

Determination of the Stresses Concentration Factor and Cracks Growth in the Buildings by Finite Element Method

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Abstract

The novel analysis of two buildings A and B, by finite element method via ANSYS software and experimentally are presented. The investigation is carried out to show the stresses distribution and the deflections and the cracks propagation in the walls and concrete slabs and beams for the two buildings. In both buildings the investigation included load-deflection curves, stresses and cracks patterns. The stress concentration factor is calculated for two buildings. Results are shown that the factor of concentrated for building A is between (8.4-11.4) for walls contain four windows and (6.1-7.4) for walls contain two doors, while in building B the factor of concentrated is between (13.4-14.1) for walls contain one door, and (13.9-14.6) for walls contain three windows. Also the results indicated that the cracks growth in the sites of high concentrated stresses and the load-deflection curve are approximately linear even with different loads.

Keywords: concrete; cracks ;finite element method; stress concentration factor

حساب معامل تركيز الاجهادات ونمو الشقوق في الابنية بواسطة طريقة العناصر المحددة

الخلاصة

في هذا البحث تم دراسة وتحليل بنايتين (A و B) عمليا وبطريقة العناصر المحددة من خلال برنامج ANSYS. حيث أجريت الدراسة لمعرفة معامل تركيز الاجهاد و توزيع الاجهادات و الأزاحات ومدى تغلغل الشقوق داخل الجدران والسقوف الكونكريتية والأعتاب. تم الحصول على منحنيات الحمل مع الأزاحة، الاجهادات ونماذج التشققات. وتم حساب معامل تركيز الاجهادات للبنايتين ، فكانت قيمته للبناية (A) (8.4-11.4) للجدران التي تحتوي على أربع شبابيك و(7.4-6.1) للجدران التي تحتوي على بابين , أما للبناية (B) فكانت قيمته (13.4-14.1) للجدران التي تحتوي على باب واحد و(13.9-14.6) للجدران التي تحتوي على ثلاث شبابيك. وأظهرت النتائج أن التشققات تتمركز في المناطق ذات الاجهادات العالية وكذلك تبين النتائج أن منحنيات الأزاحة - الحمل تقريبا خطية بالرغم من إختلاف الأحمال.

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Nomenclature

- {σ} stress vector
- [D_c] constitutive matrix for concrete
- {ε} strain vector
- {dσ} stress increment vector
- {dε} strain increment vector
- σ_h hydrostatic stress
- E Young's modulus
- ν poisson's ratio
- Kt Stress concentrated factor

Introduction

Reinforced concrete structures are largely employed in engineering practice in a variety of situations and applications [1]. Huyse et. al [2] are studied the analysis of reinforced concrete structures using ANSYS nonlinear concrete model. Fanning [3] is presented nonlinear models for reinforced and post-tensioned concrete beams. Prickett and Driver[4] are tested eleven full-scale columns with high-strength concrete under either concentric or eccentric axial loading. Muhsen [5] is carried out a three dimensional nonlinear finite element analysis of short concrete filled steel tube columns using ANSYS5.4. In present study; two buildings (A , B) are analyses by finite element method using ANSYS software as a three-dimensional finite element method with different types of materials (concrete and bricks) were chosen for the nonlinearity analysis due to cracking and crushing. The investigated of the effects of the distributed loads on the behavior of this materials is done. Experimentally, the monitoring of the cracks in the two buildings are investigated. The cracks width is measured by microscope and the cracks length is measured by length measuring tape.

Concrete Models Adopted in the Present Study

In the current study, the concrete material model deal with the nonlinear three dimensional analysis of reinforced concrete members under static load is considered. These models treat the concrete as being a linear elastic-perfectly plastic-brittle-fracture material as shown in Fig.(1). The concrete under a triaxial stress state is assumed to crush or crack completely once the fracture surface is reached. The complete stress-strain relationship for a perfectly plastic-brittle fracture model is developed in three parts[6]:

- (1) Before yielding,
 - (2) During plastic flow,
 - (3) After fracture.
- Stress-strain relationship is expressed by a single value of Young's modulus, E, and a constant poisson's ratio, ν. So this relation can be written in matrix form as:

$$\{\sigma\} = [D_c] \{\epsilon\} \dots (1)$$

The matrix [D_c] for uncracked elastic concrete can be defined by [6]:

$$[D_c] = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} (1-\nu) & \nu & \nu & 0 & 0 & 0 \\ \nu & (1-\nu) & \nu & 0 & 0 & 0 \\ \nu & \nu & (1-\nu) & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{(1-2\nu)}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{(1-2\nu)}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{(1-2\nu)}{2} \end{bmatrix} \dots (2)$$

The equivalent uniaxial stress-strains in the various stages are given by:

- 1) For $\sigma \leq f'_c$ then $\sigma = E\epsilon$
- 2) For $\epsilon \geq \frac{f'_c}{E}$ then $\sigma = f'_c$

The incremental stress-strain relationship can be expressed as:

$$\{d\sigma\} = [D_c] \{d\epsilon\} \dots (3)$$

Determination of the Model Parameters

A total of five strength parameters are needed to define the failure surface as well as an ambient hydrostatic stress state ($f'_c, f_t, f_{cb}, f_1, f_2$ and σ_h^a), these are shown in Fig.(2). f'_c and f_t can be specified from two simple tests. The other three constants can be determined from :

$$f_{cb} = 1.2 f'_c \quad \dots(4)$$

$$f_1 = 1.45 f'_c \quad \dots\dots(5)$$

$$f_2 = 1.725 f'_c \quad \dots\dots(6)$$

However, these values are valid only for stress states where the following condition is satisfied:

$$|\sigma_h| \leq \sqrt{3} f'_c \quad \dots\dots (7)$$

where:

$$\sigma_h = \text{hydrostatic stress state} = \frac{1}{3}(\sigma_{xp} + \sigma_{yp} + \sigma_{zp}) \quad \dots (8)$$

Condition (7) applies to stress situations with a low hydrostatic stress component. In Fig.(2), the lower curve represents all stress states such that ($\theta = 0^\circ$), while the upper curve represents stress states for ($\theta = 60^\circ$). where q is defined as the angle of symmetry. The axis ξ) represents the hydrostatic length. The materials properties of the present study is taken as in table(1).

Finite Element Model of Concrete

In the current study, three dimensional 8-node solid elements are used to model the concrete. The element has eight corner nodes, and each node has three degrees of freedom "u, v and w" in the "x, y and z" directions respectively, as shown in Fig.(3). (Solid element 65 in ANSYS) [7].

Reinforcement Idealization

In developing a finite element model for reinforced concrete members the authors are suggested three alternative representations of reinforcement can usually be used, these are given as follows:

1. Distributed Representation:

In this approach, the reinforcement is assumed to be distributed in a layer over the element in any specified direction. To construct the constitutive relation of a composite concrete - reinforcement, perfect bond is assumed, Fig.(4.a).

2. Discrete Representation:

One dimensional bar element may be used in this approach to simulate the reinforcement. Discrete representation has been widely used due to its versatility and capability to adequately account for the bond-slip and dowel action phenomena, Fig.(4.b).

3. Embedded Representation:

The embedded representation is often used with high order isoparametric elements. The bar elements are assumed to be built into the brick elements. In this approach a perfect bond is assumed between the reinforcing bars and the surrounding concrete. The stiffness of steel bars is added to that of the concrete to obtain the global stiffness matrix of the element. It is assumed that the bars are restricted to be parallel to the local coordinate axes ξ, η and ζ of the brick element, Fig.(4.c).

