RCC Fly ash Silo Repair Based on Visual Inspection and PDT/NDTs

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Abstract *– RCC Silos are unique industrial construction widely used for gritty materials storage like Cement, Fly ash, Grains, etc. in bulk. They are subjected to various unorthodox loading stipulations resulting into their peculiar failures. Such failure may occur because of errors in their Design, Construction, Utilization, Maintenance, etc. Thus, based on a Silo's Visual Inspection, Partial/Non Destructive Tests, an effective and efficient repair methodology using suitable repair materials and techniques is adopted to repair and strengthen the affected regions. Moreover, the repaired Silo is then cross examined for its adequate gain in strength along with its confirmation of longevity using post NDT (UPV). However, Silos can also be repaired and upgraded using some latest strengthening techniques based on their deterioration type.*

Key Words: RCC Silo, PDT/NDT, GPR, UPV, Repair techniques.

1. INTRODUCTION

Structure for the storage of any particular solid is usually termed as a Bin. Bin including shallow containers are called Bunkers and deep tall structures as Silos. Generally, 500 to 2000 tons of granular material is stored in a single bin. The cross-sectional shape of silos is commonly adopted as circular or rectangular and stocks cement, fly ash, grains etc. in bulk. Reinforced Concrete bins are usually rectangular but tall Silos are Cylindrical in shape. Circular Silo walls usually acts as Tension members horizontally and as Compression members vertically which may lead to its buckling. However, Non-Circular units will always have horizontal Bending moment. It has been accepted that greater is the depth of Silage, better will be its pressure account. If the height of Silage is more than 24 feet, it would be of the best quality.

The diameter of a Silo would be determined by the nature and size of the herd to be fed, whereas the height would be by the number of feeding Cement/Fly ash type granular materials days per year for which it is desired to be provided. The weight of a cubic foot of silage usually varies according to the pressure to which it is subjected to. Silo types include Tower, Pit, Conventional, Oxygen-Limiting, Pre-stressed units, etc. They fail due to Faulty Design, Inappropriate Usage, Improper Maintenance, Construction Errors, etc.

Irrespective of the actual cause, their failure may lead to various small or large scale industrial, equipment and material, or even mankind loss. Distressed concrete surface on a Silo is better to be repaired and strengthened rather than its new construction as a whole as this practice is feasible and effective in terms of cost as well as time. This can be achieved by introducing an effective repair methodology that can be implemented using certain repair materials and techniques. This would surely promise an efficient and effectively productive long life working of such Silos.

2. LITERATURE REVIEW

J.W Carson and R.T Jenkyn (1993) studied about the root cause behind Silos failures and the straight forward steps to minimize the same. [1] **Adem Dagungun et al. (2009)** focused their study towards silo damage and its failures occurring across the world followed by their all possible devastating loses. [2] **Nicola Zaccari et al. (2016)** discussed structural behavior of silos leading to buckling during eccentric discharge followed by proposing a possible reinforcement design to minimize such problems. [3] **John T. Petro Jr et al. (2012)** preferred Indirect transmission method, to measure the transit times of Longitudinal and Rayleigh waves and determine the Dynamic Young's modulus, Poisson's ratio and Static modulus of concrete slabs by varying its sizes. The location and size of distress in the respective slabs were then evaluated and studied using direct transmission method. [4] **Yehia S et al. (2007)** detected the common defects in Concrete bridge decks using Non Destructive Testing (NDT) techniques and noted that such NDTs in concrete structures has received growing attention in recent years, especially for quality assessment of any infrastructure. [5] According to, **American Concrete Institute (ACI 228) (1998)** Ultrasonic Pulse Velocity (UPV) is one of the NDT methods that have been successfully used in evaluating concrete properties. The theory of wave propagation allows us to measure material depth, to determine the presence of cracks and damages into the concrete surface, to determine Young's modulus and Poisson's ratio, and even to estimate the Compressive Strength of concrete. [6] **Qixian L et al. (1996)** noticed under UPV test that, depending upon the accessibility, Direct (through-thickness) or Indirect (surface) transmission of wave propagation can be implemented in testing Concrete structures. [7] **Komlos K et al. (1996), Prassianakis IN et al. (2003)** used direct transmission method to evaluate the Compressive Strength of concrete by creating a co-relation curve between the P-wave velocity and the Compressive Strength. The curve was created using cube specimens or core samples taken from various sections of the structure being tested. [8, 9] **Nagy (1997)** suggested a conversion formula for calculating the Static Modulus from the Dynamic Modulus in order to predict the Compressive Strength of early-age Concrete. [10] **Panesar DK et al. (2007)** used UPV test measurements to determine the Compressive Strength of concrete based on Dynamic-to-Static Elastic Modulus ratios. [11] **Carino NJ (1984)** concluded that when the wave front encounters another side of the concrete or distress within the slab, the P-wave is both reflected and refracted. It has been shown that when a wave front propagates into a sharp edge of distress, diffraction of the wave occurs. [12] **Mirza, Jahangir et al. (2013)** studied and worked upon the behavior of Microfine Cement grout. [13] **Pantazopoulos et al. (2012)** worked on the overall development of Micro fine Cement grouts in a unique way using fine cements preferring their development by pulverizing ordinary cements. [14]

