SAND99-1359J

ASSURING THE PERFORMANCE OF BUILDINGS AND INFRASTRUCTURES:

REPORT OF DISCUSSIONS

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TF 9711-635

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INTRODUCTION

How to ensure the appropriate performance of our built environment in the face of normal conditions, natural hazards, and malevolent threats is an issue of emerging national and international importance. As the world population increases, new construction must be increasingly cost effective and at the same time increasingly secure, safe, and durable. As the existing infrastructure ages, materials and techniques for retrofitting must be developed in parallel with improvements in design, engineering, and building codes for new construction. Both new and renovated structures are more often being subjected to the scrutiny of risk analysis. An international conference, "Assuring the Performance of Buildings and Infrastructures," was held in May 1997 to address some of these issues. The conference was co-sponsored by the Architectural Engineering Division of the American Society of Civil Engineers (ASCE), the American Institute of Architects, and Sandia National Laboratories and convened in Albuquerque, NM. Many of the papers presented at the conference are found within this issue of *Technology.* This paper presents some of the major conference themes and summarizes discussions not found in the other papers.

OVERALL STRUCTURE PERFORMANCE

Much of the discussion at the May 1997 conference centered around the topic of how to improve and prolong the performance of buildings in such a way as to make them more cost effective and more robust to natural hazards.

Norman J. Glover, AEGIS Institute. Norman Glover represented the ASCE viewpoint. He expressed concern about the tendency of engineers and architects to pursue their specialized professions at the expense of the whole project. He maintained that the various design disciplines should be integrated at the earliest stages to produce attractive, energy efficient, cost effective structures that satisfy the owner's intentions and needs. Unfortunately, in the effort to design and build structures that fulfill ever larger and more sophisticated appetites, engineers frequently fail to consider adequately the conditions, natural and man-made, that make total systems engineering necessary. In Hurricane Andrew in Florida, miles and miles of tapered light standards on Florida's Turnpike collapsed identically by buckling at the wiring junction box. Glover speculated that one engineer designed the road lighting and another designed a handsome, economical light standard, possibly even designed to resist a high wind load. However, a third engineer realized that the light had to be wired up and cut a section out of the pole for a junction box. That was the weak point where the system collapsed. The engineers were neither speaking to each other nor asking each other the right questions.

Gabor Lorant, FAIA, Gabor Lorant Architect, Inc. Gabor Lorant, chair of the AIA Building Performance Center, represented the American Institute of Architects, one of the sponsors of the conference. He said that the American Institute of Architects (AIA) has 60,000 members, about 60% of all the architects in the United States. The Institute encompasses design, professional practice, continuing education, public relations, and government affairs—more than 20 functional categories that are linked with professional interest areas that members join to acquire specialized knowledge. Building Performance, Codes & Standards has been a long-standing major interest area. The creation of a single model code for the United States was initiated by the AIA. Its members have been instrumental in bringing about the collaboration of the many and diverse entities into the International Code Council. As a result, the first single model code is expected to be issued in the year 2000. Current model codes are *prescriptive*; in contrast, the International Building Code will be *performance based*. Each requirement will state its purpose and the expected result. This approach gives more opportunity for alternative solutions, innovation, and general progression to improvement from design to construction and long-term operation. Both government and corporate building owners are beginning to recognize that facilities should be created to perform predictably for a given *life cycle*, simply because the capital cost is only a fraction of the life-cycle cost of most projects. Hurricane, flood, fire, earthquake hazard mitigation, operational costs, employee productivity, etc., are all factors in life-cycle performance and must be dealt with in a prudent way. Several case studies indicate that appropriate design can increase productivity and lessen the cost of operation to the extent that the overall life-cycle cost is significantly reduced. The facility thus pays for itself, and the entire operation becomes more productive, an important element in worldwide competition. Lorant concluded by saying that the national laboratories represent a great intellectual asset and will serve the national interest by adapting the knowhow achieved in serving the military during the past 40 years to civilian purposes such as design and building technology in a collaborative effort with professional organization like the AIA.

