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# SEISMIC DESIGN AND THE INTERNATIONAL CODES - THE SOUTH CAROLINA EXPERIENCE -

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## SUMMARY

The State of South Carolina was the first major jurisdiction to adopt the 2000 *International Residential Code*. Immediate resistance from the homebuilders' associations resulted in a moratorium being placed on all seismic and wind-borne debris provisions of the Code. This was viewed by the engineering community as irresponsible and dangerous in light of South Carolina's established hurricane and seismic hazard exposure.

This paper discusses aspects of the new International Codes series directly relevant to South Carolina residential construction practice and documents efforts to relieve the resistance to the codes and thus affect their full adoption. Issues raised in this paper offer an insight into the unique situation where significant building code changes are made without the building community being educated as to the reasons and basis for the changes. Such cases may continue to arise as seismic hazard determination is continually refined.

## INTRODUCTION

The State of South Carolina was the first major jurisdiction to adopt the 2000 International Code series. The 2000 Code series was adopted May 24, 2000 to be fully implemented by July 1, 2002. The *2000 International Residential Code* (IRC) [1] replaces the regional Southern Building Codes Council International (SBCCI) *1997 Standard Building Code* (SBC) [2], and the national Council of American Building Officials *1995 CABO One and Two Family Dwelling Code* (CABO) [3] for residential construction.

Shortly after its statewide adoption, a coalition of interests, headed by the homebuilders' associations successfully lobbied for a moratorium to be placed on all seismic and wind-borne debris provisions of the IRC. Additionally, some jurisdictions opted out of adopting the new code series altogether. A few progressive jurisdictions, some of those most effected by seismic and wind events, were able to adopt the

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complete 2000 International Code series without the moratorium, although not without considerable resistance from area homebuilders.

As of this writing, it is expected that South Carolina will adopt the 2003 International Code series as of July 1, 2004. It is still unclear whether the seismic and wind-borne debris moratorium will be continued.

In an effort to alleviate the resistance to the adoption of the International Codes and to develop enough understanding and support to lift the seismic and wind-borne debris moratorium, the South Carolina Department of Insurance undertook an activity to develop a prescriptive multi-hazard *Commentary* [4-5] for the IRC. This paper documents some of the activities and observations made during the preparation of the *Commentary*.

The International Code Series is a collaboration of many code development organizations, in an effort to produce a code series which is uniform across the United States. As a result of this collaboration, there are several significant differences between the IRC and residential building codes previously in place in South Carolina. The IRC addresses design for natural hazards more aggressively than past building codes, requiring residential construction practices to shift to accommodate the new design criteria.

South Carolina is well suited to strict design criteria due to multi-hazard issues across the state. South Carolina's vulnerability to natural hazards results in the potential for large losses, recovery costs and mitigation costs. A building code which reduces the potential for damage will reduce insurance premiums, reduce potential personal loss, and reduce the need for federal aid in the event of a disaster – and most importantly, will save lives and property.

## SEISMIC AND MULTI-HAZARD VULNERABILITY OF SOUTH CAROLINA

The State of South Carolina (SC) is a unique multi-hazard environment in North America. In addition to Atlantic hurricanes and associated wind and flood hazards, the Middleton Place-Summerville Seismic Zone (MPSSZ) also results in the entire state being a moderate to high seismic zone. Nowhere else in North America is a region as susceptible to natural hazards. The susceptibility of South Carolina to natural hazards is well documented through the historic record. A brief summary of this vulnerability is presented in the following sections.

### Overall Vulnerability

Vulnerability is characterized as a combination of possible hazards, resistance to those hazards, risks to life safety, and financial impacts associated with an event. South Carolina, especially the coastal region, is subject to multiple natural hazards including earthquakes, high winds from hurricanes and tropical storms, and flooding. A discussion of hazard exposure in South Carolina is presented below. Coastal areas in South Carolina are prone to extensive property damage, as a result of a number of factors. Obvious factors are the presence of multiple natural hazards themselves and the common practice of building in coastal areas which are prone to hurricanes, and in the case of the Charleston area, earthquakes. Among the less obvious factors are the inadequacies of past building codes (meaning a large number of homes are not compliant with the current code and will require retrofit upon substantial improvement) and the tendency to design for one hazard under the assumption that it will provide protection for other hazards as well.

