STRESS ANALYSIS OF REINFORCED CONCRET SLAB SUBJECTED TO SEISMIC LOAD

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ABSTRACT

The present study is aimed to investigate the nonlinear dynamic analysis of reinforced concrete one way ribbed slab subject to seismic load using finite element method. Three cases of slabs considered; the first case is a analysis of reinforced concrete solid slab in three-dimensional building subject to unidirectional seismic load, the second case is a one way ribbed slab subject to unidirectional seismic load parallel to ribs direction and the third case is a one way ribbed slab subject to unidirectional seismic load perpendicular to ribs direction.

SAP2000 v16.0.0 program is used to conduct the nonlinear direct integration analysis and estimation of stress, maximum displacement and base shear. The reinforcement of layered shell element is assumed as a smeared bar. In the analysis, the finite element method is used for spatial integration, and the (Newmark-β) method is used for nonlinear direct time integration with Rayleigh damping (*proportional damping*) and damping ratio 2% is used for analysis .The results showed that the stress ,maximum displacement and base shear for one way ribbed slab are less when compared with those solid slab.

Keywords: ribbed slab; material nonlinearity, finite element modeling, time history analysis, seismic load, structural dynamics.

1. INTRODUCTION

Reinforced concrete slabs are one of the most commonly used structural elements. There are many type of reinforced concrete slab such as flat slab , solid slab and ribbed slabs (one and two way). Ribbed slabs provide a lighter and stiffer slab than an equivalent flat slab. Because of the mathematical complexity required to describe the behaviour of a slab, the load path through a slab is typically not known or considered in its design [1].

There are several numerical analysis methods for solving nonlinear dynamic problems such as finite element method. Several finite element models have been suggested to study the nonlinear behaviour of reinforced concrete slabs. SAP2000 finite element computer program is one of the programs that are used to deal with the history the analysis of engineering systems. The reinforced concrete ribbed slab was modeled by using 4- node nonlinear layered shell element for the top slab and ribs. The edge beams were modeled by using frame element.

There are two methods of nonlinear time history analysis used in SAP2000; the nonlinear direct integration method and an extension of the Fast Nonlinear Analysis (FNA) method developed by Wilson[2]. The aim of this study is to determine the drift and stresses in solid and ribbed slab.

1.1 Methods of earthquake analysis

The analysis of earthquake response of buildings under seismic loads can be carried out by one of the following methods:-

a. Elastic static analysis (push over analysis)

This method is commonly used in the preliminary stages of planning the building, where the suitability for number of choices for the lateral load resisting systems is being investigated. The analysis is carried out on the system model subjected to the equivalent static seismic forces [3].

b. Seismic analysis by response spectra

Response spectrum analysis is perhaps the most common method used in design to evaluate the maximum structural response due to the seismic action. This is a linear approximate method based on modal analysis and on a response spectrum definition. The maximum response is established for each mode by means of the adequate response spectrum [4].

c. Seismic response by time-history analysis

Time-history analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments, (Δt – *steps*). During each step the response is evaluated from the initial conditions existing at the beginning of the step (displacements and velocities) and the loading history in the interval. With this method the non-linear behaviour may be easily considered by changing the structural properties (stiffness, k) from one step to the next. Therefore this method is one of the most effective for the solution of non-linear response, among the many methods available [4].

In this paper the method of time-history is adopted.

2. Equation of Motion

For many structural systems, the approximation of linear structural behavior is made to convert the physical equilibrium statement. The second-order linear D.E of motion is

$$M\ddot{u}(t) + C\dot{u}(t) + K\,u(t) = F(t) \qquad (1)$$

in which M is the mass matrix (lumped or consistent), *C* is a viscous damping matrix (which is normally selected to approximate energy dissipation in the real structure) and K is the static stiffness matrix for the system of structural elements. The time-dependent vectors $u(t)$, $\dot{u}(t)$ and $\ddot{u}(t)$ are the absolute node displacements, velocities and accelerations, respectively. The right-hand side term F(t) is external force.

For multi-degree-of-freedom (MDOF) systems, the equation of motion is expressed as:

$$[m]\,\ddot{u}(t) + [c]\,\dot{u}(t) + [k]\,u(t) = F(t) \qquad (2)$$

The development and the solution of equation (2) forms the basis of the dynamic analysis subroutine implemented in SAP2000 program.

The basic seismic motions are the three components of free-field ground displacements $u(t)_{ig}$ that are known at some point below the foundation level of the structure. Equation (2) can be written in terms of the displacements $u(t)$, velocities $\dot{u}(t)$ and accelerations $\ddot{u}(t)$ that are relative to the three components of free-field ground displacements [5]. There are several different classical methods that can be used for the solution of equation (2) each method has advantages and disadvantages that depend on the type of structure and loading .In this work, the finite element method is used for spatial integration, and the (Newmark $-\beta$) method is used for nonlinear direct time integration with Rayleigh damping (*proportional damping*).

2.1 Modeling of shell element with SAP2000 program.

In SAP2000 program the shell element is a three or four node formulation that combines membrane and plate- bending behaviour. The shell element can be of two types [6]:

a) Homogeneous is the most commonly used type of shell. It combines membrane and plate behaviour

b) The layered shell allows any number of layers as shown in figure (1) to be defined in the thickness direction, each with an independent location, thickness, behaviour, and material. Material behaviour may be nonlinear.

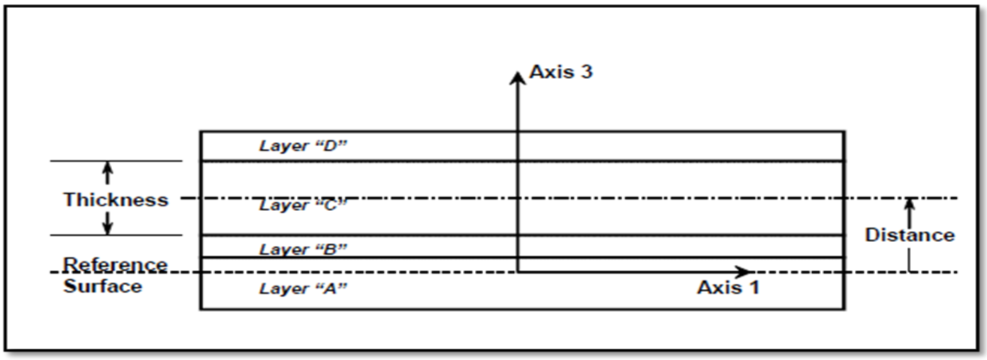


Figure (1) Four-layer shell, showing the reference surface, the names of the layers, and the distance and thickness for layer "C"[2]

Out-of-plane displacements are quadratic and are consistent with the in-plane displacements. The layered shell usually represents full-shell behavior, although this can be controlled on a layer-by-layer basis.

The reinforced concrete ribbed slab was modeled by using 4- node nonlinear layered shell element for the upper slab and ribs.

