THE FEASIBILITY OF MODERN TECHNOLOGIES FOR REINFORCED CONCRETE CONTAINMENT STRUCTURES OF NUCLEAR POWER PLANTS

by

SARAH CZERNIEWSKI

B.S., Kansas State University, 2009

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Architectural Engineering and Construction Science
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2009

Approved by:

Major Professor
Kimberly Waggle Kramer, P.E.

Abstract

This report explores the requirements for the design and analysis of concrete containment and shows how newer material technologies such as self-consolidating concrete (SCC) and fiber reinforcement could assist in the constructability and durability of new nuclear power plant facilities.

SCC for example, enables concrete to flow in the forms around the reinforcement and provides a more uniform adhesion with the reinforcement. Additionally, fiber reinforcement in the concrete mix increases bonding capability, thus making the concrete less likely to fracture. In particular, the ease of constructability benefits offshore floating nuclear power plants and preapproved modular power plants. To differentiate, the offshore plant would employ the assembly line to make all the plants the same while the modular plant, designed to be used anywhere, is not site specific and is typically smaller.

Regarding research method, the report starts with the history of the nuclear industry in the United States, including the last nuclear power plant constructed, clarifying that nuclear energy was first harnessed for a submarine propulsion system before being employed to generate electricity. After these early endeavors, two major accidents, Three Mile Island (March 28, 1979) and Chernobyl (April 26, 1986), provided information regarding the lack of safety of nuclear power plant design and operation.

Since the containment building is the focus of this report, recognizing the loads and the load combinations for design was the next step in research. Following that, the next step was to determine the design considerations and analyze the containment structure. New material technologies clearly have opened the door to new construction techniques, and the combination of new materials and methods offers structural engineers opportunity to build inherently safer nuclear power plants.

Table of Contents

List of Figures

List of Tables

Abbreviations/Acronyms

ACI – American Concrete Institute

ACRS – Advisory Committee on Reactor Safety

AEC – Atomic Energy Committee

AISC – American Institute of Steel Construction

ANL – Argonne National Laboratory

ANSI – American National Standards Institute

ASCE – American Society of Civil Engineers

ASME – American Society of Mechanical Engineers

BAPL – Bettis Atomic Power Laboratory

BWR – Boiling Water Reactor

FEMA – Federal Emergency Management Agency

GE – General Electric

JCAE – Joint Committee on Atomic Energy

KAPL – Knolls Atomic Power Laboratory

LOCA – Loss of coolant accident

NOAA – National Oceanic and Atmospheric Administration

NRC – Nuclear Regulatory Commission

NSSS – Nuclear Steam Supply System

ORNL – Oak Ridge National Laboratory

OPEC – Organization of Petroleum Exporting Countries

PWR – Pressurized Water Reactor

SCC – Self consolidating concrete

SEI – Structural Engineers Institute

Dedication

I want to dedicate this report to my family: to my father for instilling the initial interest in the nuclear industry when I was a child, to my mother and brothers for their continuous support and encouragement for finishing this report, and to my friends Katherine, Clare, Lisa and Kim, all of whom have supported me while I finished the report.

Preface

In the United States, nuclear power is one of many alternative energy sources currently being considered to reduce carbon emissions. Reducing carbon emissions will help reduce damage to the Ozone layer in the Earth's atmosphere, decreasing global warming effects. Nuclear power does not have carbon emissions and is a more reliable energy source for the future than fossil fuel plants.

Specifically, this report investigates the history of the development of the reactor, the importance of the concept of containment learned from the Chernobyl accident, the design considerations and analysis for the nuclear reactor containment structure, and the introduction of new construction materials and concepts for the future of nuclear power plant facilities.

My primary reason for selecting nuclear power plant structures as my report topic is the influence of my father who works in the nuclear power generation field. As a young child, I learned about the splitting of atoms, the danger of radiation, the purpose and mechanics of turbines and generators, and the fact that a fuel pellet the size of a tootsie roll could undergo a process that would produce power. Also, I realize that many of the engineers who designed these initial facilities are retired or will be retiring in a few years. Once these experienced engineers are out of the workforce, younger engineers might not have ready access to information regarding the design background of nuclear power plant structures. The information that would be inaccessible includes engineering judgment and rules of thumb.

CHAPTER 1 - History of Nuclear Technology

The history of nuclear power in the United States provides insight into how and why initial developments in the nuclear industry affect all Americans even today. Accordingly, this chapter covers application of nuclear energy and the steps towards nuclear power production. To define, nuclear power, also known as nuclear energy, atomic power, and atomic energy, is the energy released by a nuclear reaction (fission or fusion) or by radioactive decay. All of the commercial nuclear plants in the United States use fission, the result of a massive nucleus being split into smaller nuclei while simultaneously releasing energy.

With this background knowledge of nuclear energy and the nuclear industry, the use of emerging technologies, discussed in Chapter 4, will be better received. Through construction experimentation with the new technologies for nuclear power plant application, safety and reliability of containment structures may be improved.

1.1 The First Reactor

In the United States, the beginning of the development of nuclear power as an electrical power source started on December 2, 1942 when at the University of Chicago Enrico Fermi conducted an experiment with fellow scientists (Morris, 2000). Fermi and his colleagues constructed a crude reactor container called a “pile” that was roughly the size of a two-car garage (Morris, 2000). The pile was constructed of highly purified graphite, which was stacked in “piles” to absorb any neutrons trying to escape from the nuclear fission within the pile (Simpson, 1995). These men with their makeshift reactor were able to maintain a chain reaction that produced one watt of electricity (Morris, 2000). By today’s standards, one watt is very small; for instance, a one watt LED requires three AAA batteries to operate. By contrast, commercial nuclear power plants today are rated in Megawatts.

1.2 Governmental Regulations

Initially, technology involving nuclear power was controlled by the military, which harnessed atomic energy to use as a weapon. But after the end of World War II, the United

States government pursued a more peaceful use for atomic energy. Thus, the federal government took a major role in its early research and development.

1.2.1 "Atoms for Peace" Speech Lays International Groundwork for Non-military Development

On December 8, 1953, President Eisenhower presented his "Atoms for Peace" speech to the United Nations General Assembly. In this speech, the President encouraged applying the technology of nuclear fission to peaceful and constructive applications. The speech was written to appeal to the leaders of other countries by involving the United States' government to cooperate with both allies and perceived enemies by employing an international agency to designate nuclear responsibilities.

Eisenhower's speech starts out reminding the United Nations of the atomic potential of the world in which they were living. He emphasized that this was a world in which nuclear technology could be shared with other countries, and reminded them that an unexpected attack could lead to a horrendous death toll. By reasoning that no one wants to be remembered in history for global nuclear destruction, Eisenhower encouraged the United States to make every effort along with the other principal countries, which were Great Britain, France and the Soviet Union, to invest in peaceful applications for atomic energy. Additionally, the areas President Eisenhower noted as potentially beneficial for atomic innovation were agriculture, medicine, and electrical energy. He also presented the idea of an international atomic energy agency that could oversee the storage and protection of fissionable material, such as uranium-235, uranium-238, and plutonium-239.

However, the most compelling reason for pursuing peaceful solutions in Eisenhower's view was as follows: "Thus the contributing Powers would be dedicating some of their strength to serve the needs rather than the fears of mankind."

1.2.2 United States Military Controls Nuclear Technology

The United States military worked on harnessing nuclear power as an energy source following Fermi's experiment in 1942, for example to develop propulsion systems for naval vessels. In January of 1954, the USS Nautilus was unveiled as the first nuclear powered submarine in history, which was only twelve years after the experiment with the "pile" at the University of Chicago (Simpson, 1995).

The success of the nuclear submarine program could be attributed to Hyman Rickover and the perseverance and hard work of Westinghouse employees. Rickover had been sent to Oak Ridge National Laboratory (ORNL) to learn about reactor design. Also, engineers from Westinghouse and General Electric (GE) were also brought in to ORNL to learn about nuclear reactors in order to include both companies in the development of nuclear propulsion (Simpson, 1995). After Rickover's time at ORNL, he strongly recommended the importance of nuclear propulsion for submarines to the Navy (Simpson, 1995).

Once the Navy decided this was an important strategic concept to national defense, it requested the Atomic Energy Commission (AEC) to take action per the Atomic Energy Act of 1946, discussed later on p.6 (Simpson, 1995). Since Rickover pushed for the research into nuclear submarine propulsion, the Navy put him in charge of their nuclear power division on August 4, 1948. A month later, he was appointed head of the AEC's naval reactors branch. When questions of financing occurred, he could switch his authorization and determine which group would produce the funding. This provided continuous funding to develop nuclear power systems (Simpson, 1995).

Meanwhile, Westinghouse Electric Corporation was the first private industry enlisted by the United States military to develop nuclear propulsion. Westinghouse's role in nuclear power started with the Bettis Contract, signed December 10, 1948, under which Westinghouse engineers designed an engine, the Mark I, and a nuclear propulsion plant for a naval ship, the Mark II, for the United States Navy (Simpson, 1995). In turn, the Navy provided Westinghouse with the design criteria for a submarine, mainly involving the propulsion equipment and the generation of speed of the submarine (Simpson, 1995).

Westinghouse engineers, in cooperation with the employees at what became the Bettis Atomic Power Laboratory (BAPL), had many technical challenges to overcome since nuclear reactor theory was still developmental and therefore not as accurate as design is today (Simpson, 1995). Then, nuclear reactor theory consisted of the necessary use of enriched uranium fuel components that during the fission process would produce heat. Subsequently, a coolant would be used to flow over the fuel components and then turn into steam, which would then turn the turbine, which in turn would rotate the propeller shaft, causing forward propulsion, whereas current technology produces electricity via a generator (Simpson, 1995). However, initial nuclear reactor theory was not as extensive as the engineers needed; therefore they had to develop the theory further through experimentation to determine the amount of fuel, the specific coolant to use, and the corrosion resistance of the hardware or cladding (Simpson, 1995). Meanwhile, GE was working separately under an AEC contract, which provided GE with the Knolls Atomic Power Laboratory (KAPL), allowing the company to develop a liquid-metal-cooled intermediate-energy spectrum breeder reactor (Simpson, 1995).

Determining the amount of fuel necessary to sustain the chain reaction was very important. In particular, the coolant's importance stems from the process' dependence on the chain reaction to produce thermal energy (heat); therefore, the coolant would need to change into a gaseous state to turn the turbine. Initially, three types of coolant were considered: pressurized water, helium gas, and extremely hot liquid metal (Simpson, 1995). GE's power laboratory decided to pursue liquid metal, but Westinghouse chose pressurized water by the spring of 1949, which Rickover preferred as the correct coolant choice following his experience at ORNL (Simpson, 1995). Pressurized water was chosen because it was considered "most likely to be completed successful in a reasonable amount of time" (Simpson, 1995). Pressurized water as a coolant has the disadvantage that water is highly corrosive at high temperatures (Simpson, 1995). Liquid metal could be used as a coolant for a fast neutron reactor because it has low neutron absorption as well as high melting and boiling points, but each of the common liquid metals used has disadvantages, such as flammability and toxicity. However, even into today's nuclear industrial world no consensus for the type of coolant used for reactors exists, although sixty percent of the world's nuclear reactors use pressurized water reactors (PWR) (Simpson, 1995).

The Bettis Group, comprising both Bettis engineers and Westinghouse engineers, worked on integrating the component parts of a nuclear system (Simpson, 1995). A major component part would be the cladding or fuel pellet casing, which would need to be accurately determined due to the extremely high temperatures of the water. Additionally, a corrosive resistant material was needed for the reactor to run continuously to avoid deterioration of materials. After innovating the hardware and instrumentation, as well as performing extensive time-consuming mathematical calculations, the Bettis group tested each component and the whole system to confirm the efficiency of the new technology as it was developed (Simpson, 1995).

To save time in the development of the first nuclear submarine, Rickover and those in charge of the Bettis group decided not to build a small pilot plant; instead, they opted to build a full size prototype, the Mark I, that would fit into an exact replica of the USS Nautilus' hull

(Simpson, 1995). Before the actual construction of the USS Nautilus began, every component had to fit into the replicated hull, with no exceptions (Simpson, 1995). In fact, not only was the prototype plant built into an exact replica of the hull of the USS Nautilus, but for proper shielding design, a large water tank was built for studying the back scatter from the replica reactor compartment to better simulate the environment of a submarine (Simpson, 1995). Back scatter is when radiation or particles are reflected in an opposite direction from which they were traveling depending upon the material, which is why radiation shielding for the workers from is so important, to prevent cell damage and cancer. The water tank was necessary because the prototype had been built in Idaho at the National Reactor Testing Station, which was in the desert (Simpson, 1995). From the knowledge and experience gained from building the full size prototype, the Mark I engine became a reality as well as a good foundation for further development (Simpson, 1995).

Subsequently, in June of 1953, the USS Nautilus was subjected to many tests, including crossing the Atlantic Ocean in 96 hours without surfacing, extending previous submarine ranges. Before the USS Nautilius, most submarines were not actually fully functional submarines, as they could only go thirty to forty miles underwater before having to resurface or stop, which causes obvious tracking limitations (Simpson, 1995). After completing these tests, researchers fixed problems that presented as simply as possible. With an exact size prototype already built, any necessary repairs could be engineered in detail following corrections to the prototype (Simpson, 1995). According, the Nautilus' nuclear power system was completed in eighteen months from the launch of the submarine reactor prototype program, a rapid turnaround. To put it into perspective the first commercial nuclear power plants built in the United States were constructed in four to five years from start of construction to power production (Simpson, 1995).

However, the development of the nuclear reactor for the navy could not be directly translated into a commercial power plant because commercial power needed to be in the form of electricity, not propulsion. Obviously, basic technology such as materials for the reactor, heat transfer, and reactor physics transferred to the fundamental foundation of a commercial plant (Simpson, 1995). However, the initial venture into commercial nuclear plants would require the development of uranium dioxide (based on nuclear weapons technology and Fermi's experiments) into fuel pellets, management of the fuel, engineering of control drive mechanisms, and the concept of containment (Simpson, 1995).

1.2.3 Energy Acts

The United States military was not the only part of the federal government advancing development of the nuclear industry; the Congress also had a vital role. Following World War II, research continued regarding nuclear technology as a viable energy source. The United States Congress, with encouragement from President Eisenhower, passed the following acts: the Atomic Energy Act of 1946, the Atomic Energy Act of 1954, and the Price Anderson Act of 1957, each of which is discussed below.

1.2.3.1 Atomic Energy Act of 1946

The Atomic Energy Act of 1946 was designed for the United States military to control all nuclear technologies to keep their monopoly of atomic weapons (Okrent, 1981). Thus, the Act established the Atomic Energy Commission (AEC) and the Joint Committee on Atomic Energy (JCAE). The AEC was in charge of the production and ownership of fissionable material (Simpson, 1995). Further, the AEC would be comprised of five members appointed by the President and approved by the Senate, but the JCAE would be comprised of nine Senate and nine House members, Senate members being appointed by the President of the Senate (the vice president of the United States), and House members by the Speaker of the House. The Atomic Energy Act also stated that no one political party could have five members appointed by the President of the Senate or the Speaker of the House, thus ensuring that no political party could enact their party's political agenda. The JCAE was established to review the AEC's activities and issues with atomic energy, as well as to inform the House and Senate of recommendations for legislation with regards to atomic energy.

The AEC was established to control the production, ownership, and distribution of fissionable material and to control the scientific and technical information that would arise from overseeing the governmental and civil research and development of atomic energy. The AEC was responsible for producing standards to handle fissionable material and for writing reports to Congress regarding their activities and any future recommendations for atomic energy in legislation. But, the AEC was required to share any and all information regarding atomic energy with the military that its representatives viewed as significant to military applications. This information involved the research and development of atomic bombs, atomic bomb parts, and other possible military use of atomic energy.

1.2.3.2 Atomic Energy Act of 1954

The Atomic Energy Act of 1954 stripped the military of sole control of nuclear technology by allowing licensure of commercial nuclear power plants to further develop atomic energy for non-military purposes (Okrent, 1981). However, while the nuclear power field was opened for the private energy industry, the Atomic Energy Act of 1954 still prohibited private ownership of fissionable material (Simpson, 1995). Ultimately, while the private industry's role was to produce power, responsibility for the safety of the public still rested with the AEC (Okrent, 1981).

The Atomic Energy Act of 1954 limited a power plant's "life," or term of operation, to forty years for an operating license, although a plant is allowed to extend its license another twenty years providing it meets all NRC requirements.

The purpose of the Atomic Energy Act of 1954 was to implement atomic energy for the protection of the country, improve the standard of living through inexpensive energy, and encourage the start of the atomic energy industry through private enterprise. To fulfill this threefold purpose, the AEC was given power for overseeing the licensing and protocol concerning the atomic energy industry. For instance, Chapter 10, Section 103b of the Atomic Energy Act of 1954 outlines the requirements of licensing a person to observe and document data regarding a nuclear system, mandating the protection of the public and the sharing of information gathered in research and observations that could help "promote the common defense and security" with the AEC. In the next section of the Act, 103c, the life of the building or length of the license is stated to be a maximum of forty years, although the license may be renewed after the license expires. In Section 106, the AEC has the power to classify an atomic facility to produce electrical energy, for research purposes not restricted to commercial electrical energy, or both based on the activities of the facility. In Section 107, the AEC is responsible for establishing the requirements and qualifications to license the operators within a power plant.

Most sources of information cited in this report referenced the Atomic Energy Act of 1954 as the first step taken for the commercial power companies to develop the nuclear power industry likely because it was a well thought out document that provided a sound basis for future development once more was learned. In fact, the Atomic Energy Act of 1954 did become the basic document for the atomic energy field, amended throughout the years, most recently in 2005, through public laws.

1.2.3.3 Price Anderson Act of 1957

With the Price Anderson Act, which was designed as an amendment to the Atomic Energy Act of 1954, the nuclear power industry was required to provide liability insurance for the construction of new power plants. This act established the insurance and liability issues regarding the possibility of a nuclear accident (Okrent, 1981). The Price Anderson Act came about as the result of the AEC approving a construction permit without a report from the Advisory Committee on Reactor Safety (ACRS) and the fact that questions were raised about determining the safe operation of a plant before the issuance of an operating license (Okrent, 1981).

The liability insurance would be provided by a third party according to the Price Anderson Act (Simpson, 1995). At the time of the original amendment, the maximum third party liability coverage was \$60 million plus \$500 million from government funding for a total of \$560 million in liability coverage (NEI, 2008). Today, the liability insurance coverage is \$10 billion. Approximately \$200 million has been paid out in claims since the enactment of the Price Anderson Act in 1957 (NEI, 2008).