Carlos Ventura, University of British Columbia. Carlos Ventura discussed the nature of materials and their effective use in civil engineering structures. We are currently in a global infrastructure crisis: bridges collapse, roadways crumble, and pipelines crack. The estimated world-wide demand for infrastructure repair is $900 billion. The global infrastructure building boom of the post-second world war era has given way, and now structures built decades ago are disintegrating under limitations of concrete and steel construction materials. The industrialized countries face the intimidating and costly task of replacing or repairing vital roads, bridges, pipelines, and buildings, but building, replacing, or repairing structures using traditional materials only feeds the cycle of deterioration and costly repair. One possible solution is to break the cycle by providing alternatives destined to become new standards in engineering and construction. Engineered wood products (EWPs), advanced composite materials (ACMs), and fiber-reinforced composite (FRC) materials are all examples of new types of construction materials. The evolution of EWPs in North America began with the introduction of plywood in the 1930s and continued with fiber cement board in the late 1940s, particle board in the late 1950s, oriented strand board (OSB) in the early 1960s, medium density fiberboard (MDF) and laminated veneer lumber (LVL) and I-joists in the late 1970s, parallel strand lumber (Parallam) in the early 1980s, and laminated strand lumber (Timber Strand) in the early 1990s. These products result from taking wood apart and reassembling it in a manner that it will yield a useful material with predictable engineering properties at competitive value. ACMs are strong, light and corrosion free. They can double the life cycle of a bridge when used for patching and wrapping existing concrete, giving old structures superior performance and durability. ACMs can compete now with conventional structural materials because glass, aramid, and carbon fibers and epoxies, vinyl esters, polyesters, and bonding agents are also available. The development of our understanding of materials has enabled engineers to establish the forces that can be safely imposed on structures or components, or to choose materials appropriate to build or repair structures that must withstand given loads without affecting their proper function.

Peter I. Yanev, EQE International, Inc. Peter Yanev noted that the Northridge (USA) and Kobe

(Japan) earthquakes were the first truly urban seismic events affecting large numbers of modern buildings. Certain types of buildings were tested in large numbers for the first time. The only real surprise was the poor performance of certain types of steel-frame buildings. The Northridge Earthquake struck in an area of California containing the highest concentration of locations that had been previously evaluated by an engineering research project, and thus the destructive event created a unique research opportunity. In the weeks following the earthquake, the team of engineers revisited 40 locations in the areas of greatest damage and compared the physical damage that actually occurred with the damage that was predicted. The results of the damage study have been well documented, with the following highlights: (1) the damage that occurred was predicted with considerable accuracy; (2) the cost to have prevented several large (more than $1 million) losses would have been in some cases no more than a few thousand dollars; and (3) nearly 70% of the time, fire-protection systems failed exactly as had been predicted in areas of intense shaking. Yanev concluded that design beyond code can vastly improve building performance and dramatically reduce damage.

Mukund Srinivasan, Hart Consultant Group. Mukund Srinivasan noted that the concept of surety as a means of ensuring behavior or performance has long been held in the financial arena. Recently, it has been carried over into architectural and structural design. In performance-based design, the design engineer first quantifies levels of acceptable deformation and then uses limit-state behavior to identify the states of the various sub-elements that form part of the building. Such design is common among historical buildings in California. These buildings often have brittle facades that cannot be allowed to fail, because this would change the look of the building and pose a hazard to pedestrians. The first step in performance-based design is to identify the level of motions at which failure would occur and use it as a limit for the deformation of the building under a specified level of ground motion. The building can then be strengthened by any seismic retrofit scheme that limits deformation to this pre-specified level. Currently, building design codes are based on a level of performance called "life safety." Under a specified level of ground motion, the building will not collapse and will allow its occupants to be evacuated safely; however, it may be so damaged that demolition is the only solution. New technologies available to structural engineers can be used to ensure structural surety with the goal of immediate occupancy. This performance level can be defined as one whereby the building under the specified level of ground motion (currently a 475-year earthquake in the Uniform Building Code) will suffer no structural damage and will be ready for occupancy immediately after the earthquake. Two technologies that could support immediate occupancy are base isolation and viscous dampers. A base isolator is a rubber element used as the base of the columns in the building. Such an isolator may or may not have a lead core to add hysteresis. Under earthquake loads, the soft structure of the isolators reduces the ground acceleration to relatively low levels that can be sustained by the superstructure with no damage. The building moves significantly (up to 20 inches), however; a moat has to be constructed around the building to allow movement. This scheme is not practical for tall structures with large aspect ratios. Viscous dampers look like and act much like shock absorbers in cars. Motion is resisted by a fluid-filled damper where the resisting force is proportional to some power of the velocity. These dampers are used like braces between two floors in a building and can reduce the overall earthquake effects by increasing effective damping in the building from 5% to 30%. Both methods have been used successfully in new and retrofitted structures and performed well in both the 1994 Northridge and 1996 Kobe earthquakes. Srinivasan concluded that structural surety is more than just a concept: it is a reality with its own problems, challenges, and promises. It makes economic sense in allowing owners to stretch the building cost over a longer period of time. It makes intellectual sense in challenging the designer to understand building performance completely and not hide in safety factors. And finally, it makes sense in making the profession stand behind its products like all others.

