Analytical Behavior of Multi-Storied Building with Base Isolation Subjected to Earthquake Loading

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Abstract:

This study involves analysis of multi-storied building to explain the behavior under seismic earthquake loading in two cases, (i.e. with or without base isolation system). The buildings of the same properties of five stories were analyzed consist of steel parts (beams and columns) with reinforced concrete slabs and isolated system supported provided by fixed or Nllink supports. The responses of building at each case are determined to evaluate the base isolation systems that used under static and dynamic (earthquake) loading. The analysis was done by used the finite elements procedure provided by SAP2000 version14 program.

In this studied covers concept, Analysis, working and other aspects of using isolator or not with building and effect when using (isolator) in reduction translation, base shear and moment due to ability to dispersion the energy.

From the analysis results it was found that when using rubber bearing pad to isolate the base building gives reduction the values of absolute maximum acceleration of basement in the isolated building by about 90% (i.e. decrease inertia forces), and reduction in base shear, base moment and base translation displacement by about (83% ,91.5% and 9.1%) respectively,also it was found that the building with rubber pad to isolate moved at same values of translation displace at all floors level compared with building without base isolation therefore the content of building (with base isolation) and instrument become safer under the damage of earthquake.

***Key word**: Base isolation, Nllink, Time History Analysis, Dynamic Response, SAP2000.*

السلوك النضري لبيانات متعددة الطوابق مع عزل القاعدة معرضة إلى أحمال الهزات الأرضية

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الخلاصة :

هذه الدراسة شملت تحليل بناية متعددة الطوابق لبيان سلوكها تحت تأثيراحمال الهزات الارضية في حالتين مع او بدون انظمة العزل للقاعدة. نفس الخصائص للبناية بخمس طوابق تم تحليلها ومؤلفة من اجزاء معدنية (الاعمدة والعتبات) مع سقوف خرسانية مسلحة ونظام عزل المساند جهز بواسطة مساندة ثابتة او نقاط رابطة. استجابة البناية في كلتا الحالتي تم حسابها لتقييم انظمة عزل القاعدة المستخدمة تحت الاحمال الساكنة والحركية (الهزات الارضية). التحليل عمل بواسطة استخدام خطوات العناصر المحددة المجهزة في برنامج (SAP2000 v14)في هذه الدراسة تم بيان الفكرة والتحليل والعمل وغيرها عند استخدام العازل او بدون وجود العازل وتاثير استخدام العازل في تقليل الانتقالات والقص والعزم القاعدي نتيجة قابليتها على تبديد الطاقة. من نتائج التحليل وجد ان استخدام مخمد من النوع المطاط لعزل قاعدة البناية يعطي تقليل في قيمةالمطلقة العظمى للتسارع القاعدي للبناية المعزولة بحدود ٩٠ % (اي تقليل قوى الممانعة)و تقليل القص والعزم وازاحة الانتقال القاعدي بحدود(٨٣% و ٩١.٥ % و٩١.٩ %) على التوالي بالمقارنة مع البنايةبدون عزل للقاعدة. وكذلك وجد ان ابنية المعزولة بمخمد من المطاط تتحرك بنفس القيم لازاحة الانتقال في كل مستويات الطوابق بالمقارنة مع البناية الغير معزولة لذلك فان احتوى على عزل قاعدي واجهزة تصبح اكثر سلامة تحت اضرار الهزات الارضية.

1. Introduction:

Base isolation is one of the most widely accepted seismic protection systems in earthquake prone areas. It mitigates the effect of an earthquake by essentially isolating the structure from potentially dangerous ground motions, especially in frequency range where building is mostly affected. Seismic isolation is a design a strategy, which uncouples the structure for the damaging effects of the ground motion. The term isolation refers to reduced interaction between structure and the ground. When the seismic isolation system is located under the structure, it is referred as “base isolation”. The Base isolation is obtained by using Dampers, in this studied used rubber bearing pad.

Seismic isolation problem which can be considered an important method in providing an effective engineering solution for the prevention of earthquake damage to buildings, bridges and other structures. Its principle is based on uncoupling the building or structure from the damaging effects of ground motion by providing additional horizontal flexibility and energy dissipation capability through using specially designed isolator.

