The SOUTH CAROLINA
ENGINEER

AN ACTION PLAN TO IMPROVE THE SAFETY OF EXISTING AND NEW SCHOOL BUILDINGS FOR THE NATURAL HAZARDS ENVIRONMENT IN SOUTH CAROLINA

By
Charles Lindbergh, PhD, PE
The Citadel
Charleston, SC

**Reprint from the
SOUTH CAROLINA ENGINEER
Vol. XL, No. 2, Winter 1990**

AN ACTION PLAN TO IMPROVE THE SAFETY OF EXISTING AND NEW SCHOOL BUILDINGS FOR THE NATURAL HAZARDS ENVIRONMENT IN SOUTH CAROLINA

BY
Charles Lindbergh, PhD, PE
The Citadel
Charleston, S.C.

Introduction

Building standards and practices directly d significantly affect the general health, ety, and welfare of each and every commu- y member of South Carolina. Collectively, y also impact the welfare of the State as a ole. The effectiveness of building standards d practices depends upon many factors. e principal ones are (a) whether or not lding codes have been adopted, (b) the quacy of adopted building codes and stan- ds, (c) how well building officials and er local regulatory personnel are trained l motivated to enforce them, and (d) the ication and quality of services provided by building contractor and professional engi- ring and architectural communities. All of e factors are basically regulated for the lic through appropriate legislation.

uilding standards and practices can rapid- ecome obsolete and faulted in the service he public. State-of-the-art building tech- ogy, community developments and public rest and needs can markedly change. ding standards and practices need to be odically reviewed and upgraded.

uring the past five years, several impor- relevant studies have been conducted by ous broadly based citizen and organiza- al groups within the State. Although con- ed in an independent manner, they all sed on various aspects of state building tices and standards and collectively repre- an excellent critical review of them. e assessments underscore that state build- standards and practices are seriously in- uate and in need of major prompt up- e. This condition is especially unfortunate o the uncommon combination of natural rds confronting the communities of h Carolina. These include earthquakes, , and water. There have been several r assessments by state institutions, nizations, and individuals that have con- d these natural hazards as serious threats e and property. In all cases, these studies ort the conclusion that the threats to pro- and human life could be significantly ated by the enforcement of appropriate num building standards and procedures. e studies and results have been discussed veral prior issues of the South Carolina eer (Lindbergh, 1984; Lindbergh, 1989; s, 1990; Sparks, Murden and Sill, 1990). e principal cause is clearly established.

Despite this basic and undeniable threat to the general health, safety, and welfare of the public, there remains no statewide building code system mandated in South Carolina. The matter of enactment and administration is left to the individual local jurisdiction. As a result, building codes in varying forms have not been adopted by all cities, only about one-third of S.C. counties have taken such action, there is no mechanism in South Carolina to ensure that municipalities that have adopted codes are effectively administering them, and certain state agencies charged with construction responsibilities remain unobligated to adopt or enforce building codes. The consequences continue to grow at ever increasing rates due to record population advancements and developments in commercial and public sectors—as well as the corresponding steady expansion of the statewide building inventory containing far too much substandard construction.

Appropriate action is being taken to address these issues regarding general construction statewide. Remedial legislation has been refiled in the State Senate that would mandate the use of building codes statewide and require the appropriate certification of building inspectors who administer the provisions. Consideration during early 1991 is expected.

Schools—The Special Problem

The problem of substandard state building practices and standards is particularly critical in regard to public school construction which is regulated under special provisions. Despite their special importance, educational facility construction is similar to that of other buildings in the respective school district. They demand even more careful design and construction control. Application of state-of-the-art building code technology and building practices should be ensured, particularly given the serious threat of natural hazards. Despite these known conditions, there are schools that are not capable of withstanding the high pressure loads exerted on roofs during a hurricane event (S.C. Sea Grant Consortium, 1987). Only since 1988 has the S.C. Department of Education strongly encouraged new school construction at least in some select region(s) to be seismic-resistant by design. Charleston County is such a region. The official policy continues to be that earthquake provisions are left to the local jurisdictions for optional adoption. As a result, earthquake strengthening has been largely ignored. All schools can and should be designed with cost effective wind/earthquake resistance.

In regard to natural hazards, elementary and secondary schools demand close attention. There are several reasons. First, the occupancy of such schools by society's most precious resource, its children, is required by law and, therefore, the moral and legal responsibilities for properly protecting occupants are very great. Second, the occupancy density is very high. The Standard Building Code specifies planning for 1 person per 20 square feet. Emergency egress, after an earthquake for example, can be most difficult and hazardous at best and virtually impossible in a badly damaged building. Certainly, the fatality rate would be higher than under standard occupancy should the facility collapse. Third, school buildings are important to immediate and long-term disaster relief and recovery efforts. After a damaging wind storm or earthquake, people will seek shelter in the school buildings. If they are not functional, they become other disaster-related liabilities instead of assets. Finally, closure of schools for any length of time represents a very serious community problem and major school damage can have disastrous and long-term economic effects on a community.

Certainly, the public school problem regarding natural hazards is not all construction related. An acceptably safe built environment and emergency response training and planning are essential partners. As demonstrated in Armenia, many lives of school children and teachers can be spared through effective public education and disaster response planning prior to the earthquake or wind storm.

The Necessary Corrective Actions

A long-term improvement state program is necessary to mitigate the serious threat of natural hazards to the students, faculty and staff members of our schools in South Carolina. School facilities must be strengthened to provide effective shelters to the public in times of natural disasters. The serious compromises of the school environment must be brought into public review and effective remedial measures taken.

Cooperative action by the Governor and Legislature is necessary to establish a South Carolina Natural Hazards School Building Safety Improvement Program. The goals of the long-term program would be to achieve within a prescribed period the improvement of all existing schools to incorporate minimum adequate resistance to natural hazards and the construction of new schools to design criteria consistent with their essential functions. This program to improve the safety of the built-environment would complement ongoing state and local efforts to implement emergency response training and equipment programs in all schools.

al South Caroliona School Building Panel should be appointed by the Legre to develop an integrated Action Plan guide the formulation and implementation the South Carolina Natural Hazards Building Safety Improvement Program. The development of the Action Plan should benefit from the participation on the Commission of the Department of Education and other education-relevant state institution and professional organizations. It would consider the real world constraints of limited state budgets.

This Article

A study has been published (Lindbergh, 1990) that examines the natural hazards safety of the school built-environment in South Carolina and recommends a 12-Point Action Plan for essential improvements. The Action Plan would seek to (1) review and establish a baseline consensus of natural hazard risks and school vulnerabilities statewide, (2) review and upgrade school design criteria considering vulnerability and functional use, (3) develop a Natural Hazards School Building Safety Improvement Program, (4) contribute to the contents of emergency preparedness provisions as they relate to the built-environment, (5) recommend a reorganization and strengthening of the Office of School Facility Planning and Building, Department of Education, as necessary for it to discharge its increased management and control of school design and construction activities, and (6) prepare and submit to the South Carolina Legislature in cooperation with the Department of Education a proposed Natural Hazards School Building Safety Improvement Program for the State of South Carolina incorporating the preceding developments. This article is an abridgment of this study.

2. Earthquakes and South Carolina

The development and implementation of a prudent natural hazard earthquake mitigation program for the public schools to include earthquake measures require a basic understanding of the seismic threat. This knowledge must be sufficient to ensure reasoned public acceptance that earthquakes represent unacceptable risk to our school children in South Carolina. In terms of implementation, sound planning criteria must be used. Earthquake resistant construction and emergency response preparation require a significant commitment of resources including time as well as dollars. These expenditures must focus on proper threat assessments if mitigation efforts are to be cost effective in saving lives and reducing building damage losses.

In 1982, a detailed assessment of the earthquake hazard and risks in South Carolina was conducted by local and regional engineers and scientists with the technical assistance of national authorities. It was sponsored by the South Carolina Seismic Safety Consortium to ensure a sound underpinning for the ongoing seismic safety program in South Carolina. In 1986, this assessment and a description of ongoing mitigation activities were published in a book entitled "Earthquake Hazards, Risk, and Mitigation in South Carolina and the Southeastern United States," by The Citadel. Copies of the earthquake mitigation book were provided to all middle and high schools in South Carolina as well as all members of the state legislature.

This section provides an overview of the earthquake risk to South Carolina.

Statewide Historic Seismicity

The earthquake history of South Carolina extends from a tremor in 1698 (Visvanathan, 1980). Since that date, more than 550 felt earthquakes have occurred in the state. The Appalachian and Piedmont areas are more active than the Coastal Plain area (exclusive of Charleston). About 70 quakes have been experienced during the past 12 years, one-half of which were located around Charleston. However, the earthquake history is dominated by the catastrophic Charleston earthquake of epicentral intensity MMI* X that occurred in 1886.

Since the 1886 earthquake, there have been 14 earthquakes within South Carolina of sufficient size to cause structural damage (i.e. MMI VI or more). Seven of these occurred beore 1893 and are judged to be aftershocks of the main shock of 1886 and hence not representative of South Carolina seismicity. The other damaging earthquakes are listed in Table 1.