### Earthquake History

The probability of earthquakes in the Southeastern United States is surprisingly high, and earthquakes are quite common in South Carolina. Although most earthquakes occur at the boundaries of tectonic plates, intra-plate earthquakes, the type experienced in South Carolina, can also occur. Two major examples of this type of earthquake are the New Madrid, Missouri earthquakes of 1811-1812 and the Charleston, SC earthquake of 1886. The Charleston area alone has experienced more than 60 earthquakes in recent geological history [6]. Although the Charleston area is the most vulnerable region (about 70 percent of South Carolina events occur in the MPSSZ, north of the Charleston peninsula), the entire state is at risk from earthquakes. South Carolina experiences 10-15 minor earthquakes annually, though they are rarely noticed [7]. It has been reported [8] that "There is a 40 to 60 percent chance of a magnitude 6 earthquake somewhere in the central and eastern United States within the next 30 years."

*Great Charleston Earthquake of 1886*

Charleston SC experienced an earthquake at 9:51 p.m. on August 31, 1886, having an estimated intensity of X on the Modified Mercalli scale (estimated Richter magnitude 7.3 – 7.6). Seven aftershocks occurred within 24 hours of the first shock. Damage is estimated at $23 million (1886 dollars) for what is known as one of the worst earthquakes in United States history, causing the greatest damage ever in the Eastern United States. The death toll is estimated between 60 and 100, with countless injuries as well. Von Hake [9] reports:

> "Within a radius of 160 kilometers, the cities of Columbia, South Carolina and Augusta and Savannah, Georgia, also experienced damage. The total area affected by this earthquake covered more than 5 million square kilometers and included distant points such as New York City, Boston, Milwaukee in the United States and Havana Cuba, and Bermuda. All or parts of 30 states and Ontario, Canada, felt the principal earthquake.
>
> Two strong aftershocks were reported on October 22, 1886, and another on November 5. The first of these was felt (intensity VI) at Charleston, at Atlanta and Augusta, Georgia, and at other towns. The second shock was intensity VII at Summerville which received significant damage from the August 31 earthquake. Another tremor caused intensity VI effects on November 5 at Charleston and was felt over the same area as the previous aftershocks. The total felt area covered approximately 78,000 square kilometers."

Evidence of damage from the 1886 earthquake can still be seen in Charleston today. Numerous other events having Mercalli Intensities greater than V have been recorded through the 20$^{th}$ century to the present day [9 and USGS records]. A consistent characteristic of these events is that they are typically felt over a relatively large geographic area often affecting the now major population centers of Charleston and Columbia SC, Charlotte, North Carolina and Augusta, Savannah and occasionally Atlanta, Georgia.

**Earthquake Hazard Vulnerability**

South Carolina's main vulnerability lies in the fact that historically, very few homes have been constructed with adequate earthquake protection. This vulnerability is perpetuated by the resistance to constructing new homes to meet updated seismic design requirements. Often, design earthquake loads are less than design wind loads, and no further seismic design or detailing is done. This approach is inappropriate because earthquake forces are very different from wind forces.

Several factors affect the vulnerability of South Carolina to earthquakes. First and foremost are the high levels of ground motion which are probable in the state. Current National Earthquake Hazards Reduction Program (NEHRP) maps (see Figure 1) of the maximum credible earthquake (MCE) ground motion for a rock site (Site Class B) and 5% critical damping in the Charleston SC area give peak ground accelerations of 1.66g and 0.47g for the 0.2 second and 1.0 second period spectra, respectively [10]. The MCE is defined as the event having a probability of exceedance of 2% in 50 years. Geology also plays an important role in South Carolina seismic vulnerability, affecting ground motion magnitude, attenuation and liquefaction potential. Most soils in the South Carolina "low country", the region surrounding the

MPSSZ, will result in a characterization of Site Class E and those that are liquefiable will be Site Class F. As a result, the spectral accelerations corresponding to the design basis earthquake (DBE) for 0.2 second and 1.0 second period spectra are as high as 1.0g and 0.75g, respectively. The DBE is defined as the event having a probability of exceedance of 10% in 50 years.

