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# Structural Retrofitting of a Reinforced Concrete Chimney

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***Abstract*****—** *In this study, structural strengthening on Turkey's oldest iron and steel factory, Iskenderun Iron and Steel Co. Ltd. (ISDEMIR)'s No:1 Blast Furnace Aspiration Concrete Chimneys were examined. These reinforced concrete chimneys were built according to the Russian standard in 1975. For reinforced concrete chimney concrete and reinforcing rebar, Russian Norm standards have been translated into norms that used in Turkey. For years, industrial dynamic effects, occurring in the region through strong winds and heavy industrial dust circulation in the chimney consisted of visible damage to the chimney. For the determination of the current status of the chimney infrared detection devices were used for the location, identification of reinforcement steel bars. Tensile tests were used on reinforcing bars to determine the material properties of steel rebar. Compressive tests were performed on concrete core samples. After a detailed investigation a concrete jacketing method is utilized to strengthened the 59.2 m long chimney. This study will summarize details of the strengthening on the chimney.*

***Keywords*****— Reinforced Concrete Chimney, Dynamic Analysis, Strengthening of Chimney, Reinforced Concrete Jacketing, Ambient vibration records.**

## I. INTRODUCTION

In parallel with the growth rate of industrial facilities, industrial buildings in our country are increasing. However Turkey does not have a standard about chimney design and construction. But dynamic analysis of the chimney is particularly important for industrial plants. If chimney collapsed any reason, not only it also many structures around it will be damaged. Therefore, engineers carry out studies on this subject for many years. Analytical methods for dynamic analysis the slender structures such as chimneys widely used (Chopra 1995, Karem and Hseih 1986). Especially in high chimneys, there are many studies that examine the effect of wind load (Ciesielski and Oruba 1996, Christens and Askegaard 1978). About dynamic behaviour of chimneys besides the analytical methods, experimental studies using the vibration records are also available (Brownjohn et al. 2010, Chmielewski et al. 2005, Cheng and Kareem 1992). Measurements technology is developing rapidly in recent years as a result of this some studies were carried out using GPS for vibration record from chimneys (Gorski 2015). Seismic analysis of reinforced chimneys and the causes damage in chimneys were also investigated (Huang et al. 2007). Tall and slender structures such as reinforced concrete chimneys need repair and strengthening in their service life. Two common methods are used fort his purpose. One of them is strengthened with fibber-reinforced polymers-FRP the other way is reinforced concrete jacketing. Karaca et al. 2015 is investigated effect of FRP strengthening in 75 meters high reinforced concrete chimney.

In this study, ISDEMIR (Iskenderun Iron and Stell) Factory, No:1 Blast Furnace Aspiration reinforced concrete chimneys will be evaluated according to the ACI 307-98 and the 2007 Earthquake Standard (Figure 1).

*Fig. 1: General view of the chimney*

Analyses of the current state and decided strengthening of reinforced concrete sections with jacketing. A careful examination was performed on the chimneys by field crews. The current status of the chimney was determined. Chimneys have been modelled in SAP2000 program. A total of 6 concrete cores, 3 rebar samples from each chimney were taken and tested in Building Material

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Laboratory. Quality of the concrete and rebar are determined. As a result of the assessment on the chimney concrete quality, rebar and general properties of chimneys were determined. The system features have been studied with the terms of use.

## II. TECHNICAL INFORMATION ABOUT THE CHIMNEY

During the raw materials transportation by the conveyor belt (iron ore and coal) a large amounts of power is created. Retaining powder, unloading and delivery system is called aspiration system. The chimney is a part of aspiration system and its construction was completed in 1975. Chimneys are also subjected to wind loads and the effects of vibration. According to the Russian Norms the B-225 (C-18) and AISI concrete reinforcement steel bars are used in the chimney that was calculated by the Russians. According to this standard reinforcing steel bars has got three stress values (AI: 2400 kg/cm2 , AII: 3000 kg/cm2, AIII: 4000 kg/cm2). As shown in Figure 2, the height of chimney is 59.20 m. In first 6 m the wall thickness is 0.60 m after this point the wall thickness is 0.20 m along to the chimney. The section continues with the same width to the 6 m and then top to the chimney. There are climbing ladder on the chimney and platforms at the 19.70 m and 56.70 m heights. Ladders 0.25 m x 0.25 m are mounted to the chimney with embedded members. In the section corresponding to the platforms spaces are left for the window. It's necessary to take dust measurements on the chimney.