3. MATERIALS AND METHODOLOGY

3.1 MATERIALS USED

Chemical materials include an Epoxy Putty as **SALSEAL-PT HR** (Resin and Hardener) system for fixing nozzles into the drilled holes. A Micro fine Cement grout powder known as **ALCCOFINE 1108 SR** is used for grout injection into the fixed nozzles. The two components Polymer Grout cum Water Proofing Polymer as **SALOPOL-LV HR** are to be grouted into the nozzles. A liquid system (Base + Hardener) solvent free Epoxy Resin based Injection Grout as **MAXGROUT™ E10 HR** is used for grouting the same nozzles. A carbon reducing alkaline Rust Remover as **MAXCURE® RR HR** is used to remove rust from the corroded reinforcement bars. A Cementitious Corrosion Inhibitor such as **MuCis PROTEZIONE FERRO MONO HR** is used as a coating to cover the exposed reinforcement bars. A multifunctional liquid Corrosion Inhibitor as **MuCis Mia 200 HR** is applied to resist corrosion. A Cementitious Micro Concrete **BS 66 MuCis-U HR** is mixed only with water and is ready to use to give final patch cover for patch depth >40 mm whereas a corrosion resistive single component Polymer Modified FR Cementitious Mortar **BS 5F-U HR** is used for patch depth ≤40 mm. A two component (Resin and Hardener) solvent free Epoxy Resin based Concrete Bonding Agent **TM-BOND EP HR** applied after grouting in place of **MuCis Mia 200 HR** in cases where Polymer Modified Mortar Patch Depth is ≤40 mm.

3.2 METHODOLOGY ADOPTED

The RCC Fly ash Silo considered here in the study was a 61.60 m height construction built in the year 2012 and was having its outer diameter as 14 m with 350 mm thick outer walls. It was having its storage capacity as 5000 Metric Tons. Its material storage location was from 15.8 m to 55 m height of the Silo i.e., the storage height in total was of about 39.2 m. It was constructed of M35 Grade concrete using 43 Grade Portland Pozzolanic Cement and Fe415 reinforcing Steel. Considering its inspectional observations for repair work, the Silo was studied by dividing its periphery into four equal quadrants as angle faces. For our study, the Zero degree face was considered to be observed, tested, repaired and strengthened.

The preliminary work comprises Visual Inspection of the RCC Fly ash Silo at its Zero degree wall face (Bottom to Top) to assess the distressed and deterioration of concrete. Non Destructive Tests (NDTs) including Ground Penetration Radar (GPR) followed by Ultrasonic Pulse Velocity (UPV) were carried out. For better and accurate results, Partial Destructive Test (PDT) named Core Cutter/Extraction test was also carried out with all its associated chemical tests. Depending upon the PDT/NDTs data, an appropriate Repair Methodology was introduced to repair and strengthen the Silo. Repair Chemical materials (as discussed in 3.1) were then introduced for efficient and effective repair of distressed concrete and to enhance strength of concrete. Finally, Post UPV test was done on all the repaired locations of the Silo wall and the readings were recorded and compared with the Pre UPV readings as to ensure an adequate and competent Silo strengthening.