However, insurance was not the only important part of the Act; every application to build a power plant had to be reviewed by the AEC, which then had to review the application with the ACRS (Simpson, 1995). Additionally, the Price Anderson Act also mandated a public hearing before any license could be issued, thus providing the public with a chance to review the report and intervene by voicing any concerns and doubts regarding construction of a nuclear power plant during the process of obtaining a permit (Simpson, 1995).

1.3 International Nuclear Power Plants Producing Commercial Power

The United States was not the only country capable of producing nuclear power in the 1950s. The United States started their commercial nuclear plants with a rating of 100 MW(e)and increased the electrical power rating with each subsequent plant (Simpson, 1995). By June of 1954, the Russians had a working reactor that could produce up to 100 megawatts of electricity (MW(e)) (Graham, 1999).

In the United States, meanwhile, the JCAE focused on the political value of being the first to control the power of the atom for singularly peaceful purposes (Simpson, 1995). Because Britain as a military ally of the United States was the recipient of the technology for developing nuclear propulsion for naval vessels, the British were in parallel development with the United States for the world's first commercial nuclear power plant (Simpson,1995). Britain finished first with a plant named Calder Hall, which produced electricity and weapons material and began operations in October of 1956 (Simpson, 1995). Calder Hall was commissioned by Winston Churchill to be designed in 1952 with construction to begin the following year ("A Brief History," 2008). Calder Hall was completed from initial design to complete construction in forty-two months as compared to estimates of 96 to 144 months for current plants (Simpson, 1995). Other countries, such as Germany, France, and Italy, intrigued by the race between the United States and England, were also looking to this new potential energy source (Simpson, 1995).

In France, the commercial nuclear power industry did not start until the 1960's when Westinghouse began international sales of nuclear power production designs and materials. (Simpson, 1995) France originally thought pressurized water reactors would not produce enough power as their own gas-cooled reactors, eventually they realized pressurized water was better; they wanted to learn the pressurized water technology for developing their submarine program (Simpson, 1995). France has continued to support nuclear energy since then, as evident by the fact that over seventy percent of the country's power is currently being supplied from nuclear plants.

However, internationally nuclear power is not limited to Russia, Britain, and France. Japan, India, China, Republic of Korea, Spain, Canada, Germany, Sweden, Belgium, and many more technologically developed countries have commercial nuclear power plants. While nuclear power is not currently a growing industry in the United States, it may be in the future, the American companies Westinghouse and GE are still involved internationally through their nuclear technology patents and maintenance agreements with countries such as Japan, China, and Spain.

1.4 Commercial Nuclear Power in the United States

The United States was not far behind the British in constructing commercial nuclear power plants. The first one in the United States was a demonstration plant built in Shippingport, Pennsylvania, which started construction in September of 1954 and started operation in December 18, 1957. One of the reasons for the fast completion of this plant was the technology engineers developed from previous experience working on similar reactor technology in nuclear submarines (Simpson, 1995). With a budget of $70 million (the final cost, however, was $72.5 million, which would be approximately $589.7 million today), the combined efforts of the Naval Research Branch, Duquesne Light Company of Pittsburgh, and Westinghouse Electric Corporation would create the world's first large scale commercial nuclear power plant (while Calder Hall was the first plant in the world, it was not solely dedicated to the production of power) (Simpson, 1995).

For the next twenty years, the nuclear power industry flourished partly because of predictions in electricity demand for an annual growth of 4% to 7% (Simpson, 1995). By 1977, the nuclear power industry then came to an abrupt halt in the United States for multiple reasons. One of the reasons was economic problems incurred from lawsuits against private commercial power companies (Simpson, 1995). Environmental activists continually sued utilities over environmental impact including the transportation and disposal of nuclear waste; these actions effectively stopped construction until the issues could be resolved and resulted in lengthened construction schedules (Simpson, 1995). As a result of the longer construction schedules, the utilities had to decide whether to borrow more funds to finish construction or to stop construction and tear down what they had already built (Simpson, 1995). Most utilities stopped construction (Simpson, 1995).

Then the Organization of Petroleum Exporting Countries' (OPEC) oil embargo of 1973 caused oil prices to rise considerably, which effectively reduced the demand for electricity as people conserved energy (Simpson, 1995). This lack of demand for electricity caused construction of some nuclear plants to be cancelled (Simpson, 1995). Then, in 1977, the JCAE was dissolved, and its responsibilities were divided among the Committees on Armed Services, Interior and Insular Affairs, Foreign Affairs (now International Relations), Interstate and Foreign Commerce (now Energy and Commerce), and Science and Technology (now Science). The JCAE, which had become very knowledgeable regarding nuclear power was replaced by committees that did not have this expertise and could not by themselves approve any action (Simpson, 1995).

Another significant reason for reduced nuclear power plant construction was high profile reactor accidents in the news, causing public panic.

1.5 Lessons Learned From Nuclear Power Plant Accidents

Nuclear reactor accidents have caused significant public concern. On March 28, 1979, the Three Mile Island accident made headlines as the worst nuclear accident in the United States. Although no deaths or injuries occurred, it is the worst on American soil due to a partial meltdown of one of the reactor cores. Another concern involving the Three Mile Island Accident was the release of a small amount of radioactivity.

The partial meltdown of the reactor was due to equipment malfunction and plant operator errors. The chain of events that started the partial meltdown began with the failure of the feed water pumps, which means it was a loss of coolant accident. Since the water was no longer flowing, the turbine and the reactor automatically shut down as was designed, but after the reactor shut down the pressure in the coolant system increased due to equipment failure. A pair of valves was then opened to release some of the increased pressure, but one of the power actuated relief valves stuck open, which allowed the primary system coolant to leak. However, the signal for the valve in the control room indicated that the valve was closed. The situation then became worse when control operators, not realizing the valve was stuck open, read the pressure in the reactor and estimated the reactor was full of coolant, because levels of coolant were not tracked; only the pressures in valves and in the reactor were tracked. As a result, the control operators turned off the primary coolant system pumps, leading to overheating of the fuel rods since the coolant in the reactor was slowly leaking out. The fuel rod cladding was made of a zirconium alloy that undergoes a chemical reaction when exposed to steam. The result of the chemical reaction was a hydrogen bubble that gathered in the top of the reactor, which the bubble was eventually reduced and removed. However, some of the hydrogen escaped into the containment building, along with some of the gaseous fission products released from the fuel rods. While most of the radioactive products were contained in the containment building, but a small amount of radioactive gases was released into the auxiliary building which in turn was released into the atmosphere to relieve pressure on the primary coolant system.

Changes as a result of Three Mile Island included updating safety of equipment, requiring reliability of individual components (such as pressure relief valves and electrical circuit breakers), upgrading and strengthening fire protection systems, installing automatic plant shut down, and isolating the containment building (NRC Fact Sheet). Other changes included enhanced training for plant operators and other staff, development of a detailed emergency preparedness plan for each plant, and expansion of performance and safety-based inspections (NRC Fact Sheet).

In 1986, another nuclear accident took place in Chernobyl, Ukraine. This accident was the world's most devastating nuclear accident, in which two deaths occurred within hours of the event (NRC Fact Sheet). Additional deaths and environmental contamination have been studied but are outside the scope of this report. Two of the major factors leading to this catastrophe were that the operators had purposely turned off safety precautions to perform testing, and that the early Soviet plant designs did not have a containment structure for power plants (Simpson, 1995). With concerns that the reactor core would melt through the bottom of the building and continue into the ground water, a large concrete block was placed under the plant to help slow the melting core (Condon, 1999). The concrete block was finished in June of 1986 and was constructed by tunneling under the foundations of the nuclear plant and using liquid nitrogen to freeze the soil in order to pour the concrete (Condon, 1999).

Once the fire from the melting core was put out, the Soviets turned the Unit 4 reactor in which the accident occurred into a concrete steel-lined tomb, or sarcophagus. However the integrity of the sarcophagus has been called into question by experts, due to the highly radioactive environment (NRC Fact Sheet). Also questioned was the long-term safety of the sarcophagus, resulting in the approved proposal to add a new steel structure over the sarcophagus (NRC Fact Sheet). This additional structure is to be designed to last for a minimum of a hundred years (NRC Fact Sheet).

Following the devastation of the Chernobyl accident, the Nuclear Regulatory Commission (NRC), which replaced the AEC, was determined to approach the accident in three ways: (1) determine what caused the accident, (2) investigate the safety implications of the accident, and (3) evaluate the need for more information, among other things the application of long term contamination control.

The Commission determined that the cause of the accident was a power surge, an unexpected increase in power, in the reactor. The safety implications investigation found that no immediate changes needed to be implemented in nuclear power plants in the United States. However, a few issues, already under review by the NRC, were recommended for further study, some of these issues being administrative controls and operational practices, containment, emergency planning, and severe accident phenomena (NRC Fact Sheet). Evaluation of the need for more in-depth information showed the industry needed to concentrate more on decontamination, ingestion pathways, and relocation of people (US NRC Fact Sheet).

These two accidents caused the NRC to review more carefully the existing and proposed facilities in the United States. Consequently, the NRC recommended changes were suggested to increase the safety and reliability of all systems in nuclear plants, whether critical or not, as mentioned above.

CHAPTER 2 - Structural Design Loads

Due to the development of new technology and the necessity for stronger safety precautions as evidenced from the accidents at Three Mile Island and Chernobyl, the design of nuclear power plant facilities has changed. Also, design of equipment and systems for nuclear power generation has advanced, giving a greater understanding of the forces that act on the entire system and the impact of interaction with other forces. For example, a force is a motion or strength applied to an object, and a design load is the maximum force a system is intended to withstand. With particular attention to design loads and added criteria to protect against worst case scenarios, structural system design has evolved from what it was thirty years ago. With this in mind, the following sections address design loads for containment facilities, environmental loads, extreme loads, and load combinations.

2.1 Structural Design Loads for Containment Facility

"A structure's primary purpose is to transmit all imposed loads safely through its constituent parts to the supporting ground." (Taly, 2003) Specifically, a containment structure acts as a barrier between imposed loads and nuclear material. Therefore, structural design involves arrangement and sizing of various members in a structure so that they are able to perform their intended function of carrying these imposed loads safely as they are transmitted through the structure to the ground. Typically, the first step in structural design is to determine of loads acting on buildings and their components. For nuclear facilities, these loads also include extreme loads, such as tornadic or impact loads. For the purpose of this report, structural design loads will be categorized into three types: normal loads, environmental loads, and extreme loads. These loads do not change the design containment as a whole whether the new material technologies in Chapter 4 are used or not. This section focuses on the many different loads that are applied to a nuclear containment structure over its life, or the estimated number of years of use, with a more in-depth look at extreme loads. First, the report will assess operating life of a typical nuclear power plant.

The operating life of a nuclear power plant structure can be anywhere from forty to sixty years in the United States, based on federal laws. Also, the operating life assumes the occurrence of all applicable loads. However, the forty year life of a nuclear power plant is not based on safety, technical issues, or even environmental issues. Rather, the building life is based on the length of time needed to pay off the investment and generate profit for the utility company (Oyster Creek website). When building a nuclear plant, the utility company must be able to predict a net profit over the life of the plant (Oyster Creek website).

Today, the oldest operating commercial nuclear power plants in the United States are Oyster Creek and Nine Mile Point 1 (EIA website). Both of these plants have been in operation since December 1, 1969, and both licenses are due to expire in 2009 (EIA website).

2.1.1 Structural Normal Loads

Structural normal loads are the most basic loads, dead and live, and as such are loads that are typically applied through the duration of construction and the anticipated life of the building.

2.1.1.1 Dead Loads

Dead loads are loads caused by the weight of the structure. Thus, architectural components such as ceilings, partitions, finishes, cladding, and permanent equipment, such as mechanical units or fire protection piping, create loads within the structure that must be considered during the design phase.

2.1.1.2 Live Loads

All gravity loads other than dead loads are considered live, such as transient or occupancy loads. Live loads may or may not act on a structure at any one given time and may be caused by humans, machines, or movable objects such as railroad and trucks for the transportation of heavy equipment and material shipment (ASCE 58, 1980). These loads can be applied uniformly or as concentrated point loads. Uniform loads are routinely based on the occupancy of the building and the intended use of the space, whereas concentrated loads can be created from heavy equipment, for example, transporting a spent fuel cask.

Another type of live load is a construction load that occurs during the construction phase of the building and is typically dependent on the structure type and the erection methods used. Most structures are not designed for construction loads; however, these loads need to be considered in the design of a nuclear power plant facility to find the governing load combination for design (ASCE 58, 1980). Since assembly of the facility cannot be allowed to compromise the integrity of the finished plant, the construction loads, though temporary, may be very high.

Construction loads come in a variety of delivery methods, which often lead to problems. According to Taly in *Loads and Load Paths in Buildings* (2003), some construction loads to consider are as follows: temporary storage of materials, transportation and erection of prefabricated members, and the design intent. First, temporary storage of materials can cause overloading on members if the materials stored are not evenly distributed. Next, transportation and erection of prefabricated members may affect the behavior and stability of the member. Finally, the design intent can affect members like concrete where the member is loaded before meeting the necessary or required design strength. Since construction load errors can easily lead to failures, designers often state that the construction loads should not exceed the live loads.

2.1.2 Structural Environmental Loads

Structural environmental loads can be described as forces based on the surrounding environment and not on human interaction. The environmental loads are separated into three sub-categories: (1) snow loads, ice loads, and temperature effects, (2) wind, and (3) seismic effects. First, snow loads and ice loads add physical weight to the structure. Second, wind-induced loads include hurricane wind-induced loads, but tornado wind-induced loads will be discussed in the extreme loads section. Seismic induced loads are broken into two separate loading conditions for a nuclear power plant facility: (1) operating basis earthquake loads and (2) safe shutdown earthquake loads. The operating basis earthquake load is discussed in the environmental loads section that follows while the safe shutdown earthquake load is reviewed in the extreme loads section.

2.1.2.1 Snow Loads, Ice Loads, and Temperature Effects

"Snow loads, ice loads, and temperature effects are natural climatic phenomena that occur because of atmospheric conditions outside and inside the building." (Taly, 2003)

<u>Snow loads</u> are gravity loads due to snow based on geographic location as well as the designated ground snow load at the site. However, snow loads change for different roof configurations to account for snow drift loads and sliding snow loads; even rain on top of snow

may be taken into design considerations. Ultimately, a snow load design is based on a 100 year recurrence (ASCE 58, 1980).

Ice loads should also be considered in design. If the roof is sloped, the projected area increases the ice load on the horizontal projected plane. If ice is not taken into account, it may produce failures in members due to the increased load (Taly, 2003). For containment structures, this rarely governs the design but should be considered because not all parts of the country will see ice loads. The individual ice load does not govern, but with load combinations it may be part of the governing situation. Refer to Section 2.2 for more on load combinations.

Temperature effects that induce forces into the structure occur when temperature differentials occur. These changes can cause members to shrink or expand and elongate, which induces a strain within the member. The members that are strained, such as metal that expands and contracts in this way, can suffer deformations that can affect the whole structure (Taly, 2003). Notably, the typical interior temperature of a containment structure is 120°F whereas the outdoor thermal gradients range from -20°F to 100°F (ASCE 58, 1980). Temperature effects do not govern the design of containment structures alone.

2.1.2.2 Wind-Induced Loads

Wind loads are lateral loads caused by the movement of air parallel to the ground (Taly, 2003). Even though in basic design considerations, wind loads are typically assumed as horizontal loads, wind loads can act in a vertical direction as well; which typically is designed as uplift. Both of these wind loads are applied to the structure statically, or as if they are fixed loads acting on the structure.

The wind loads are pressures based on wind speed, which are dependent on geographic location, and roof configuration. Most United States designs factor for wind speeds of ninety miles per hour (mph) for a three second gust, except in regions where hurricanes occur, where engineers must account for wind speeds up to 150 mph. Further, wind speed is based on a 100 year recurrence (ASCE 58, 1980). According to the American Society of Civil Engineers (ASCE) 58 Design Manual (1980), wind load designs should be determined from the "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures," which was the American National Standards Institute (ANSI) A58.1-1972 standard when the Design Manual was published; however now the "Minimum Design Loads for Buildings and Other Structures" is published as the ASCE/SEI 7-05, which supersedes ANSI A 58.1-1972. Since nuclear containment facilities are also designed for tornadic events, the wind-induced loads in this section do not govern the design.

Hurricane loads are not separately designed for because the load was incorporated into the design basic wind load in the ANSI A58.1-1972, now the ASCE/SEI 7-05. However, the ASCE 58 (1980) assures the hurricane design is adequate if the tornado design is correct. Since the hurricane loads are covered, therefore, engineers must then consider and evaluate storm surge and flooding factors specific to each site.

2.1.2.3 Earthquake (Seismic)-Induced Loads

Earthquake loads are induced into structures when the energy released from the earth causes a vibratory force that acts on the part of the structure in contact with the ground. Such force can cause the building to oscillate until the motion dampens to nothing, but this oscillating motion may cause significant damage to the structure depending on the materials and the rigidity of the building. Also, earthquake loads vary depending on the weight of the structure and the geographic location; the geographic location also affects the design seismic recurrence. These earthquake loads are applied to the structure as vertical and horizontal (lateral) loads and are applied statically.

For nuclear power plants, the typical earthquake in design is referred to as the operating basis earthquake. The formal definition of the operating basis earthquake provided in 10 CFR Appendix A to Part 100 (10 CFR, 2008) states, "the operating basis earthquake is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional." Quite simply, the nuclear plant is designed to continue to function following a seismic event. Typically, this design is at least one-half of the safe shutdown earthquake, see Section 2.1.3.1 (ACI Standard 359, 2007).

2.1.3 Structural Extreme Loads

Structural extreme loads constitute extreme environmental conditions that may occur throughout the life of the building. These loads can be safe shutdown earthquake, tsunami loads, hurricane loads larger than the basic wind speed, tornado loads, or missile loads. All extreme load occurrences are assumed to occur during the operational life of a nuclear containment structure (ASCE 58, 1980).

2.1.3.1 Safe Shutdown Earthquake-Induced Loads

Safe shutdown earthquake-induced load is a seismic load that designers use to make sure the systems and components of nuclear facilities important to safety remain functional for a plant shutdown (ASCE 58, 1980). This includes the safety of the systems and components as regards the structural soundness of the containment structure (which becomes the reactor coolant boundary), the ability to shut down the reactor, and the capability to prevent or mitigate offsite exposure in case of an accident. (10 CFR Part 100.3, 2008) As with all extreme load possibilities, a worst case scenario is assumed for construction design, therefore the greatest magnitude of historic earthquakes in the site's location is used as the design basis (10 CFR Part100 Appendix A, 2008).

