Case Study for the Construction Repair of Destructive Skeleton Concrete Building by Lateral Forces

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ABSTRACT: The study deals with construction repair for destructive members in a skeleton concrete building which had been affected by lateral loads (explosive forces). The explosive forces came from the destruction of neighboring buildings by using explosive materials. This lead to breaking of a group of columns and cracking of the beams and slabs in this building .The failure of columns caused vertical displacement in levels of beams and slabs at different floors, the lower limit of deflection was 2.5 cm and the upper limit was 42.5 cm. The degree of destruction of members in the building was different according to the distance of members from the outside of the building, as the range affected lateral loads due to explosive forces.

The aim of the study was the application and evaluation of scientifically sound construction repair on this building, so that the building would be able to carry design loads and architectural requirements could be restored. This treatment was carried out by using Epoxy Adhesive Resin - type I material for crack widths less than 1mm and fixing plates and using epoxy material for crack widths more than 1mm. The parts of building having vertical displacements were jacked up by using hydraulic jacks having a capacity of 50 tones or 100 tones with jacking applied carefully and in equilibrium to avoid new cracks in the building. Those members (columns, beams, slabs) too severely damaged were removed and recast , and reconnected to the existing old concrete in these members by using expansive cement. The original design parameters and specifications used in the original design were retained.

1 INTRODUCTION

Exposed reinforced concrete structures either through age or to damage caused by errors in design or the manner of implementation or by the use of poor quality materials can cause problems in service. Typically deterioration results from the impact of environmental factors and circumstances surrounding it, such as sulfate salts or chlorides attacking the building (Neville, 2000), or by exposing buildings to forces exceeding the calculated design (Lateral Forces) which can result from impact or blast. These Lateral forces are not taken into account in the design and especially the design of the columns, and can thus lead to additional damage to the columns or can break them in multiple areas. Such destructive forces can also lead to vertical displacement (Deflection) in the levels of beams and slabs of various decks and this difference in vertical deflection can lead to the generation of strong shearing and bending moments in flexure, which generates stresses additional to these members of the construction (Wang- 1953), and hence the occurrence of damage, cracks and displacement resulting from the cracking of the columns. The result of either deterioration due to environmental factors or to destruction by explosive forces leads to problems for the construction and service sectors.

The process of demolition of damaged buildings and the impact of brainstorming requires economic costs and expensive waste of effort and time compared with the costs and efforts of repairing structurally when possible, while maintaining the final form of the building and fulfilling the basic requirements to them.

2 STRUCTURAL EVALUATION

The evaluation of the degree of damage to buildings is done through evaluation of the structural parts affected, which is an essential stage before taking the decision on the possibility of repair or even partial reconstruction of the building or whether to resort to demolition, and it should stand on some important details, including:-

2.1 *A general description of the building*

The building was an industrial building, built at the end of the 1970’s. The structure of the building was from reinforced concrete, consisting of two parts, each part consisted of seven portals, each containing part on two floors and the ground floor as well as shown in Figure (1).

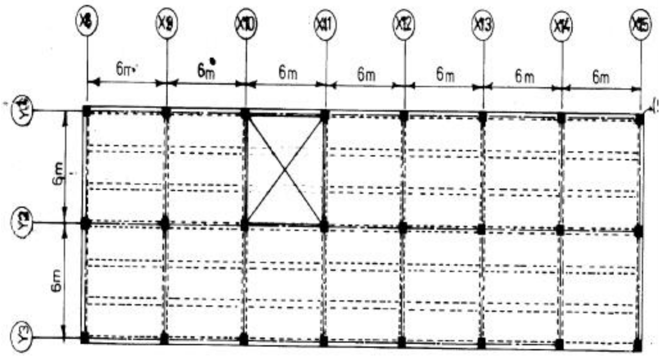


Figure 1.- The structural plan of the one part of the building

The buildings adjacent to the building in this study were destroyed as a result of bombardment with explosives, and this led to the failure of a set of columns which failed completely, and also to cracking of another set of columns, beams, and slabs which caused vertical displacement (Deflection) in the levels of beams and ceilings with different values for the various decks and beyond - in one of the areas to causing it to offset by 42.5 cm from the original level of the slab in the region of the column (X7-Y3), as shown in Figure (2) and Picture (1)