2.2 Nonlinear material Behavior

Modeling of concrete properties should include the description of the stress-strain model to represent the behavior of concrete. The many approaches for defining this complicated stress-strain behaviors of reinforced concrete under various stress states can be divided to four main group [7] :-

- Representation of given stress-strain curves by using curve-fitting methods, interpolation.
- Linear and nonlinear –elasticity theories
- Prefect- and work-hardening plasticity theories.
- The endocuronic theory of plasticity.

The modeling of concert is separate material modeling for the reinforced steel and concrete because differences in short- and long-term behavior of the constituent materials. In this study the model of reinforced concrete of stress-strain relationships can be linear or nonlinear relationships.

3. Time history application.

3.1 Case (I)

The first case is identical to that investigated by Takashi N. et. al. [8] to examine the accuracy of the present model. They tested using shaking table the one fourth-scale three story reinforced concrete frames to investigate the effects of bidirectional earthquake motions on overall nonlinear response of reinforced concrete frame buildings. Two identical models were constructed, one of them was subjected to bidirectional horizontal earthquake motions and the other was subjected to unidirectional earthquake. Two seismic record were used of El Centro (1940) and JMA Kobe of Hyogo-ken Nanbu Earthquake (1995). In the present study the investigation assumes the model to be subjected to El Centro NS (483 cm/s^2) unidirectional earthquake only.

The 1/4th-scale model was a three-story, single bay by single bay space frame with span length of (1500x1500mm) and each story height is of 750mm. Section dimensions and reinforcing bar arrangements of the column, beam and slab are summarized in Table (1). All stories had the same sections and reinforcement details of columns, beams, and slabs.

Table (1): Members of the model for the 1/4th-scale three story reinforced concrete frames [8].

Member	Column	Beam	Slab
Section	140x140mm	80x150mm	t=45mm
Reinforcement	Main 8- D6 Hoop D3 @25mm	Main upper 2- D6 Lower 2- D6 Stirrup D3 @60mm	UpperD3 @60mesh LowerD3 @60mesh

Considering both the similitude requirement and the arraignment of ingots, forty pieces of ingot (472N per each) were fixed on each slab of the model. As a result, the live load considered for the model was 1.67kN/m2. The axial stress of the first story columns without earthquake loads was determined to be 0.9N/mm^2.

Maximum responses from SAP2000 program:-

The maximum interstory drift angles and the story shear forces of the model are listed in Table (2).

Table (2): Maximum responses for interstory drift angles and the story shear forces of the models by(Takashi N.ect) and present study .

Story No.	Interstory drift (rad)			Story shear (kN)		
	Experimental date [8]	Present study	difference percentage	Experimental date [8]	Present study	difference percentage
3	1/122	1/124	1.6%	26.8	24.42	8.8%
2	1/85	1/85.3	0.35%	43.8	45.03	2.8%
1	1/131	1/121	8.2%	56.1	54.08	3.6%

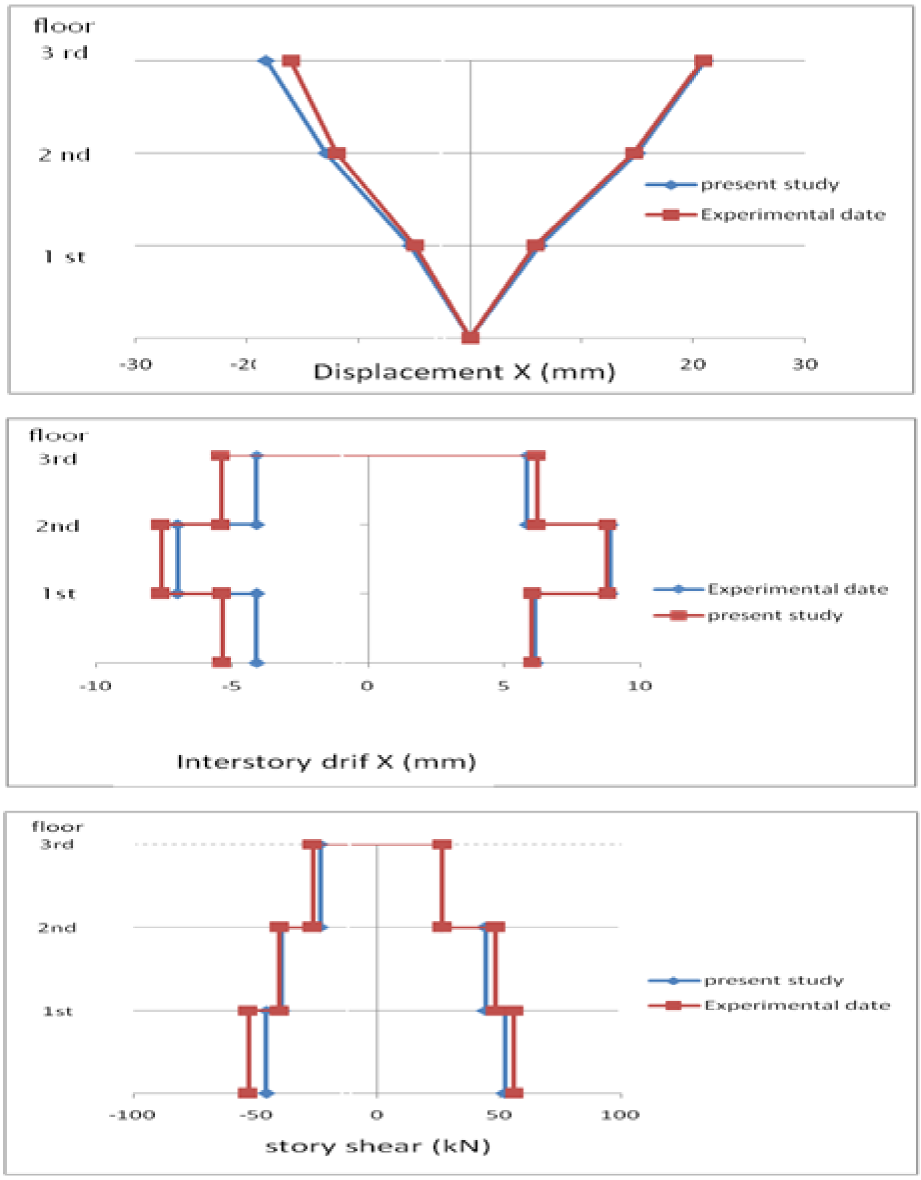


Figure (2): Maximum response displacement X (mm), Interstory drift X (mm)and response story shear force.

3.2 Case (II)

In this case the full scale of the building investigated by (Takashi N. ect.) [8] is considered. The building is of three story with four columns at each corner. The dimensions and details of the building as shown in figure (3).

Two case of slab are examined, solid and ribbed. The details of the slabs are shown in figure (4). The slab design according to ACI cod [9]. The dead load in each slab is (8 kN/m^2) , live load is (1.67 kN/m^2) , fc^{-} =25 kN/m^2 and fy = 420 kN/m^2.