2.1.3.2 Tsunami-Induced Loads

A tsunami is a series of waves created by an earthquake under the seabed or from an underwater volcanic eruption. According to the ASCE 58 design manual, the tsunami basic criterion is in the Nuclear Regulatory Commission's Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. "The factors for evaluating tsunami's follow:

1. Location of the underwater fault line or explosion, relative to the plant's site;
2. Magnitude of the offshore underwater earthquake or explosion;
3. Tsunami wave height at the source;
4. Tsunami wave height offshore;
5. Influences of hydrography and harbor or breakwater on tsunami;
6. Historical tsunami records of the region."

Tsunami loads evaluate flooding, scouring, deposition, dry intake (for plants that depend on water intakes for cooling), and hydrostatic and hydrodynamic forces on a structure assuming the most severe tsunami for the individual site (NUREG/CR-6966, 2008). Also, water-borne missiles from debris being carried by the tsunami should be considered in design (ASCE 58, 1980; NUREG/CR-6966, 2008). Moreover, consideration of tsunami loads should be given to plants proximal to coastal areas and inland bodies of water (NUREG/CR-6966, 2008). The offshore nuclear power plants, discussed in Chapter 4, would consider tsunami loads.

According to the ASCE 58 (1980), the tsunami load parameters can be found in the ANS-2.4 "Guidelines for Determining Tsunami Parameters at Power Reactor Sites," and flooding design parameters can be found in the NRC Regulatory Guide 1.59, Design Basis Floods for Nuclear Power Plants. However, the NRC completed a "Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America" in August 2008, which is a document that provides a procedure to identify sites that should consider tsunami design and how to design the associated tsunami forces, and the NRC plans on updating the NRC Regulatory Guide 1.59.

2.1.3.3 Hurricane-Induced Loads

As categorized by the Saffir-Simpson Hurricane Scale, a hurricane is defined as a cyclonic storm over water with sustained winds of 74 mph or greater; typically the storm will be in the western Atlantic Ocean. Storm surge from a hurricane would produce damage similar to tsunami effects, including the potential for water-borne missiles. Refer to Section 2.1.2.2 for associated wind-induced loads and refer to NRC Regulatory Guide 1.59, Design Basis Floods for Nuclear Power Plants, for associated flood loads similar to tsunami effects.

2.1.3.4 Tornado-Induced Loads

A tornado is a column of strong rotating air that extends from the clouds to the ground, often causing localized damage. Tornado loads, according to the ASCE 58 Design Manual, *Structural Analysis and Design of Nuclear Plant Facilities,* are designed for safety class structures, those structures that meet the design basis requirements previously discussed in 2.1.3.1, to resist maximum tornado conditions corresponding to each site. Safety class equipment design requires the functionality of the equipment in order for it to be shut down safely without harm to people and the surrounding environment. The containment building has a safety class designation because the containment building is considered part of the pressure boundary and holds all radioactive materials in a potential accident until cleanup begins.

For the design of structures, a design basis tornado is established and a tornado-structure interaction evaluation. The design basis tornado is based on geographic location and the Atomic Energy Commission (AEC) Regulatory Guide 1.76, but considers the basic wind velocity and differential pressures found in the Regulatory Guide 1.76. The tornado-structure interaction applies the design basis tornado to pressures and forces that act on the structure and corresponding components to find the net effect.

Tornado effects regarding structural damage are wind, differential atmospheric pressure, and wind-borne missiles. The damage for each of these effects respectively is caused by the following:

1. Drag and lift pressures all over the building;
2. The change in atmospheric pressure between the interior and exterior of the building;
3. Penetration, spalling, and impact forces created by projectiles, known as wind-borne missiles in this report.

(FEMA 361, 2000)

The wind-borne missiles mentioned are pieces of debris, such as tree branches, which are lifted off the ground by the tornadic winds and accelerated by the wind forces until the tornadic forces no longer act upon it. The impact of the wind-borne missiles can cause a significant amount of damage; heavier objects like cars are not necessarily lifted off the ground but can be rolled into the structure. Since the impacts from the wind-borne missiles last less than one second, it is unlikely that the highest impact force and the highest wind load occur at the same time (FEMA 361, 2000).

A force caused by a tornado has been commonly categorized using the Fujita Scale until recently. The Fujitia Scale is based on the damage observed and not on wind speed. Therefore, since February of 2007, tornadoes are no longer categorized by the Fujita Scale but rather by the Enhanced Fujita Scale, reference Table 2.1, p.22. The Enhanced Fujita Scale still estimates wind speeds associated with a tornado category, and the evaluation is now based on an average damage (Storm Prediction Center website). Accordingly, nuclear containment facilities are designed for a maximum tornadic wind speed of 230 mph in the central portion of the United States (NRC Regulatory Guide 1.76, 2006), which accounts for environmental wind loads. The east coast, northern border, and western Great Plains are designed for maximum tornadic wind speeds of 200mph, and design in the western portion of the United States uses a maximum of 160mph (NRC Regulatory Guide 1.76, 2006). The tornadic wind speeds are used to obtain the necessary extreme wind loads that act on the exterior of the containment structure, as well as better predict the force of the wind-borne missiles.

Table 2.1 The Enhanced Fujita Scale

[Reference Storm Prediction Center website]

EF Category	3 Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	>200

2.1.3.5 Missile Induced Loads

Safety class structures, components, and equipment are designed not to lose function due to missiles. Whether plant-generated missiles or projectiles from extreme environmental forces, both of which will be in discussed in further detail in the following sub-sections of the report. Another type of extreme environmental missiles is aircraft. If the site is near an airport, aircraft missiles should be considered, more so since the World Trade Center attack on September 11, 2001. Since missile damage is hard to predict, a probability assessment is used, which employs a number of hypothetical sequences and events, "which include potential for missile generation, ejection, striking, and finally damage (ASCE 58, 1980)."

2.1.3.5.1 Extreme Environmental Missiles

Extreme environmental missiles are typically tornado borne projectiles and aircraft. Tornado generated missiles are limited to the objects lying in the path of a tornado, but once again it is hard to predict how the missiles generated from tornadoes are going to act. At any rate, extreme environmental missiles are measured by three factors: surface area, density, and shape (ACSE 58, 1980). In the NRC Regulatory Guide 1.76 in revision 1 from March of 2007, the missile that nuclear power plant structures use for design is a six inch diameter Schedule 40 steel pipe that is 15 feet long (a penetrating missile) and an automobile (a massive missile).

Consideration of an aircraft crash depends on the proximity of the site to the airport. If the plant is located within five miles of an airport, then various aircraft from small military jets to commercial airliners should be analyzed (ASCE 58, 1980). The NRC has recently ruled (NRC News No. 09-030, 2009) that large commercial aircraft impact is "beyond-design-basis events" and is exempt from the NRC design basis requirements for redundancy. However, if the design is incorporated then the following design features and function capabilities must be met: core cooling capability, containment integrity, spent fuel cooling capability and spent fuel pool integrity. Also, existing nuclear power plants must mitigate dangers from large fire and explosions from any cause, including the beyond-design-basis aircraft impact; the NRC voted to include this in the code for new nuclear power plant design (NRC News No. 09-030, 2009).

2.1.3.5.2 Plant-Generated Missiles

Plant-generated missiles are caused when parts of equipment are cast off due to deterioration or malfunction in the power production system. Thus, they vary in size, weight, and impact velocity with designations of heavy, moderate, or light whenever possible. The design basis of plant-generated missiles accounts for two variables: the physical layout in regards to the component or equipment in question, and the external restraints, which also accounts for the redundancy and fabrication quality of the restraints.

Plant-generated missiles will vary to a degree depending on the type of plant, but for the most part, these types of missiles are created from a mechanical system rupture "due to high-energy levels" (ASCE 58, 1980). Some plant-generated missiles to consider for design are valve stems, valve bonnets, and turbine rotor pieces (ASCE 58, 1980). The forces associated with these heavy plant-generated missiles are 6,290 ft-lbs, 1,050,000 ft-lbs, and 53,800,000 ft-lbs, respectively (ASCE 58, 1980). However, even if system parts or equipment could potentially become missiles, the design considerations may not include them since their probability occurrence is low (ASCE 58, 1980).

2.2 Structural Design Load Combinations

The structural design load combinations can be found in either ACI Standard 359-07, which is the same as the 2007 ASME Boiler & Pressure Vessel Code Section III – Division 2, or ACI Standard 349-01. The scope of ACI Standard 359 encompasses the structural concrete pressure resisting structure and components, containment metal liners, and penetration liners extending through the containment structure concrete. The ACI 349 applies to concrete structures that support, house, or protect nuclear safety class systems or components; this would be for internal containment structures.

2.2.1 ACI 359 Load Combinations

The following are the load combinations in ACI Standard 359-07, Table CC-3230-1:

Service Load Combinations:

1. $1.0D + 1.0L + 1.0F + 1.0P_t + 1.0T_t$
2. $1.0D + 1.0L + 1.0F + 1.0T_o + 1.0W$
3. $1.0D + 1.0L + 1.0F + 1.0G + 1.0T_o + 1.0R_o + 1.0P_v$

Factored Load Combinations:

4. $1.0D + 1.3L + 1.0F + 1.0G + 1.0T_o + 1.5E_o + 1.0R_o + 1.0P_v$
5. $1.0D + 1.3L + 1.0F + 1.0G + 1.0T_o + 1.5W + 1.0R_o + 1.0P_v$
6. $1.0D + 1.0L + 1.0F + 1.0G + 1.0T_o + 1.0E_{ss} + 1.0R_o + 1.0P_v$
7. $1.0D + 1.0L + 1.0F + 1.0G + 1.0T_o + 1.0W_t + 1.0R_o + 1.0P_v$
8. **$\mathbf{1.0D + 1.0L + 1.0F + 1.0G + 1.5P_a + 1.0T_a + 1.0R_a}$**
9. $1.0D + 1.0L + 1.0F + 1.0G + 1.0P_a + 1.0T_a + 1.25R_a$
10. $1.0D + 1.0L + 1.0F + 1.25G + 1.25P_a + 1.0T_a + 1.0R_a$
11. **$\mathbf{1.0D + 1.0L + 1.0F + 1.0G + 1.25P_a + 1.0T_a + 1.25E_o + 1.0R_a}$**
12. $1.0D + 1.0L + 1.0F + 1.0G + 1.25P_a + 1.0T_a + 1.25W + 1.0R_a$
13. $1.0D + 1.0L + 1.0F + 1.0G + 1.0T_o + 1.0E_o + 1.0H_a$
14. $1.0D + 1.0L + 1.0F + 1.0G + 1.0T_o + 1.0W + 1.0H_a$
15. **$\mathbf{1.0D + 1.0L + 1.0F + 1.0G + 1.0P_a + 1.0T_a + 1.0E_{ss} + 1.0R_a + 1.0R_r}$**

Where:

D = dead loads, including hydrostatic and permanent equipment loads

E_o = loads generated by the operating basis earthquake. Only the actual dead load and existing live load weights need be considered in evaluating seismic response forces

E_{ss} = loads generated by the safe shutdown earthquake. Weights considered shall be the same for E_o

F = loads resulting from the application of prestress (post tensioning)

G = loads resulting from relief valve or other high energy device actuation

H_a = load on the containment resulting from internal flooding, if such an occurrence is defined in the Design Specification as a design basis event.

L = live loads, including any movable equipment loads and other loads which vary with intensity and occurrence, such as soil pressures

P_a = Design Pressure load within the containment generated by the design basis accident (DBA), based upon the calculated peak pressure with an appropriate margin

P_t = pressure during the structural integrity and leak rate tests

P_v = external pressure loads resulting from pressure variation either inside or outside the containment

Ra = pipe reaction from thermal conditions generated by the DBA including R_o

R_o = pipe reactions during normal operating or shutdown conditions, based on the most critical transient or steady state condition

R_r = the local effects on the containment due to the DBA

Ta = thermal effects and loads generated by the DBA including T_o

T_o = thermal effects and loads during normal operating or shutdown conditions, based on the most critical transient or steady state condition

T_t = thermal effects and loads during the structural integrity and leak rate tests

W = loads generated by the design wind specified for the plant site

W_t = tornado loading including the effects of missile impact

The live load includes all temporary construction loading during and after construction of the containment (ACI Standard 359, 2007). The effects of P_a, T_a, R_a, R_r, and G are combined unless a time-history analysis determines lower values are allowed (ACI Standard 359, 2007). The load combination that most likely governs is 8, 11, or 15, which are in bold (ASCE 58, 1980).

2.2.2 ACI 349 Load Combinations

The following are the load combinations in ACI Standard 349-01, Section 9.2:

1. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7R_0$
2. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7E_0 + 1.7R_0$
3. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7W + 1.7R_0$

4. $U = D + F + L + H + T_0 + R_0 + E_{SS}$
5. $U = D + F + L + H + T_0 + R_0 + W_t$
6. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.05T_0 + 1.3R_0$
7. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.3E_0 + 1.05T_0 + 1.3R_0$
8. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.3W + 1.05T_0 + 1.3R_0$

Where :

D = dead loads, including piping and equipment dead loads

E_0 = load effects if operating basis earthquake (OBE), including OBE-induced piping and equipment reactions

E_{SS} = load effects of safe shutdown earthquake (SSE), including SSE-induced piping and equipment reactions

F = loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights

H = loads due to the weight and pressure of soil

L = live loads

R_0 = piping and equipment reactions which occur under normal operating and shutdown conditions, excluding dead load and earthquake reactions

T_0 = internal moments and forces caused by temperature distributions within the concrete structure occurring as a result of normal operating or shutdown conditions

W = wind load

W_t = loads generated by the design basis tornado (DBT). These include loads due to tornado wind pressure, tornado created differential pressures, and tornado generated missiles.

CHAPTER 3 - Structural Design and Analysis of Containment Structures

The assorted buildings that make up a nuclear power plant are discussed in this chapter. These buildings include the containment building, internal containment structures, and other surrounding buildings. The containment structure, usually referred to as containment, is the physical building that separates the reactor from the atmosphere and houses the internal containment structures and nuclear reactors. Nuclear power plants are site-specific and vary in size based upon the power plant's power rating and size of equipment, but typical containment buildings range from 150 to 200 feet tall with a diameter of approximately 150 feet. Below, in Figure 3.1, is a typical nuclear power plant site plan to show the location of the containment building with respect to the overall plant.

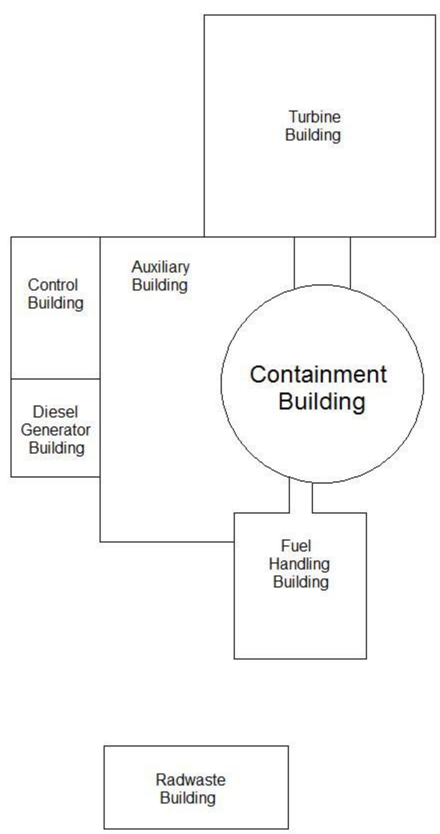

Figure 3.1 General nuclear power plant site plan

3.1 Containment

The containment building is the primary building for the design of a nuclear power plant; the reactor and its primary system components are located inside this structure. This building is airtight to prevent the release of radioactive particles into the atmosphere. Every equipment hatch, personnel lock, and pipe penetration, indeed every opening in the containment structure is sealed to ensure no leaks can occur (ASCE 58, 1980). The containment building can be constructed from steel or concrete, with reinforced concrete design being the focus of this report because the most current containment buildings have been designed as reinforced concrete structures. Concrete containment structures lined with steel are more economical than steel containment structures, for dry containment, since a steel containment structure would require a concrete shield structure, thus concrete is required in either instance, and the more economical choice should be used (ASCE 58, 1980). . Over half of the nuclear power plants in the United States are designed for dry containment, and according to the ASCE 58 (1980), "a limitation of 1.75 in. on shell plate thickness without ASME Code requirements for stress relieving, freestanding steel cylinder dry containments are seldom used above the 900 MWe size," hence concrete containment is preferable to steel containment.

The use of modern material technologies, further discussed in Chapter 4, may assist in construction and the durability of the containment building with regards to concrete. However, the design loads applied to the structure and the analysis of the structure in this instance will not change whether the new technologies from Chapter 4 are used or not.

3.1.1 Reinforced Concrete Containment Structures

This section discusses the different parts of the containment structure that need to be designed and analyzed with regards to reinforced concrete construction. When a containment structure is constructed of reinforced concrete, the structure can be divided into three sections: the shell, the cylindrical walls, and the slab. All three sections are reinforced, but the shell requires further reinforcement to resist additional tensile loads from the shell's geometry, especially if openings are in the shell (ASCE 58, 1980). In general, the concrete is designed not to exceed the allowable stresses for compression, tension, shear, torsion, and bearing for the loads used in the load combinations found in Section 2.2.1 (ACI Standard 359, 2007). Allowable stresses for factored loads also account for radial shear, tangential shear, peripheral shear, and brackets and corbels (ACI Standard 359, 2007). The reinforcement is designed for tension and compression stresses (ACI Standard 359, 2007).

The shell of the containment structure is designed for the load combinations in Section 2.2.1 (ACI Standard 359, 2007). Typically the shell is analyzed as a thin shell structure, which assumes an elastic behavior for estimating internal forces, displacements, and shell stability (ACI Standard 359, 2007). When verifying the shell's stability for the whole containment structure, engineers are permitted a reduction for the buckling capacity due to large deflections, creep, and construction tolerances (ACI Standard 359, 2007). However, model tests can be used for analysis as long as they are conservative or the model tests validate mathematical analysis assumptions (ACI Standard 359, 2007).

The walls of a containment structure apply the load combinations found in Section 2.2.1. The walls are to be analyzed on basic mechanical engineering principles that consider the geometry (ACI Standard 359, 2007). Thus, local sections should be designed for the transfer of moments and forces from the cracking of concrete in a statically indeterminate containment structure (ACI Standard 359, 2007). The steel liner loads, mentioned in the following section, should also be considered in the design and analysis of the containment structure's walls.