Table 1. South Carolina Earthquakes Since 1892 of MMI Intensity VI Or More

1893	June 20	VII	Charleston
1912	June 12	VII	Summerville
1913	Jan. 1	VIII	Union
1945	July 26	V-VI	Columbia
1959	Aug. 3	VI 4.4**	Summerville
1959	Oct. 26	VI	McBee
1974	Nov. 22	4.3**	Charleston

*Using the Modified Mercalli intensity scale of I to XII
**Using the Richter Magnitude scale

The Charleston, SC earthquake of 1886 was one of the two largest earthquakes to have occurred in the United States. The other one was the larger of the two and was an eastern earthquake, the New Madrid earthquakes of 1811-12. The New Madrid events had areas of structural damage five times larger than that of the 1906 San Francisco earthquake and areas of nonstructural damage twenty times larger.

Earthquake Risk Within South Carolina

A. *Risk Based Upon Statewide Historic Seismicity*

The frequency with which earthquakes will recur in South Carolina can be estimated using the seismicity catalogs discussed above that list all known earthquake occurrences. The process involves first relating the "Cumulative Number (N_c)" of earthquakes in South Carolina to maximum Modified Mercalli Intensity (I_0) for a particular historic time period. From this development, the probable recurrence rates for earthquakes in South Carolina can be estimated. Given the recurrence interval, the probability of occurrence of a particular intensity earthquake can be calculated using the Poisson probability distribution density function. In this manner, the probability of occurrence for earthquakes of various intensity levels were established for the Charleston-Summerville (C-S) area (Amick and Talwani, 1986) and for the remainder of the state (Tarr, 1977).

Table 2 is based on probabilities of occurrences within a 50-year time interval. This period is commonly used in building code development and design as it is assumed to represent fairly well the lifetime of a regular building. Properly accounting for attenuation with distance, these developments are used to provide similar recurrence relationships for peak ground acceleration and peak ground velocity which, in turn, are used to develop response spectra for the design of buildings.

Earthquake preparedness planning and procedures, as well as building design, should consider the full range of possible earthquake intensities with due consideration of probability of occurrence. All earthquakes occurring within a region during a particular time period - and not just the large catastrophic ones - are of importance. Toward the lower end of the intensity scale are the smaller and moderate earthquakes capable of structural damage, death and injury. At the upper end of the scale is the 1886 Charleston-like event that must be appropriately considered, despite its low probability of occurrence. The possible consequences of unreasoned disregard are too great. The Armenian earthquake experience provided still another example of the earthquake that occurred being of much greater intensity than that anticipated in building design (Lindbergh, 1989.)

Table 2 Earthquake Recurrence Intervals For South Carolina

Earthquake MMI Intensity	Charleston, SC Area		South Carolina Outside the Charleston Area	
	Rate (yrs)	Probability (within 50 yrs)	Rate (yrs)	Probability (within 50 yrs)
XI	1,513	3	2,913	2
IX	575	8	1,056	4
VIII	219	20	384	12
VII	83	45	139	30
VI	32	79	51	63
V	12	98	18	93

B. *Pending Upgrade of Seismicity Definition*

For several reasons, the current national risk map is in need of reassessment and upgrade. This is particularly true in regard to South Carolina. It is not adequately consistent with current knowledge and local risk mapping based on historic statewide and regional seismicity as discussed above. Fortunately, the U.S. Geological Survey is beginning a multi-year effort to develop a new generation of seismic risk maps for the national NEHRP building code provisions. Arrangements have been reached between The Citadel and the U.S. Geological Survey for the remapping of South Carolina to be conducted on an expedited basis and completed during the spring of 1991. The upgraded seismic risk mapping would be promptly released to the S.C. Building Codes Council and the S.C. Department of Education for prompt adoption.

Can Earthquakes Affect Our Schools School Children?

cts Of Earthquakes On School Buildings

A. *Effects of Earthquakes*

The effects of earthquakes include ground shaking, ground rupture in fault zones, ground failure (landslides, settlement and liquefaction) and tsunamis (seismic sea waves). Based on historical records, it is believed that there is little risk of ground rupture in fault zones and tsunamis to South Carolina. Seismic design focuses primarily on ground shaking and ground failure.

B. *Structural Damage Effects on School Buildings*

The nature of building damage caused by earthquakes reflects the building's resistance to collapse and the structural system design used to achieve that resistance. Accordingly, it is useful to consider how an earthquake loads a building and the basic structural building design schemes used to resist those loads. First, consider the nature of the earthquake loading. The shaking ground surface accelerates the building, generating dynamic "inertial" forces against the building that are proportional to the building's mass and that act through its mass. Basically, any element of the building system that has mass (or weight) experiences a dynamic force that is proportional to the magnitude of its mass and its responsiveness to ground motion intensity. In effect, the earthquake loading is somewhat like that of gravity (at reduced levels) acting on a horizontal building cantilevered from its support. An acceleration is experienced through the entire structure. Interior items such as partitions and desks would be subjected to dynamic forces. This is unlike a situation of wind loading where only exterior elements and the interior basic structural frame components resisting the lateral loads are influenced. In any event, these earthquake loads are resisted by structural systems that include shear walls, moment-resisting frames, and frames with diagonal bracing. Buildings may also consist of any combination of these.

There are noticeable differences in the types and extent of earthquake damage observed in relation to different structural materials. Unreinforced masonry buildings deserve special mention. They have uniformly performed poorly and are especially vulnerable as witnessed by the 1886 Charleston earthquake (Lindbergh, 1986) and others throughout the world. This includes old brick masonry buildings as well as the newer buildings constructed of unreinforced or under-reinforced (according to seismic design requirements) concrete block masonry buildings. Buildings that can deform to a large extent before failing, such as many constructed of steel or wood, are less vulnerable to severe damage or failure provided their elements have been adequately connected. Inherently brittle materials such as concrete and masonry can be effective when used with properly designed and fabricated reinforcement. Buildings so fabricated have performed very well in earthquakes.

C. *Nonstructural Damage Effects on School Buildings*

The protection of nonstructural elements is of considerable importance in schools due to the age of the occupants and the high occupancy density. The elements of a building that hold it erect and resist gravity, earthquakes, wind and other loads are structural elements. All other elements in the building such as nonloadbearing partitions, mechanical systems, overhead light fixtures, filing cabinets, etc. are nonstructural elements.

Especially for school buildings, it is most important that nonstructural elements withstand the applied forces and deformations such that: (1) they will not collapse or endanger life safety and (2) they will remain functional, if required. Design strategies for a particular nonstructural element may include one or more of the following: increased flexibility, anchorage, bracing, increased stability, strengthening, isolation, slip or control joints, mass reduction and relocation.

There are numerous examples of nonstructural earthquake damage in school buildings and other facilities that caused injury and death or denied contingency functional use.

D. *The Performance of A Public School in Armenia*

A photographic record (Lindbergh, 1989) is provided of two precast concrete public schools damaged by the Armenian earthquake of 1988. Figures 1 through 4 are photographs taken from this report of a public school building in Spitak, Armenia in which only 2 students reportedly survived the magnitude 6.9 earthquake. Figure 1 is an exterior view of one wing of the building showing distress to the exterior panel and glassless window openings. Figure 2 shows an interior view of a damaged auditorium. A dislodged ceiling, missing roof sections, and collapsed interior masonry partition sections are visible. Figure 3 shows collapsed interior partitions.

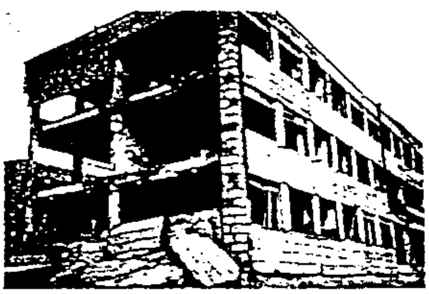

Figure 1. Exterior of Damaged School, Spitak, Armenia (Lindbergh, 1989)

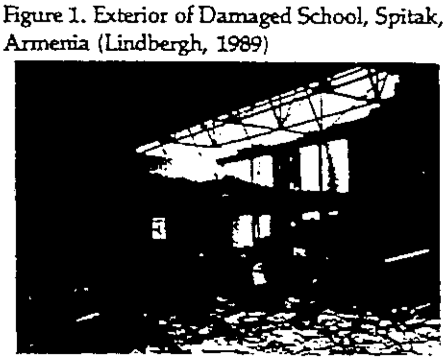

Figure 2. Damaged School Auditorium, Spitak, Armenia (Lindbergh, 1989)

Figure 3. Damaged School Interior, Spitak, Armenia (Lindberg, 1989)

Figure 4. Partition Debris in School Hallway, Spitak, Armenia (Lindbergh, 1989)

Failed joints, disarrayed frame members, and collapsed interior masonry block partitions are also visible. Figure 4 shows an interior hallway littered by masonry debris from hallway masonry partitions.

The Charleston, SC Earthquake Vulnerability Study

As discussed earlier, past earthquakes have shown that the vulnerability of schools has serious consequences. Many schools were destroyed in the Long Beach, California, area by the 1933 earthquake; others were so badly damaged they had to be demolished and replaced. Investigations of the damaged school buildings revealed that building designs had not, in most cases, included provisions to resist seismic forces, or where included, were inadequate. Much of the loss and damage could have been avoided if the buildings and other structures had been properly constructed. The public knowledge that school buildings were not designed to resist earthquakes caused the California State Legislature to respond quickly to pass the Field Act, signed into law exactly one month later on April 10, 1933.