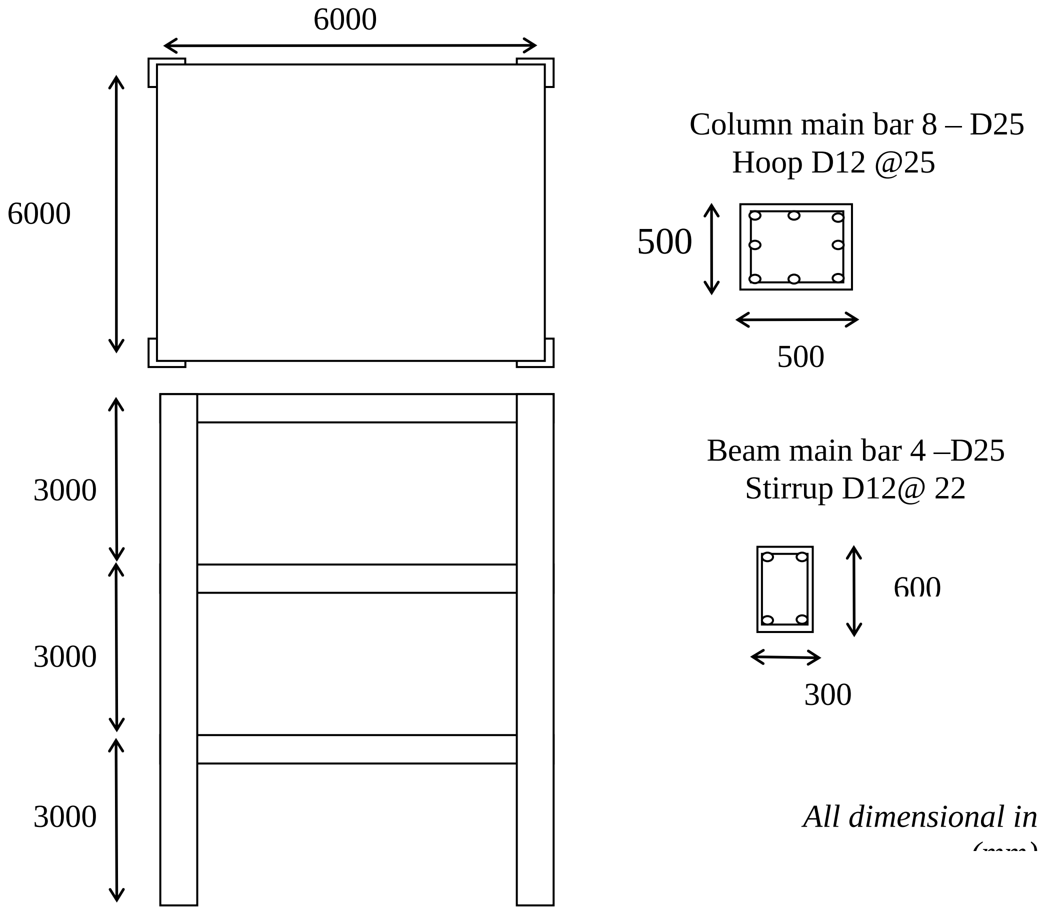


Figure (3): Model analysis in this study by SAP2000 program

3.2.1. Input earthquake motions and measurements:-

The records of earthquake in two adjacent locations are implemented .The first is of Badra earthquake in Kut government, Iraq in (2009).The second is of Tabas earthquake in Iran in (1987).The maximum acceleration of Iraq Badra (2009) was (0.1 g), and maximum acceleration of Iran Tabas Earthquake (1978) was(0.83g) as shown the time - acceleration graph of two earthquakes in figure (5) .

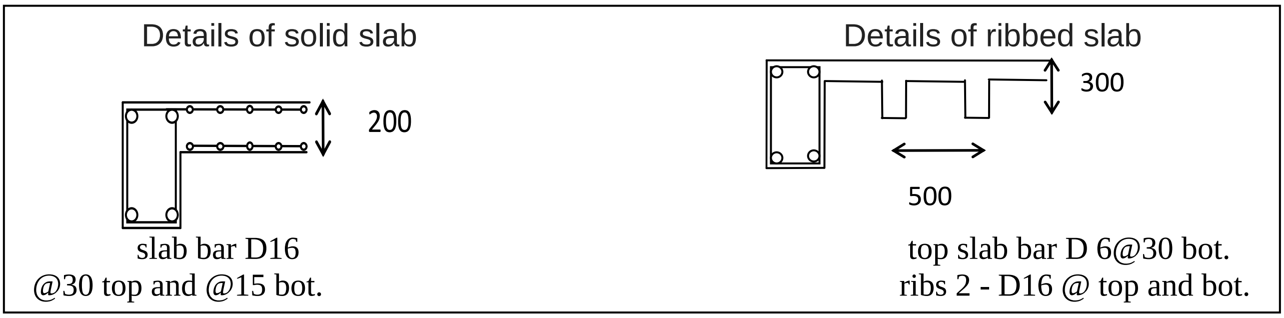
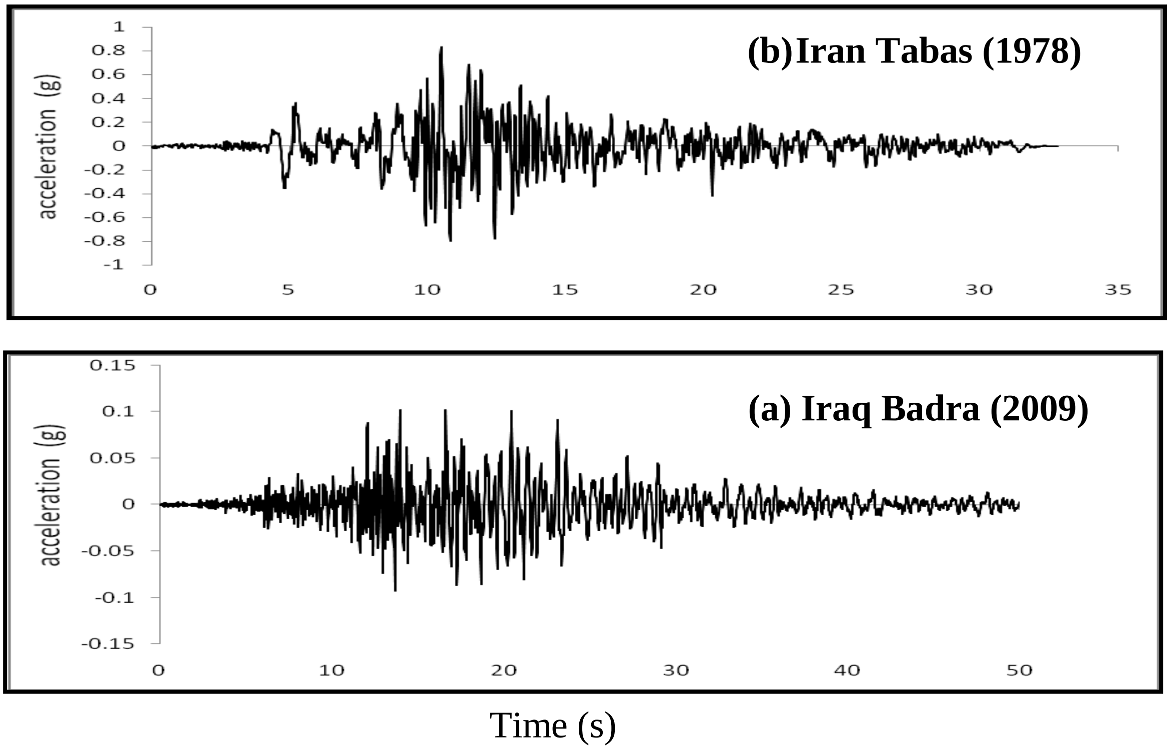


Figure (4): Details of the solid and ribbed slabs analysis in this study.



