SDMC Training Programme

# Retrofitting Techniques of Existing Buildings

## Reinforced Concrete Structures


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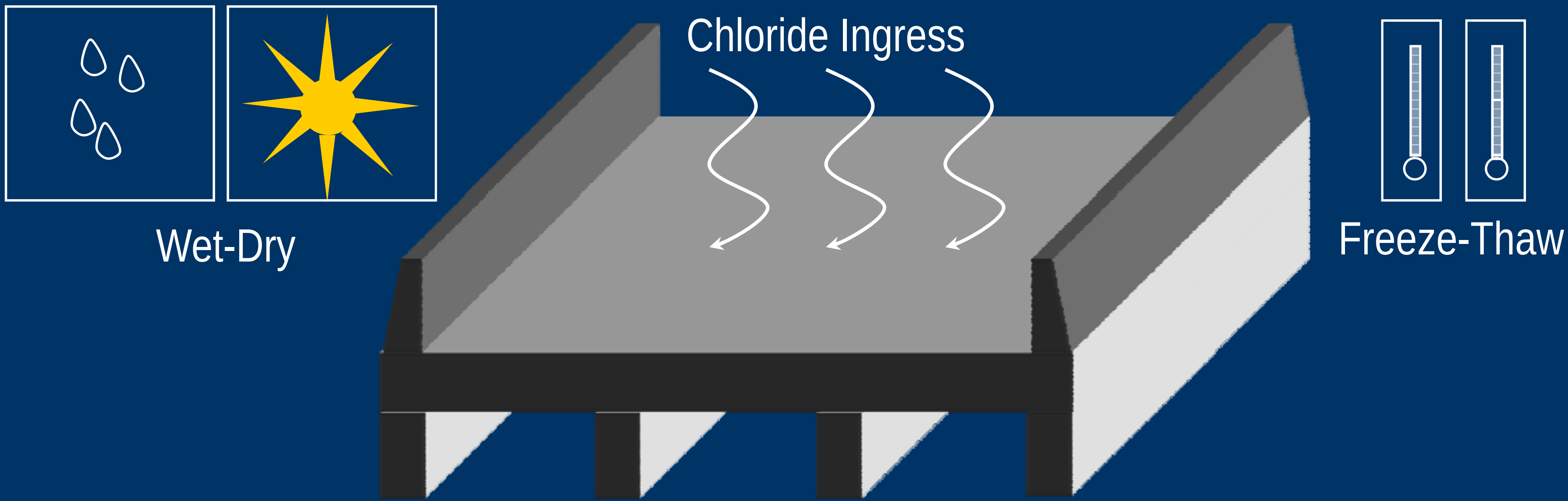
# INTRODUCTION

- Concrete is one of the most widely used construction material in the world.
- Concrete is the third largest consumed material after air & water.
- Construction Industry contributes to 20 % of the country's GDP.

# DISTRESS OF EXISTING STRUCTURES



- Deficiencies due to:

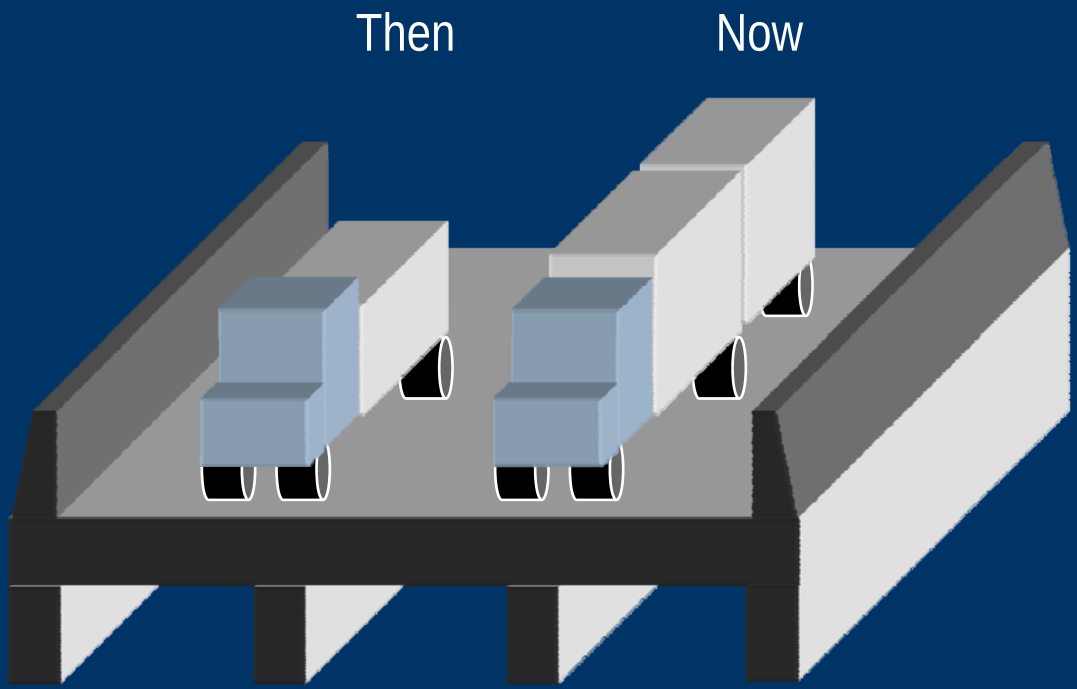



❶*Environmental Effects*

# DISTRESS OF EXISTING STRUCTURES



- Deficiencies due to:



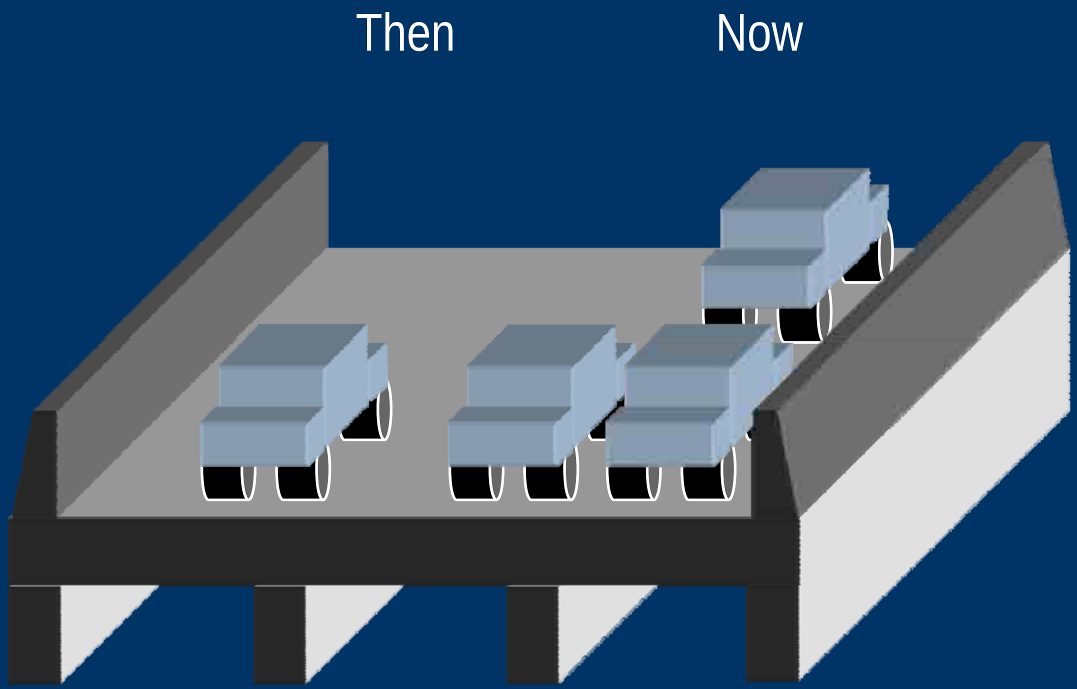

❷ *Updated Design Loads*

❸ *Updated design code procedures*

# DISTRESS OF EXISTING STRUCTURES



- Deficiencies due to:




