Structural Evaluation for Iraqi Ministry of Trade Building Exposed to Fire During 2003 War

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Abstract. Existing concrete structures may, for a variety of reasons, be found to be unsatisfactory. This could manifest itself by poor performance under service loading in the form of excessive deflections, cracking or inadequate ultimate strength and changing the main function. In such circumstances, there are two possible solutions i.e. demolish and rebuild or carry out a program of repair and strengthening. In this investigation, the structural evaluation and suggested repairing works were studied for Iraqi Ministry of Trade building, the building was exposed to fire, vandalism and looting during the war on Iraq at 2003. The building consists of twelve stories, ten stories have area about 1428m² and about 1150 m² area of middle and basement stories. Each story has height of 3.5m. The structure of building consists of one way ribbed slab with 900mm slab thickness and 0.15x0.7m rib sectional dimensions. The columns have dimensions 0.6x1.2m and height 3.5m. The girders, ribs, floors and columns were peeled and decayed, there are a several cracks wider than 0.4mm distributed on the beams and floors and several columns, the concrete floors were destroyed and that caused appearance of steel reinforcement, parts of concrete of column at the second floor were destroyed and the longitudinal reinforcement steel buckled outside dragging the transverse reinforcement, a high possibility of reduction in concrete strength caused by the fire effects happened during 2003 war but the steel dose not affected by the fire because of the concrete cover which protected reinforcement. From this investigation, there is no serious damage in the sense that it is imperative to demolish the building and recreate. The damage in the building, as indicated in this study require some repairs, known in the field of rehabilitation through chemical additives and steel structures are additional materials available in local markets. It necessary to minimize the additional dead loads and the use of Limestone partitions in their implementation Gypsum Board partitions or imported light partitions.

1. Introduction

These existing concrete structures may, for a variety of reasons, be found to be unsatisfactory. This could manifest itself by poor performance under service loading in the form of excessive deflections, cracking or inadequate ultimate strength and changing the main function. In such circumstances, there are two possible solutions i.e. demolish and rebuild or carry out a program of repair and strengthening. The choice between these alternatives depends on many important factors, such as basic material and labour costs, time during which the structure is out of the commission, and disruption of other facilities, in the presence of economic climate, the second alternative is becoming much more suitable, particularly if a simple, quick strengthening technique is available (1).

An important part of the responsibility of the structural engineer is to select, from many alternatives, the best structural system for the given conditions. The wise choice of a structural system is far more important, in its effect on overall economy and serviceability than refinement in proportioning the individual members (2).

The cost of repairing or strengthening and the time and disruption involved can often be considerable. Evacuation of all or part of a building, or a road closure in the case of bridges, may be necessary while the work is being carried out and these all add to the cost (3).

Other factors to be given consideration at similar work are (4):

- Effects of repair work on the environment (e.g. noise, dust, etc…).
- Structural considerations
- Preventing or slowing continued deterioration.
- Appearance of repaired concrete.
- Durability of chosen repair method.
Health and safety.
Rehabilitation of old or damaged structures as an alternative to replacing them is an option that is gaining importance. The repair of structural concrete elements following damage is not uncommon. Such repairs are often necessary in earthquake or hurricane zones (5), (6).

2. Building Description
The building consists of twelve stories. Ten stories have area about (1428m²) and about (1150 m²) area of middle and basement stories. Each story has height of (3.5m). The structure of building consists of one way ribbed slab with (0.09m) slab thickness and (0.15x0.7m) rib sectional dimensions. The columns have dimensions (0.6x1.2m), see Figure (1) and Figure (2).

Damage of Building
After visiting the building of the ministry of the trading, the following damages were recorded:
1. The girders, ribs, floors and columns were shelled and decayed; see Figure (3).
2. There are a several cracks wider than (0.4mm) distributed on the floors; see Figures (4).
3. The concrete floors were destroyed and that caused appearance of steel reinforcement, see Figure (5).
4. There are different wide cracks towards the longitudinal direction of the beam and extend through the beam width.
5. Parts of concrete from one of the sides view of column at the second floor were destroyed and the longitudinal reinforcement steel buckled outside dragging the transverse reinforcement. The column does not affect by the fire but perhaps by an explosion or shots; see Figure (6).
6. The concrete covers of the main and secondary beams were dropped out and the steel reinforcement was appeared; see Figure (7).
7. The interior faces of walls, beams, and columns of the basement were moisture with oxidation and the crowd of equipment led to deform the interior faces with several simple damages.
8. The scum was distributed over a large area of the interior of walls.
9. A high possibility of reduction in concrete strength caused by the fire effects happened during 2003 war but the steel dose not affected by the fire because of the concrete cover which protected reinforcement, so the cracks don't appear on the faces of the Reinforced concrete structural elements.
3. Test Results