To more directly assess the potential effects of an earthquake on a community in South Carolina, an earthquake vulnerability study was conducted of the Berkeley-Charleston-Dorchester tri-county region (Harlan and Lindbergh, 1988). This study was conducted by The Citadel under a grant provided by the Federal Emergency Management Agency through the S.C. Emergency Preparedness Division. It assessed the local earthquake hazard, and, considering the damage susceptibility of existing facilities and systems, determined the extent of probable damage resulting from a seismic event that may reasonably be expected to occur. From this determination, the impact on the community was quantified in terms of killed or injured people, reduced critical services, and property loss. In recognirange of damaging intensities pos- varying levels of probability, two were used in the study. These included MI VII and MMI IX events. All critical fa- ties, including schools, and lifeline systems uch as bridges were examined.

The vulnerability survey of public school buildings in the Charleston tri-county area revealed that area schools are essentially in the same seismic safety state as California schools in 1933. The time of day of an earthquake will determine whether the lives of school children are lost. Regardless of the time of day, the property damage to schools may be of catastrophic proportions. The survey included virtually all public school buildings in the tri-county metropolitan area. Only a few public schools in the more distant towns of Dorchester county were omitted. Private schools were not included in the survey. The losses to schools not in the survey is expected to be comparable to those surveyed. The damage assessment study concluded that an earthquake of MMI IX could result in an estimated Probable Maximum Loss of 78 percent and an Average Percent Loss of 39 percent of the value of public school buildings. The probability that public school buildings will be damaged less than 30 percent is 44 percent. In other words, 56 percent of public school buildings will probably be greater than 30 percent damaged. The restoration times for public school buildings are estimated to be 30 days to achieve 30 percent usability, 90 days for 60 percent usability, and 365 days for full restoration of operational capability of public school facilities.

For an earthquake of MMI VII, the study concluded an estimated Probable Maximum Loss of 38 percent and an Average Percent Loss of 19 percent of the value of public school buildings. The probability that public school are estimated to be 6 days to achieve 25 percent usability, 15 days for 65 percent usability, and 90 days for full restoration of operational capability of facilities.

Casualties for students and teachers in public schools and other school occupancy, including other school employees and students and teachers in private schools are shown in Table 3. Approximately 97 percent of the estimated casualties are expected to occur in unreinforced masonry buildings which are occupied by only 73 percent of the educational personnel. The casualty rate in unreinforced masonry public school buildings is 11.3 times the casualty rate in public school buildings constructed using other than unreinforced masonry. Therefore, if the alternative types of construction were used throughout, the total fatalities in Table 3 would be 118 instead of 1,005 for an earthquake of MMI IX. But the estimated casualties can and should be even further reduced by designing school buildings to effectively resist seismic forces.

In summary, the most serious problem faced by the Charleston community during and after an earthquake will be the safety of school

Table 3. Probable Maximum Daytime Casualties In Schools

Earthquake Intensity	No. of Persons	Minor Injuries	Major Injuries	No. of Deaths
MMI IX				
Public Schools*	83.947	19.053	2,540	635
Other Persons**	48,854	11,088	1,478	370
Total	132,801	30,141	4,018	1,005
MMI VII				
Public Schools*	83,947	1,902	254	64
Other Persons**	48,854	1,107	148	37
Total	132,801	3,009	402	101

*Public school casualties include only students and teachers.

**Other persons include students and teachers in private schools and other educational employees in both public and private schools.

children, teachers, and other persons in school buildings. The number of fatalities would be unacceptable by any conceivable estimate. The number of injured would likely be well beyond the capability of the medical resources of the community, increasing the number of deaths for lack of medical care. Even if the medical capability could handle the number of casualties, communications and transportation difficulties may preclude transporting casualties to appropriate hospitals. Contacting parents may be impossible. Children will be worried about their parents and parents will be panic stricken for the safety of their children. If the children are taken from the school for medical care, the parents will have difficulty locating them. In short, the concern for family and friends will probably result in chaos. In addition to the direct damage to the school building structure, earthquake ground motion may cause equipment, furnishings, and building components, such as suspended ceilings and lights, to become hazards as they move or fall. Shorted electrical systems, spilled flammables, or broken gas lines may cause fires. The first concern will be rescue of anyone trapped in the rubble and medical care for the injured.

School buildings are generally the first structures to be used for disaster relief. Other buildings, such as churches, may provide space. In addition to floor space in a safe building, a shelter should have power, potable water, eating and sanitary facilities, and heat if required by the weather. Many schools fill these requirements. Public schools offer the advantage of being controlled by governmental agencies and, thus, may be made available promptly for disaster relief usage. However, a large percentage of schools, as well as other potential shelters, will require safety inspections by competent individuals prior to use as a shelter. Many will be found to be unusable.

In the longer term, the school buildings may be required for emergency shelter of the homeless. School buildings which are still usable will be organized to house and feed those whose homes have been destroyed or are unsafe. The restoration or replacement cost of public school buildings damaged by an earthquake is estimated to be the largest cost of any category of critical facility. The time required for restoration and replacement of public school facilities will have a serious impact on education of children for at least a year and probably longer. Even if school buildings are repaired or replaced in kind from existing construction plans, the construction time is long. Use of limited construction resources on higher priority requirements may impact the restoration of school facilities further.

The schools should have an emergency preparedness plan for any foreseeable disaster and earthquake preparedness measures should certainly be included. School children, as well as teachers and staff, should be instructed on what to do in an earthquake disaster. The entire earthquake preparedness plan should be exercised using simulation.

It is readily seen from these comments and the anticipated earthquake scenario, that construction of earthquake resistant school buildings would be in the best interests of the community. Considering that the normal life expectancy of school buildings is probably about 50 years (some of our present school buildings are older than 50 years), the replacement of the existing seismically deficient inventory of school buildings will take at least 50 years. Of course, the program could be accelerated by upgrading and strengthening existing structures that are otherwise not obsolete. The incremental cost to incorporate seismic resistant construction is minimal when included in the original design of a building. The cost to retrofit an existing building is greater.

4. Wind and Flood — The Companion Natural Hazards

Wind and Flood As Historic Threats

South Carolina, including its inland as well as coastal regions, has always been threatened by winds as well as earthquakes. A vivid reminder of this combination of natural hazards embedded in South Carolina's history is provided by Charleston and the lowcountry. A disastrous cyclone caused very heavy damages to Charleston in 1885, the year before the great earthquake struck the city. Mayor Courtenay stated in the 1887 Annual Review that the community had only just managed to recover from this natural disaster through great public expense when, during the following year of 1886, "disaster overtook our city in the earthquake shocks of August and September, covering with ruins the whole extent of our city, from river to river, and to its northern boundary, and involving a loss of certainly five million dollars." Mayor Courtenay cited the severe resource demands of recovery from the cyclone damage in explaining why Charleston was in no position not to accept the external relief funding that was being offered.

In the coastal areas, major storms bring flooding as well as high winds. According to the South Carolina Coastal Council, "as a rule, hurricanes strike our shores on the

...ge of once every twelve years, carrying ...h them the potential for death and destruc...on on a tremendous scale. And that poten...tal is even greater now than ever before because of our increased coastal growth." Of course, this includes many additional school facilities. Hurricane-caused flooding accompanying high winds further aggravate the hostile environment faced by school facilities and their occupants located in the coastal regions of South Carolina.

Hugo - The Reminder

Earlier studies have documented the multi-hazard threat to South Carolina and the vulnerability of the built-environment to the natural hazards. They also underscored that South Carolina does not need to wait for a destructive earthquake or hurricane to demonstrate the priority need for better constructed schools and improved emergency response procedures. We do not need a 1933 Long Beach earthquake experience to prompt a prudent school construction program in South Carolina. There is enough clear and compelling evidence of the need. Unfortunately on September 21-22, 1989, the unwanted and unnecessary catastrophic reminder occurred. South Carolina has now been struck by Hurricane Hugo.

The Hugo experience has been widely documented (Sparks, 1990 and Sparks, Murden and Sill, 1990). Most importantly, it has served as a major validation of the concerns regarding inadequate statewide construction practices and standards, especially as they relate to schools. It is considered adequate to only highlight these supporting results of the Category 4 storm. First, reported measurements indicate that the actual flood and wind conditions were basically consistent with that prescribed in applicable building code criteria. Despite this condition, serious damage was experienced. Twenty-four counties were presidentially declared disaster areas. These counties constitute the entire eastern half of the state. These results must be taken as evidence of inadequate statewide building standards and practice. Gary Wiggins, Executive Director of the South Carolina Building Codes Council, noted that in numerous South Carolina communities struck by Hugo there was a "marked difference" in the level of damage to homes built after codes were installed or improved, compared to earlier construction. "Those built under code sustained minimal damage and were back in service much earlier than those built before code enforcement." The report "Surviving the Storm" published by the All-Industry Research Advisory Council in 1989 provides a good examination of the effects of Hugo and other hurricanes and ways to lessen the damage and injuries they cause. Second, according to an impact assessment report published on October 3, 1989 by the South Carolina Department of Education, many of the schools located throughout the hurricane stricken counties suffered significant damage. A total of 369 schools were reported as damaged, with repair costs estimated at $55,167,197. The report lists serious losses in school days. Third, many schools were found to be unfit for emergency service as shelters. The situation of the severely flooded Lincoln school in McClellanville and certain of its occupants who nearly drowned has been widely publicized. Fourth, a large section of the State was placed under emergency recovery conditions. Recovery operators and equipment had to be brought in from neighboring states and other national regions. A large earthquake would seriously disrupt even greater regions. Fifth, emergency procedures and training need to be improved. The recent Hurricane catastrophe and that of the earthquake in California should lead to valuable improvements in emergency preparedness such as that suggested in the subject study for schools.

