

[www.structuralintegrity.in](http://www.structuralintegrity.in)



# **STRUCTURAL INTEGRITY**

## **ENGINEERING PVT. LTD.**

# ***PROJECTS PORTFOLIO***



info@structuralintegrity.in

+91 81435 32542/ +91 63016 00200

## **LIST OF PROJECTS**

*Project 1*

**STRUCTURAL ASSESSMENT OF RESIDENTIAL HOUSES**

*Project 2*

**CONDITION ASSESSMENT OF RESIDENTIAL HOUSES**

*Project 3*

**CONDITION ASSESSMENT OF COOLING TOWER**

*Project 4*

**CONDITION ASSESSMENT OF SEAWATER INTAKE STRUCTURE**

*Project 5*

**REPAIR OF WATER STORAGE CONCRETE TANKS**

## Project 1

# STRUCTURAL ASSESSMENT OF RESIDENTIAL HOUSES

### Project Overview

- Two-storey residential villas (about 400 in number) comprising reinforced concrete framed structure (beam-column), Hardy slab and raft foundation (see Fig. 1)
- Housing for petrochemical industries group
- Jubail, Saudi Arabia

### Problem Description

- Cracks were observed in slab, beams and columns after 3-5 years of construction.
- Cracks were mainly due to reinforcement corrosion. Some of the cracks in columns were due to structural deficiency.
- Concrete cores were retrieved from some of the columns of some of the houses and tested in compression. Some of the compressive strength results were less than the specified value of 25 MPa.
- This prompted detailed sampling, testing and structural assessment to identify the deficient columns and address their strengthening.

### Methodology Adopted

- Retrieved 75x150 mm cores from columns and beams and tested for compressive strength
- Structural assessment was carried out in accordance with ACI 562.
- Compressive strength values were used to compute equivalent compressive strength (ECS) using procedure as per ACI 562 (see Fig. 2). If the ECS was more than 25 MPa, no action was taken.
- If ECS was less than 25 MPa, structural analysis was carried out using ETABS and SAFE.
- If columns, beams or raft foundation was found to be deficient in the structural analysis, detailed strengthening procedure was provided.

### Results

- The roof slab was safe in the structural analysis.
- Some of the beams showed deficient structural capacity.
- Some of the columns showed deficient structural capacity.
- Some portions of the raft foundation showed bearing pressure more than the soil bearing capacity.

### Proposed Repair Design

- The deficient beams were proposed to be strengthened by CFRP wrapping and section enlargement. Detailed strengthening procedure was provided (see Fig. 3).
- The deficient columns were proposed to be strengthened by jacketing. Detailed jacketing procedure was provided (see Fig. 4)
- For raft areas where the bearing pressure was more than the soil bearing capacity, raft enlargement was proposed (see Fig. 5).

### Benefits

- *The proposed strengthening procedure was easy to implement and made the otherwise deficient structure safe.*
- *Estimated service life extension due to the repair was 20 years plus.*



## Project 1 (cont'd...)

### STRUCTURAL ASSESSMENT OF RESIDENTIAL HOUSES

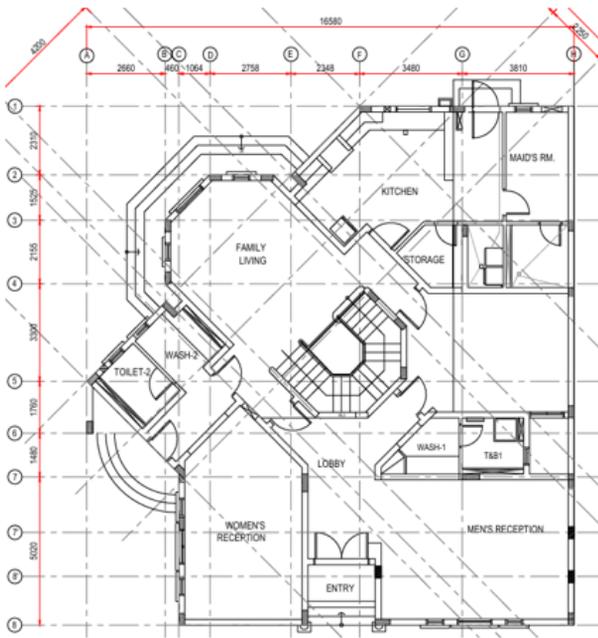


Fig. 1: Typical Floor Plan

**6.4.3 Concrete**—The cores shall be selected and removed in accordance with ASTM C42 and ASTM C823. The equivalent specified concrete strength  $f_{ceq}$  shall be calculated using Eq. (6.4.3).

