The Impact of Material Selection on the Resilience of Buildings

A White Paper by the
American Institute of Steel Construction
April 2017

Executive Summary

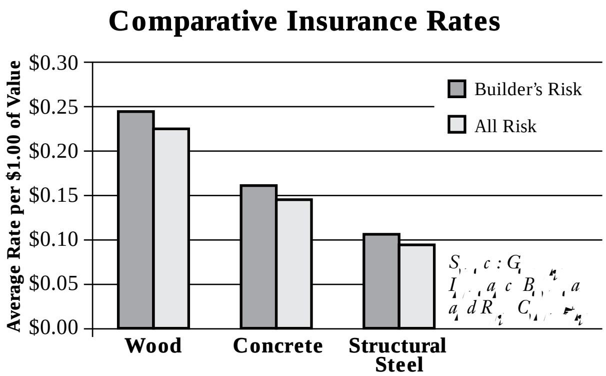
Resilience is the ability of an object or system to absorb and recover from an external shock. The material selection for a building's structural framing system impacts the resilience of the structure by reducing the cost of the risk associated with the ability of the structure to absorb and recover from the stress of an extreme event. Of all the materials used for structural framing systems, structural steel has demonstrated the greatest level of resilience relative to extreme events. This is veri ed by signi cantly lower Builder's Risk and All Risk premiums in the current insurance market for structural steel framing systems compared to concrete and wood. The reasons for these lower rates and the greater resilience of buildings built with structural steel is structural steel's inherent durability, strength, elasticity, non-combustibility, and resistance to decomposition. It also is helped by the capability of structural steel framing systems to resist extreme loads, be rapidly repaired, and adapt to changing structural requirements.

How can resilience be quanti ed?

Addressing resilience in building design is like purchasing insurance: you hope you don't need it but you're grateful if you ever do...[1] The difference is that instead of buying insurance throughout the life of a building to cover the risk of an extreme event, you design for resilience up front. And the result is that a building is better able to recover from an extreme event, be it natural (such as an earthquake or hurricane) or human induced (such as a terrorist attack or re).It might seem that quantifying that risk and those damages would be dif cult. It is not. Insurance companies regularly assess the loss records of buildings subject to both anticipated and extreme events. It is from those actuarial studies that insurance rates are set. For a given set of risks, a lower rate means less damage and a lower cost of repair. For the same building in the same location framed with different building materials, current insurance rates per $100 of value in today's market for Builder's Risk (insurance insuring the building during construction) and All Risk (insurance purchased by the owner insuring the building after occupancy) will be in the following ranges[2]:

	Builder's Risk During Construction	All Risk After Occupancy
Wood	$0.22 – $0.27	$0.20 – $0.25
Concrete	$0.14 – $0.18	$0.13 – $0.16
Structural Steel	$0.08 – $0.12	$0.08 – $0.11

Obviously, these rates will change based on project location and the particular risks associated with that locale or if the project has a specialized feature or aspect. But the general trend is the same. Insurance rates for wood buildings and concrete buildings are 2.3 and 1.5 times higher, respectively, than for structural



steel framed buildings. The difference is not the level of risk to the building from an extreme event, but rather the resilience of the building in responding to that event.

For a building valued at $100 million, the savings in insurance costs over a 50-year period would be $6.75 million for a structural steel framed system compared to a wood framing system.

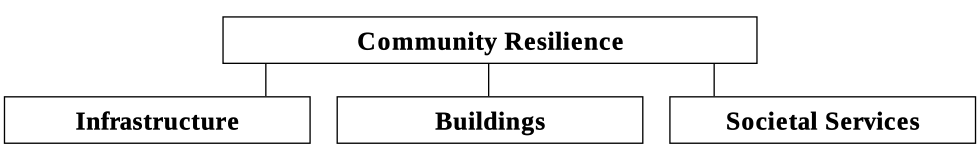
Why? The structural steel system is simply more resilient.

What is resilience?

