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<u>Introduction</u>

Concrete is one of the most popular materials for buildings because it has high compressive strength, flexibility in its form and is widely available. The history of concrete usage dates back to over a thousand years. Concrete is the principal choice of material for the construction of large civil engineering structures. The developed world has demonstrated its faith in the material by choosing concrete for the main structures of industrial and chemical plant as well for transport, water and energy-related infrastructures [1]. However, concrete has limited tensile strength, which is only about ten percent of its compressive strength, whereas zero strength after cracks develops. In the late nineteenth century, reinforcing materials, such as iron or steel rods, began to be used to increase the tensile strength of concrete. Today steel bars are used as common reinforcing material. Reinforced concrete became the most important building material and is widely used in many types of engineering structures. The economy, the efficiency, the strength and the stiffness of reinforced concrete make it an attractive material for a wide range of structural applications. Reinforced concrete structures are widely used in nuclear energy plants. Reinforced concrete structures play an important role in the economic and social fabric of many countries and are required to perform their function with integrity and reliability for long-term serviceability in the case of nuclear safety related structures. Usually steel bars have over 100 times the tensile strength of concrete, but the cost is higher than that of concrete. Therefore, the most economical solution is when concrete resists compression and steel provides tensile strength. Also it is essential that concrete and steel deform together and deformed reinforcing bars are being used to increase the capacity to resist bond stresses.

Advantages of reinforced concrete can be summarized as follows [2]:

- It has a relatively high compressive strength;
- It has better resistance to fire than steel or wood;
- It has a long service life with low maintenance cost;
- In some types of structures, such as dams, piers, and footing, it is the most economical structural material;
- It can be cast to take any shape required, making it widely used in precast structural components.

Disadvantages of reinforced concrete can be summarized as follows:

- It has a low tensile strength (zero strength after cracks develops);
- It needs mixing, casting, and curing, all of which affect the final strength of concrete;
- The cost of the forms used to cast concrete is relatively high. The cost of the forms used to cast concrete is relatively high;
- It has a lower compressive strength than steel (about 1/10, depending on material), which requires large sections in columns of multi-story buildings;
- Cracks develop in concrete due to shrinkage and the application of live loads.

The economy, the efficiency, the strength and the stiffness of reinforced concrete make it an attractive material for a wide range of structural applications. For its use as a structural material, concrete must satisfy the following conditions [3]:

- The structure must be strong and safe. The proper application of the fundamental principles of analysis, the laws of equilibrium and the consideration of the mechanical properties of the component materials should result in a sufficient margin of safety against collapse under accidental overloads.
- The structure must be stiff and appear unblemished. Care must be taken to control deflections under service loads and to limit the crack width to an acceptable level.
- The structure must be economical. Materials must be used efficiently since the difference in unit cost between concrete and steel is relatively large.

One of the main requirements for reinforced concrete building structures is that during extreme internal and/or external loading, the

structural integrity of the buildings and components installed in the building should be retained. The design or structural integrity analysis of complex building structures are a sophisticated task. Analytical solutions and sophisticated numerical models are used to evaluate the structural integrity of these structures. The development of analytical models for the response of the reinforced concrete structures is a complicated task. Difficulty of the analysis of reinforced concrete structures is related with the following factors [4]:

- Reinforced concrete is a composite material made up of concrete and steel, two materials with very different physical and mechanical behaviour;
- Concrete exhibits non-linear behaviour even under low level loading due to non-linear material behaviour, environmental effects, cracking, biaxial stiffening and strain softening;
- Reinforcing steel and concrete interact in a complex way through bond-slip and aggregate interlock.