Figure(5) Time history ground motion of (a) Iraq Badra (2009) and (b) Iran Tabas (1978) Earthquake used in present study.

3.2.2. Solid slab

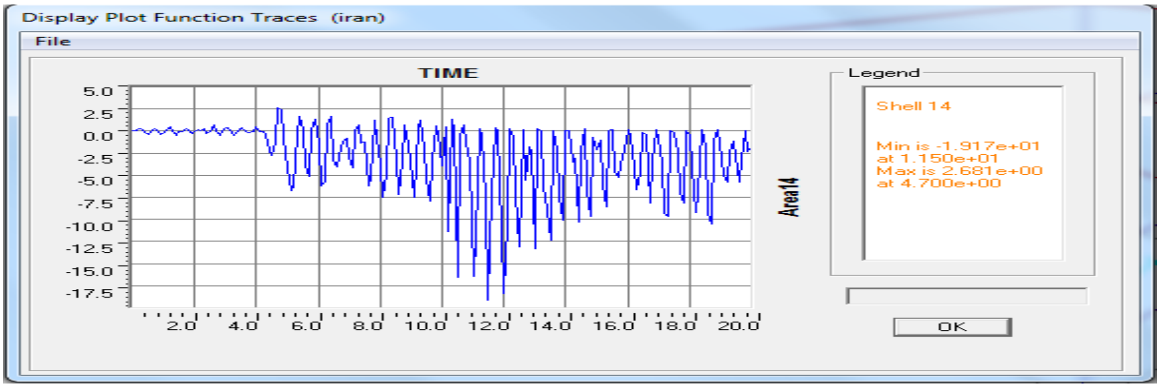
The maximum displacement and maximum stress of solid slab in x and y direction for Iraq Badra (2009) and Iran Tabas(1978) earthquake from present study are shown in tables and figures below.

Table (3) Maximum displacement of solid slab in x and z direction and interstory drift for Iraq Badra(2009) and Iran Tabas(1978) earthquake.

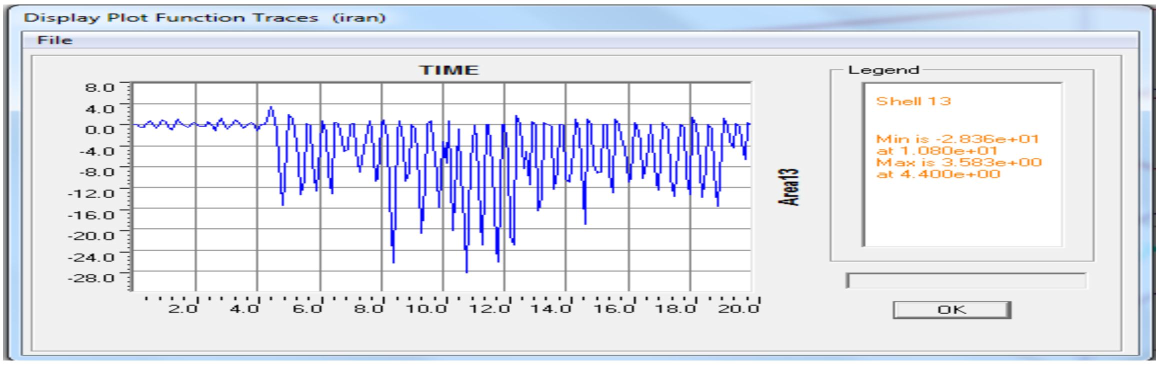
Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Dis. in slab	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)
3	39.5	-0.47	1/285	124	-1.6	1/103
2	29	-1.4	1/181	95	-4.7	1/56
1	12.5	-1.85	1/240	42	6.7	1/71

Table (4)Maximum stress of solid slab in x and y direction and for Iraq Badra(2009) and Iran Tabas(1978) earthquake.

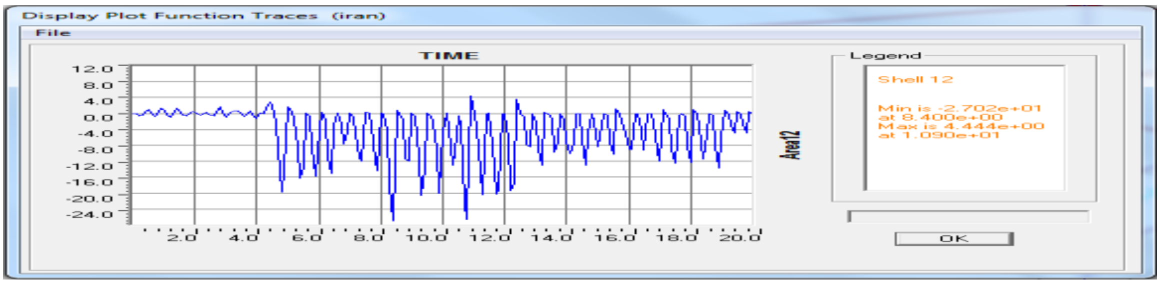
Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Stress in slab	σ_x (MPa)	σ_y (MPa)	σ_{xy} (MPa)	σ_x (MPa)	σ_y (MPa)	σ_{xy} (MPa)
3	4.068	1.118	1.964	6.346	2.121	3.149
	-7.573	-1.084	-1.964	-19.166	-3.189	-3.149
2	4.146	1.962	2.883	6.985	3.637	5.994
	-14.925	-1.898	-2.883	-28.603	-6.405	-5.994
1	4.622	2.266	3.363	7.749	6.192	6.192
	-18.157	-3.026	-3.363	-27.434	-8.746	-6.192



3rd(slab)

