# STATE OF THE ART ASSESSMENT OF 800 NON ENGINEERED AND ENGINEERED BUILDINGS IN MUMBAI

## CORROSION DAMAGE & RESIDUAL LIFE

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# INTRODUCTION

In last two decades, Mumbai city witnessed major collapses of RC buildings. Mumbai experiences heavy rainfall and saline climate. Scientific and statistical interpretation of structural health assessments of 800 old buildings in Suburbs viz Thane and Ulhasnagar, where frequent building collapses during monsoons has become common, is dealt in this paper.

The assessments took six years and the relationship with respect to age and damages was monitored. Degree of corrosion and carbonation was related to loss of section & load carrying capacity, so that it helps the engineering community and city planners to deal with these structures to improve their performance, make directives for their safety/stability, safeguard life in these buildings and take appropriate steps to rehabilitate & build sustainable future.

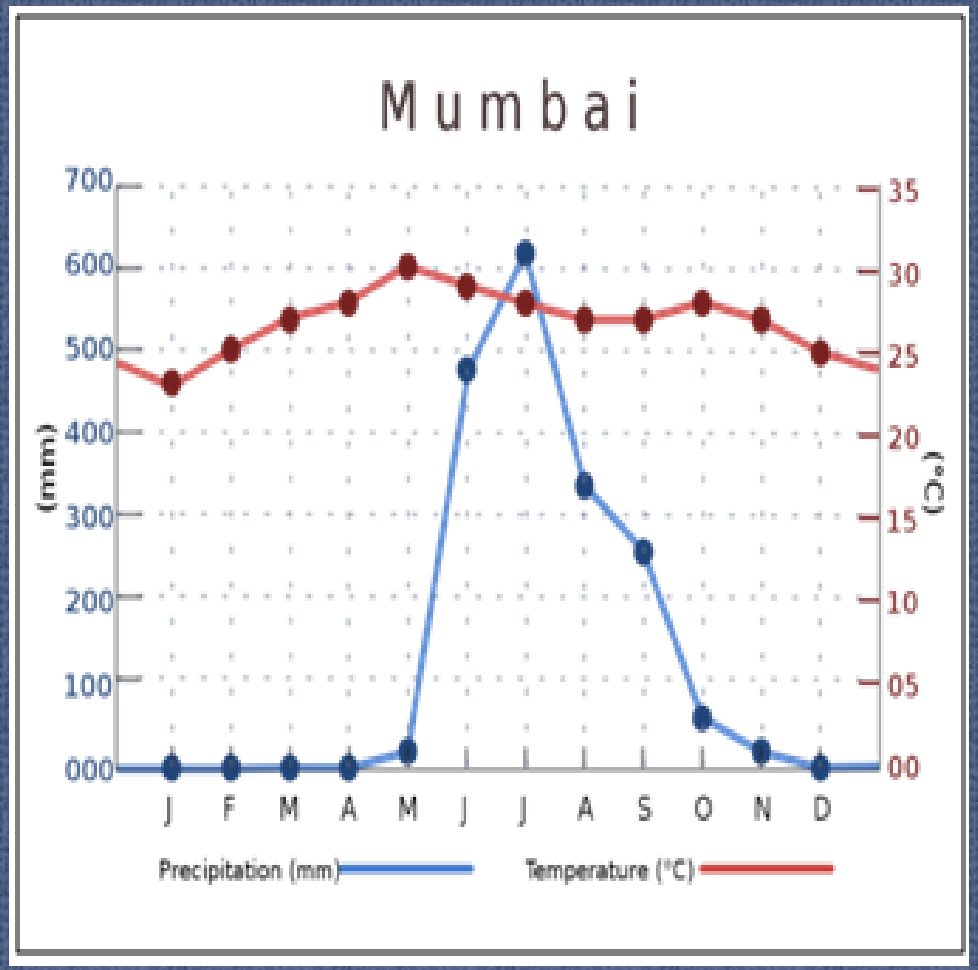
NDT & NDE observations are corroborated with visual condition assessment. A scientific and statistical interpretation of the data has been done with the objective to estimate the residual life of the building structures.