The slab is analyzed for elastic behavior while considering discontinuities and foundation soil loads (ACI Standard 359, 2007). Within the foundation soil loads, analysis of the soil sample from the site is considered, as well as the location of the bottom of the foundation to prevent possible flood loads (ACI Standard 359, 2007). Also, soil moisture changes, foundation material deterioration, and long term containment settlements are considered in the foundation analysis (ACI Standard 359, 2007). The foundation settlement applies the load combinations from Section 2.2.1 with the exception that all the load factors are 1.0 (ACI Standard 359, 2007). To provide an idea of how massive a concrete containment structure, is the following description is based on Figure 4.11 from the ASCE 58, which is shown in Figure 3.2, p.30 (1980). The reinforced concrete shell is typically three and a half feet thick with two layers of reinforcing for the typical containment structure ranging from 150 to 200 feet tall with a diameter of approximately 150 feet; #18 bars at 12 inches on center each way and each face. The cylindrical walls are even larger in order to carry the entire dead load, including the shell, to the base slab. The walls are at least four feet thick with #18 vertical bars at 12 inches spacing for each face and #18 horizontal bars on both sides of the vertical reinforcing; the ties are made of #8 bars. The

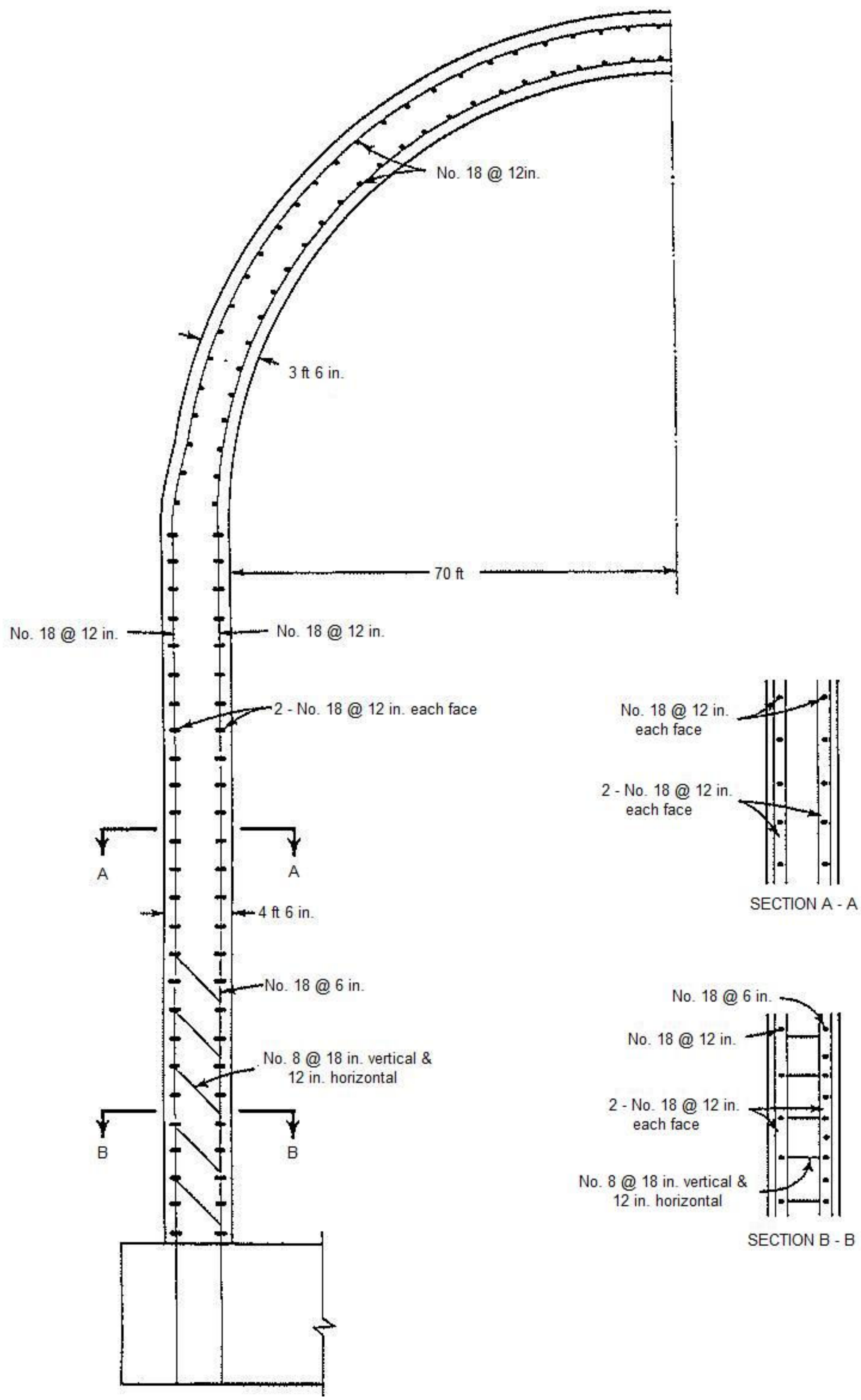

Figure 3.2 Reinforced deformed bar concrete containment

[Reference ASCE 58, 1980, Fig. 4.11]

walls are massive and lined with steel to prevent as much radioactive particulate as possible from escaping as well as to retain structural integrity after an impact by loads described in Chapter 2.

3.1.1.1 Steel Liners

The containment structure must be airtight to prevent any fission products from escaping, which concrete cannot do alone because it is porous, and therefore the structure utilizes a steel liner on the entire interior surface (ASCE 58, 1980). The steel plate is anchored into the concrete by welded shear studs to the plate or by connection to continuously rolled members that are embedded into the concrete and closely spaced (ASCE 58, 1980). This plate, which varies in thickness from a quarter of an inch to three-eighths of an inch, supports itself during construction and acts as a part of the forming system for the concrete since it is typically assembled first (ASCE 58, 1980). The required minimum thickness for the steel plate is a quarter of an inch (ASCE 58, 1980). Evaluation of the steel liner over prolonged exposure to radiation shows degradation of the steel liner: therefore, using a thicker plate allows future minimum standards to be met (NRC website).

However, the steel plate can be analyzed by plate or beam theory as long as assumptions are conservative (ACI 359, 2007). Also, the steel plate requires the load combinations previously shown in Section 2.2.1, except all load factors may be taken as 1.0 (ACI 359, 2007).

The steel plate and anchors are designed for primary loads, but the anchors also account for the design of unbalanced loads that occur from changes in the plate thickness and curvature (ASCE 58, 1980). According to the ASCE 58 Design Manual (1980), other considerations for the steel anchors include welded seam offsets, anchor spacing and stiffness, plate biaxial loads, and localized concrete crushing. These considerations for the anchors accommodate shear loads and displacement at the anchor (ACI 359, 2007).

All building pipe penetrations are often steel tubes welded to the steel liner, as well as anchored into the concrete. For larger penetrations like equipment hatches and personnel access, the steel plate thickness is increased and additional reinforcing is provided around the location to transfer the localized forces (ASCE 58, 1980).

3.1.2 Post-Tensioned Reinforced Concrete Containment Structures

This section reviews the information and the different parts of the containment structure that need to be designed and analyzed for post-tensioned construction. A engineer should consider post-tensioned concrete to reduce concrete thickness, increase span lengths, and reduce the number of joints. Reducing concrete thickness for the containment structure may seem counterintuitive, but if the load conditions and load combinations are met, then a reduction of material will reduce construction costs.

The most notable difference between the reinforced concrete containment and the post-tensioned concrete containment is the type of reinforcement used. The concrete is also affected though, the steel strands pull the concrete into compression before loads are applied so that the system does not go into tension as easily, allowing the concrete to do more of the work. The slab is still traditionally reinforced concrete, but the walls and dome are post-tensioned (ASCE 58, 1980). Even in the post-tensioned concrete, mild steel (billet reinforcing bars) is provided for extra strength and transfer shear and bending forces at shell discontinuities, around containment penetrations, and near tendon anchoring in the buttresses to control cracking in the end anchor zone (ASCE 58, 1980). Post-tensioning employs high strength steel. These steel strands are pulled through ducts placed in the concrete; when pulled (post-tensioned), the tendons place a compressive force on the concrete. These ducts can be filled with non-corrosive grout (bonded post-tensioning) or grease (unbonded post-tensioning) that prevents corrosion; typically the grease is used in nuclear containment structures (ASCE 58, 1980). However, like any post-tensioning system, the tendons should be checked periodically to ensure the proper stress levels are maintained. The first, third, and fifth years after the containment structure integrity test is performed require the tendons be inspected followed by every five years after the first five years (NRC Regulatory Guide 1.35, 1990).

The concrete for the post-tension reinforcing is designed for the same load combinations as mildly reinforced concrete, the differences being the allowable stress design for the concrete and the reinforcement design. However, load combinations 2 and 3 found in Section 2.2.1, account for creep effects and the geometry at thickened sections; this would apply to the ring girders and buttresses (ACI Standard 359, 2007). In ACI Standard 359-07, the design for the reinforcing tendons begins with the assumptions that "strains vary linearly with depth through the entire load range," followed by "at cracked sections, the ability of the concrete to resist tension is neglected."

The cylindrical walls of the prestressed containment structure use vertical and horizontal post tensioned strands for reinforcing; refer to Fig. 3.3, p.33, and Fig.3.4, p.34, for description layouts. The horizontal strands are often referred to as hoop tendons since they are circular. These tendons are spaced equally vertically while rotating their tendon anchorage point amongst the vertical buttresses to provide a more relatively uniform load to the walls, see Fig. 3.5, p.35 (ASCE 58, 1980). The vertical strands extend from the base slab to the top of the wall into a concrete ring girder (ASCE 58, 1980). Access to the tendons in the base slab is provided by a gallery in the base slab and below the containment wall (ASCE 58, 1980). However an alternative layout for post tensioning tendons in the wall, a coil configuration anchored at top and bottom achieves the necessary vertical and horizontal forces to prestress the wall (ASCE 58,

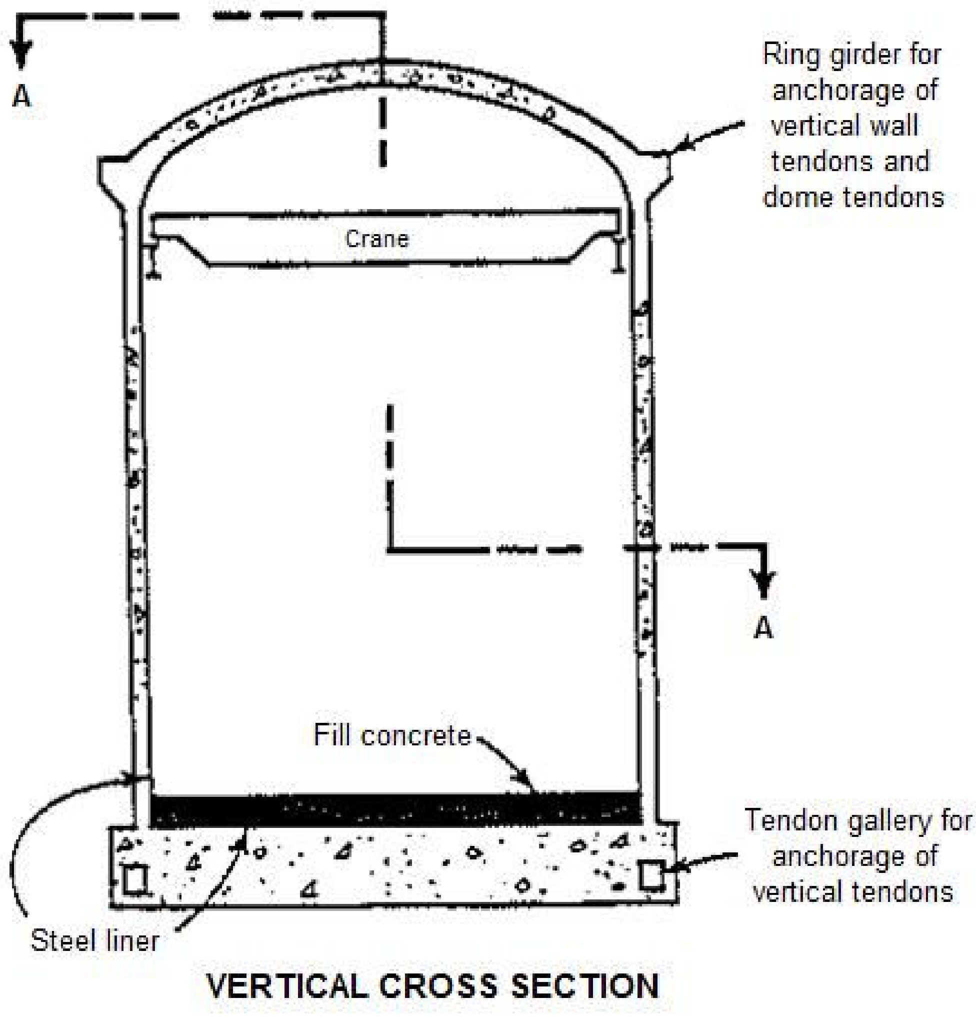

Figure 3.3 Steel-lined post-tensioned concrete containment for Pressurized Water Reactor: Vertical Cross Section

[Reference ASCE 58, 1980, Fig 4.12]

1980). With the coiled strand configuration, buttresses are not required since the strands do not need to be anchored at any horizontal levels (ASCE 58, 1980). The coil loops around the structure from the slab to the ring girder (ASCE 58, 1980).

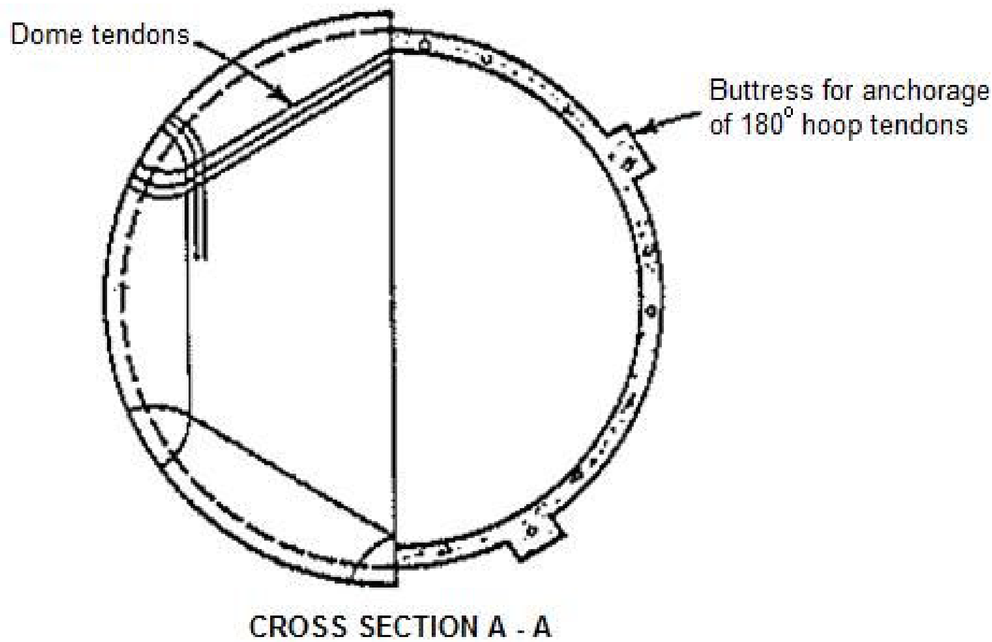

Figure 3.4 Steel-lined post-tensioned concrete containment for Pressurized Water Reactor: Cross Section A-A

[Reference ASCE 58, 1980, Fig 4.12]

Another difference between the concrete containment structures is the type of dome; however, all domes have the same purpose of preventing radiation from escaping the containment building in order to keep the public safe (ASCE 58, 1980). With post-tensioned containment structures, engineers may choose between an ellipse shaped dome or a hemispherically shaped dome, based on how reinforcing is to be designed to meet the volume necessary to contain postulated pressures (ASCE 58, 1980).

The hemispherical dome, the same shape as seen for a mildly reinforced concrete containment structure, applies a two-way pattern for the reinforcing strands through the dome; refer to Figure 3.6, p.37 (ACSE 58, 1980). Supplemental U-shaped strands are provided vertically and horizontally throughout the dome to achieve the necessary reinforcing in the shell (ASCE 58, 1980).

The elliptically shaped dome uses three groups of tendons near the edges of the dome to achieve the required post-tensioning forces (ASCE 58, 1980), which are said to have ultimate capacities of up to 1,000 tons (ASCE 58, 1980). The tendon groups are anchored into the same ring girder as the wall's vertical strands (ASCE 58, 1980).

No matter what tendon configuration is used for the post tensioned containment building, the entire interior must be lined with steel plates just like a reinforced concrete containment structure (ASCE 58, 1980).