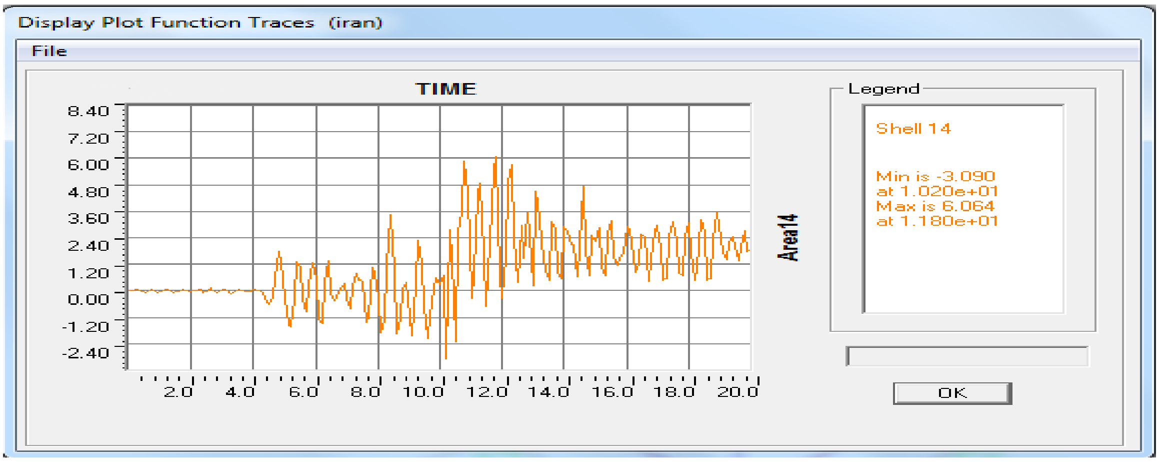


2nd(slab)



1st(slab)

Figure (6) Maximum compression stress ($-\sigma_x$) (MPa) for solid slab for Iran Tabas(1978) earthquake in three floor slabs.



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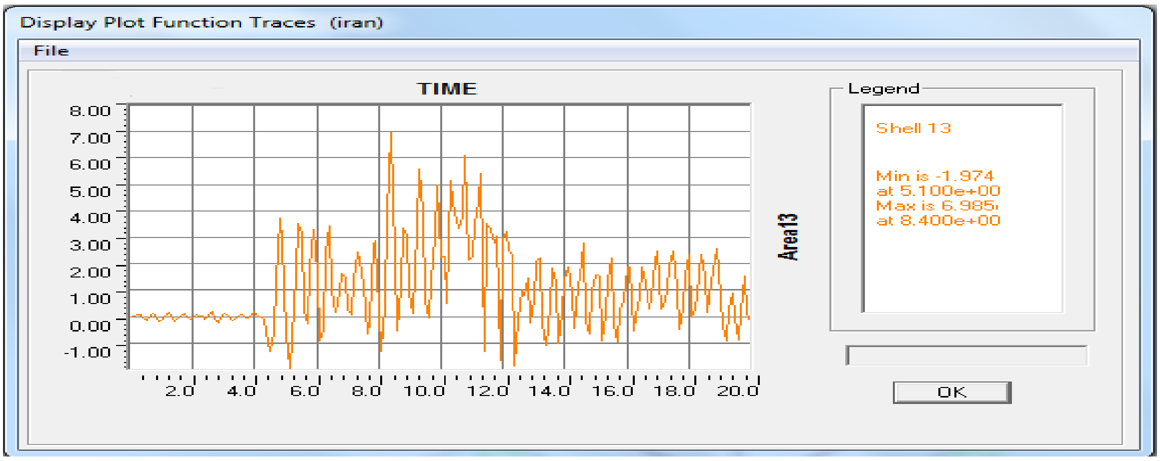

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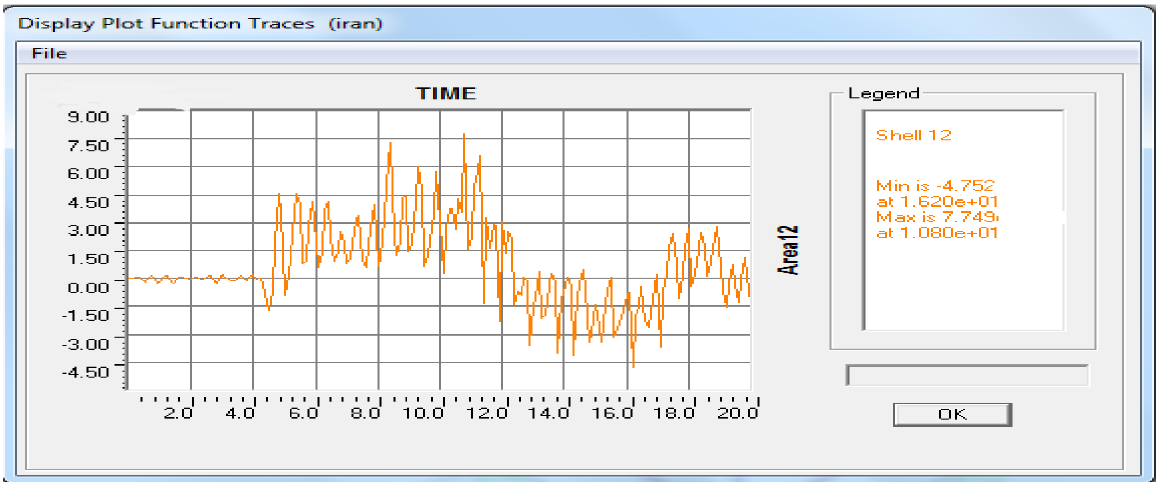


1st(slab)

Figure (7) Maximum tension stress ($+\sigma_x$) (MPa) for solid slab of Iran Tabas(1978) earthquake in three floor slabs.

3.2.3. Ribbed slab.

In the case of ribbed slab, the earthquake are applied in two direction:-

a- Parallel to ribs.

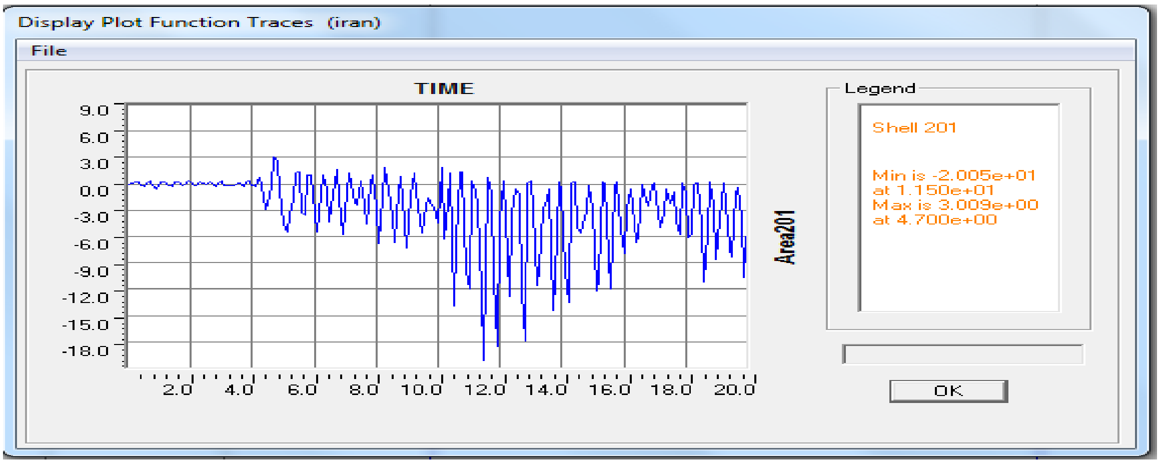
The maximum displacement and maximum stress of ribbed slab from present study are shown in tables and figures below.