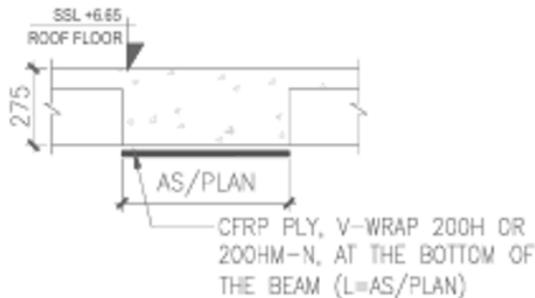
$$f_{ceq} = 0.9\bar{f}_c \left[ 1 - 1.28\sqrt{\frac{(k_c V)^2}{n}} + 0.0015 \right] \quad (6.4.3)$$

where  $\bar{f}_c$  is the average core strength, as modified to account for the diameter and moisture condition of the core;  $V$  is the coefficient of variation of the core strengths;  $n$  is the number of cores taken; and  $k_c$  is the coefficient of variation modification factor, as obtained from Table 6.4.3.

**Table 6.4.3—Coefficient of variation modification factor  $k_c$**

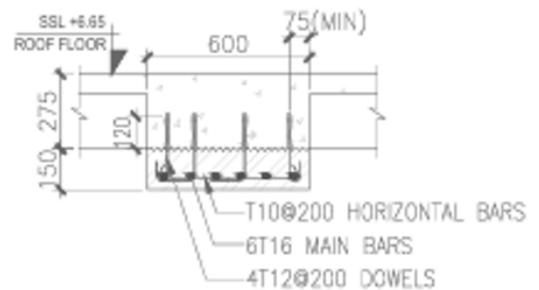
$n$	$k_c$
2	2.4
3	1.47
4	1.28
5	1.20
6	1.15
8	1.10
10	1.08
12	1.06
16	1.05
20	1.03
25 or more	1.02

