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An Introduction to the Architectural Surety Program

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ABSTRACT

This paper provides a summary introduction to the nationally emerging area of Architectural and Infrastructure Surety that is under development at Sandia National Laboratories. This program area, addressing technology requirements at the national level, includes four major elements: education, research, development, and application. It involves 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 Department of Energy. The changing responsibilities of engineering design professionals is addressed in light of the increased public awareness of structural and facility systems vulnerabilities to malevolent, normal, and abnormal environment threats. A brief discussion is presented of the education and technology outreach programs initiated through an infrastructure surety graduate Civil Engineering Department course taught at the University of New Mexico and through the architectural surety workshops and conferences already held and planned for the future. A summary description is also presented of selected technologies with strong potential for application to specific national architectural and infrastructure surety concerns. These technologies include 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.

An Introduction to the Architectural Surety Program

Overview

The new and emerging threats to the infrastructure faced by today's engineering design and facility management community demand solutions that are innovative and increasingly based on risk management approaches. In the wake of the World Trade Center, Oklahoma City, and Saudi Arabian bombings, global civil and ethnic unrest, criminal and political terrorism, the Chunnel fire, recent natural disasters, and other indicators of a rapidly transforming social world, there is a growing awareness of public vulnerability. This awareness leads to increased expectations and responsibilities for the design, engineering, and construction professionals. The destruction, for example, that follows in the wake of such natural disasters as hurricanes, tornadoes, floods, and earthquakes also underscores the need for enhanced structural safety, security, and reliability to protect the public from potential injuries, death, and heavy property losses.

The escalating threats and risks to the public and the as-built infrastructure change the roles of the designers, architects, planners, engineers, and builders by increasing the focus on the importance of applying viable surety principles to the built environment. To save lives and significant costs, surety principles incorporate a systematic approach in the planning, design, engineering, contracting, construction, operation and management, and final disposal processes in the total life cycle of the as-built infrastructure systems (e.g., buildings, bridges, tunnels, airports, transportation systems). The principles of surety are also served by applying risk management approaches to facility designs through the process of identifying, assessing, analyzing, and mitigating risks. Sandia National Laboratories (Sandia) has developed a multidisciplinary program to address many of the critical national issues in this area by applying surety concepts and procedures as appropriate.

Surety Considerations

Threats to buildings and facilities can be identified in three categories: normal, abnormal, and malevolent. Normal threats to the built environment are those that are considered to be usual insults to the structure and operation of a building or facility, such as aging, weathering, and other easily predicted naturally occurring or manmade loads. Abnormal threats include natural disasters, such as Hurricane Andrew in 1992, the 1994 Northridge Earthquake, or the recent flooding in South Dakota. Malevolent threats are deliberate in nature, resulting from terrorist activities or other intentional human-induced damage to structures.

Surety technologies and principles were developed through the Department of Energy programs to assure the safety, security, reliability, and quality of nuclear weapons. Nuclear surety in national security and national defense was the original total quality management program of the United States. There is no margin for error with nuclear weapons; zero tolerance is the only acceptable approach to nuclear risk. Applying the tried and true fail-safe surety policies, principles, and procedures developed in the nuclear arena to the constructed architecture and infrastructure is the first contribution Sandia made to the national infrastructure requirements.

Sandia scientists and engineers are working with design and construction professionals to develop a process and an approach for determining the level of threat and risk attached to particular structures. The goal is to assist architects, engineers, and other design professionals in designing for surety. To this purpose, interactive workshops, undergraduate and graduate-level classes, seminars, and conferences have been coordinated by Sandia in conjunction with other professional institutes and organizations.

Interactions with design professionals will enable the Architectural Surety activities at Sandia to determine more specifically those surety needs of the design community. Various technologies, several of which are discussed briefly below, show promise for use in assuring the safety, security, and reliability of the structures and facilities currently under design and to be designed in the future. Applying currently available technologies with architectural surety objectives, performing research to identify the surety needs of structure and facility designers, developing projects to meet those identified needs, and educating the professionals and the public are the obvious contributions Sandia can make to this important area.