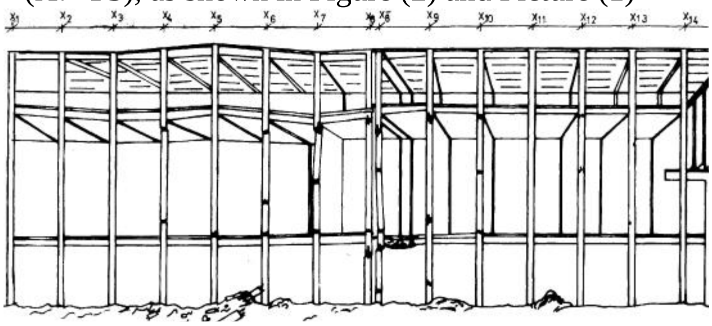


Figure 2. Graphic illustration of the building at the stage of the survey and pre-treatment

2.2 *Structural members were damaged*

The evaluation was based on the amount of exposure to the destructive structural forces and stresses that impacted on the assessment of the structural efficiency of the affected members and this can be summarized as follows:-

2.2.1 *Columns*

The initial survey of the columns showed that the damage occurred could be divided into two types:-

A - Columns affected by substantial damage (total failure), any breakup of the three areas of the end, the upper and the lower, middle and thus pushing the column from the end, or the upper to the bottom of the inside beams, as in the Picture (2), which generates a displacement in the level of beam and the slab for that area of various values, as shown in Table (1), and therefore require treatment to remove the broken columns, and to be near to the point of lift of the building.

Picture 1. The state of the building during the initial pretreatment (evaluation) stage.

Table 1. Columns damaged and the amount of deflection generated as a result of this damage in the slabs level

Floor	Column Position	Deflection (cm)
Ground Floor	X8--Y3	٢٫٥
Ground Floor	X8/ --Y3	٨
First Floor	X4--Y3	٧٫٥
First Floor	X6--Y3	٢٣٫٥
First Floor	X7--Y3	٤٢٫٥
First Floor	X8--Y3	٣٥٫٥
First Floor	X8/ --Y3	٣
First Floor	X9--Y3	٠
First Floor	X10 --Y3	٠

B- Columns less affected (with cracks in that could be treated: they were on the ground floor columns on the axes (X6-Y2), (X7-Y2) or on the first floor columns on the axes (X5-Y3), ((X11-Y3, (X12-Y3), ((X13-Y3).

2.2.2 *Beams*

Because of the differences for vertical deflection, shear forces and bending moments caused stresses in the beams which thus got cracks in the most confined beams between the affected columns and the size of this damage depended on the amount of damage to adjacent columns, as shown in Figure (3).

Picture 2. Samples of the columns affected by the substantial damage

Although inspection of the slab showed some areas where there was minor damage, some areas such as those located between grids (Y2-Y3/X8-X9), were much more damaged as in Picture (3), which required removal and re-casting.

Picture 3. damage occurring from the slab and secondary beams in the slab, located between grids (Y2-Y3/X8-X9)

3 STAGES FOR CONSTRUCTION TREATMENT

The Stages were included the following:-

3.1 *Soil Investigations*

The purpose of the investigation was to know the possibility of the soil to carry the foundations of the building, especially after the forces of a seismic impact on the soil, through a change in some of the engineering properties. After conducting these investigations (by the National Center for construction Laboratories, NCCL) the results were positive, so the effect was limited, and this stimulate the decision-making resulting in repair and partial reconstruction of the building.