RISK MANAGEMENT

Financial risk assessment has long been used by insurance companies, but risk analysis has been little used in the past to assess the probable performance of individual structures. Now scientific and engineering aspects of risk analysis for buildings constitutes a growing field. Several conference participants described applications of risk-management tools to buildings and infrastructures.

Financial Perspectives

Ronald Polivka, EQE International, Inc. Dr. Ronald Polivka noted that no site is safe from the risk posed by natural hazards (e.g., earthquakes, hurricanes, floods, fires). In addition, for certain business sectors such as the high-technology industry, the value of exposed assets at risk has been increasing exponentially over time, but the level of protection has not. There are three key steps in implementing a successful natural-hazards risk-management program for a corporation or entity having a multitude of sites at risk. The first step is to perform a software-based portfolio analysis for all sites (to approximately quantify and rank the expected losses and to better understand which sites control the overall exposure); this analysis is followed up with selected engineering site assessments of both buildings and equipment for high-risk sites to better quantify potential property damage and to address issues such as expected downtime and associated business interruption, market share loss, and related financial effects. The second step is to maintain the program, both through engineering-based risk assessments for new properties and through an annual portfolio analysis. The final step is to conduct cost-benefit analyses to determine what loss-control measures make sense. In summary, understanding and managing the risk posed to assets by natural hazards can dramatically reduce their effects. Once these risks are quantified, informed decisions can be developed and implemented. The risks posed by natural hazards can be managed and controlled in the same way as other business risk.

Paul A. Croce, Factory Mutual Research Corporation. Paul Croce discussed risk management from the perspective of an industrial insurer. The Highly Protected Risk (HPR) approach to risk management combines informed underwriting with state-of-the-art loss prevention technology, prudent risk-management policies, and diligent loss adjustment. The Factory Mutual (FM) System arose from the Manufacturers Mutual Fire Insurance Co. in Rhode Island, founded in 1835. FM began sprinkler testing and approvals in 1884 and established laboratories in 1886. Installation guidelines were first issued in 1893. Sprinkler research began in 1948. The Factory Mutual System today includes three insurance companies, with 2000 engineers worldwide performing state-of-the-art scientific research that leads to installation guidelines and standards, approval testing and certifications, loss adjustment services, and education and training. Research on loss prevention investigates (1) protection systems (sprinklers and fine-spray technologies, gaseous agent and additive systems, detection and smoke/contaminant control); (2) materials (flammability and reactivity, non-thermal damage, other material characteristics); (3) structures (response to dynamic loadings and macro vs. micro environments from natural hazards and fires), and (4) risk engineering methods (industrial risk analysis and reliability, availability, maintainability of systems). The HPR concept has been effective in reducing the "burning loss" cost per $100 insurance from 84 cents in 1835 to 1 cent in 1995.

