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Rehabilitation of Reinforced Concrete Building Structurally and Geotechnically

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ABSTRACT: Cracks and slots in buildings occur due to various reasons, for example water leakage (rain water, sewerage, fresh water feeding pipes etc ...) to the foundations of the building. The aim of this paper is to know the reasons that lead to cracking and collapsing buildings and the solutions of the cracks appeared in the buildings through the study of the College of Commercial Studies building, in Sudan University of Science and Technology (Sudan) as a case study. In 2012 cracks appeared in walls and floors in the eastern side of the building case study and it was increased in 2013, therefore it was necessary to study the causes of these cracks and processed before they grow and lead building to collapse .a comprehensive study was conducted to the building included digging around and under the building to know if there were sources of water under the ground of building and also to study the type and properties of the soil layers. From the study it was found that there was a leakage of water from sewage pipes and fresh water supply pipes. Excavation work was done by digging 2 meters depth to know the foundations types. Soil samples were taken and tested in laboratory also destructive test for pile caps reinforced concrete and redesign of the building according to existing loads was done. Based on the results of the building structure design a number of solutions to resolve the problem of the settlement resulting from the water leakage and fracture in some piles was adopted .the pile caps enlarging solutions was adopted in order to distribute loads over large area and to reduced the loads on piles.

Keywords - *Rehabilitation; Building; Concrete; Cracks; Settlement; Sudan University of science and technology*.

I. INTRODUCTION

Buildings in ancient and classical ages (Greek and Roman) were constructed from light materials such as mud, or heavy materials such as rocks [1]. After the 18th century, the reinforced concrete was discovered as a main building material as well as structural steel, since that time, cracks, slots and collapse of building appeared that were constructed with reinforced concrete for different reasons [1]. It is known that cracks and slots occur on reinforced concrete when exposed to bending, shear or torsion. Also cracks and slots happen especially in the concrete when exposed to the hot weather or inappropriate environment or unfit position [2].

The buildings that collapse have structural defect or affected by circumstances that affected the components of the building and its materials as a result of the building being old or affected by destruction. The collapse of the building leads to catastrophic losses of losing people in addition to financial loses [3].

This paper discussed the reasons that cause cracks and slots of buildings through a study of building for commercial studies college at Sudan University of Science and Technology as a case study as well as solutions that were followed to solve cracks problems which appeared in the building.

II. THE COLLAPSE OF BUILDINGS

Buildings, like all structures, are designed to support certain loads without deforming excessively. The loads are the weights of people and objects, the weight of rain and snow and the pressure of wind--called live loads--and the dead load of the building itself. With buildings of a few floors, strength generally accompanies sufficient rigidity, and the design is mainly that of a roof that will keep the weather out while spanning large open spaces. With tall buildings of many floors, the roof is a minor matter, and the support of the weight of the building itself is the main consideration. Like long bridges, tall buildings are subject to catastrophic collapse.

The causes of building collapse can be classified under general headings to facilitate analysis. These headings are [4]:

- Bad Design
- Faulty Construction
- Foundation Failure
- Extraordinary Loads
- Unexpected Failure Modes
- Combination of Causes

Bad design does not mean only errors of computation, but a failure to take into account the loads the structure will be called upon to carry, erroneous theories, reliance on inaccurate data, ignorance of the effects of repeated or impulsive stresses, and improper choice of materials or misunderstanding of their properties. The engineer is responsible for these failures, which are created at the drawing board [4].

Faulty construction has been the most important cause of structural failure. The engineer is also at fault here, if inspection has been lax. This includes the use of salty sand to make concrete, the substitution of inferior steel for that specified, bad riveting or even improper tightening torque of nuts, excessive use of the drift pin to make holes line up, bad welds, and other practices well known to the construction worker [4].

Even an excellently designed and constructed structure will not stand on a bad foundation. Although the structure will carry its loads, the earth beneath it may not. Extra ordinary loads are often natural, such as repeated heavy snowfalls, or the shaking of an earthquake, or the winds of a hurricane. A building that is intended to stand for some years should be able to meet these challenges. A flimsy flexible structure may avoid destruction in an earthquake, while a solid masonry building would be destroyed. Earthquakes may cause foundation problems when moist filled land liquefies [4].

