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MODELING BASED STUDY OF IMPACT LOADS GENERATED BY TORNADOES AND HURRICANES ON SAFETY-CRITICAL STRUCTURES FOR NUCLEAR STRUCTURES

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Abstract— Safety-related buildings and structures for nuclear plants require the design and analysis of tornado and hurricane generated missile impact load. Several Canadian provinces, including Ontario, Quebec, Manitoba, Saskatchewan and Alberta are tornado prone. In Canada during the years 1980 to 2009, a total of 1,217 tornados were observed, including one F5 scale, five F4 scale, 24 F3 scale and 119 F2 scale tornadoes. These tornadoes pose critical risks to nuclear infrastructure due to the potential for missile generated impact loads from debris present in the tornado that can impact the nuclear structures. During the years, 1918 to 2014, seven F4 scale, 18 F3 scale and 126 F2 scale tornadoes were observed in Ontario. Meanwhile, several hurricanes hit the Eastern region provinces of Canada in recent history, including Hurricane Juan in September 2003 in Nova Scotia and Prince Edward Island, and four hurricanes in Nova Scotia and New Brunswick in 1963. In this work, an ANSYS based advanced computational simulation model framework was developed to investigate the effect of the tornado and hurricane generated missile impact load on nuclear structures. The explicit dynamics module in the ANSYS software was used for simulations and the preliminary results are presented. A database of materials and potential missile impact loads were identified for future investigations. For example, concrete, reinforced concrete, steel, and reinforced concrete walls with steel liner are relevant for further study. The 0.158 meter diameter and 4.58 meter long steel pipe missiles in 103 m/sec, 89 m/sec and 72 m/sec maximum wind speeds were also identified for further investigation. Lab based impact loading tests on scaled down samples were also studied.

Structural Design; Impact Loading; Extreme Events; Climate Change; ANSYS

I. INTRODUCTION

The analysis of impact loading for nuclear structures is growing in importance given the increased number of severe and extreme weather events and storms as a result of climate change. Furthermore, the need for clean and reliable base load power from nuclear power plants for society's growing energy needs has motivated a surge in new nuclear power plant projects. Given the challenges of severe and extreme events, such as tornados, hurricanes and microbursts from thunderstorms, the in-depth analysis, characterization and modeling of impact loading from these extreme events requires further investigation. In this work, a summary of the hurricane and tornado risk in Canada, a characterization of the ranges of impact loads which require consideration and the initial development of ANSYS modeling and framework for analyzing the impact loads on nuclear power plant structures are provided.

II. LITERATURE REVIEW

Preliminary studies of missile impact loads for nuclear power plants have identified roadmaps for future detailed analysis on a regulatory standpoint [1], however a framework for detailed analysis in ANSYS and methods to interpret the outcomes of these analyses were not provided. Antaki [1] focused on the regulatory perspective and high-level methods of analysis. Similarly, Scheer [2] conducted extensive in depth modelling and analysis for missile impact loads from hurricanes, tornadoes and microbursts, but focused on the State of Florida and Residential and Commercial buildings instead of critical civil infrastructure such as nuclear power plants.

A. Tornado Occurrence and Risk in Canada Hurricane Occurrence and Risk in Canada

The extent of tornadoes in Canada and Ontario are outlined in the tornado maps of the respective jurisdictions provided by Environment Canada. From 1918 to 2014 more than 100 category F3-F5 tornadoes occurred in Canada (Figure 1) [3]. In Ontario from 1918 to 2004, there have been seven 'Devastating tornadoes' of severity four on the Fujita scale (F4) [3]. A 'Devastating tornado' is a F4 tornado with instantaneous wind speeds of 92.5 ms-1 to 116 ms-1.

The tornado occurrences have been concentrated in the most densely populated region of Ontario, called the 'Greater Golden Horseshoe' region, with a population density of 278 people / km2 and with the largest built-up area in Canada [4]. The 'Greater Golden Horseshoe' region in Ontario has the highest risk of tornadoes. This region is also where the critical infrastructure is located, such as the Pickering Nuclear Generating Station, the Darlington Nuclear Generating Station, the transmission corridor. Civil infrastructure, such as water treatment plants, and hospitals are also located in this densely populated corridor in Ontario.

There has been an increase in the number of tornadoes recently with 95 tornadoes between 2004 and 2005 and only 105 tornadoes in the preceding ten years (1995 to 2004). In contrast, during the time period from 1918 to 1994 a total of only 526 tornadoes were recorded. Furthermore, climate change modelling shows that extreme events and storms are expected to increase in occurrence and severity [5]. Full scale modelling of thunderstorms to adequately measure wind speeds remains an area of active research [6], [7].