❹*Increase in Traffic Loads*

# EVALUATION OF EXISTING STRUCTURES



- Evaluation is important to:
  - Determine concrete condition
  - Identify the cause of the deficiency
  - Establish the current load capacity
  - Evaluate the feasibility of strengthening

# EVALUATION OF EXISTING STRUCTURES

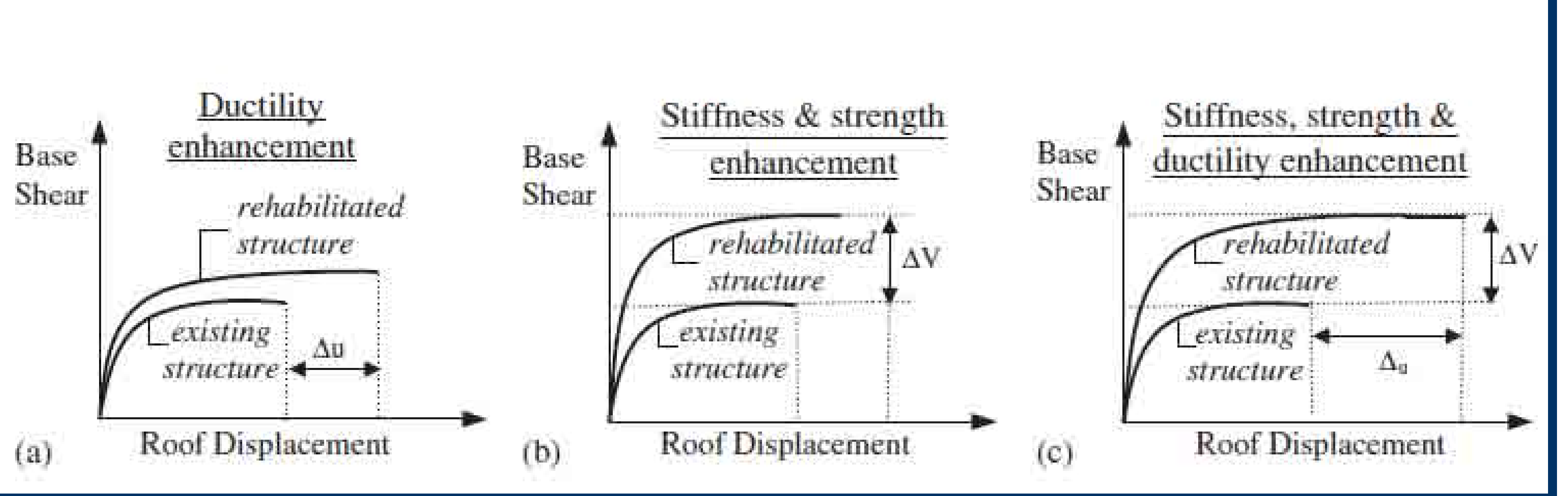


- Evaluation should include:
  - All past modifications
  - Actual size of elements
  - Actual material properties
  - Location, size and cause of cracks, spalling
  - Location, extent of corrosion
  - Quantity, location of rebar

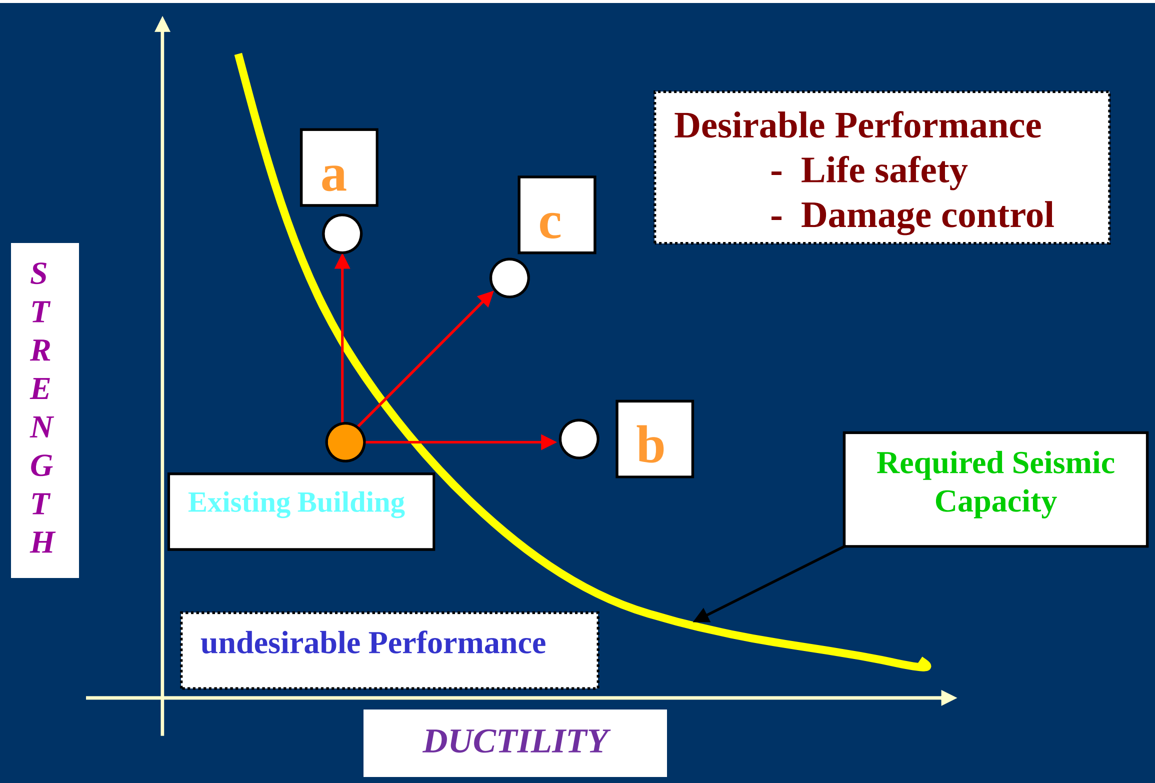
# REMEDIAL ENGINEERING

- **REPAIRS** — visual or cosmetic modifications
- **REHABILITATION** — rebuilding of cracked walls, stitching of cracks, grouting, placement of reinforcement etc. - such that the original performance of the building are restored,
- **RETROFITTING** — structural modifications such as jacketing, addition of shear walls, bracing etc., - higher performance of the building is achieved than that of original structure.
- **CONSERVATION**

# VIRTUES OF RETROFIT STRATEGIES



# CONCEPT OF RETROFIT




a. to increase the ultimate strength of overall structure, ***RC wall, Steel Framed Brace***

b. to improve the deformation capacity, i.e. ductility, ***Jacketting with steel section or RC***

c. combination of (a) and (b)

# VARIOUS METHODS

- Portland Cement Mortars
- Polymer Modified Cement Mortars
- Epoxy Mortars
- Dry Pack and Epoxy Bonded Dry Pack
- Pre-placed Aggretage Concrete (PAC)
- Shotcrete
- Concrete Replacement
- Epoxy Bonded Concrete
- Polymer Concrete System
- Strengthening concrete by Surface impregnation using Vacuum Methods
- Thin Polymer Overlays

# VARIOUS METHODS

- Resin/Polymer modified Cement Slurry injection
- Protective Seal Coats on the Entire Surface
- Ferro – cement
- Plate bonding
- RCC Jacketing
- Propping and Supporting
- Fibre Wrap Technique
- Foundation Rehabilitation Methods
- Chemical and Electro-chemical Methods of Repair
- Active systems (Prestressing)

# EPOXY RESIN & CEMENT GROUT INJECTION

# SHEAR WALL

- Most commonly employed approach to seismic upgrading
- Increasing both building strength and stiffness
- Economical and tends to be readily compatible with most existing concrete structures