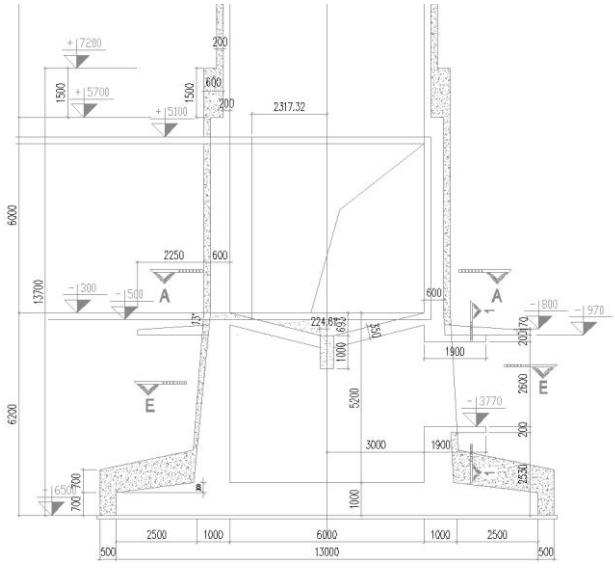


*Fig. 2: Detail of the chimney*

Chimney operating system can be summarized as follows: Absorbed dust from the Aspiration Systems goes to the collector. In here coarse powders are eroded by their weight to the dust bunker. Fine-grained dust which can not be retained by 7 bunkers enters into the dust battery. Fine-grained dust collapse with three drive to the bottom of the battery by the effect of cyclone. There are dry dust collection hopper and vacuum hoppers in the bottom of each dust bunkers. Fine-grained dust which can not be retained in the cyclone groups transported to the chimney with the aid of fans. Substituted dust is precipitated by showering system. In the chimney precipitated dust is sent through the channels to the mud pool. The water is cleaned in the mud pool and is given Aspiration System for use, the precipitated raw material powders are blended and dried in the mud channel for use as a raw material.

## III. DETERMINATION OF THE EXISTING STRUCTURAL SYSTEM (DESTRUCTIVE METHOD)

6 pieces of concrete core samples and 5 rebar samples were taken to determine the material properties of chimneys structures. According to the information level of The Turkish Earthquake Code 2007 "Comprehensive Information Level" has been assessed. Accordingly, the material strength is calculated by the following formula.

$F_{ck}$ = Min. Strength (cube compressive)

$F_{cd}$ = 0,85 x $F_{ck}$ (Cylinder design strength)

After the evaluation of the material properties of the existing structure, following processes are determined; The average strength of the concrete shows unexpected quality. A large difference between the experimental results are observed. The quality of the concrete was determined according to the results of the core samples: No. 1 characteristic compressive strength is (YF1) 142 kg/cm². The quality of the concrete is lower than expected, also received the aggregate gradation of cores was found poor. The rebar class determine close to the St-I class by the reinforced steel bar pull detection and tests (Figure 3).

*Fig. 3: Reinforced Steel Bar Pull Detection Activities*

The concrete samples were taken from chimney and tested (Figure 4). The average of carotene concrete samples is 23.13 Mpa. Standard deviation is calculated for this samples as 6.55. $F_{ck}$ value to be used in the model are calculated as follows $f_{ck}$= 0.85*(23.13-6.55)= 14.195.

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*Fig. 4: Taken concrete samples from chimney*

The results of the core samples from chimney presented in Table 1.

*Table.1: Results of the concrete pressure tests*

| No | Elevation (m) | Height (mm) | Diameter (mm) | Weight (gr) | Compressive strength (Mpa) |
|---|---|---|---|---|---|
| 1 | 1,5 | 75 | 75 | 762 | 29.80 |
| 2 | 20,0 | 75 | 75 | 700 | 16.7 |
| 3 | 30,0 | 75 | 75 | 658 | 22.90 |
| The average pressure value | | | | | 23.13 |

## IV. STRUCTURAL ANALYSIS AND DESIGN STUDIES

Even though the structure was built 1970, the seismic safety work of the structure is performed according to Turkish Earthquake Code 2007. The earthquake situation was taken as a main load. The wind loads was smaller than the earthquake loads (80 ~ 40 Tons). Iskenderun of Hatay Province is located in Seismic Zone 1 according to the 2007 Earthquake Code. For the structures located in Seismic Zone 1 the effective ground acceleration coefficient is Ao = 0.4, the industry structure of the building is used as, according to the 2007 earthquake building regulations importance factor is I = 1.0. According to Comprehensive information on the structure, the priority level coefficient is determined as 1. 2007 Earthquake performance assessment of the building's design influenced by the "safety of life" should be tried to capture a level of performance. Average of the existing structure characteristic compressive strength in accordance with the minimum compressive load values are shown as follows $f_{ck}$= 141.95 Kg/m² (cylinder) is taken as. The modulus of elasticity of concrete according to TS500 (Turkish Standard) , $E = 3250x\sqrt{fck} + 14000$, and No:1 chimney E = 262 447 Kg/m² . This value is determined as the present structural system is used in the analysis. The present structure as reinforcing steel $f_{yd}$ = 2 450 Kg/m². The structural behaviour factor R = 3 was adopted. Loads in the solution used is as follows: 20 cm shell weight 2,5 x 0,20 = 0,500 T/m² . The structure was modelled three dimensionally with material properties in SAP2000. Analysis results are shown in Figure 5.