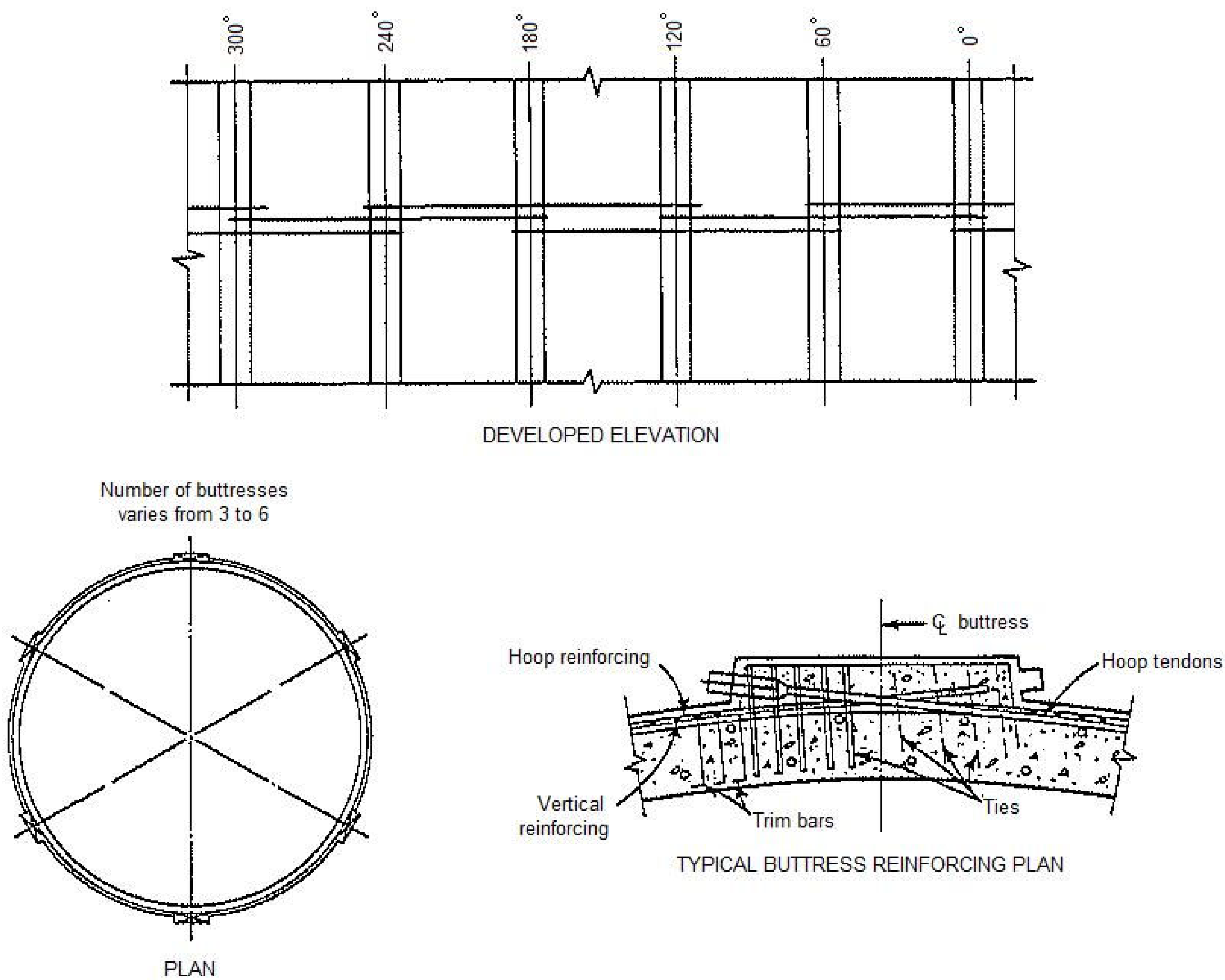

Figure 3.5 Containment buttress tendon arrangements

[Reference ASCE 58, 1980, Fig 4.14]

3.1.3 Containment Structure Proportioning and Layout

This section presents the considerations required for a structural engineer to determine clearances and dimensions pertaining to the containment structure. If the structural engineer is not aware of clearances then the structure could be undersized. Internal clearance requirements provide a starting size for the containment structure, but equipment arrangement for the Nuclear Steam Supply System (NSSS) and the accompanying auxiliary equipment should also be considered (ASCE 58, 1980). The piping layout and the internal structures, which will be discussed in section 3.2, are also accounted for in clearances and dimensioning of the containment structure (ASCE 58, 1980). The internal containment systems definitely influence the containment size because of the required air volume for dissipation of pressure in the event of a loss of coolant accident (LOCA) (ASCE 58, 1980). Logically, the dome shape is optimal for the dispersion of interior pressure. The minimum containment structure design may require changes even with these considerations in place, the containment may need to be increased (typically in height) to reduce the design pressure that could act on the containment in a LOCA (ASCE 58, 1980).

The mat foundation is sized based on contact pressure with the soil during a seismic event, refer to Section 2.2.1 on page 20 for load combinations (ASCE 58, 1980). However, seismic design is not covered in this report; seismic design is in itself a report due to the complexity and continuous updating with recent codes. Mat foundations are used due to the internal containment structures, refer to Section 3.2, and other plant buildings sharing one foundation (ASCE 58, 1980).

According to the ASCE 58 Design Manual (1980), the building interior height considers the vertical requirements for the reactor and steam generators and the level where they are supported. The partial removal of the reactor necessary for refueling and the removal of steam generators for retubing should also be considered for minimum clear height within the structure (ASCE 58, 1980). The final considerations with regards to the interior clear height are the refueling pool depth, crane clearances, and the dome's shape (ASCE 58, 1980). After all considerations are accounted for, the actual final height may be more than the required minimum (ASCE 58, 1980). If this is the case then the design pressure calculated for a LOCA can be reduced because of the increase of volume within the containment structure from the minimum (ASCE 58, 1980).

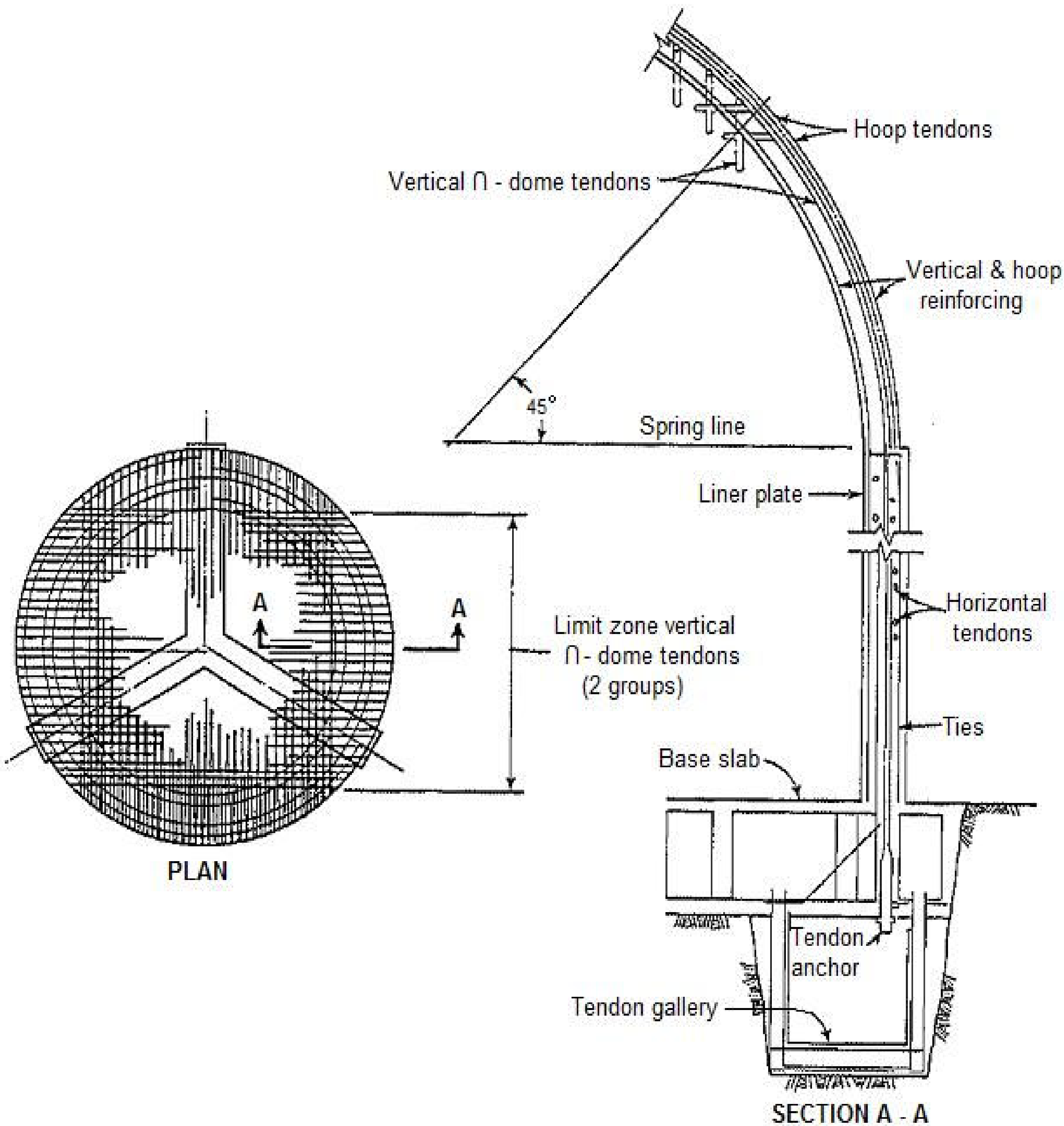

Figure 3.6 Wall and dome reinforcing elements for hemispherical dome containment
[Reference ASCE 58, 1980, Fig. 4.13]

3.1.4 Economic Considerations

Structural engineers design the structural system for a project based on many factors, and some of these factors are monetary. This section examines the economic considerations for containment structure design provided by the ASCE 58 Design Manual (1980):

1. Type of containment preference whether steel or concrete from the supplier of the NSSS. The engineer should ensure that the supplier's reason regarding a structural preference is valid before deciding on the containment design. Design will also be determined by available materials.
2. The location of the plant and the labor force nearby needs to be considered for the containment design. If the design requires more skilled labor, the cost to transport or train local laborers should be considered. This affects post-tensioned reinforced concrete construction because of the skill necessary for the construction.
3. The construction sequencing required for different containment designs affects the overall construction schedule, so an engineer should opt for the more advantageous schedule. This applies to material supplies and material delivery.
4. The factors outside of the containment structure may increase the project costs if a secondary containment structure is necessary. The need for a secondary containment structure is based on whether the site is close to a large population, site size, and the shortest distance in which the atmosphere can efficiently disperse released gases. If the site is too close to a population, then precautionary measures would require a secondary containment system to further prevent the escape of radioactive particulate. If the site is small, a secondary containment system would be required to capture particulate; on a larger site it would not be necessary because in the event of some radioactive release, there would be enough area for dissipation. Even if the site has a large area, but is located a short distance upstream from a small town, if there is not enough air space for any possible radioactive particles to disperse, then a secondary containment system would be required.

5. The long-term maintenance cost for the life of the building for post-tensioned concrete containment is another consideration since the post-tensioned strands need to be tested to ensure they are at the necessary stress levels. The long-term maintenance associated with post-tensioned systems stems from the fact that over time, the post-tensioned tendons can creep, which reduces the tendon's stress. Another concern is leaking non-corrosive grout or grease; this would make the tendons more susceptible to water penetration.
6. The containment foundation should consider the bearing elevation and the finished elevations of entries into the containment building. The required elevations may determine whether or not rock or soil needs to be excavated.

While the previous considerations may make an impact on the time and cost of the project, the considerations are not restricted to only these economic considerations.

3.1.5 Design Process

The first place to start any structural design is by determining the applied loads as discussed in chapter 2. From the applied loads and load combinations, the primary and secondary forces are found within the containment shell structure (ASCE 58, 1980), primary forces being those acting directly, or applied, on the containment shell structure, and secondary forces being those induced into the containment structure through deformations and shape considerations, and not by applied forces. When all the necessary loads for the containment structure are found, the appropriate load combinations should be evaluated to find the critical design loads. Also, engineers need to be sure that all concrete is properly designed for thermal forces for possible reduction of reinforcement (ASCE 58, 1980).

The engineer should pay extra attention to shell discontinuities, prestressed tendon anchors for the design of the concrete supports, and analysis of the base slab as a plate because these criteria are not typical design considerations for the overall containment structure (ASCE 58, 1980).

The containment dome is designed differently from the rest of the containment structure; it is designed as a shell (ASCE 58, 1980). The shell is designed for the primary and secondary forces, as well as thermal stresses, which may be approximated from ACI 307, although the thermal stresses can be calculated using the equilibrium equations and strain compatibility (ASCE 58, 1980).

The preliminary analysis, especially for the containment dome, is used to layout a finite element mesh for the containment structure and foundation; this allows the engineer to obtain a more accurate structural system analysis. Finite element analysis is a computer process that allows the user to define a mesh of specific points and solves unknown information using a system of equations. According to the ASCE 58 Design Manual (1980), the preliminary design of axisymmetric loads is used to establish a layout of the finite element plates, or mesh, for analyzing the shell of the containment structure. The finite element analysis takes into account the steel liner and the type of concrete reinforcing required for containment design (ASCE 58, 1980). Depending on the program, analysis of the shell can produce stresses or forces and moments when the shell is composed of elastic elements. Naturally, the layout of the finite element mesh may affect the output of a finite element analysis if thermal changes in the concrete and prestressing loads are not applied at the correct mesh nodes (ASCE 58, 1980). Other forces to consider in the analysis are the loads from internal structures and the possibility of uplift, from external wind surface forces, acting on the shell (ASCE 58, 1980).

Notably, when the preliminary analysis yields asymmetric loads, a computer program capable of analysis for an axisymmetric structure for asymmetric loads must be used to obtain the resultant forces and moments (ASCE 58, 1980). Today's computer programs are capable of this and have more advanced analysis features than those of the 1970s. The top finite element analysis programs today are SAP 2000, RISA 3D, ABAQUS, and SIMULIA.

3.1.6 Primary Containment Design

Given the concrete containment building components, and the required mild reinforcement and post-tensioning, the shell can be ellipsoidal or hemispherical (ASCE 58, 1980).

Access into the containment vessel is through a hatch, for equipment, and locks, for plant workers (ASCE 58, 1980). The hatches are designed to be large enough for the removal of specified equipment when the plant periodically shuts down (ASCE 58, 1980). The locks provide workers with access through the containment building by interlocking doors at each end of the passage when the plant is in operation (ASCE 58, 1980).

The NRC has approved ACI Standard 359 and the ACI-ASME Joint Technical Committee on "Code for Concrete Reactor Vessels and Containments, ASME Boiler and Pressure Vessel Code Section III – Division 2" for the proper loads and load cases with regards to concrete containment, refer to Section 2.2. The general steps for the actual design are similar to the evolution of design, by means of a preliminary design, the use of finite elements, and a final design (ASCE 58, 1980). For the preliminary design, the procedure follows most closely that described in the evolution of the design, but with the inclusion of soil support (ASCE 58, 1980). The soil, which can be modeled with finite element analysis, soil springs, or compliance functions, is analyzed when an interaction of the different containment vessels occurs through the slab (ASCE 58, 1980). The different containment vessels are the containment structure, the secondary containment structure, and the internal concrete structures (ASCE 58, 1980). This analysis is important because any interaction with the slab during an earthquake can amplify the oscillation of the containment vessel (ASCE 58, 1980). Consequently, the final design requires that the containment analyst knows what behavior to expect from the specified loads, how to prepare a model, and to confirm from the results the validity of the assumptions (ASCE 58, 1980).

3.1.7 Secondary Containment

In a few instances, the containment building is structurally sound but due to the high level of radiation and proximity to a population a second containment structure is required. This secondary containment is necessary when radiation levels at the site boundary exceed the allowable limits. Accordingly, two kinds of secondary containment buildings correspond with the two types of containment buildings: an enclosure building and a shield building (ASCE 58, 1980).

An enclosure building is the secondary containment used for concrete containment structures and is made of either a thin reinforced concrete dome, which is self-supporting, or a light structural steel covered with metal siding, which frames directly into the primary containment structure (ASCE 58, 1980); refer to Fig. 3.7, p.42. The enclosure building is built close to the primary containment building to maintain a negative pressure to keep any radioactive materials within the airtight space between the two buildings (ASCE 58, 1980).

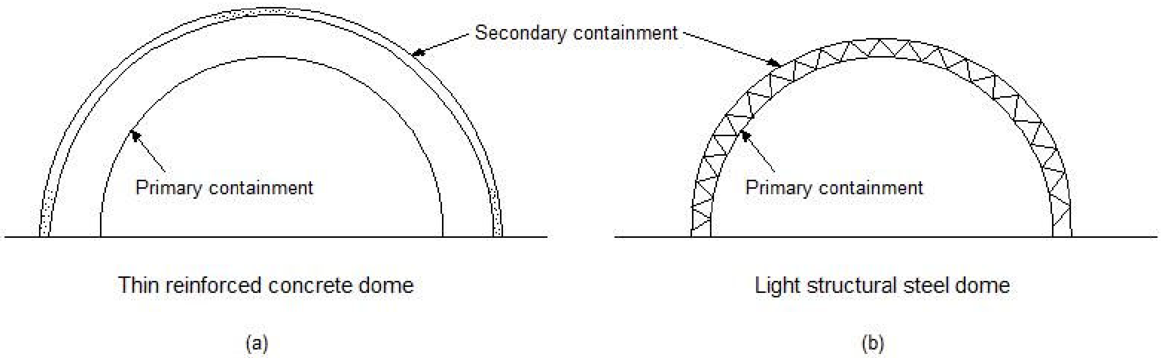

Figure 3.7 Enclosure Buildings

The secondary containment associated with steel containment structures is referred to as a shield building. The shield building is a reinforced concrete structure that typically is constructed on the primary containment foundation, but is self-supporting (ASCE 58, 1980). The purpose of the shield building is to protect the relatively thin, steel containment building from extreme environmental loads and missiles (ASCE 58, 1980). The airspace between the primary and secondary containment may be used in the same manner as it is for enclosed buildings (ASCE 58, 1980).

The design of secondary containment is governed by the ACI or AISC standards, depending on the selected construction material for the secondary system (ASCE 58, 1980). However the design of the secondary containment should consider the airspace in between the primary and secondary containment structures. These considerations account for leakage of radioactive gases from the primary containment and the necessary size of gap between the two buildings (ASCE 58, 1980). The size of the gap depends on equipment located in the space, access requirements, and the cost for the size of the secondary containment (ASCE 58, 1980).

3.2 Internal Containment Structures

Internal containment structures are located entirely within the boundaries of the primary containment structure. The internal structure layout, function and loads for design, and the analysis for Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs), due to the differences between the two systems, are examined in this section (ASCE 58, 1980). Although the arrangement varies with reactor design, all the internal containment is constructed of reinforced concrete or composite construction. One of the reasons reinforced concrete is used is to provide the primary shielding from any negative biological effects such as those caused by radiation damaging cells, which can cause cancer (ASCE 58, 1980). Constructing the internal compartments with concrete enables a secondary shielding for workers, extra support for floors, mechanical systems, and components, and protection for the containment structure by reducing the damage from a LOCA (ASCE 58, 1980). As previously mentioned a LOCA is the loss-of-coolant accident that produces the internal pressures that act on the containment structure (ASCE 58, 1980). Refer to Section 2.2.2 of this report for the appropriate load combination applications to internal containment structures.

3.2.1 Pressurized Water Reactor

The Pressurized Water Reactor (PWR) has two options for internal containment: dry or ice. Dry containment is similar to a large balloon in that it can take in all the steam initially released from a LOCA; however some dry containment has been "designed to operate at vacuum to reduce the air inventory, thus the design LOCA pressure of the containments," (ASCE 58, 1980). On the other hand, ice containment uses ice condensers to condense the released steam from the NSSS during a LOCA to energy, which the containment then absorbs.