John J. Mulady, USAA Property & Casualty Insurance. John Mulady noted that the property insurance industry has changed dramatically as a result of recent natural disasters, starting with Hurricane Hugo in 1989. Until 1989, the property lines were profitable for the industry. No catastrophe losses exceeded $1 billion before that time, but since then hardly a year has gone without such losses. The industry as a whole is overexposed in areas that suffer natural disasters, and some companies have chosen to cease writing new business. This has created a tremendous increase in the writings of the state's plans and pools. For example, the Florida Windstorm Underwriting Association, which provides Wind and Hail coverage in the coastal state of Florida, has increased from writings of $16 billion to over $50 billion since Hurricane Andrew. Companies that are licensed to write business in Florida participate in the losses of the pool, as they do in all residual plans and pools. The insurance companies cannot totally walk away from their social responsibilities, so they have had to rethink their business in the property lines. A speaker at the National Hurricane Conference predicted in 1997 that the industry will first design new forms for the property lines, then will increase prices, and finally will insist on mitigation. The Insurance Institute for Property Loss Reduction (IIPLR) was formed in January, 1994. IIPLR is an advisory organization supported by industry, and its mission is to reduce loss of life and injury and to support structural integrity. The insurance industry is interested in mitigation, improved design and construction, and building-code enforcement. Individuals also have a responsibility to accept part of the risk and prepare for it. They need to realize that they can demand better-built homes that will withstand environmental hazards. They must also realize that if they want to live on the water, on the hills in California, or at the foot of the mountains in Colorado, they will have to pay more for their insurance and take steps to mitigate their exposure through better construction. A better built environment means less damage from catastrophes, less disruption to our economy, fewer loss payments for the insurance industry and subsequent lower insurance premiums, and less depletion of materials for rebuilding, making the life cycle longer and less costly.

Technical Perspectives

Rudy Matalucci, Sandia National Laboratories. Sandia National Laboratories is active in the development of the nationally emerging area of Architectural Surety^{SM}. The Sandia program is organized into four major elements: education, research, development, and applications. These elements are defined to better provide the necessary technologies for a well-integrated approach to surety. In combination, they will result in (1) the evolution of training in surety principles and of university curricula, (2) the demonstration of constitutive models and new materials, (3) the development of system models and computer simulation techniques, and (4) the ultimate provision of surety products to the customer for application to real-world conditions. Sandia National Laboratories takes a risk-management approach to solving problems of the as-built environment through the application of security, safety, and reliability principles developed in the nuclear weapons programs of the U.S. Department of Energy (DOE). The responsibilities of engineering design professionals are changing in light of the increased public awareness of structural vulnerabilities to malevolent, normal, and abnormal environment threats. Education and technology outreach programs have been initiated through an infrastructure surety graduate Civil Engineering Department course taught at the University of New Mexico and through ongoing workshops and conferences. Selected technologies—including super-computational modeling and structural simulations, window-glass fragmentation modeling, risk-management procedures, instrumentation and health-monitoring systems, and three-dimensional CAD virtual-reality visualization techniques—have great potential for application to specific national architectural and infrastructure surety concerns.

Paul Bryant, Federal Emergency Management Agency (FEMA). Paul Bryant talked about the way in which the perception of risk serves to increase actual risk. The United States has become increasingly urban, moving from farms to cities, from the interior to the coasts, and from the plains to the river banks. Much of this movement has resulted from a perception of decreased risk. The Army Corps of Engineers has built dams and levees that seem to have tamed our rivers, at least most of the time. Flood insurance is available in many riverine communities. There are even rules on how to build yourself out of the flood plain by elevating the house. These elevated houses and developments are known to change the flood plain, but we take years to change the published risk by re-mapping the flood hazard zones. The climate over the past forty years cooperated in creating the perception of reduced risk by being abnormally mild. Hurricanes have happened less frequently, and with less strength, since 1950. From the numbers, tropical storms with their associated floods are the big risk. The floods that occur are so well controlled by levees and dams that the impression was gained that rivers should be safe to build by. When the hurricanes are divided into those whose damage is mostly water, both flood and surge, and those whose damage is caused by wind, the risk of wind damage is even lower. Between 1963 and 1989, there was only one wind-dominant storm. Population, both vacation and residential, flocked to the shores. Florida became the favorite location of retirees. Developments were built to avoid surge and flood. Emergency planners ignored wind as a major risk factor—until Hurricanes Hugo, Andrew, and Fran. Unfortunately, when we do get wind-dominant storm damage, the victims tend to number in the tens of thousands instead of in the hundreds as with surge. The irony is that we know how to build structures resistant to wind damage. Apartment buildings tend to suffer less than half the damage of single family dwellings. It is not a lack of knowledge that causes us to build structures that are going to blow away, it's a lack of perception of risk. The first line of defense for American society is the architects and engineers that are building the future. They can build to resist the wind. They can build to prevent trucks bearing bombs from parking too close to the building. They can hook in smoke detectors with battery backups to household sprinkler systems to prevent fires. But to do the design right, they have to be aware of the risks.