Cracks and slots occur in buildings due to different reasons, some external reasons which are e.g. big trees near buildings, high building near low one, and fast roads near them. There are also some natural reasons such as natural catastrophes which are unexpected e.g. earthquakes, volcanoes, storms etc. which should be considered when designing buildings adding to that winds, temperature, ice, salts, water vapor and humidity. Some of reasons also are deficiencies soil studies which cause an overall collapse to building [4].

Some of the reasons of cracks and slots are deficiencies of studying footings which are transfer building loads to suitable establishment soil. Some of the important reasons of cracks are underground water that exist in the foundation level which lead to a defect in the footings causing building to collapse, also appearance of cracks and slots, or a complete collapse in case of no repair[2].

Some of the reasons also are deficiencies in studying reinforced concrete by adjusting proportions constituent materials mix concrete (cement, aggregates, sand, water, and various additives, if any), and the deficiencies in the structural design of the building leads also to the occurrence of cracks and fissures[2].

III. TREATMENT OF CRACKS AND REPAIRING OF CONCRETE BUILDINGS

Concrete buildings need to be treated when cracks and slots appear in any part of the building. There are many ways for treating. There are also many materials used to treat cracks and slots in concrete buildings [4].

Organic and cement polymers and epoxy binders are used; they are flexible compounds or resinous or solidified. Epoxy is characterized by adhesive to concrete and iron and less contraction and high pressure. Some of the organic binders used to treat cracks are thermoplastic and acrylamide binder which quickly hardening and also used to fill cracks when damp to stop running out water.

Cracks and fissures of concrete are treated with injection, where some holes are made around the crack in the external wall by a machine and then fixing a material of two chemical materials after mixture in blender and operating the machine that gives 600 bar and injection materials that interact with water and humidity so get bigger and stop running out water when wearing out concrete and fibered modified cement (small holes) is used that the mixture is soft. When wearing out concrete largely, micro concert aureate (big holes) is used that the mixture is hard by adding gravel [4].

IV. BUILDING GENERAL DESCRIPTION

The building under consideration is located in Khartoum city, Sudan at Al Mugran area at Sudan University of Science and Technology. The building was constructed in the mid-fifties of the last century, as housing for teaching staff (occupational college).The building consists of five storeys, the ground storey is free of building and was used as parking, and the four storeys consist of two apartments for each storey as housing for staff until 2004. In 2005 the building was turned into offices for education. A redesign took place to the building architecturally to include libraries and offices in the ground storey, whereas the four storeys were architecturally redesigned to include offices, study halls, seminar halls and a library as shown in Fig 1, 2, and 3**.**

The building under study is a reinforced concrete framed building. The foundations of the building are the piles foundations to a depth of about 6 meters and concrete columns, beams and slabs with beams. The building consists of five storeys used as mentioned above .internal and external joints constructed of ordinary red bricks and cement mix with painting and other parts were covered with thermal bricks as shown in Fig.1.

Figure 1. The exterior of building before rehabilitation

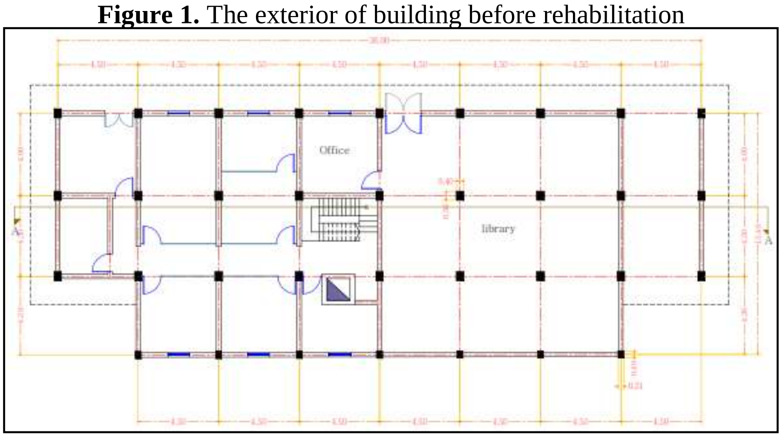

Figure 2. Ground floor after it has been transferred from parking to library and offices