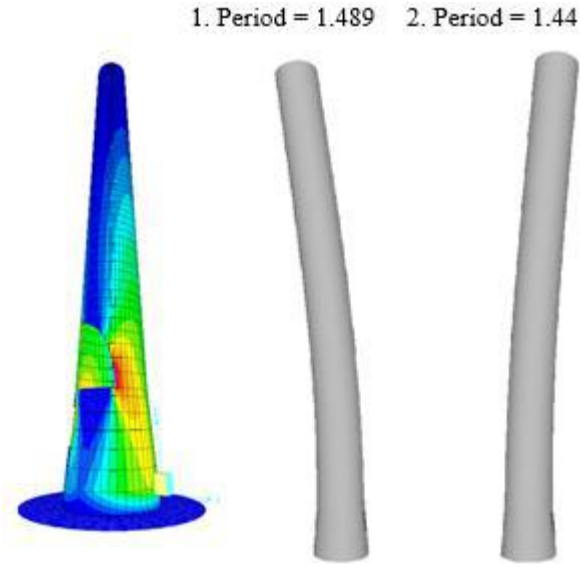


*Fig. 5: Chimney Model Results in SAP2000*

Vertical loads were investigated by the seismic effects according to the 2007 Turkish Earthquake Code. Seismic safety of structures were determined based on lateral loads. The capacity control table of reinforced chimney is presented in Table 3.

*Table 3. Capacity control of reinforced chimney*

| Section (cm) | High (meter) | Current reinforcement | Capacity of current RC (Ton/m) | Loading (Ton/m) |
|---|---|---|---|---|
| 100 | (-6.5)-(-0.3) | φ16/20 | 33.60 | 140.00 |
| 60 | -0.3—5.7 | φ32/20 | 134.40 | 170.00 |
| 20 | 5.7—20.0 | φ20/20 | 52.75 | 90.00 |
| 20 | 20.0—59.2 | φ16/20 | 33.60 | 60.00 |

Based on the analysis the utilization of jacketing system has been decided. The stress on the shell of the structure was analyzed with finite element method and jacket thickness was decided to be 0.20 m. The capacity control table for strengthened reinforced chimney with new section area in Table 4.

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*Table 4: New section properties of chimney*

| New Section (cm) | High (meter) | Capacity of current RC (Ton/m) | Demand reinforced area ($cm^2$) | New reinforcement in jacketing |
|---|---|---|---|---|
| 120 | (-6.5)-(-0.3) | 33.60 | 45.59 | φ26/20 |
| 80 | -0.3-5.7 | 134.40 | 17.97 | φ26/20 |
| 40 | 5.7-20.0 | 52.75 | 29.38 | φ22/20 |
| 40 | 20.0-59.2 | 33.60 | 15.45 | φ22/20 |

## V. STRUCTURAL STRENGTHENING WORKS

Anchor foundations made available to the chimney mantle has been initiated. Excavation width, taking into consideration the depth of the excavation is set. All necessary precautions to avoid contamination of the environment has been taken by the contractor. The rebars put the holes which was prepared before and filled by the chemical grout.

*Fig. 6: Anchor works in chimney foundation*

*Fig. 7: Anchor works in chimney body*

After fixing rebars to the existing structure, other reinforcement bars placed. After concreting the new reinforcement 7 days curing time was applied for maintenance. After curing period the material from the foundation excavation was refilled to existing holes and compaction was measured with proctor to be 95%. After filling according to the current state and the section the ground level covered with plain concrete of 200 dose. The surfaces of concrete elements were cleaned with compressed air from paint, plaster or mortar fragments. Additional jacket of concrete was specified in the project. Chimney anchors were driven into the body (Anchor works can be seen in figure 6 and 7). Roughening was made on the surface of the chimney from the top to down. Existing chimney surface was broken with a hammer to be 0.5 cm or 1 cm. Then the cleaning process was complete by pressure water. Anchor holes were drilled after cleaning the chimney surface. Jacketing process was done from bottom to top. The anchor hole diameter was larger than the diameter of rebar at least 4 mm. Anchor holes detected by metal detectors before opening existing rebar location. For the anchors at the most 5 cm horizontal or vertical displacement was allowed. After the opening of the drill hole, the hole was cleaned with compressed air. Moisture, dust etc. elements were removed from the holes. Process was performed with epoxy to prevent dusting of the anchor hole. Anchor rod holes were plated using the epoxy-based chemicals. During this action half-way anchor holes were filled with epoxy. Then the anchor rod pushed into the holes, it was observed that the epoxy come out a little. Thixotropic chemicals are used to prevent leakage of the chemicals flowing out from the anchor holes.

