Impact of Global Warming on Reinforced Concrete and High Rise Building Structures: A Review

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Abstract—*This paper deals with the effects and correlation between the direct and indirect impacts on reinforced cement concrete (RCC) structure due to the exponentially rise in global warming during the last few decades. Effects includes the induced corrosion of RCC concrete and also change in wind pattern & velocity resulting in weakening or shortening of life span of structures under various conditions and factors. The impact parameters of main importance on structure include durability, corrosives, service life of reinforced concrete and safety. Corrosion, one of the key activities for deterioration of reinforced concrete structure is observed mainly due to factors such as chloride ingress corrosion, carbonation, humidity and temperature. The main mechanism of induced corrosion on RCC is due to carbonation of CO_2 from atmosphere reacting with calcium hydroxide in concrete forming calcium carbonate. This result in mechanical strengthening of the concrete however decreases alkalinity which leads to corrosion. Above these effects, the global warming is predicted to effect the change of surface winds and exceed that of 2001 by 2046 with Model for Assessment of Greenhouse -gas Induced climate change (MAGICC) predicted the emission of CO_2 with 360 ppm approximately in the year 2000 to increase by three folds by 2100. This paper gives a review on several probabilistic and realistic approaches for the concrete effects and strategies applied to nullify or decrease the effects with increase in CO_2 concentration due to global warming.*

Keywords: *Global warming, RC structure, chloride ingress, carbonation, high rise building.*

1. INTRODUCTION

Global warming is one of the greatest environmental threats and its happening is manifested in a range of ways with increase in the average temperature of the Earth's atmosphere and oceans as a result of the build up of greenhouse gases in the atmosphere. Greenhouse gases can either be released by natural events or human activities such as burning of fossil fuel, cutting and burning the trees in forest as mentioned by UNEP and UNFCC(2002)[1]. The main greenhouse gases are carbon dioxide, methane, nitrous oxide, ozone, etc. These gases trap heat leading to heating up of earth which leads to global warming or climate change.

Over the last few decades, many global ecological crises are increasing in an alarming rate. Industries are considered to be one of the main contributors for global warming all over the world as they depend highly on the burning of fossil fuel to run their production. Combustion of fossil fuels to generate electricity produces atmospheric CO_2 emissions in which 41% were produced from fossils fuel out of the total CO_2 emission of 26.6 billion tons in 2005 and is expected to increase to 46% by 2030 and act as the primary cause of global warming [2, 3]. The global climate change has impacts on local coastal and urban climate and the temperature of the oceans is influenced by the heating and moisture content of the atmosphere [4, 5]. Tropical cyclone occurs in a climatologically warm sea surface temperature [6, 7, 8] and evidence shows that over past decades the magnitude of sea surface temperature have increased by 0.25-0.5^{0}C. [9, 10]

Nevertheless, recent international researches are leading to understand the potential insight problems on structural engineering due to the adverse effect of global warming. Many researches have been performed focusing on the assessment of climate change on durability of reinforced concrete structures. There are several possible impacts of global warming on structures. Generally, possible consequences to be mentioned subjected to environmental action affecting RC structures are frequent freezing-thawing cycles may give a challenge in concrete technology, foundation problem due change in the ground water level.Also, different wind profiles and higher wind impulse may lead to the modification of codes available for tall building structures as well as a response for the existing structures to overcome the impact becomes an important issue. Long term variations of precipitation and temperature is also one of the consequences of global warming which is partially responsible for increasing floods tendency.[10] Change of climate variables leads to the probability of existing concrete deterioration due to reinforced concrete structures subjected to carbonation or chlorides induced corrosion resulting from elevated CO_2 levels and temperature. Cracking and spalling of

concrete are the common damages which are visible. [11, 12] Deterioration significantly changes the long term performance of concrete structures and deterioration rate also relies on the climatic environment during its serviceability apart from its dependent on material compositions and construction process.[13, 14] It has been predicted that environmental CO_2 concentration will be about 1000 ppm by the year 2100.[15] Furthermore, with the increase of sea surface temperature, the wind speed over sea surface is also increasing. These fluctuations in the wind speed patterns will have an impact on the design criteria used in the construction of high rise buildings considering the wind speed design code. M.A.Hussain et al. 2012 has predicted the increase in the average wind speed pattern due to changes in global climate as in the vicinity of Karachi which is located at the coast of Arabian Sea. Following the IPCC A1B scenario with the advance of global warming, wind speed are expected to be increasing gradually. [16]

