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POTENTIAL IMPACT OF CLIMATE-INDUCED NATURAL DISASTERS ON THE CONSTRUCTION INDUSTRY

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ABSTRACT

This paper discusses the potential impact of climate-induced natural disasters on the construction industry. Following a general overview of climate change and its influence on natural disasters, the question of how present construction practice will be influenced by climate change is addressed. The need for risk assessment as an efficient tool for planning and tailoring adaptive measures, e.g., retrofitting, coastal management for communities at risk is examined.

BACKGROUND

Damage to constructed facilities due to extreme winds and storm surge currently is in the billions of dollars annually in the United States, and it is expected to increase every year due to the rapidly accelerating growth of coastal developments and movement of population to these communities[1]. Such disasters, besides causing the region devastating economic losses and hardship, also disrupt the community lifelines, i.e., the communication links, transportation, and supply. The situation will be further exacerbated by global warming and the resulting rise in sea level. Coupled with the climatic changes, coastal hazards will further increase as a result of accelerated erosion, higher sea levels, transformation of wetlands, and intrusion of salinity. The frequency of hurricanes may not increase, but their intensity and associated wind speeds are speculated to increase[2,3]. Furthermore, those regions that escaped hurricane landfalls in the past may become more likely candidates as warmer waters will further assist in steering storms further north; e.g., California, New England, and Nova Scotia/Newfoundland. The major threat will be posed by a possible increase in the storm surge level. Unless significant measures are taken to lessen the impact of wind/wave/surge catastrophe coupled with climate change effects on the built environment, the cost of replacement or repairs and loss of lives is likely to escalate.

GLOBAL WARMING

In the past few decades, attention has been focused increasingly on global climate warming. This is primarily resulting from the heating caused by emissions of greenhouse gases that are trapping outgoing infrared radiation. The worldwide burning of fossil fuels is a primary source of these gases. The impending threat of global warming and associated sea level rise are gaining fast recognition as a new natural hazard in the making that also has the potential of intensifying known hazards, such as hurricanes. There is still a considerable controversy over this; nevertheless, should the warming trend continue, the implications are staggering. The nature and magnitude of weather conditions and events that might accompany greenhouse warming at a location are extremely uncertain. The reason for the uncertainty stems from a specific deficiency in the general circulation models employed for climate simulation. These models represent climatic forcing on two different spatial scales, namely, large scale—1000 Km to global—and mesoscale that encompasses a few kilometers to several hundred kilometers. The larger scales are responsible for determining sequences of weather events which characterize climate change, whereas mesoscales regulate the regional distribution of climatic variables. Current models are too coarse to adequately describe mesoscale forcing for a more accurate prediction of regional climatic details[4]. Furthermore, the clouds resulting from initial warming subsequently end up offsetting the effect of warming by blocking the sun. This cycle is not well understood. The role of oceans in the climate dynamics is an important one. Despite the level of overall uncertainty in data stemming from the types of thermometers used, reading practice, location of measurements, and a possible urban bias, some believe that climatic warming has a definite identity and it is distinguishable from the climatic noise[5]. Recent developments in the theory of dynamical systems will make it possible to learn more about the underlying dynamics of weather and climate and to find out, independently of any modeling, to what extent these are predictable[6].

SEA LEVEL RISE SCENARIO

Unlike the quantitative assessment of global warming, the historical records of sea level changes taken from tide gauges around the world are less ambiguous. The compiled data indicates a century-long rise from 10–30 centimeters suggesting a global warming trend. Atmospheric warming would cause melting of glaciers and ice sheets that will ultimately travel down to the ocean. Also, the warming of ocean waters results in an expansion of the water volume. Both scenarios would lead to a sea level rise and a confirmation of the global warming. Nevertheless, questions remain regarding the role of uneven distribution of tide gages, land subsidence, and crustal motion on the sea level rise scenario.

In addition to sea level rise by global warming there are climate change-induced changes in waves, winds, and tides density of water that cause spatio-temporal variations. IPCC7 Business-as-Usual Scenario in the year 2030, projects global-mean sea level 8–29 cm higher than today, with a best estimate of 18 cm. That implied rate of rise for the best-estimate projection corresponding to the IPCC Business-as-Usual Scenario is about three to six times faster than that over the last century. It is noted that even if the emission of greenhouse gases is reduced, the sea level will continue to rise due to time lag in the climate system. Other sea level rise scenarios and their impact may be found in the literature[7,8,9,10,11,12].

