BREATHING LIFE INTO EXISTING STRUCTURE - ENHANCING SAFETY OF A CHEMICAL PLANT

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INTRODUCTION

Chemical plants are complex facilities with significant structural demands. Over time, various factors such as corrosion, weather-related deterioration and heavy machinery usage contribute to structural distress. This study focuses on a single storied chemical plant, heavily affected by persistent corrosion and leakages, leading to concrete cracking and spalling. The aim was to evaluate the structural integrity using NDT methods, followed by targeted strengthening to enhance the building's safety and serviceability.

BACKGROUND

The chemical plant in question exhibited multiple distress signals, including exposed corroded reinforcement, dampness, leaching, spalling, and cracks in concrete surfaces. These deteriorations posed significant risks to the structural stability, necessitating a thorough investigation and rehabilitation strategy.

Fig. 1: Distress in structural element

DETAILED STRUCTURAL ANALYSIS AND STRENGTHENING SOLUTIONS

STRUCTURAL ANALYSIS

1. **Initial Assessment:**
   - **Visual Inspection:** A thorough visual inspection was conducted to identify visible signs of distress such as cracks, spalling, and exposed reinforcement. This preliminary assessment provided a broad understanding of the extent of damage and helped pinpoint areas needing detailed investigation.
   - **Load Assessment:** Considering the industrial nature of the building, the loads acting on the structure were calculated. This included dead loads from the building materials and live loads from the machinery and operational activities. Special attention was given to take into consideration the impact of equipment vibrations.

2. **Non-Destructive Testing (NDT):**
   - **Ultrasonic Pulse Velocity (UPV) Test:** This test helped assess the quality and uniformity of the concrete. The results indicated significant variations, with many areas falling into the 'poor' and 'doubtful' categories, suggesting internal flaws and voids.
   - **Rebound Hammer Test:** This test measured the surface hardness of concrete and provided an estimation of the compressive strength. Results consistently showed values below the acceptable threshold, indicating weakened concrete.
   - **Core Strength Test:** Core samples were extracted and tested for compressive strength. The average strength was found to be below 15 MPa, significantly lower than the design requirements.
   - **Cover Meter Study:** This test determined the depth of concrete cover over the reinforcement bars, which is

crucial for protecting against corrosion. Inadequate cover was noted in several areas.

- **Carbonation and Half-Cell Potential Difference Tests:** These tests identified the depth of carbonation and the corrosion potential of reinforcement bars. High levels of carbonation and severe corrosion were detected.
- **Chloride Measurement Test:** Elevated chloride ion concentrations were found, which exacerbate corrosion of reinforcement bars.

STRENGTHENING SOLUTIONS

CONCRETE JACKETING FOR BEAMS AND COLUMNS

Concrete jacketing was identified as a primary strengthening technique for both beams and columns. The process began with unloading the existing structural elements as much as possible by using temporary supports like shoring and jacks. This was critical to reduce the stress on the beams and columns during the strengthening process.

For beams, the first step involved meticulous surface preparation, which entailed roughening the surface to remove contaminants such as grease, oil, and external dust particles. This preparation was crucial to improve the bond between the old and new concrete. Once the surface was adequately prepared, longitudinal and transverse reinforcement bars were added around the existing beams, with the longitudinal bars running parallel to the beam's length and the transverse bars positioned perpendicularly.

> **“This comprehensive process ensured the beams were significantly strengthened and made more durable, capable of bearing increased loads and having an extended service life.”**

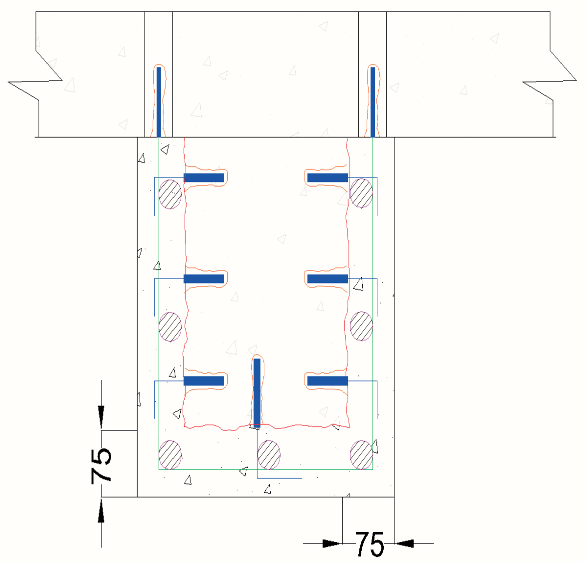
The beams were then encased on three sides with a 75 mm thick layer of reinforced concrete, forming a protective jacket that significantly enhanced the load-bearing capacity. Formwork was carefully installed to shape this new encasement, ensuring precision in the dimensions and contours. Following the setup of formwork, micro-concrete, known for its high strength and non-shrink properties, was poured to form the new jacket.