*Comments*

- Large number of shear walls are added to a building, can result in a significant increase in building mass and therefore increase seismic forces and strength requirement
- Result in significant architectural impact
- Produces large overturning forces at their base
- Requires supplemental foundation work, which is expensive

# CAST-IN-PLACE INFILL WALLS

# BRACED FRAMES

- Another method of enhancing building's stiffness & strength (comparatively lower level than do shear wall)
- Adds far less mass to the structure
- can be constructed with less disruption of the building

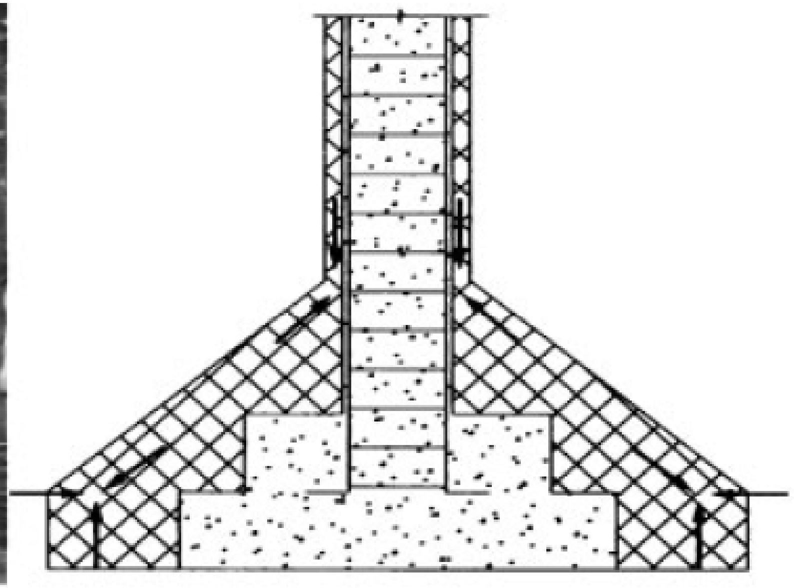
*Comments*

- Difficult to effectively attach braced frames to concrete building because large forces must be transferred between the structure and the braced frame

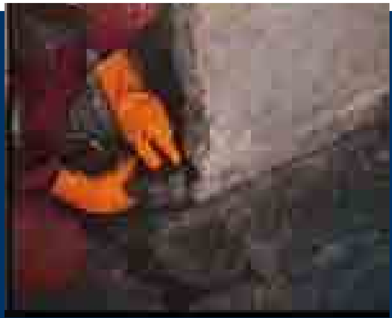
# RC COLUMN JACKETING

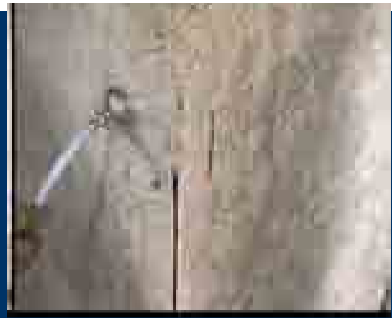
# STEEL PLATE / ANGLE JACKETING

# STRENGTHENING OF FOOTING – RC JACKETING



# FIBER REINFORCED PLASTIC WRAPPING


Grinding Process


Grouting


Putty Application


Primer Application


Saturant Application

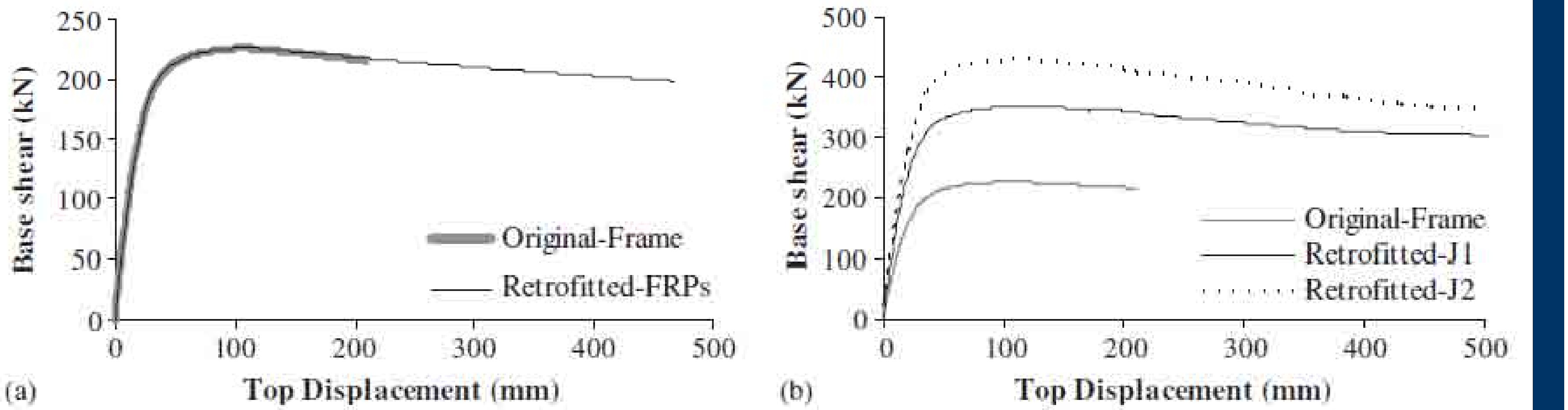

Superwrap Application


Second Saturant Coat


Bonding Agent


Plastering

# DUCTILITY ENHANCEMENT




FRP JACKETS ` RC JACKETS

# EFFECT OF RETROFIT ON LOCAL & GLOBAL RESPONSE

| Methods | Deficiency Type | Local Effect | Global Efffect |
|---|---|---|---|
| **Injection of Crack** | Shear or Shear-flexural crack | Flexural strength & stiffness restoration. Shear Strength is regained in concrete to concrete joints | Repair Method –No modification of the response of the original structure |
| **Shotcrete (Gunite)** | Extensive crack patterns at concrete members or masonry, converting non-structural to structural walls | Reinstatement of the Original characteristic s of the elements for repair, increase in force demands if applied as a retrofitting option | Minimum effect when applied as a repair method if layer is very thick & with wire mesh only. complete change of response when applied otherwise. |
| **Steel Jacketing – plate adhesion** | Insufficient shear strength & ductility due to old type of detailing (sparse confinement reinforcement insufficient lap splicing) | Jacketing: Deformation capacity is increased Plate adhesion: Shear & flexural strength enhancement | Deformation capacity is enhanced .Strength capacity may be increased or remain the same depending on the effect of the retrofit scheme at the local level. |