In the present work, the reinforcement is included within the properties of the 8-node brick elements (embedded representation) to include the reinforcement effect in

the concrete structures, excluding the reinforcing bars that are crossing the joint, which are represented by using "bar elements" (Discrete representation) (Link8 in ANSYS). In the two manners, the reinforcement is assumed to be capable of transmitting axial forces only and perfect bond is assumed to exist between the concrete and the reinforcing bars.

Model Generation

Two different methods are used in the current study to generate a model: Solid model and direct generation. In solid modeling some one can describe the boundaries of the model, establish controls over the size and desired shape elements automatically, by contrast. In the direct generation method, determine the location of every node and size, shape and connectivity of every element prior to defining these entities in ANSYS model. The analyses of two buildings are investigated

Model (1):- Building A with large hall is consist of two symmetrical floors, the plan of slab of this building for ground floor and first floor are shown in Figs.(5) and (6); each floor is consist of seven symmetric parts, due to symmetry one part of this building is analysis, in which the length (10.5 m), width (6.5 m), and height (4 m) for each floor, thickness of slab (0.18 m), thickness of wall (0.25 m), dimensions of window (1.5 m x 1.5 m), dimensions of door (1m x 2m), dimensions of column (0.25 m x 0.5 m), dimensions of beam (0.25 m x 0.5 m) all supports of building are fixed, columns and beams of this building are shown in Fig.(7) for one floor and Fig.(8) for two floors.

Three dimensional reinforced concrete element (SOILD 65) and bricks element (SOILD45) are used.

In other words, the structure is divided into a number of small elements, and after applying the loads, stresses are calculated at integration points of these small elements. An important step in the finite element modeling is the selection of the mesh density. A convergence of results is obtained when an adequate number of elements are used in a structure. Therefore, in the current finite element modeling, a convergence study was carried out to determine an appropriate mesh density. The convergence study was made by increasing the number of elements (mesh) in each direction x, y and z respectively. The loads are used in the analysis were distributed loads; the mesh of building A is shown in Fig.(9); three cases are tested below:
Case one : concrete only as shown in Fig.(10) and the mesh is shown in Fig.(11).

Case two : concrete and bricks as shown in Fig.(12), and the mesh of this case is shown in Fig.(13).

Case three: bricks (wall) only, as shown in Fig.(14), the mesh of this case is shown in Fig.(15).

Model (2): Building B is used a large multi-purpose hall, this building consist of one floor. The details of building (geometrically), length (21.24 m), width (17.98 m), height of building (4 m), thickness of slab (0.18 m), thickness of wall (0.25m), dimensions of window (1.5 m x 1.5 m), dimensions of door (1m x 2m), one door of (2m x 2m), dimensions of column (rectangular section) (0.25m x 0.5m), diameter of column (circular section) (0.5 m), dimensions of beam (0.25m x 0.5m). All supports of building are fixed, the loads are used in the analysis of building B were distributed loads, (beams and

concrete) is shown in Fig.(16) the plan of slab of this floor is shown in Fig.(17), three cases in this model will be described below:

Case one: building B concrete only is shown in Fig.(18). Mesh of this case is shown in Fig.(19).

Case two: concrete and bricks (wall) as shown in Fig.(20). Mesh of this case shown in Fig.(21).

Case three: bricks (wall) only as shown in Fig.(22). Mesh of this case is shown in Fig.(23).

Analysis of Model One

Case one: Model(1) (part of building A concrete only), building A consist of two floors, ground floor and first floor. The designed loads for this case are (30kN/m²) for first floor and (4kN/m²) for ground floor (total designed load is equal to (70 kN/m²). The deflection shown that when loads (70 kN/m²) is equal to (0.001919 m), maximum stress is equal to (8.50 MPa) and minimum stress is equal to (0.006793 MPa) as shown in Fig.(24).

Cracking in Finite Element Modeling

ANSYS computer program displays of cracking or crushing in concrete elements. Cracking is shown with a circle outline in the plane of the crack, and crushing is shown with an octahedron outline. If the crack has opened and then closed, the circle outline will have X through it. Each integration point can crack in up to three different planes. The first crack at an integration point is shown with a red circle outline, the second crack with a green outline, and the third crack with a blue outline. Symbols shown at the element center are based on the status of all of the element's integration points. If any integration point in the element has crushed, the crushed (octahedron) symbol is shown at the center. If any integration

point has cracked and then closed, the cracked symbol is shown at the element center. If at least five integration points have cracked and then closed, the cracked and closed symbol is shown at the element center. Finally, if more than one integration point has cracked, the circle outline at the element center shows the average orientation of all cracked planes for that element .

The cracks operation at designed loads (30 kN/m² for first floor and 40 kN/m² for ground floor) (total distributed designed loads for one part of building A are equal to 70 kN/m²) are shown in Fig.(25).

Case two: Model (1) (part of building A concrete and bricks (wall)), as shown in Fig.(26). The designed loads are equal to (70 kN/m²), have the deflection equal to (0.000824 m), maximum stress is (3.45 MPa), minimum stress is (0.002704 MPa). The deflection, maximum stress and minimum stress in this case is less than the case one (concrete only). The first crack of this case at distributed loads (30 kN/m²) for first floor and 40 kN/m² for ground floor) (total distributed load for part building A (70 kN/m²) as shown in Fig.(27).

Case three: Model (1) (part of building A bricks (wall) only, the distributed loads as in the case one and case two, as shown in Fig.(28), part of building A at total designed loads equal to (70 kN/m²) for each floor, the results are shown that the deflection at a load (70 kN/m²) is equal to (0.000337 m), maximum stress is equal to (0.710311 MPa) and minimum stress is equal to (0.179137 MPa).

The deflection of this case is less than case one (concrete only) and less than of case two (concrete and bricks). The maximum stress of this

case is less than of case one and case two. The minimum stress of this case is more than of case one and case two. The wall (bricks) is analysis by ANSYS5.4 program using element SOLID 45.

Stress Concentrated Factor

The Stress concentrated factor (Kt) [8] for wall only was calculated as in table(1). The relations between load and deflection curves for building A are shown in Fig.(29). It can be shown that the factor of concentrated is between (8.4-11.4) for wall contains four windows and (6.1-7.4) for wall contain two doors.

Cracking for Building A

The measurement of cracks width by microscope and cracks length by length measuring tape is investigated, and the pictures are capture of cracks in building A as shown in Fig.(30). The period of the growth of cracks were for two months as in table(2).

Analysis of Model Two

Case one: Model (2) building B (concrete only), building B consisted of one floor, the designed value of the distributed loads are equal to (15kN/m^2), the deflection at loads (15kN/m^2) is equal to (0.000981 m), maximum stress is equal to (25.6 MPa), minimum stress (2.84 MPa), as shown in Fig.(31). The cracks in building B (concrete only) are shown in Fig.(32).

Case two: Model (2)(building B concrete and bricks), the steps of distributed loads as in case one, is shown in Fig.(33). The deflection when distributed loads (15kN/m^2) is equal to (0.000979 m), maximum stress is equal to (150 MPa), minimum stress is equal to (16.7 MPa). The deflection of this case at load (15kN/m^2) is less than case one, maximum and minimum stresses are more than case one. The crack

operation at designed distributed loads (15kN/m^2) as shown in Fig.(34).

Case three: Model (2) (building B wall (bricks) only, the steps of distributed loads as in case one and case two are shown in Fig.(35). The building B at total designed loads equal to (15kN/m^2), deflection is equal to (0.000108 m), maximum stress is equal to (1400 MPa), minimum stress is equal to (0.000073935 MPa). The deflection of this case at designed loads is equal to (15kN/m^2) less than the case one (concrete only) and less than of the case two (concrete and bricks). The maximum stress of this case is less than of the case one and case two. The minimum stress of this case is less than of case one and case two.