Objectives

The goals of the architectural surety program are to enhance public safety and security, ensure the reliability and quality of buildings and facilities, and increase public awareness of the benefits of applying surety principles to the design or retrofit of public, commercial, and private structures. The success of this program depends upon gaining a consensus within the technical and design professional communities. Developing a clear vision of the benefits of applying architectural surety principles and technologies to the design and construction of buildings and structures is the first step toward achieving these goals. Identifying the needs of the design community will assist in clarifying and broadening this vision.

Once identified, the surety needs of the design community must be addressed. The development of new technologies and the adaptation of currently available technologies are one way to address these needs. Adapting the surety principles developed through the nuclear weapons program to the design of structures is a challenge that can be met through appropriate interfaces and technical networking. Educating architects, engineers, and other design professionals through the development of new course material is another important segment of the architectural surety program. It is the intention of the program to create a national constituency that will foster the aforementioned goals of the architectural surety program.

As described earlier, changes in our society are impacting the safety, security, and reliability requirements of our buildings and infrastructures. The increases in malevolent threats such as crime, violence, and terrorist attacks have increased public awareness of the vulnerability of buildings and facilities, creating new demands on the engineering and design community. The destruction wrought by natural disasters continue to horrify our citizens. In addition, the infrastructure is aging and failing through expected usage and through normal weathering and inevitable deterioration. Accidents and human error also contribute to system failures that threaten the as-built environment. The public's increased awareness of these threats to our constructed world has in turn increased the demands upon the architectural and engineering communities. It is everyone's responsibility to be concerned about techniques and innovative approaches that will mitigate the risks imposed by both these newly identified and previously recognized threats.

Risk Reduction

There are a number of steps that can be taken by a national laboratory to address this national concern and awareness regarding safety and security of public gathering places, offices, and facilities. Forming technical partnerships between academia and the practicing professional community is one such step. Technical and industrial exchanges at conferences is certainly another means for developing an enhanced understanding of the national needs and for deciding how to apply appropriate measures to these roblems. Integrating performance-based concepts and standards into the existing prescriptive building codes might be another significant step to enhance infrastructure surety. Although performance-based criteria and codes would demand verification testing of design before implementation, they would also encourage innovation in design approaches and material applications that will provide for increased surety.

Cost-benefit analyses of surety plans and designs are expected to provide improved confidence in the viability and affordability of protecting life and property investments through adequate design. By networking with professional associations and with the construction industries and by building confidence through teaming, the architect-engineer will be better prepared to demonstrate the feasibility of designing and constructing safer, more secure, and more reliable structures at a reasonable cost. Such buildings and facilities developed through total life-cycle analyses will better support the national interest and build public confidence in the as-built environment.

Accepting the responsibility for improving the performance and surety of buildings and infrastructures will require a systematic risk management approach and a strong commitment to excellence from the design community. Designing solely to building codes and existing standards will soon be regarded by the public as insufficient for future construction projects. Figure 1 illustrates a new dimension to be introduced into the engineering and design profession. Thinking outside the box that is constrained by existing building codes and standard practices means that new ideas and techniques applied for surety purposes must also be considered rationally in the design process in order to meet effectively the variety of threats that impact infrastructure systems today. To achieve this surety goal, the demand to be creative and innovative must be responded to with some level of passion, technical judgment, and intuition. Otherwise, the concerns of the public and the numerous technical alternatives that might apply for enhanced safety and security across the board would not be evaluated.