The primary impact of sea level rise entails the direct physical impact of increased sea level on various components of coastal resources system, whereas the secondary impact concerns socio-economic effects on human activities or interests. The primary impact will be exacerbated by the impending threat of increase in intensity, frequency, duration, and region of influence of tropical storms. The warmer seas provide essential ingredients critical to the developments of these storms. It is noted that upwelling of cooler subsurface water due to stronger winds would offset any increase in intensities. However, there are regions in the Gulf of Mexico where loop current and its eddies bring warm Caribbean water to depths of 60 meters which would negate adverse effects of upwelling[12]. While the debate over the linkage between the frequency of storms and global warming is still on, there is some evidence that more intense storms may result from global warming. Even in the absence of an increase in the intensity and frequency of storms, the sea level rise threatens the coastal construction due to higher storm surge. The frequency of extreme events, e.g., wind gusts and storm surge, varies with changes in the mean and standard deviation of these processes. These changes are possible and are being speculated as a consequence of projected global climate change. An increase in the standard deviation is reflected in an increase in the probability of both high and low extremes. Due to an increase in the mean value with constant variability, as expected with global warming, the probability of high extremes rises. Therefore, a change in the mean of only one standard deviation would increase the frequency of occurrence of an event with MRI of twenty years by many fold. Other issues of concern are in the context of two successive extreme events that have significant influence on damage due to their cumulative impact. If the MRI of one hurricane is reduced by a factor of 2, there is a corresponding reduction of the MRI of two hurricanes in successive years by a factor of 4. Accordingly, the projected global warming threatens to increase the likelihood of damaging double events from being unlikely to happen within an average lifetime to a hazard which we can expect to experience. The prospect of sea level rise coupled with the potential of super-storms threaten the low-lying coastal areas with flooding under high tide, storm surge and wave action, beach erosion, and damage to coastal construction around the world. An increase in sea level would also threaten earlier flooding of some major hurricane evacuation routes. Accordingly, the present margins of safety may become inadequate, thus necessitating the implementation of adaptive measures. For the existing construction, this will entail retrofitting structural components and the system, and construction of levees and seawalls. There is a concern, however, that despite protecting the coastal buildings from being swallowed by ocean pounding, seawalls have led to the destruction of beaches[13].

IMPACT OF GLOBAL WARMING

Despite the controversy over the several global warming aspects stated above, it is essential that the question concerning the impact of these climate-induced changes be addressed. Any anticipatory adaptation measures on the one hand will certainly be very effective and timely in lessening the impact of the impending climate change as feared by many, and on the other hand should the projected climate change not materialize these measures will pay for their cost in improved performance under hazards precipitated by natural climatic variability.

Should the climate change start having an impact, most cities would opt for adaptation rather than abandoning their present sites. In most cases this cost will be much lower than the cost of moving an entire city. In the coastal communities, the cost will be much higher due to added storm protection needed from rising sea and protection from coastal erosion. In some cases of less populated regions, protective zoning or retreating may be more suitable. The construction industry will face many challenges in such undertakings that will require innovative techniques, such as submerged barriers in lieu of sea walls to protect beaches, the use of special equipment, and construction activity that promises not to disturb the remaining environmentally critical wetlands[14].

The coastal communities will have to make major adjustments in construction practice to cope with such changes. Places like Manhattan, Miami, New Orleans, Galveston, Charleston, and surrounding barrier islands will need to address serious and costly issues like elevated future construction, raising existing structures, and the building of dikes, levees, berms, and pumping facilities[15]. For example, the cost of building a seawall in Charleston is estimated to be $6,000/linear meter. Once the structures are elevated these are further exposed to the enhanced wind gusts which needs to be addressed in future design codes. Estimated cost of raising a house by 3 ft. is 10 to 40 thousand dollars. Strengthening the U.S. coastal property for wind resistance may cost between 30 to 90 billion dollars. Besides new construction practice, the transportation network will need to be elevated to avoid flooding during storms as these serve vital evacuation routes for coastal communities in the event of a hurricane landfall threat. Coastal erosion will result in shifting sand dunes and eroding recreational beaches that may require dredging and replacing sand at strategic locations. The cost of this effort may vary between 15 to 60 billion dollars for the recreational beaches based on an estimated sea level rise of 50 cm by year 2100[16].

The design practice will have to take into account possible climate change for structures with long life, e.g., bridges, levees, coastal structures, and offshore installations. The safety margins for such structures are generally computed based on the historical frequency of extremes, like storms. The possibility of greenhouse warming may now be considered in evaluating these safety margins. Regarding future construction, attention must be paid to account for climate change when long-lived structures are built or renovated through enhanced building codes and land-use planning. In this regard, different issues need to be addressed, e.g., economic tradeoff where the damage to or loss of a structure is gambled against the cost of incorporating extra safety margins, justification of investment in a wider safety margin in view of upfront cost or additional cost of retrofitting in light of the probability that the alteration will in fact be needed. An exercise in utility theory may help to systematically sort out these questions.

The construction industry can also offer additional measures to help mitigate the effects of global warming. The first step should be the adoption of nationwide energy efficient building codes that include efficient lighting systems to reduce energy consumption; more efficient building envelopes, claddings and curtain walls to cut down heating and cooling demands; the development of white roofs and pavement surfaces that reflect sunlight; the development of a new glazing to retain heat in winter and deflect in summer; and the utilization of passive solar techniques in locating windows on the south side of buildings and overhangs and other architectural features for shade in warmer months.