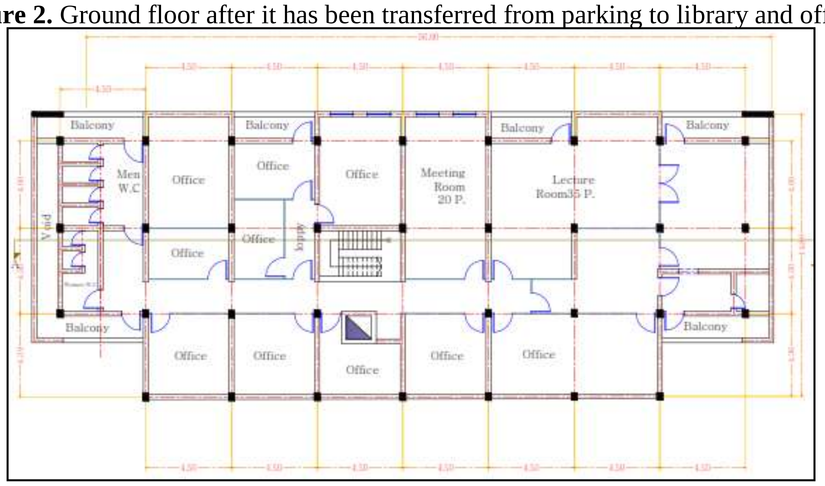

Figure 3. First floor after it has been transferred from two apartments to offices

V. THE PROBLEM OF THE STUDY

The problem which encountered this building was the appearance of cracks since 2012 in different parts of the building, especially eastern part. Cracks appeared in walls, floors and beams. The workers noticed these cracks in 2013 and when they increased, they informed the university directorate to treat the building. A team of engineers from engineering administration in Sudan University of science and technology was formed to check the building and write a report about it. The team concluded the following observations:

1) There are long cracks and springs in the dean's office, electronic library, the internal bathroom of the dean's office, dean's vice office in the first and third storeys in the southern eastern part of the building.
2) A collapse of part of false ceiling in those offices as a result of floor movement and walls and their cracks.
3) Appearance of cracks also in the third and fourth storeys in the office lying in the southern eastern part of the building.
4) The team noticed increase of cracks remarkably during two months.
5) Water leaking appeared from drainage network of bathrooms.

According to these observations, it was very important to make an accurate study to know the reasons of cracks and slots and treating them urgently as shown in Fig.4.

Figure 4 shows pictures of the cracks that have occurred in the building at different floors (the eastern and south-eastern part of the building)

VI. CASE STUDY METHODOLOGY

This study adopted survey method and visual observation to implement the building and laboratory test and different test to elements of building and soil that is through the following points:

1) Study of soil under the building to know its engineering characteristics.
2) Following up building decline through survey study making two reference points in the northern and southern side for cadastral survey.
3) Observing cracks in walls.
4) Diggings around the building to particular depths to know water sources under the building.
5) Digging and uncovering some foundations to know their types and conditions.
6) Making drawings to the building and calculating loads on footing at the level of founding.

6.1 Study of the soil under the building to know its engineering characteristics and the level of underground water

6.1.1 soil mechanic study:

Two pits of 10 and 15 meters were dug by a digging machine placed in a vehicle and by using a drilling rig as shown in Figure 5 to take sample of the soil to test it and know the level of underground water, two samples of the soil were taken, and the first sample was stabled soil. And was taken by meter until 3-meter-deep from each pit, the second sample was dislocated soil, it was taken by meter of drilling rig and from standard penetration test tube.

Figure 5 shows the drilling machine to a depth of 10 to 15 meters

Standard penetration test was made in the location by inserting ironic tube 50 mm diameter and 450 lengths by knocking by a hammer weighing 64 kg from 760 mm height to penetrate the soil in depth of 450 mm, then counting number of knocking (N) to last 300 mm. The result of this test as follows:

1) High plasticity clay layer (CH) extending from land surface until 7 meter deep.
2) Low silt layer to high plasticity (MH to LH) extending from 7-meter-deep to 14 meter.
3) Sandy layer under 14 meter deep.

Laboratory tests were made according to British standards (BS 1377 "1990") [5] depending on a consultant office (Engineering Services& Design) for the purpose of physical and chemical characteristics for soil samples which was taken during digging, and they included:

1) Atterberg limits, these tests are made in the soil to determine its structure; also this test gives limits of liquidity and plasticity.
2) Grain size distribution test. It was determined to location soil in the laboratory.
3) The natural water content, it was determined in the location of dislocated soil and in the laboratory of stabled soil. It was found that the natural water content higher than plasticity limit in this location what indicates soil saturation with water under building.
4) Undrained and unconsolidated triaxle test. It was done from stabled soil sample to assess soil for cutting.
5) Consolidation test result. It was done for two samples of stabled soil to assess pressure and deformation of soil.