Reinforced concrete structures are subjected to many environmental actions affecting its serviceability, performance and safety. One of the major factors that change the long-term performance of concrete structure is deterioration which not only depends on material compositions and construction process but all depends on the climate changes during its service life. [13, 14, 17]As mentioned by Bhide S, 1999 bridges on the interstate system of US are structurally deficient or functionally obsolete due in part to corrosion. Hence, understanding the mechanism of corrosion becomes a compulsion for the service life of reinforced concrete structure. The time to corrosion initiation is influenced by the time variant nature of humidity and temperature. [11] Therefore, many evidences indicate the influence of weather conditions in the chloride ingress. Since studies on climate changes due to the influence of global warming are predicted, adoption of measures to control and mitigate its impact on the serviceability and durability of structures becomes a need to face a substantial and unanticipated threats.

Currently, no doubt human activities are already having a measurable impact on global climate. However, there is large overall uncertainty about how much and up to what extends global warming can affect and hamper the serviceability of reinforced concrete and tall building structures. However, with the increasing trend of climate changes, it becomes a compulsion to study the condition of existing RC structures and revised the design criteria as many tremendous bridges, skyscrapers and other huge structures have been built.

2. PERSPECTIVE AND CONSEQUENCES

The paper provides a review on the researches so far performed studying the impact of climate changes especially global warming scenarios on the deterioration of existing reinforced concrete structures, code of design criteria of RC structures and tall building structures affecting its durability,

serviceability and structural safety adopting various modelling and approach (realistic as well as static)

A review on the researches of probable and realistic consequences like deterioration of the RC structure due to chloride ingress and carbonation and other uncertain parameter related to concrete properties and model are considered by appropriate probability distribution as random variables and the effect on high rise structures with the change in wind speed.

2.1. Carbonation and chloride ingress

Penetration of chloride and carbonation in RC structures are governed by diffusion coefficients depending on the surrounding humidity and temperature. For this purpose, a linear time-variant function is used to model the change of temperature and humidity caused by global warming. This repercussion is also further illustrated with numerical examples based on the limit state of bending using a cumulative distribution function of the time to failure and the effect of three types of weather models: constant, time and stochastic are used to study the influence of climate change under several environmental conditions. [12]

$$\bar{\Phi}(t) = \Phi_0 + \left(\frac{\Phi_{t_a} - \Phi_0}{t_a}\right) t \text{ ------------   ------------ (1)}$$

ф represents the weather parameter (temperature or humidity) which is a function of time t. Eq. (1) shows the annual mean value of ф for a period of analysis t_a=100 years where Φ_0 and Φ_a are the values of the annual means of temperature or humidity at the initial analysis i.e. t=0 year and t= t_a year respectively. Here, humidity and temperature variations in a year are divided into two seasons: hot and cold for temperature and wet and dry for humidity.

To normalise the duration of the cold or dry season, R (normalised duration) with respect to time (t) is given as:

$$R(t) = R_0 + \left(\frac{R_{t_a} - R_0}{t_a}\right) [t] / t_a \text{ ----------------------- (2)}$$

Where, [t] represents the floor function. Thereby, simulating the seasonal variation ф linearly (Eq. (1)), the seasonal mean of ф for hot or wet seasons is:

$$\bar{k}(t) = \bar{\Phi}(t) + \frac{\Phi_{max} - \Phi_{min}}{2} \sin\left(\frac{t-[t]}{1-R(t)}\pi\right) \text{ ---------- (3)}$$

For cold or dry seasons, the seasonal mean ф is:

$$\bar{k}(t) = \bar{\Phi}(t) - \frac{\Phi_{max} - \Phi_{min}}{2} \sin\left(\frac{t-[t]}{1-R(t)}\pi\right) \text{ -------- (4)}$$

ф $_{max}$ and ф $_{min}$ are the maximum and minimum values obtained during time t = 1 year.