# INTRODUCTION Contd..(1)

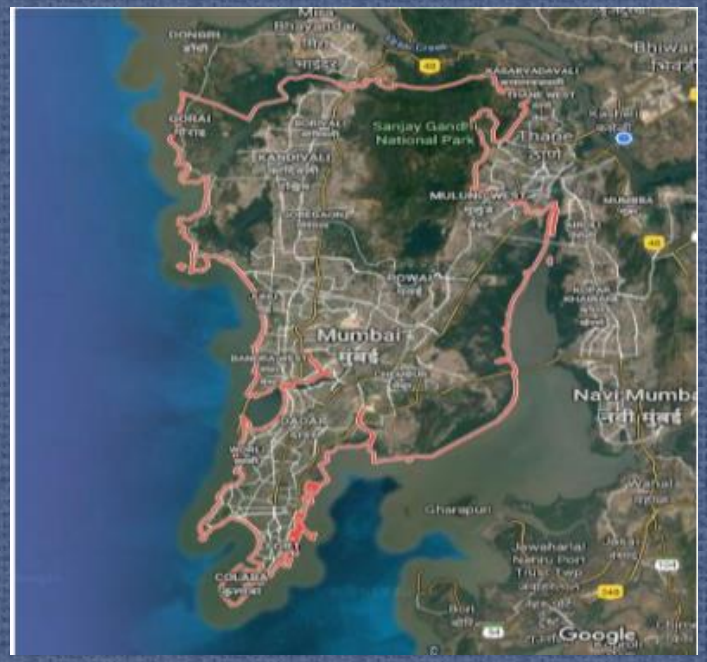
We live in an urban century, where more than 50% of the global population lives in urban areas. The United Nations estimates that by 2030, five out of eight billion of the world's population will live in urban areas.

Mumbai has a tropical climate. The rainy season falls in June to September for four months, known as Monsoon season.. Mumbai experiences extreme saline climate and almost 100% humidity during rainy season with the average of 68% throughout the year.

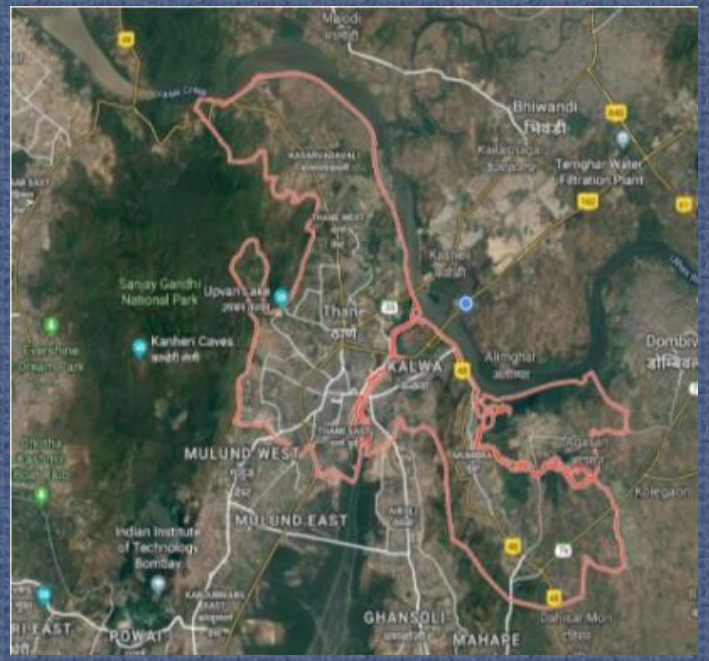
Thane and Ulhasnagar cities, near Mumbai form Western side coastal part of India.