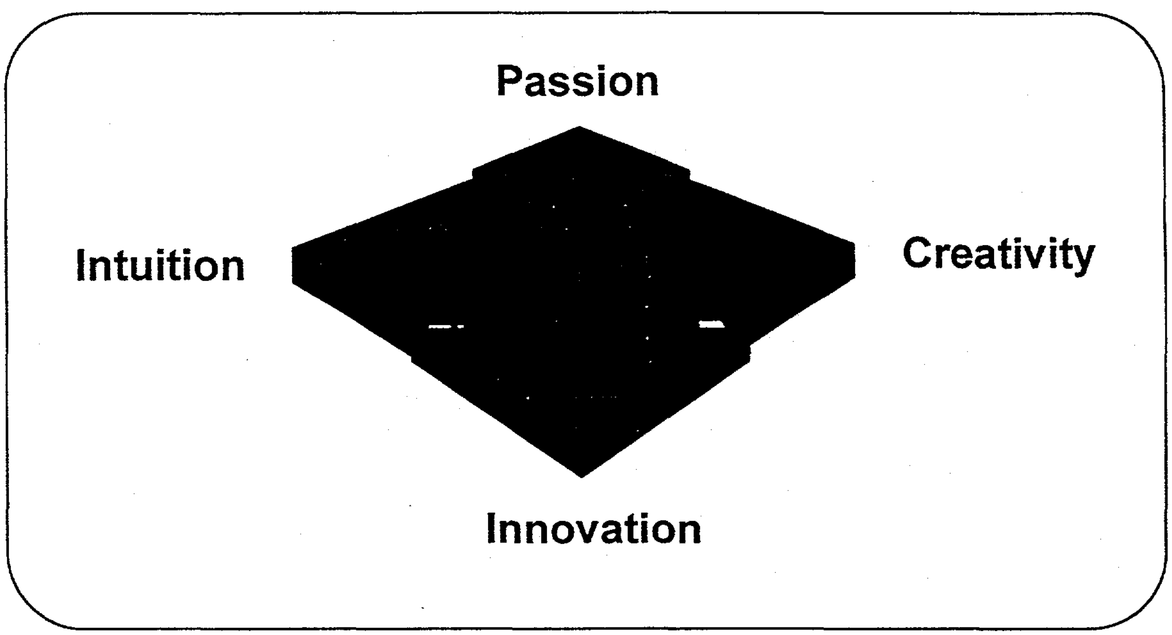

Figure 1. Thinking Outside the Box

Life-Cycle Sustainable Development

Surety considerations must be addressed throughout the life cycle of the structure. The design professionals must be responsible for including the other necessary team members in planning for the safety, security, and reliability of the structure. Figure 2 shows the major players involved at various stages in the life cycle of a constructed project. Each player indicated in Figure 2 further represents numerous technical supporting disciplines that form the teams to resolve the surety issues involved. For a surety plan to be in effect through all these stages, the architect-engineer must incorporate the plan at the earliest stage and pursue those issues throughout the total project life-cycle.