Table (1), (2) and (3) demonstrate the non-destructive test results of core test (7), Schmidt hammer test (8), and ultrasonic test (9), (10) respectively, the position of each point are mentioned in these table. The beams, columns and girders were tested using ultrasonic test and hammer test, and the floors were tested by core test, see Figures (8), (9) and (10) respectively. From these tables, it can be concluded that the compressive strength of concrete members can be considered a structural concrete, these results will be used to reanalysis the building frame.

Table 1. Core Test Results

| No.   | Diam. D (mm) | Length L (mm) | L/D   | Compressive Strength (MPa) | Average |
|-------|--------------|---------------|-------|---------------------------|---------|
| 5th-F | 96           | 88            | 0.917 | 32.8                      |         |
| 4th-F | 96           | 86            | 0.895 | 39.4                      |         |
| 6th-F | 96           | 91            | 0.948 | 31.4                      | 34.14   |
| 7th-F | 96           | 76            | 0.792 | 36.6                      |         |
| 1st-F | 96           | 131           | 1.31  | 30.5                      |         |
Table 2. Ultrasonic Compressive strength Test Results
Where C : column, F : floor, B : beam, and G : girder
1, 2, 3 .... etc : is the position of the tested member on grid-1, grid-2, grid-3 ....etc.

| Floor          | Beam       | Column | Girder   |
|----------------|------------|--------|----------|
| Basement       | B1= 24.00  | C1=21.33| G1=19.33 |
|                | B2= 21.00  | CL=21.59|          |
|                | B1= 27.12  | C1=20.00| G1=26.41 |
| Ground Floor   | B2= 28.68  |        |          |
|                | B1= 38.36  |        |          |
| Mid Floor      | B1=28.65   | C1=19.89| G1=21.04 |
|                |            | C2=18.90|          |
| 1st Floor      | B1=26.58   | C1=23.00| G1=23.33 |
| 2nd Floor      | B1=18.00   | C1=25.00| G1=25.00 |
|                | B2=18.60   | C2=26.00| G2=26.00 |
|                | B1=25.50   | C1=22.00| G1=27.50 |
| 3rd Floor      | B2=21.50   | C2=26.50| G2=27.80 |
|                |            | G3=28.00|          |
| 4th Floor      | B1=20.00   | C1=21.10| G1=28.50 |
|                | B2=21.84   |        |          |
| 5th Floor      | B1=25.00   | C1=22.62| G1=28.23 |
|                | B3=20.00   | C1=18.50| G1=25.00 |
|                | B1=26.00   | C1=16.00| G2=25.00 |
| 6th Floor      | B2=24.00   | C1=18.00| G1=26.00 |
|                |              | C2=18.20| G2=20.00 |
|                |              | C3=22.50|          |
|                |              | C3=22.00|          |
| 7th Floor      | B2=28.40   | C1=18.20| G1=26.00 |
|                | B3=24.00   | C2=18.20| G2=20.00 |
| 8th Floor      | B1=26.00   | C1=20.36| G1=27.50 |
|                | B2=26.50   |        |          |
| 9th Floor      | B1=25.76   | C1=20.05|          |

Table 3. Hammer Test Results
Where C : column, F : floor, B : beam, and G : girder
1, 2, 3 .... etc : is the position of the tested member on grid-1, grid-2, grid-3 ....etc.