Richard G. Little, National Academy of Science. Richard Little said a number of risk factors affect the performance of constructed facilities, including design issues such as form, function, location, and access; natural and anthropogenic loadings; analytical techniques for modeling and computation and determining prudent margins of safety; and construction and durability. An integrated facility-delivery process can help ensure that all technical risk factors are included in an overall risk-management strategy. Five recent instances of structural damage—damage in Florida from Hurricane Andrew, 1992; the New York City World Trade Center bombing, 1993; the bombing of the Alfred P. Murrah Federal Building in Oklahoma City, 1995; damage to steel buildings in the Northridge Earthquake, 1994; and winter storm damage in Washington, Oregon, and California, 1996—are examples of the exponential increase in economic and insured losses (including building losses) over the past 35 years. If recognized early in the facility-delivery process, the technical risk factors can be managed to achieve improved durability and structural performance. Loadings (dead, live, earthquake, wind, rain, snow, ice) should be carefully considered at the time of design. The standard building code loadings are minimum values that in many cases must be increased for desired structural performance. Little agreed that performance-based building codes hold some promise for a better quality of structure, with more consistent margins of safety; however, merely interspersing performance-based criteria in a force-based building code will not achieve the desired goal. Construction quality must be emphasized and enforced through more rigorous inspection. Where architectural or structural features or new structural concepts incorporate details or materials whose performance is not well documented, the performance should be verified by testing as well as analysis. Computer software for design, which is an important part of structural design practice today, must be carefully benchmarked and documented, with flags to indicate possible areas of questionable performance. Guidelines for structural modeling are generally absent from textbooks, handbooks, and guidance documents at this time. Such guidelines could contribute to better understanding of structural behavior and thereby to enhanced structural performance. Redundancy in load paths and mechanisms of energy absorption in the event of overloading need special attention during the design stage. Such issues as the potential for progressive collapse need more careful attention during design and review, as does column/frame behavior under overload conditions, and lack of continuity in supposedly connected elements. The facility-delivery process should have as its goal the identification and successful management of risk factors that can adversely affect the performance of constructed facilities. Forensic investigations have usually determined that performance failures were preventable. Many of these failures could be traced, at least in part, to poor communication between individual elements of the project delivery system. This shortcoming is inherent in the traditional design and construction process, which is linear and compartmentalized—characteristics that tend to inhibit free and interactive communications between elements and across disciplines. As risk factors are introduced at different steps in the facility-delivery process, the process must be sufficiently flexible to identify and address them. Although some risk will always remain, facilities can be designed both to reduce the overall level of risk and to manage the residual risk effectively.

Keith Ortiz, Sandia National Laboratories. Keith Ortiz discussed methods for the probabilistic analysis of structural safety. Because load and resistances are random, a rational approach to structural analysis can be based on the probability of failure, P_f, where risk is calculated as the expected cost of failure. Risk-management strategies include avoiding, accepting, or transferring the risk and controlling risk by reducing the probability of failure or by mitigating the cost of failure. Ortiz said that there are applications for this approach in civil structural design codes and in the analysis of offshore oil platforms, turbine blade fatigue and fracture, and other aerospace and automobile components. Non-structural applications include insurance or investment decision making.

Joan Woodard, Sandia National Laboratories. Joan Woodard described how surety principles could be applied to protecting the nation's infrastructure. Surety technologies are the science-based disciplines and capabilities needed to assure the safety, security, reliability and control of high-consequence systems in normal and abnormal environments. Sandia's unique surety technologies were developed specifically for the DOE's Nuclear Weapons Program and underlie the Laboratories' national-security mission. These technologies are essential for managing the modern nuclear-weapons stockpile. Now Sandia is beginning to apply these surety technologies to the nation's critical infrastructure; publicly available studies on the vulnerabilities of energy systems, telecommunications, and U.S. Department of Defense communications, for example, have shown that many systems in the United States' infrastructure are vulnerable. Even though most attacks to date have been directed at government facilities, the United States could also be crippled by attacks on systems that are owned by private entities, including infrastructure systems that encompass buildings. Buildings are subject to varied environmental conditions: dead weight, live weight, snow, soil and hydrostatic pressure, floods, rain, windstorms, thermal radiation, foundation settlement, earthquake loads, icing, and blast and dynamic forces. In addition to natural disasters, buildings are often victims of terrorist attacks (Oklahoma City, World Trade Center). Architectural Surety^{SM} is a risk-management approach to providing confidence that buildings will perform in acceptable ways when subjected to normal, abnormal, and malevolent environments.