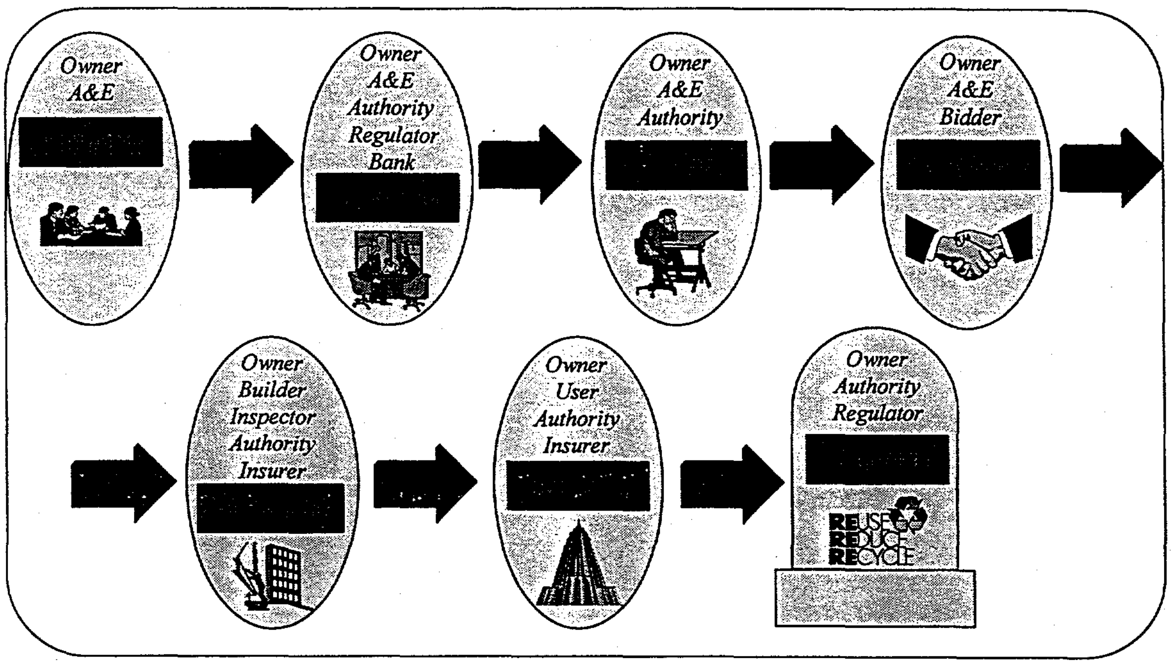

Figure 2. Life-Cycle Sustainable Development

Program Structure

Figure 3 shows the organization of the Architectural Surety Program at Sandia. Further details of the program are provided throughout this paper.

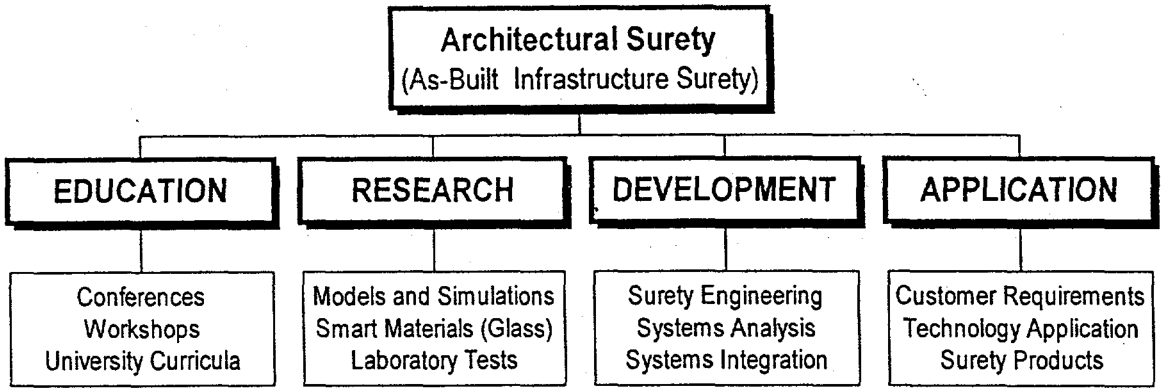

Figure 3. Elements of the Architectural Surety Program

The Architectural Surety Program is organized into the following four major elements: (1) Education, (2) Research, (3) Development, and (4) Applications. These elements are defined and categorized to better provide the necessary technologies for a well integrated approach to the surety issues and needs. The results of work in all these elements combined is expected to 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.

Education - This task addresses the development of future surety education and training requirements that would support federal and non-federal engineering and construction requirements and processes. This supplemental education approach considers first an evaluation of any apparent deficiencies in existing engineering curricula to meet the safety, security, reliability, and quality needs of an infrastructure system or building or facility of national significance. The surety principles that would form the basis for revised architectural, structural engineering, and/or civil engineering curricula will be developed and incorporated within the engineering and architecture programs with the guidance and direction of university faculty and staff.

A one-semester graduate course was developed and presented through the Civil Engineering Department of the University of New Mexico (UNM) between January and May 1997. The major portion of the syllabus was developed from the technologies available within the nuclear weapons programs and from current literature documented in professional journals and periodicals. Guest lecturers from specific Sandia technology areas and industry were invited to participate. Security systems approaches, safety procedures, reliability assessments and methodologies, risk management assessment and procedures, and other quality assurance procedures were factored into this initial course plan.