3.2 Stages of Repairs

In the light of the positive results of the soil investigations the decision was made to address the building problems and not to resort to destroy it. In other words to address the members affected and to perform the functions required in terms of construction, service and the procedures for treatment in stages, as follows:-

3.2.1 *The Stage of Engineering Surveys for Levels of Columns , Beams and slabs.*

Surveys were completed of the building as illustrated in table (1), which showed the largest group of vertical displacement (42.5 cm) and horizontal displacement (25 cm) in the axis (X7-Y3).

3.2.2 *The Stage of Temporary Supporting (Initial) of the Building*

This phase required calculating the existing loads as shown in Table (3), by using Mechanical Jacks see Picture (4), because the building wasn't able to carry any vibrations' result removal the finishes floors of the work, especially the group of columns were had large damage, to provide safety work

Picture 4. Building during the initial phase of the supporting by Mechanical Jacks

3.2.3 *Removal of Finishes and restoring Flatness for the all Floors*

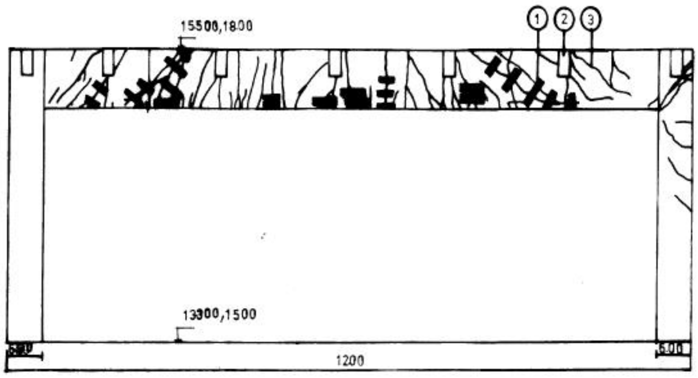
In order to reduce loads and to facilitate the process of lifting by hydraulic jacks, as well as damage to a section of the layers some materials were removed, ranging from a layer of concrete with waterproofing (15 cm), and with the removal of a flat layer, consisting of tiling by pre cast concrete units with a layer of tar and moisture-proofing materials.

3.2.4 Stage of Treatment of Cracks in Roofs and Main Beams.

Treatment is classified into two categories namely:-

A - Injection (Epoxy Adhesive Resin -Type I) with low viscosity, and properties as in Table (2). The resin was selected to satisfy the American Society for Testing and Materials (ASTM C881-02) for shear and flexural cracks with width (0.5-1) mm (U.S. Army Corps Engineers- 2001) as shown in Figure (3).

B - Injection (Epoxy Adhesive Resin -Type I) with fixed sheets of steel Plate width 5 cm and a thickness 0.5 cm, and a length depending on the location of cracks, by screws (Anchor Bolts), and perpendicular to the direction of cracks. This treatment was used for cracks greater than 1 mm (Minour-2001), as is shown both in Figures (3) and (4), in beams at ground and first floor beams on the axes (X4, X6, X7, X8, X8/, X9, X10).



1:The use of Epoxy with the installation of sheet steel width 5 cm and thickness of 0.5 cm to deal with crack widths larger than 1 mm.
2: Lintel secondary beam.
3: Use the Epoxy only to treat the crack widths less than 1 mm.

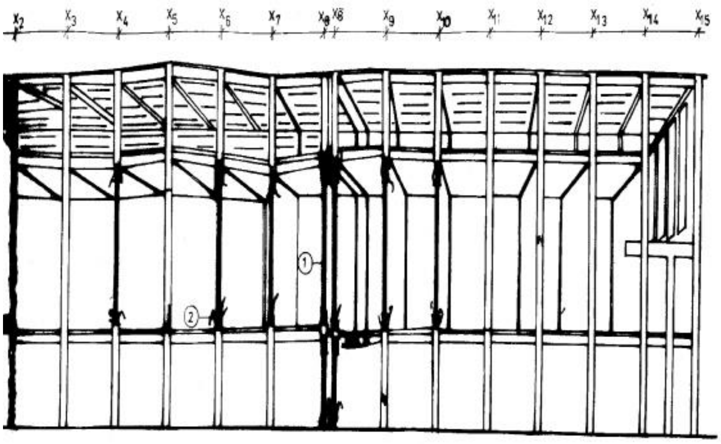
Figure 3. Section in a sample of beam described by the types of cracks occurring and methods of Repair