Fig. 2: Equivalent Compressive Strength as per ACI 562



TYP. SECTION FOR CFRP  
SCALE 1:25

#### BEAM STRENGTHENING OPTION-1



TYP. SECTION D-D  
SCALE 1:25

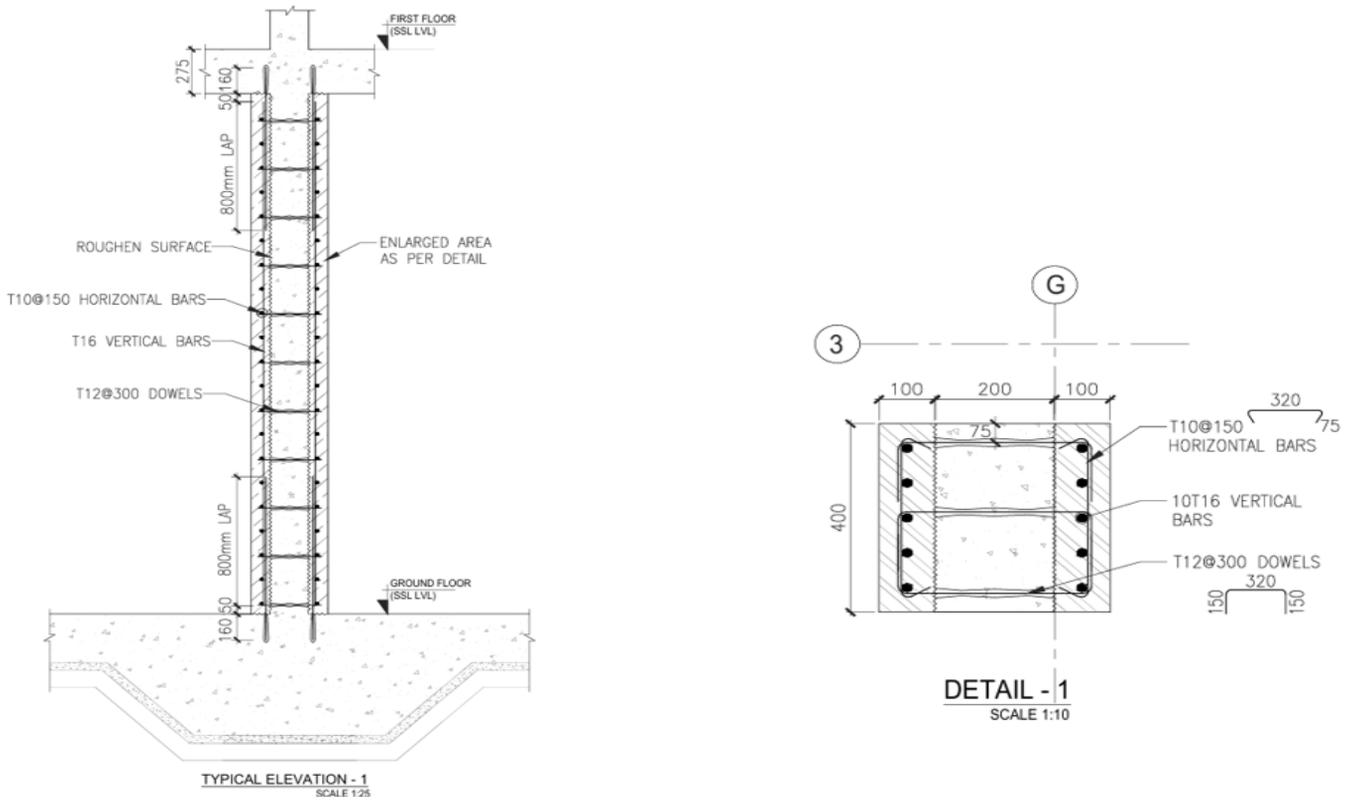
#### BEAM STRENGTHENING OPTION-2

Fig. 3(a): Strengthening of Beams using CFRP

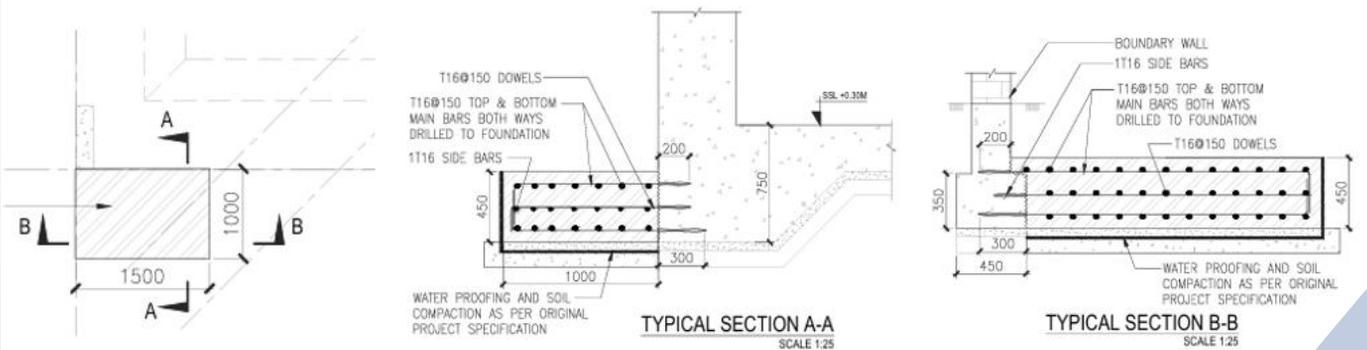
Fig. 3(b): Strengthening of Beams by Enlargement

*Project 1 (cont'd...)*

**STRUCTURAL ASSESSMENT OF RESIDENTIAL HOUSES**



**Fig. 4: Strengthening of Columns**



**Fig. 5: Enlargement of Raft Footing**

## Project 2

# CONDITION ASSESSMENT OF RESIDENTIAL HOUSES

### Project Overview

- Two-storey residential villas (about 400 in number) comprising reinforced concrete framed structure (beam-column), Hardy slab and raft foundation.
- Housing for petrochemical industries group.
- Location: Jubail, Saudi Arabia (severe exposure class).

### Problem Description

- Cracks were observed in slab, beams and columns after 3-5 years of construction.
- Cracks were mainly due to reinforcement corrosion. Some of the cracks in columns were due to structural deficiency.
- Detailed investigation was carried out to identify the causes and extent of concrete deterioration and to provide procedures for repair to restore the lost structural integrity and to protect to extend the service life.