Students in this UNM class were eligible for either graduate credit and/or CEU credits. The outline of topics discussed in the class included:

- Threat Assessment
- Security
- Safety
- Risk Management
- Modeling and Simulation
- Project Development and Life-Cycle Engineering
- Performance Codes and Standards
- Ethics and Legal Issues
- Failure Analysis and Case Histories

The metrics for evaluating the success and effectiveness of the course material and presentation format was developed and implemented. Feedback from students, faculty, and interested architectural and engineering firms were part of the evaluation process. Surety applications to other engineering disciplines such as electrical, electronic, mechanical, and manufacturing were to be reviewed in this effort by interacting with other UNM Departments.

This education element also included the organization of workshops, seminars, and conferences that address the issues and needs for surety applications. These three forms of technical information exchange have all proven to be effective and beneficial to participants for understanding the concepts involved and for networking on larger issues and projects in the future.

<u>Research</u> - This task calls on the core competencies in structural and constitutive modeling, computational simulations, material properties and behavior, and systems analysis to address the issues of surety products for the federal and non-federal engineering and construction requirements. Structural models for evaluating buildings and infrastructures, including components and subsystems, will be obtained from ongoing weapons programs and adopted as the possible tools for making decisions on design parameters and variables. Material identification, characterization (including fracture and failure modes and patterns), and modeling of more resilient materials and composites including glass, metals, concrete and other construction materials will be evaluated as potential alternatives for building designs. The instrumentation systems and techniques for monitoring existing structures to assess the life-cycle history, longevity in terms of aging, and potential and incipient fatigue modes of failure will be developed and evaluated.

Development - This task includes the development of architectural surety analysis tools for addressing systems integration. The computer model-simulation techniques and methodologies that will result from this effort include system models, procedures, and other analysis tools that would be used for concept designs, parametric studies, and comparative analyses of buildings, structures, and infrastructure facilities of interest to government agencies and non-government organizations. These developments will be proposed to the interested agencies and to their technical support contractors as the technologies are sufficiently mature for application to specific concerns and project implementation.

Application - This task addresses the requirements as specified by the customer for a particular or general engineering and construction application. This effort focuses the developed technology on the specific situation and appropriate performance of the building, structure and/or facility systems. The surety products to be delivered include some proposed performance- based building codes, standards, and/or guidelines; safety measures that provide a sufficient level of protection to the public and/or facility occupants; security provisions that ensure a desired level of access control, intruder detection and assessment, and delay of unauthorized entry; and a required degree of facility and material reliability and quality to ensure the total life-cycle endurance of a particular structure or system.

Applicable Technologies

Currently available technologies at Sandia that have a strong potential for adaptation to national architectural surety issues are briefly discussed below.

Computational Simulation of Blast-Structure Interactions - These simulations could be adapted to predict structural responses to bomb blasts through the application of existing computer simulation capabilities, developed earlier for nuclear weapons programs. Computational simulations and modeling can also be used to identify and test potential new designs, building codes, and retrofits for blast mitigation.

Sandia is developing a coupled hydro-dynamic and structural-response computer code that will model the structural and material elements of buildings and their response to explosive effects. Model simulations will be verified through small- and large-scale test data. This will be accomplished by measuring explosive effects on barrier walls and multi-story structures and verifying the results of computations using the super-computer capabilities at Sandia through collaborations with the Department of Defense and other federal agencies.

Necessary improvements that would enhance the results of computational simulations will be made after comparative analysis with the data from actual explosive mitigation systems tests.

Window Glass Fragmentation Model - Computer models and calculations at Sandia could be used to simulate the behavior of the complete window assembly, including the effects of various frames, the fracturing of window glass, and the effects of protective films subjected to explosive blast loads and possibly windstorms. The capability will be developed for predicting the performance of effective glass types including the use of fragmentation mitigation measures (e.g., film coatings, protective curtains, lamination, tempering) and for understanding glass fracture and debris flow. The associated human injury potential from flying glass will be addressed with physiological and medical information from other sources. Collectively, these efforts are designed to provide the technical basis for glass protection design standards and guidelines for anti-terrorism and for force protection applications.