6.1.2 underground water level:

The level of underground water is considered of the important elements for geo-technical studies especially if the underground water level to implement bases that most technical problems related to the soil is due to underground water. The water level is measured just after discovering it and daily measured at the beginning and end of work day, it was found that the water level in the two pits 4.5-meter-deep under normal land surface, this water is not underground water, it is, surface water.

6.1.3 Manual digging of soil:

Five manually pits were dug as shown in Table 1 for the purpose of uncovered tests and examining soil layers in nature and taking a photo of if, and uncovering bases to know kind of foundation and depth. Fig.6 shows location of digging. Through describing soil samples and laboratory tests, it was clear that soil layers consist of clay soil with high plasticity.

Table 1 shows the number of hand-dug digging and deep inside

Test pit (T.P) No	Depth(m)
1	3.0
2	3.0
3	3.0
4	1.5
5	2.0

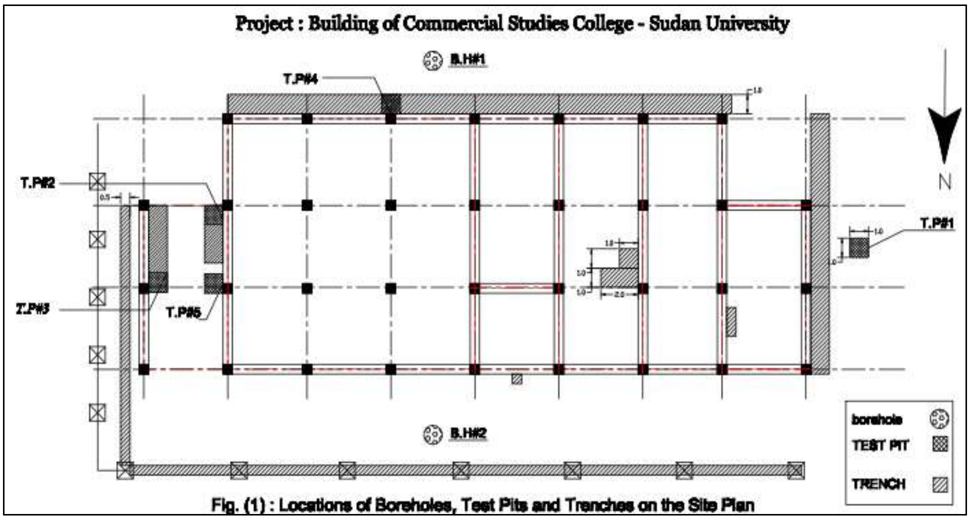

Figure 6 The plan of building shows the locations of digging

6.2 Settlement observation*:*

Observation of the building was made during study period and appropriate suggestions were made and they included:

1) Appointing control points in the location (Bench Mark) (BM1, BM2) to take readings of the building.
2) Appointing and fixing on a number of columns around the building for reading on and then comparing them to (Bench Marks).
3) Taking survey reading of pillars by a device 2-NKA with dates shown in the table 2 below.
4) Through survey observation from 3/6/2013 - 27/6/2013. There were no significant differences of reading taken indicating relative settlement of the building unlike what was in the period 2012 and 2013, as well as settlement degree did not exceed 3 mm.

Table .2 shows survey reading of columns from 3/6/2013 to 27/6/2013**.**

	3/6/2013		6/6/2013		13/6/2013		20/6/2013		27/6/2013	
BM1 100	1.402	101.402	1.519	101.519	1.493	101.493	1.51	101.51	1.553	101.553
BM2 (99.867)	1207	101.074	1.276	101.263	1.236	101.103	1.239	101.106	1.297	101.164
N1	0.911	100.491	1.027	100.492	1	100.493	1.019	100.491	1.061	100.492
N2	0.896	100.506	1.014	100.505	0.988	100.505	1.006	100.504	1.048	100.505
N3	0.805	100.597	0.921	100.598	0.896	100.597	0.913	100.597	0.955	100.598
N4	0.901	100.501	1.019	100.5	0.993	100.5	1.011	100.499	1.054	100.499
N5	0.904	100.498	1.020	100.499	0.994	100.499	1.012	100.498	1.055	100.498
E1	0.93	100.381	0.761	100.382	0.721	100.382	0.725	100.381	0.782	100.382
E2	1.1	99.974	1.17	99.973	1.13	99.973	1.132	99.974	1.19	99.974
S1	0.837	100.237	0.904	100.24	0.863	100..24	0.867	100.239	0.925	100.239
S2	0.791	100.283	0.861	100.282	0.821	100.282	0.824	100.282	0.882	100.282
S3	0.803	100.271	0.872	100.271	0.832	100.271	0.836	100.271	0.894	100.27