| Location No | Compressive Strength (MPa) | Location No | Compressive Strength (MPa) | Location No | Compressive Strength (MPa) |
|-------------|-----------------------------|-------------|-----------------------------|-------------|-----------------------------|
| 9th Floor - C. 1 | 28.3                     | 6th Floor - B.15 | 26.4                     | 1st Floor - B.50 | 32.7                    |
| 8th Floor - F. 3 | 29.0                     | 5th Floor - C.20 | 26.7                     | 1st Floor - G.52 | 32.0                    |
| 8th Floor - F. 4 | 29.0                     | 5th Floor - B.21 | 26.5                     | Intermediate Floor B. 53 | 31.1                    |
| 8th Floor - F. 5 | 22.7                     | 5th Floor - G.24 | 23.1                     | Intermediate Floor - C. 54 | 33.9                    |
| 8th Floor - F. 6 | 31.0                     | 5th Floor - G.25 | 19.64                    | Intermediate Floor - G. 55 | 32.0                    |
| 7th Floor - G.7 | 33.3                     | 4th Floor - G.31 | 20.21                    | Basement-B.50 | 30.8                    |
| 7th Floor - C. 8 | 23.95                    | 4th Floor - B.28 | 24.5                     | Basement-C. 62 | 36.2                    |
| 7th Floor - B. 10 | 26.4                    | 3rd Floor - G. 38 | 33.3                     | Basement-C. 63 | 35.4                    |
| 7th Floor - F. 10 | 23.1                    | 3rd Floor - C. 33 | 20.8                     | G. Floor-G. 59 | 30.7                    |
| 7th Floor - B. 11 | 23.6                    | 3rd Floor - B. 35 | 35.3                     | G. Floor-B. 58 | 30.0                    |
| 7th Floor - C. 12 | 23.1                    | 2nd Floor - C. 40 | 29.20                    | G. Floor-C. 59 | 30.2                    |
| 6th Floor - C. 13 | 24.9                    | 2nd Floor - C. 41 | 27.20                    | G. Floor-G. 56 | 28.8                    |
| 6th Floor - G.19 | 28.9                    | 2nd Floor - G. 45 | 28.4                     | G. Floor-B. 57 | 28.7                    |
| 6th Floor - C. 14 | 24.8                    | 1st Floor - C. 48 | 35.4                     |                     |                      |
4. Calculation and Rapier Work

4.1 Structural Design Criteria

Checking the exits structural members according to ACI 318-10 (Building Code Requirement for Structural Concrete) (11).

Design Loads According to ASCE 7-10 (12):
- Live load on roof = 2 kN/m2
- Live load on floor = 2.4 kN/m2

Materials:
- Tested yield stress of steel bars fy = 400 MPa.
- Clear Cover brought from site: · Roof = 10 mm, · Columns = 40 mm

4.1.1 Slab Design

Table (4) illustrates the calculations of slab reinforcement adopting the calculated minimum compressive strength (26.94 MPa) from non-destructive test and yield strength of steel.

Table 4. Slab Design Calculations

| Description                                             | Calculations                           |
|---------------------------------------------------------|----------------------------------------|
| Thickness of ribbed slab                                | 0.09 m                                 |
| Weight of slab                                          | 0.09x24 = 2.16 kN/m²                   |
| Compressive strength                                    | 26.94 MPa                              |
| Weight of tiles (thickness = 25mm) and weight of mortar | 1.25 kN/m²                             |
| Weight of gypsum plastering                             | 0.25 kN/m²                             |
| Weight of false ceiling                                 | 0.05 kN/m²                             |
| Extra load for furniture and others                     | 1 kN/m²                                |
| \[ \sum \text{Dead load} \]                             | 4.71 kN/m²                             |
| \[ \sum \text{Live load} \]                            | 2.4 kN/m²                              |
| \[ W_u = 1.2 \ D.L + 1.6 \ L.L \]                      | 9.49 kN/m²                             |
| \[ M_u = \frac{W_u L^2}{b} \] (Assumed as Simply Supported Slab for more Safety) | 0.87 kN.m/m

\[ \frac{d}{h} = 90 - 20 - 5 \]                           | 65 mm                                  |
| \[ \frac{R_u}{f_y} \frac{\sigma_{eq} \sigma_{es}}{f_y} \] | 0.228                                  |
| \[ M = \frac{0.85 \tau l'}{f_y} \]                     | 17.46                                  |
| \[ \rho = \frac{1}{\mu} (1 - \sqrt{1 - \frac{2MR}{f_y}}) \] | 0.00057                                |
4.1.2 Damaged Column Design

Table (5) illustrates the calculations of column reinforcement adopting the calculated minimum compressive strength (28.27 MPa) from non-destructive test and yield strength of steel.