3.2.1.1 Dry Internal Containment Structures

Typically, reinforced concrete surrounds the major components and is frequently used for the floor, although a steel grating is suggested as a floor wherever possible to help reduce the build-up of pressure in the sub compartments (ASCE 58, 1980). Only a few major internal structures exist for dry containment, all of which have to support themselves or be anchored into the containment building base slab, Figure 3.8, p.44, and 3.9, p.45 (ASCE 58, 1980). All of the internal containment structures are designed according to the ACI 349-76 for concrete (ASCE 58, 1980); however the current version is the ACI 349-06. The design loads consist of the normal, environmental, and extreme environmental loads discussed in Chapter 2. Finally, the internal containment structures are analyzed by finite element analysis due to their complexity (ASCE 58, 1980).

The primary containment shield supports the reactor and forms the reactor cavity from the base slab to the operating floor (ASCE 58, 1980). This reinforced concrete structure surrounds the entire reactor and is the first protection for workers from radiation effects from the reactor.

The secondary shielding is also a reinforced concrete structure that spans from the slab to the operating floor. It encloses the steam generators and reactor coolant system around the primary shielding; the secondary shielding even provides some lateral support to the mechanical systems within (ASCE 58, 1980).

The concrete canals transport the fuel, new and spent, between the reactor and the fuel building. The canals are not only constructed of reinforced concrete; stainless steel lines in the interior of the canal help prevent any radiation leaks (ASCE 58, 1980).

The last major internal structure to consider for dry internal containment is the missile shield, is a precast concrete slab that sits above the reactor cavity and is removable, whose purpose is to protect the containment building from any possible missiles from the reactor (ASCE 58, 1980).

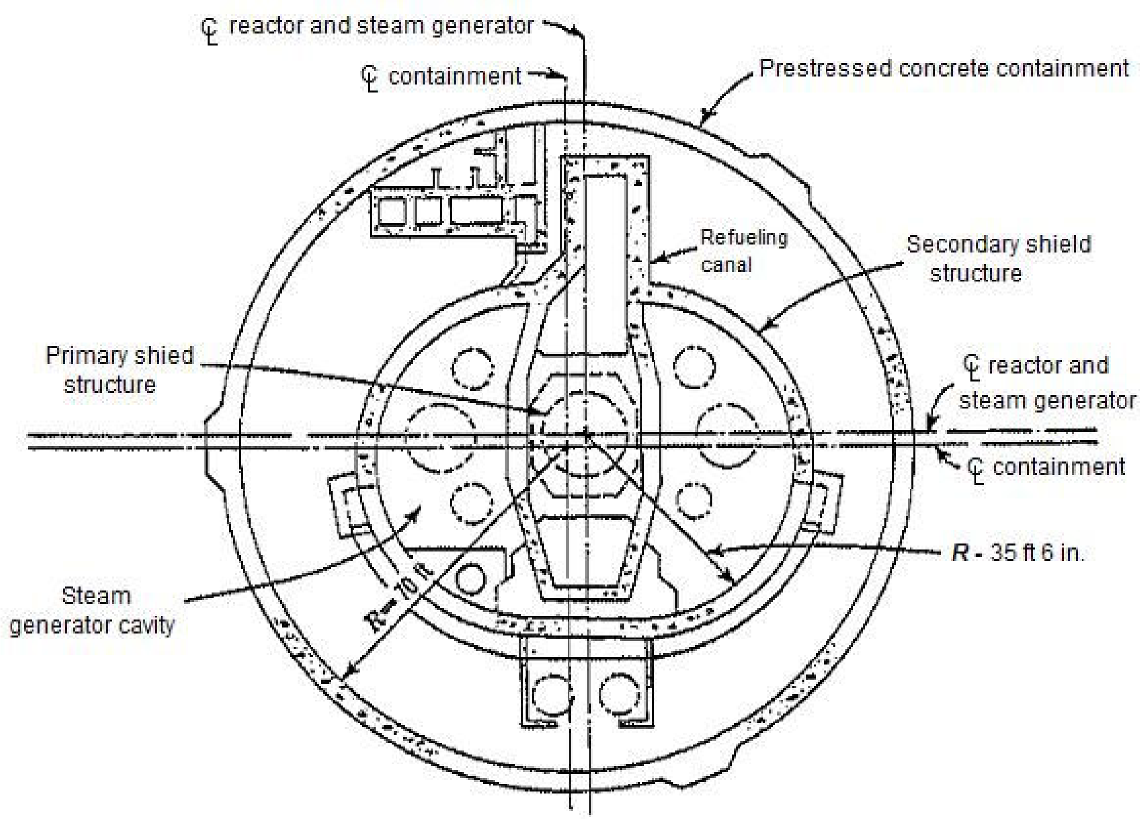

Figure 3.8 Pressurized Water Reactor dry containment general arrangement, plan

[Reference ASCE 58, 1980, Fig. 4.32]

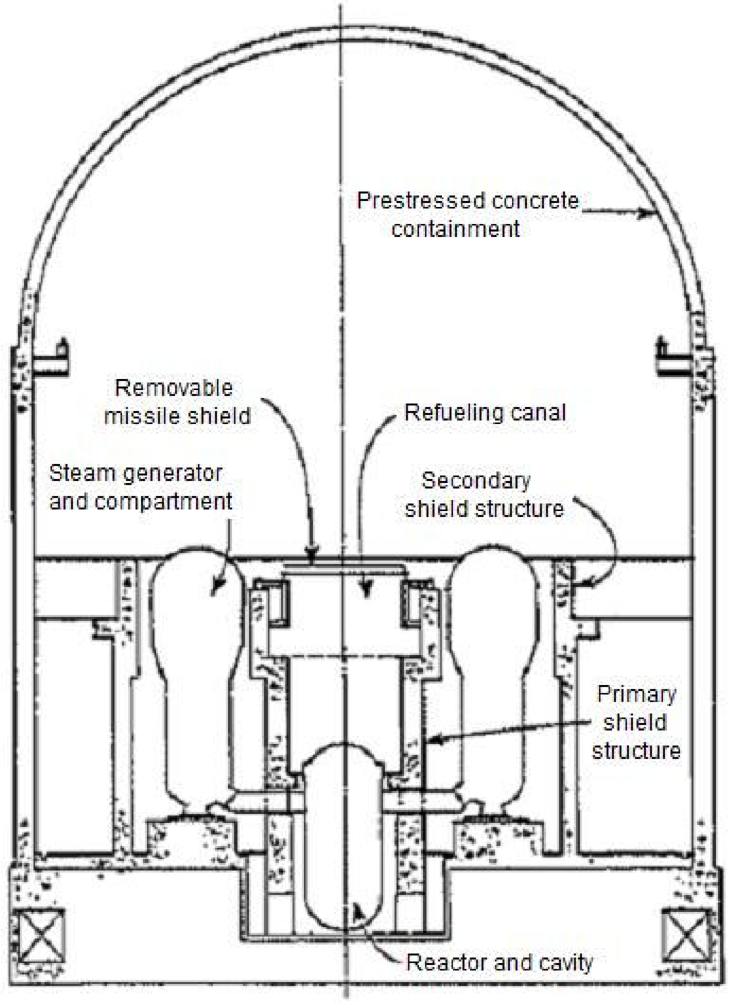

Figure 3.9 Pressurized Water Reactor dry containment general arrangement, section
[Reference ASCE 58, 1980, Fig. 4.33]

3.2.1.2 Ice Condensing Containment Structures

Compared to dry containment, the ice condenser internal containment structures have more compartments and not only radiate from the reactor core, but even build upon other compartments, as seen in Figure 3.10, p.47, to control the path of the released steam from a LOCA. The ice condensing containment compartments consist of the cylindrical crane wall, pressurizing compartments, and the ice condenser in addition to the reactor cavity, generator, refueling canal, and missile shield (ASCE 58, 1980). All of these concrete subsections distribute their loads to the base slab of the entire containment building. Furthermore, the concrete compartments are placed in a manner to control the stream flow from a LOCA to the ice condenser (ASCE 58, 1980). This is because if one concrete barrier fails, it could cause other internal structure failures because of the increased pressure from the possibility of bypassing the ice condenser due to the initial barrier failure (ASCE 58, 1980).

The design considerations are therefore more extensive the ice condenser containment. According to the ASCE 58 Design Manual (1980), the engineer needs to be aware of the following possible problems:

1. “The non-uniform pressure loads created from a postulated pipe break acting on the reactor cavity walls. Another possible problem concerning the reactor cavity structure is the columns; the columns are in between the vents to lower surrounding compartments which support the operating deck. Pressure loads through the vents act on the operating deck and can create extreme loads that may exceed design capacity. However the ASCE 58 Design Manual does offer simple recommendations to account for these potential problems. For instance the postulated pipe break could be remedied by the use of piping restraints, and the columns supporting the operating deck could be post-tensioned in order to increase the load carrying capacity.
2. The next concern to address is the columns supporting the ice condenser and crane wall. Due to the proximity to the operating deck and generator compartment, large stresses from the operating deck and generator compartment act on the columns. The simple solution here is to thicken the columns rather than pursue post tensioning; this is due to the risk of more radiation exposure with post tensioning maintenance requirements.
3. Since the ice condenser’s internal containment design has more compartments some of these sections are dead ends for air in order to reduce the pressure in the containment building. These compartments would allow pressure to buildup during a LOCA, but the pressure could be diffused by designing blowout panels to open at a specific pressure in order to provide the necessary ventilation.
4. Between many of the internal containment structures is a sealant that is typically made of “flexible elastomer coated fabrics.” (ASCE 58, 1980) The sealant is used to produce an airtight barrier while allowing for relative movement amongst the internal structures. The seal is only expected to last

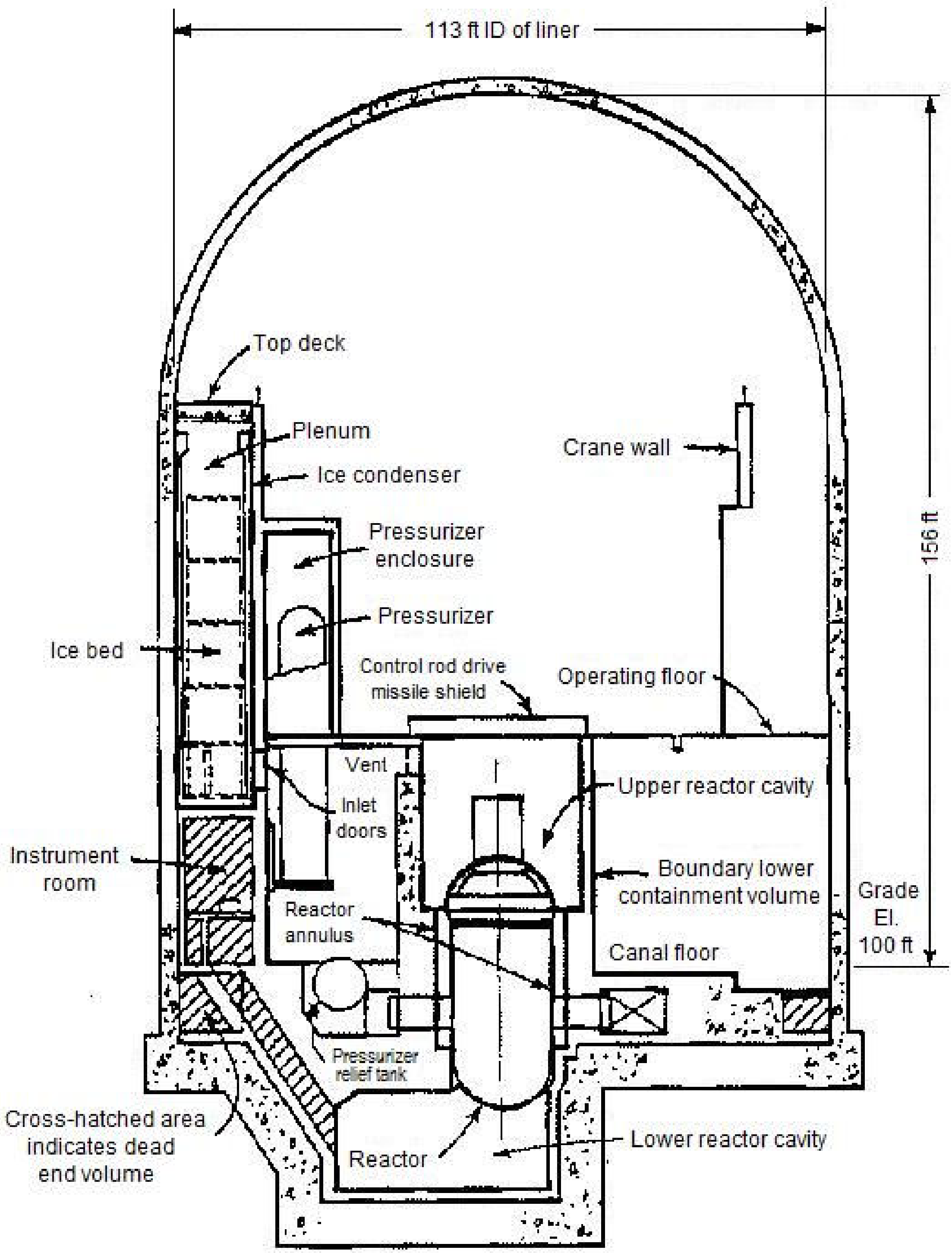

Figure 3.10 Ice condenser concrete containment

[Reference ASCE 58, 1980, Fig. 4.35]

ten years though, even without loss of bond integrity during a seismic event. While the ASCE 58 Design Manual offers no solution to this design concern, special attention should be paid since it is a maintenance issue.

5. The last design consideration is to account for the possibility of fluid forces acting upon the ice condenser's walls during a LOCA when the reactor coolant piping breaks. Since the ice condenser's inlet doors are part of the lower internal compartments any escaping fluid during a LOCA would flow into and up within the ice condenser. The pressure from the fluid on the ice condenser's wall could cause shear and bending forces on the wall. Also a vibratory motion could be seen when the pressures fluctuate within the internal structures."

Surprisingly, additional design considerations for internal ice condenser containment structures are not necessary even though it has so many more sections than do dry internal containment structures.

3.2.2 Boiling Water Reactor

When the ASCE 58 Design Manual (1980) was written, only three generations of internal containment existed for the Boiling Water Reactor (BWR): the Mark I, Mark II, and Mark III. The Mark generation containments use a suppression pool to condense steam for reducing pressure in the event of a LOCA. The Mark I and Mark II generation containment designs differ from the Mark III in that the drywell surrounding the reactor is considered an internal structure for the Mark III (ASCE 58, 1980): see the plan view in Figure 3.11, p.49, and section cut in Figure 3.12, p.50. Therefore the focus of this section will be the Mark III containment design but the section will occasionally refer to similarities to the Mark I and Mark II systems.

The major internal structures of the Mark III containment system consist of the drywell, the upper containment pool, the reactor pedestal, the reactor shield wall, and the weir wall.

The <u>drywell</u> that completely surrounds the reactor is constructed out of reinforced concrete for the upper portion and is a composite structure for the lower portion (ASCE 58, 1980). The composite part of the structure is formed by two steel cylinders filled with concrete in between except where the three steel tubes, which are openings to the suppression pool, connect the large steel cylinders together (ASCE 58, 1980).

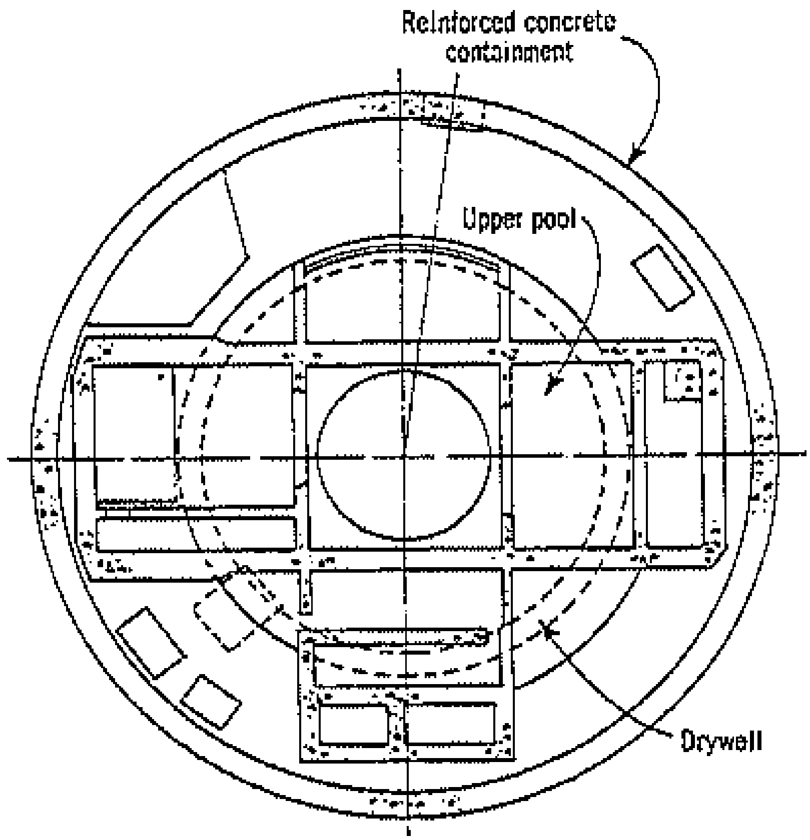

Figure 3.11 Mark III general arrangement section

[Reference ASCE 58, 1980, Fig. 4.37]

The upper containment pool is a stainless steel-lined, reinforced concrete structure (ASCE 58, 1980). The pool is located in part of the area above the reactor on the operating deck, to help reduce radiation levels, since water slows down the radiation and absorbs heat very well, but this pool of water also provides an area of storage for fuel as well as the steam dryer and moisture separator (ASCE 58, 1980).

The reactor pedestal supports the actual reactor vessel and the reactor shielding wall (ASCE 58, 1980). It is similar to the composite construction discussed for the drywell, but has vertical stiffeners to tie the two steel cylinders together instead of vent openings (ASCE 58, 1980).

The reactor shielding sits on top of the reactor pedestal to surround the sides of the reactor vessel (ASCE 58, 1980). It is composite construction of steel and concrete and the primary biological shielding for plant workers (ASCE 58, 1980).

The weir wall is the inner boundary of the suppression pool and surrounds the reactor pedestal (ASCE 58, 1980). The surface in contact with the water in the pool is lined with stainless steel, but the actual weir wall can be either composite construction or reinforced concrete (ASCE 58, 1980).

The Mark I and II containment systems are designed with the reactor pedestal and shielding as well (ASCE 58, 1980).