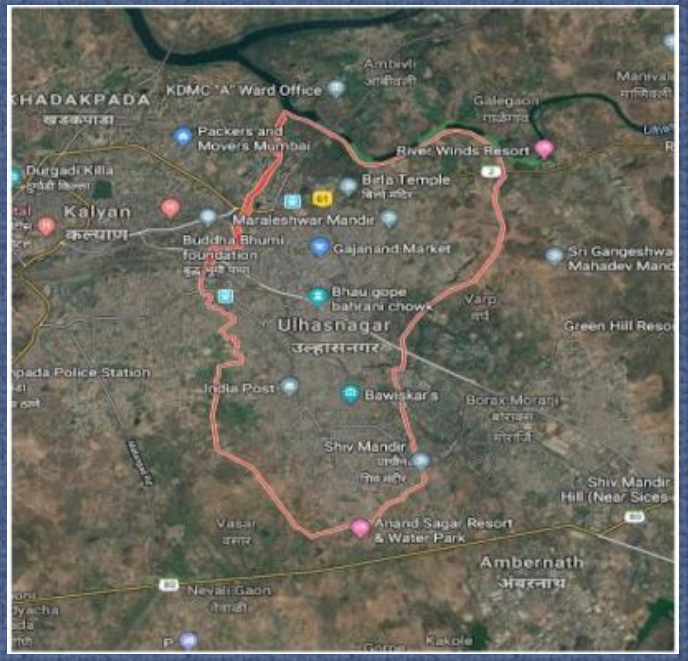
# Cities on Google Earth




Mumbai
800 year old City




Thane
800 year old City




Ulhasnagar
Post independence
development

# INTRODUCTION Contd..2

The 800-year historic Suburb Thane City with a population of 18.5M is distributed over a 147 square kilometer. It is the 16th most populated city in India (2011 Census). Evidently it is heavily populated city on the coast.

According to civic records nearly 20% of the Thane city's population is residing in structurally unsafe buildings, which have been declared as dilapidated structures by the authorities. Moreover, these buildings are unauthorized and occupied at risk of fatalities, which may arise due to structural failures, earthquakes and fire hazards. In the last two decades more than 162 fatalities and 120 injuries have been caused due to incidences related to such dilapidated buildings. When we look at the scene, a small city like Ulhasnagar is comparatively of recent origin, has around 10,000 buildings with almost 95 percent of these buildings constructed are non-engineered buildings. 864 buildings of these have been declared as dilapidated by the civic body. *(Courtesy : P.R.O. TMC and UMC).*

| City | Population | Dangerous Buildings |
|---|---|---|
| Thane | 2.6 M | 2624 |
| Ulhasnagar | 0.6 M | 834 |

# INTRODUCTION Contd..3

As mentioned earlier there is a large inventory of non-engineered and semi-engineered structures in and around Mumbai, Thane & Ulhasnagar. These structures come for repairs, restoration as well as, collapses at regular intervals. This not only results into the loss of property and invaluable life of ignorant and gullible occupants. The process happens year after year.

This is an effort on large sample of 800 structures to assess the present engineering status with help of non destructive testing and evaluation. This data is considered as a pre-requisite to look at the model to enhance the residual life of structures in the India/world which face similar weather conditions and quality of construction, and safeguard valuable property & more precious life at large.

# Methodology Adopted

**DATA -** Sample Size – 800 Buildings

Sample Type – Low Rise as well as High Rise up to 9 storey
RC Framed as well as Load Bearing Structures
Combination of Both

Year of Construction of the Sample - 1900 - 2007

Period of Inspection - 2013 to 2019

**Methodology -**

Structural Health Assessment - behavior with respect to age and damages was monitored including NDT & NDE.

Representation data for 800 buildings on worksheets

Typical representation data for 800 buildings (sample worksheet).

| Sr No | Job No/ Location | Name | Year of Construction | Age at Test Date | Type of Structure | Carbonation Depth (mm) | USPV (km/s) | Potential (-mV) |
|---|---|---|---|---|---|---|---|---|
| 1 | Thane | Abc | 1978 | 35 | RCC | 31 | 2.5 | -275 |
| 2 | Ulhasnagar | Xyz | 1980 | 37 | LB | 18 | 2.6 | -250 |

# Methodology Adopted ..Contd.(1)

In order to ascertain the level of distress, damages, arrive at appropriate conclusions and derive recommendations, the conventional structural health assessment (referred as “structural audit” in India) is carried out by adopting sequential procedure.

Study architectural & structural drawings. Design criteria & Design calculations considered

Prepare As Built Drawings (ISSN 2278-3652)

Visual Inspection  (ISSN 2278-3652)

Non Destructive & Partial Destructive Testing.

Pushover Analysis

Conclusions & Recommendations

# Methodology Adopted (contd..2)

The audited buildings were categorized based on the conclusions and recommendations arrived in each individual case and categorized as below..