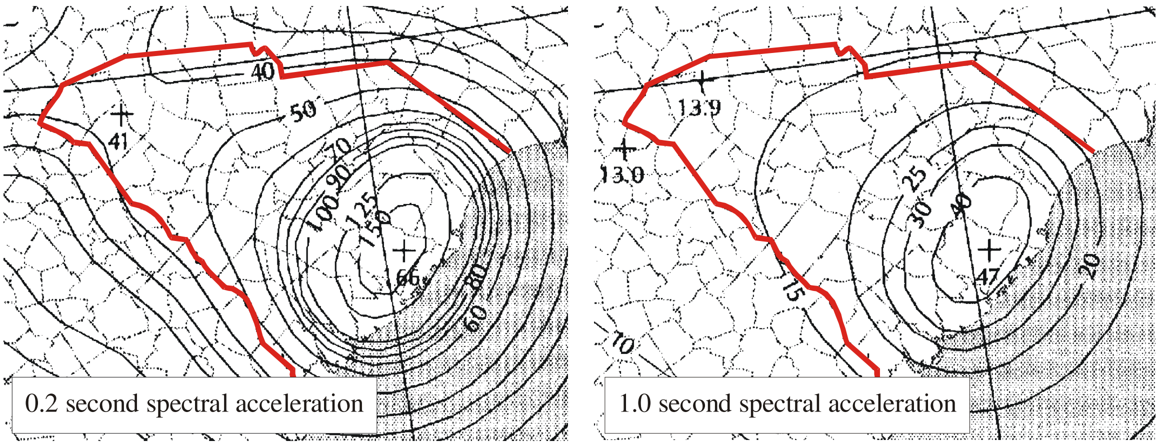


**Figure 1. MCE ground motion for South Carolina (5% of critical damping), Site Class B. [10]**

Beyond a HAZUS-based study [11] of the seismic vulnerability of South Carolina, little has been done to address mitigation of seismic risk in South Carolina. The study reported here reflects an isolated proactive activity focusing on improving the adherence to the seismic provisions of the International Residential Code [1].

**Relationship Between Maximum Credible and Design Basis Seismic Events**

Significant concern has been raised, particular among East Coast engineers, over the use of the NEHRP generated maps and the IBC procedure for determining design level ground motion. The design loads can be significantly greater than those considered previously.

The intent of the NEHRP/IBC seismic provisions is to develop a uniform level of risk against seismic hazard nationwide, regardless of the seismicity of the region. In so doing, it was determined that the maximum credible earthquake (MCE) shall be the event having 2% probability of exceedance in 50 years (2%/50). For regular building structures, the design basis earthquake (DBE) represents the event having a 10% probability of exceedance in 50 years (10%/50). These correspond to events having approximately 2500 and 500 year return periods, respectively.

NEHRP [12] recognizes a "seismic margin" of 1.5. This margin is intended to account for overstrength inherent in most structures. NEHRP reports that the seismic margin is incorporated as a 2/3 factor in IBC Equation relating MCE to DBE ground motion intensity. NEHRP, further reports that, with the exception of coastal California, the ratio of the magnitudes of the 2%/50 event to the 10%/50 event exceed 1.5. Therefore it was decided to develop design level seismic forces as being equal to 2/3 the 2%/50 event rather than simply employing the 10%/50 event directly. This results in conservative design level forces but a "uniform hazard exposure" when one considers the MCE (2%/50).

Based on existing seismic records and geophysical evidence, shown in Figure 2 [12], NEHRP reports that the ratio of the 10%/50 event to the 2%/50 event in San Francisco and Los Angeles is approximately 0.60, approximately the 2/3 factor. However, as one considers Central and East Coast seismicity, this ratio falls to 0.30 in New York City and 0.20 in Charleston SC and Memphis Tennessee. The implication of this is that application of the 2/3 factor to the mapped 2%/50 spectral accelerations results in design earthquake accelerations as much as 0.66/0.20 = 3.3 times greater than those actually corresponding to the 10%/50 probability. Thus, while there is uniform hazard exposure for the MCE, there is not a uniform hazard exposure for the design event nationwide.