Resilience is the ability of an object or system to absorb and recover from an external shock. A simple concept, but for today's design and construction professional resilience has taken on an increased level of importance and a broader context. Resilience has become the new buzzword supplanting the past decade's focus on sustainability. For some the discussion of resilience focuses on the resilience of a community to be able "to withstand or bounce back quickly following major disruptions ensuring that critical infrastructures have continuity of service (especially water, energy, transportation and communication lifelines); emergency services; and local governance."[3] Inherent in that de nition is ability of critical infrastructure components to be resilient in their own right maintaining or rapidly recovering functionality from disruptive events such as earthquakes, intense storms, coastal ooding or terrorism.[4]

At the same time, all of the buildings in the community must be able to provide occupant safety during the event and a some of those building must be able to continue providing critical services. In essence, resilience is the ability of a community, an infrastructure system or a building to anticipate, prepare for and adapt to changing conditions, and withstand, respond to and recover rapidly from disruptions.[5] It is de ned by the 4R's—robustness, resourcefulness, recovery and redundancy.[6]

Community resilience is built on the building blocks of its infrastructure, buildings and essential societal services such as police, re, health and governance.



Any discussion of resilience becomes more complex when the discussion extends beyond the three building blocks of community sustainability to extreme events, often referred to as "stressors" that need to be accounted for. *[illegible]* such as hurricanes, tornados, wildfires, earthquakes, flooding and tsunamis are generally included, yet not all of these stressors have the same likelihood of occurrence in every community; some may never occur in some communities. Events resulting from *[illegible]* including arson and terrorism also need to be considered. In some cases *[illegible]* with no direct natural or human cause such as the faulting of an electric grid or the overloading of a communications gateway are included. And finally the anticipation of *[illegible]* such as increased storm intensity, elevated water levels and increased snow loads driven by global climate change may also need to be taken into account. Clearly, any discussion of resilience is a multi-dimensioned challenge combining discrete components, stressors, risk assessments and future trends.

The result is that every group discussing resilience comes to the topic with its own perspective, develops its own definition, sets its own priorities and drives the discussion down a different path. Perhaps the definition of resilience developed by the Rockefeller Foundation summarizes resilience best by stating "resilience means different things across a variety of disciplines, but all definitions are linked to the ability of a system, entity, community or person to withstand shocks while still maintaining its essential functions. Resilience also refers to an ability to recover from catastrophe, and a capability of enduring greater stress."[7]

How does framing system selection impact resilience?

So, why is the cost of risk less with a structural steel framed building compare to buildings framed with concrete or wood? What does that difference mean to an owner preparing to build a new building or to an architect or structural engineer selecting and designing the structural framing system of a building? And how does the demand for structural resilience balance with the inevitable consideration of cost? Simply put it means that selecting a structural steel framing system provides the greatest ability to withstand, respond to and recover rapidly from extreme events in a cost effective manner based on the level of anticipated risk.

At the same time the resilience of that structural framing system needs to take into account the underlying resilience of the material composing that framing system.

Building Resilience
Structural System Resilience
Material Resilience

Material Resilience

When the resilience of a material is assessed the primary attributes of the material must be evaluated. For a structural framing material like structural steel, concrete or wood these would include durability, strength, elasticity, combustibility and resistance to decomposition.

Durability is the ability of the material to withstand outside forces in a manner which results in minimal wear, fatigue or damage. Of the major building materials wood was ranked last in durability in a survey of 910 design and construction professionals conducted by FMI.[8] Both concrete and steel were rated highly with steel's durability considered its leading benefit. Durability was topped only by fire resistance as wood's leading weaknesses.

Strength – Steel is the strongest of the common framing materials. The design strength of most hot-rolled structural steel sections in use today is 50 ksi (50,000 psi) in both tension and compression with some common special applications using sections with strengths higher than 70 ksi. Compressive strength for concrete is typically between 3 ksi and 5 ksi with some applications calling for high-strength concrete with compressive strengths as high as 15 ksi. Concrete tensile strength averages about 10% of concrete's compressive strength or in the range of 0.5 ksi.[9] The weakness of concrete in tension requires the addition of reinforcing steel in a building's beams and columns. The compressive strength of wood varies by the variety of wood, moisture content and whether the load is applied parallel or perpendicular to the grain of the wood. Hardwoods have compressive strengths parallel to the grain in the range of 7 ksi to 10 ksi (1 ksi perpendicular to the grain) while softwoods range from 5 ksi to 8 ksi parallel to the grain (under 1 ksi perpendicular to the grain). The tensile strength of wood perpendicular to the grain averages about 1 ksi. While wood is relatively weak in tension perpendicular to the grain, it is strong in tension parallel to the grain exhibiting strengths in the range of 10 ksi.[10]