Russell D. Skocypec, Sandia National Laboratories. Russell Skocypec discussed Modeling and Simulation-Based Life-Cycle Engineering (MSBLCE) as a means of assuring the performance of buildings and critical infrastructures. Because the low probability of some types of failures precludes a test-based approach to quantifying risk, predictive simulation is the key to managing the risk of high-consequence, low-probability events. MSBLCE represents a change from traditional prototype- and test-based engineering to modeling- and simulation-based engineering, and it demands considerable knowledge about the structure and how it responds to its environment. Once the predictive tools are validated, MSBLCE enables faster, better, and cheaper life-cycle engineering. The analyst may conduct life-cycle design trade-offs, optimize designs, explore new concepts at comparatively low cost, predict aging effects, and characterize catastrophic failure conditions, all of which allow surety principles to be embedded in the design. Assuring the performance of buildings and critical infrastructure requires many of the same capabilities required for assuring the performance of the nation's nuclear-weapons stockpile. On August 11, 1995, the President announced the United States' intention to pursue a "zero yield" Comprehensive Test Ban Treaty by "maintaining our nuclear deterrent . . . through a science-based stockpile stewardship program without nuclear testing." The Accelerated Strategic Computing Initiative (ASCI) is a critical element needed to make the shift from test-based confidence to science-based confidence. ASCI will accelerate the development of simulation capabilities needed to ensure confidence far beyond what might be achieved in the absence of a focused initiative. The ASCI Red Teraflop Computational Engine has a peak performance of 1.81 teraflops using 9072 Pentium Pro processors; 583,000 megabytes of memory, and 2419 gigabytes/second memory communication bandwidth. These simulation capabilities can be used to enable the design and construction of structures that are affordable, reliable, environmentally compliant, profitable, and appealing while remaining safe, secure, and controllable in normal, abnormal, and malevolent environments.

STRUCTURAL RESPONSE TO TERRORISM

Terrorism is an unfortunate reality of the late twentieth century. Several conference participants discussed the implications of terrorist activities for design, construction, and retrofit.

Kent L.Goering, Defense Special Weapons Agency (DSWA). Kent Goering discussed blast threats to buildings and blast mitigation technology. Several recent terrorist incidents illustrate the kind of threats that are present in today's world. The World Trade Center in New York City was damaged in 1993 by the internal detonation of about 1100 pounds of explosives. The damage included an 80 ft x 120 ft crater in level B2, 200 vehicles destroyed in the garage, severe damage to the building infrastructure (electricity, HVAC, and water supply), and fire damage to towers. Casualties included six deaths and more than 1000 injured—mostly from dust and smoke inhalation. The Alfred P. Murrah Building in Oklahoma City was severely damaged in 1995 as a result of an external explosion of about 4800 pounds adjacent to the building. The casualties were 167 deaths and 592 injuries. Most of the deaths occurred in the collapsed part of the building. The Khobar Towers in Saudi Arabia were damaged in 1996 by an external explosion of about 20,000 pounds 85 ft from the building. Casualties were 19 deaths and more than 500 injured. Impacting debris appeared to be a major factor in the deaths at Khobar Towers. In defining potential threats, source region details are important; these include explosive type, charge geometry, truck mass, barriers, and terrain features. In dynamic loading by conventional blast, the key issues are high frequency response, component response, and brittle behavior. The key design/retrofit challenge is to change brittle behavior to ductile behavior in an effort to reduce the risks from progressive collapse and impacting debris. Blast mitigation measures can be divided into load modification and hardening measures, both structural and non-structural. Load modification considers standoff, blast walls, energy absorbing materials, sacrificial walls, and controlled venting. Structural hardening aims (1) to prevent progressive collapse (using ductility of joints, reverse loading of concrete slabs, and compartmentalization), and (2) to reduce debris hazards (from building debris, windows, and doors). One hardening measure involves the construction of protected spaces within a building. Non-structural hardening focuses on reducing accessibility and vulnerability, reducing debris hazards, and enhancing rescue and recovery. As new methods and materials become available, they will have broad application in commercial and government buildings, for the protection of U.S. personnel overseas, and in both new construction and retrofits of existing structures.