An all-inclusive program of blast-resistant glazing for multiple purposes would be accomplished through collaborations with interested agencies and other technology resources and participants by integrating the following activities: (1) compiling and analyzing data from existing national and international glass breakage studies; (2) extending existing capabilities in analyzing glass response, developed for nuclear weapons, to modeling the effects of blast loads on window glass; (3) conducting specific testing to verify and improve window glass fragmentation and debris flow models; and (4) developing design guidelines and performance standards for retrofit and new projects through architect-engineer firms.

Instrumentation and Health Monitoring - The development of a mobile and reusable instrument package for building response is a potentially effective architectural surety application of Sandia technology. This possibly relocatable package could be used at different sites to measure response of structures subjected to threat conditions. Alternatively, similar measurement sensors can be installed into the structural systems to record response and performance over the full life cycle of the facility. The integrated sensor package would measure and record accelerations, strain, pressure, particle velocities, and displacements, and thus provide health monitoring of structural systems throughout their lives. This relocatable instrument package, designed to measure blast and wind effects, could be trailer-mounted and applied for the test and evaluation of structures subjected to a variety of actual threat environments.

To develop this relocatable package, Sandia would identify existing microsensors and data acquisition technologies, developed for the nuclear weapons program, which will best meet the needs of threat environments; design a mobile monitoring system that integrates the microsensors and data acquisition technologies; construct the health monitoring system; and verify the package through testing and simulations.

Risk Management Techniques for Buildings and Infrastructures - Another potential architectural surety application of Sandia technology would be the performance of risk analyses including probabilistic risk assessments (PRAs). These procedures would be used for evaluating the impact of proposed design, construction, and mitigation and remediation actions upon structural response to explosions, earthquakes, windstorms, floods, and fires by accommodating human security and survivability aspects. Design professionals would be able to utilize a PRA-based methodology to uncover previously unidentified vulnerabilities and unexpected consequences. This would allow them to evaluate the benefits associated with mitigation measures for known vulnerabilities to defined threat scenarios.

Sandia would accomplish this by developing personal computer software that will perform PRAs for the evaluation of explosives and other environmental threats to structures. This would involve adapting procedures to a known structural system, simplifying existing Sandia nuclear power plant PRA software (utilized by the Nuclear Regulatory Commission) to operate on personal computers, incorporating existing Sandia physical protection analytical methods into simplified PRA software, and verifying methodologies with performance information.

Virtual Reality Visualization of Architectural Systems - Application of Sandia's virtual reality capabilities to architectural surety would include easily applied, three-dimensional, interactive visualization, from three-dimensional CAD files, including simulated effects of proposed mitigation measures. This would permit virtual reality evaluation of anti-terrorist measures (e.g., security devices) prior to the construction or retrofit of structures. In addition, a realistic virtual environment for the planning and training of counter-terrorism responses, including law enforcement, search-and-rescue, and medical first-responder personnel, would be a boon to designers of vulnerable public and private buildings and facilities.

Such a virtual reality system would be based on software for creating virtual reality visualizations from three-dimensional CAD files for security, safety, and reliability evaluations. Sandia would extend existing capabilities in networked, multi-user virtual reality systems to develop visualization systems that are applicable for emergency response and situational training systems for small teams (e.g., fire, rescue, medical, and law enforcement), sensor and structural visualizations, simulation models for force-on-force analysis, and finite-element analysis of structural integrity.

Summary

Infrastructure surety is a concern of national significance. The concepts of architectural surety are conveyed to design professionals through education, workshops, conferences, seminars, and publications. The development and application of surety technologies are a likely result of increased public and professional awareness and the development of professional networks and partnerships with industry, academia, and institutes.

Building and infrastructure performance assurance is the payoff for the owners, the design professionals, the users, and ultimately the nation.

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