3.2.1EXPERIMENTAL PROGRAMME

a) GROUND PENETRATION RADAR (GPR; NDT)

A concrete scanning test gives complete concrete rebar profile. It provides identification of the reinforcement bars in the concrete, Cover thickness, Rebar spacing, Rebar diameter, etc. The test uses Electromagnetic energy to get information about the subsurface of the testing specimen. Thus, the test was performed on the zero degree Silo wall face at an elevation ranging from 15 m to 55 m at various rebar locations by keeping Di-electric constant as 4.7 throughout the scan to obtain data.

b) ULTRASONIC PULSE VELOCITY (UPV; NDT)

Concrete surface is tested by measuring Electronic Pulse Velocity passing through it from a transmitting transducer to a receiving transducer. The test examines the concrete quality as per the codal provisions provided in the Indian

Standard Code, **IS: 13311(Part 1)-1992.** Since the Fly ash Silo dimensions were large, **Indirect** (Same Face) **Method** was adopted to perform the test at various height levels beginning from 9.5 m to 41 m. The Path length was fixed to 200 mm. Depending upon the detailed analysis of the Pulse Velocities recorded and considering the associated codal guidelines, the concrete surface was categorized in the sequence of Doubtful to Excellent.

c) CORE EXTRACTION/CUTTER (PDT)

Concrete surface is cut in the form of cylindrical cores of length and diameter as per the codal guidelines provided in **IS: 516-1959.** Total 5 no. of cores of avg. length 128 mm and avg. diameter of 68 mm were extracted at specified elevations of the zero degree wall face of the RCC Fly ash Silo and were observed for any visible distress. Later on, the cores were tested into the laboratory for their chemical evaluation for parameters including Carbonation Depth, pH Value, Chloride Content, Sulphate Content, etc as per the codal guidelines provided in their respective Indian Standard code. Finally, the same cores were then tested under Compression Testing Machine so as to find their Equivalent Compressive Core Strength.

3.2.2 SEQUENTIAL REPAIR METHODOLOGY

Surface Check: Initially, the Silo periphery was required to be checked for sounding using hammer. Hollow sounding locations were marked in regular geometries and were treated as distressed areas.

Grooving: Marked geometries were grooved through their edges using Mechanical cutter.

Drilling: Holes of 16 mm diameter, 200 mm deep with a spacing of 600 mm c/c in a staggered pattern were drilled on the zero degree face of Silo wall followed by cleaning dust from them using spiral brush.

Nozzle Fixing & Cement Grouting: Twin lock nozzles of approximately 75 mm length and 15 mm outer diameter were fixed into the drilled holes using Epoxy Putty and were then grouted with Micro fine Cement grout at a pressure of 1.5-3.5 kg/cm^2 up to refusal.

Chipping & Cleaning: Loose material within the grooved area was chipped off using mechanical chippers followed by cleaning the surrounding area for dust and debris using air blowers.

Drilling: Holes of 12 mm diameter, 175 mm deep with a spacing of 300 mm c/c were drilled followed by cleaning dust from them using spiral brush.

Nozzle Fixing & Grouting: Twin lock nozzles with an approximate 35 mm length and 11 mm outer diameter were fixed into the drilled holes using Epoxy Putty and were then filled with Monomer grout first and with Epoxy grout after 30-60 minutes of Monomer grout at a pressure not more than 2.5 kg/cm^2 up to refusal.

Reinforcement Cure: The exposed bars were first cleaned by a wire brush and then a Rust Remover was applied to them using a paint brush followed by coating them with Cementitious Corrosion Inhibitor right after 15-20 of the application of Rust Remover.

Final Repair (Repair Depth: ≤40 mm): Coating of an Epoxy Bonding agent was done on the prepared patch followed by the application of Polymer Modified Mortar (PMM) in a two coat system at an interval of 24 hours.

Final Repair (Repair Depth: >40 mm): Coating of a liquid Corrosion Inhibitor was applied on the exposed area followed by fixing appropriate ply form shuttering to the exposed area and Micro concreting was done into it.

De-shuttering and Grinding: Shuttering was removed off as and when the filled Micro concrete gets hard and the repaired patch was then smoothened to its edges and joints using mechanical grinder.

Curing: Finally, water curing was done to the finished repaired patch.