In any event, Hurricane Hugo has underscored the serious need to improve the natural hazard safety of the school building environment in South Carolina. Certainly now after Hurricane Hugo, South Carolina does not need to wait for still another catastrophic event to demonstrate the priority need for better constructed schools and improved emergency response procedures. It must act now.

Need To Consider Wind And Earthquakes Together In School Design

Wind and earthquakes should be conjunctively considered in the design of public schools. Although there are differences in their nature as discussed in the following paragraph, they both produce related dynamic effects that can be more cost-effectively countered with integrated earthquake and wind provisions. Recent structural design studies at The Citadel (Fallon and Lindbergh, 1989) indicate that structural construction costs should not increase by more than about one percent above wind provisions if deliberate earthquake-resistance is also included. State safety policy and mitigation measures, as well as design and building code requirements, should prescribe integrated earthquake and wind provisions.

As stated above, there are important differences in the effects of wind and earthquake loads. One difference is in the manner in which the lateral forces are transmitted. An earthquake load is transmitted to the building from its base. Thus, the magnitude of force is proportional to mass. Consisting of mass, the entire building (interior as well as exterior components) as well as the building contents will experience the force. On the other hand, wind forces are transmitted to the building frame through its envelope. The cladding and its supporting members experience the initial effects of the wind load. Except for the structural members, the interior of the building, including its contents, will not experience the wind loads directly as long as the envelope remains intact. Excessive swaying can occur unless adequate building stiffness is provided.

Another difference is in design provisions. In earthquake resistant design, it is generally impractical or uneconomical to design buildings to resist the maximum credible earthquake without allowing the structure to respond inelastically. Accordingly, the structure is designed and detailed to provide energy-absorption capacity through yielding such that the structure can survive earthquake forces of magnitude far greater than the design forces associated with allowable stresses in the elastic range. It is expected that some components of the structure may exceed the elastic limit in responding to significant earthquakes and therefore some damage may occur under these conditions. On the other hand, in wind resistant design, it is expected that buildings will resist wind loads without damage of any kind. The building is expected to perform entirely within the elastic limit of its materials. This difference in design concept must be recognized. Whereas many buildings with brittle materials and brittle connections have survived wind loads for many, many years, they would not stand a chance in a significant earthquake. In the case of wind and earthquake resistant design, the building components must be tied together to ensure a continuous load resisting path from the foundation to the roof components. However, earthquake resistant buildings must be "tied" together in all respects and contain the ductility and toughness sufficient to survive the omni-directional violent actions of an earthquake.

In the coastal regions, the integrated wind and earthquake natural hazards design of schools must be more comprehensive in that it should conjunctively consider the effects of flooding too.

A Flood Hazard Boundary Map provided by the Federal Emergency Management Agency provides a preliminary delineation of special flood hazard areas within a particular community. In order to participate in the National Flood Insurance Program, the community must satisfactorily regulate new construction and development in special flood plain areas. These areas include all land inundated by the flood that has a 1 percent chance of being equaled or exceeded in any given year. This event is termed the "base flood" or "100 year flood." The 100 year flood plain area is divided into two adjacent zones that define the different degrees of hazard present and require different flood plain management techniques. The V zone indicates the inland extent of a 3-foot breaking wave, when the stillwater depth during the 100 year flood decreases to less than 4 feet. The A zone is that portion of the 100 year flood plain not subject to wave action. However, the residual forward momentum of the breaking wave may be present in this zone.

Some Wind And Flood-Damaged School Buildings

Hurricane Hugo produced many examples of wind and flood damaged school buildings. Figures 5 and 6 are photographs of two schools in Charleston damaged by wind and fallen trees. Figure 7 is an interior view of a school that suffered roof damage. Figure 8

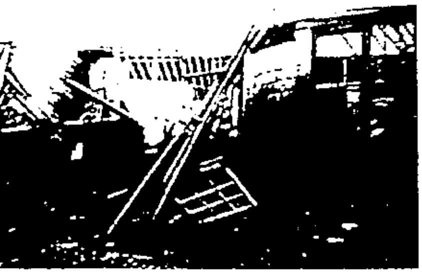

Figure 5. Wind Damaged School Building, Charleston, SC (Charleston County School District)

Figure 6. Wind and Tree Damaged School Building, Charleston, SC (Charleston County School District

Figure 7. Interior of Wind Damaged School Building, Charleston, SC (Charleston County School District)

Figure 8. Wind and Flood Damaged Lincoln High School (City of Charleston Police Department)

shows the Lincoln High School that was significantly flooded by Hugo, greatly risking the lives of many people who were using the school building as a shelter. This situation provides a vivid example of the need to insure school designs are properly checked under the direction of the South Carolina Department of Education. Reportedly, the cause of this near catastrophe was an engineering design error that was not discovered through a design review. In particular, the plans drawn some 20 years ago reflect a site elevation of 20.52 MSL whereas the actual elevation is now known to be 9.2 MSL. Shortly after Hurricane Hugo occurred, a destructive tornado struck Birmingham, Alabama. Figure 9 shows

Figure 9. Tornado Damaged School, Birmingham, Alabama

Figure 10. Classroom Building at the Richard Winn Academy (Sparks, 1985)

Figure 11. Classroom at the Richard Winn Academy (Sparks, 1985)

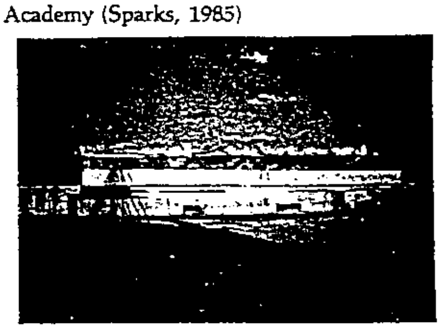

Figure 12. Gymnasium of the Richard Winn Academy (Sparks, 1985)

a school building damaged by that tornado. Sparks (1985) provides other examples of wind building damage in South Carolina, considering the tornadoes of March 28, 1984. Figures 10, 11 and 12 show damage done to the Richard Winn Academy of Winnsboro. This school building was constructed with unreinforced masonry walls. Fortunately, school activities had been canceled due to the bad weather.

5. What is the South Carolina School Building System and How Does It Work?

Who Influences The School Building Program

As in most states, South Carolina has both public and private schools at the elementary and higher school levels. The vast majority of students in the state attend public schools, particularly in rural areas. This discussion concentrates on public schools and the sources of influence thereon. However, as will be discussed, the South Carolina state school design and construction requirements, by state law, also relate to the private schools.

The oversight of the public school building program in South Carolina appears to be somewhat fragmented. There are four sources of direct influence upon building standards for construction of public school buildings in South Carolina. These include (1) the State Department of Education, (2) the local political subdivision of the state, either the County for unincorporated areas or the municipality for incorporated areas, (3) the owner, the governing body of the local school district, and (4) the design professional. This section discusses these sources as well as several major *indirect* sources of influence on the state school building program that also need to be considered. The four sources of direct influences will be discussed first.

The Primary Responsible Agent - The State Board Of Education

The South Carolina Code of Laws assigns in Title 59, Chapters 5 and 23, the basic authority and responsibilities for public school construction to the Department of Education. The following are key provisions from these legal mandates:

Section 59-5-60, Code of Laws of South Carolina, 1976, gives the State Board of Education authority to adopt policies, rules and regulations for the conduct and furtherance of the public school program in South Carolina. Such policies, rules, and regulations as adopted by the S.C. Department of Education in its "South Carolina School Facilities Planning and Construction Guide" are deemed to have the effect of law.

Section 59-23-40, Code of Laws of South Carolina, 1976, requires that drawings and specifications for all public school buildings be submitted to, and approved by, the State Superintendent of Education or his agent, prior to being constructed.

Section 59-23-190, Code of Laws of South Carolina, 1976, requires that all public school buildings be inspected and approved by the State Superintendent of Education or his agent, before first being occupied.

In addition to the preceding legislative requirements, the State Board of Education, through the State Superintendent has promulgated certain standards in its Regulations 43-180, 43-190, and 43-191. These regulations adopt the criteria stated in the publications, "South Carolina School Facilities Planning and Construction Guide," "South Carolina Guide and Minimum Specifications for Construction of Relocatable Classroom

...s," and "Kindergarten Facilities Guide..." These publications are available from ...state Department of Education.

Of the preceding regulations, the requirements of the "South Carolina School Facilities Planning and Construction Guide" relate to the following, regardless of the source of funding for the project:

1. All new structures, and additions and/or renovations to existing structures, in connection with the public education program in South Carolina. This shall include student-related as well as non-student related facilities. (In the Guide, it is noted that "it may not be feasible to apply all requirements of the Guide to renovation or alteration projects involving existing structures and it shall be discretionary with the Department of Education to determine the extent of such requirements, particularly where life and building safety are concerned.")

2. Adjunct work related to the preceding facilities whether included as part of an overall construction contract or awarded as a separate contract.