To ensure the new and existing concrete sections functioned as a composite whole and to prevent delamination under load, stirrups were placed in drilled holes, and dowels with adhesive anchors were installed, effectively interconnecting the two layers of concrete. Specific reinforcement details were meticulously followed: 16 mm diameter bars were provided as main bars, with 7 bars in total, essential for bearing tensile loads. Additionally, 8 mm diameter bars were used as shear keys with spacing of 150 mm center-to-center (c/c), which helped resist shear forces, and 8 mm diameter ties were also provided at 150 mm c/c spacing to maintain the shape and integrity of the concrete encasement. This comprehensive process ensured the beams were significantly strengthened and made more durable, capable of bearing increased loads and having an extended service life.

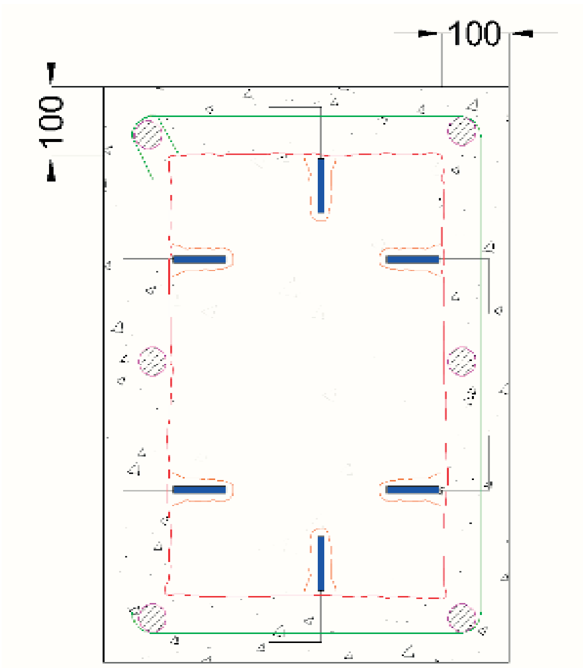
For the columns, a similar approach was taken with some key differences. First, the load on the existing columns was reduced by temporarily supporting the structure. Then, the column surfaces were roughened, cleaned, and a bonding agent was applied for good adhesion. The columns were encased with a 100 mm thick layer of reinforced concrete.

For longitudinal reinforcement, six 20 mm diameter bars were used, crucial for carrying the axial load and ensuring structural integrity. Transverse reinforcement involved 8 mm diameter bars, serving as shear keys and ties, spaced at 150 mm center-to-center. These bars resist shear forces and prevent diagonal cracking and buckling.

A clear cover of 40 mm was maintained to protect the reinforcement from environmental effects and ensure durability. Finally, non-shrink cementitious micro-concrete was used for encasing, chosen for its low shrinkage properties to minimize thermal cracking. This combination of materials and reinforcement ensures the strengthened columns can effectively support the structure while maintaining durability and safety.



Beam jacketing details



Column jacketing details

Fig. 2: Column & Beam Jacketing Details

SLAB STRENGTHENING

The slabs in the chemical plant were strengthened by adding additional steel reinforcement and laying welded wire fabric to reduce shrinkage cracks. This process began with a detailed assessment of the existing slab conditions, followed by the placement of the new reinforcement. Shotcreting, a method of spraying concrete onto a surface, was used to increase the slab thickness. This technique provided an additional layer of concrete, enhancing the load-carrying capacity of the slabs. The new concrete was carefully applied to ensure a uniform and consistent layer, avoiding any voids or weak spots.

EPOXY INJECTION GROUTING

For addressing cracks in various structural elements, low-viscous epoxy injection grouting was employed. This method involved injecting epoxy resin into cracks and microfissures in the concrete using non-returnable packers. The epoxy resin filled the cracks and voids, restoring the integrity and strength of the affected areas. The process was carefully controlled to ensure even distribution of the resin, which was critical for achieving a durable repair. The use of non-returnable packers helped ensure that the epoxy resin penetrated deep into the cracks and did not backflow, providing a long-lasting solution to the problem of cracks and fissures.