6.3 Cracks observation*:*

There are two types of cracks that occurred in the building, they are vertical cracks and another inclined with angle 45 approximately as mentioned in Table 3. Glass slices were put on the wall in places of cracks to observe them; these slices were fixed by cold welding in perpendicular directions on crack sides during study period (2/6/2013 to 26/6/2013). In case of move cracking, this leads to glass slices to move or breaking them. The slices were daily observed during mentioned period, it was found that they were stabled, but cracks may increase if under land water saturation continues.

Table 3 shows number of slices and their places in the building

storey	Number of glass slices	office	Kind of cracks
First	5	College's dean	Inclined crack angle 45
	1	Dean's vice	
Second	1	Costing department	Vertical cracks
	1	Lecture-office	Inclined crack angle 45
Third	1	Computer lab	Vertical cracks

Fourth	2	Graduate studies library	Inclined crack angle 45
Fifth	1	surface	

6.4 Water sources under the building:

After digging under the building it was found the elevator room was full of water and walls saturated with water nearly to the normal land. Through study it was clear that water sources under the building perched in sewerage and some leaking from supply pipes. When following up and uncovering sewers of sewerage and supply pipes, the following water sources appeared:

1) There was water around toilets which located in distance 1.0 meter south of the building. This water resulted from a break in drainage pipes extending into inspection and leaking room from internal vent vales to supply water. This water caused fall of passage between the building and toilets leading to water running out under the building.
2) There are toilets in western part of the building for all storeys; they are drained by the line extending down at the northern-western corner. An apparent break was found at convergence of line extending down with the horizontal line. This led to water leaking under the building.
3) The main inspection room was found lying at distance of 2.5 meter from northern-western side and also cracks in its wall and separation of walls from the basis, this leads to water running out under the building especially in case of closing general sewerage pipes.
4) It was found also cracks and slots in the inspection room lying west of the building leading to water running out under the building.
5) Other breaks were found in drainage line extending from services until in the first and second storey ranging from 15-20 cm. The water of this line flow around the building and the leaking under the building.

Figure.7 some pictures show cracks of drainage pipes leading to water leaking under the building

6.5 Identifying size and depth of building foundations and testing the reinforcing concrete:

Digging was made to uncover five footings, three internal footings (footing No 1), (footing No2) and (footing No 5) and two end footings (footing No 3), (footing No 4) digging was 1.7-meter-deep the following Table 4 shows that.

Table 4 Pile cap shape, numbers and dimensions

Kind of pile cap	Shape of pile cap	number	Dimension of pile cap	Thickness of pile cap	Depth of footing
1	Semi-triangle	17	0.4x1.7x1.7	0.9	6
2	Rectangle	15	0.7x1.75	0.9	6
3	square	2	0.7x1.7	0.9	6

- Effect of water leaking and cracks on the highest piles at the point of joining with the pile cap and some corrosion on the columns as a result of crust or relative settlement or weak happening swelling.
- Appearance of a break in two piles at the columns B-8.
- A hammer test was made for crown concrete and identifying resistance and strength of concrete.
- A test was made to identify resistance of reinforcement steel used and kind of diameters and number and method of distribution.


Figure 8. Pictures of the building during a digging to see the foundation type and water sources under building


Figure 9 shows the rectangular and triangular pile caps

6.6 **Characteristics of materials used and implemented actually according to test results*:***
- Concrete strength may be considered 25 N/mm^2 from average of pulpar tests, hammer tests and visual inspection.
- Using Ukrainian reinforcement steel with tensile strength of 400 N/mm^2.
- Soil bearing capacity on which the building is constructed is 250 kN/m^2 at distance 2.5 meter from land surface.
- Vertical spring parameter of soil 25000 kN/m^2/m and horizontal parameter 12500 kN/m^2/m.
- Concrete density 24 kN/m^3. Concrete cover for all sections underground is 50 mm.
- Weight of walls of normal red bricks with cement coverage on both sides which in the buildings in all storeys 18 kN/m^3.