Table(5)Maximum displacement and interstory drift of ribbed slab when Iraq Badra(2009) and Iran Tabas(1978) earthquake applied parallel to ribs .

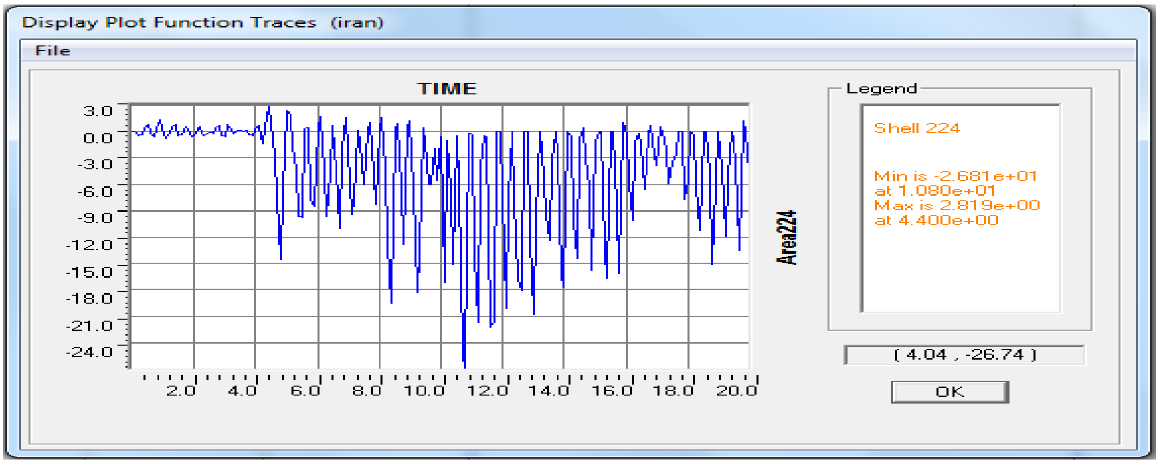
Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Dis. In slab	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)
3	20.5	-0.4	1/566	95.2	-1.5	1/104
2	15.2	-1	1/353	66.6	-4	1/77
1	6.7	-1.4	1/447	27.6	4.8	1/108

Table (6) Maximum stress of ribbed slab when Iraq Badra(2009) and Iran Tabas(1978) earthquake input applied parallel to ribs.

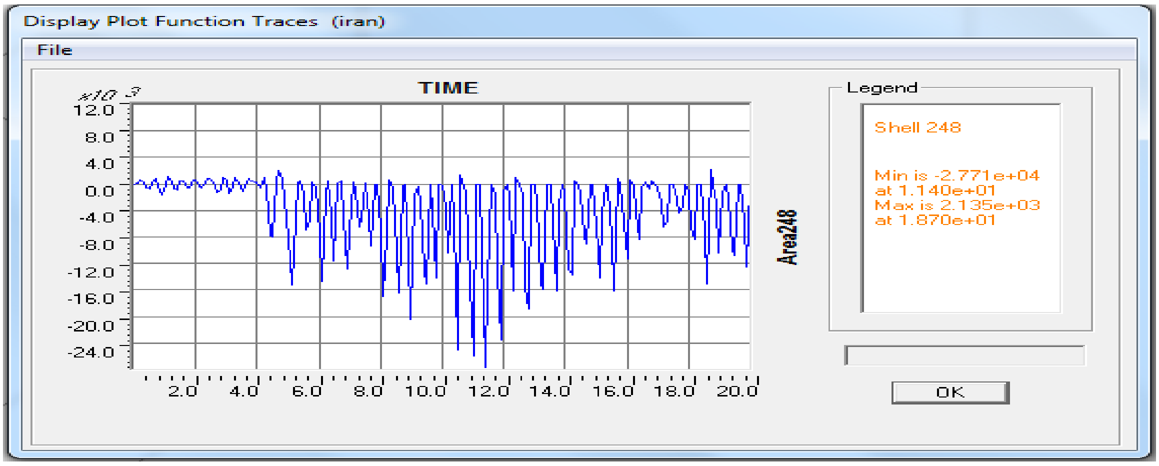
Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Stress in slab	$_x\sigma$ (MPa)	$_y\sigma$ (MPa)	$_{xy}\sigma$ (MPa)	$_x\sigma$ (MPa)	$_y\sigma$ (MPa)	$_{xy}\sigma$ (MPa)
3	3.799	0.841	1.216	5.125	3.910	5.120
	-4.927	-0.828	-1.216	-20.050	-4.287	-5.120
2	3.811	1.947	2.236	6.792	4.448	5.972
	-9.617	-1.844	-2.236	-26.812	-8.228	-5.972
1	3.978	2.322	2.659	7.631	4.406	5.989
	-11.804	-2.203	-2.659	-27.708	-8.906	-5.989



3rd(slab)

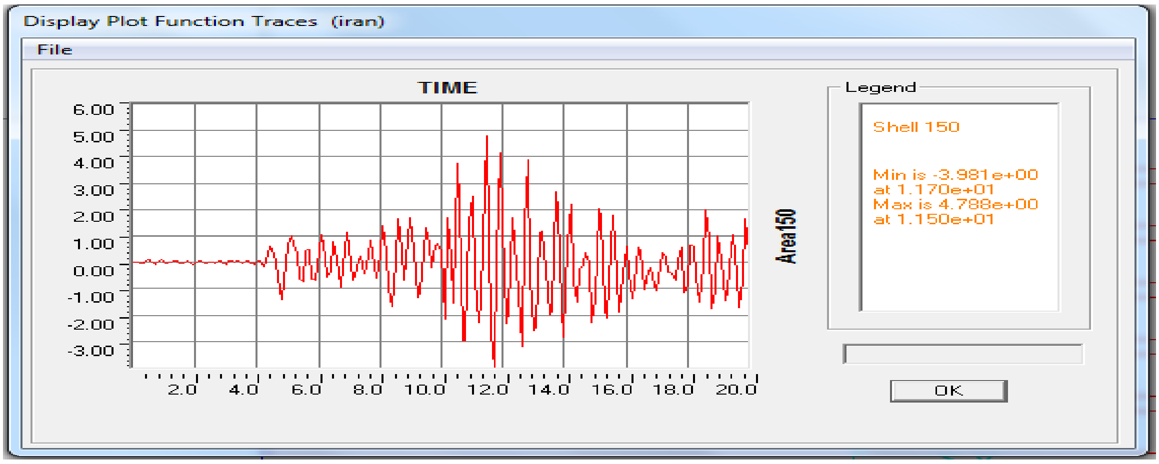


2nd(slab)