3.2.4 The Stage of Main Supporting of the Building

During this phase the building was supported by using steel columns section. The section of this columns is consist of (HP14 *17) installed on base plates at upper and lower ends with a dimension (50*50*3 cm) , and then insert in between the HP and the girder a built- up section in I –shape . This built- up I shape is consist of (W8X67) in web and welding to it two steel plates at the open sides and the same composite section will be used at flange as shown in Figure (5, 6), where the choice of these sections was not solely to prop up the building (AISC-Manual Steel-2003), but to provide greater space for freedom of action to the movement of hydraulic jacks on these sections to make it possible to break down and remove columns in damaged areas by lifting of the building as a whole in the areas of the columns of the ground floor on the axes (X8-Y3), (X8 /-Y3), and columns on the first floor on the axes (X4-Y3), (X6 - Y3), (X7-Y3), (X8-Y3), (X8 /-Y3), (X9-Y3) and (X10-Y3), taking care not to damage or generate shear forces at the beams on the ground floor.

Table 2. Properties of Epoxy Adhesive Resin -Type I used in the treatment of cracks

Test	Result test	(ASTM C881- 90) Limits
Viscosity (pa.s) grade 1	2	Not more than 2
Consistency (mm)	7	-
Setting time (sec.)	35	Not less than 30
Bonding strength at age (4days) N/mm^2	12	Not less than 10.3
Absorption (24 hours) Upper limit %	1	Not more than 1
Tensile strength at age (7days) N/mm^2	36	Not less than 34.5
Elongation at failure %	2	Not less than 1



1: A section of a steel column (HP14 * 17) with a base of sheet thickness 3 cm , 2: (Dowels Bar)

Figure 5. Graphic illustration of the building in the main supporting phase by the steel sections and lifting stage

3.2.5 Stage Crushing and Removal of Damaged Columns

The stage was of the process of crushing and removal of columns damaged completely (Full Failure) and where there was a vertical displacement and failure in the areas of connectivity with the beams with the plan to restore them later, as well as facilitating the process of lifting of the building, taking into account leaving the dowel bars from all ends of the top and bottom of the column where it been crushed and removed from its position , as shown in Picture(2) and Figure (6).

3.2.6 The Stage of Raising the Building

The lifting of the building was from the focal points (areas of broken column) as shown in Table (1) by two hydraulic jacks, with a capacity of 50 tons and the other 100 tons, to be equivalent to the loads that were actually present in the building in those points as shown in Table (4). Lifting was performed in a series of stages and parallel extent at sites lifted for the maintenance of the building, because the concrete is a brittle material (Neville-2000), where the amount of phase raised one (2.5 cm), and then supported and then directing the second phase so as to ensure beams and slabs were maintained level without the emergence of new cracks as a result of lifting, Table (5) illustrates the sequence and the amount of lifting at each point in the axes of the columns.