Categorization of Buildings as per the Assessment Reports.

| Sr No | City/ location | Building Category as Concluded in Reports | | | |
|---|---|---|---|---|---|
| | | C1 | C2 | C3 | Total |
| 1 | Thane/Mumbai | 88 | 288 | 259 | 635 |
| 2 | Ulhasnagar | 10 | 075 | 080 | 165 |
| 3 | Total | 98 | 261 | 258 | 800 |

Note C1 – Structure to be raised down,
C2 – Structure to be repaired &
C3 – Structure is satisfactory & maintenances required

The results of 800 buildings were plotted graphically for two different places Thane (TNA) 635 Nos and Ulhasnagar (UNR) 165 Nos.

The NDT & NDE data of all buildings is analyzed to evaluate every individual case.

# Methodology Adopted (contd..3)

The interpretations are presented in statistical form and results are plotted by segregating the buildings according to their age as on the day of testing.

The Sample of 800 Buildings was further clustered as per age, the period (in decades) of construction.

The results of individual structures becomes part of the data of decade it belongs.
The NDT results are plotted for parameters as below

1. Age of buildings versus Carbonation Depth (mm)
2. Age of buildings versus Ultrasonic Pulse Velocity(UPV)
3. Age of buildings versus Half Cell Potential (-mV)

At outset, for 800 buildings - More than..

28000 Nos UPV readings
12000 Nos Half Cell Potentials readings, and
12000 Nos Carbonation depth readings,

had been recorded & interpreted on-site visually & analyzed graphically as well.

# Methodology Adopted (contd..4)

The NDT results of TNA region are divided into time period calculated from the year of construction and day of testing.

These periods include buildings

existed before1958, 1959-1969, 1969-1979 , 1979-1989, 1989-1999 and1999-2019.

Similarly, UNR region is divided into 2 time period based on year of construction from 1970-1990 and 1990-2019.

The NDT results for the buildings existed in both the cities are plotted for carbonation, corrosion and UPV with respect to age of building (at the time of NDT testing). These comparisons are plotted separately for each decade from 1959 to 2019. Further, for the global interpretation all these parameters are plotted independently for both cities over the 60 year period

The Factor of Safety for the individual members of the typical buildings are calculated based on the geometry of the building, visual inspection (damages and loss of section), NDT results, core testing, design load and actual load.

# Methodology Adopted (contd..5)

Typical work sheet for calculating factors of safety from push over analysis results.

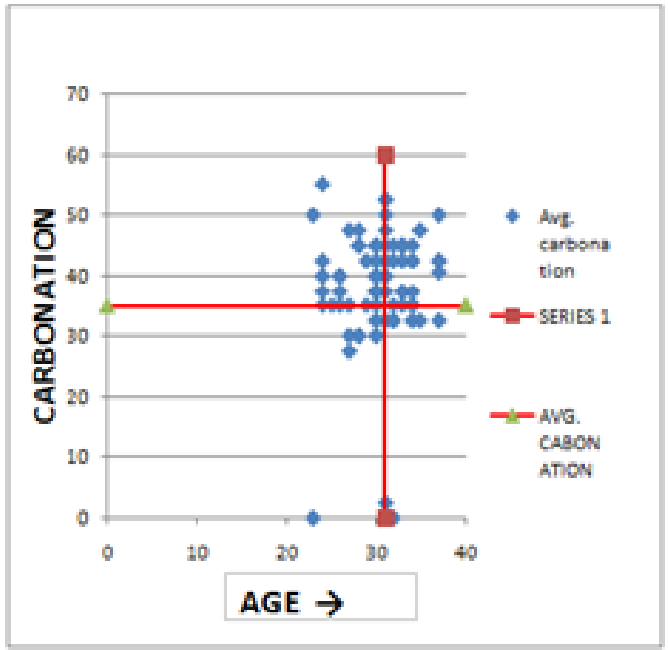
| Sr No | Member ID | Concrete Section | | Reinforcement | | Actual load kN or kNm | Section capacity | | Factor of Safety | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Design $cm^2$ | Effective $cm^2$ | Design $mm^2$ | Effective $mm^2$ | | Design kN or KNm | Actual kN or kNm | | |
| 1 | Column | 1035 | 555 | 904 | 452 | 35 | 86.7 | 45.6 | 1.3 | Limiting Condition |
| 2 | Beam | 1380 | 840 | 405 | 203 | 13.6 | 34 | 22.66 | 0.66 | Unsafe |
| 3 | Slab | 1500 | 1250 | 156 | 78 | 6.5 | 15.75 | 10.5 | 0.67 | Unsafe |