### Methodology Adopted

- Visual inspection and hammer tap survey to identify and record extent and location of cracks and delaminated concrete on top and sides of raft, columns, beams and soffit and top of slab.
- Cover-meter survey to determine cover to reinforcement for raft, columns, beams and slab.
- Retrieved 50x100 mm cores from raft, columns and beams and tested for chloride content profile in concrete. Chloride profiles were drawn from the data which show chloride content variation with depth. Chloride content at rebar level was noted for different members.
- Corrosion potential mapping was carried out to locate corrosion hot spots.
- Corrosion rate was carried out using LPR (linear polarization) technique.
- Detailed procedures were provided for (a) repair of delaminated concrete and (b) protection of sound concrete with chloride content at reinforcement level in excess of the threshold value (a threshold value of 0.5% acid soluble by weight of cement was used).

### Results

- The sides and top of raft, columns, top of beams/slab suffered concrete delamination due to reinforcement corrosion. The reinforcement corrosion was caused by chloride contamination in concrete.
- Chloride content was found to be high in delaminated concrete.
- Chloride was also found to be more than the threshold value in sound concrete in some of the members.
- The shape of the chloride profiles indicated that there was minimal chloride in the original concrete mix and that the chloride contamination was caused by curing water which contained high chloride content.

### Proposed Repair Design

- Drawings were provided showing delaminated concrete on raft, columns, beams and slab. Detailed repair procedure was provided to repair the delaminated concrete.
- Drawings were provided showing concrete areas with chloride content more than the threshold value on raft, columns, beams and slab. These areas were proposed to be protected using a three-layer coating system comprising first coat of corrosion inhibitor (Sika FerroGard 903<sup>R</sup>), intermediate coat of pore sealer and top coat of epoxy.

### Benefits

- *The proposed repair procedure for delaminated concrete provided restoration of the lost strength and extended the service life by at least 20 years.*
- *The proposed protection technique (three-layer coating) provided service life extension of chloride-contaminated concrete by at least 20 years.*



*Project 2 (cont'd...)*

**CONDITION ASSESSMENT OF RESIDENTIAL HOUSES**



Fig. 1: General view of the house



Fig. 2: Raft foundation suffered severe reinforcement corrosion



Fig. 3: Column with severe rebar corrosion



Fig. 4: Beams with severe rebar corrosion



Fig. 5: Repair of top of raft, in progress



Fig. 6: House after repair

## Project 3

# CONDITION ASSESSMENT OF COOLING TOWER

### Project Overview

- Cooling tower of a steel plant suffered reinforcement corrosion and concrete scaling due to salt weathering after about 20 years in service.
- The cooling tower was used for cooling seawater. It was a rectangular reinforced concrete structure with a basin (water tank) at the bottom and fans on the top for cooling the hot seawater. The basin was a L-shape structure (49.4 m long and 22 m wide longer side and 25.2 m long and 12.9 m wide shorter side). The basin walls were 3.85 m high and 400 mm thick. The floor slab is 800 mm thick. There were seven (7) fans on top of the basin.
- The operation of the cooling tower caused intermittent seawater splash on the external walls causing wetting and drying of concrete by seawater.
- The reinforced concrete members were protected by an impressed current cathodic protection (CP) system.
- Location: Steel plant in Jubail industrial city of Saudi Arabia (severe exposure class).

### Problem Description

- The wetting and drying caused by intermittent seawater splash on the external walls caused concrete scaling due to sulfate attack and salt weathering.
- Seawater splash also caused reinforcement corrosion. The CP system was not providing intended protection as it was not designed and installed properly.
- Detailed concrete assessment investigation was carried out to identify the causes and extent of concrete deterioration and to provide procedures for repair and protection to restore the lost structural integrity and to extend the service life of the structure.
- Detailed assessment of the CP system was also carried out to provide scope of work for rectification/upgrading of the CP system.