| Description       | Calculations                                                                 |
|-------------------|------------------------------------------------------------------------------|
| Load on rib       | 9.49 \times \frac{1}{2} = 4.7 kN/m                                      |
| Weight of rib     | 0.15 \times 0.9 \times 9.49 = 1.28 kN/m                                    |
| Compressive strength | 28.27 MPa                                                                |
| Ultimate load on rib Wu rib | 1.28 \times 1.2 = 1.54 kN/m                              |
| Total weight on rib | 2 (4.7 + 1.54) = 12.48 kN/m                                      |
| Load on Column    | P_n = 12 \times [5.6 \times 12.48 \times 2 + 8.9 \times 12.48 \times 2] |
| Axial load        | P_n = 12 x [5.6 \times 12.48 \times 2 + 8.9 \times 12.48 \times 2] |
| Reinforcement     | P_n = A_g [0.85 f_c' + \rho_g (f_y - 0.85 f_c')]                           |
|                   | 4342 = 0.5 \times 1.2 \times [0.85 \times 28.27 + \rho_g (400 - 0.85 \times 28.27)] |
|                   | \rho_g = 0.0036                                                            |
|                   | use \rho_{min} = 0.01                                                       |
|                   | As = 0.01 \times 500 \times 1200 = 6000 mm^2                               |
|                   | Use 14Ø25 mm                                                               |

5 Structural Treatment

Initial steps to execute work required:

- Building is cleaned of all debris and waste with the removing of tiles mortar for floors.
- Structure is cleaned using the sand blast to show the true face of the member of construction and disposal of the residues of scam to be use of chemical treatment.
- It is necessary to ensure the surfaces of structural member are clean and dry before using the chemical process of repair. The repair process as follows:
  3.1 Floor Repair

As shown in Figure (11) and (12), the following procedure can be achieved to execute floor repair:

1. Injecting the cracks with low viscosity epoxy after ensuring a good cleaning of the dust.
2. The damaged steel bars were cut.
3. Damaged parts of slab are removed and replaced it with new concrete having same of properties and specifications as in drawings.
4. Casting the concrete floor and joined with the adjacent ceiling by using epoxy materials to get full interaction between old and new concrete surfaces. The compressive strength must be used not less than (25 MPa) and (400MPa) yield strength of steel as mentioned in design calculations.

![Figure 11. Replacing the Damaged Slab](image1)

![Figure 12. Injection of Cracked Slab](image2)
5.2 Beam Repair
As shown in Figure (13) and (14), the following procedure can be achieved to execute beam repair:
1. Injecting the cracks with low viscosity epoxy after ensuring a good cleaning of the dust.
2. Grouting works by using special cement and painting old concrete by using epoxy materials.
3. Installing carbon fiber strip around the beam (100mm width each 300mm) by using special epoxy.
4. Plastering the exterior face of the beam to give more strengthening and fair face of beam.

Figure 13. Injection the Cracked Beams

Figure 14. Wrapping the Beam with Carbon Fiber strips

5.3 Column repair
As shown in Figure (15) and (16), the following procedure can be achieved to execute column repair:
1. Injecting the cracks with low viscosity epoxy after ensuring a good cleaning of the dust.
2. Grouting works by using special type of cement and connect old and new concrete by using epoxy materials.
3. Reinforcing the column with ($24 \times 25$mm) as longitudinal reinforcement and ($4 \times 10@300$mm) as transverse reinforcement, is the same exist reinforcement, supposed that old steel was damaged.
4. Casting new concrete to confine new steel bars.
5. Installing steel angles at the corners of column connect together by steel strip a the corners.
6. Wrapping the column with carbon fiber strips.

Figure 15. Repairing of Columns

Figure 16. Procedure of Repairing Columns
6. Conclusions

The following conclusions and recommendations can be adopted in this study:

1. From what is mentioned in the above study and test results show us there is no serious damage in the sense that it is imperative to demolish the building and re-create. And the fact that the damage in the building, as indicated above require some repairs, known in the field of rehabilitation through chemical additives and steel structures are additional materials available in local markets.

2. To ensure the safety of building it necessary to minimize the additional dead loads and the use of Limestone partitions in their implementation Gypsum Board partitions or imported light partitions.

3. Repair work on damaged column by adding a new reinforcement around the column and the grouting of the damaged parts from the column and then install the steel angles at the corners.

4. The calculations of the load on building appeared that the live load that were originality located on the building are more than the weight of the water that entered to the basement. This is an indication that there is no damage due to the presence of the water in the basement of the building.

5. A walkway around the building must be constructed to avoid water entering to the basement due to the difference in level of the road and level of building.

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