Cracks for Building B

The measurement of cracks width by microscope and the cracks length by length measuring tape are investigated, and the pictures are capture of cracks in building B as shown in Fig.(35) as shown in table(3).

Stress Concentrated Factor

Stress concentrated factor (Kt), (wall only) for building B as shown in table(4). It can be shown that the factor of concentrated is between (13.4-14.1) for wall contains one door, and (13.9-14.6) for wall contains three windows (in building B). The relation between load and deflection curves of the three cases for building B are shown in Fig.(37).

Conclusions

Finite element modeling and analysis could be used for more complicated geometry and loadings where hand calculations are impossible or hard to perform. In present study; two buildings A and B are analyze by finite element method

using ANSYS software as a three-dimensional finite element method with different types of materials (concrete and bricks) were chosen for the nonlinearity analysis due to cracking and crushing. Experimentally, the monitoring of the cracks in the two buildings are investigated. The cracks width is measured by microscope and the cracks length is measured by length measuring tape. The results are indicated that the cracks growth in the sites of high concentrated stresses and the load-deflection curve are approximately linear even with different loads. The stress concentration factors are calculated for two buildings. It is shown that the factor of concentrated is between (8.4-11.4) for wall contains four windows and (6.1-7.4) for wall contains two doors (in building A). Factor of concentrated is between (13.4-14.1) for wall contains one door, and (13.9-14.6) for wall contains three windows (in building B).

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Table (1) Concentrated stress factor for part building A

Distributed load (N/m ²)	Concentrated load (N)	S _{Max} from ANSYS (N/m ²)	S _{Normal} (wall contain 4 windows)	Stress concentrated factor (Kt)	S _{Normal} (wall contain 2 doors)	Stress concentrated factor (Kt)
20000	1451250	214782	18847.403	11.396	29025	7.40
40000	2902500	429565	37694.805	11.396	58050	7.40
44000	3192750	464172	41464.286	11.195	6385.5	7.269
48000	3483000	507129	45233.766	9.784	69660	7.28
55000	3990937.5	570082	5183.36	10.998	79818.75	7.14
70000	5079375	710311	65965.909	8.375	101587.5	6.99
90000	6530625	0.114*10 ⁷	84813.312	9.306	130612.5	8.73
130000	9433125	0.134*10 ⁷	122508.117	10.938	188662.5	6.16
150000	40884375	0.155*10 ⁷	141355.519	10.965	217687.5	6.28
170000	12335625	0.155*10 ⁷	160202.922	9.675	24672.5	6.28
190000	13786875	0.178*10 ⁷	179050.325	9.941	275737.5	6.46
210000	15238125	0.199*10 ⁷	197897.727	10.056	304762.5	6.53

Table (2) Dimensions of cracks in building A

Time (day)	Crack width (mm)			Crack length (m)		
	C1	C2	C3	C1	C2	C3
1	0.06	0.08	0.12	0.93	1.07	2.03
20	0.06	0.08	0.12			
39	0.06	0.08	0.12			
56	0.06	0.08	0.12			

Where: C1, C2 and C3 are cracks locations.

Table (3) Dimensions of cracks in building B

Time (day)	Crack width (mm)		Crack length (m)	
	C1	C2	C1	C2
1	0.08	0.12	0.615	3.61
20	0.08	0.12		
39	0.08	0.12		
56	0.08	0.12		

Where: C1 and C2 are cracks locations.

Table (4) Concentrated stress factor for building B

Distrib uted load (N/m ²)	Concentrated load (N)	S _{Max.} from ANSYS (N/m ²)	S _{Normal} (side wall contain 1door) (N/m ²)	(Kt) of side wall	S _{Normal} (front wall contain 2 doors) (N/m ²)	(Kt) of front wall	S _{Normal} (back wall contain 3 windows) (N/m ²)	(Kt)of back wall
13000	5195623.55	1210000	90453.0562	13.377	83209.858	14.542	87043.450	13.901
13100	5235589.885	1220000	91148.8489	13.385	83849.993	14.549	87713.015	13.901
13200	5275556.22	1230000	91844.642	13.392	89888.503	13.684	88382.580	13.917
13300	5315522.555	1240000	92540.434	13.399	85130.086	14.566	89052.145	13.924
13400	5355488.89	1250000	93236.227	13.407	85770.062	14.57	89721.710	13.932
13500	5395455.225	1260000	93932.0110	13.414	86410.237	14.582	90391.275	13.939
13600	5435421.56	1270000	94627.813	13.421	87050.313	14.589	91060.840	13.947
13700	5475387.895	1280000	95323.605	13.428	87690.389	14.597	91730.405	13.954
13800	5515354.23	1290000	96019.398	13.435	88330.465	14.604	92399.970	13.961
13900	5555320.565	1300000	96715.191	13.442	88970.541	14.612	93069.535	13.968
14000	5595286.9	1310000	97411.02	13.448	89610.617	14.619	93739.1003	13.975
14100	5635253.235	1320000	98106.776	13.45	90250.692	14.626	94408.665	13.982
14200	5675219.57	1330000	98802.569	13.461	90890.768	14.633	95078.230	13.988
15000	5994950.25	1400000	104368.911	13.414	96011.375	14.582	100434.750	13.939
16000	6074613.6	1490000	1057.585	14.089	97287.213	15.315	101769.368	14.641
20000	7993267	1870000	139158.548	13.438	128015.167	14.608	133913.00	13.964
30000	11989900.5	2800000	208737.822	13.414	192022.750	14.582	200869.500	13.939
40000	15986534	3730000	278317.096	13.402	256030.333	14.568	267826.001	13.927

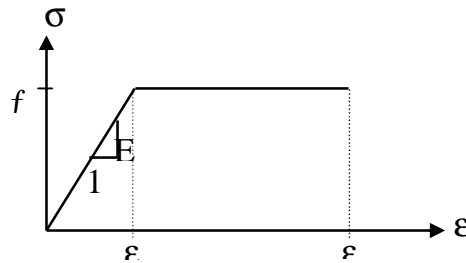


Figure (1) Uniaxial stress-strain relationship used for concrete.