The fact that the compressive and tensile strengths of structural steel are identical is a major factor in the ability of a structural steel framing system to resist and respond to extreme events. In an extreme event unanticipated loads are often experienced by the structure. In many cases this is not just an increase in an anticipated load but rather the structural member unexpectedly transitions from being in compression to being in tension. Steel's equal ability to handle compressive and tension loads helps to mitigate any failure that may result from this condition. In addition, the actual strength of the structural steel exceeds the stated minimum compressive and tensile strengths of the specified grade providing additional strength to handle unanticipated loads.

	Compressive Strength		**Tensile Strength**	
	Parallel to Grain	Perpendicular to Grain	Parallel to Grain	Perpendicular to Grain
Hardwoods	7 – 10 ksi	1 ksi	10 ksi	<1 ksi
Softwoods	5 – 8 ksi	1 ksi	10 ksi	<1 ksi
Concrete	5 ksi (High Strength 15 ksi)		0.5 ksi	
Structural Steel	50 ksi (as high as 70 ksi)		50 ksi (as high as 70 ksi)	

Structural framing systems can be designed to satisfy building code requirements using structural steel, concrete and wood. The central purpose of building code provisions is to provide short-term human survivability and safety in the event of an extreme event. The *International Building Code* in Section 1604 even includes enhanced designed requirements and integrity checks for high-rise buildings in risk category III or IV.[15] In those cases structural integrity is evaluated independently, not in combination with other effects and deformations are allowed as long as failure does not occur. The goal is to provide for the redistribution of loads in the event of damage. A competent structural engineer can accomplish this using structural steel, concrete or wood. But the question isn't whether those design goals can be accomplished using any of these materials, but the efficiency of using that material in the design, the cost of the system, the level of additional redundancy gained by the system and the ease and speed of repair if the structural system is damaged in an extreme event.

It is not an efficient use of building materials if addressing the design requirements of high-risk buildings requires a bunker style solution necessitating significantly increased material quantities. Increasing the mass of a structure, particularly a concrete structure, to address the challenges presented by extreme events is not an efficient solution. In contrast, structural steel supports a multitude of design approaches and innovative systems that address the challenge of resilient design from a technical rather than an increased mass perspective. Steel provides multiple options for lateral load resistance in a highly ductile environment that allows adequate member deformation while still keeping access to critical services intact and operational.

The use of systems with specially designed connections and buckling restrained braces as

Building Resilience

The resilience of the framing material and the selection of a structural framing system using that material contribute directly to the resilience of the building. Additional factors not related to the structural frame of the building also impact the overall resilience of the structure and in some cases the selection of the structural framing material can benefit those factors.

For instance, in an area at risk from flooding, hurricanes and tsunamis it may not be possible for the building to be located above the floodplain. The building can be built with the occupied floors elevated above the flood level. This can be accomplished by using slender members to create stilts to support the building or designing a lower level to function as a garage or utility space where the flood waters can pass through without harming the structure or any contents. As discussed previously, structural steel is the ideal framing material for such a system.

To fully appreciate the required resilience of a building is not only to assess the level of damage and the cost of repairs, but also the amount of time required to return the building to functionality. The required time to return to functionality is a function of the criticality of the services provided in the building and should be taken into account in the initial design of the building. The return of a building to functionality may require the repair of the structural system, the replacement of structural components and the temporary removal of portions the structural frame to gain access to other building service components that may need to be repaired or replaced. Unlike concrete framing systems that would typically require demolition and replacement or wood systems that face the challenge of replacing numerous structural members after a flood or fire, structural steel can be strengthened in place through the use of doublers and stiffeners, structural members can be added and beams can be penetrated to allow the addition of other services. And this can be done using materials that are readily available through a network of local steel service centers and fabricators.