Fig -1: Distressed Concrete Chipping (Initial Repair Stage)

Fig -2: Curing of Repaired Patch (Final Finished Stage)

4. RESULTS AND DISCUSSIONS

4.1 VISUAL INSPECTION

The zero degree wall face of the RCC Fly ash Silo was found to be in a critically damaged condition. The Silo periphery was suffering from some major issues as: **Hand Patching,**

Honeycombing, Pot holes, Spalling, Horizontal as well as Vertical major and minor cracks, etc.

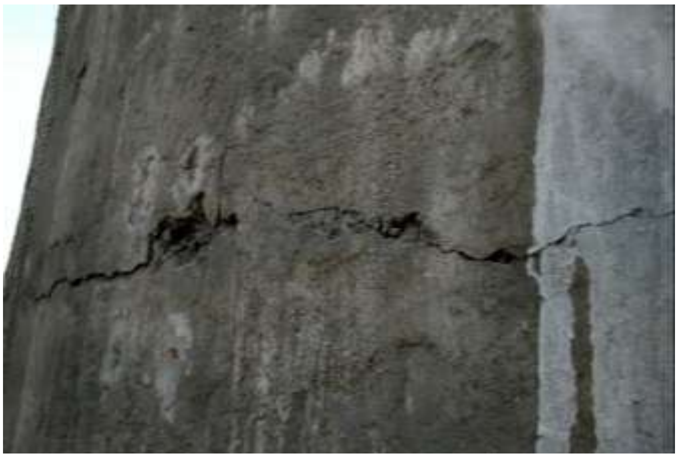

Fig -3: Major Horizontal Cracks

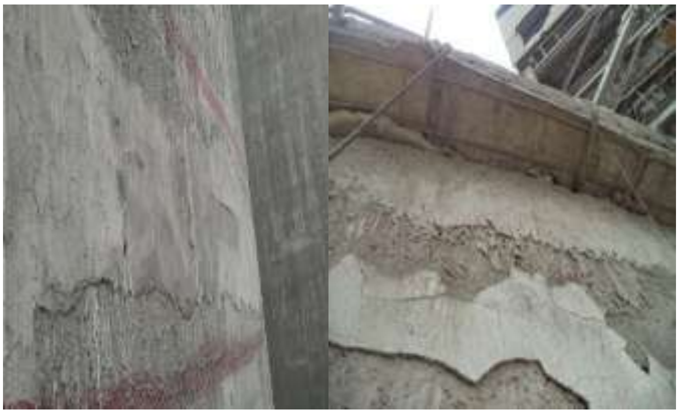

Fig -4: Hand patching and Honey combing of Concrete

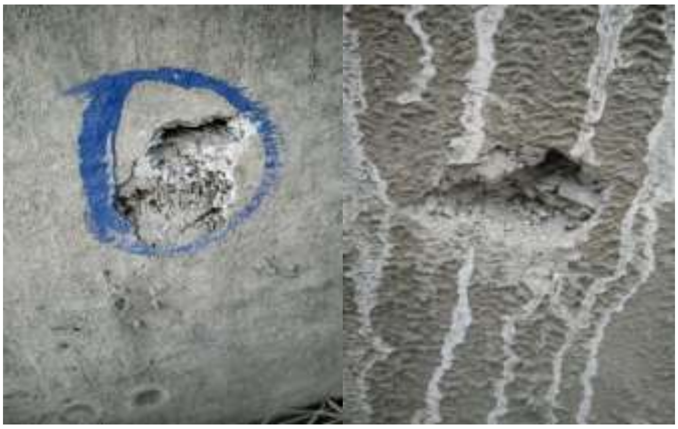

Fig -5: Pot holes Observed

4.2 GROUND PENETRATING RADAR SCAN TEST

Table -1: GPR Scan results for various Rebar Locations

Rebar Location (m)	Avg. Cover Thickness (mm)	Avg. Spacing (mm)	Avg. Rebar Diameter (mm)
15-20	51.35	194	24.50
20-39	43.06	250	25.91
39-45	42.31	281	25.97
45-51	39.91	263	24.20
51-55	56.82	187	20.43

The tabulated results shows that the avg. cover thickness was found minimum for the rebar location range of 45-51 m (39.91 mm) and maximum for 51-55 m (56.82 mm). However, avg. rebar diameter was approximately 25 mm for all the rebar locations till 51 m. Also, 20 mm for 51-55 m range.