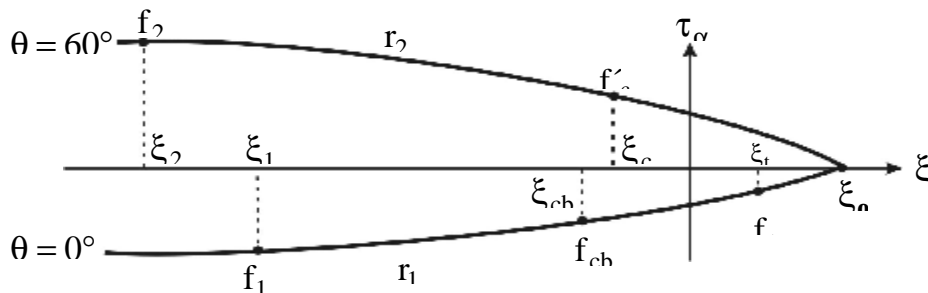


Figure (2) A profile of the failure surface as a function of five parameters

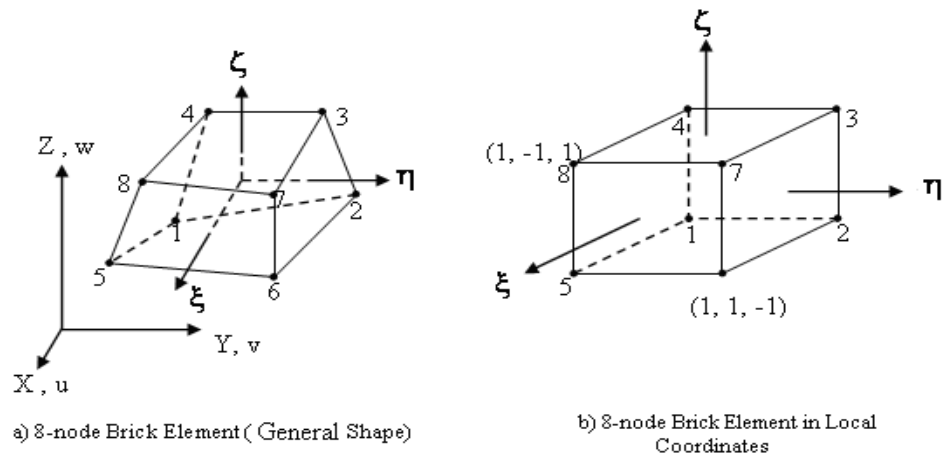


Figure (3) Three dimensional 8-node brick element (Solid65).

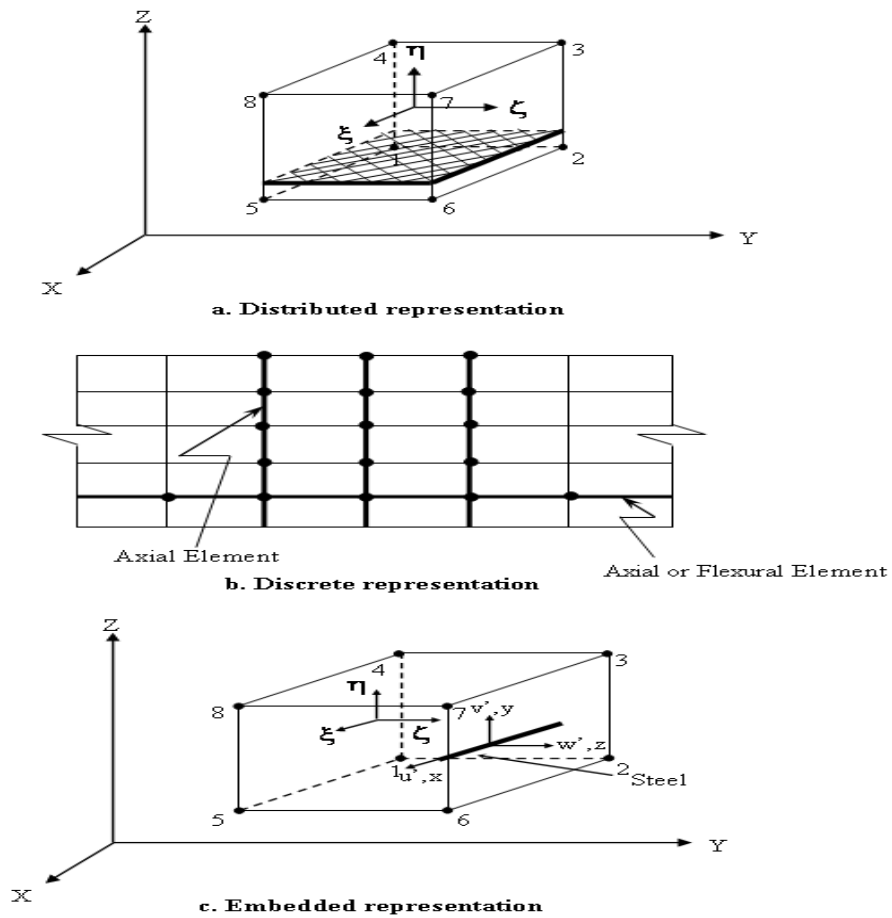


Figure (4) Reinforcement representation type

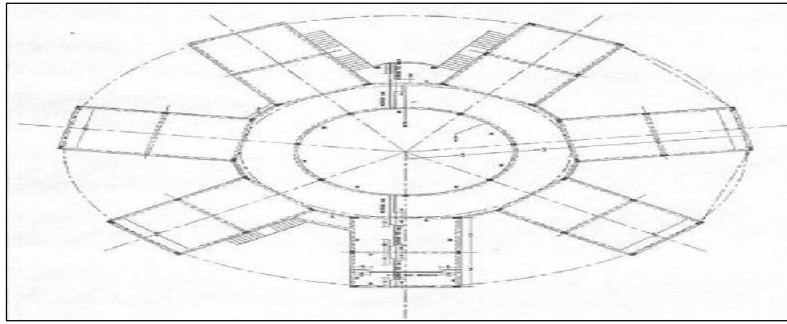


Figure (5) The plan of the slab of the ground floor of building A

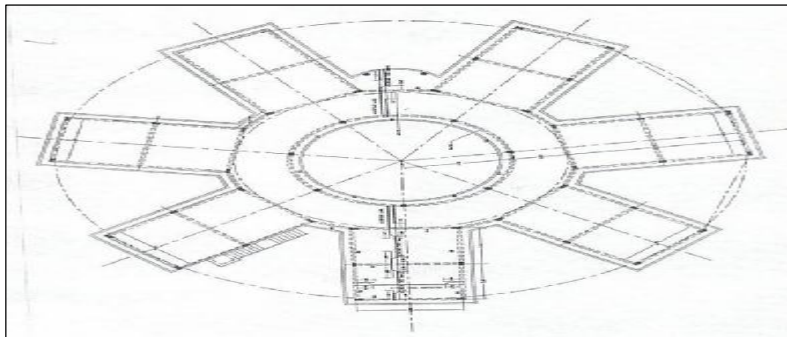


Figure (6) The plan of the slab of the first floor of building A

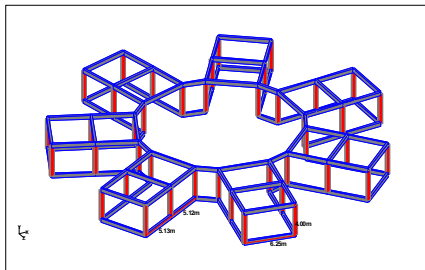


Figure (7) Building A for one floor (beams and columns)

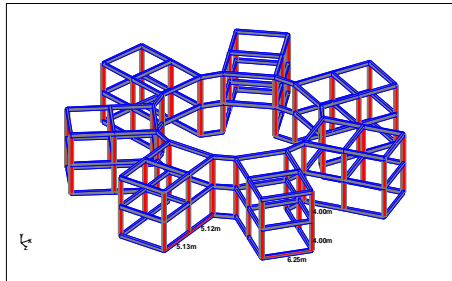


Figure (8) Building A for two floors (beams and columns)

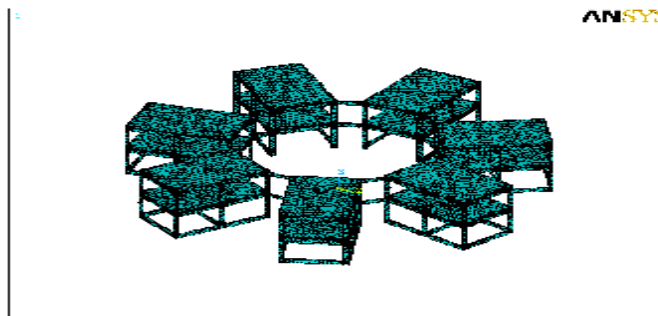


Figure (9) Mesh of building A ;concrete only; carried out by ANSYS computer program