2. Objectives of the Study:

The study is directed to:

- Investigate, analytically behavior of multi story building with or without base isolation subjected to earthquake ground motion.
- Study the response of building under earthquake ground motion (maximum floor displacement, base shear and base moment in X and Y direction).

3. Earthquake Effects on Buildings:

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements (like glass facades) and to some structural members in the building. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional in the aftermath of the earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Buildings with such improved seismic performance usually cost more than normal buildings do. However, this cost is justified through improved earthquake performance [1]. Two basic technologies are used to protect buildings from damaging earthquake effects. These are Base Isolation Devices and Seismic Dampers. The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. Seismic dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building (much like the way shock absorbers in motor vehicles absorb the impacts due to undulations of the road).

4. Seismic Isolation Principles:

The basic objective of the seismic isolation is to introduce horizontally flexible but vertically stiff components (base isolators) at the base of a building to substantially uncouple the superstructure from high-frequency earthquake shaking. The basic concept of base isolation system is lengthening the natural period of the fixed base building. The benefits of adding a horizontally compliant system at the foundation level of a building can be seen in **Figure(1a**), using an acceleration response spectrum. Increasing the period of the structure reduces the spectral acceleration for typical earthquake shaking. Displacements in isolated structures are often large and efforts are made to add energy dissipation or damping in the isolation system to reduce displacements as shown in **Figure(1b)** using a displacement response spectrum. The addition of damping to the isolation systems serves to reduce displacements in the seismic isolators, which can translate into smaller isolators [2].

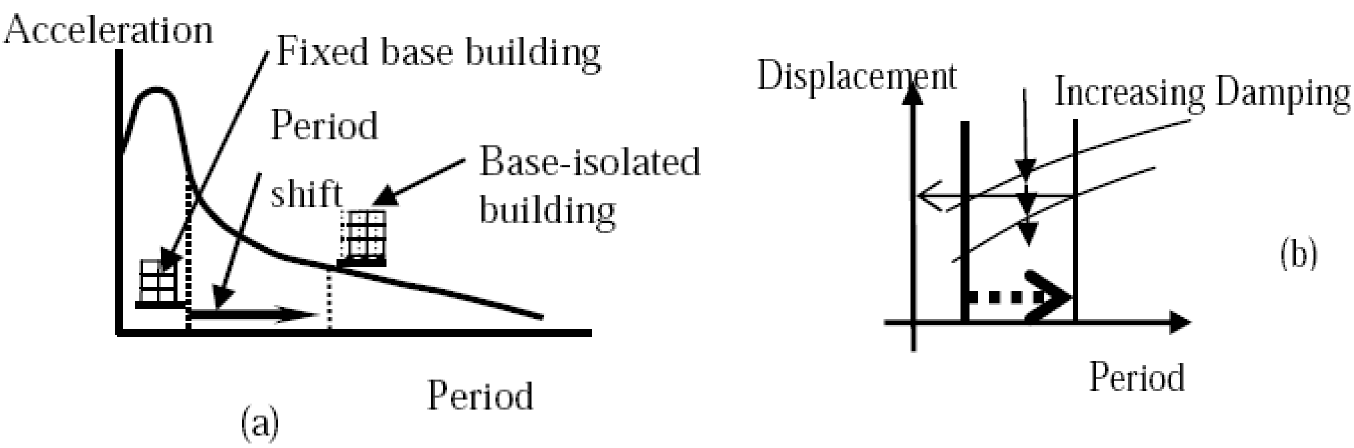


Fig.(1) Period Shift Effect on (a) Acceleration Curve[2], (b) Displacement Curve[2].

5. Dynamic Analysis of Buildings:

The engineer, when designing, is in need to information about natural behavior of the structures; the details are different according to type of design (preliminary or final). In general, the behavior which can be evaluated by mathematical model is the same as that for true structure. The mathematical model should contain all members or parts that form the structure and also contribute to the resistance of lateral forces. It must also contain the stiffness, strength of material that affects the distributed forces. Finally the model should be able to represent the basic distributions of masses, stiffness in structures.