The Superintendent discharges these responsibilities through a deputy who functions as the Director of School Facility Planning and Building. The Director has a staff of five. It appears that there is little opportunity for the Department of School Facility Planning and Building to do more than review the designs for handicapped access and other special requirements of the guidelines. No review is undertaken to determine if local building codes are met, although the guidelines require compliance with local codes where there is no conflict with the guidelines. According to the present Director, the only difference between the guidelines and the Standard Building Code is the prohibition in the guidelines of school buildings with wooden siding, which are presently allowed under the Standard Building Code. The determination of actual school needs and provision of school buildings is accomplished on a school district by school district basis. There are 91 independent school districts within the state.

The Local Political Subdivision Of The State

The second source of direct influence is the local political subdivision of the state, either the County for unincorporated areas or the municipality for incorporated areas. In addition to state regulations, there are two sources of local governmental regulation. First, the state school building legislation specifically provides in Section 180, that it is cumulative to any local regulations. Under Title 6, Chapter 9, Sections 10 et seq. of the South Carolina Code of Laws, municipalities may adopt building codes for incorporated areas and counties may adopt building codes for unincorporated areas. Thus, the governing body may require compliance with duly adopted building codes. Under Section 60 of the same title and chapter of the code listed above, municipalities and counties are authorized to adopt the Standard Building Code.

The Local School District

The third source of direct influence (and the second source of *local* control) over school buildings is the local school district. School buildings are owned by the individual school districts across the state. Title 59, Chapter 19 of the South Carolina Code of Laws places the school districts under the management of boards of trustees and prescribes the rules and procedures for such management. While counties, municipalities, and the State Superintendent of Education have the levels of control and influence specified above, approval of individual school building plans and specifications is initiated by the local school boards, as owners. As such, the local school boards are the most direct influence on school designs, but will most likely depend upon the judgment of the design professional for such technical matters as natural hazards mitigation design.

The Design Professional

The final source of influence is the design professional. The South Carolina School Facilities Planning and Construction Guide states that "The services of an architect registered to practice in South Carolina shall be required for the design of all new structures, additions, and/or renovations or alterations to existing structures, and adjunct work ... except as otherwise stipulated herein. Such services shall include what is commonly termed "basic services," consisting of the schematic and design development, construction documents, bidding and award, and construction phases of the project." The Guide further requires that "The scope of the architects' services shall include the services of professional engineers, registered to practice in South Carolina and who are qualified, by education and experience, to design the structural, plumbing, mechanical, and electrical portions of the drawings and specifications." The Guide notes that "By joint resolutions of the South Carolina Architectural Registration Board and the Engineering Examiners' Board, dated July 25, 1962, it is permissible for an architect to perform work in the field of engineering if it is incidental to his practice of architecture, if it is of a minor nature, and if he is qualified to perform the work. Conversely, professional engineers may perform incidental work in the field of architecture under the same conditions."

The Indirect Sources Of Influence

As stated above, there are four direct sources of influence upon building standards for the construction of public buildings in South Carolina. There are also several major sources of important indirect influence.

Because the number of school boards in South Carolina is large, it is necessary, at least initially, to establish contact with a parent organization. In South Carolina, that organization is the South Carolina School Boards Association.

Similarly, the number of counties and municipalities is too numerous to contact on an individual basis. There are three organizations which provide a medium for contact with these entities. For counties there is the South Carolina Association of Counties. For municipalities there is the Municipal Association of South Carolina. For both counties and municipalities which have adopted building codes, the Building Officials Association of South Carolina provides contact.

Identification Of Sources Of Indirect Influence

Each of the sources of direct influence identified above is subject to some level of influence from other sources. Thus, it is appropriate to investigate these indirect influences to determine those organizations with probable interest in enhancing seismic and wind safety of schools.

While schools are owned by the governing body of local school districts, they are occupied by pupils, teachers, and administrators. As a result, the Parent-Teacher Associations (PTAs) should play an important role in shaping improvements in school building design criteria and quality.

Teachers in South Carolina by and large belong to the South Carolina Education Association. Again, this organization may also influence school design, since it involves the safety of the workplace of its members.

The administrators of the various schools also play an influential role in the construction of new schools. The state organization which forms an umbrella for these individuals is the South Carolina Association of School Administrators.

Finally, there are many other education-related institutions and organizations that are involved in education within South Carolina.

6. What's Wrong With The System?

The development, promulgation and implementation of the South Carolina public school building design and construction program are complex processes involving participants from both the public and private sectors. These complexities are functions of many considerations such as limited fund availability, the ever increasing school needs of new and expanding communities, the growing demand for facility repair and modernization, as well as the public/private sector institutional framework within which the process takes place. A major challenge is to maintain these processes in a manner that meet statewide school facility space requirements but without compromise of health, safety and welfare of the school children and their faculty and staff.

There is sufficient evidence that state school facility planning, design and construction standards and processes are seriously inadequate, especially considering the statewide high risk of multiple natural hazards. These shortfalls need to be collectively addressed and a sufficient mitigation program implemented. They include the following items which will be discussed more fully in this section:

. Schools are of special importance and serve construction standards as essential rather than as common community facilities.

2. School design and construction are not technically reviewed and adequately controlled at the state level.

3. Mandatory school emergency preparedness design criteria statements are inadequate and continue to exclude earthquake design provisions despite established threat.

4. Emergency disaster response training of students, faculty and staff is seriously inadequate.

Schools As Essential Rather Than Common Facilities

South Carolina school buildings are essential facilities. There are several reasons for this designation. First, the occupancy of elementary and secondary schools by the most precious resource of our communities, its children, is required by law; therefore, the moral and legal responsibilities for properly protecting occupants are particularly great. Second, schools have critical contingency roles during natural disasters. For example, after an earthquake, community damage will result in an influx of people in need of shelter. If the school building is not functional, it becomes another disaster-related liability rather than an asset. Finally, the closure of schools for any length of time represents a very serious community problem and major school damage can have a disastrous and long-term effect on a community.

As essential facilities, school design and construction standards should be specially developed and above that assigned to common community facilities. Among the current criteria statements that should be reviewed and revised are the following two statements regarding "Shelter Considerations in New Buildings" taken from page 5-1 of the South Carolina School Facilities Planning and Construction Guide.

1. It is recommended that districts give serious consideration to providing disaster shelter in the design of all new schools. If this is taken into account in the initial design stages, such areas can be specially developed and above that assigned to common community facilities. Among the current criteria statements that should be reviewed and revised are provided in many cases at modest or little additional cost and is often as simple as arranging the building configuration in such a way as to provide protection, as well as serving the normal educational functions.

2. For natural disasters, shelter protection simply means providing areas for large numbers of people to eat and sleep for a relatively short time on an emergency basis.

These statements are completely inconsistent with the serious natural hazards faced by all South Carolina communities and that, as commonly encouraged during a disaster, the public seek *protective* shelter in school buildings fully believing them to be constructed to safer standards than the common community buildings. Certainly, they are inconsistent with the high density of student, teacher and staff occupation of schools.

Inadequate Natural Hazards Design Criteria

As previously noted, South Carolina communities and their schools face an uncommon combination of natural hazards. These include earthquakes, wind, and water. The threats to property and human life can be significantly mitigated by the enforcement of appropriate minimum building standards and emergency procedures and training. Whereas the threat of flooding is principally a concern for the coastal region, high wind and earthquakes are statewide threats. Earthquake and wind resistant design requirements have many similarities. Considerable economy is achieved in constructing for the integrated threats. In any event, the threat of high winds makes even more urgent the necessity to provide the type of lateral force resistance provided through earthquake-resistant design.

There is no mandatory requirement that schools be designed to resist earthquakes. The Guide merely notes that the seismic risk map of the Standard Building Code "inidicates in a general way the parts of South Carolina that are considered to be subject to earthquake risk as determined by past experience. Seismic design shall be mandatory where required by local authorities, but is not mandated by OSP&B otherwise." As a result of this policy, very few, if any, of the approximately 1,000 schools in South Carolina have been deliberately designed with earthquake resistance.

School Designs Not Technically Reviewed By Department of Education

As essential facilities facing a serious uncommon combination of natural hazards, school facility construction, repair and alterations require special attention. This they have not had. The school construction process and standards as described above have not ensured an adequately safe environment for students, teachers and administrators. Design criteria including that relating to the risks of wind and earthquake and construction adequacy has been largely left to the local administration officials, design professionals, and contractors. No technical design reviews or construction surveillance are conducted by the Director of School Facility Planning and Building. This lack of quality control is a serious deficiency considering schools as essential facilities. It is of particular concern considering that state building standards and practices are seriously inadequate and in need of prompt upgrade. The error made in the design of Lincoln High School and the near-tragic consequences illustrate the imperative need for conducting thorough technical reviews. As confirmed by the South Carolina State Board of Registration for Engineers and Land Surveyors, the conduct of a design review by the Department of Education would in no way reduce the professional responsibilities and liabilities of the professional engineer of record.

In summary, school building design and construction standards and practices need to be improved. The following measures are among those that should be established.

1. That mandatory upgrade design criteria be resolved to govern school design considering a competent definition of natural hazard threat and the essential nature of schools. This action would consider updated wind and seismic risk maps and state-of-the-art building code provisions.

2. Plans and specifications be prepared by duly registered professional architects and engineers as currently required with demonstrated proficiency in natural hazards design.

3. Plans and specifications be checked for safety of design and approved by the Department of Education to ensure appropriate natural hazards mitigation features are incorporated in the plans before a contract for construction is let.