# EFFECT OF RETROFIT ON LOCAL & GLOBAL RESPONSE

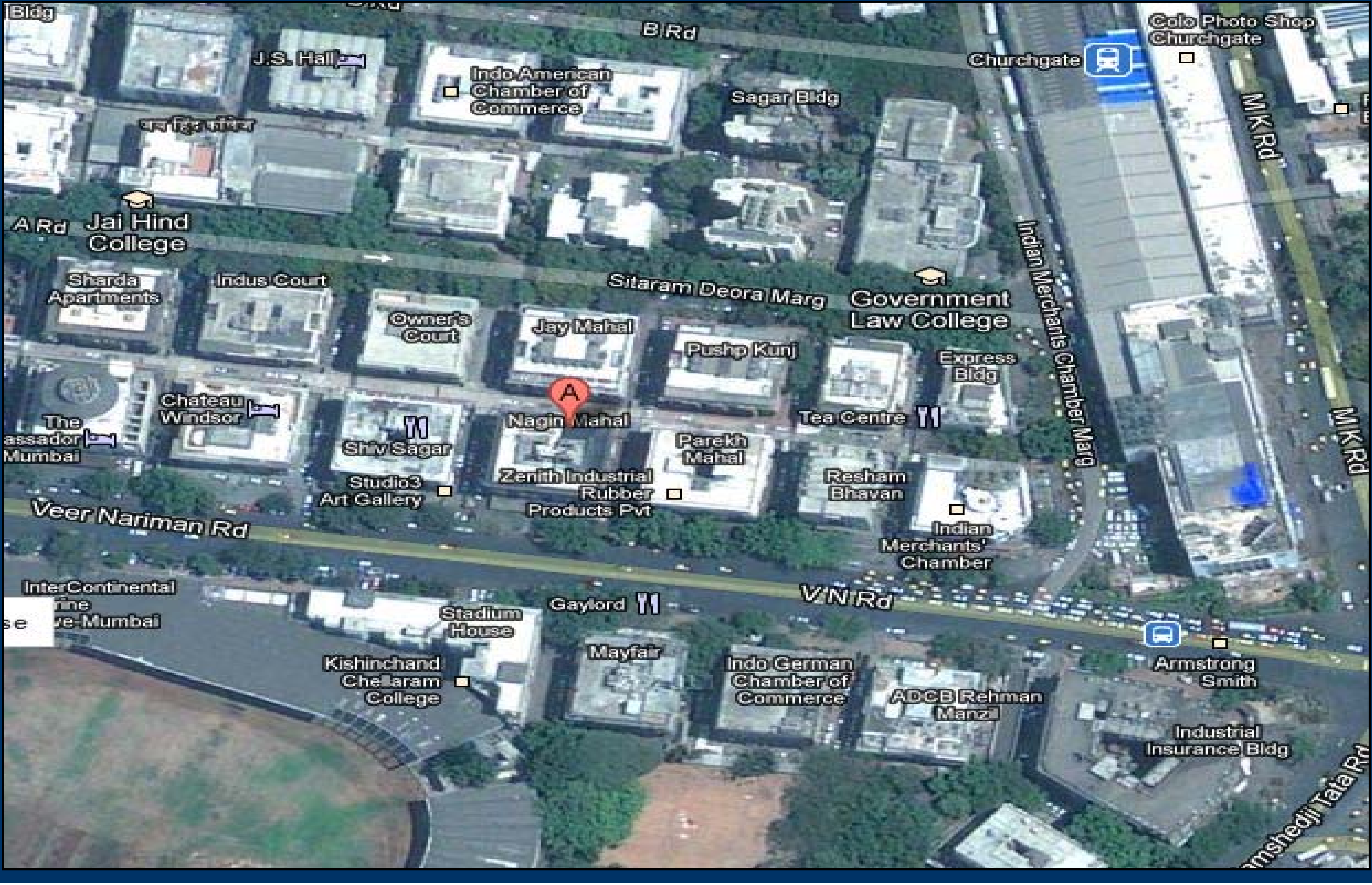
| Methods | Deficiency Type | Local Effect | Global Efffect |
|---|---|---|---|
| **FRP jacketing** | Insufficient shear strength & ductility due to old type of detailing (sparse confinement reinforcement insufficient lap splicing) | Columns: Deformation capacity is enhanced . Beams: Shear & flexural Strengthening Beam- Columns joints: shear failure is eliminated in connection | Ductility & shear strength at structural level are improved |
| **Selective Intervention Methods** | The damage pattern Varies depending on the deficient parameter | Increase of stiffness,strength or ductility | Structural response can be tuned to met the performance objectives |
| **RC Jacketing** | Insufficient lateral Strength, Insufficient deformation capacity & stiffness discontinuity between successive floors. | If the jacket is applied at floor level, both axial & shear strength of the column are improved, while flexural strength & strength of the beam – column joints remain the same. | If the jacket Continues between successive Floors,stiffness,strength & ductility are enhanced. |

# EFFECT OF RETROFIT ON LOCAL & GLOBAL RESPONSE

| Methods | Deficiency Type | Local Effect | Global Efffect |
|---|---|---|---|
| **Addition of the walls or external buttresses** | Insufficient lateral stiffness & strength ,torsionally unbalanced structure | Deformation demand at the member level is decreased, while strength demand may be increased. High demand at connection between existing structure & walls or buttresses is generated | Global lateral drifts are controlled . Considerable strengths & stiffness are added to the existing structural system. Resulting system is totally different from the original structure requiring full reassessment |
| **Steel Bracing** | Insufficient lateral Stiffness & strength | High Level of force may be introduced at the brace ends & Connection between brace members & existing structure | Lateral Stiffness & Strength of the existing structure are increased. Additional energy dissipation is provided. |
| **Base Isolation** | Rehabilitation of critical or essential facilities | The seismic impact on structural & non-structural components is reduced | The seismic energy is absorbed by isolation devices inserted at the bottom or at the top of the first floor column. |

# CASE STUDIES

# BUILDING IN COASTAL REGION



# NAGIN MAHAL

# ISSUE

- Certain portion of the slab had collapsed due to heavy corrosion.
- Heavy leakages were observed from the terrace slab.
- Beams and columns were also corroded.
- However this was limited to terrace slab only.

# CHALLENGE

- No structural drawings or details were available
- Certain portion of the slab had collapsed due to heavy corrosion. We had to ensure that the remaining portion was restored keeping in mind the safety of the building and the occupants and also the road traffic as the structure is on a main road

# PARTLY COLLAPSED SLAB

# DAMAGED SLAB

# DAMAGED COLUMN

# ANALYSIS

- From the roof beam and slab plan provided, the most critical and largest panel was chosen for reanalysis as there were no structural drawings or details available.
- Slab thickness is 100 mm as reported. (This was derived by drilling through the slab at several locations)
- The reinforcement was not known but from the soffit with exposed reinforcement, it was found to be Mild Steel FE250 of 10 dia. at 150 c/c.
- Slab is 5.02 mtr x 4.31 mtr clear and the Lx = 4.61 (Assuming 300 mm bearing) and Ly = 5.32 mtr. This is assumed to be a s/s beam and no corner reinforcement is provided (Table used is Table 27 of IS456 -2000)

# ANALYSIS

- Loads considered are: Terrace floor LL is 150 kg/$m^2$, Self weight of slab= 100x2.5 = 250 kg/$m^2$, Waterproofing load 150 thk avg x 2 = 300 kg/$m^2$, Total Load = 700 Kg/m2 = 7 KN/$m^2$.
- Lx/Ly= 5.32/4.61 = 1.154
- Interpolating from the table Alpha x = 0.079 and Aplha y= 0.060
- Mx = Short span moment = 0.079x 700 x 4.61^2 = 1175 kgm/mtr working = 17.63 KNm/ mtr
- My = Long span moment = 0.060x 700 x 4.61^2 = 893 kgm/mtr working = 13.4 KNm/ mtr
- Critical ultimate moment used in the slab capacity program is 17.63 KNm

# COMPARISON OF STRENGTHENING SCHEMES

| SR NO | DESCRIPTION | MOMENT CAPACITY (KN -M/MTR) | |
|---|---|---|---|
| | | BEFORE STRENGTHENING | AFTER STRENGTHENING |
| | | | |
| 1 | SLAB AS CAST | 7.06 | 7.06 |
| | | | |
| 2 | SLAB AS CAST - CORRODED REINFORCEMENT | 3.78 | 3.78 |
| | | | |
| 3 | SLAB AS CAST ONLY WRAPPING | 3.78 | 19.36 |
| | | | |
| 4 | SLAB AS CAST- ONLY DEPTH INCREASE | 3.78 | 7.21 |
| | | | |
| 5 | SLAB AS CAST - DEPTH INCREASE + WRAPPING | 3.78 | 40.04 |

Ultimate Moment for short span moment in this slab is 17.63 KN-mtr/mtr

**COMPARISON OF STRENGTHENING SCHEMES OF TYP BEAM**

| SR NO | DESCRIPTION | MOMENT CAPACITY (KN-MTR) | SHEAR CAPACITY (KN) |
|---|---|---|---|
| | | | |
| | | | |
| 1 | BEAM BEFORE STRENGTHENING | 38.42 | 66.47 |
| | | | |
| 2 | BEAM AFTER STRENGTHENING | 78.66 | 231.54 |

IN BOTH THE CALCULATIONS CANADIAN CODE FOR FIBERWRAP STRENGTHENING HAS BEEN USED
THE RESULTS SHOULD BE TAKEN AS IMPROVEMENT IN % TERMS OVER UNSTRENGTHENED AND NOT COMPARED WITH IS 456 CALCULATIONS.