Table 3. The actual load at each point of the floors

Floor	Amount of Load during the Supporting Stage (Ton)	Amount of Load during the Lifting Stage (Ton)
Ground Floor	80	50
First Floor	60	42
Second Floor	27	27

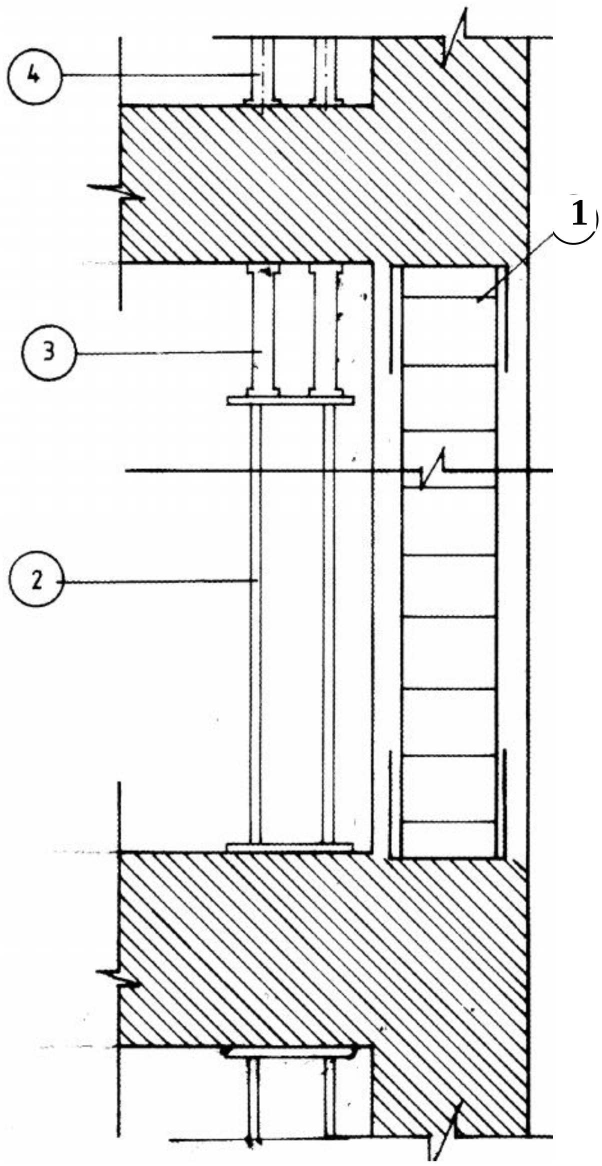
Floor	Axes Position	Amount of Lift at each Point (cm)
Ground Floor	X8-Y3	8
First Floor	X8-Y3	3
First Floor	X7-Y3	10
First Floor	X8-Y3	7.5
First Floor	X7-Y3	7
First Floor	X6-Y3	10
First Floor	X8-Y3	7
Ground Floor	X7-Y3	5
First Floor	X8-Y3	2.5
First Floor	X7-Y3	7
First Floor	X8-Y3	7.5
First Floor	X8-Y3	5
First Floor	X7-Y3	7.5
First Floor	X6-Y3	١٣٫٥
First Floor	X7-Y3	٦
First Floor	X8-Y3	٨٫٥
First Floor	X4-Y3	7.5

Table 4. The sequence and the amount of lift at each point of the columns

3.2.8 *Stage of Treatment and Repairs of the Damaged Members of the Building*

This stage was made after the process of lifting the building and included the repairs of each of the columns, the beams and ceilings as follows:-

A-Beams and Slabs: this included treatment of cracks in the beams that had emerged after lifting by the same method in paragraph (3.2.4). The treatment of failure in secondary beams for the slab in the confined region (X8-X9/Y2-Y3) as shown in Picture (3), had been broken and re-cast with reinforced concrete with a compressive strength of grade 25N/mm^2 and the distribution of the same reinforcement as was originally used in the structural design of the building, taking into account the interdependence between the treatment of old concrete and modern concrete mixes by using Expansive Cement (Orchard -1979).



1: The part that has been treated using expanded cement with link connection with dowel bars , **2**: A column of steel section (HP14 * 117) with the base plate thickness 3 cm. , **3**: The supports from steel built up section (W8 * 87) with plate thickness 1 cm. , **4**: Mechanical jacks.