A model to represent a realistic temperature and humidity variables, Karhuenen-Loève expansion is considered to be appropriate.

$$k(t,\Theta) \simeq \bar{k}(t) + \sum_{i=1}^{n_{kl}} \sqrt{\lambda_i}\, \xi_i(\Theta) f_i(t) \text{ ------------ (5)}$$

$k(t, \Theta)$ is a random process which is a function of time, t and defined over the domain **D** with Θ with respect to random events **Ω**. $\bar{k}$ is the mean of the process (Eq.(3) and Eq.(4)). Here, temperature and humidity are assumed to have exponential covariance since closed –form solutions for $f_i(t)$ i.e. a complete set of deterministic orthogonal functions] and λ_i i.e. eigen values of the covariance function C (t_1, t_2) are to be obtained.[18]

A realisation of the stochastic process in comparison with time-variant mean which highlight that stochastic process follows similar path with that of time-variant mean.[11,12] Nevertheless, its consequence with reference to exposure time has to be included in which further real exposure conditions are also observed which is considered to contribute higher damage due to corrosion. Based on the model for assessment of Greenhouse gas Induced Climate Change (A1 scenarios and subcategories) prediction, atmospheric CO_2 concentrations for various global warming scenario from 1990 which are to be used in determining the durability assessment of reinforced concrete structures are shown in Table I(a) &(b). [19] From this it was concluded that considering risks, cost, benefits and environmental impact, an optimal adaptation strategy is necessary. [12]

Table I (a) For A1F1 scenario:

Year	CO2 concentration range approx (ppm)		
	Low	Mid	High
2000	360	360	360
2020	400	420	440
2040	480	520	540
2060	620	660	680
2080	800	840	880
2100	920	1000	1060

Table I (b) For A1B

Year	CO2 concentration range (ppm)(approx)		
	Low	Mid	High
2000	360	360	360
2020	400	420	440
2040	460	480	500
2060	500	540	560
2080	640	680	720
2100	660	720	760

A probabilistic and reliability based approach describing probability of corrosion initiation, corrosion damage which leads to loss of reinforcement of an RC structure resulting from higher temperature and CO_2 concentration was also performed.[15] In this approach too, as an anthropogenic aspect of climate change, the climate scenarios prediction based on the Model for Assessment of Greenhouse-gas Induced Climate Change, known as MAGICC is used especially A1 scenario and its sub-categories which is given in

Table II(a) & (b). The approximate carbonation depth due to the average CO_2 concentration over the time period and not the peak time is calculated as follows: [20,21]

$$x_c \approx \sqrt{\frac{2 f_T(t) D_{CO_2}(t)}{a}}\, k_{urban} \int_{2000}^{t} C_{CO_2}(t)\,dt \text{ X } \left(\frac{1}{t-1999}\right)^{n_m} \text{ (6)}$$

where, t ≥ 2000, x_c (in cm) is the carbonation depth, $f_T(t)$ is the effect of temperature at time t, $D_{CO_2}(t)$ is CO_2 diffusion coefficient in concrete, $C_{CO_2}(t)$ is the time-dependent mass concentration of ambient, n_m is age factor for microclimate conditions, k_{urban} is a factor depending upon the CO_2 concentrations in urban environment.

Time to corrosion initiation occurs when carbonation fronts equals concrete cover. Corrosion rate increases with increase in temperature and carbonation- induced corrosion rate is calculated based on the model described by DuraCrete, 2000 in which it has a close correlation with Arrhenius equation for temperature below 20^0C but conservative for T(t) > 20^0C.

$$i_{corr}(t) = i_{corr-20}[1 + K(T(t) - 20] \text{ --------- (7)}$$

Where $i_{corr-20}$ is the corrosion rate at 20^0C; K= 0.025 if T(t) < 20^0C and K = 0.073 if T(t) >20^0 C.

Fick's second law of diffusion describe the penetration of chlorides though its assumption are different with chloride penetration process and field condition [22] and calculation of chloride concentration at depth x mm at time t is based on model proposed by DuraCrete, 2000.[23]

$$C(x,t)= C_o\left[1 - \operatorname{erf}\left(\frac{x}{2\sqrt{k_e.k_t k_c f_T(t) D_c \left(\frac{t_0}{t-1999}\right)^n .(t-1999)}}\right)\right] \text{ ----(8)}$$

Where k_e is the environment factor, k_t is the test method factor (1.0), k_c is the curing factor (1.0), $f_T(t)$ is the temperature effect on diffusion co-efficient, D_c is the apparent chloride diffusion coefficient, t_0 is the reference time in years(28 days or 0.0767 years) and n is the aging factor. Also time dependent corrosion loss of reinforcement (i.e. reduction in diameter in mm) is calculated as

$$\Delta d(t) = 2 \text{ x } 0.0116 \int_{T_i}^{t} i_{corr}(t)\,dt \text{ ---------------- (9)}$$

where i_{corr} is given by Eq.(7)

Reinforced concrete structures placed in marine environments are exposed to chlorides all the time. [12] Nonetheless, higher temperature and humidity accelerate chloride ingress reducing corrosion initiation time. However, for tropical environment global warming induced reductions in mean time to failure is lesser as compared to that of oceanic environment. Therefore, global warming has more influence in environments where humidity and temperature are characterised by important seasonal variation in which global warming can either reduce the time to failure upto 31% or shorten the service life by upto 15 years for moderate levels of aggressiveness.