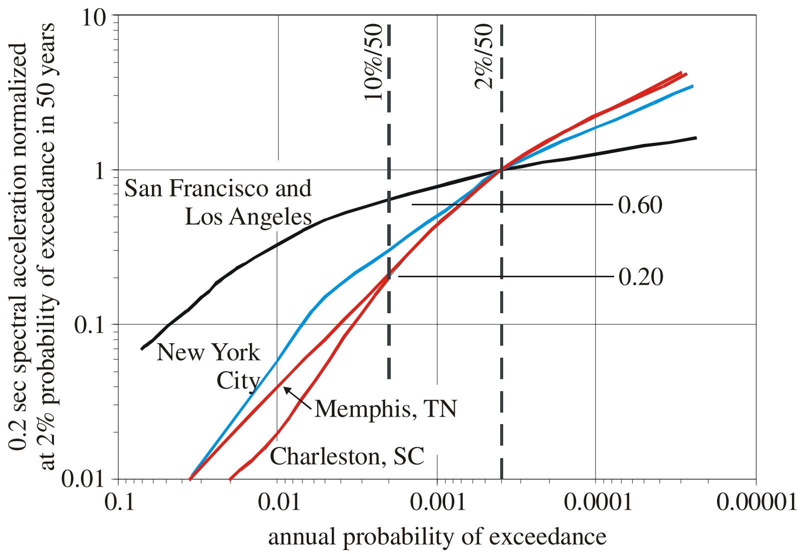


**Figure 2. Probability of normalized ground motion intensity for various locations across North America (adapted from FEMA 303 [12]).**

It is very important to understand the implications of this varied seismicity in the context of the I-Codes expressed goal of ensuring a uniform hazard exposure: The intent of the IBC is to design a structure at the 10%/50 level and verify that it satisfies collapse prevention performance criteria at the 2%/50 level. Therefore, it would be consistent to determine these two levels from appropriate maps directly and use them in design. Thus, in San Francisco, a structure would be designed for a 10%/50 event and verified at the 2%/50 level, a level approximately 1.7 times greater. In Charleston, however, although the design 10%/50 event may be determined to be 3.3 times lower than it currently is (2/3 times 2%/50) when determined from 10%/50 maps, to satisfy the uniform hazard exposure, the structure would still need to be checked for collapse prevention at the 2%/50 level, now 5 times greater.

In South Carolina practice, therefore, properly maintaining uniform hazard exposure criteria results in a relatively low seismic design force but a significantly greater maximum credible force under which the structure must not collapse. Current IBC practice results in a significantly greater design force than is strictly necessary, however, the relationship between the design and maximum credible forces remains reasonable.

Both paradigms present challenges and difficulties to the design engineer. While it may be argued that the present IBC requirements are overly conservative, the requirements of the consistent alternative will be very difficult, if not impossible, to achieve. The only way of practically addressing this issue is to actually re-examine the appropriateness of uniform hazard exposure in the context of East Coast seismicity.

**Wind Hazard Vulnerability**

South Carolina has almost 200 miles of coastline, all of which is vulnerable to the impacts of hurricane activity. Some of the hazards associated with hurricanes are severe winds, storm surge, increased rainfall and resulting flooding. Several factors affect the vulnerability of South Carolina to hurricanes. The primary factor is geography. South Carolina's coastal area accounts for a large portion of the overall area of the state, and the coastline is concave in shape. The effects of hurricanes (especially storm surge) are compounded by the concavity of the coast. The Eastern portion of South Carolina is relatively flat, with barrier islands and a wide coastal plain. The flat topography worsens windborne debris and flooding concerns. Code prescribed design wind speeds based on the maximum 3-second gust speed having a 50-yr mean recurrence interval are as high as 63 m/s (140 mph) in coastal South Carolina [10].

**Flood Hazard Vulnerability**

South Carolina is vulnerable to many types of flooding, including storm surge, flash floods, river inundation, and dam failure. Most severe flooding which occurs in South Carolina is secondary to another natural hazard such as a drought or hurricane, therefore the effects of flooding can be especially disastrous since they are combined with other hazards. South Carolina ranks sixth in the United States in the number of flood insurance policies held [13]. By contrast, South Carolina is ranked 26$^{th}$ in terms of total population [14] and 40$^{th}$ in terms of geographic area. Furthermore, there are far more homes vulnerable to flooding than flood insurance statistics suggest. There are 10240 square kilometers of floodplain in South Carolina, with over 150,000 residences vulnerable to flood hazards [13].

The relatively flat terrain of South Carolina typically produces floods which rise and fall very slowly, and cover a very wide area. The slow rise of these floods allows some time for proper preparation, but the damage occurs over a large area, and the long periods of time which the flooded areas remained inundated causes significant property damage, as well as intangible losses such as the suspension of business [13]. Coastal flooding is the most severe type of flooding experienced in South Carolina. The destructive force of coastal flooding is a combination of rising water levels, wave impact, erosion, and flood borne debris. The heavy rains associated with the storms which cause coastal flooding can also affect the river system, causing riverine flooding in addition to coastal flooding.

