strength of new buildings can vary by a factor of 3 over the space of 100 miles, without anybody noticing its effect on purchase price.

Stronger and stiffer buildings produce quantifiable benefits to offset the added costs. The US Geological Survey’s HayWired scenario estimated that building all new buildings 50% stronger and stiffer than the building code requires would reduce the number of collapsed, red-tagged, and yellow-tagged buildings by 3/4ths in a large metropolitan earthquake in Northern California. The National Institute of Building Technology’s study, Natural Hazard Mitigation Saves, shows that every $1 of additional cost to make new buildings stronger and stiffer saves society $4 on average in the long run, and that it is cost effective to exceed code requirements over much of the United States. The same study shows that it can be more cost effective to build even stronger and stiffer—2 to 3 times code level—in some parts of the country. Not only does it appear to be inexpensive to design new buildings stronger and stiffer, it appears costly not to do so.

LAND VALUE CAN REPRESENT HALF OR MORE OF PURCHASE PRICE

That earlier statement about land value cutting the 1% increase to ½ % bears some explanation. Much of the cost of a new building is just the cost of the land. In the San Francisco Bay Area, for example, where a building might cost $250 to $300 per square foot to build, housing can cost $800 per square foot to buy, triple the cost of construction, as shown in Figure 1. Where the construction cost is half the purchase price, as is fairly common, an increase of say 1% to the construction cost adds ½ % to the purchase price, because the land price doesn’t change when you build the building to be more resilient. That is, for every $200 of purchase price, if the building...
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costs half of that, the building costs $100 to build. A 1% increase in construction (1% of $100) adds $1 to the $200 of purchase price—an increase of ½ % of the $200.

How can such a large increase in strength and stiffness cost so little? Because only a small part of construction cost goes into seismic strength. Most of the cost of construction (about 2/3rds) is for carpets, windows, plumbing, lighting, paint, and other nonstructural components that don’t contribute to strength or stiffness. See the pie chart in Figure 2, drawn from a commonly used construction cost manual [2]. About 17% goes to the construction contractor for overhead and profit. About 8% pays for the labor involved in building the structural parts of the building (such as the beams, columns, floors, and structural walls). The rest (about 8%) goes into the structural materials (buying the concrete, steel, and so on). Of that 8%, only 2% goes into the part of the structural system that resists earthquake forces. One makes a building stronger and stiffer by building bigger columns, using larger rebar, and generally increasing that last 2%. So, making a building 50% stronger and stiffer might increase that 2% by half again, meaning about a 1% increase in construction cost. Remembering that land is half the purchase price, that 1% increase in construction cost might equate with a ½% increase in purchase price.

OTHER STUDIES FOUND SIMILARLY SMALL COST OF LARGE STRENGTH INCREASES

Cost manuals like the one used to create the pie chart in Figure 2 give generalities—square-foot costs for kinds of buildings nationwide. What do we know about making particular buildings stronger and stiffer? The National Institute of Standards and Technology (NIST) examined the cost of making six particular buildings in the central United States comply with a newer building code (Figure 3). The authors found that the newer code required the buildings to be about 60% stronger than the older code required. Adopting the newer code added between 0% and 1% more construction cost (i.e., about 0 to ½ % more purchase price). In another study for the Federal Emergency Management Agency, engineers thought about
how much more it would cost to build a woodframe house (Figure 4) strong and stiff enough to be immediately occupiable after an earthquake, above and beyond what the code requires for safety. They found an added construction cost of about $7,000 for a 2,400-square-foot house, about $10,000 in current dollars. The median California house costs about $600,000. In the San Francisco Bay Area, the median home purchase price is over $1 million [3], so the greater strength amounts to about 1% of the purchase price.