Taking 100 years as reference period possible scenarios of global warming can be taken under consideration which is as follows: [12]

- If there is no global warming, climate changes and its effect can be neglected.
- If global warming is expected with use of alternative and fossils sources of energy and pattern is continued thereafter, change in the temperature(ΔT) will be about 2.5^{0}C along with change in relative humidity(Δh) and normalised cold duration(ΔR) of 0.05 and -10% respectively.
- If vast utilisation of fossil sources of energy with increase in rate of population growth happens then ΔT will be about 6.5^{0}C along with Δh = 0.1 and ΔR = -20%.

A long- term periodic water contact with concrete surface, concrete inside buildings with moderate-to-high air humidity and external concrete protected from rain are prone to have higher carbonation as compared to concrete inside buildings with low air humidity or those which are permanently submerged in water. Hence, structure exposed to splash and tide in maritime condition have a significant risk of corrosion due to chloride induced than those of structure exposed to airborne salt but not directly in contact with sea water. [15] Nevertheless, it is also shown that deterioration model selection will have significantly less influence on comparative risks as different models will produce different estimates of absolute risk. It also indicates that chloride induced corrosion is most sensitive to increase in atmospheric CO_2 and a significant extent of corrosion damage which leads to costly and disruptive repairs of concrete structures will occur affecting the structure's service life.

2.2 Variation in wind speed

Winds are sensitive to natural as well as anthropogenic variability in climate [24]. Due to this it reveals variation of wind velocity in some places. [25]

For the assessment of impact of the global climate change on urban wind speed pattern, a linear trend model (Eq.10) is given in which 50 years wind speed (m/s) data divided into two sets of 25 years is used in which to test statistically significance trend Mann- Kend trend tests are also applied. [26] Probability distribution to describe the long term urban average monthly wind speed pattern is given correlating with the Weibull and Rayleigh Distribution Functions of wind speed and Weibull parameter estimation shown by F.A.L.Jowder, 2006 and H. Basumatary et al. 2005 respectively.

$$y(t) = \alpha t + \beta \qquad \text{------------------ (10)}$$

where, $\alpha = \frac{\sum y_i \sum t_i^2 - \sum t_i \sum t_i y_i}{n \sum t_i^2 - (\sum t_i)^2}$ $\beta = \frac{n \sum y_i t_i - \sum t_i \sum y_i}{n \sum t_i^2 - (\sum t_i)^2}$

t_i represents years in wind data series and y_i is monthly wind speed

Changes in wind speed pattern are seen indicating the effect of global warming on wind velocity. In a place where no high rise buildings is there in the data collection area that in summer season the rate of increase of wind speed is almost higher than the rate of increase of wind speed in winter season indicating a positive trend. Even though, presently urban wind speed data cannot predict specific events for some types of extremes it will be of importance to have knowledge of urban climate change in future. [26] Depending on land surface and topographical condition, wind speed differs in which highest annual wind speed is found in mountain and coastal regions. Changes of surface winds due to global warming will be greatest during 2001-2046 in which the wind speeds in 2046 and 2099 are expected to exceed the wind speed in 2001 based on the average wind speed data in Central Japan. [26] Based on the up–to-date prediction, it can also be expected that the changes in wind pattern due to global warming will give an adverse effect on the wind speed design criteria which were used in designing and building of the existing high rise building structures.

3. CONCLUSION

This paper gives a review for an assessment to some of the discovery and invention done by many researches giving probabilistic, reliable prediction and results that shows the adverse effect of global warming direct or indirectly through carbonation, chloride ingress causing corrosion as well as fluctuation in the wind speed patterns. From various facts, predictions and results, it is an important concern to adopt some strategies or measures to counter all the consequences from the effect of global warming considering its risks, costs, benefits and environment impact. Some adaptation strategies that can be mentioned: concrete surface treatments, re-alkalization, increase concrete durability, replace existing cover with new concrete, etc. [12]

A framework for further research with an aim to include those adverse changes that may happen in the design criteria used in the construction of reinforced concrete and high rise building structures due to climates changes and global warming are illustrated and encourage to assess optimal level of adaptation measures both now and for future.

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