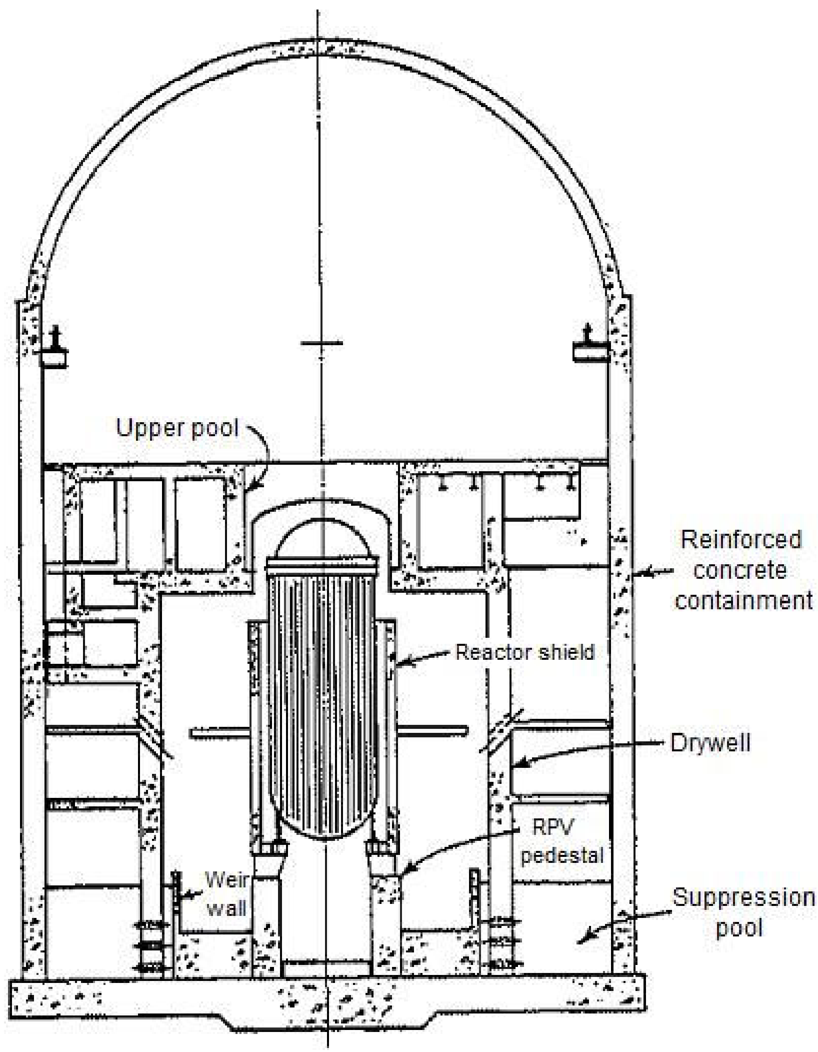

Figure 3.12 Mark III general arrangement section

[Reference ASCE 58, 1980, Fig. 4.36]

3.2.2.1 Design and Analysis

All the major containment structures except the drywell are designed with the load combinations from ACI 349 and use the loads described in Chapter 2 with the addition of the mainstream safety relief valve load. This safety relief valve load is a normal load that considers the dynamic pressure from the suppression pool when the relief valve is used; this valve load is applied to the drywell and the weir wall (ASCE 58, 1980). The drywell is designed with ACI Standard 359 (ASCE 58, 1980).

The BWR internal containment structures are analyzed using computer programs, however localized analysis of the internal structures uses traditional methods and techniques for preliminary proportioning (ASCE 58, 1980). With regards to the major internal structures, except the upper containment pool, preliminary proportioning allows these structures to be evaluated as fully fixed shells at the supports (ASCE 58, 1980). Separately, the upper containment pool is analyzed with its walls as rectangular plates for preliminary proportioning (ASCE 58, 1980). The final design for all the internal structures uses finite element analysis (ASCE 58, 1980).

3.2.2.2 Special Design Considerations

The BWR containment also has special design considerations for the internal structures, according to the ASCE 58 Design Manual (1980), which follow:

1. The vibratory load from the mainstream safety relief valve and how a possible vertical vibration load affects the components that are attached to the structure, such as conduit and piping.
2. The accidental loads caused by changes in the water of the suppression pool, such as condensation and pressure build up in the drywell.
3. The pressure load of the drywell structural integrity and pressure suppression system, must be proof tested due to a requirement of the NRC.
4. The hydrostatic loads from when the drywell and containment structures are flooded, almost seven feet above the active fuel in the reactor, in order to remove fuel from the reactor after a LOCA.
5. The design of the flat slab that is integrated with the upper containment pool structure; it is designed with the same considerations as the drywell.

CHAPTER 4 - Industry Outlook

While a new nuclear plant has not been ordered in the United States for at least thirty years, research regarding reactors, systems, and components has been ongoing. Moreover, other countries have become proficient in using nuclear power to supply electricity to their citizens; two of the most prominent are France and Japan. The nuclear power industry in the United States could evaluate the knowledge from other countries for more efficient and effective methods of design and construction of nuclear power plants.

In the United States, nuclear energy could also make a positive comeback if enough political support and enough interest with the “green” movement occurs. The “green” movement is a global initiative to reduce carbon emissions to reduce the “global warming” effect. Nuclear energy does not produce any carbon emissions. Although, some “green” political groups remain anti-nuclear because of the environmentalists concerned about nuclear waste, which will be discussed more in depth in Section 4.2.

This chapter discusses new power plants in terms of design and construction, and the future of nuclear energy. The design and construction section discusses emerging technologies in the nuclear industry, or that could benefit the nuclear industry. The future of nuclear energy discusses the role of nuclear energy in the United States with a relation to public concerns and the Energy Act of 2005.

4.1 Design and Construction

When nuclear power plants were originally constructed in the United States start of construction to beginning of power operations, it only took five years (Simpson, 1995). While no new plant has been built in the United States in over 20 years, estimates for construction range from a minimum of 8 years to 10 years (Simpson, 1995). Since the last new nuclear power plant was built, many new technologies have been developed. Some of these new methods and concepts include self-consolidating concrete (SCC), fiber and steel mesh, offshore power plants, and modular power plants. The following sections consider these technologies and materials for their applicability to nuclear containment structures.

4.1.1 Self-Consolidating Concrete (SCC)

Self-consolidating concrete (SCC) is concrete that while in a liquid state is able to reduce aggregate settling after the concrete is poured. For typical concrete applications (non SCC), after the concrete is poured, a vibrator is stuck into the concrete to redistribute the aggregates and space them out more evenly. This process makes a much more uniform consistency of the concrete and eliminates voids around reinforcement (NRMCA, 2008).

However more research needs to be done on how SCC could benefit the nuclear industry. Because aggregates are what gives the concrete its strength, the larger aggregates are spaced in a way that they are uniform throughout the concrete and provide a more constant strength with less cracking and spalling of the concrete. Another benefit of SCC is that time and labor can be saved since fewer steps during placement of the concrete are necessary; this is a benefit on a job that in todays market (NRMCA, 2008). However, a potential problem with SCC for power plants is the ACI recommendation for formwork that then the formwork, should be designed to fully resist the hydrostatic pressure unless an experimentally based method of figuring head pressure of the SCC could be found. This could lead to very large forms given the size of a nuclear plant concrete containment structure (SCC website).

4.1.2 Fiber and Steel Mesh

Fiber and steel mesh when added to the concrete during the mixing process enhances the integrity of the concrete. The fiber pieces can be very thin, like hair, a small plastic piece that is designed to open up into a web-like structure once mixed with the cement mix, and a long thin piece of plastic that's about a sixteenth of an inch wide (Propex website). The steel mesh could come crimped like a wave or as a thin round bar that is bent down at the ends (Propex website). The purpose of the meshes is to provide a secondary reinforcement to the concrete and to reduce the size of cracks in the concrete by holding the concrete closer together; thus, the meshes throughout the concrete statistically would be bridging the cracks. These meshes could help the nuclear concrete structure reduce spalling and cracks due to impacts sustained from various possible missiles.

For nuclear power plant applications, the steel fiber in the round bar form should be used since this improves impact resistance (Fibermesh website). The amount of steel fibers used varies with each job since it is dependent on the type of structure, the relative toughness desired, and of course the concrete mix design: however, a typical range is given of 25 lbs to 75 lbs per cubic yard for steel fibers (Fibermesh website).

4.1.3 Offshore Power Plants

In the 1970s Westinghouse came up with the idea to build offshore floating nuclear power plants, due to the lack of space for sites on the eastern shore of the United States and the decision to attempt a standardization of nuclear plants (Simpson, 1995). Standardization of nuclear power plants was nearly impossible on land due to the high costs, each utility desiring special features and site variances (Simpson, 1995). However, the standardization of offshore plants would be achieved through the construction process with the plant being assembled in a large shipyard assembly line by the same construction crew (Simpson, 1995).

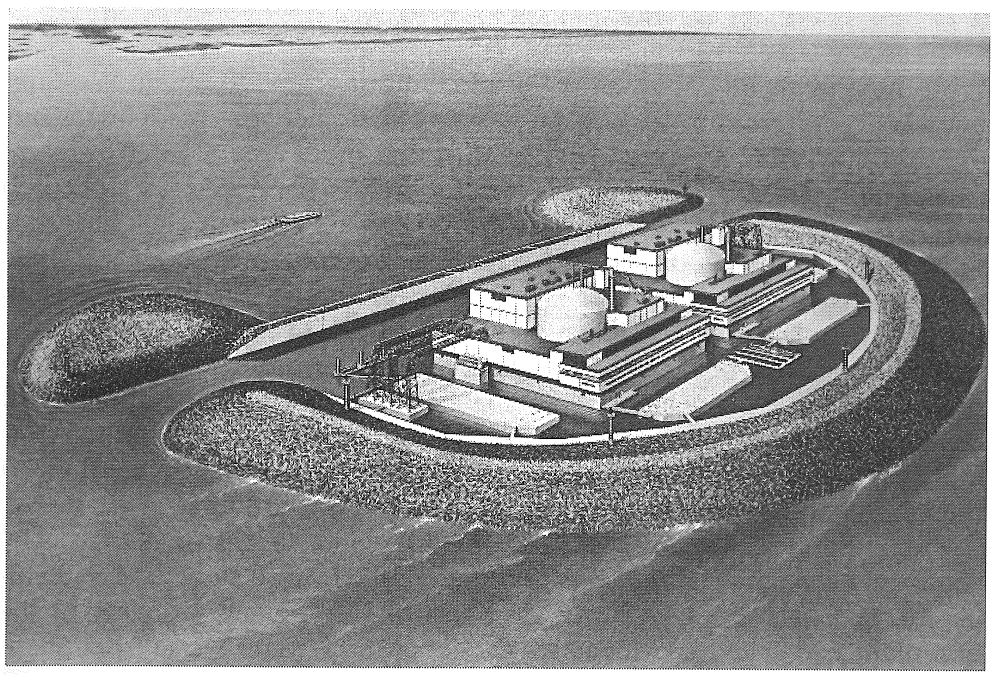

Figure 4.1 Artist's sketch of a floating nuclear power plant

[Copyright 1995 by the American Nuclear Society, La Grange Park, Illinois]

These offshore power plants were designed to be floated in river estuaries or approximately three miles offshore as the offshore plant would require a large breakwater to surround it, refer to Figure 4.1 (Simpson, 1995). In fact, a model of the offshore power plant was tested at the University of Florida at Gainsville with feedback regarding 1100-foot tankers hitting the breakwater (Simpson, 1995). Design also included the breakwater and the plant to withstand hurricane winds of 180 miles per hour (Simpson, 1995). While an offshore plant has never actually been built, a lot of time and research went into proving that it could be built. In fact there were orders for offshore plants, but they were canceled once they were not needed during the OPEC oil embargo (Simpson, 1995).

4.1.4 Modular Power Plants

What the nuclear power industry initially lacked was standardization of nuclear power plants. However, within the past fifteen years companies involved with reactor design have designed new reactors and structures to have preapproved by the NRC to ease construction and licensing. Designs of these modular power plants are certified based on how the design accounts for nuclear power plant safety issues and it is not designed for a specific site (NRC Fact Sheet). According to the NRC, four designs have been approved, three of which are Westinghouse designs, and the other one being a GE design (NRC Fact Sheet). However, four more designs are being reviewed with another two designs a few years away from being submitted for review (NRC Fact Sheet). Some of the companies submitting designs are from outside the United States but would like to enter the nuclear industry in the United States if it ever really restarts.

4.2 The Future of Nuclear Energy

The future of nuclear energy in the United States is uncertain. While nuclear plants have been built around the world since their commercial development for electricity, no new plant has been ordered in the United States since 1978. Public approval is necessary to rejuvenate the nuclear power industry in the United States. A second nuclear era will not come if the public continues to disapprove of new nuclear plants. The public tends to focus on negative, often incorrect, information regarding nuclear power, so the following information addresses some of the dangers and benefits associated with nuclear power. Public education is a key step toward future nuclear plant production.

Understanding the process for handling nuclear materials could ease public concern. A critical aspect associated with nuclear power is the mining and processing of the uranium for the fuel rods. Uranium itself has a low level of radioactivity, but if it undergoes spontaneous radioactive decay, it emits radon gas; radon gas is radioactive and if inhaled can increase the chances of lung cancer (Morris, 2000). With most of the world's uranium mining being done in

Canada and Australia, there are international standards to reduce any negative effects to uranium miners (WNA website).

Another perceived nuclear problem is nuclear waste disposal. There is no national repository for nuclear waste, mainly due to the “Not in my back yard” mentality, so nuclear waste is stored at each nuclear plant site. The spent fuel rods on a site are located in a large pool of water to slow as much of the fission process as possible before being transferred into concrete casks. Eventually these spent fuel casks are moved to another part of the site that is fenced off to be housed there until a national nuclear waste site is designated. The choice of a designated site is dependent highly on the ground water level and the depth of bedrock because the plan is to store the waste at least 2000 feet below the surface in a concrete and steel lined hole. However, the French have encased the spent fuel in glass by way of vitrification; when glass is in hard, thick layers it is virtually impenetrable even to water (Morris, 2000).

The last real danger produced from nuclear power is radiation. From Chapter 1 we know that radiation can cause damage to our cells and could possibly lead to cancer: however, it is not the general idea of radiation we should be concerned with but rather the amount of radiation, which is typically measured in millirem. When comparing the amounts of radiation, the lay person should realize that they are exposed to radiation everyday of their lives in the form of background radiation often from cosmic rays as well as the earth itself. Typically a person daily will absorb more incidental environmental background radiation than they will if they are in a nuclear power plant or live near a nuclear power plant.

When comparing fuels in power plants, nuclear fuel has some benefits, over the other fuels, which are: fuel efficiency, relative lack of air pollution, and recyclability. The main difference among different types of power plants is the fuel used to create the power, often in the form of heat that changes water into steam, which turns a steam turbine and ultimately a generator. Specifically, the fission process of the nuclear fuel through a chain reaction produces heat. This chain reaction could be increased to produce more than enough heat to create steam so that the efficiency for nuclear power is dependent upon the steam turbine and generator rather than the fuel. Next, the nuclear plant has no air pollution versus the visible air pollution from coal plants. For example, when coal is burned, the ash is more radioactive than a nuclear plant because of the uranium, radium, and thorium particles in the coal (Morris, 2000). Another benefit of nuclear power is that nuclear waste from uranium – 235 can be reprocessed into plutonium, which can also be used as fuel in other nuclear reactors and plants. However, President Jimmy Carter signed into a law that the United States would not reprocess any of the nuclear waste into plutonium for fears that the plutonium could be used for making bombs. However today, countries such as France and Sweden routinely reprocess fuel for European countries.

Today the political arena has shed some light on the feasibility of nuclear power for hydrogen production and has voiced interest in the future of nuclear power. Even within in the past year presidential nominees were asked their opinion on the future of nuclear power and whether they would support any endeavors if they were elected President. With the fluctuating cost of oil, alternative sources for energy, not just for transportation, will be pushed to the forefront of politicians' minds as options to reduce our dependency on foreign oil. Also, any new plants will require subsidies from the government to help offset high construction costs.

In fact the Energy Policy Act of 2005 makes amendments to the Atomic Energy Act of 1954. The Energy Policy Act of 2005 actually increases liability limits for indemnification, offers definitions regarding newer reactor technology, establishes new deadlines and timelines, establishes guidelines for the NRC scholarship and fellowship programs, and includes tax credits and incentives for construction of new, advanced power facilities. However, these are small changes and additions regarding nuclear energy. The larger more substantial parts of the Energy Policy Act of 2005 applying to the nuclear energy industry follow: the plan to establish a permanent radioactive waste facility for Class C or greater waste, which would include spent fuel rods from nuclear plants, as well as cost-analysis and alternative sites; the feasibility of adding a hydrogen-producing plant to an existing nuclear power plant facility; contract information regarding the building of advanced nuclear facilities including the government's covered costs regarding these facilities; and security for nuclear facilities and materials.

The most important section regarding the push for nuclear energy from the Energy Policy Act of 2005 is subtitle C of Title VI, which is the next generation nuclear plant project. This whole section has given the Idaho National Laboratory the charge of setting up two research facilities, one for research purposes and one for industry applicability, for the design and implementation of Generation IV reactor technology for generating electricity and/or producing hydrogen. The deadline of September 30th, 2011 is to establish which technology will be used in the project, or if no technology is selected, then a report as to when this decision would be made should be submitted. However, Congress has set a deadline for complete construction from concept to initial operation at the test facility for September 30th, 2021; again, if the facility is not completed then a report should be issued as to when a test facility would be completed.

As people in the United States look for "greener" energy sources, if they take the time to understand all the options and all the positives and negatives then perhaps society might see how nuclear power may be beneficial.

CHAPTER 5 - Summary

The first instance of nuclear energy pursued for power occurred in 1942 in an experiment at the University of Chicago under Enrico Fermi's supervision. The United States Navy decided this technology could prove useful. So under a contract with Westinghouse, a nuclear propulsion system was created for the navy's submarines. Then, from the propulsion technology, a central commercial nuclear power plant was planned, constructed and operated.

However, the United States military was not the only reason for the development of commercial nuclear power. The United States Congress passed the Atomic Energy Act of 1946, the Atomic Energy Act of 1954, and the Price Anderson Act of 1957. The passage of these three acts provided the basis of the initial set-up of the nuclear industry. President Eisenhower also urged that nuclear technology be used for peaceful purposes in the famous "Atoms for Peace" speech.