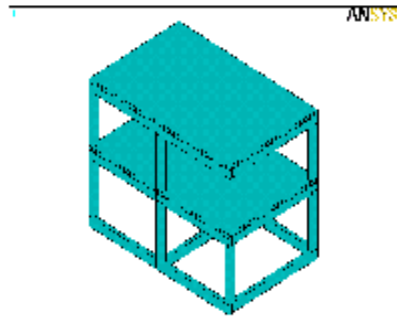


Figure (10) Part of building A; concrete only

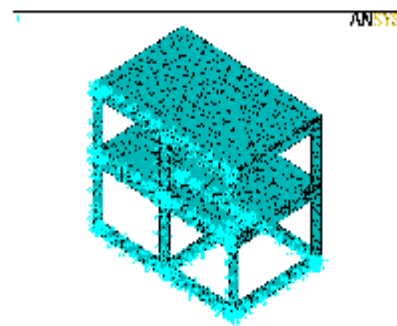


Figure (11) Mesh for part of building A; concrete only

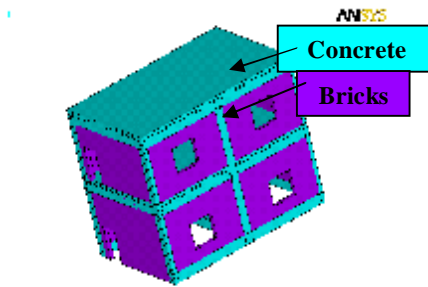


Figure (12) Part of building A; building concrete and bricks

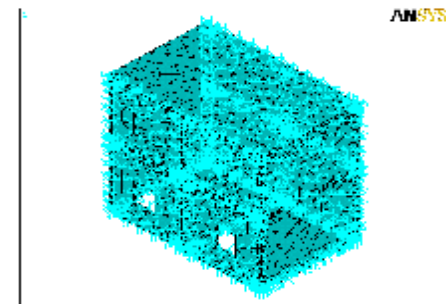


Figure (13) mesh of part of A ;concrete and bricks

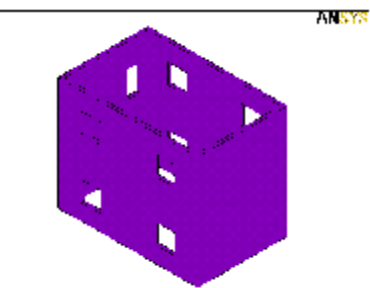


Figure (14) Part of building A; bricks (wall) only

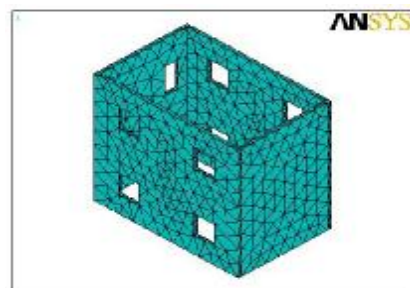


Figure (15) Part of building A; mesh of bricks (wall) only

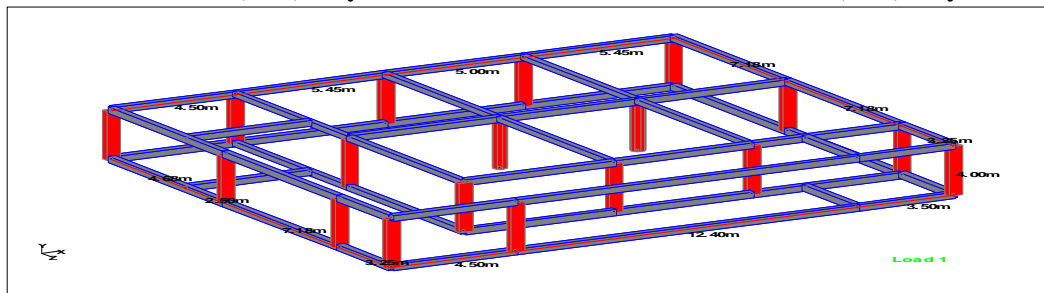


Figure (16) Building B (beams and columns)