# SLAB AFTER REPAIR

# GRIDING FOR FIBRE WRAPPING IN PROGRESS

# ROUNDING OF BOND-CRITICAL JUNCTIONS

# PRIMER APPLICATION IN PROGRESS

# SLAB & BEAMS AFTER STRENGTHENING

# SLAB & BEAMS AFTER STRENGTHENING

# INDUSTRIAL BUILDING : FIRE

# TEMPERATURE (° C) / CHANGE OBSERVED IN CONCRETE

| | |
|---|---|
| <300 | Boundary cracking alone |
| 250 – 300 | Aggregate colour changes from pink to red |
| 300 | Paste develops a brownish or pinkish colour |
| 300 – 500 | Serious cracking in paste |
| 400 – 450 | Portlandite converts to lime |
| 500 | Change to anisotropic state |
| 500 – 600 | Paste changes from red or purple to grey |
| 573 | Quartz gives a rapid expansion resulting from a phase change from alpha to beta quartz |
| 600 – 750 | Limestone particles become chalky white |
| 900 | Carbonates start to shrink |
| 950 – 1000 | Paste changes from grey to buff |

# STRUCTURE AFTER FIRE

# STRUCTURE AFTER FIRE

# STRUCTURE AFTER FIRE

# STRUCTURE AFTER FIRE

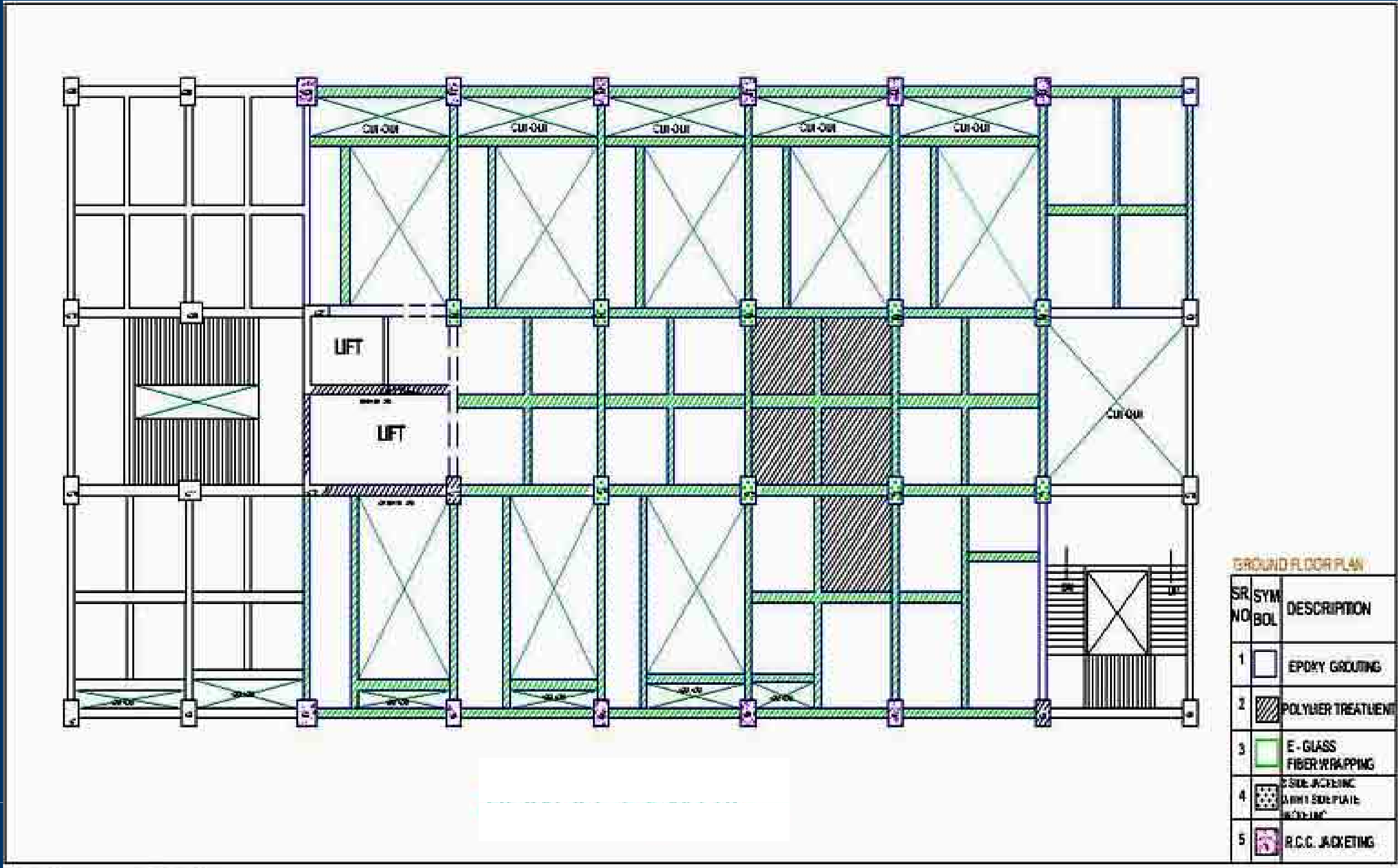
# DAMAGED RCC COLUMN

# DAMAGED R C C BEAM AND SLAB

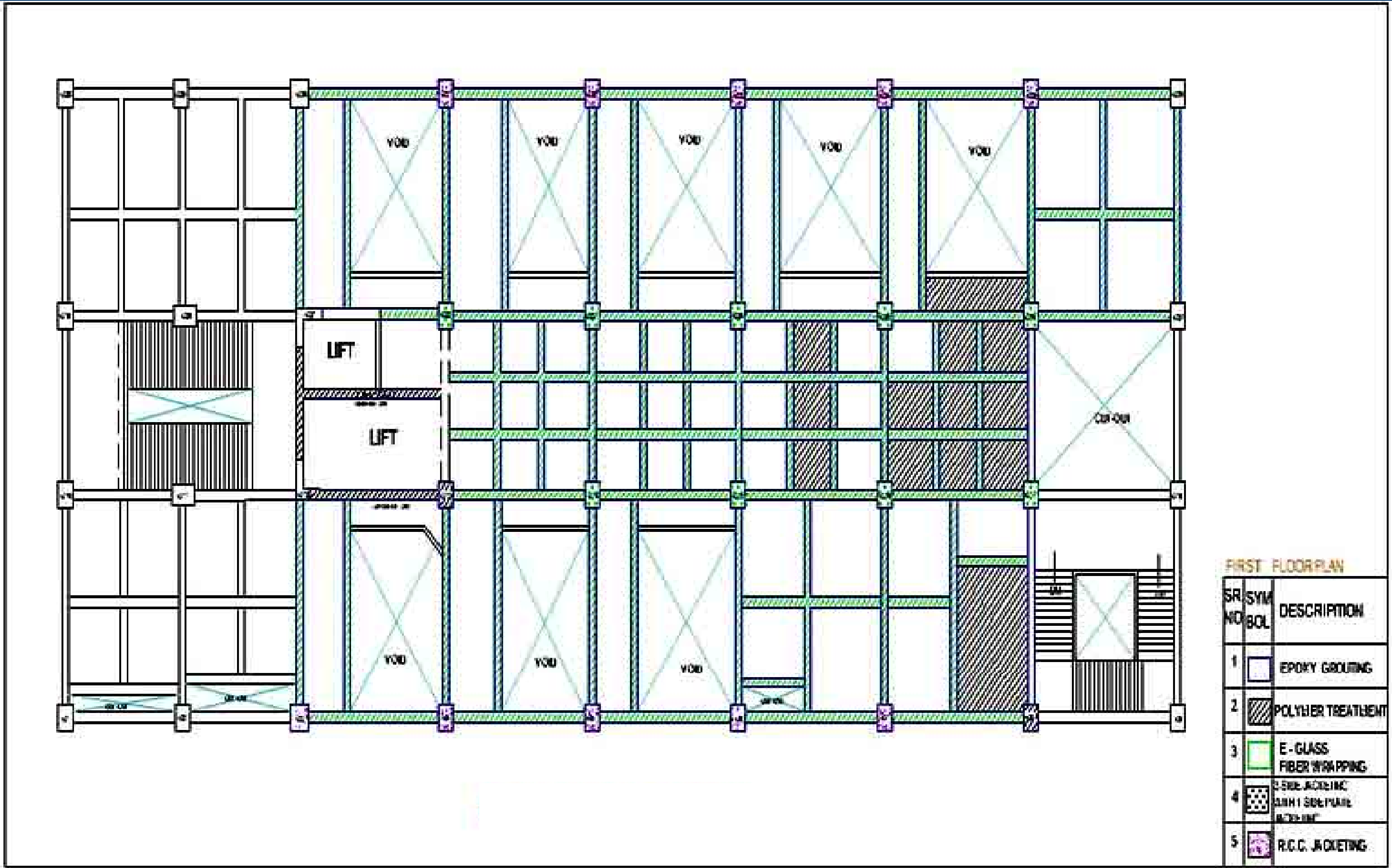
# PARTLY COLLAPSED STRUCTURE

# DEFORMED SLAB AND BEAMS

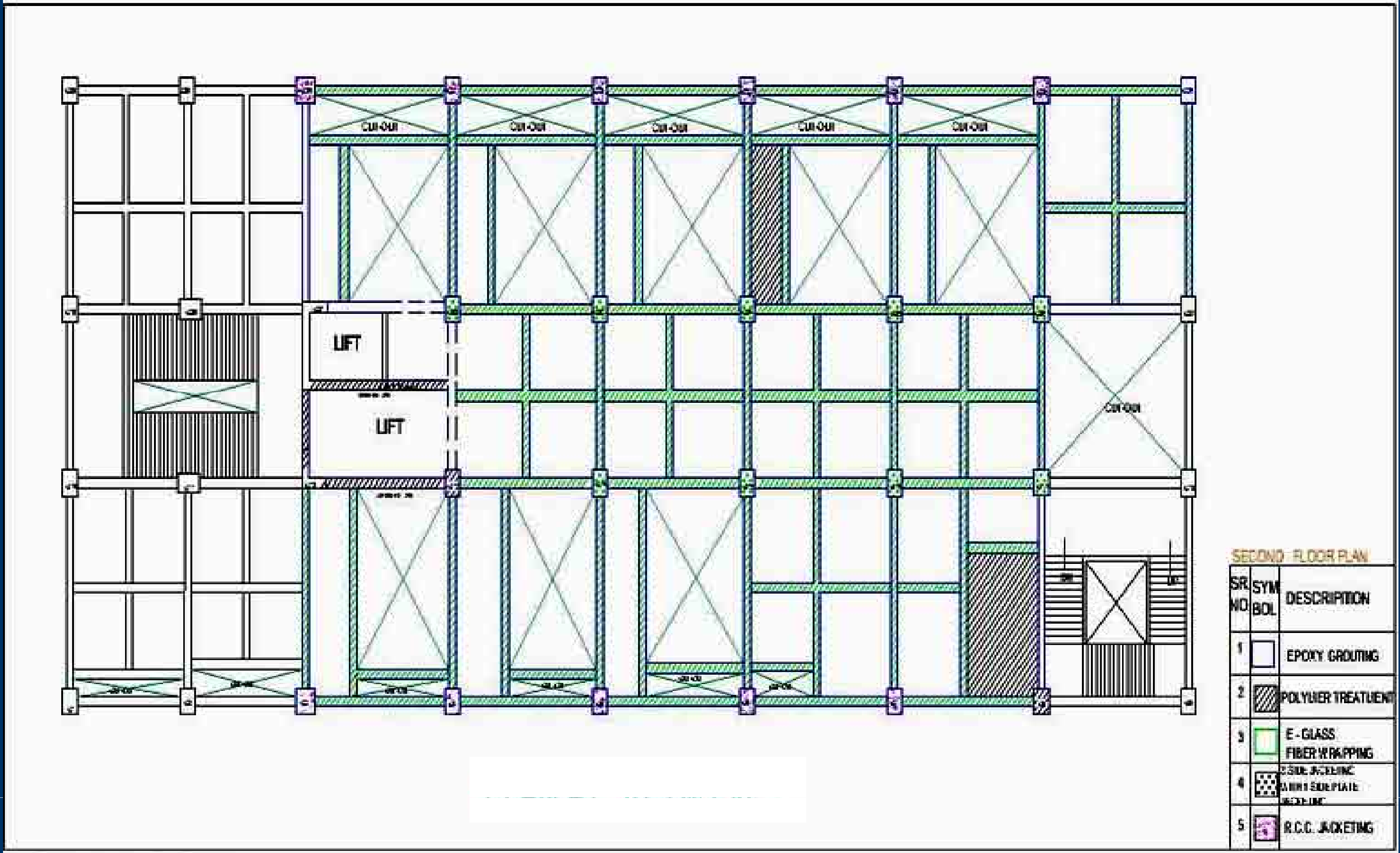
# PLAN AT 6.5 M LEVEL



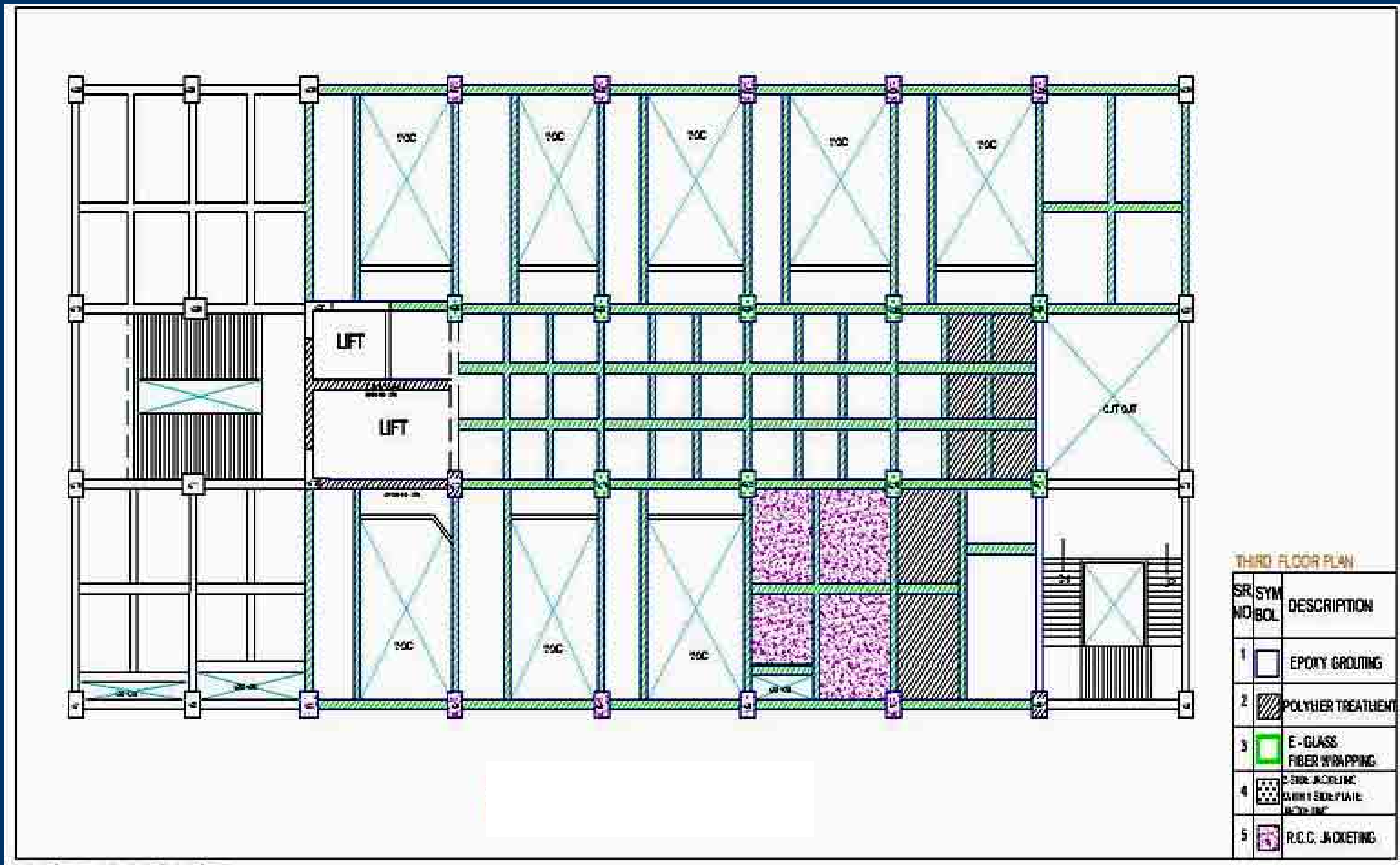
# PLAN AT 11.5 M LEVEL



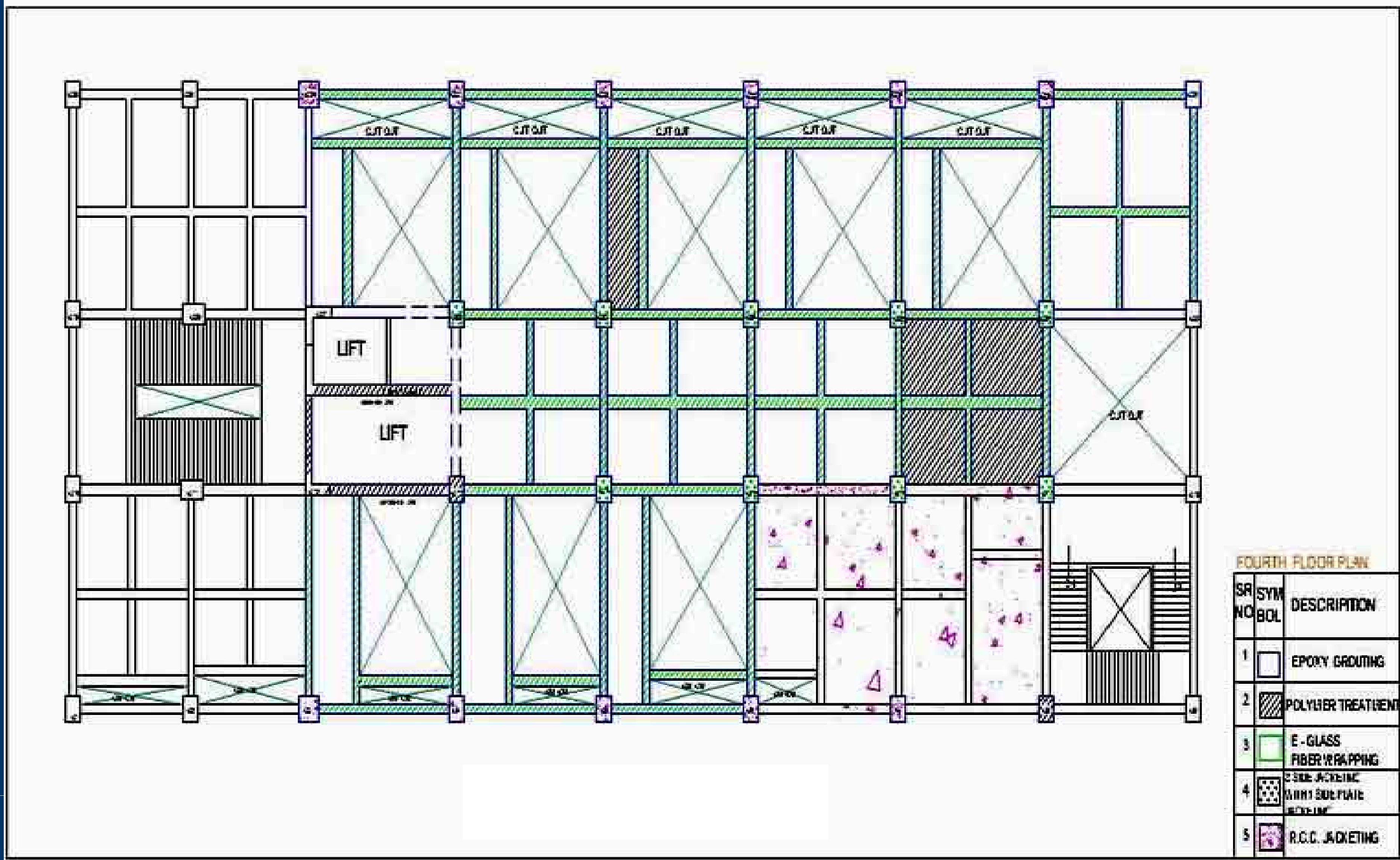
# PLAN AT 16.5 M LEVEL



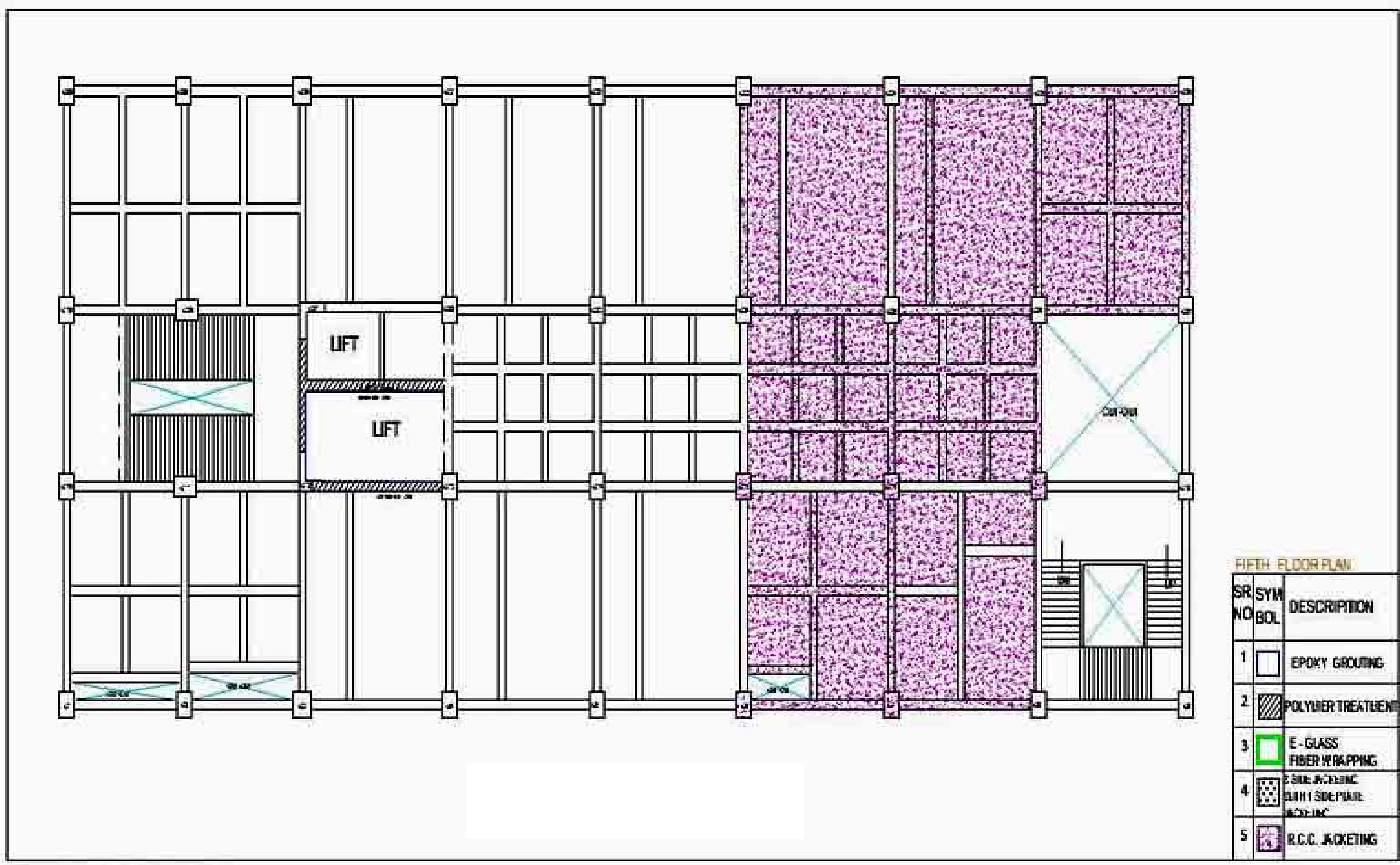
# PLAN AT 21.5 M LEVEL



# PLAN AT 26.5 M LEVEL



# PLAN AT 31.5 M LEVEL



# COLUMN JACKETING IN PROGRESS

# COLUMN AFTER JACKETING

# RE-CONSTUCTRUCTION IN PROGRESS

# STRENGTHENING OF BEAM IN