Concrete load carrying capacity for compression member $p = (\sigma cc * Ac) + (\sigma sc * Asc)$ (IS 456-2010)

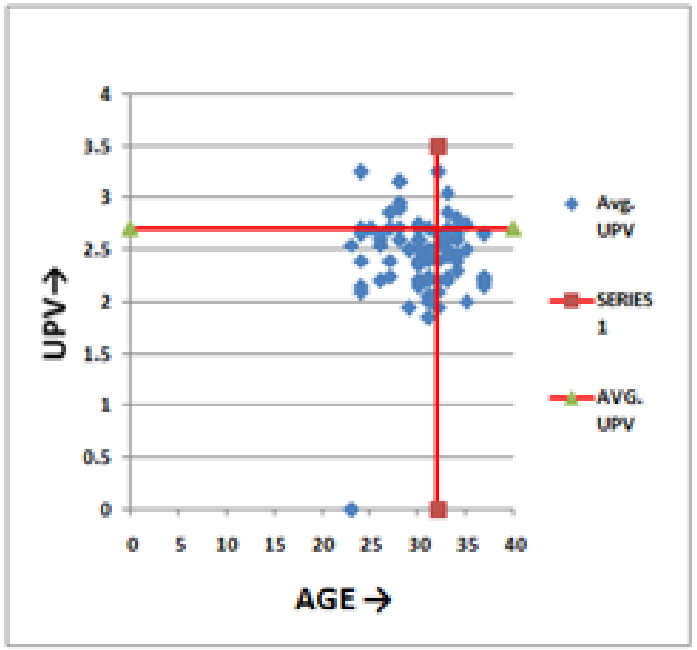
Concrete load carrying capacity for flexure member $Ast = M/(\sigma st * Z)$ (IS 456-2010)

# Result & Interpretation

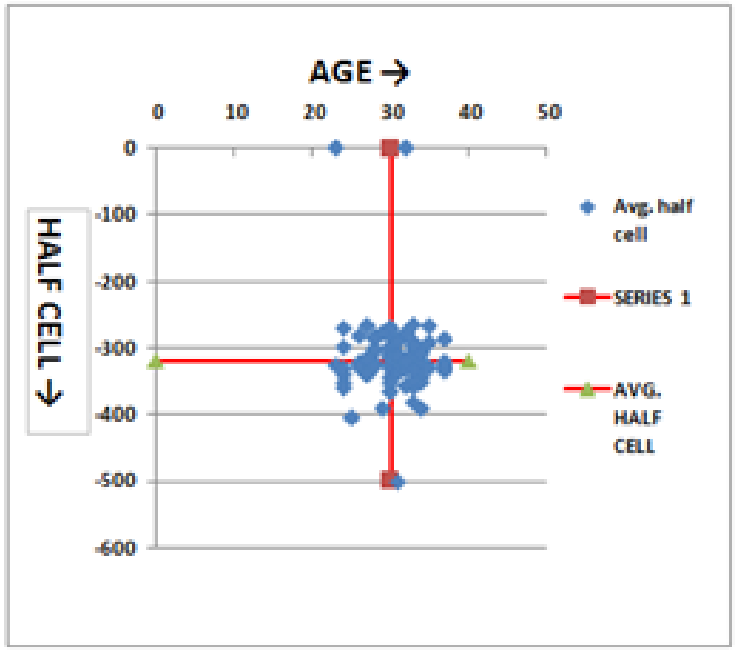
The interpretation of NDT results for Thane & Ulhasnagar Cities are plotted in decade wise with respect to the age & test parameters . A typical graphical representation can be seen below..