The basic steps for design or analysis are:

a. Development of mathematical model to represent the structure and loading cases.
b. Running static and dynamic, analyses.

c. Evaluating results and making comparisons.

In the present study program SAP2000 was used to develop a mathematical model for analysis of the studied structure. For isolation system that used the nonlinear link parts (Nllink) to represent its. The (Nllink) system that is usually used to model nonlinear local behavior in structures such as gaps, dampers, isolators and others was used to simulated seismic isolation. Every (Nllink) part consists one node representing single spring fixed to earth. Any link part has very small length or consists of two nodes connected together by a link [3].

The (Nllink) system consists of six springs or dampers. Every one represents a degree of freedom (a axial force, two shear forces, a torque or an overturning moment). In the present study the (Nllink) system was used to simulate the base isolation produced by rubber bearing pad.

6. Finite Element Program:

In the present study two five-story buildings consist of (five stories) one is without base isolation and the other is with base isolation, was analyzed.

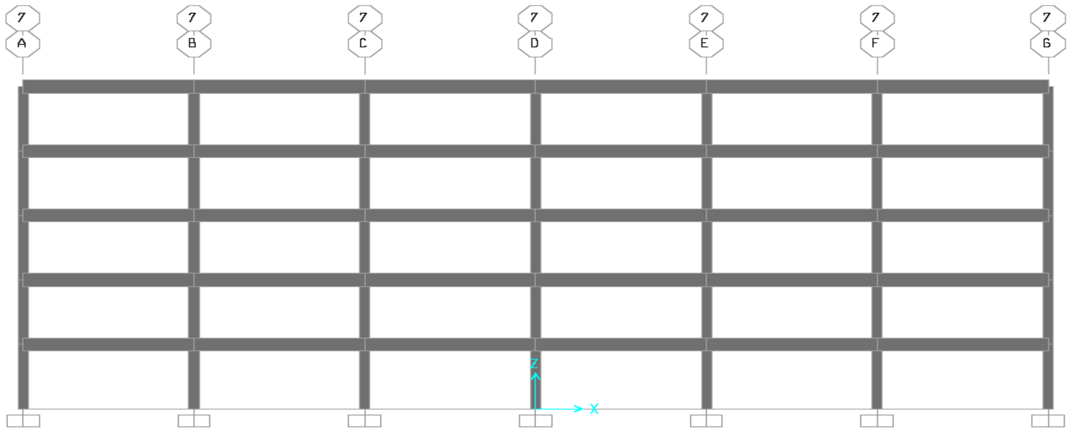
The same properties were used for two cases (**i.e**. with and without base isolation). The two buildings consist of frames in two directions of 36x36 m horizontal dimensions i.e. six bays in each of two principle plan directions. Each story is (3 meter high). All dimensions are shown in **Fig.(2).**

All beams dimensions are of the AISC standard section (W24x76), while each column is of (W14x99) standard section. The reinforced concrete slab thickness of 200 mm.

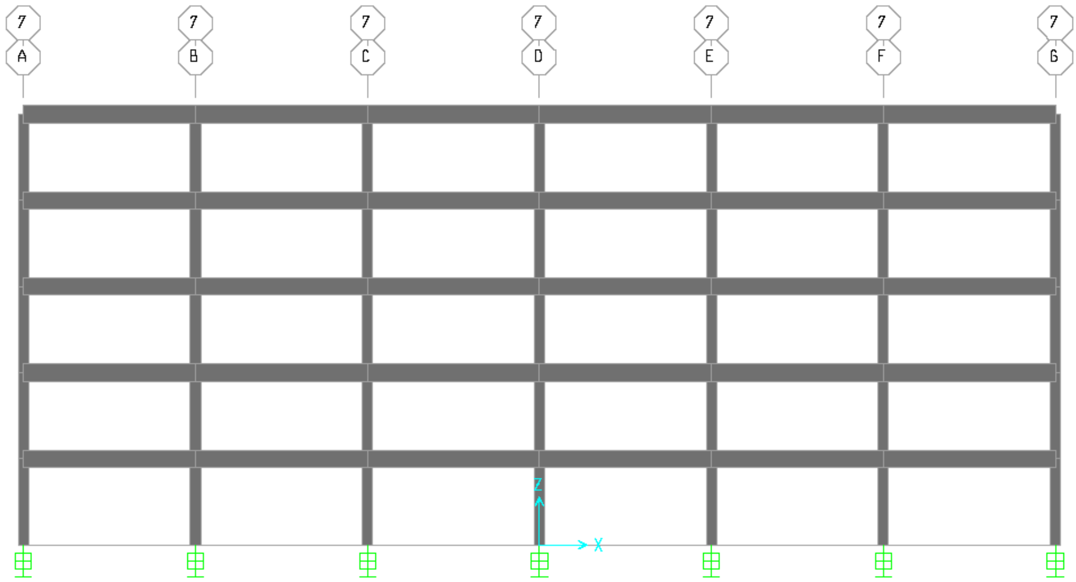
Those properties of beams, columns and slab are selected to study the analysis of building under time history with or without base isolation. The dead load is of (5kN/m^2) value, while the live load value is equal to (3kN/m^2) uniformly applied to slabs.