Community Resilience

Community resilience is the ability of the community to withstand the stress of an extreme event. Community resilience is a combination of infrastructure, building and societal resilience. As such, the selection of the material for a structural framing system of a particular building with a specified level of serviceability may seem rather distant from the community as a whole. It is. Yet, the proper selection of building materials does contribute to overall community recovery and performance. This is probably no more evident than in the area of waste management.

Extreme events that impact an entire community rather than just a single building generate significant amounts of waste of which the majority is wood. Wood waste will be either burned or landfilled. While some wood waste is reused or recycled in the normal construction cycle, it is most likely that the wood waste resulting from an extreme event will not be suitable for reuse. Burning or landfilling wood releases greenhouse gases into the atmosphere. Burning also generates particulate matter harmful to human health.[18] Landfilling requires sufficient landfill volume to be available to handle the increased flow of waste. While concrete may be crushed and down-cycled for use as road base, it is also often landfilled. Structural steel on the other hand is a fully recyclable material with an active market for its sale. It will not end up in landfills, but be returned to steel mills for recycling into new steel products. It will not be a burden on the community as the community seeks to rebuild. Deconstruction of a structural steel building can often occur at no cost to the building owner as the demolition contractor will offset their costs with the income gained from the sale of the steel. This is not true for concrete framed buildings where a greater percentage of the waste flows to a landfill and particularly not true for wood framed structures where nearly all the waste must be landfilled.

When structures have to be renovated, remodeled, or rebuilt after a devastating event, utilizing a material that can be reused or recycled is beneficial from a cost, convenience and sustainable standpoint. Materials, such as structural steel, that can be quickly retrofitted, replaced and eventually recycled make a positive impact on the environment and community. 100% of deconstructed steel structures can be recovered and recycled for the production of new steel (domestically produced structural steel has an average recycled content of 93% and a recovery rate of 98%).

There is also a balance point when it comes to sustainable design. The concrete industry has long argued that the load requirements in the building codes be increased to minimize the level of damage caused by extreme events and thereby minimize the amount of waste generated and replacement material required. While this may seem reasonable on the surface, there is a potential unintended consequence. By increasing the load requirements significantly, more material will be required to meet those requirements, particularly when a concrete framing system is used. Extreme events impact only a small percentage of structures, yet increasing the load requirements for buildings will impact all buildings. If this bunker mentality is adopted all buildings would need to be overbuilt resulting in greater construction costs and more material being required to build these buildings than would have been required to reconstruct the buildings damaged in an extreme event. The solution is not to build bunkers but to use resilient materials to address the challenge of resilient design from a technical rather than a mass based perspective.

Community resilience also assumes that some buildings will be used to provide housing and work areas for the population even before energy based infrastructure services are reestablished. This requires these buildings to be able to maintain passive survivability during this period by maintaining livable temperature levels. It has been shown that structural steel buildings with concrete floor and wall systems designed to maximize the thermal capacity of the building and proper detailing of areas where thermal bridging may occur can effectively address the issue of thermal capacity.[18]

End-of-Life Scenarios

What's the Bottom Line?

Structural steel contributes the most of any material you can choose to the resilience of the structural framing system, the building supported by that system and the community of which the building is a part.

It is not surprising that insurance rates for structural steel framed buildings are less than the rates for comparable wood and concrete framed buildings facing the same level of risk from extreme events. Compared to other building materials structural steel is a highly resilient material that can be effectively used in the design and construction of structural framing systems that are also highly resilient. The potential savings in repair costs and the rapidity of that repair reduces the exposure of the insurance carrier resulting in the lower rates.

All levels of resilience are often discussed in terms of the 4R's—robustness, resourcefulness, recovery and redundancy. Structural steel, structural steel framing systems and buildings supported by structural steel framing systems rank highly in each of those categories. Structural steel is a strong, durable material that provides for innovative, ef cient structural systems with inherent redundancy that can be rapidly returned to service following an extreme event. A resilient outcome for the building owner and the community in which the building is located that is superior to that of wood or concrete.

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