The United States began commercial operation of a nuclear plant in 1957 with the plant in Shippingport, Pennsylvania. The nuclear power industry continued to thrive until approximately 1977 when activists repeatedly sued power companies as a means of preventing construction of some nuclear power plants. Then, two major nuclear accidents occurred at Three Mile Island and Chernobyl. Each of these accidents prompted the NRC to review existing systems for potential problems. This review concluded that the most obvious error was the lack of a containment structure at Chernobyl.

The process of design of a nuclear containment structure in the United States begins with identifying the loads that may act upon the structure. This report breaks these loads into normal loads, environmental loads, and extreme loads. Each of these sections describes individual loads that are required for design. The interaction of the various loads is found using the load combinations designated for nuclear power plant concrete design.

The major focus of the report is the design and analysis of the concrete containment structure with proposed new material technologies for nuclear plant facilities. This is critical since the purpose of the containment structure is to prevent any radiation or fissionable products from escaping into the atmosphere. Therefore, the containment building is required to be leak-tight. In reinforced concrete construction, this is achieved with a steel liner on the interior of the containment structure.

The containment structure houses the interior containment structures, which support the reactor and operating deck. Depending on the reactor, whether PWR or BWR, the internal containment structure may also support the suppression system. Further, a PWR reactor utilizes either a dry containment (large volume containment structure) or an ice condensing containment (series of multiple compartments leading to an ice coil), whereas the BWR uses a pool of water as its suppression system.

Since a new plant has not been ordered in the United States in over thirty years, new material technologies could aid in the increase of strength of the nuclear plant structures. Self consolidating concrete could aid in the placement of concrete in nuclear facilities where tight reinforcement is located, mitigating possible voids with conventional concrete placement. Fibers, whether steel or polypropylene, could help make concrete more durable by bridging more efficiently between the cement and aggregates. Where coastal cities could need more power, an offshore nuclear plant could be both optional and economical due to the modulated design. Several modular designs have already been approved by the NRC for land based plants, which would expedite the construction process and lower overall project costs.

The potential for new nuclear power plants leaves those involved with design and construction to update design and construction to current practices.

References

2007 ASME Boiler & Pressure Vessel Code Section III - Division 2 (ACI Standard 359-07) Code for Concrete Containments - Rules for Construction of Nuclear Facility Components. (2007). New York, NY: American Society of Mechanical Engineers.

A Brief History. (2006, March 21). Retrieved May 21, 2008, from Calder Hall Nuclear Power Station: http://www.calderhall.co.uk

Atomic Energy Act of 1946. Retrieved May 28, 2008, from U.S. Department of Energy: http://www.science.doe.gov/bes/Atomic_Energy_Act_of_1946.pdf

Atomic Energy Act of 1954. Retrieved May 28, 2008, from US Senate Committee on Environment & Public Works: http://epw.senate.gov/atomic54.pdf

Atoms for Peace. Retrieved July 11, 2008, from International Atomic Energy Agency: http://www.iaea.org/About/history_speech.html

American Concrete Institute (ACI). (2001). *Code Requirements for Nuclear Safety-Related Concrete Structures (ACI Standard 349-01) and Commentary.* ACI.

Committee on Nuclear Structures and Materials of the Structural Division of the American Society of Civil Engineers (ASCE). (1980). *Structural Analysis and Design of Nuclear Plant Facilities (Manual and Report No.58).* New York, NY: ASCE.

Condon, J. (1999). *Chernobyl and othe Nuclear Accidents.* Italy: Raintree Steck-Vaughn Publishers.

Energy Information Administration (EIA). (2008, October 3). *Nine Mile Point Nuclear Station and Oyster Creek Nuclear Power Plant.* Retrieved November 12, 2008, from EIA: http://www.eia.doe.gov/cneaf/nuclear/page/at_a_glance/reactors/nuke1.html

Energy Policy Act of 2005. Retrieved May 28, 2008, from U.S. Department of the Interior: http://www.doi.gov/iepa/EnergyPolicyActof2005.pdf

Federal Emergency Management Agency (FEMA). (2000). *Design and Construction Guidance for Community Shelters, FEMA 361.* U.S. Department of Homeland Security.

Fibermesh. (2007). *Novocon 1050.* Retrieved November 12, 2008, from Propex: http://www.fibermesh.com/downloads/Novocon%201050.pdf

Graham, I. (1999). *Nuclear Power.* Austin, TX: Raintree Steck-Vaughn Publishers.

Morris, R. C. (2000). *The Environmental Case for Nuclear Power: Economic, Medical, and Political Considerations.* St. Paul, MN: Paragon House.

National Ready Mixed Concrete Association (NRMCA). (2008). *Benefits.* Retrieved June 28, 2008, from Self Consoldating Concrete: http://www.selfconsolidatingconcrete.org/benefits.htm

Nuclear Energy Institute (NEI). (2007, July). *Price-Anderson Act Provides Effective Liability Insurance at No Cost to the Public.* Retrieved November 24, 2008, from Nuclear Energy Institute: http://www.nei.org/filefolder/price-anderson_0707.pdf

Nuclear Regulatory Commission (NRC) Fact Sheets. (2008, February 20). *Chernobyl Accident, New Nuclear Plant Design, and Three Mile Island Accident.* Retrieved May 24, 2008, from United States Nuclear Regulatory Commission: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/.

Nuclear Regulatory Commission (NRC). (2009). *NRC News No. 09-030 NRC Issues Final Rule on New Reactor Aircraft Impact Assessments.* Washington, DC: United States Nuclear Regulatory Commission.

Nuclear Regulatory Commission (NRC). (2008, November 3). *Title 10, Code of Federal Regulations (10 CFR).* Retrieved November 14, 2008, from NRC Regulations: http://www.nrc.gov/reading-rm/doc-collections/cfr/.

NUREG/CR-6966. (August 2008). *Tsunami Hazard Assessment at Nuclear Power Plant Sites in teh United States of America.* Washington, DC: U.S. Nuclear Regulatory Comission.

Okrent, D. (1981). *Nuclear Safety: On History of the Regulatory Process.* University of Wisconsin Press.

Oyster Creek Generating Station. (2006). *Frequently Asked Questions About Oyster Creek.* Retrieved November 12, 2008, from Exelon Corporation: http://www.oystercreeklr.com/faq.html.

Propex. (2006). *Concrete Systems.* Retrieved November 12, 2008, from Propex: http://www.propexinc.com/product.aspx?name=Concrete+Systems.

Regulatory Guide 1.35. (Revision 3, July 1990). *Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containments.* Washington, DC: U.S. Nuclear Regulatory Commission.

Regulatory Guide 1.59. (Revision 2, August 1977). *Design Basis Floods for Nuclear Power Plants.* Washington, DC: U.S. Nuclear Regulatory Commission.

Regulatory Guide 1.76. (Revision 1, March 2007). *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants.* Washington, DC: U.S. Nuclear Regulatory Commisssion.

Simpson, J. W. (1995). Nuclear Power from Underseas to Outer Space. In J. W. Simpson, *Nuclear Power from Underseas to Outer Space* (pp. 8,15, 20-33,43-65,103,157,170,171,205,213-223,386). La Grange Park, Illinois: American Nuclear Society.

Storm Prediction Center. (2007, February 1). *Enhanced F Scale for Tornado Damage.* Retrieved March 29, 2008, from NOAA's National Weather Service: http://www.spc.noaa.gov/faq/tornado/ef-scale.html.

Taly, N. (2003). *Loads and Load Paths in Buildings: Principles of Structural Design.* United States: International Code Council.

World Nuclear Association (WNA). (2008, August). *Environmental Aspects of Uranium Mining*. Retrieved November 24, 2008, from World Nuclear Association: http://world-nuclear.org/info/inf25.html

Appendix A - Permissions

The images contained within this report are not created by the author and are used with permission contained in this section.

American Nuclear Society (ANS) Permissions

AMERICAN NUCLEAR SOCIETY

555 North Kensington Avenue
La Grange Park, Illinois
60526 USA

Tel: 708/ 352-6611
E-Mail: NUCLEUS@ans.org
http://www.ans.org
Fax: 708/ 352-0499

August 15, 2008

Ms. Sarah Czerniewski
8504 W. 80th Terrace
Overland Park, KS 66204

Deae Ms. Czerniewski:

ANS is granting you permission to reprint the following material provided that you comply with the conditions listed below.

Figure 9.1 (pg. 217), excerpts from pages 8, 15, 20-33, 43-65, 103, 157, 170, 171, 205, 213-223, 386 from the book "Nuclear Power from Underseas to Outer Space," by John W. Simpson (1995)

Our conditions are:

1. That you give appropriate credit to the author and to the American Nuclear Society, including in your citation volume number, page numbers, issue and year.

2. That you include the statement: Copyright___ (date as appropriate) by the American Nuclear Society, La Grange Park, Illinois.

Sincerely,

Mary Beth Gardner/e

Mary Beth Gardner
Manager, Scientific Publications

ASCE Permissions

Included is permission for copying the book and permission to use the figures found in the book.

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE TERMS AND CONDITIONS

Jul 26, 2008

This is a License Agreement between Sarah J Czerniewski ("You") and American Society of Civil Engineers ("American Society of Civil Engineers"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

License Number	1981050474658
License date	Jul 02, 2008
Licensed content title	Structural Analysis and Design of Nuclear Plant Facilities
Licensed content author	
Licensed content publication	book
Licensed content publisher	American Society of Civil Engineers
Type of Use	Photocopy
Number of copies of article	1
Total	$0.00

Terms and Conditions

A Terms and Conditions agreement is a document that describes the terms and conditions of a license to the licensee. ASCE Terms and Conditions are available during the order process, although you may review the Terms and Conditions below, before placing an order.

The publisher for this copyrighted material is The American Society of Civil Engineers (ASCE). By clicking "accept", you agree that the following terms and conditions apply to this transaction, along with the billing and payment terms and conditions established by Copyright Clearance Center, Inc. (CCC) at the time that you opened your Rightslink® account. The terms and conditions information is available when you log in to Rightslink.

One Time Permission
Each license is unique, covering only the terms and conditions specified in it. Even if you have obtained a license for certain ASCE-copyrighted content, you will need to obtain another license if you plan to reuse that content outside the terms of the existing license. For example: If you already have a license to reuse a figure in a journal, you still need a new license to use the same figure in a magazine.

Embargo
Permission will be denied if the content is requested within 3 months of the publication date.

No-Fee License
A $0 license is granted to authors who wish to reuse their own content and to authors who wish to reuse ASCE-copyrighted content in their works prepared for another ASCE publication.

Credit Lines
A full credit line must be added to the material being reprinted.

- For reuse in non-ASCE publications, add the words "With permission from ASCE" to your source citation.
- For reuse in ASCE publications, add a comma and "ASCE" after the author-date citation. For example: (Jones and Taylor 2003, ASCE)
- For online posting, add the following additional notice: "This material may be downloaded for personal use only. Any other use requires prior permission of the American Society of Civil Engineers. This material may be found at [URL/link of abstract in the Civil Engineering Database]." (Online use is a limited use that is essentially equivalent to or substitutes for the print version, and embedded material (or a specific link to it) remains in situ; it does not include use as part of a database or other uses that might conflict with or prejudice the usage of the material by ASCE.)

Online Coursepack
The site must be password protected and posted for the semester only.

ASCE Magazines
Permissions granted only for text from Civil Engineering magazine and ASCE News. Permission to use photographs, graphics, figures, or tables must be requested from the copyright owner as noted in the credit line.

Materials Not Copyrighted by ASCE
The requesting party is responsible for ensuring that the material is original to ASCE and that it does not contain the copyright of another entity or reference that it was reprinted by ASCE with permission from another source.

General
The foregoing License shall not take effect unless and until ASCE or CCC receives the payment in accordance with the CCC Billing and Payment Terms and Conditions (including all payment provisions), which are incorporated herein by reference. Failure to fully comply with the terms of this License or the CCC Billing and Payment Terms and Conditions shall automatically render this License null and void.

ASCE or CCC may, at any time, deny the permissions described in this License at their sole discretion, for any reason or no reason, with a full refund payable to you. Notice of such denial will be made using the contact information provided by you. Failure to receive such notice will not alter or invalidate the denial. In no event will ASCE or CCC be responsible or liable for any costs, expenses or damage incurred by you as a result of a denial of your permission request, other than a refund of the amount(s) paid by you to CCC for denied permissions.

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE
TERMS AND CONDITIONS

Jul 26, 2008

This is a License Agreement between Sarah J Czerniewski ("You") and American Society of Civil Engineers ("American Society of Civil Engineers"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

License Number	1993731225771
License date	Jul 21, 2008
Licensed content title	Structural Analysis and Design of Nuclear Plant Facilities
Licensed content author	
Licensed content publication	book
Licensed content publisher	American Society of Civil Engineers
Type of Use	Doctoral Thesis
Portion used	Figure
Number of figures	20
Institution	Kansas State University
Title of your work	http://krex.k-state.edu/dspace/
Publisher of your work	Kansas State University
Publication date of your work	12/19/2008
Website	http://krex.k-state.edu/dspace/
Usage	both
Total	$0.00

Terms and Conditions

A Terms and Conditions agreement is a document that describes the terms and conditions of a license to the licensee. ASCE Terms and Conditions are available during the order process, although you may review the Terms and Conditions below, before placing an order.

The publisher for this copyrighted material is The American Society of Civil Engineers (ASCE). By clicking "accept", you agree that the following terms and conditions apply to this transaction, along with the billing and payment terms and conditions established by Copyright Clearance Center, Inc. (CCC) at the time that you opened your Rightslink® account. The terms and conditions information is available when you log in to Rightslink.

One Time Permission
Each license is unique, covering only the terms and conditions specified in it. Even if you have obtained a license for certain ASCE-copyrighted content, you will need to obtain another license if you plan to reuse that content outside the terms of the existing license. For example: If you already have a license to reuse a figure in a journal, you still need a new license to use the same figure in a magazine.

Embargo
Permission will be denied if the content is requested within 3 months of the publication date.

No-Fee License
A $0 license is granted to authors who wish to reuse their own content and to authors who wish to reuse ASCE-copyrighted content in their works prepared for another ASCE publication.

Credit Lines
A full credit line must be added to the material being reprinted.

- For reuse in non-ASCE publications, add the words "With permission from ASCE" to your source citation.
- For reuse in ASCE publications, add a comma and "ASCE" after the author-date citation. For example: (Jones and Taylor 2003, ASCE)
- For online posting, add the following additional notice: "This material may be downloaded for personal use only. Any other use requires prior permission of the American Society of Civil Engineers. This material may be found at [URL/link of abstract in the Civil Engineering Database]." (Online use is a limited use that is essentially equivalent to or substitutes for the print version, and embedded material (or a specific link to it) remains in situ; it does not include use as part of a database or other uses that might conflict with or prejudice the usage of the material by ASCE.)

Online Coursepack
The site must be password protected and posted for the semester only.

ASCE Magazines
Permissions granted only for text from Civil Engineering magazine and ASCE News. Permission to use photographs, graphics, figures, or tables must be requested from the copyright owner as noted in the credit line.

Materials Not Copyrighted by ASCE
The requesting party is responsible for ensuring that the material is original to ASCE and that it does not contain the copyright of another entity or reference that it was reprinted by ASCE with permission from another source.

General

The foregoing License shall not take effect unless and until ASCE or CCC receives the payment in accordance with the CCC Billing and Payment Terms and Conditions (including all payment provisions), which are incorporated herein by reference. Failure to fully comply with the terms of this License or the CCC Billing and Payment Terms and Conditions shall automatically render this License null and void.

ASCE or CCC may, at any time, deny the permissions described in this License at their sole discretion, for any reason or no reason, with a full refund payable to you. Notice of such denial will be made using the contact information provided by you. Failure to receive such notice will not alter or invalidate the denial. In no event will ASCE or CCC be responsible or liable for any costs, expenses or damage incurred by you as a result of a denial of your permission request, other than a refund of the amount(s) paid by you to CCC for denied permissions.

Websites

Here are the permissions or site disclaimers regarding the websites used for information in the report.

Nuclear Regulatory Commission (NRC)

Site Disclaimer

The U.S. Nuclear Regulatory Commission (NRC) provides access to the information and material on this site as a service to the public. The NRC regularly updates and adds information to this Web site. However, because we do not know how you are using the information found on this Web site, we do not make any warranties (express or implied) about the information in the NRC Web site for your particular use.

Information generated by the NRC or developed under an NRC contract is not copyrighted, unless indicated otherwise. Non-copyrighted material can be reproduced without permission; citation of the NRC as the source of the information is appreciated. Permission to reproduce any copyrighted material (including photos or graphics) must be obtained from the original source.

NRC provides links to non-NRC servers and Web sites solely as a reference for the convenience of users. These links are identified with EXIT icons. NRC cannot guarantee the authenticity of documents or the validity of information obtained at these non-NRC Web sites. These links do not imply any official endorsement of, or responsibility for, the opinions, data, or products available at these locations. It is also the user’s responsibility to take precautionary steps to ensure that information accessed at or downloaded from such sites is free of viruses, worms, or other potentially destructive software programs.

Web addresses at our site may change periodically because information has been moved, deleted, or reorganized. When this occurs, the old addresses are no longer accurate. When you use an old address, you will get a Page Not Found screen. It will provide you with several ways of finding out about the missing page, such as contacting the agency's Public Document Room or Web staff. It also directs you to a variety of information locator options: the site Search Engine, the site Subject Index, and the Site Map.

Privacy Policy | Site Disclaimer
Tuesday, February 13, 2007

National Oceanic and Atmospheric Administration (NOAA)

Use of Data and Products

The information on government servers are in the **public domain**, unless specifically annotated otherwise, and may be used freely by the public so long as you do not 1) claim it is your own (e.g. by claiming copyright for NWS information -- see below), 2) use it in a manner that implies an endorsement or affiliation with NOAA/NWS, or 3) modify it in content and then present it as official government material. You also cannot present information of your own in a way that makes it appear to be official government information..

Before using information obtained from this server special attention should be given to the **date & time** of the data and products being displayed.

The user assumes the entire risk related to its use of this data. NWS is providing this data "as is," and NWS disclaims any and all warranties, whether express or implied, including (without limitation) any implied warranties of merchantability or fitness for a particular purpose. In no event will NWS be liable to you or to any third party for any direct, indirect, incidental, consequential, special or exemplary damages or lost profit resulting from any use or misuse of this data.

As required by 17 U.S.C. 403, third parties producing copyrighted works consisting predominantly of the material appearing in NWS Web pages must provide notice with such work(s) identifying the NWS material incorporated and stating that such material is not subject to copyright protection.