### Methodology Adopted

#### (a) Condition Assessment

- Condition assessment was carried out for the external walls and top of roof slab during the operation of the cooling tower. Internal surfaces were not inspected as the access was not available.
- Visual inspection and hammer tap survey to identify and record extent and location of concrete scaling and delaminated concrete.
- Compressive strength of cores retrieved from sound concrete and rebound number of sound concrete to assess the quality of concrete.
- Cover-meter survey to determine concrete cover to reinforcement using micro-cover meter. Ground penetrating radar (GPR) mapping was also used to measure the cover.
- Carbonation depth in cored samples.
- Concrete resistivity using 4-pin Wenner probe.
- Rapid chloride permeability test on 100 mm diameter cored concrete samples.
- Half-cell potential mapping at 250 x 250 mm grid after switching off the CP system.
- Corrosion rate of reinforcing steel after switching off the CP system.
- Electrical continuity of reinforcing steel by measuring dc resistance.
- Chloride content profile in 50x100 mm cores. Chloride profiles were drawn from the data which show chloride content variation with depth. Chloride content at rebar level was noted for different samples.
- Chemical analysis of seawater samples to measure TDS, chloride content and sulfate content.



## Project 3 (cont'd...)

### CONDITION ASSESSMENT OF COOLING TOWER

#### (b) Assessment of CP System

- CP system assessment was carried out for the entire structure including buried concrete, external concrete and internal concrete.
- Visual inspection of the CP hardware (transformer rectifier, junction boxes and chemical analysis of transformer rectifier oil).
- Output voltage and current of each channel of the TR was recorded.
- Output current of each anode feeder was recorded.
- ON and instant-off potentials were recorded for the permanent reference electrodes as well as at twelve (12) selected locations on the external walls of the basin. At each location, potentials were measured on an area of 2 x 2 m at a spacing of 250 x 250 mm.
- The CP system was switched off and depolarized potentials after 24, 48, 72 and 96 hours were recorded for the permanent reference electrodes as well as at the twelve (12) selected locations on walls.
- The instant-off and depolarized potential data is analysed to check compliance with the protection criteria.

#### Results

- The concrete scaling was caused due to sulfate attack and salt weathering and was caused by seawater splash on the external walls from the basin.
- Concrete delamination was caused due to non-performance of the CP system.
- The original quality of concrete was good (where there was no deterioration).
- Tests indicated that active corrosion of reinforcement was taking place.
- The CP system was not providing intended protection to the structure. The potential measurements of the permanent and portable reference electrodes showed that cathodic protection was not achieved at about 75% of the areas.
- Anode current measurement showed that about half of the anodes were not delivering the protection current.
- The review of IFC drawings for the CP system showed that the spacing of the conductor bars was more which affects the protection level at areas away from the anode feeder connection.

#### Proposed Repair Design

- Drawings were provided showing extent and location of the scaled and delaminated concrete on external walls and top of roof slab. Detailed repair procedure was provided to repair the scaled and delaminated concrete. It was recommended to protect the concrete surfaces by applying high alumina (calcium aluminate) cement mortar to protect against scaling due to sulfate attack and salt weathering.
- The CP system was recommended to be rectified by abandoning all existing conductor bars, and anode feeder connections and cables and installing new conductor bars, anode feeder connections and cables as per the new design provided. Detailed CP system design was provided with new locations of conductor bars, anode feeder connections and cables. It was recommended to leave the existing MMO mesh ribbon anodes, junction boxes and transformer rectifiers as is.

#### Benefits

- *The proposed repair procedure for scaled and delaminated concrete would provide restoration of the lost strength and the high alumina (calcium aluminate) cement mortar would extend the service life by at least 20 years.*
- *The proposed rectification of the CP system would extend the service life of the structure by at least 40 years.*

*Project 3 (cont'd...)*

**CONDITION ASSESSMENT OF COOLING TOWER**



Fig. 1: General view of the external wall of the cooling tower showing concrete deterioration



Fig. 2: Concrete scaling on external wall of the cooling tower



Fig. 3: Concrete delamination & spalling reinforcement corrosion



Fig. 4: Anode ribbon and anode cables due to exposed due to spalled concrete

## Project 4

# CONDITION ASSESSMENT OF SEAWATER INTAKE STRUCTURE

### Project Overview

- The Seawater Intake structure includes Phase 1 and Phase 2 structures, which comprise four (4) units each. The seawater enters the reinforced concrete pits (4 in Phase 1 and 4 in Phase 2) and then is pumped out to the Plant Units.
- Cathodic protection (CP) systems were installed few years after construction to protect the concrete reinforcement using MMO mesh anode embedded in cementitious overlay. A separate CP system was installed to protect submerged metallic items (stop log guides, pumps, travelling screens and chain rake bar screen).
- Location: Power Plant in coastal area of Eastern Saudi Arabia (severe exposure class).