The load time histories are used to represent load verses with time. These loads are the SAP2000, load history named (LACC_NOR-1.TH and LACC_NOR-2.TH) were used in the present study. These loads were selected in order to give maximum responses. The side, isometric and top view of the two building are shown in **Figs.(2, 3 and 4),** respectively for the two cases of base isolation (existing or not existing).

Location of the nonlinear link used to simulate the support providing base isolation system is shown in **Fig.(5).**

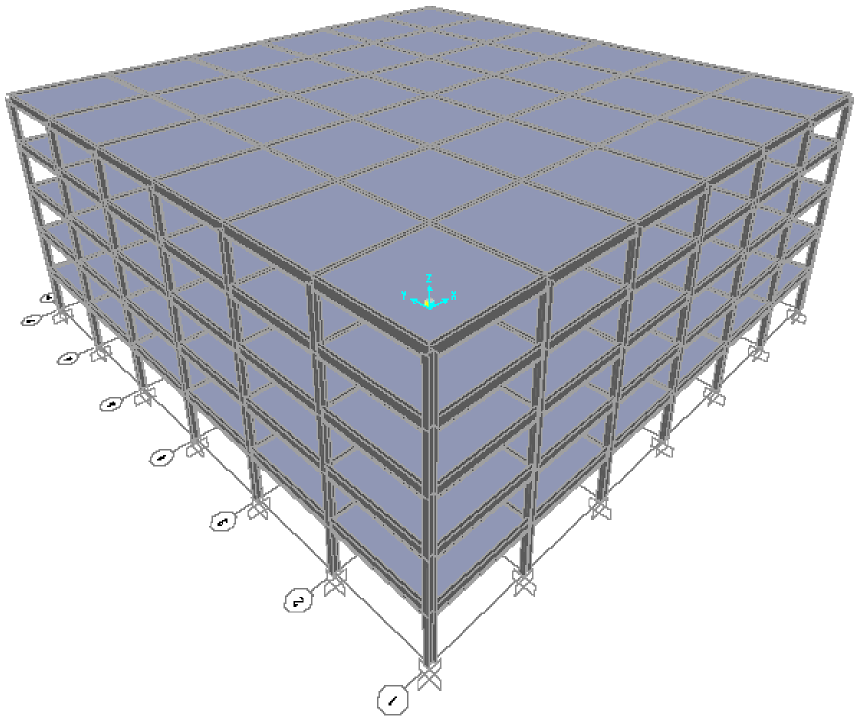


(a) Without Base Isolation.