4. Construction be continuously inspected by a qualified person in the employment of the school board who shall see that plans are complied with.

5. The responsible architect or structural engineer shall supervise the work and prepare plan changes as necessary to overcome unforeseen field conditions.

6. All parties concerned (architect, engineer, inspector, contractor) must file verified reports that approved plans were complied with in the construction.

7. The Department of Education, upon request of a school board or 10% of the parents having children enrolled in a school district, shall examine an existing school building to determine if it is safe or unsafe for use.

8. A fee schedule be established to cover the State's cost of carrying out the preceding requirements.

Improved Built Environment And Emergency Response Preparation - The Essential Partners

The high potential of high winds and earthquakes to damage and destroy school buildings is now well accepted. There is considerable risk to our students, teachers, and administrators of being injured or killed, primarily due to failures to design and construct school buildings with sufficient wind and earthquake resistance and to ensure effective school earthquake/wind safety programs. An acceptably built environment and emergency response training and planning are essential partners. As in Armenia, there is often very little evidence of public education and disaster response planning prior to the earthquake. Even with the building damage that occurred, many lives could have been spared, especially of school children, had the public been properly educated in seismic safety. Only after the devastating earthquake are school children being properly trained and other contingency measures implemented.

It is believed that each public or private school of 50 students or more should establish an earthquake and wind emergency system that would include appropriate training,

..s, disaster plans, and protective measures ..o take before, during, and after a natural disaster.

Special Concern For The Earthquake Vulnerability of Existing Schools

Most if not all existing elementary and secondary schools in South Carolina were constructed without mandated earthquake-resistant design provisions and, with few recent exceptions, operate without the benefit of mandated earthquake emergency procedures and training. These vital actions have been left to voluntary implementation by the local governing boards. For several reasons, including probably assumed funding limitations and lack of informed public opinion as to the earthquake risk, they have largely been ignored. This condition is particularly demanding of expedited remedial action as the occupancy of such schools by South Carolina's most precious resource, its children, is required by law. Certainly, the moral and legal responsibilities for properly protecting these occupants are great. The condition is found even more unacceptable when considering that the occupant density is one of their highest of any building type and that, after an earthquake, badly shaken and frightened children may find emergency egress from a damaged building either difficult and hazardous or impossible.

In the face of mounting concern for the earthquake risk, some recent progress has been achieved. Recently, the Standard Building Code which is usually adopted for school construction was amended to include required minimum earthquake design provisions. While certainly a positive measure, it is not the solution for the school built environment. It addresses only new construction when required by local school authorities, leaving the vast system of existing schools without promise of planned strengthening. It fails to adequately consider proper treatment of the other potentially hazardous aspect of the school built environment, the "non-structural" elements such as ceilings, windows, files, and inventory stored on shelves.

The prescribed standards are for normal building types and not appropriate for high-occupancy, critical facilities like school buildings. Some early improvements in earthquake emergency procedures and training have developed during the past few years. The administration of the Charleston County Schools has asked each of the 70 principals to incorporate earthquake safety planning within their school safety plan by May, 1989. This current state of critical unpreparedness is not unique to the public school system. Aside from its special importance to the welfare of children, these shortcomings in building standards and practices as well as emergency planning and training are fairly typical of statewide conditions within South Carolina today.

The Need For Action - We Do Not Need To Be Told Again

South Carolina does not need to wait for a destructive earthquake or hurricane to demonstrate the priority need for better constructed schools and improved emergency response procedures. We do not need a 1933 Long Beach earthquake experience to prompt a prudent school construction program in South Carolina. We do not need another Hurricane Hugo or 1886 Charleston earthquake. There is enough clear and compelling evidence of the need. Fortunately, good evidence that cost-effective remedial design and construction measures is available. There is also the solid evidence that they work. The successful performances of well designed and constructed schools in California during recent earthquakes provide irrefutable proof.

The school construction system needs to be changed to ensure a safe built environment with the schools. It needs to be upgraded in a manner consistent with today's environment of dynamic growth and other changes, including increased public awareness and concern for improper regulating standards and construction practices as well as the imperative need to far better cope with the statewide high risk of multiple natural hazards. It needs to be improved consistent with the other actions aimed at general statewide improvements in design and construction standards and practices.

As has been done in other similar situations, the school districts could be required to pay the Department of Education fee at the time of application for approval of the plans. These fees would pay for the enhanced operation of the Office of School Planning and Building. Upon appropriate request, the structural condition of any public school building will be examined and reported.

7. An Action Plan To Improve the School Building Safety Environment

Introduction

As discussed in the preceding section, there is critical need to iprove the public school building environment in South Carolina regarding the historic natural hazards threats of wind, flood and earthquakes. State building practices and standards for public schools are in need of significant and prompt upgrade. Existing school facilities must be strengthened and the new buildings constructed to improved standards, especially considering their role as public shelters when natural disasters strike.

Emergency preparedness provisions are being integrated into the school environment by the Department of Education in cooperation with the South Carolina Emergency Preparedness Division. This training and education work needs to be extended. There is no such program to upgrade the school built-environment for the natural hazards environment. As a complement to the emergency preparedness training program, a comprehensive, long-term statewide school building safety improvement program is essential to mitigate the serious threat of natural hazards to the students, faculty and staff members of our schools in South Carolina. This section recommends an action plan to achieve this objective.

The Ball Must Now Be Carried By The State

A significant awareness, experience and technical knowledge base has been established in support of potential school safety improvement efforts. Several detailed studies and the Hugo experience have confirmed the seriousness of the uncommon combination of natural hazards threats and defined the exceptional vulnerability of South Carolina public schools to these threats of earthquakes, winds and flood. They have also established tools by which an effective state mitigation program can be constructed. Of added value, they have influenced ongoing state building code improvement measures that will further contribute to improved school building construction standards.

However significant, these efforts only represent potential improvements in the safety of the school built-environment. They must now be translated into actual upgrades. The South Carolina state government must lead this continued progress. It must establish a long-term improvement state program to consolidate these early gains and to begin their comprehensive and focused application to the mitigation of natural hazard threats to the public school environment in South Carolina. The serious compromises of the school environment must be brought out into the light and effective remedial measures taken.

Natural Hazards School Building Safety Improvement Program

Cooperative action by the Governor and Legislature is necessary to establish the necessary State of South Carolina Natural Hazards School Building Safety Improvement Program. The long-term program would focus on the safety of the school built-environment in cooperation with emergency preparedness activities. It would be (1) to achieve within a prescribed time period the improvement of all existing schools to incorporate minimum adequate resistance to natural hazards, (2) to ensure that new schools are constructed to natural hazards design criteria consistent with their essential functions, and (3) to improve the contents of emergency response training and equipment programs as they relate to the school built-environment.

A special South Carolina School Building Safety Panel should be created by the Legislature with the recommendations of the Governor to develop an integrated action plan to guide the formulation of this safety program and to provide advise regarding its continued operation.

It is recommended that the Panel consist of ten members appointed by the Governor and confirmed by the Senate. The Panel membership should represent the professions of architecture, electrical engineering, fire protection, geotechnical engineering, geology, mechanical engineering, structural engineering, and seismology and that such representation the public interest.

In view of the necessity to consider statewide building conditions and standards, it is recommended that the Panel operate under the full cooperation and support of the South Carolina Building Codes Council, the South Carolina Department of Education, The South Carolina State Geologist, and the South Carolina Emergency Preparedness Division. The voluntary contributions should be solicited of the South Carolina Parent Teachers Association, the South Carolina Plant Management Association and certain other education-related professional organizations from those listed in Table 5.

Table 5. Other Potential Panel Advisors

Palmetto State Teachers Association
School Council Assistance Project
South Carolina Association for School Psychologists
South Carolina Association of School Administrators
South Carolina Association of School Business Officials
South Carolina Association of Secondary School Principals
South Carolina Association of Vocational Home Economics Teachers
South Carolina Education Association
South Carolina Industrial Technology Education Association
South Carolina Public Health Association
South Carolina School Boards Association
South Carolina Trade and Industrial Education Association
The Citadel, Clemson University and Baptist College at Charleston

An Integrated Action Plan To Define The Improvement Program

Once appointed, the South Carolina Schools Building Safety Panel would form an action plan for its development of the Natural Hazards School Building Safety Improvement Program. Its integrated improvement efforts should include structural and nonstructural building improvements as well as building-related refinements to emergency preparedness programs. The Panel would have to consider the technical aspects of natural hazard threats and the engineering avenues to mitigation within the real world constraints of limited state budgets as well as relevant social and political issues. In resolving design criteria, careful consideration would need to be given the viewpoints and requirements of the functional user - the educator. Maximum advantage would need to be taken of the steadily growing national technology base regarding the strengthening and construction of buildings in a natural hazards environment.

Given these and other considerations discussed in this document, the action plan can include areas of work as follows:

I. Establish risk and vulnerability,

II. Review and upgrade design criteria considering vulnerability and functional use,

III. Develop a national hazards school building safety improvement program,

IV. Review and include emergency preparedness procedures,

V. Reorganize for effective implementation, and

VI. Submit for legislative approval and implementation.

Details of twelve action items for this plan are shown in the box.

8. Some Opportunities For Safety Improvements In The School Building Environment

Several initiatives that represent potential improvements in the school building environment have been completed or are in progress. All initiatives are supportive of the improvements in the school building system and its workings as recommended in the preceding sections. These are summarized below.