Carbonation (1979-1989)



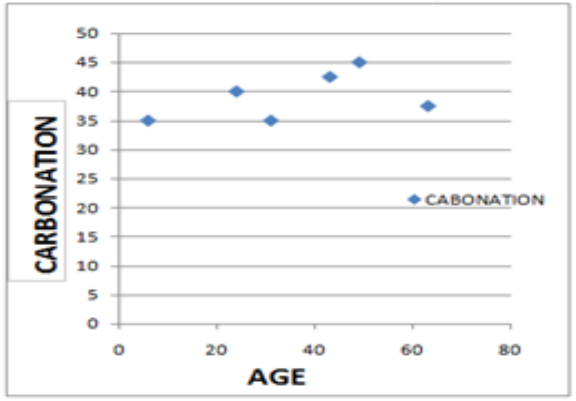

UPV(1979-1989)



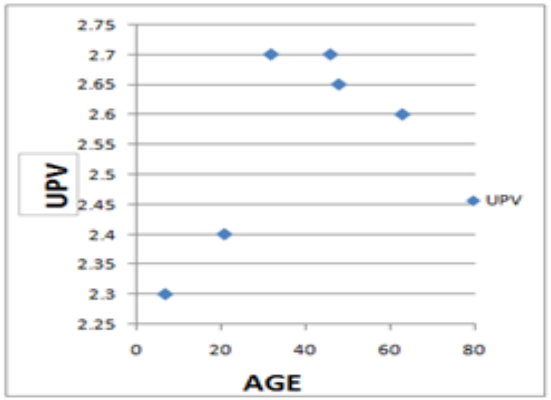

Corrosion (1979-1989)

# Result & Interpretation ..contd (1)

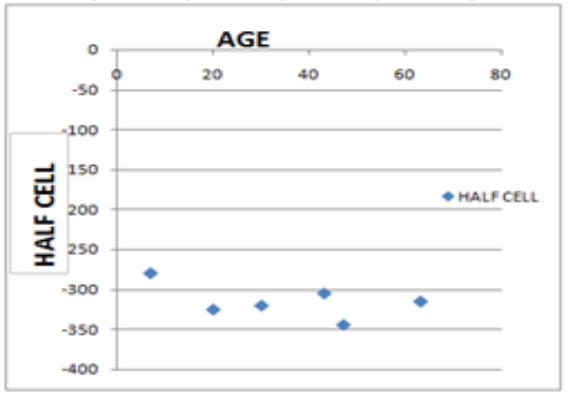
Average on Overall Period – Thane City




Carbonation (Avg.)

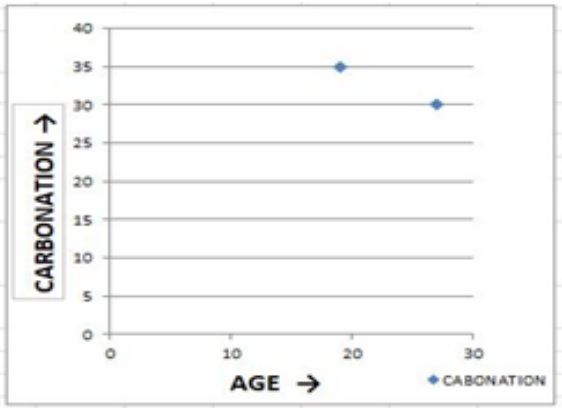



UPV(Avg.)

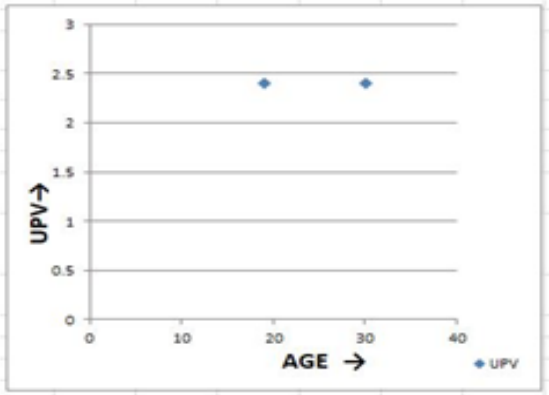



Corrosion (Avg.)