On the surface of rebar, dirt, oil, loose rust, burrs, any substance were not left to reduce or prevent adhesion to the concrete. The samples were taken from the rebars and tensile and chemical tests were performed on them. According to the results of the tests the rebars were permitted to use.

Climbing formwork system has been selected as the formwork system. However at the point of the aspiration system passes near the surface by flue pipe climbing formwork cannot be used. At these points formwork system was changed. Construction has been started with C30 quality concreting (1.5 m) on climbing formwork. For jacketing concrete vibration applied and segregation was not allowed. The jacketing thickness tolerance at least 6 mm up to 10 mm were considered. Concrete were allowed to spill with the pump up to 0.14 m slump. Because of the climbing formwork applications the slump and the range of aggregate were decided together with the company. The new concrete design was prepared by concrete plant. The samples were taken from the new design concrete that was made in the concrete plant and the test results received. During the pumping of decided concrete, the temperature in the mixer was controlled.

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Prepared and ready for spilling concrete mixture spilled within 2 hours after the plant output clock. The referral report which includes the mixture ratios and class has been requested in every shipment. 7-14-28 days samples were taken for pressure testing from the concrete. During this process in order to prevent labour errors samples were cast from the mixer which was waiting for spilling.
After the jacketing application the cores were taken the concrete after at least 1 month pouring and the situation of the core has been confirmed about pressure (Figure 8).

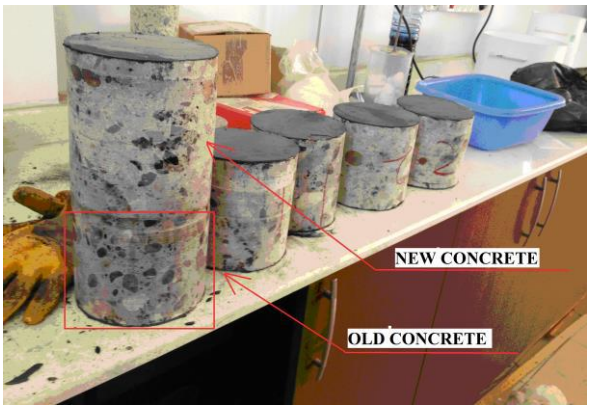


*Fig. 8: Concrete samples from chimney after jacketing*

Detected holes in the concrete before painting has been repaired with structural repair mortar. After jacketing application on the concrete surface 50 µ thick epoxy concrete primer was applied by roller with a roll of 200 µ thick surface tolerant epoxy intermediate coat paint, as top coat 50 µ thick polyurethane paint one coat is applied by a roller. Concrete primer and epoxy paint colours were chosen can be distinguished. Thus, the application could be controlled.

*Fig. 9: View of chimney after jacketing and after painting*

Starting from the top of the chimney last coat of paint to the red (RAL 3020) and white (RAL 9003) was to be painted as shown in figure 11. 25 m from the top portion red and white was chosen for the warning. The rest was painted gray (RAL 7040). (Figure 9.)

## VI. CONCLUSION

In this study structural retrofitting at the Blast Furnace Aspiration System which is located in ISDEMIR Inc. in Iskenderun were discussed. The chimney was built with different standards. Destructive and non-destructive tests were performed for determining the current status of the chimney. According to the results, reinforced concrete jacketing has been decided to increase the chimney section according to test results. Structural model was created using the results of the experiment. The stress on the shell of the structure was analyzed with finite element method and jacket thickness was decided to be 0.20 m. required tests are performed on construction materials before and after use of the work. As mentioned earlier there are no standards about the construction of the chimney in our country. In this study, a chimney which had been built with Russian Standard was analyzed with American and Turkish Standards (TS 500). At the end of the study jacketing method was decided to apply on the chimney. Strengthening application must focus the region between old and new concrete surfaces. Anchoring applications are related in various publications research but the adhesion between the two surfaces does not account for the anchor placement.

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