Seismic Design Building Code Improvements

With the release of its 1988 edition, the Standard Building Code now has mandatory earthquake engineering design provisions. As a consequence, all municipalities and agencies that have adopted the Standard Building Code are requiring earthquake as well as wind design provisions for new construction. As previously discussed, the State Superintendent of Education establishes school building design criteria that incorporates most but not necessarily all provisions of the Standard Building Code.

Unfortunately, the South Carolina School Facilities Planning & Construction Guide has not been adjusted to be consistent with the new edition of the Standard Building Code. The guide continues to allow seismic design to be a local option. It is understood that school districts in the Charleston area are more deliberately encouraged to incorporate seismic de-

A 12-Point Action Plan for the Natural Hazards School Building Safety Improvement Plan

I. Risk and Vulnerability

a. Review and validate the definition of natural hazard risks (wind, earthquake, and flood) to schools in South Carolina, considering their collective as well as individual effects.

b. Conduct a wind, earthquake and flood vulnerability survey of all existing schools to establish their structural and nonstructural deficiencies.

II. Upgrade Design Criteria

c. Review the special importance of school buildings to the community welfare, health and safety and upgrade functional and protective criteria accordingly.

d. Review and recommend upgrade as deemed appropriate of the natural hazards building code provisions of the Standard Building Code and South Carolina coastal construction regulations consistent with the emerging new generation building code technology such as that developed under the national Earthquake Hazard Reduction Program for seismic mitigation.

e. Establish and recommend any more stringent technical design criteria for school design and construction that may be necessary beyond the provisions of Action Item 4, considering the special functional importance of schools.

f. Assess and recommend appropriate revisions of the provisions of the South Carolina School Facilities Planning and Construction Guide considering the results of Action Items 3, 4, and 5 as they relate to the design and construction of school facilities to mitigate natural hazards.

III. Natural Hazards School Safety Program

g. Considering results of statewide school vulnerability study and proposed new generation school design and construction criteria, define requirements for improved existing schools and upgraded new construction.

h. With the cooperation of the South Carolina Budget and Control Board, develop budget constrained alternatives to funding necessary school building improvements.

i. Establish a comprehensive prioritized and phased program for the appropriate natural hazards safety improvement of existing and proposed new school buildings (integrating such upgrades where possible into currently defined projects) based upon the results of Action Items 7 and 8.

IV. Emergency Preparedness Procedures

j. Review and recommend any necessary refinements of statewide emergency preparedness training and education program to ensure that each school establishes and maintains an effective School Natural Hazards Safety Program proven through regular drills and other exercises.

V. Effective Implementation

k. Consider and recommend the reorganization and strengthening of the Office of School Facility Planning and Building as necessary for it to discharge its responsibilities for school design and construction activities.

VI. Legislative Approval and Implementation

l. Prepare and submit to the South Carolina Legislature in cooperation with the Department of Education a proposed Natural Hazards School Building Safety Improvement Program for the State of South Carolina incorporating the preceding developments.

provisions. It is by local professional ...ce when and if seismic design provisions are incorporated in Charleston County. The SBC adoption of mandatory seismic design provisions represent a significant improvement potential for the school system.

Statewide Adoption of Building Code System

The principal cause of inadequate building standards and practices in South Carolina is the absence of a statewide building code system, including the means of effective code application. Important remedial action is in progress.

Legislation was introduced during the last legislative session that would require all cities, towns, and counties to adopt building codes within a specified time period, based on population. Companion proposed legislation was introduced which would require all code enforcement officers within the state to be certified and to maintain their proficiency through continuing education. This legislation was introduced in the Senate as Legislative Bill S.0460 under the sponsorship of Senator Glenn McConnell. Representative G. Ralph Davenport introduced the measures in the House as Legislative Bill H.3675.

Committee action had been completed in both the Senate and House when the legislative session ended. The measure has been prefiled in the Senate by its sponsor, Senator McConnell (S.0140) and should be voted upon during the beginning of the next legislative session to commence in January 1991.

In addition to the legislative proposals, the following complementing initiatives are under consideration by the South Carolina Section, American Society of Civil Engineers:

1) Improved Education Opportunities for Building Officials.

2) Technical Peer Review.

3) Specialized Registration of Structural Engineers.

4) Improved Delineation of Architect and Engineer Responsibilities.

Guidelines For Rehabilitation Of Existing and Historic Buildings

The proper rehabilitation of existing schools is of highest concern. Unlike for new construction, there are no guidelines established for the strengthening of existing schools and other buildings. Given the added emphasis of Hugo experiences, a project to develop guidelines for the rehabilitation of existing and historic buildings for the multi-hazard environment has been included in the South Carolina Post-Hugo Mitigation Plan. Overall direction of the project will be provided by the Berkeley-Charleston-Dorchester County Council of Governments and the Historic Charleston Foundation. The technical direction will be provided by the Applied Technology Council and The Citadel. Primary support will be provided by the U.S. Park Service and Cornell University.

The primary objectives are to establish (1) building code standards and supporting technology for the rehabilitation of existing essential buildings including schools and (2) recommended guidelines for the rehabilitation of historic buildings. The immediate focus is to establish such codes and guidelines for the Charleston area and South Carolina. This work will involve (1) the evaluation of existing buildings to establish the nature and priority of rehabilitation need as well as (2) the development of rehabilitation guidelines. Ultimately, it is expected that these developments will be offered for inclusion in the Standard Building Code and the Secretary of the Interior's guidelines for historic buildings.

Maximum advantage is to be taken from existing buildings methodologies and technologies continuing to be developed for earthquake applications under the National Earthquake Hazards Reduction Program (NEHRP) as directed by the Federal Emergency Management Agency. These include that produced through ATC-22, *Handbook on Seimic Evaluation of Existing Buildings* and ATC-28, *Development of Guidelines for Seismic Rehabilitation of Hazardous Buildings*. The U.S. Postal Service is building upon this technology base in conducting ATC-26, *Development of a National Program for the Seismic Evaluation and Rehabilitation of Existing Post Office Buildings*. This project includes (1) development of seismic structural evaluation methodology; (2) development of nonstructural evaluation methodology; (3) development of seismic retrofit criteria and methodology; and (4) development of cost impact studies and program cost projections. The South Carolina project will also take advantage of this ongoing U.S. Postal Service development, extending it to include wind and flood.

Remapping Of Statewide Seismic Risk

Considering available information including Hurricane Hugo data, the wind risk of South Carolina appears to be acceptably represented by the Standard Building Code. This is not true for the statewide earthquake risk. Cooperative actions are now underway with the U.S. Geological Survey to reassess the seismic risk in South Carolina consistent with national risk mapping developments. This project is being led by The Citadel and conducted with the direct participation of the South Carolina Building Codes Council and the South Carolina State Engineer. It is expected that this upgrade will be available for adoption during the early part of 1991 by the Department of Education and the South Carolina Building Codes Council for use throughout South Carolina.

Upgraded Earthquake Design Building Code Provisions

During the past several years, the Federal Emergency Management Agency has developed new generation provisions for the development of seismic regulations for new buildings. This work has been done under the National Earthquake Hazard Reduction Program (NEHRP) by the national community of building specialists and trade organizations. With the support of the Federal Emergency Management Agency provided through the Building Seismic Safety Council (BSSC), The Citadel has developed improved earthquake engineering design standards for typical new school construction based upon these recommended national provisions. An integrated wind-seismic design approach was taken. Charleston County school buildings were used as design prototypes. The objective is to produce new generation building standards and building code provisions for South Carolina new school construction based upon the NEHRP Provisions. These developments are now available for consideration and adoption by the South Carolina Department of Education.

As part of the development of the upgraded earthquake design standards, "microzonation" maps were prepared for the greater Charleston, South Carolina, area that delineate regional variations in potential for soil liquefaction and site amplification of ground shaking. Communities at risk should develop such maps for construction planning and design purposes. The importance of the value of the natural period of the soil column is well established (Lindbergh, 1990). The closer these two values, the greater is the magnitude of potential earthquake damage to the building.

Post-Natural Hazards Building Assessments

As demonstrated in the recovery from Hugo, contingency capability to rapidly assess the condition of buildings after an earthquake, wind storm or flood. ATC-20, *Procedures for the Postearthquake Evaluation of Buildings* has been extended by the U.S. Postal Service to include wind and flood events as well as earthquakes. The basic procedures were used by volunteer engineers in South Carolina in the aftermath of Hurricane Hugo. This capability is available for adoption by the South Carolina Department of Education to promote the safe reutilization of school buildings after a natural hazard event.

Natural Disaster Emergency Preparedness Training

Under the direction of the South Carolina Emergency Preparedness Division (EPD), several important actions are being taken to improve the emergency preparedness of school students, faculties and staffs.

The Charleston County Emergency Preparedness Office has conducted earthquake search and rescue exercises. With the assistance of the Earthquake Education Center at Baptist College of Charleston, "drop and cover" school drills are being conducted.

The National Science Teachers Association (NSTA) and the Federal Emergency Management Agency have completed a 280-page curriculum on earthquake science and safety. The curriculum is designed for K-6 grades. The curriculum guide features interdisciplinary lesson plans and hands-on activities. A hands-on workshop of the Southeastern

...onal Science Teachers Association Conference was held in Charleston during December 1988. The South Carolina Department of Education is cooperating.