PROGRESS

# PANEL – AFTER REPAIR

# BEAMS – AFTER FIBRE WRAPPING

# GROUND FLOOR – AFTER REPAIR

# GROUND FLOOR – BEFORE REPAIR

# GROUND FLOOR – AFTER REPAIR

# APPROACH & JETTY STRUCTURE

# APPROACH & JETTY STRUCTURE

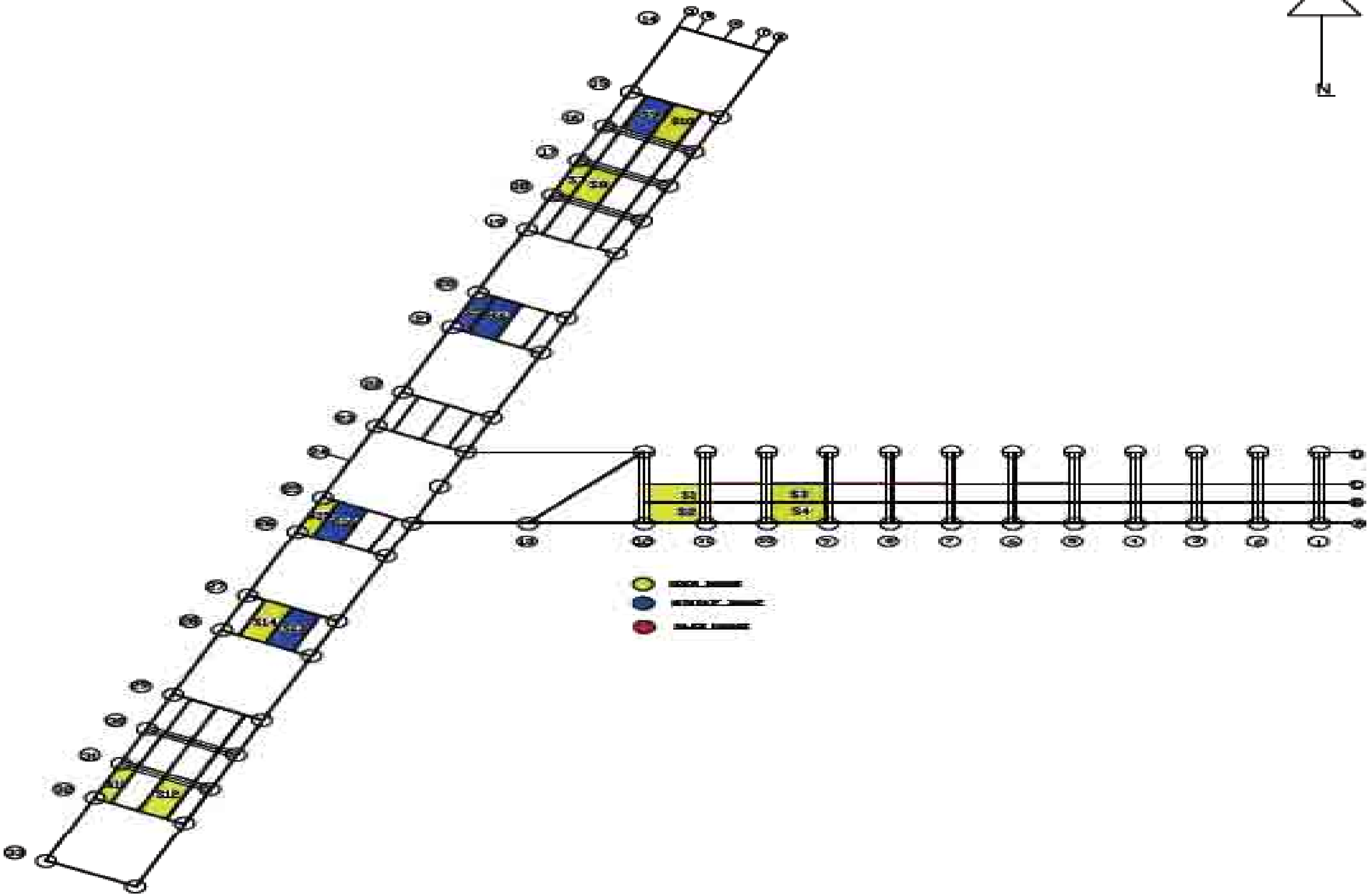
# ISSUE

- Chloride induced corrosion of steel, resulting in de-lamination of concrete and reduction in reinforcement size.

# CHALLENGE

- Due to tidal variation, the maximum duration of dry period available for work was 6 hours at a stretch. As a result all the materials were modified to set within that period and were also insensitive to moisture
- The scaffolding provided had to be suspended from the deck with anchors
- Work had to be carried out round the clock