### Problem Description

- The CP overlay on top of the deck slab suffered delamination
- The cantilever slab of Phase I Structure suffered severe reinforcement corrosion.
- Some of the equipment foundations and pipe supports on top of the deck slab also suffered severe reinforcement corrosion.

### Methodology Adopted

#### Condition Assessment

- Condition assessment was carried out for deck slab, four Intake chambers, concrete surfaces above seawater line and equipment foundations on top of the deck slab,.
- Visual inspection and hammer tap survey to identify and record extent and location of concrete scaling and delaminated concrete.
- Cover-meter survey to determine concrete cover to reinforcement using micro-cover meter.
- Concrete resistivity using 4-pin Wenner probe.
- Half-cell potential mapping at 250 x 250 mm grid after switching off the CP system.
- Chloride content profile in 50x100 mm cores. Chloride profiles were drawn from the data which show chloride content variation with depth. Chloride content at rebar level was noted for different samples.

#### Assessment of CP System

- Objective: Performance evaluation of the existing CP systems for reinforced concrete and submerged metallic structures and to provide recommendations for rectification and upgrading of the CP systems.
- Review of as-built drawings and previous monitoring reports.
- Inspection of the CP hardware including transformer rectifiers (TRs), junction boxes and other items.
- Troubleshooting of the TRs to the extent possible including replacing fuses.
- Measurement of output voltage and output current for all TRs and making adjustments, as required.
- Measurement of anode current for all anodes before and after adjustments of the TR output current.
- Measurement of "on" and instant off potentials and potential decay at the permanent reference electrodes and using portable reference electrode at selected locations before and after adjustments of the TR output current.

## Project 4 (cont'd...)

### CONDITION ASSESSMENT OF SEAWATER INTAKE STRUCTURE

#### Results

- The cementitious overlay on top of the deck slab suffered cracking, delamination and spalling at isolated locations due to salt weathering caused by ponding of seawater. However, the underlying concrete was in sound condition. The concrete cover, rebound number, electrical resistivity, chloride content in concrete and half-cell potentials were within the acceptable limits.
- The cantilever precast slab panels at Phase 1 suffered severe concrete cracking, delamination and spalling due to reinforcement corrosion. The cantilever cast-in-place slab at Phase 2 was in sound condition.
- The coating and concrete on the floor, walls and soffit on internal of the Intake chambers were in good condition.
- Some of the equipment foundations and pipe supports on top of the deck slab suffered severe and advanced concrete deterioration due to reinforcement corrosion and needed to be replaced.
- The transformer rectifier units (TRU) were malfunctioning; Out of 33 TRU channels, only 8 were functioning and providing protective current. The malfunctioning TRU units were rectified by replacing the solid state relays (SSR).
- After replacing the SSR, 27 out of 32 zones were functioning properly and were achieving adequate protection.
- The CP system for submerged metallic items was functioning properly and provided the intended protection. However, some anodes were missing and needed to be installed.

#### Proposed Repair Design

- Detailed repair procedures including drawings were provided to repair and protect the deteriorating concrete members (deck slab and foundations). The repair scope included replacing the deteriorated CP overlay. The anode mesh was also recommended to be replaced by connecting the new mesh to the existing anode mesh in adjacent areas. The scope also included to apply heavy duty industrial grade epoxy floor coating on top of the entire deck slab for future protection against attack of the cementitious overlay by seawater.
- The repair procedures also included detailed drawings and scope to remove the existing precast concrete panels of the cantilever slab of Phase 1, repair the cantilever beams and install new reinforced concrete pre-cast panels. Alternatively, it was recommended to install fiberglass beams and grating in place of the concrete slab.
- The equipment foundations and pipe supports were recommended to be replaced. Drawings were provided to show the foundations to be replaced and replacement procedure.
- For the CP system, it was recommended to rectify the malfunctioning TRU channels in order to provide protection to the entire area. It was also recommended to install missing anodes for the submerged CP system.