6.7 Loads taken in designing review according to British and European code:
- Self-weights of concrete used for concrete density is 25 kN/m^3.
- Finishing load is 1.5 kN/m^2.
- Walls load is 4.5 kN/m^2.
- Walls load on great beam 13.5 kN/m, all buildings of red bricks with cement coverage with measure of 20 x 20 x 5 cm.

6.8 Structural model of the building:
- Structural software (axis VM) version 10, (it is a licensed program for structural analysis and design of the building) was used.
- Data entry was made about the building, defining beams, slabs, stairs and footings. The height of every storey was considered (3.2 meter).
- Three-dimensional Structural model was made for the building twice. In the first time the type was made before suggestion of treating footings and the second time after the suggested treating by transferring footings to isolated footings, the pillars were defined and ceilings grade beam and entering test results related to the building of concrete and steel. The loads mentioned in item 6.7 were adopted in reviewing design.

VII. PROPOSED REHABILITATION SYSTEM

A study of two proposals was made to strengthen the building and they are as follows:

a. **The first suggestion**:

Making additional piles with 600 mm diameter and 6-meter length that is by adding two piles for each bases and increasing the pile caps to that bases in order to achieve structural safety from shearing force , deflection and design load. This case requires safety of all piles previously implemented.

***b.* The second suggestion:**

Transferring current system of bases to isolated footings and ignoring implemented piles exiting and determined dimension of basis based on soil bearing capacity and allowed settlement and making sure that (one-way shear) and (two-way shear) have no effect at piles and around implemented basis as shown in Figure 10. In case of selecting this suggestion, the following must be checked:

1) The previous system has no any effect with regard to (one-way shear) and (two-way shear) and that around the greater force the columns exposed to.
2) All bases fulfilled design conditions according to British or European code that used.

Figure 10 .Shows The Pile Caps Suggestion Rehabilitation System process

VIII. ANALYSIS RESULTS AND SELECTING APPROPRIATE WAY OF STRENGTHENING

After reviewing design and making structural model for the two mentioned proposals, we found that the best is to transfer current system of footings to completely isolated footings and ignoring exiting implemented piles especially after appearance of fracture in some piles, marking measurement of footing based on soil bearing capacity and allowed settlement after making sure that (one-way shear) and (two-way shear) have no effect at piles and around implemented basis (the exiting pile cap). By using these suggestions and from analysis results we concluded the following:

1. Load combinations were used according to British and European codes.
2. Making all current footings (pile cap) bigger to a basis of (3.00 x 3.00 x 1.00 m) by increasing the current pile cap and implanting steel bar 16mm diameter and 13 cm space and fixing by epoxy and bottom and top reinforcement φ 16 @ 15 mm c/c in the two directions as shown in Figure. 10.
3. Structural analysis found the working load is 1929kN and this is the force which taken in bases design and was appointed for equally settlement.
4. Swelling pressure value 50 kN/m^2 equal to 540 kN of bases and 500 kN of piles (total of 1040 kN) comparing it to self-weight a force of 1540 equal to 1.48 parameter safe against any reversal move that may affect the building.
5. No need for lateral beams on base to prevent differential settlement.
6. Increasing basis thickness of 1000 mm to resist shear and settlement force.
7. The greatest settlement value calculated of structural model 25 mm which is allowed.
8. The greatest crack with value 0.19 mm which is allowed.
9. It was made sure that one-way shear and two-way shear- allowed.
10. Current concrete resistance of piles caps allows strengthening.
11. At all levels of analysis and design, water leaking was considered and adopting final control plan and permanent corrective.

12. Triangular pile caps were considered that enlargement will be appropriate for implanting which must be paralleled for reinforcement steel exiting in pile caps.

IX. RECOMMENDATIONS

The suggestion adopted to solve the problem of this building by increasing size of pile caps and transferring them to isolated footings, was the optimum solution that increase efficiency of bases keeping them safe and distribute loads of five storeys building .also this solution is easy to implement compared to other solutions, therefore, we recommended the following for similar projects which may have such problems:

1. Digging around the building when necessary to identify if there is water leaking from different sources under it.
2. Digging to uncover bases and identify their types and safety, if there is water under bases and around.
3. Studying the soil and analyzing it to identify its engineering characteristics.
4. Testing structural members to make sure it is safe and identifies descriptions of building materials consisting them especially steel reinforcement, number of bar, diameter of bar and concrete strength .
5. Redesign of the building structurally based on loads given.
6. Making different suggestions for treatment process.

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