Accordingly, the analysis of reinforced concrete structures using classical analytical methods is complicated for reliability of the results and experimental studies are costly. Advanced sophisticated numerical tools can be an indispensable aid in the assessment of the safety and serviceability of reinforced concrete structures. This is especially true for many complex modern structures, such as nuclear power plants, bridges, off-shore platforms for oil and gas exploration and underground or underwater tunnels, which are subjected to very complex load histories. The safety and serviceability assessment of these structures necessitates the development of accurate and reliable methods and models for their analysis. Moreover, it should be noted that the transient behaviour of the structures during transient loading is a complex phenomenon due to various factors, such as inertia effects, large deformations, and inelastic behaviour. It is, thus, not possible to obtain analytical solutions for general cases; so sophisticated numerical models are necessary for the analysis. The most popular method for the advanced analysis of complicated structures is finite element method [5, 6]. It is a general method of structural analysis in which the solution of a problem in continuum mechanics is approximated by the analysis of an assemblage of finite elements which are interconnected at a finite number of nodal points and represent the solution domain of the problem. Applications range from the stress analysis of solids to the solution of acoustical phenomena, neutron physics and fluid dynamic problems. The finite element method is established as a general

numerical method for the solution of partial differential equations subject to known boundary and initial conditions. In the case of linear analysis, the finite element method is widely used as a design tool [7]. In solving the problems of non-linear analysis, the use of the method depends on two major factors. First, the increase in computational effort required for non-linear problems necessitates that considerable computing power was available to the designer at low cost. The second major factor is related to the level of complexity of non-linear analysis.

Nowadays the finite element method (FEM) has been extensively used to simulate many applications in structural dynamics [8 - 12]. Finite element codes are able to accurately model the plastic deformation via bending, compression or full collapse of the structures. After the terrorist attacks in New York and Washington D. C. using commercial airliners, the structural integrity assessment of civil airplane crashes into civil structures has become very important. During the recent years the researchers from many countries have been simulating aircraft crashes to building structures. The FEM methodology was mainly used for the aircraft crash analysis [13 - 17].

Due to the tendency of increased nuclear safety, the analysis of transient loading will demand multidisciplinary optimization of the methods used. However, simulation-based multidisciplinary optimization generates deterministic optimum design, which is frequently pushed to the limits of design constraints boundaries, leaving little or no room for tolerances (uncertainty) in modelling, simulation uncertainties, and manufacturing imperfections. Consequently, deterministic optimum designs that are obtained without consideration of uncertainty may result in unreliable designs, indicating the need for Reliability-Based Design Optimization [18].

In structural integrity analysis of the buildings it is very important to evaluate uncertainty associated with loads, material properties, geometrical parameters, boundaries and other parameters [19]. This can be resolved using probabilistic analyses methods [20, 21]. Therefore, a probability-based structural integrity analysis was performed as the integration of deterministic and probabilistic methods using existing state-of-the-art software for both the whipping pipe event and the aircraft crash event.

The methodology of the deterministic structural integrity analysis of the reinforced concrete structures using finite element method and methodology probability-based structural integrity analysis that integrates deterministic and probabilistic methods is explained in this

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book. The application of these methodologies to Ignalina Nuclear power plant (NPP) for postulated accidents is presented as examples.

The Ignalina NPP has a RBMK type reactor that is quite different in comparison to the power plants with PWR or BWR type's reactors. Several events have been identified for these plants that can compromise the integrity of critical structural components. The Chernobyl RBMK reactor accident is the most serious accident in the history of the nuclear industry. Typically, RBMK reactors do not possess the conventional containment structure. Only Ignalina NPP contains two RBMK 1500 reactors, which are the most advanced version of the RBMK reactor and have a pressure suppression type confinement, which is referred to as the Accident Localisation System (ALS) [22]. However the ALS encloses only about 65% of the entire cooling circuit. It does not enclose the sections of piping most vulnerable to rupture in case of the dangerous loss-of-coolant accident. The structures of ALS are very important system to nuclear power plants safety not only during operation, but also when it is shutdown. The fuel is located in the pools of ALS during shutdown. The unloading of the fuel after shutting down the reactor takes several years. Therefore, for the reliability of the analysis of these structures, deterministic and probabilistic methodologies of the structural integrity analysis were used.

The finite element method is used for deterministic strength analysis of the reinforced concrete structures. The deterministic finite element software NEPTUNE [23] was used here for structural integrity analysis. This software can analyze the transient structural response of the concrete and steel structures, which undergo large displacements and non-linear material response in case of transient loading, including object impact onto the structures.

The ProFES [24] software was used for the probabilistic analysis of structural failure. ProFES is a probabilistic analysis system that allows performing probabilistic finite element analysis in a 3D environment that is similar to modern deterministic finite element analysis.