The area of Sitakunda is vast and so an area needed to be chosen for the research. Based on secondary data from Chemist without Borders, the area of Bariadyala was chosen for the study area (Figure 1).

A series of measurements were made of the Arsenic from the tubewells in the Bariadyala area using Hatch Kits. The Arsenic levels were above both the WHO limit and the Bangladesh limit. In the elevation map (Figure 2), the variation of concentrations is shown to be non-correlated with elevation in this specific Bariadyala area.

Mapping for finding toxic metals has been previously done for different countries. Peng et al. [33] have recently done similar mapping projects for the soils of Qatar. Peng et al.'s research [33] focused on different parameters (soil and groundwater), the mapping approach outlined here are similar.

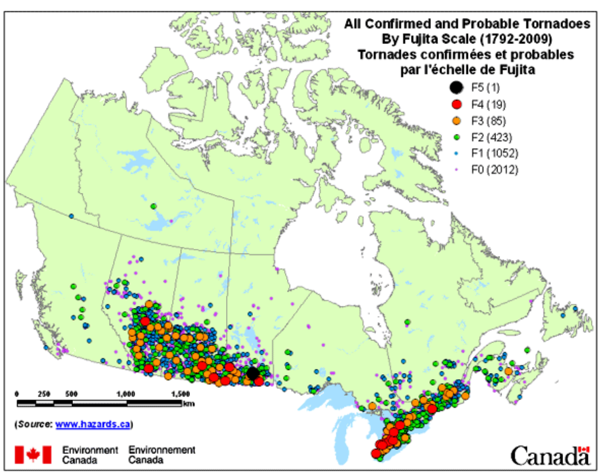

Figure 1. Hazard map of tornadoes in Canada from 1792-2009 both confirmed and probable tornadoes measured by the Fujita scale) [3].

B. *Hurricane Occurrence and Risk in Canada*

In Canada's history since 1900, there have been 163 hurricanes which have made landfall [8]. Most of these hurricanes have been downgraded to a post-tropical storm, since the hurricanes typically either have travelled over land for significant periods of time, or because the hurricanes have travelled large distances from tropical or warmer waters south of Canada. With climate change impacting Canada at a more drastic level than other countries, there could be an increase in the number of hurricanes which make landfall in the future [5]. The track of the hurricanes which have made landfall from 1900 to 2014 were located in Eastern Canada [8] shown in Figure 2. The most severe hurricanes that have impacted Canadian cities have been Hurricane Juan in 2003 with Category 2 winds (43 ms-1 to 49 ms-1) that hit the City of Halifax and caused 8 deaths; and Hurricane Hazel in 1954 with 81 deaths but it was an extra-tropical storm when it hit the City of Toronto.

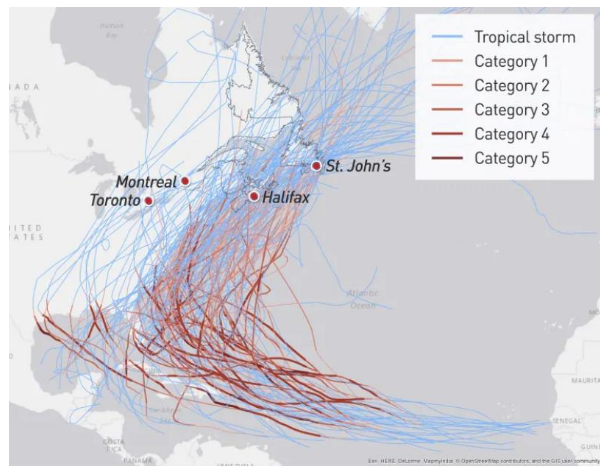

Figure 2. Tracks of the hurricanes which have made landfall in Canada (1900-2014) from data of the U. S. National Oceanic and Atmosphere Administration [8].

C. *Research Required to Mitigate Tornado and Hurricane Missile Impact Loads*

A thorough analysis of the missile impact loads from tornadoes and hurricanes are required for adequately strengthening and protecting these critical structures under the extreme loads of F4, and F3 tornadoes and Category 2 winds from hurricanes. ANSYS modelling offers a dynamic means of testing the effectiveness of concrete walls, reinforced concrete walls and concrete walls reinforced with new materials. A wide range of new materials and wind speeds require analysis.