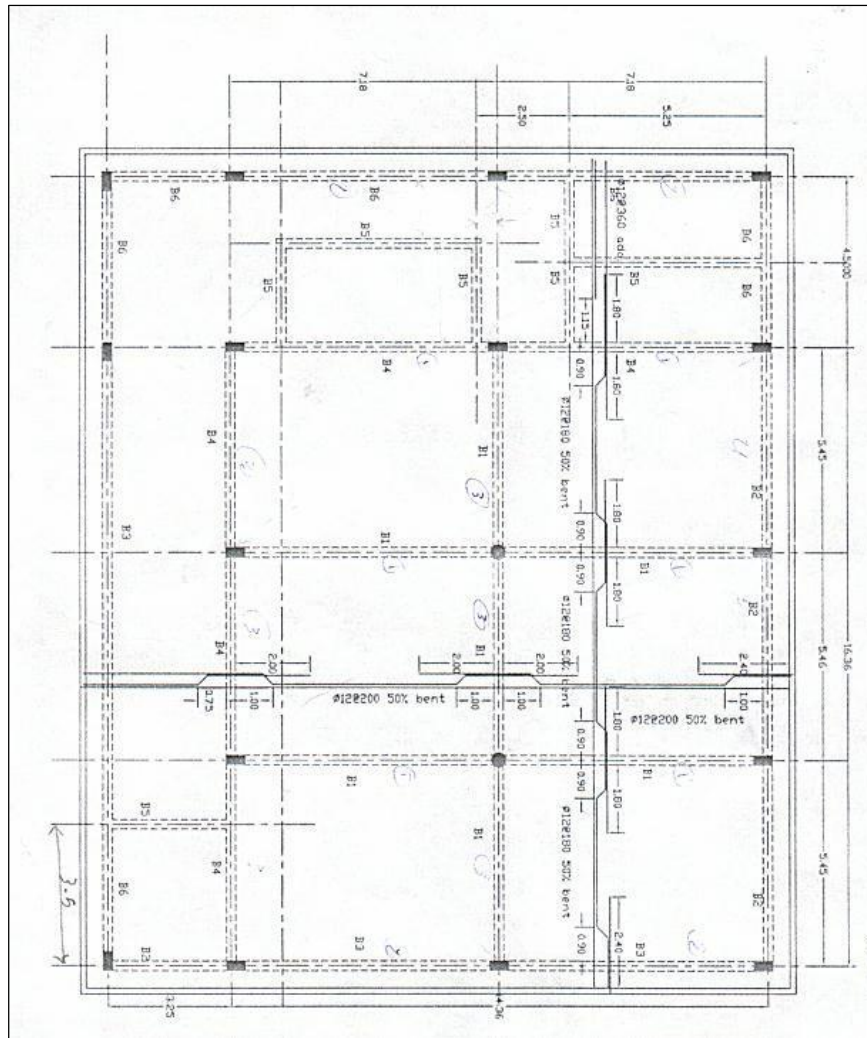


Figure (17) The plan of the slab of the building B

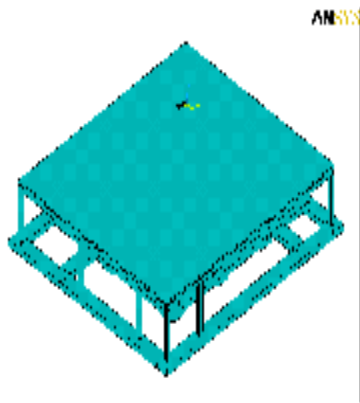


Figure (18) Building B; concrete only

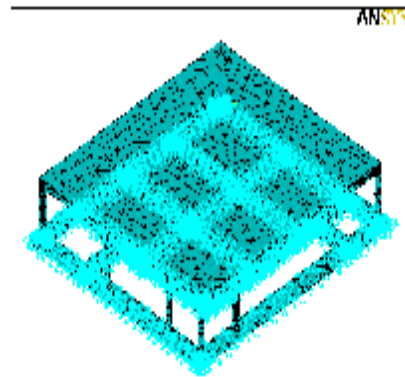


Figure (19) Mesh of building B; concrete only

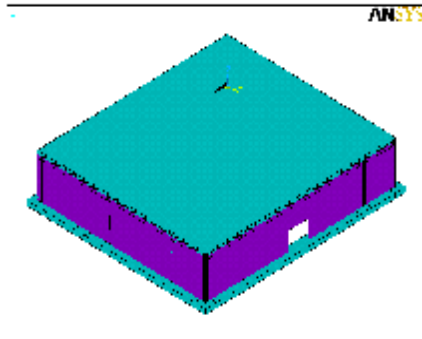


Figure (20) Building B; concrete and bricks (wall)

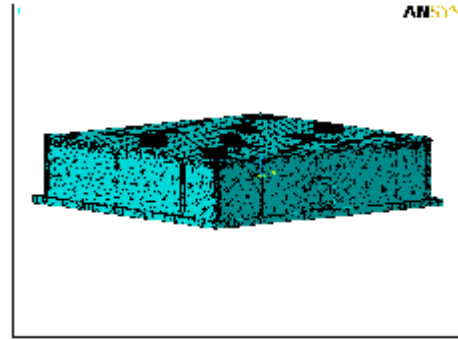


Figure (21) Mesh of building B; and bricks (wall)

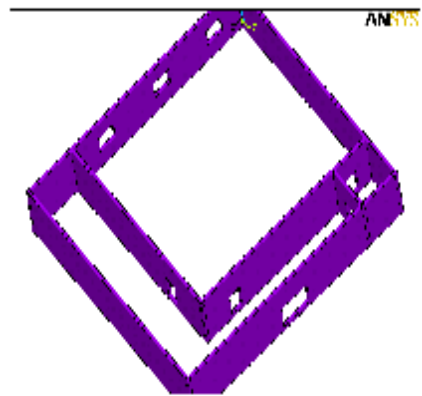


Figure (22) Building B; bricks (wall) only

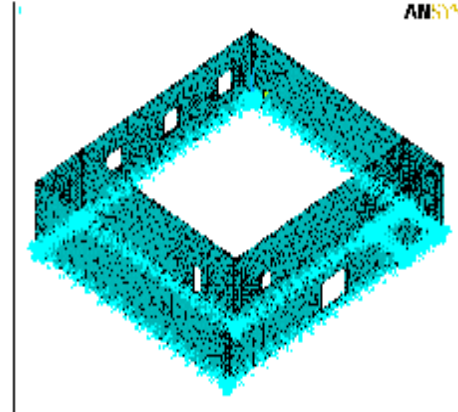


Figure (23) Mesh of building B; bricks (wall) only

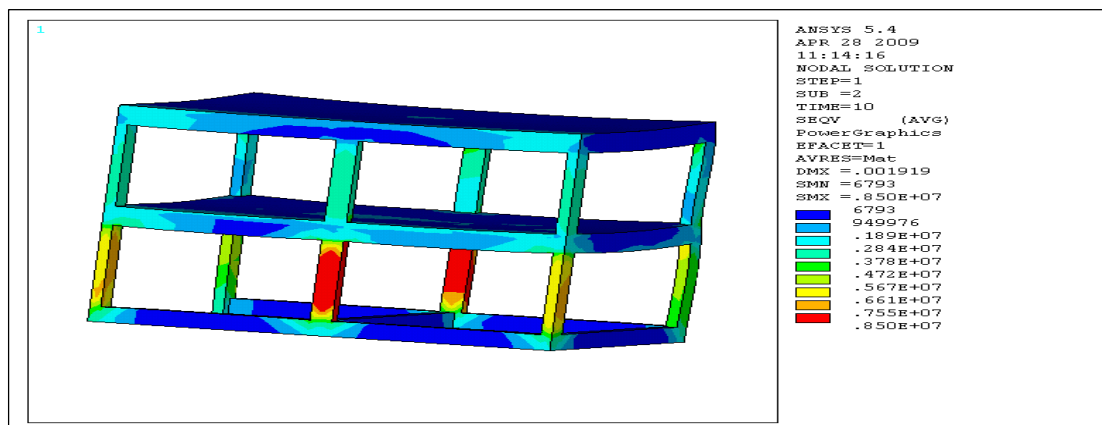


Figure (24) Part of building A; concrete only; distributed and design loads (70 kN/m^2)

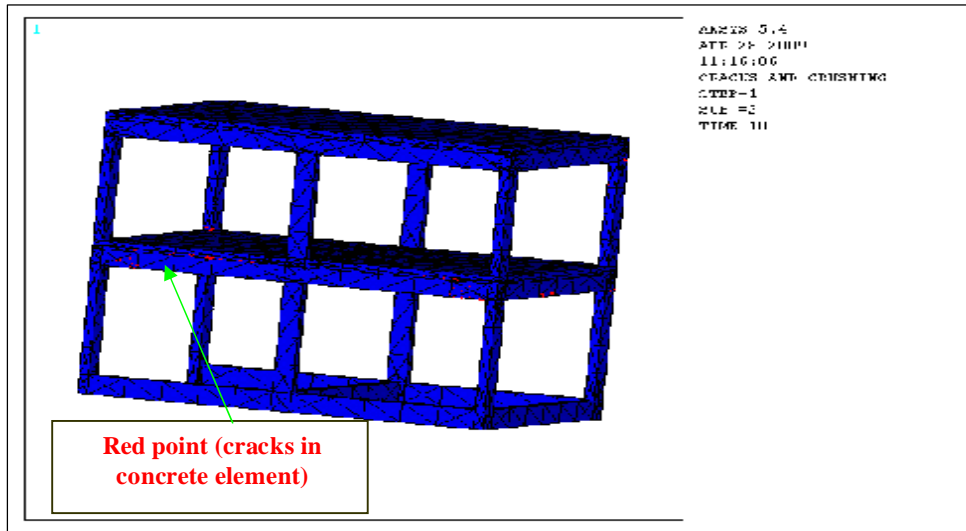


Figure (25) Cracks pattern of a part of building A; concrete only, at distributed designed loads (70kN/m^2)

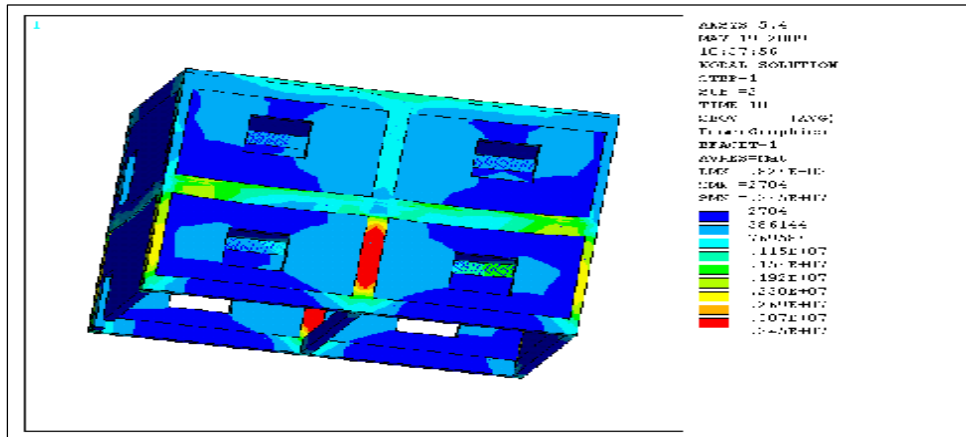


Figure (26) Part of building A; concrete and bricks (wall); distributed and designed load (70kN/m^2)