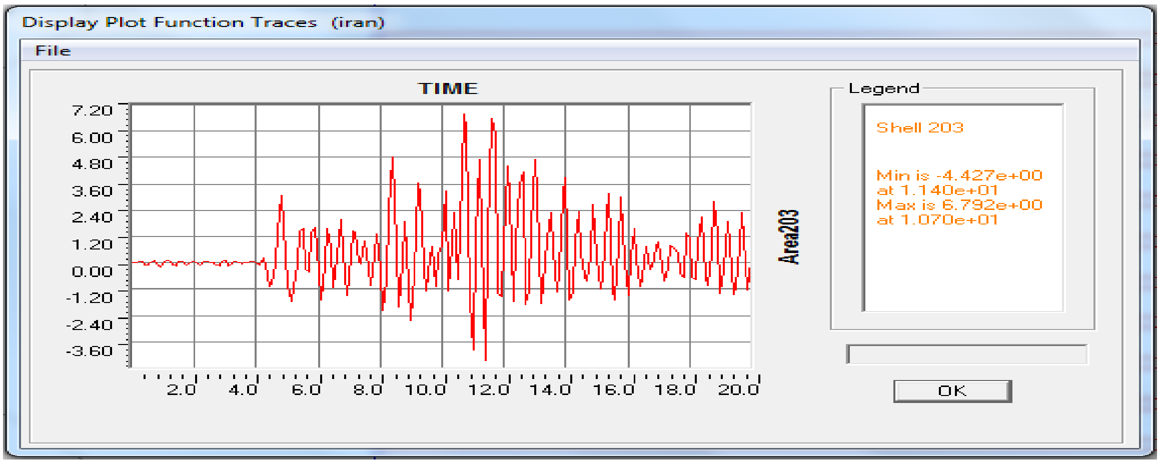


1st(slab)

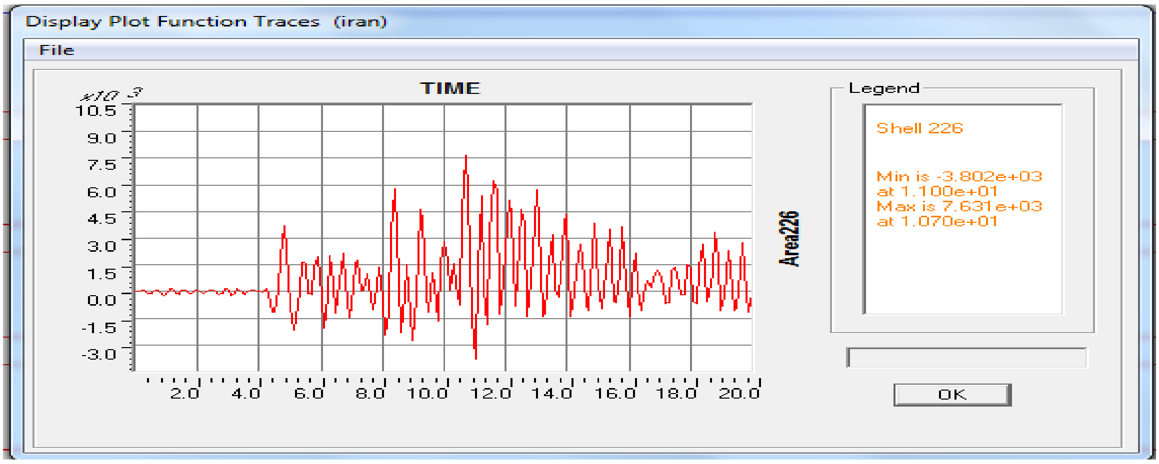
Figure (8) Maximum compression stress ($-\sigma_x$) (MPa) of ribbed slab in three floor slabs when Iran Tabas(1978) earthquake input parallel to ribs.



3^{rd}(slab)



2^{nd}(slab)



1^{st}(slab)

Figure (9) Maximum tension stress ($+\sigma_x$) (MPa) for ribbed slab in three floor slabs when Iran Tabas(1978) earthquake input parallel to ribs.

b-Perpendicular to ribs.

The maximum displacement and maximum stress for ribbed slab from present study are shown in tables below.

Table (7) Maximum displacement and interstory drift of ribbed slab when Iraq Badra(2009) and Iran Tabas(1978) earthquake input perpendicular to ribs.

Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Dis. In slab	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)	Dis. (x)mm	Dis. (z)mm	Interstory drift (rad)
3	25.6	0.3	1/428	110.5	-2.4	1/88
2	18.7	-1	1/272	76.6	-4.8	1/64
1	8.1	-1.3	1/357	30.8	-5	1/97

Table (8) Maximum stress of ribbed slab in x and y direction when Iraq Badra(2009) and Iran Tabas(1978) earthquake input perpendicular to ribs.

Input E.Q.	Iraq Badra(2009)			Iran Tabas(1978)		
Stress in slab	σ_x (Mpa)	σ_y (Mpa)	σ_{xy} (Mpa)	σ_x (Mpa)	σ_y (Mpa)	σ_{xy} (Mpa)
3	4.325	0.780	1.257	4.431	3.730	4.558
	-6.464	-0.761	-1.257	-23.91	-3.676	-4.558
2	4.454	1.637	2.213	5.47	4.079	5.439
	-12.429	-1.685	-2.213	-30.31	-6.402	-5.439
1	4.385	1.889	2.590	5.558	4.434	5.483
	-14.930	-2.084	-2.590	-28.41	-5.962	-5.483

Table (9) Maximum base shear of solid and ribbed slab when Iran Tabas(1978) and Iraq Badra(2009)earthquake input .

Case of slab	Soild slab	Ribbed slab	
		parallel to ribs	perpendicular to ribs
Input E.Q.	Base shear (kN)		
Iraq Badra(2009)	1398	765	863
Iran Tabas (1978)	4641	2889	2923

Table (10) Maximum displacement of solid and ribbed slab when Iran Tabas(1978) and Iraq Badra(2009)earthquake input .

Case of slab	Soild slab	Ribbed slab	
		parallel to ribs	perpendicular to ribs
Input E.Q.	` Maximum displacement (mm)		
Iraq Badra(2009)	39.5	20.5	25.6
Iran Tabas (1978)	124	95.2	110.5

Analytical results and discussion for Iran Tabas(1978) earthquake

- maximum response displacement

From the table(9) it can be noted that the maximum response displacement in case of ribbed slab subject to seismic loading in (x) direction is reduced by 23% than displacement of solid slab. This can be justified due to the higher stiffens of the ribbed slab and its lighter weight compared to the solid slab. This conclusion agrees with the results obtained by (Mohamed A. A. El-Shaer)[8]. When seismic force is applied perpendicular to the ribs the displacement reduced by 11% due to reduction in weight of ribbed slab.

-base shear: From the table(10) it can be noted that the maximum base shear in case of ribbed slab subject to seismic loading in (x) direction is reduced by 38% than base shear of solid slab. When seismic force is applied perpendicular to the ribs the base shear reduced by 37% due to reduction in maximum displacement of ribbed slab.