Several new materials, such as Carbon Fibre Reinforced Polymer plates [9]–[17], Glass Fibre Reinforced Polymer and Basalt Fibre Reinforced Polymer offer a useful means of reinforcing concrete structures for nuclear power plants to more effectively withstand tornado generated missile impacts. Similarly, these new materials can also be used in Civil infrastructure including water treatment plants [18]–[22]. The design of long-term storage sites for both nuclear waste and carbon capture and storage technology [23]–[25], for example carbon dioxide injection well super structures could also require detailed analysis of the impact of tornado and hurricane generated impact loads. Secondary impacts on community water sources and civil infrastructure include devastating effects on spreading of industrial waste whose original source can be traced using PIXE [12].

III. Preliminary Analysis

The analysis of wind induced missile impact loads requires several steps using numerical modeling software such as ANSYS or ABAQUS. First, the development of an appropriate and representative geometry is required. As a preliminary analysis, a simple 3D wall of concrete 10 m in width, 10 m in height and 0.25 m in thickness is shown in Figure 3. Second, the geometry of the debris impacting the wall must be designed in the software. In this preliminary analysis, a 6-inch schedule 40 steel pipe was analyzed with a diameter of 0.158 m and 4.58 m long. This is aligned with NUREG-0800 for the analysis of missile impact loads for nuclear structures [32]. The pipe was assigned a velocity of 72 ms-1 in Explicit Dynamics (Figure 4).

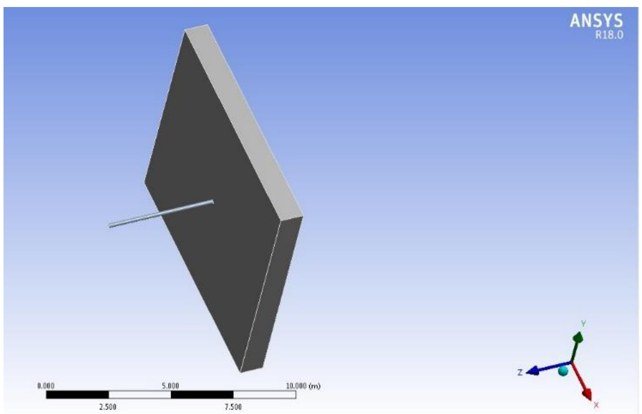

Figure 3. Initial ANSYS-based geometric model of a concrete wall impacted by a steel pipe.

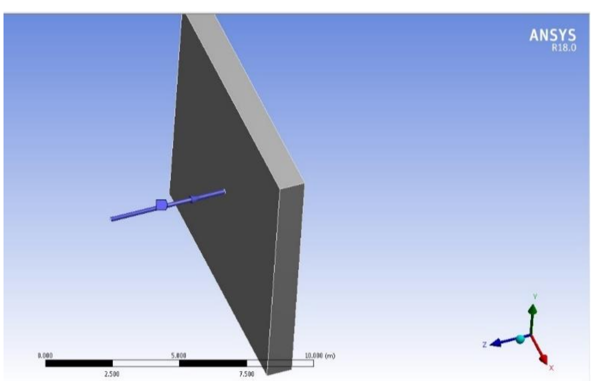

Figure 4. Diagram of Explicit Dynamics ANSYS-based analysis of a concrete structural wall being impacted at a velocity of 72 ms-1 by a steel pipe, shown with the purple arrow overlaying the grey steel pipe.

A database of materials and potential missile impact loads were identified for future investigations (Table 1). Walls made of concrete, reinforced concrete, steel, and reinforced concrete walls with steel liner, or pre-stressed CFRP plates or GFRP rods are relevant for future investigations. The 0.158 meter diameter and 4.58 meter long steel pipe missiles in 103 m/sec, 89 m/sec and 72 m/sec maximum wind speeds are also useful sample tornado and hurricane generated missiles for further investigation as recommended by the NUREG-0800 for nuclear structures.

Table 1: Missile impact loads generated from tornadoes and hurricanes in ANSYS Explicit Dynamics

Materials	Wind speeds (ms^{-1})		
	1	2	3
Steel Pipe (0.158 m diameter, 4.58 m long, 130 kg)	72	89	103
Wood Plank (0.092 m x 0.289 m x 3.66 m, 52 kg)	66	83	97
Automobile (5 m x 2 m x 1.3 m, 1810 kg)	59	52	41

IV. Conclusions

The risk hazards of tornadoes, hurricanes and increased severity of thunderstorms and microbursts from climate change necessitate a renewed effort to modeling and analyzing the impact tornado and wind generated missile loads on structures. Future studies are required to systematically analyze the damage missile loads generated by debris flying at high wind speeds can have on critical infrastructure such as nuclear plants, water treatment plants and hospital buildings. As well, these future studies should thoroughly investigate the role new materials such as Carbon Fibre Reinforced Polymer plate reinforcement in concrete walls can play to mitigate the risks posed by tornado and hurricane generated missiles.

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