**Population Vulnerability**

Another factor influencing the vulnerability of South Carolina is population growth. The three fastest growing counties, experiencing between 64% and 94% growth from 1980 to 2000 [14], are those which also have the highest probability of experiencing a severe earthquake.

In addition to large population growth, coastal areas are seeing exponentially increasing property values. Increasing development in coastal South Carolina increases the probability of catastrophic loss in the event of an earthquake or hurricane. Coastal population growth places a great deal of high value property in harm's way and complicates situations associated with storm warnings and evacuation.

It is becoming more and more difficult to protect coastal communities. Hurricane evacuation decisions must be made long before accurate hurricane warnings can be issued, and it is difficult to ensure that the growing number of residents and summer visitors can be evacuated and placed in shelters during storm events. Additionally, a significant percentage of the coastal population is seasonal and has not experienced a hurricane. This population is less likely to handle preparations and response properly, ranging from evacuating in a timely manner to hurricane-proofing a residence. Earthquake preparation in South Carolina is untested at the emergency management level and nonexistent at the community level.

## INTERNATIONAL CODES APPROACH TO NATURAL HAZARD MITIGATION

Natural hazard protection in building codes differs from other design criteria in several ways. The principal difference between the development of design criteria to mitigate the effects of natural hazards versus design criteria such as those for resisting gravity loads, is the probabilistic nature of natural hazard load determination. Gravity loads are determined based on the design and occupancy of the structure. While a probabilistic approach is used to determine so called load factors, the variability is relatively well understood and residential structures rarely encounter gravity loads outside the predicted range. The loads are seen regularly in typical use of the structure, therefore the criteria are extremely well documented and accepted by the designer, contractor and homeowner. In contrast, the structure is rarely, if ever, subjected to the effect of high wind, earthquake and/or flood loads. Moreover, the probability of the occurrence of a particular natural hazard is based almost entirely on the location of the structure, independent of the structure's design and use. The same probabilistic approach is used to determine hazard risk for all types of structures to establish the so called "design event." The structure is then designed to withstand the design event experiencing an acceptable level of damage based on the importance and/or use of the structure. This concept is the basis of performance based design and is the underlying tenet of design for hazard mitigation, particularly seismic design.

**Performance Based Design**

Performance based design is typically a displacement based design method (traditional design methods are force based) defined by the *ICC Performance Code for Buildings and Facilities* [15] as:

> "An engineering approach to design elements of a building based on agreed upon performance goals and objectives, engineering analysis and quantitative assessment of alternatives against the design goals and objectives using accepted engineering tools, methodologies and performance criteria."

When used in structural engineering, the "performance goals and objectives" and "performance criteria" are generally measured in terms of displacements although this need not be the case. More generally, "performance goals and objectives" and "performance criteria" are stated as outcomes in the event of a hazard event such as "life safety" or "collapse prevention". Engineering practice and knowledge permits these generalized criteria to be translated to measurable engineering criteria such as building displacement.

The three main concepts which present themselves in the definition of performance based design are: 1) carrying the design through from concept to construction as an integrated process; 2) measuring and predicting performance under both common and rare load cases; and 3) involving the client (society) in decisions about the desired performance of the structure [16].

While the nature of the process is controlled by ideas rather than numbers, the actual design methodology relies on what the term "performance" means. From a structural standpoint, "performance is measured in terms of the amount of damage sustained by a building, when affected by earthquake ground motion [or other natural hazards], and the impacts of this damage." [17] The term performance has replaced the term behavior, implying that instead of designing a structure for certain loads and then predicting its "behavior", designers are now deciding how a structure should "perform" and designing the structure to respond to loads in this manner. In essence, the traditional design philosophy of "design-then-analyze" is replaced with "analyze-then-design."

The problem with pre-2000 building codes is that they "strive mainly to protect occupants from severe injury or death during a strong earthquake, not to prevent building damage." [18] From an economic, and therefore societal view, it is not enough to save lives. Rising construction costs, property values and society's expectations of mitigating losses, are fueling the push toward performance based design because many owners and insurers want their structures to exceed the standards set forth in building codes, and retain their structural integrity throughout an earthquake. Traditionally, if the serviceability limit state was exceeded, the structure may have to be demolished for safety reasons. This practice protects lives, but does nothing to prevent the huge monetary cost of a catastrophe since many buildings have to be demolished and rebuilt. Performance based requirements allow for a predetermined level of serviceability to be maintained following the design event if this is desired by the client [19].