Jim Chapek, Sandia National Laboratories. Jim Chapek said that physical-protection systems can be integrated into the overall structure in ways that can lead to interesting, efficient, and functional designs. The analyst must first determine the objectives of the physical protection systems, characterize the facility, and understand all applicable policies and procedures. Physical protection systems are typically designed for detection, delay, and response to specific threats. Detection may demand exterior and interior sensors, alarms, and entry control. A structured method for design evaluation allows assumptions about the characteristics of an attacker to be combined with more conventional considerations, such as heating, ventilation, and air conditioning systems, fire safety, the requirements of the American Disabilities Act, and electrical codes.

Norman J. Glover, AEGIS Institute. Norman Glover agreed that explosions must now be addressed. For the past few years, Glover has headed an American Society of Civil Engineers Working Group on the Mitigation of the Effects of Terrorism. The terrorist has a wide repertoire of tactics, although bombing is the tactic of choice, but there are things that engineers and architects can do to protect the public. The Working Group held a series of seminars to scope the problem, to identify the things they knew and didn't know, and to identify the things they could do to make buildings more protective. The Working Group was especially interested in blast-resistant glazing. Other investigators using both existing and new technologies have shown encouraging, even startling, increases in damage resistance. Methods are being studied or have developed for (1) retrofitting square reinforced concrete columns using composite jackets (usually FRP); (2) externally reinforced concrete beams and slabs with FRP panels; (3) creating blast-absorbing wall systems and energy-absorbing connectors; (4) hardening buildings against exterior explosions while also protecting against interior explosions using vented suppressive shielding. Other researchers are examining letter and package bombs. Despite the information derived by these and other studies, one problem in mitigating the effects of terrorism is the absence of a readily usable body of scientific data. Controlled test data are sparse because of the high costs of security, safety, and test installations that are destroyed during a single use. Because of the properties of the materials and the complexity of the systems, the data obtained are not necessarily linear and the ability to extrapolate them to other conditions may be limited. The Working Group is attempting to develop a program that will establish benchmarks by full scale testing to understand the phenomena better and allow economical expansion of our knowledge by simulations using the computing and laboratory experimental facilities of Sandia National Laboratories. As they come to understand better the phenomena, they expect to be able to integrate this knowledge with more traditional laboratory methods of testing and evaluating the mechanics of materials.