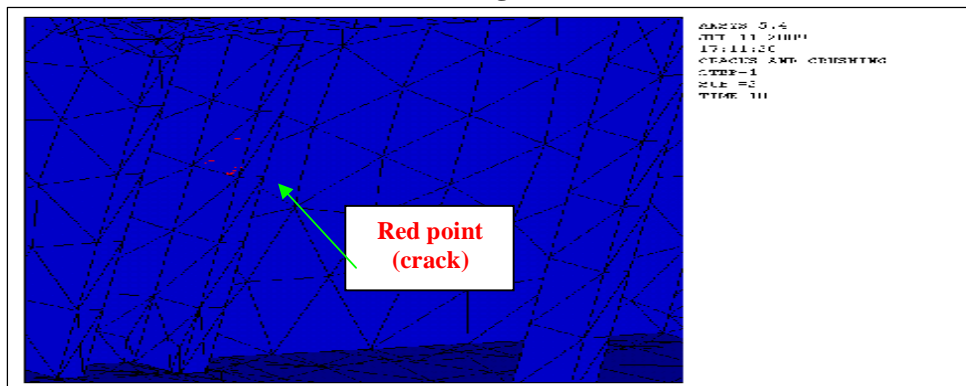


Figure (27) Cracks in part of building A; concrete and bricks; distributed and designed loads (70kN/m^2)

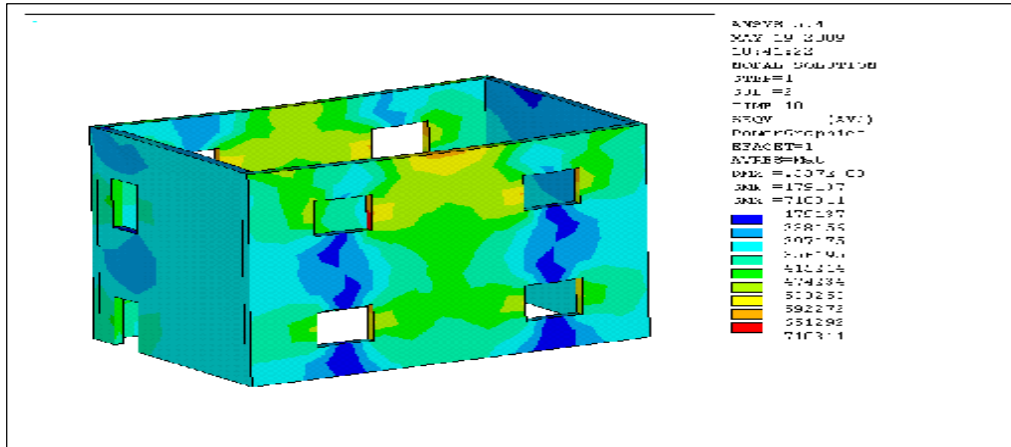


Figure (28) Part of building A; wall (bricks)only; distributed designed loads (70 kN/m²)

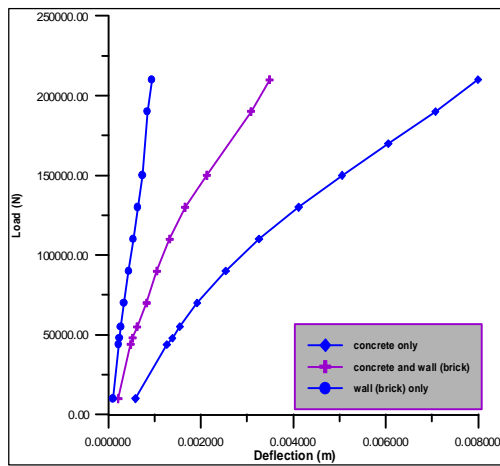


Figure (29) Load - deflection curves (three cases);

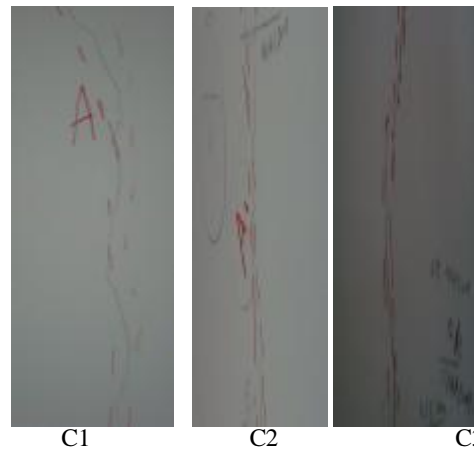


Figure (30) Cracks in building

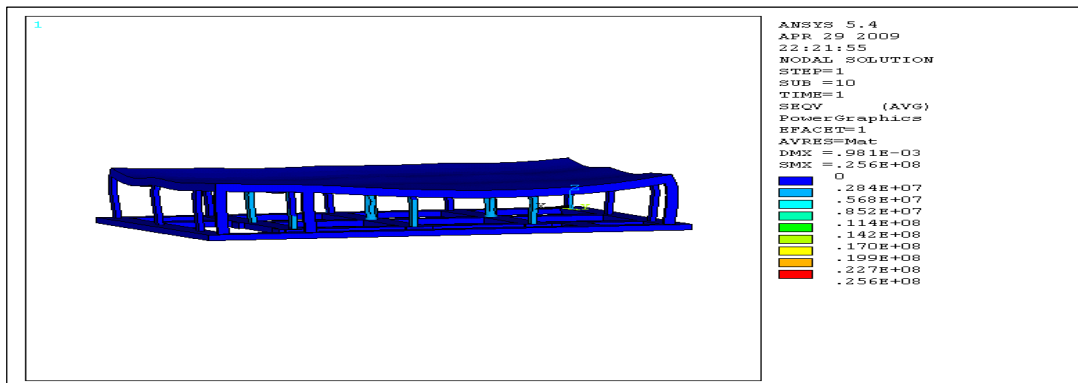


Figure (31) Building B; concrete only; distributed and designed loads (15 kN/m²)

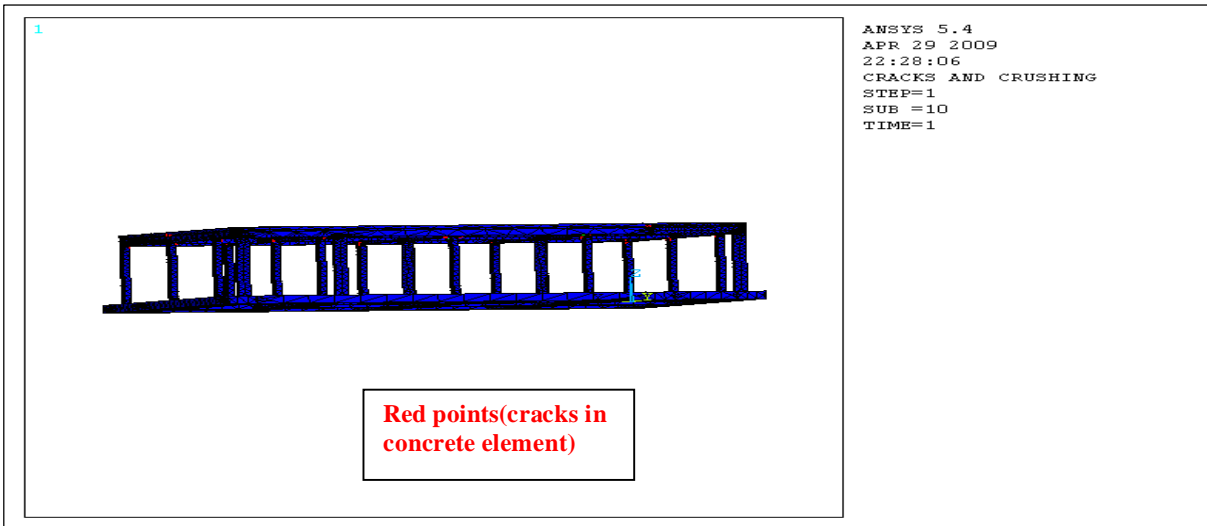


Figure (32) Cracks pattern of building B; concrete only; at distributed loads (15 kN/m²)