#### Benefits

- *The proposed repair procedure for would provide service life extension of the structure by at least 20 years.*
- *The proposed rectification of the CP system would extend the service life of the structure by at least 40 years.*



*Project 4 (cont'd...)*

**CONDITION ASSESSMENT OF SEAWATER INTAKE STRUCTURE**



Fig. 1: General view of the top of the Intake structure (Phase 1 & 2)



Fig. 2: Cracking & delamination of the CP deck overlay on top of the deck slab



Fig. 3: General view of the Intake structure from sea side



Fig. 4: Severe rebar corrosion of cantilever pre-cast concrete slab at Phase 1



Fig. 5: Sound condition of the internal of the Intake chambers

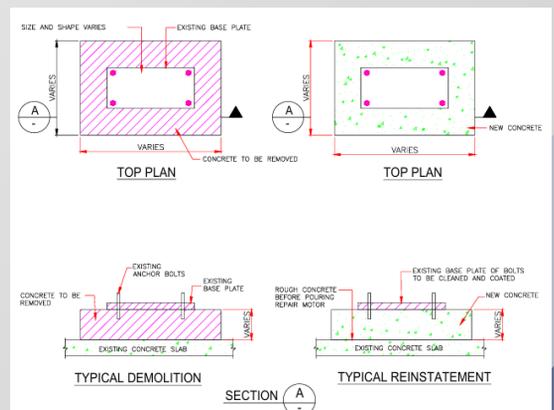


Fig. 6: Typical drawing showing replacement of foundation

## Project 5

# REPAIR OF WATER STORAGE CONCRETE TANKS

### Project Overview

- Pumping Station for water supply system to Riyadh city comprised 12 concrete tanks and associated pump houses and drain and ventilation shafts.
- Each tank was a reinforced concrete circular tank, 94 m diameter and 9.5 m height. The tank had 180 reinforced concrete columns of 550 mm diameter. The floor slab was 350 mm thick with construction joints at 9 m spacing in both directions. Water stop was installed at all the construction joints. The floor slab was thickened to 700 mm under the walls. The tank wall was constructed of 7.45 m wide and 700 mm thick wall panels with expansion joints with water stop and sealant. The roof slab was 320 mm thick and was covered with waterproofing membrane comprising covered with gravel.
- The floor slab of six tanks was covered with 10 mm thick ceramic tiles and the internal concrete surfaces was protected with a cement-based penetrating crystalline coating.
- The internal of the other six tanks, including the floor, was protected with 1.5 mm thick polyurethane coating.
- The external walls were covered with sloped backfill covered with gravel. The external walls were not protected.
- The pump houses were about 19 m by 15 m and 23 m height (partially below and partially above ground level). The internal walls were coated with decorative coating and the external walls were uncoated.
- The drain & ventilation shafts were about 1 x 2 m and 10-15 m height with 200 mm thick walls.
- Location: Pumping Station outside Riyadh city, Saudi Arabia. The facility belonged to the Desalination Company in Saudi Arabia.

### Problem Description

- The tiles on the floor were broken and dis-bonded and the concrete was exposed to water. The coating on the internal on walls, columns and roof slab soffit was in good condition for the first six tanks.
- For the other six tanks, the internal polyurethane coating suffered severe blistering.
- The external surfaces of the walls of all the tanks and pump houses suffered concrete delamination due to reinforcement corrosion.
- The internal surfaces of walls of the drain and ventilation shafts also suffered severe concrete delamination due to reinforcement corrosion.

### Methodology Adopted

- Condition assessment was carried out for the tanks, pump houses and drain and ventilation chambers.
- Visual inspection and hammer tap survey to identify and record extent and location of concrete scaling and delaminated concrete.
- rebound number, cover to reinforcement, ultrasound pulse velocity, half-cell potential mapping, electrical resistivity of concrete, retrieving cores to measure compressive strength, carbonation depth and chloride and sulfate content and pH in concrete.
- Cover-meter survey to determine concrete cover to reinforcement using micro-cover meter.
- Rebound number and ultrasound pulse velocity to assess general quality of the concrete.
- Retrieved cores to measure compressive strength of concrete.
- Concrete resistivity using 4-pin Wenner probe.
- Half-cell potential mapping to assess the corrosion status of the reinforcement.
- Carbonation depth by applying phenolphthalein indicator on freshly cut concrete cores.
- Electrical resistivity of concrete using 4-pin Wenner probe.
- Chloride content profile, pH and sulfate content in 50x100 mm cores. Chloride profiles were drawn from the data which show chloride content variation with depth. Chloride content at rebar level was noted for different samples.