ESTIMATES AGREE WITH THE JUDGEMENT OF LEADING EXPERTS

Do all these calculations pass the sniff test? I asked four leading earthquake engineers (Figure 5) what they thought it would cost to build new buildings 50% stronger and stiffer than the code required. They individually estimated figures on the order of 1 or 2% more construction price, with the caveat that some buildings might require big changes to design that could cause bigger jumps in cost, but again, the same order of magnitude as described above.
WE DO THIS ALL THE TIME AND NEVER NOTICE

One more observation tends to prove that, not only is the cost very small, but is highly practical. In a sense, we do this all the time without noticing the marginal cost of stronger, stiffer buildings. We design new buildings based on how far they are from nearby faults, how active those faults are, and a few other factors [6]. Those factors change over relatively short distances, so a new building on the west side of San Francisco (mapped design shaking of 2.4g in Figure 6) must be 50% stronger and stiffer than an identical-looking building on the east side, 7 miles away (1.5g). It has to be about twice as strong as an identical building in Dixon, California (1.2g), about 60 miles away, and almost 3 times as strong as one in Sacramento, 80 miles away (0.8g). And yet nobody notices the added cost to resist earthquake loads, perhaps because those costs are trivial compared with other market effects.

GREATER STRENGTH, STIFFNESS, AND DETAILING GREATLY REDUCE BUILDING IMPAIRMENT

We can quantify the benefit produced by greater strength and stiffness. The US Geological Survey’s heavily peer-reviewed HayWired Scenario [7] found that a 50% increase in design strength could reduce building impairment in a large metropolitan earthquake by 3/4ths, as shown in Figure 7. In that study, it was imagined that every building in the San Francisco Bay area could be replaced by a new, code-compliant building before a magnitude-7.0 earthquake occurred in the Hayward fault in the East Bay part of the region. The number of collapsed buildings would be relatively modest, but when one adds the number of red-tagged and yellow-tagged buildings, nearly 1 in 4 buildings would be impaired in some way. If that building stock were 50% stronger and stiffer than the code requires, the figure would be more like 1 in 20.

Designing new buildings to be stronger and stiffer than the building code requires appears to be cost effective throughout much of the United States, saving $4 on average per $1 additional construction cost, in terms of reduced future property losses, business interruption expenses, indirect economic consequences, urban search and rescue costs, and avoided deaths, injuries, and instances of post-traumatic stress disorder [8]. In some places, it can be cost effective to build new buildings up to 3 times as strong and stiff as the building code requires. The benefit-cost ratio reaches 8:1 (Figure 8).

Although greater stiffness can aggravate damage to poorly installed equipment on upper floors, better detailing can prevent most of that damage, by ensuring that all fixed equipment—mechanical, electrical, and plumbing—be anchored to the structure, and that tall or overhead equipment, suspended ceilings, and furnishings be braced against sway and overturning.
RESILIENT BUILDINGS WOULD NOT DRY UP OR DRIVE AWAY DEVELOPMENT

Builders and developers tend to assert that to increase the price of construction could reduce affordability and drive development to nearby areas that do not have costlier buildings, a sort of hidden cost not reflected in the 1% increment. The City of Moore, Oklahoma, provides a test for that assertion. After three fatal tornadoes in 15 years, Moore raised its design standards with a 50% increase in design windspeed over the level required by the local code at the time. (A 50% increase in windspeed equates with a 125% increase in strength, because of the way windspeed relates to pressure, force, and design strength.) The local change in code increased construction costs on the order of 1%, but had no effect on home prices or sales [9]. It seems reasonable to expect that the same thing would happen, or rather, not happen, if buildings in earthquake country were made more resilient. Another hidden benefit: because resilient buildings require slightly more construction material, they would add long-term jobs to satisfy demand for additional concrete, steel, and other structural materials.

CONCLUSION: WE CAN AFFORD RESILIENT BUILDINGS

The bottom line: society can afford resilient buildings. The current building code only aims to assure a reasonable degree of life safety, not to assure that we can reenter our buildings after strong shaking. Thus, it protects our lives but not our livelihoods. A simple option to construct a resilient building stock is to build new buildings significantly stronger and stiffer than the building code requires. Doing so would greatly reduce the consequences of a large earthquake, would save more than it cost throughout much of the U.S., and would only add on the order of $0.50 for every $100 of purchase price. That is a little like buying a $4.00 cup of coffee and getting a reusable metal cup for an additional two pennies. If your coffee house offered that deal, would you take it? If you owned the coffee house, could sell the metal cups for $0.02 at a profit, and the cafe across the street did not offer the same deal, would you use the deal to your competitive advantage? I would.

REFERENCES CITED

[1] Trulia.com
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