The most important statement pertaining to the evolution of performance based design is "Society will set the performance objectives, and in the design process researchers and practitioners will have to find ways to fulfill them." [20] Designers and contractors do not have the power to decide what is best for society – they can communicate their needs, abilities and shortcomings and it is society's obligation to weigh these and establish "acceptable levels of performance" – the corollary of which are "acceptable levels of risk" – under the effects of particular hazards. The evolution of performance based design therefore is largely driven by forces outside the engineering community – lawyers, insurers, developers, politicians, and parents.

As codes incorporate performance based design concepts, the designer and builder become free to try new methods of design and construction, promoting the ingenuity which is so important in the fields of engineering and construction. Promoting the understanding of this implication is, however, difficult. This is particularly the case where building codes simultaneously provide a combination of performance based and prescriptive design concepts.

As with most engineering, a large amount of emphasis is placed on constructability and quality of construction. Due to the innovative nature of performance based design, the designers, contractors and inspectors are more heavily involved in construction than ever before. It holds true that "one of the important concepts in performance-based design is that the best designs are worth little if not properly executed during construction." [18]

### Performance Criteria in IRC

Although performance criteria are not specifically called such in the International Codes or in addressing new construction, they are, nonetheless, tacitly considered in the case of seismic design. The IRC [1] states that all hazards must be accounted for and "designed in accordance with accepted engineering practice." Natural hazards are to be clearly defined for each structure through the use of IRC Table R301.2(1), which requires all hazard information for a given site be provided and implies that all hazards be considered together to ensure all are properly addressed. Table R301.2(1) does not provide complete information required for design, but instead provides an overview of the hazards to be considered in design, simplifying decisions pertaining to which hazards must be designed for, and encouraging a performance based approach.

The IRC [1] (and the I-Code series in general) was developed with an emphasis on multi-hazard design. This is due in part to the International Code Council's (ICC) attempt to incorporate design criteria from most major model codes throughout the country, and also the Federal Emergency Management Agency's (FEMA) involvement in the development process. There are prescriptive requirements for both wind and seismic design, which are developed independently to ensure expected performance. The process of designing for a controlling load – wind or seismic, and simply checking that forces associated with the other have not been exceeded – has been eliminated. The IRC approach is to design for all hazards present, regardless of controlling factors – this is the cornerstone of multi-hazard design.

## RESIDENTIAL DESIGN FOR MULTIPLE HAZARDS

A common misconception in multiple hazard design is that a structure can be adequately designed based only on the load case resulting in the largest force effects. The interpretation is often that if wind loading produces the greatest magnitude lateral forces, there is no reason to consider (lower) seismic lateral forces any further. Differences in the way wind, seismic, and hydraulic loading affect a structure, however, must be taken into account.

Conflicting effects of hazard mitigation requirements on structural design are common. It is important to balance aesthetic and economic criteria with the criteria set forth by the IRC [1]. By establishing what changes can be made to the overall plan of the building and considering the effects of the relevant hazards, construction costs can be reduced, while complying with the desires of the homeowner.

Once the overall plan of the home is optimized for multiple hazard design, it is often necessary to employ specific mitigation measures for individual hazards. While intended to mitigate risk from one hazard, these measures can decrease a structure's resistance to other hazards (such as raising a structure on piles to mitigate flood or storm surge hazards).

In considering multiple hazards, it is not sufficient to consider only resisting forces. The expected performance of a structure when subject to these forces is also a concern. For example, design seismic forces are based on an event having a mean return period of approximately 500 years; design wind forces are based on a 50 year event and design flood elevations are based on a 100 year return period. Assuming a uniform hazard exposure, the expected performance of a structure subject to a design event should improve as the return period becomes shorter. For example, the level of structural damage expected for a design wind event should be relatively minimal, confined to damage to cladding and cladding support systems. The structural damage expected due to a design seismic event may be considerable, although not life threatening.

Although complex, this performance spectrum is what allows multiple hazard design to be considered in the first place. A reasonable approach is to provide all required design details for the most common hazard provided that these do not significantly impact the response to an as yet unconsidered hazard. Improvement and incremental details are then provided to satisfy the less common hazards. An example of this paradigm is the use of hurricane ties designed to also resist seismically induced shear forces.