# DAMAGE MAPPING BASED ON NDT REPORT



# SCAFFOLDING  SUSPENDED FROM DECK SLAB

# DAMAGED JUNCTURE BEAM

# DAMAGED T-BEAM

# DAMAGED CANTILEVER SLAB

# DAMAGED BEAM, SLAB AND PILE CAPS

# COMPARISION




# COMPARISION




# GROOVING OF COVER CONCRETE

# CHIPPING OF DAMAGED CONCREE SECTION

# STEEL PROTECTIVE COATING OVER EXPOSED REINFORCEMENT

# THERMAL REINFORCEMENT IN FORM OF MESH

# GROUTING WITH CORROSION INHIBITORS AND MMA GROUT

# BUILDING UP DAMAGED CONCRETE SECTION WITH MICROCONCRETE

# REPAIRED SECTION

# PATCHUP OF DAMAGED CONCRETE SECTION WITH STRUCTURAL GRADE MORTAR

# REINFORCING THE PILE BEAM WITH E-GLASS FIBRE WRAPPING

# STRENGTHENING IN FLEXURE

# STRENGTHENING IN SHEAR

# STRENGTHENED SLAB, T-BEAM, PILE BEAM & PILE CAP

# PROTECTIVE COATING IN PROGRESS

# STRUCTURE AFTER REPAIR

# STRUCTURE AFTER REPAIR

# STRUCTURE AFTER REPAIR


Thank You ...