## Project 5 (cont'd...)

### REPAIR OF WATER STORAGE CONCRETE TANKS

#### Results

- The tiles on the floor of six tanks were broken and dis-bonded and the cementitious coating on columns, walls and soffit was in good condition. The protective coating on the floor, columns, walls and soffit for the other six tanks was in good condition. Sealant between the expansion joints suffered deterioration at some locations.
- The concrete on internal surfaces of the tanks and pump houses was in good condition. Compressive strength, rebound number, ultrasound pulse velocity and concrete cover to rebars was adequate and indicated good quality concrete.
- Chloride content in concrete cores taken from internal of tanks were less than the threshold value. Half-cell potential mapping indicated that the rebars were in passive condition. Resistivity indicated low corrosion rate.
- The external surfaces of the tank and pump house walls suffered rebar corrosion.
- The waterproofing membrane on the roof slab was in good condition.
- The internal and external surfaces of the drainage and ventilation shafts suffered severe reinforcement corrosion.

#### Repair & Protection

- Repair and protection was carried out for the tanks, pump houses and drainage and ventilation shafts.
- The repair work included:
  - Removing the tiles and applying epoxy based protective coating on the floor of first six tanks
  - Removing existing polyurethane coating on the other six tanks and applying epoxy based protective coating.
  - Replacing joint sealant from the expansion joints.
  - Excavating and repairing delaminated concrete on the external surfaces of the walls of tanks and pump houses and protecting with epoxy coating.
  - Repairing delaminated concrete on drain and ventilation shafts.

#### Benefits

- *The repair carried out has restored the lost structural strength.*
- *The repair and protection carried out will provide service life extension of the structure by at least 20 years.*

*Project 5 (cont'd...)*

**REPAIR OF WATER STORAGE CONCRETE TANKS**



Fig. 1: Broken tiles on the floor of first six tanks



Fig. 2: Severe blistering of polyurethane coating on internal of other six tanks

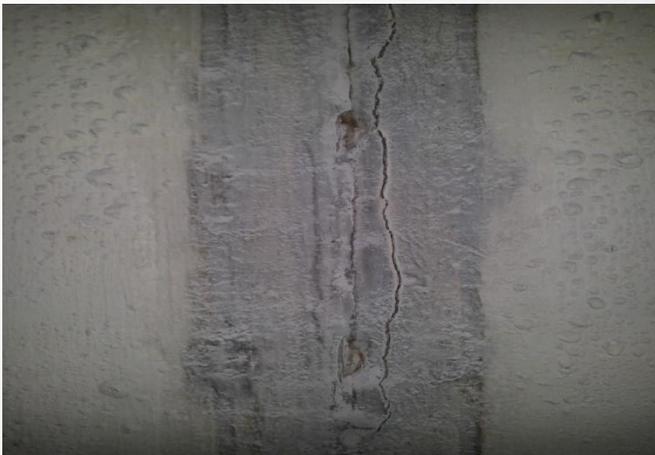


Fig. 3: Sealant at expansion joint



Fig. 4: Severe rebar corrosion on external surface of tank walls



Fig. 5: Severe rebar corrosion on external walls on drain & ventilation shafts

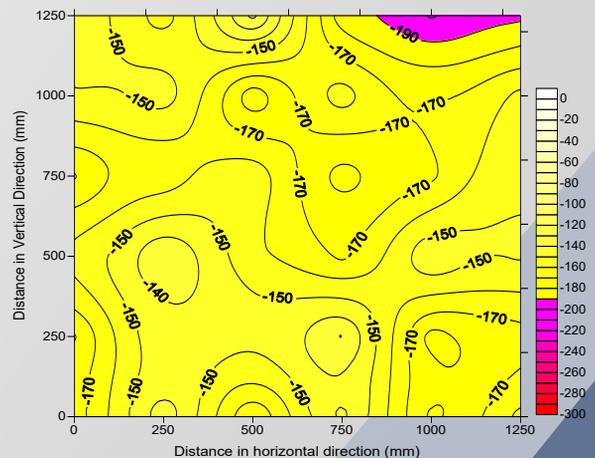


Fig. 6: Typical mapping contour showing rebars in passive condition