4.3 ULTRASONIC PULSE VELOCITY (Prior to Repair)

Fig -6: Performing UPV Test at Certain Height

Table -2: Avg. UPV readings for Zero degree wall face

Location (m)	Avg. Corrected Pulse Velocity (km/sec)	Concrete Quality
9.5	2.30	Doubtful
11	2.24	Doubtful
17	2.70	Doubtful
24.5	3.15	Medium
32	2.78	Doubtful
36.5	2.68	Doubtful
39.5	3.02	Medium
41	3.09	Medium

The avg. corrected pulse velocity readings evaluated after considering all the codal guidelines as per **IS 13311- Part 1 (1992)** was found to be minimum for 11 m location as 2.24 km/sec and maximum for 24.5 m location as 3.15 m km/sec. It was clearly seen that majority of the concrete at various locations was Doubtful. However, few of them were having Medium quality concrete. None of the readings were having Good/Excellent quality concrete.

4.4 CORE SAMPLING AND TESTING

Under the chemical testing of extracted cores as per codal provisions, it was found that there was no Carbonation in any core as none of them showed Carbonation depth as more than 1.5 cm. Also, none of the core was detected with any Sulphate content into it (<4 %). All other parameters are tabulated below.

Table -3: Extracted cores testing results

Location (m)	pH Value	Chloride Content (%)	Equivalent Cube Strength (MPa)
11	11.9	0.032	21.3024851
20	11.9	0.030	21.2743004
32	11.6	0.040	37.3732611
35	12.0	0.040	13.1131903
38	11.9	0.030	21.5104287

The results tabulated above shows that pH value was in the range of 11.6-12.0 for all the locations proving that all the cores were alkaline (Basic) in nature and were under the range of 11-13.5. Chloride content was in the range of 0.030 % to 0.040 % for all the cores (< 0.6 %). Equivalent Cube Strength was found to be minimum for 35 m location as 13.1131903 MPa and maximum for 32 m height as 37.3732611 MPa. However, it should be noted that the Silo was originally designed for M35 Grade concrete meaning 35 MPa of Equivalent Cube Strength throughout.

4.5 ULTRASONIC PULSE VELOCITY (Post Repair)

Table -4: Avg. UPV readings for repaired wall locations

Location Range (m)	Avg. Corrected Pulse Velocity (km/sec)	Concrete Quality
7-10	5.22	Excellent
11-12	4.75	Excellent
16-19	4.39	Good
23-26	5.41	Excellent
31-32	4.72	Excellent
35-36.5	4.69	Excellent
38-39.5	4.93	Excellent
41-44	5.06	Excellent

The avg. corrected pulse velocity mentioned above in the table was found to be minimum for the location range of 11-12 m as 4.39 km/sec and maximum for 23-26 m location range as 5.41 km/sec. The entire concrete surface at various locations was almost Excellent. However, only 16-19 m location range gave Good quality concrete. None of the readings were having Medium/Doubtful quality concrete.

5. CONCLUSIONS AND FUTURE SCOPE

- The Silo wall was found to be highly dealiminated and critical at various elevations.
- There was a slight variance in the Avg. cover thickness and spacing of rebar considering the GPR scan report. However, rebar diameter was almost same (25 mm) for all the locations.
- The core chemical tests were found to be ok for all the five cores extracted. None of the cores got influenced by any of these chemical effects: Carbonation, Chloride, Sulphate, pH, etc. Moreover, the Compressive Strength of all the five cores was found to be lower than the actual Compressive Strength of 35 MPa (M35 Grade concrete of RCC Fly ash Silo).
- UPV readings evaluated before and after the repair work were compared and it was found that all the Doubtful/Medium (Pre repair) readings were converted to Good/Excellent (Post repair) readings. Thus, it can be concluded that the Silo under study was successfully repaired and strengthened assuring its long life.
- However, Silo structures can also be strengthened and upgraded using certain new materials and techniques including **Post-Tensioning, Re-Hooping, Shotcreting or Guniting, Using Composite Fiber Reinforcement, Silo Liners, Ultra High Performance Fiber Reinforced Polymer (UHPFRC), Near Surface Mounted Fiber Reinforced Polymer (NSM FRP), etc.**

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