Fig 6. Graphic illustration for the side view of damaged columns during the supporting stage by steel sections, lifting and re-casting stage

B – Treatment of columns: this consisted of two types:-

1 - Columns that were damaged completely by breaking down the columns shown in the Table (1), using the master plans of the building, the columns were replaced by columns of the same design, connected by dowel bars during treatment, as in paragraph(3.2.6) ,and then re-casting the concrete for the column with a compressive strength of grade (25N/mm^2) with processing of the last half meter of the length of the column by using a mixture of concrete where it been contained expansive cement to connect between new and old concrete (Orchard -1979), and also shown in Figure(6)

2- Columns with cracks: the ground floor columns, and columns on the first floor where it was processed by adding a casing (Ali -1998) , (Kadhim -1992) , by adding a layer to the dimensions of the reinforced concrete column from all directions, with rebars added to the annular and longitudinal steel, reinforcing the old concrete through punching the old concrete and rebar and drilling new holes in the treated areas to insert the new reinforcement in the floor, slab and columns, followed by grouting with Epoxy Adhesive as shown in Figure(7).

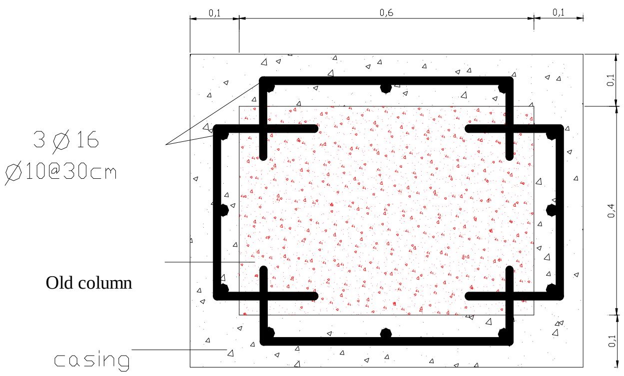


Figure7. Treatment of damage columns (simple) by using a casing of concrete

3.2.9 *Final Stage procedure to remove the supports and complete the work*

After the full maturation of the recast concrete to get the desired compressive strength of the concrete used in the new columns to remove: -

A - Mechanical supports in all floors.

B - Columns- sections of steel

Re-layer surfacing of the upper floor with the same specifications prepared with re-laying flooring to the first and second floors using a dehumidifier to remove moisture, to ensure that damaged concrete was free from dampness.

4 CONCLUSIONS AND RECOMMENDATION

Through the review of the building before, during and after treatment we reached the following conclusions:-

1 – The larger deflection observed in the column on the axis (X7-Y3) was 42.5 cm, prompting the process of lifting the building by hydraulic jacks in phases and each phase not exceeding 2.5 cm. This did not affect the nature of the building.

2 - column damage on the ground floor on the axes (X8 - Y3), (X8/--Y3), and the first floor on the axes (X4-Y3), ((X6-Y3), ((X7-Y3, ((X8- Y3, ((X8/-Y3, ((X9-Y3 and (X10-Y3), prompting the need to remove them before lifting the building by hydraulic jacks with the same method mentioned previously in paragraph (1) , and then re-casting them with the approved design specifications of the building.

3 - damage to a few columns on the ground floor and on the axes (X6-Y2),, and the first floor on the axes (X5-Y3), (X11-Y3), (X12-Y3) and (X13-Y3), which was handled by the encasing with reinforced concrete of thickness 10 cm on the perimeter columns.

4 – Treating the beams along the damaged column axes by using Epoxy resin for cracks less than 1 mm, with the use and installation of steel sheet width (5 cm) and thickness (0.5 mm) by anchor bolts for cracks larger than (1 mm).

5 - Removing the damaged portions of the slab in the area bounded by axes (X8-X9/Y2-Y3) and recasting with concrete with the same specifications and approved plans for the building design.

6- Working to open new horizons for the treatment of buildings that deserve treatment and returned to service, and on a scientific basis and to achieve the basic requirements depending on the scientific and practical experiences in this field.

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