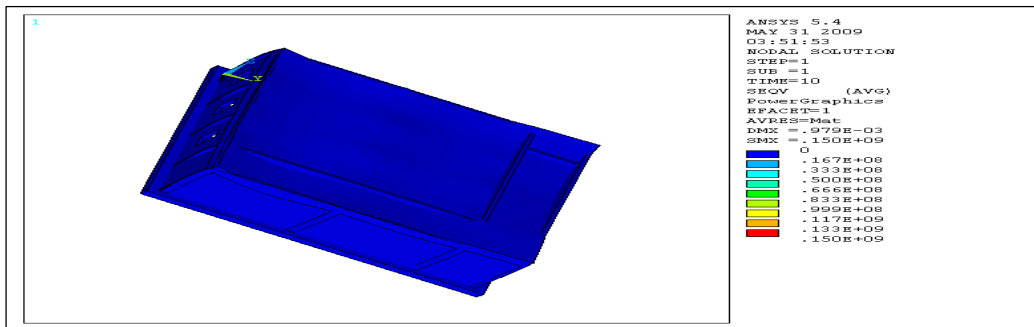


Figure (33) Building B; concrete and bricks (wall); distributed designed loads (15kN/m²)

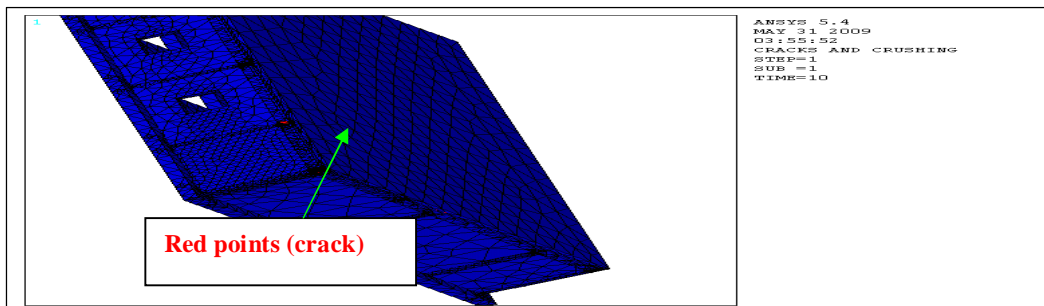


Figure (34) The cracks pattern of building B; concrete and bricks (wall); at distributed loads (15kN/m²)

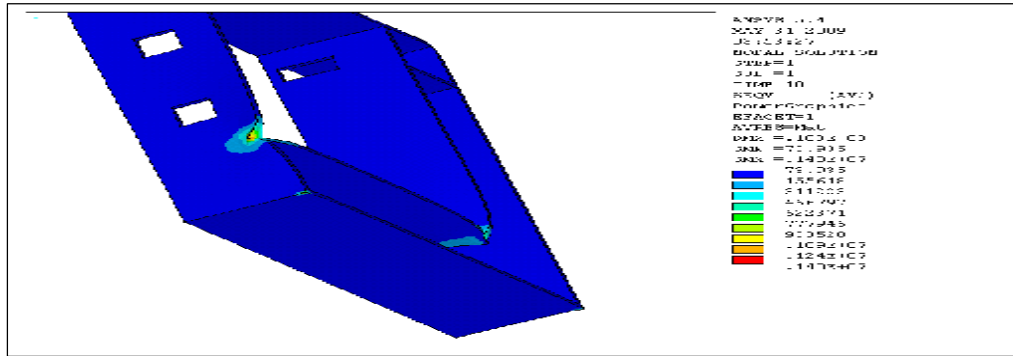


Figure (35) Building B; bricks (wall)only; distributed designed loads (15kN/m²)

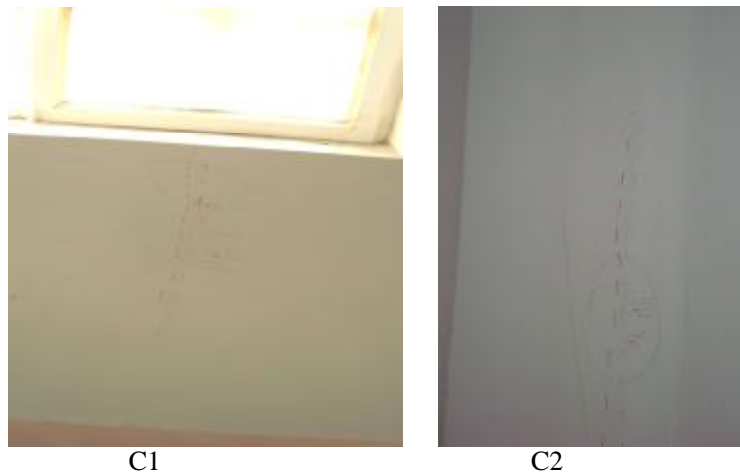


Figure (36) Cracks in Building B

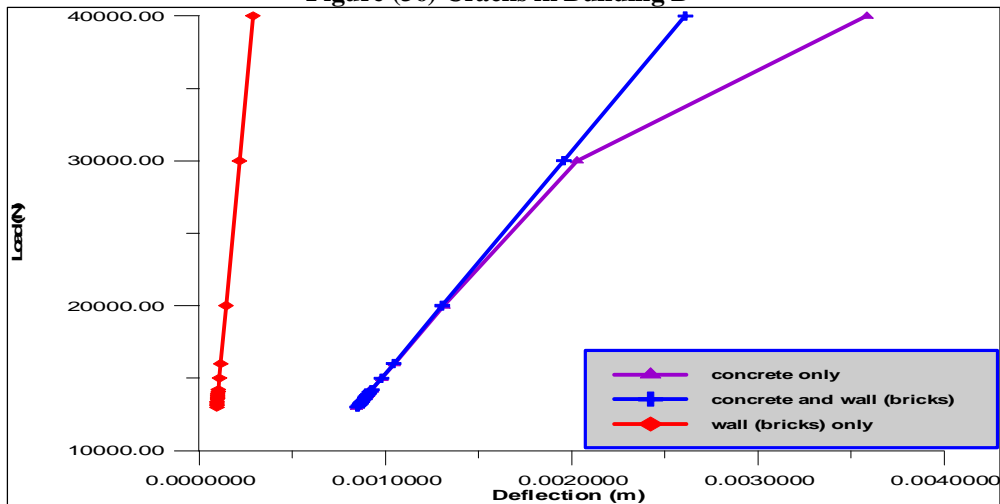


Figure (37) Load-deflection curves (three cases) for building B