It is recommended that in order to minimize uncertainty in the effects of global changes one should institute careful monitoring and cataloging of the climate, sea surface level, stream runoff, occurrence, and tracks of hurricanes and tornadic events and their relative intensities. This information will eventually provide a rational basis for code modifications and selection of specific adaptation measures. Another important initiative in the wake of uncertainty regarding the climatic change is to improve our present ability to build structures to resist current climatic extremes. Such a construction practice will not only pay for its cost in the event no climate change occurs, but it will certainly be an effective adaptation measure to lessen the impact of an extreme climate change as feared by many.

RISK ASSESSMENT OF CONSTRUCTED FACILITIES

Risk assessment for tropical storm winds, storm surge, and wave action and consequences of projected global climate change on coastal built infrastructure is an essential prerequisite for instituting measures to lessen catastrophic damage potential. Despite a spectre of staggering economic losses from tropical storms, there is only fragmentary information on the relationship between the characteristics of the geophysical event and its damaging effects. Several studies in earthquake engineering have addressed this issue in relation to earthquake risk, however, little or no work appears to have been conducted in relation to wind/surge action[17]. The need for risk assessment is further emphasized by the impending threat of global climate change to better plan and tailor adaptive measures to confront the projected magnification of tropical storm catastrophe by climate change. Of critical importance is the development of a framework for risk assessment for identifying facilities at risk in any given geographic area.

The resulting analysis framework will permit integration of future climate change scenarios in the overall tropical storm hazard and the evaluation of its impact on the risk to coastal zones. One of the outcomes of global warming is sea level rise. The prospect of a sea level rise coupled with the potential of super-storms threaten the low-lying coasts worldwide with flooding under high tide, storm surge, wave action, beach erosion, and damage to coastal construction. Accordingly, the present margins of safety may become inadequate, thus necessitating the implementation of adaptive measures.

Risk is referred to here as the chance of property damage, impairment of intended function, and lost opportunities. The determination of hazard, vulnerability, and significance of the facilities, and analysis of damage potential constitute essential prerequisites for risk assessment. The assessment of hazard entails determination of a probabilistic model that best describes the occurrence of extreme events at a site and their severity. The vulnerability and significance of a facility encompass structural characteristics, e.g., construction system and material, sensitivity to hazard, and utility. For damage analysis, a relationship is sought that relates expected damage, as a percentage, to the exposed assets, due to the occurrence of a specific event. A synthesis of these attributes leads to the risk assessment analysis framework.

Phenomenological models combined with historical records, and the Monte Carlo simulation procedure provide a reliable means of predicting tropical storms[18]. Further improvements are needed in modeling the hurricane wind field, modeling of swirling rainbands, and filling rate (degradation of tropical storms strength after land fall). Improved modeling of storm surge and wave fields driven by storm wind field is needed to better describe these hazards in light of regional topography. The projected influence of climate change in terms of modification to storm intensity, frequency of occurrence, and sea level rise need better predictive models.

The assessment of damage potential is the key element of risk assessment exercise, but it poses a very difficult challenge due to a lack of a well-founded basis for evaluation. To date only very simplistic approaches have been utilized to assess damage potential. This area needs better quantitative procedures to evaluate damage potential in light of a host of factors ranging from imprecise nature of loading, variability in structural strength, and complexity of possible load paths. Ideally, the damage potential can be derived from a series of tests conducted under varying loads applied incrementally to obtain total collapse. In addition to the difficulty in the realization of a test of this scope for different classes of structures, it is economically prohibitive. Alternatively, reliability based mathematical modelling of load effects and resistance, and expert knowledge gleaned from the exposure of similar structures to extreme events offer algorithmic and inferential means of ascertaining damage potential. These areas need focused attention to develop techniques that provide realistic measures of damage to a wide range of constructed facilities. A multi-hazard approach should be considered, i.e., damage due to wind and storm surge/wave action. This effort should cross-cut similar activities in earthquake damage assessment. One should not only concentrate on structural damage, but also rain penetrating into building enclosures subsequent to minor damage of roofing, siding, or window which can result in staggering losses (e.g., wind-related damage in Hugo was nine times the flood losses).

There is a need for demonstration projects to illustrate the effectiveness of the risk assessment scheme and its utilization as a tool for planning adaptive measures, e.g., retrofitting and coastal management for communities at risk. Galveston and Charleston present ideal sites for the demonstration study in view of their vulnerability and recent storm histories.

Future utilization of GIS (Geographical Information Systems) for cataloging inventories of built facilities in different communities will promote use of the risk assessment tools not only in the U.S., but also overseas.

CONCLUDING REMARKS

Proactive hazard management strategies that involve assessment of risk and mitigating effects to reduce the impact of hazards rather than continuing the current practice of only responding to natural hazards by disaster relief efforts need to be developed. The impending threat of an increase in exposure to hazards by climate change places a growing need to assess the risks for constructed facilities in tropical storm-prone regions. This will serve as an efficient tool for better planning and tailoring adaptive measures, e.g., retrofitting, coastal management, and construction of dikes for communities at risk.

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