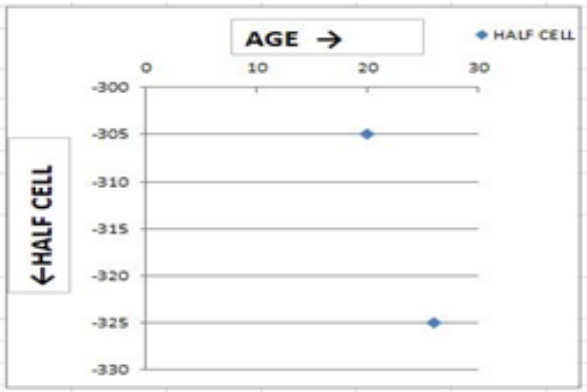
Average on Overall Period – Ulhasnagar City




Carbonation (Avg)



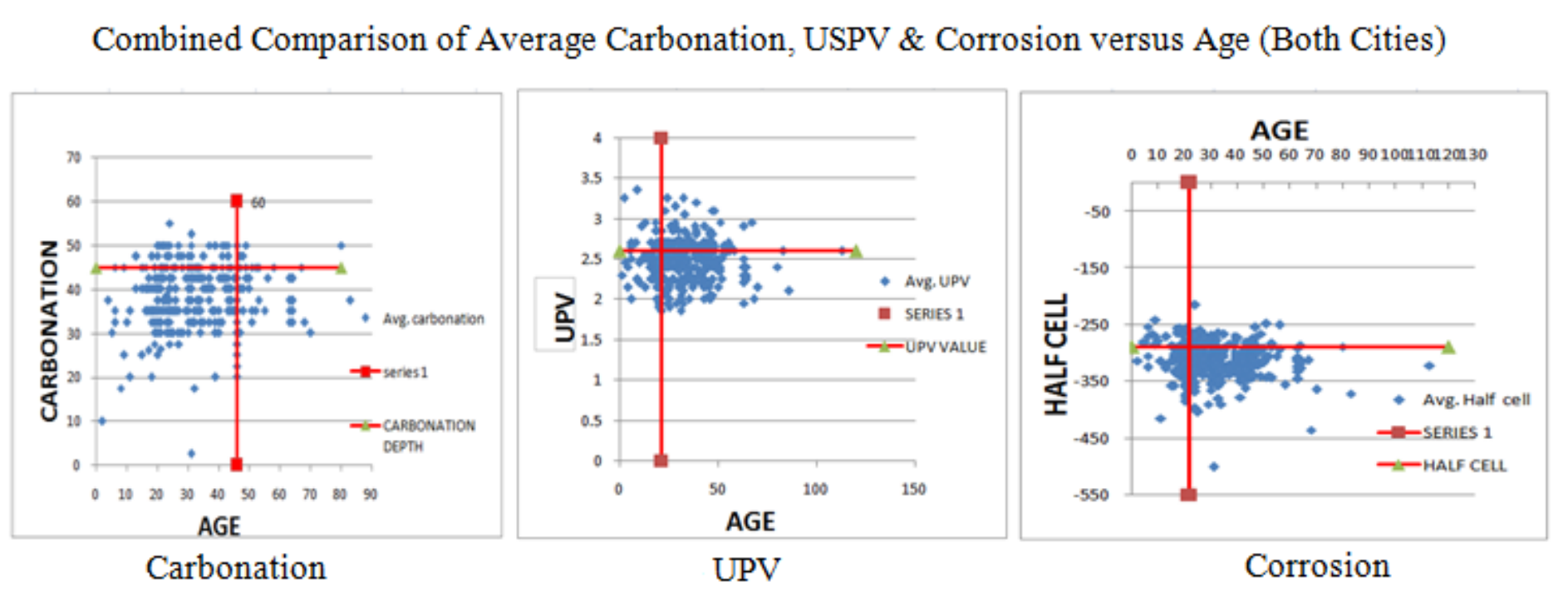

UPV (Avg)




Corrosion (Avg)

# Result & Interpretation .Contd (2)

In addition to above independent interpretation of NDT results, a combined analysis to study the effect of damage, corrosion, carbonation, environmental effects, type of exposure and use with respect to age of the buildings are presented in *Tabular as well as graphical form.*