Assistant Superintendent of Charleston County Schools has asked each of the 70 school principals to incorporate earthquake safety planning within their school safety plan by May, 1989. Mr. Tom Curio recognized the need for the administrators, staff, and faculty to set the guidelines of actions they would follow in the event of an earthquake.

Other Actions

State and regional engineers and architects have not been sufficiently trained in the design of facilities to withstand the effects of applicable natural hazards. Accordingly, special emphasis is being placed on providing the required specialized educational opportunities through integrated workshops, conferences, courses, and literature.

Under funding of the National Science Foundation and the National Center for Earthquake Engineering (NCEER), The Citadel is developing a technical handbook for the wind and seismic design of reinforced masonry structures featuring the Standard Building Code provisions and regional construction types and conditions.

9. The Essential Partner - Emergency Preparedness Planning

As stated in Section 7, the recommended 12-Point Action Plan would include efforts to review and recommend refinements of statewide school safety emergency preparedness training and education programs as they relate to the built environment. As such, this project would assist those organizations charged with primary responsibilities for these programs.

A number of schools in South Carolina have already developed earthquake school safety programs. Multihazard school safety programs are necessary. The Federal Emergency Management Agency provides a "Guidebook for Developing a School Safety Program," designated as document FEMA 88/December 1985, that is helpful in establishing the earthquake elements of the essential multihazards safety program. The following summary overview of school safety program considerations is provided to suggest the manner in which the subject school building oriented safety program can enhance the operational-oriented schools safety programs.

The Guide outlines a planning approach that can be used to work towards developing action plans for an earthquake safety program. Possible components of a safety program include (1) hazard identification, (2) earthquake drills, (3) an earthquake response plan, (4) earthquake education, (5) training programs, (6) hazard reduction projects, (7) shelter plans, and (8) equipment and supplies.

Hazard identification involves knowing what to expect. It is the foundation of quality plans and procedures for conducting classroom and post-earthquake building evacuation drills and for preparing response and shelter plans. The hazard assessment should also consider the potential impact of a major earthquake on the community and the probable hazards it could cause. For example, additional plans would be necessary if the school is located below a dam (like the North Dam on Lake Moultrie) or near a hazardous waste site (like the GMX landfill site near Rimini, SC).

Earthquake drills are the most important of all earthquake preparedness measures because earthquakes strike without warning. Life protecting measures must be taken immediately at the first indication of ground shaking. Students and staff members must learn how to REACT immediately. The essential components of earthquake drills are classroom discussions, demonstrations, and exercises designed to help students learn and practice WHERE to seek shelter and HOW to protect their heads and bodies from falling objects (e.g., debris from ceilings, light fixtures, and shattered glass). Effective earthquake drills simulate (1) actions to be taken during an actual earthquake and (2) actions to be taken after the ground shaking stops. Building evacuation following an earthquake is imperative due to the potential danger of fires or explosions.

A major earthquake will cause widespread damage and may trigger other dangers such as fires and the release of hazardous materials. Local emergency personnel will be severely overtaxed. It may be several hours before they are able to respond to every school within the effected community. Effective first-hour emergency response actions must be established. The care and safety of students during the immediate aftermath of an earthquake is especially critical. First aid must be provided.

Following an earthquake, communications systems that are dependent on electrical power may be partially or totally disrupted for several hours or longer. A communications plan must be developed that addresses this problem and prescribes alternate ways to receive and convey messages (especially with parents).

Post-earthquake shelter planning must consider extended-care as well as short-term shelter needs. Children should not be released to travel streets cluttered with debris from damaged buildings and fallen power lines. Damaged transportation routes may prevent their relocation to home or other shelters. Expert judgment may be required to determine if buildings are safe for re-entry. Buildings must be properly inspected.

10. Pending School Renovation and New Construction-A Special Reason To Act Now

School Construction Fund Requirements, 1990-1995

There are approximately 1,025 schools in South Carolina according to the Director of School Facility Planning and Building. The development of the recommended improved school building program featuring seismic and wind safety must be considered collectively with anticipated school construction costs.

On February 9, 1989, the General Assembly passed a Concurrent Resolution for the State Department of Education to conduct a survey to identify the school building facilities needed over the next five years. The survey was completed in May, 1989. Total costs for new construction, additions, and renovations of school buildings were estimated using reports from the 76 school districts. The following major results were reported in the released study:

- South Carolina's public school districts are projecting $1.5 billion in school construction needs through 1995.
- Considering all funding sources available, 76 districts are facing a total shortfall of more than $1 billion for school buildings during the next five years.
- Fifteen of the state's 91 school districts estimated that they will have more than enough funds to meet school construction needs through 1995.
- The total estimated cost for new construction, renovations and additions to public schools through 1995 is $1,480,045,748. School districts estimated a total of $494,988,857 will be available in state sources and local funds from bonds. Fifteen districts estimated an excess of almost $40 million will be available to them for school construction. The five-year projected shortage of funds in 76 districts is $1,024,974,431.
- The projections do not include costs of management plans or asbestos removal by the Asbestos Hazard Act of 1986.

In projecting costs, an inflation factor of 4 percent was applied for each year. Capital funding from state sources includes: (1) a general aid allocation of $15 per kindergarten student and $30 per student in grades 1-12 based on membership projections over the next six years, and (2) an Education Improvement Act allocation based on one-half of one percent of the projected revenue each year.

A Special Reason To Act Now

Indeed, the projected levels of construction fund requirements and anticipated funding shortfalls during the 1990-1995 time period represent significant challenges to the State and School Districts. However, they also represent significant opportunities to commence and achieve substantial mitigation of serious vulnerabilities of South Carolina schools to natural hazards. It is probable that the increase in annual program costs necessary to achieve for proper school construction would be less than the annual rate of inflation used in the estimates. These limited construction funds are critical resources. They should not be spent for construction that ignores the realities of serious natural hazard threats. To do so would be to maintain the health, safety, and welfare of the public at unnecessary and unacceptable risks.

References

Amick, D. and Talwani, P., 1986, "Earthquake Recurrence Rates and Probability of Significant Seismic Activity in the Charleston Area: The Next 100 Years," *The Third United States Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, Charleston, SC.

Bollinger, G.A. and Visvanathan, T.R., 1977, "The Seismicity of South Carolinia Prior to 1886," *Studies Related to the Charleston, South Carolina, Earthquake of 1886—A Preliminary Report*, United States Geological Survey, Professional Paper 1028-C.

Harlan, H.R. and Lindbergh, C., 1988, "An Earthquake Vulnerability Analysis of the Charleston, South Carolina Area," The Citadel, Charleston, SC.

Hays, W., 1981, "Hazards From Earthquakes," Section 2 of U.S. Geological Survey document "Facing Geologic and Hydrologic Hazards," U.S. Geological Survey Professional Paper 1240-B, U.S. Government Printing Office, Washington, DC.

Lindbergh, C., 1984, "Seismic Safety: A Challenge to the South Carolina Engineer, Part I," The South Carolina Engineer, Vol. XXXIV, No. 3, Summer 1984, Columbia, SC, pp. 6-9.

Lindbergh, C., 1984, "Seismic Safety: A Challenge to The South Carolina Engineer, Part II," The South Carolina Engineer, Vol. XXXIV, No. 4, Fall 1984, Columbia, SC, pp. 8-11.

Lindbergh, C. (Editor), 1986, "Earthquake Hazards, Risk, and Mitigation in South Carolina and the Southeastern United States," South Carolina Seismic Safety Consortium, The Citadel, Charleston, SC.

Lindbergh, C., 1988, "The Establishment of Minimum Building Standards in South Carolina," The Citadel, Charleston, SC.

Lindbergh, C., "The Armenian Earthquake of 1988-The Event and Its Implications for Charleston, South Carolina and other Cities in the Eastern United States - An Eastern Engineer's Perspective," 1989, Department of Civil Engineering Technical Report No. CE-89-1, The Citadel, Charleston, SC.

Lindbergh, C., "A Program to Improve the Safety of Existing and New Elementary and Secondary School Buildings for the Natural Hazards Environment in South Carolina," The Citadel, Charleston, SC.

NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings, Federal Emergency Management Agency, Washington, DC, 1985

Sparks, P.R., 1985, "Building Damage in South Carolina Caused by the Tornadoes of March 28, 1984, "National Academy Press, Washington, DC.

Sparks, P.R., 1990, "Wind and Surge Conditions in South Carolina During Hugo," Vol. XL, No. 1, Summer 1990, Camden, SC, pp. 2-4.

Sparks, P.R., Murden, J.A. and Sill, B.L., 1990, "Building Performance Under the Action of Wind in Hurricane Hugo," Vol. XL, No. 1, Summer 1990, Camden, SC, pp. 5-8.

Talwani, P., An Internally Consistent Pattern of Seismicity Near Charleston, South Carolina, *Geology*, Vol. 10 (12), 654-658, Dec. 1982.

Tarr, A.C., 1977, "Recent Seismicity Near Charleston, South Carolina, and its Relationship to the August 31, 1886, Earthquake," *Studies Related to the Charleston, South Carolina, Earthquake of 1886—A Preliminary Report*, United States Geological Survey, Professional Paper 1028-D.

Visvanathan, T.R., 1980, *Earthquakes in South Carolina 1698-1975*, Bulletin 40, South Carolina Geological Survey, State Budget and Control Board.