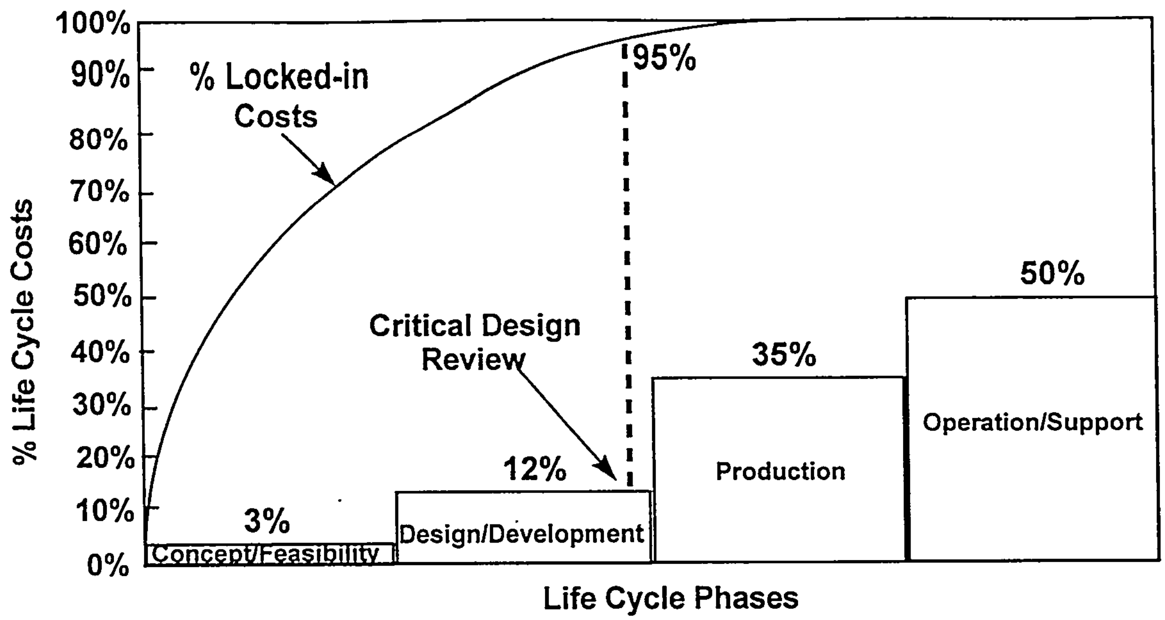
CONCLUSIONS

In general, conference participants agreed that improvements in design or construction materials to address building performance in the face of normal conditions, natural hazards, and malevolent threats would probably be beneficial in all three areas, providing that the design team approaches the problems in an integrated way. Risk management has long been used by the insurance industry; its use by the designers and users of buildings and infrastructures is emerging.

Acknowledgement — Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

Figure 1. Typical distribution of costs over the total life cycle of a product (13).

Figure 2. Cost vs. influence of various stages of design and construction on overall project cost, lifetime reliability, and maintenance cost. The figure illustrates the importance of building in constructability, reliability, and low cost at the earliest possible stages of design.



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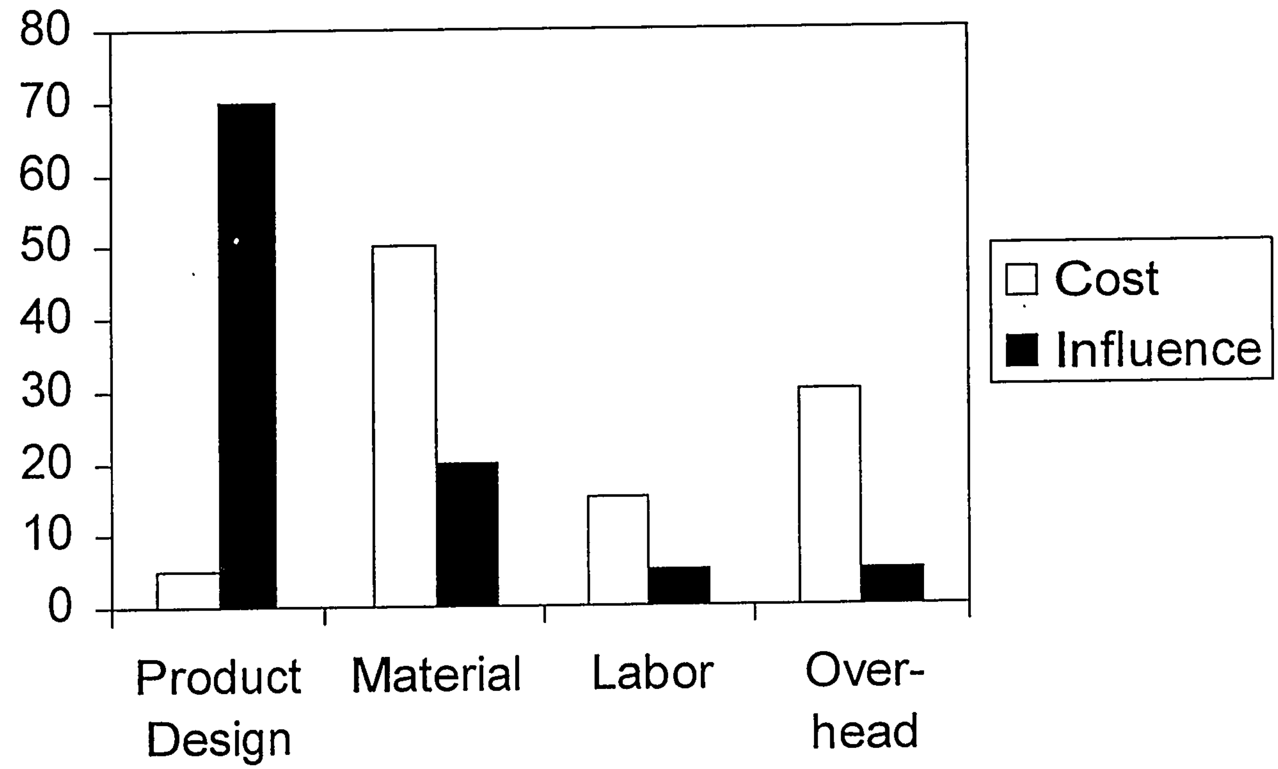

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