## STATE OF PRACTICE AND IRC KNOWLEDGE PRIOR TO ADOPTION

Individuals in the construction industry in South Carolina were surveyed in early 2002 (prior to the mandated adoption date of July 1, 2002) to determine the current state of practice for residential construction in South Carolina [4]. The survey was intended to determine the familiarity of homebuilders and designers with the IRC [1], as well as to gauge how the document is being used. A secondary purpose of the survey was to determine how the residential construction community had reacted to the adoption of the new code. The survey was voluntary, and a random sampling cannot be assumed.

In general, the survey revealed a relatively well-informed residential construction community although this may simply reflect those willing to respond. Most respondents were aware of many issues associated with the adoption of the International Codes. Some significant concerns, however, were raised in the responses. These include:

1. A general animosity toward the new documents was apparent in about 20% of respondents. Others accepted the I-Codes reluctantly, while some welcomed their adoption.
2. Failure on the part of a number of respondents to understand that seismic and wind forces are different. A number of respondents clearly subscribed to the idea that "wind controls." This is erroneous since seismic details may still be required.
3. The potential of shutters or plywood covers to effectively mitigate wind-borne debris hazards is accepted by some respondents and scoffed at by others due to impracticalities associated with installing such appurtenances.
4. A few respondents correctly point out the need to educate the homeowner in the correct use of hazard mitigation measures. One respondent astutely points out the danger of suggesting that any

measure makes a home "hurricane proof": the homeowner may not evacuate thinking that they are protected.

5. At least one respondent has an incorrect (and potentially dangerous) understanding of return periods.
6. Many respondents point out the need for professional education. Some respondents admit (others demonstrate through their responses) that they do not understand a number of code provisions and their implications.

**State of Residential Construction Practices in South Carolina**

As in any locale, the quality of construction and the conformity with existing building codes and standards varies considerably. There are two major considerations which affect the inventory of South Carolina residential structures that bear comment.

As has been discussed, the code requirements, particularly for seismic design, have changed considerably over the last decade. This "raising of the bar" has the effect of making many existing structures noncompliant with current standards. While this may not be a critical concern, it does significantly impact the costs of renovation. In many jurisdictions, renovation totaling over a certain proportion of the building's value (often 50%) triggers a requirement, called "substantial improvement," that the entire building be brought into conformity with the current code or standards. This requirement is included in both the IBC [10] and IEBC [15].

Approximately 19% of South Carolinians, the largest percentage in the nation, live in "mobile homes." While the anchorage and foundation requirements for these structures fall within the scope of the IRC [1], they are often neglected or ignored. There is a certain irony that satisfying these code requirements effectively makes a mobile home immobile as the cost of moving the structure becomes prohibitive to the owner. Mobile homes are particularly susceptible to both seismic and wind damage and pose documented threats to their inhabitants. Mitigating the effects of natural disasters in South Carolina requires that the issue of mobile homes be addressed.

Finally, the uniformity of building inspectors across the state is uncertain. If uniform hazard mitigation is to be achieved, offices responsible for inspection need to have reasonable and uniform access to resources and the inspectors must have a relatively high and uniform level of continuously ongoing training.

## ADOPTION OF THE IRC

In December 2003, 42 months after initial adoption and 18 months after complete adoption of the International Codes, a survey of South Carolina building officials was conducted. The survey included all coastal jurisdictions and all major jurisdictions elsewhere in the state. A response rate exceeding 50% was achieved. Respondents report approval of approximately 7500 residential building plans since July 1, 2002. All of these should be compliant with the IRC [1]. The objective of the survey was to assess the success of the adoption of the IRC as recorded through residential plan approvals. The survey focused on cases where plans were not approved. In this manner, it is believed, lingering problems associated with lack of knowledge or understanding of the IRC could be identified.

As expected, the survey indicated that the overwhelming choice for residential construction in South Carolina is wood frame construction on continuous foundations, slabs or masonry piers. The majority of residential plans submissions were prepared by both a registered architect and engineer (30%), an engineer alone (29%) or an architect alone (21%). This observation is critical to one of the homebuilders' greatest objections to adopting the IRC; that it will necessitate an engineer's seal on every submission, raising the cost of residential construction. Anecdotal evidence suggests that there has been little difference in the distribution of those preparing residential plans for approval and that engineers have been involved in residential construction all along. Interestingly, when one considers only those designs that are not approved, engineers are proportionally more responsible for these.