CORROSION PROTECTION

Given the severe corrosion observed in the reinforcement bars, anti-corrosive treatments were essential. The existing corroded reinforcement bars were treated with an anti-corrosive zinc-rich primer. This primer created a protective barrier on the steel surface, preventing further corrosion and extending the life of the reinforcement. Additionally, an anti-carbonation coating was applied to the entire structure. This coating was designed to prevent future carbonation, which could lead to further corrosion of the reinforcement bars and weakening of the concrete. By blocking the ingress of carbon dioxide and other corrosive elements, the anti-carbonation coating helped enhance the durability and serviceability of the structure.

Fig. 3: Concrete Jacketing of Column

IMPLEMENTATION AND QUALITY CONTROL

IMPLEMENTATION

The implementation of the strengthening process in the chemical plant was a meticulously planned and executed operation. It began with comprehensive site preparation, which involved clearing any debris, ensuring that the area was safe for workers, and setting up necessary equipment. Temporary structures, such as scaffolding and shoring, were erected to support the building loads during the strengthening process. This step was crucial to ensure the safety of the workers and the stability of the structure during the intervention.

One of the primary tasks in the implementation phase was the surface preparation of the existing concrete elements. This involved roughening and cleaning the surfaces to remove any contaminants such as grease, oil, and dust, which could impede the bonding of new concrete to the old. A bonding agent was applied to enhance the adhesion between the old and new materials, ensuring a strong and durable bond.

The next step was the installation of formwork, which was essential for shaping the new concrete and holding it in place until it cured. The formwork had to be precisely designed and constructed to match the specifications of the strengthening plan. For beams and columns, the formwork was installed to encase the elements in a new layer of reinforced concrete, typically 75 mm thick for beams and 100 mm thick for columns.

The placement of additional reinforcement was another critical task. Steel reinforcement bars and welded wire fabric were added to the existing structural elements to enhance their load-carrying capacity. This reinforcement was carefully positioned according to the structural analysis, ensuring optimal strength and stability.

Once the formwork and reinforcement were in place, the concrete pouring process began. For beam and column jacketing, non-shrink cementitious micro-concrete was used. This type of concrete was chosen for its low shrinkage properties and ability to minimize the generation of heat during hydration, reducing the risk of thermal cracking. The concrete was carefully mixed and poured to ensure uniformity and consistency, avoiding any air pockets or voids that could compromise the structural integrity.

QUALITY CONTROL

Quality control was an integral part of the strengthening process, ensuring that all activities were carried out according to the highest standards and specifications. The quality control process began with the selection of materials. Only high-quality, technically approved materials, such as micro-concrete and epoxy resins, were used to ensure durability and effectiveness.

Throughout the strengthening activities, continuous monitoring and inspection were conducted to ensure adherence to the design specifications. This included regular checks on the preparation and installation of formwork, the placement of reinforcement, and the mixing and pouring of concrete. Any deviations from the plan were promptly corrected to maintain the integrity of the structure.

Special attention was given to the epoxy injection grouting process, used to fill cracks and voids in the concrete. The injection process was carefully controlled to ensure even distribution of the epoxy resin, which was critical for restoring the structural integrity of the affected elements. The use of non-returnable packers helped in achieving precise injection and preventing backflow of the resin.

After the completion of the strengthening work, post-retrofit testing was conducted to verify the effectiveness of the interventions. This included repeat NDT methods such as ultrasonic pulse velocity tests, rebound hammer tests, and core strength tests to assess the quality and strength of the retrofitted elements. The results of these tests confirmed that the structural integrity had been significantly enhanced, meeting or exceeding the required standards.

In addition to technical inspections, the strengthening process also included rigorous documentation. Detailed records of all materials used, procedures followed, and tests conducted were maintained. This documentation served as a valuable reference for future maintenance and inspections, ensuring ongoing safety and performance of the chemical plant.

Overall, the meticulous implementation and stringent quality control measures ensured that the strengthening project was successfully executed, restoring the structural integrity and safety of the chemical plant. The combination of careful planning, high-quality materials, precise execution, and thorough testing provided a comprehensive solution to the structural challenges faced by the facility, ensuring its continued safe operation and longevity.

CONCLUSION

This case study underscores the critical importance of regular structural assessments and timely interventions in maintaining the safety and functionality of industrial facilities. The combination of thorough NDT, detailed structural analysis, and carefully executed strengthening measures successfully rehabilitated the chemical plant, ensuring its continued safe operation. The methodologies and techniques outlined provide a valuable reference for similar projects, highlighting best practices in structural strengthening.

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