# Result & Interpretation .Contd (3)

Combined Comparison of Average Carbonation, USPV & Corrosion versus Age (Both Cities)

| Sr No | City | Year of Construction | Carbonation Depth mm V/s age | | USPV km/s V/s Age | | Half Cell Potential -mV V/s Age | |
|---|---|---|---|---|---|---|---|---|
| | | | mm | years | km/s | Years | -mV | years |
| 1 | Thane (TNA) | 1999-2019 | 35.0 | 06 | 2.25 | 06 | 282 | 06 |
| 2 | | 1989-99 | 40.0 | 24 | 2.40 | 21 | 325 | 20 |
| 3 | | 1979-89 | 35.0 | 31 | 2.70 | 32 | 320 | 30 |
| 4 | | 1969-79 | 42.5 | 43 | 2.70 | 46 | 305 | 43 |
| 5 | | 1959-69 | 45.0 | 49 | 2.65 | 48 | 344 | 47 |
| 6 | | before 1959 | 37.5 | 63 | 2.60 | 63 | 315 | 63 |
| 7 | | All Decades | 35.0 | 22 | 2.70 | 43 | 349 | 41 |
| 8 | Ulhasnagar (UNR) | 1970-90 | 30.0 | 27 | 2.40 | 30 | 325 | 26 |
| 9 | | 1990-2019 | 35.0 | 19 | 2.40 | 19 | 305 | 20 |
| 10 | | All Decades | 32.5 | 23 | 2.40 | 24 | 315 | 23 |
| 11 | Both Cities | All Decades | 46.0 | 45 | 2.60 | 21 | 290 | 22 |

# Result & Interpretation .Contd (4)

Based on the above observations, it can be seen for

**Thane City (635 Buildings) -**

Maximum **carbonation** is seen to be initiated from 22 years of age, for the buildings constructed in period of 1989-2019.

The rate of carbonation is estimated in the range of 1-1.25 mm/yr for buildings constructed before 1989.

Whereas, it is seen to be increased to 1.5 – 2.0 mm/yr for the buildings constructed in period of 1989-2019.

The average rate of carbonation for all buildings estimated is 1.59 mm/yr.

The **half-cell potentials** in range of -282 to -349 mV are indicative of probability of corrosion varied from 50-90% in last 4 decades.

The average UPV is recorded below 3.0 km/s for all buildings tested.

# Result & Interpretation .Contd (5)

**For Ulhasnagar City –**

Maximum **carbonation** is seen to be initiated from 15 years of age, for the buildings constructed in period of 1990-2019.

Rate of carbonation is estimated to be 1.1 mm/yr for buildings constructed before 1990. whereas, it is seen to be increased to 1.8 mm/yr for the buildings constructed in period of 1990-2019.

**The average rate of carbonation for all buildings estimated is 1.45 mm/yr.**

The half-cell potentials varied from -305 to -325 mV, which are indicative of probability of corrosion varied from 50-90% in last 4 decades.

The average UPV is recorded below 3.0 km/s for all buildings tested.

***It can be seen that there is loss of effective cross section of concrete as well as rebar, due to carbonation and corrosion. The push over analysis showed, substantial reduction in factor of safety of the structures in individual cases and age groups considered.***

# Conclusions

The methodology was adopted to assess level of damage & corrosion with respect to age of the structure from the available scientific as well as statistical data in each individual case & groups.

From overall observations, analysis & interpretation, in this case study of 800 buildings, where more than 90% of the buildings assessed are non-engineered buildings it can be concluded that, the buildings constructed before 22 years of age (before 1997 in Thane City) and before 15 years of age (before 2004 in Ulhasnagar City), have performed better than those constructed thereafter, respectively. The Buildings constructed thereafter, in these Cities, were observed to show severe deterioration & damages, due to precipitation, chloride action, non-engineering and bad concrete practices, as result of socio-economic reasons. Further, structural additions & alterations, have also resulted in failure of major structures in this región.

# Conclusions …contd..(1)

The range of years where the design life appears to cease is where the residual life of the buildings begins. Though a critical task, but a well versed expert can have a hand on it.

It is apparent, that the buildings with age 22 years and above in Thane city & with age 15 and above in Ulhasnagar city, are strongly recommended for structural health assessments followed by appropriate strengthening measures..

The above approach is a precursor to establish a model to enhance the residual life of several non-engineered/semi-engineered structures, resulting into prevention of loss of property and life.

# CREDITS

**Building Users of all 800 buildings..**

**Thane Municipal Corporation**

**Ulhasnagar Municipal Corporation**

**Prof. V. B. Deshmukh**

**Dr. S. K. Manjrekar**

**Dr. Pedro Castro Borges**

**India Chapter of ACI and AC I**

# Thank you..

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