Only about 5 responding jurisdictions (about 15%) report that the seismic provisions of the IRC are enforced in their jurisdiction. (These jurisdictions have received state approval to not adopt the moratorium on seismic provisions.) Despite this, respondents report that plan preparers have considered seismic loads in approximately 70% of plans submitted. It is understood that “consideration of seismic loads” ranges from complete calculations, analysis and design to simply determining the Seismic Design Category [1] and identifying this in IRC-required Table R301.2(1).

Considering both seismic and wind lateral loads, responding jurisdictions report that, in terms of magnitude, wind loads govern the lateral force design of the majority of residential construction in South Carolina. In about 20% of jurisdictions, building officials report that wind and seismic lateral forces are “usually about the same.” Statewide, more than 60% of building officials report that “if only one lateral load governs a design [they] do not require consideration of the other lateral loads in the [plan submission].” This response suggests the general acceptance that wind and seismic loads are essentially the same.

Finally, the respondents who enforce the seismic provisions identified a number of seismic design deficiencies for which they have objected to residential plan submissions. These include (in descending order of citation):

1. Incorrect load calculations or incorrect selection of Seismic Design Category [1].
2. Details that are believed to require an engineer’s seal not sealed.
3. Inadequate roof, wall or foundation hold-down details (often inadequate spacing).
4. Inadequate brick veneer anchorage or details.
5. Inadequate foundation or basement wall reinforcement.
6. Inadequate braced wall details or inadequate amount of braced walls.
7. Inadequate chimney design.

Item 1, in the list above, requires professional education to address. Improved prescriptive design guidelines based on the IRC would help to address items 3-7 and therefore mitigate item 2.

A final interesting observation to come from this survey was that while those responding reported 639 formal “inspector” certifications (presumably some individuals hold multiple certifications) in their jurisdictions, only 6 officials are reported as being formally licensed as an engineer or architect. This points to the need for improved resources to be made available to building departments if adequate evaluation of seismic design is to be assured.

## CONCLUSIONS

South Carolina is one of the only true multiple hazard jurisdictions in North America. While Florida is extremely vulnerable to hurricanes, and California is at high risk for earthquakes, South Carolina finds itself in the position of slightly lower levels of risk for each individual hazard. Due to the combined presence of wind, seismic, and flood hazards, however, the overall vulnerability of South Carolina to natural hazards is extremely high. This vulnerability is addressed in the *International Residential Code* (IRC) [1]. South Carolina is in a position to suffer significant economic and societal impacts in the event of a natural disaster. The areas most at risk in South Carolina are those same areas where property values are the highest in the state, and tourism, a major economic force in South Carolina, is the primary industry. As seen recently in the devastation from Hurricane Hugo, and historically in the Great Charleston Earthquake of 1886, South Carolina is exceptionally vulnerable to natural disasters.

The State of South Carolina has made important progress towards improving hazard mitigation in residential construction. South Carolina quickly and eagerly adopted the ICC Code Series [1 and 10], which provides comprehensive multiple hazard design guidelines intended to provide a uniform level of protection. The IRC is the first residential building code to incorporate prescriptive design guidelines which successfully address important issues in multiple hazard construction. However, there has been resistance in allowing the code to perform as intended, specifically through moratoria on the adoption of seismic criteria and windborne debris criteria.

The International Codes series adopts a performance based approach toward design for hazard mitigation. Based on the severity of the event, the prescriptive requirements intend a certain level of protection to be provided, and a certain level of damage as acceptable. Contrary to popular belief, we are not designing our homes to last through a major event with no damage. The goal of these requirements is to prevent the loss of life in a major event, and prevent the need to rebuild entire communities after a smaller one.

A review of residential design and construction practice both during and after adoption of the IRC in South Carolina was undertaken. This review identified significant variability in the application of multiple hazard design. While the design community is well informed about the general nature of wind and flood resistant design, there remains a need for uniform professional education for designers, contractors and code officials in the use of the International Code series as it applies to multiple hazard design in South Carolina. Seismic resistant design, *per se*, is virtually nonexistent in South Carolina. There is an urgent need for professional education in the area of seismic design. It is believed that such a program will mitigate much of the resistance to the adoption of the IRC from the residential community.

A critical evaluation of the appropriateness of the method of determining acceleration coefficients for residential seismic design in the context of East Coast seismicity and the South Carolina building practice should be initiated. Such a study should investigate the relationship between the maximum credible earthquake and the design earthquake and may suggest an additional geographic modification to the existing IBC relationship. A more significant study may critically address the use of the same ground motion relationships for structures covered by the IBC as those covered by the IRC.

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