-stress (σ_x): The ribbed slab is give convergent results for tension stress of slab ($+\sigma_x$) than tension stress of solid slab when earthquake applied in the (x) direction and reduced by 28% than tension stress of solid slab when earthquake applied perpendicular to the ribs .

The ribbed slab is decreased the compression stress of slab ($-\sigma_x$) for by 3% than the compression stress of solid slab in (x) direction and increased by 5% than compression stress of solid slab when earthquake applied perpendicular to the ribs.

-stress (σ_y): The ribbed slab in case the earthquake applied in the (x) direction is give convergent results than tension stress ($+\sigma_y$) of solid slab and reduced by 27% than tension stress of solid slab when earthquake applied perpendicular to the ribs .

The ribbed slab is reduced the compression stress of slab (- σ_y) for by 28% than the compression stress of solid slab in (x) direction and reduced by 28% than compression stress of solid slab when earthquake applied perpendicular to the ribs.

The ribbed slab is reduced the shear stress of slab (σ_{xy}) by 3 % than shear stress of solid slab in (x) direction and by 11% when earthquake applied perpendicular to the ribs.

Analytical results and discussion for Iraq badra (2009) earthquake

- maximum response displacement: From the table(9) it can be noted that the maximum response displacement in case of ribbed slab subject to seismic loading in (x) direction is reduced by 47% than displacement of solid slab. This can be justified due to the higher stiffens of the ribbed slab and its lighter weight compared to the solid slab. This conclusion agrees with the results obtained by (Mohamed A. A. El-Shaer)[8]. When seismic force is applied perpendicular to the ribs the displacement reduced by 33% due to reduction in weight of ribbed slab.

-base shear: From the table(10) it can be noted that the maximum base shear in case of ribbed slab subject to seismic loading in (x) direction is reduced by 45% than base shear of solid slab. When seismic force is applied perpendicular to the ribs the base shear reduced by 38% due to reduction in maximum displacement of ribbed slab.

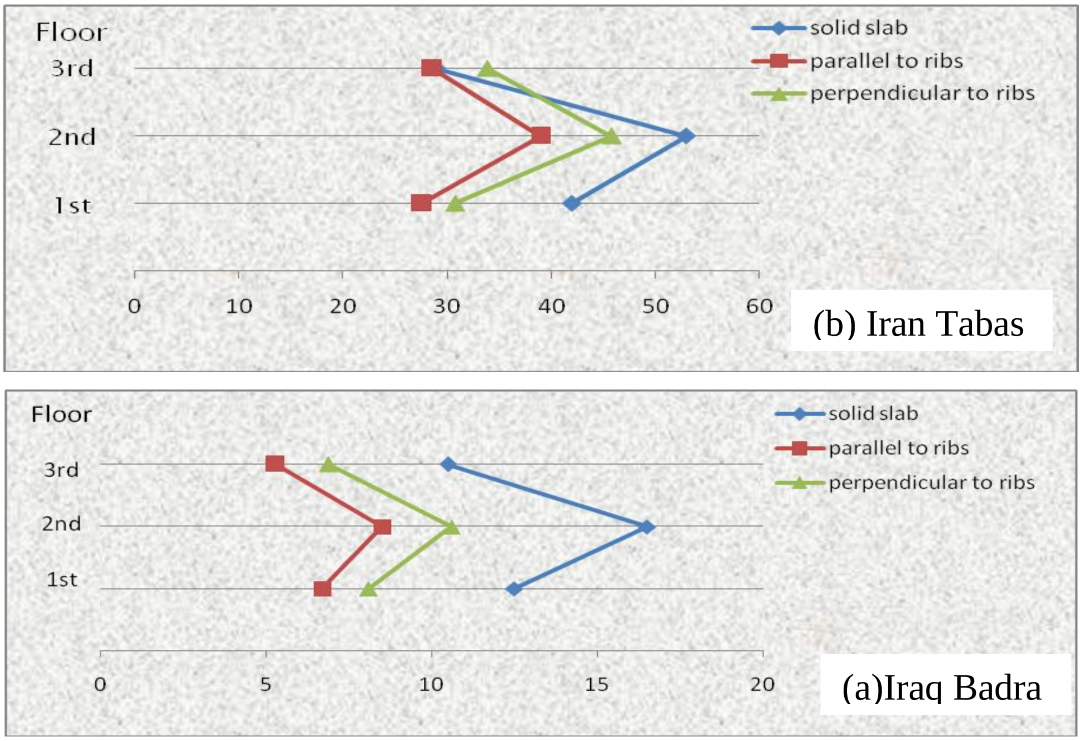
-stress(σ_x): The ribbed slab is reduced the tension stress of slab (+σ_x) by 14% than tension stress of solid slab when earthquake applied in the (x) direction and reduced by 5% than tension stress of solid slab when earthquake applied perpendicular to the ribs .

The ribbed slab is reduced the compression stress of slab (- σ_x) for by 35% than the compression stress of solid slab in (x) direction and reduced by 17% than compression stress of solid slab when earthquake applied perpendicular to the ribs.

-stress(σ_y): The ribbed slab in case the earthquake applied in the (x) direction is give convergent results than tension stress (+σ_y) of solid slab and reduced by 16% than tension stress of solid slab when earthquake applied perpendicular to the ribs .

The ribbed slab is reduced the compression stress of slab (- σ_y) for by 27% than the compression stress of solid slab in (x) direction and reduced by 31% than compression stress of solid slab when earthquake applied perpendicular to the ribs.

The ribbed slab is reduced the shear stress of slab(σ_{xy}) by 21 % than shear stress of solid slab in (x) direction and by 23% when earthquake applied perpendicular to the ribs.



Maximum drift displacement(mm)

Figure (10) Maximum drift displacement of solid and ribbed slab for (a) Iraq Badra (2009) and (b)Iran Tabas earthquake.

4. Conclusions

Based on the results from the finite element by used SAP2000 program the following conclusions could be drawn:

1- Maximum stress is occur most often in the first floor slab for both system of slab.

2- Maximum interstory is occur drift most often in the second floor slab for both system of slab.

3-The displacement of ribbed slab subjected to earthquake for in direction parallel to ribs is found to be 23% and 47% smaller than solid slab for Tabas and Badra earthquake respectively.

4-The displacement of ribbed slab subjected to earthquake for in direction perpendicular to ribs is found to be 11% and 33% smaller than solid slab for Tabas and Badra earthquake respectively.

5-The base shear of ribbed slab subjected to earthquake for in direction parallel to ribs is found to be 38% and 45% smaller than solid slab for Tabas and Badra earthquake respectively.

6-The base shear of ribbed slab subjected to earthquake for in direction perpendicular to ribs is found to be 37% and 38% smaller than solid slab for Tabas and Badra earthquake respectively.

7-Stresses value in ribbed slab are reduced by up to about 28% than stresses in solid slab.

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