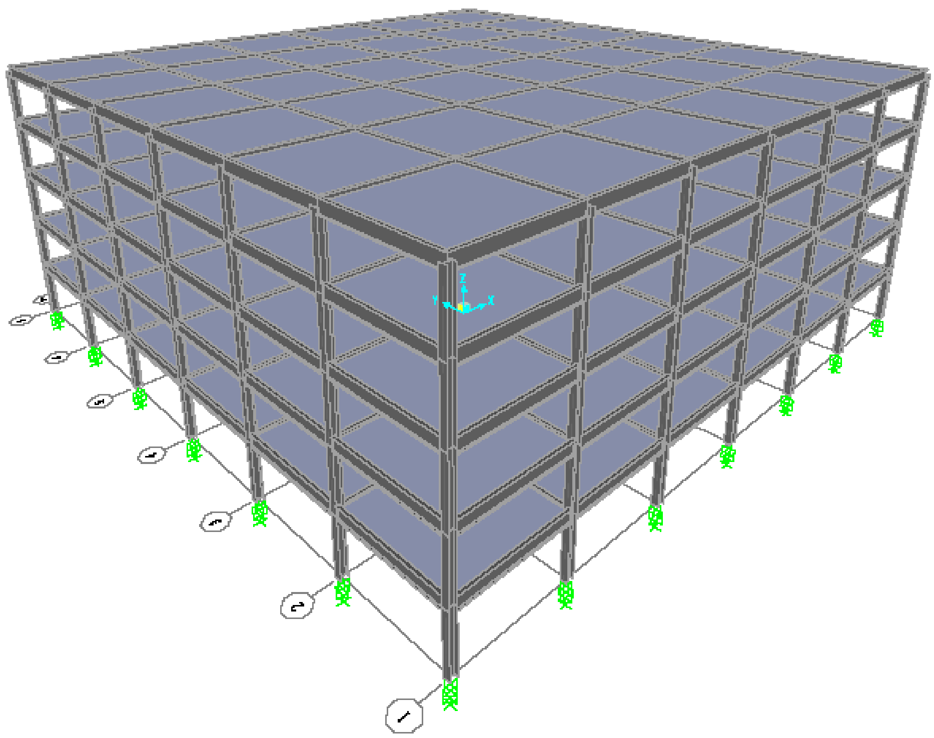


(b) With Base Isolation.

Fig.(2) Side View Of The Analyzed Building With Shown Two Cases Of Base Isolation



(a) Without Base Isolation.



(b) With Base Isolation.

Fig.(3) Isometric of the Analyzed Building With Shown Two Cases of Base Isolation

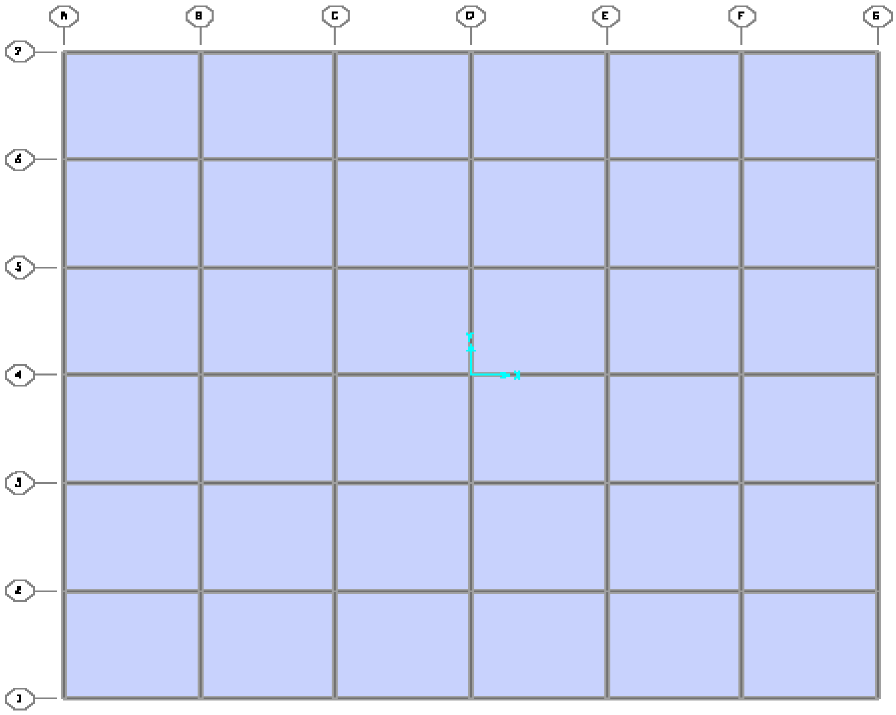


Fig.(4) Top View of Building With or Without Base Isolation.

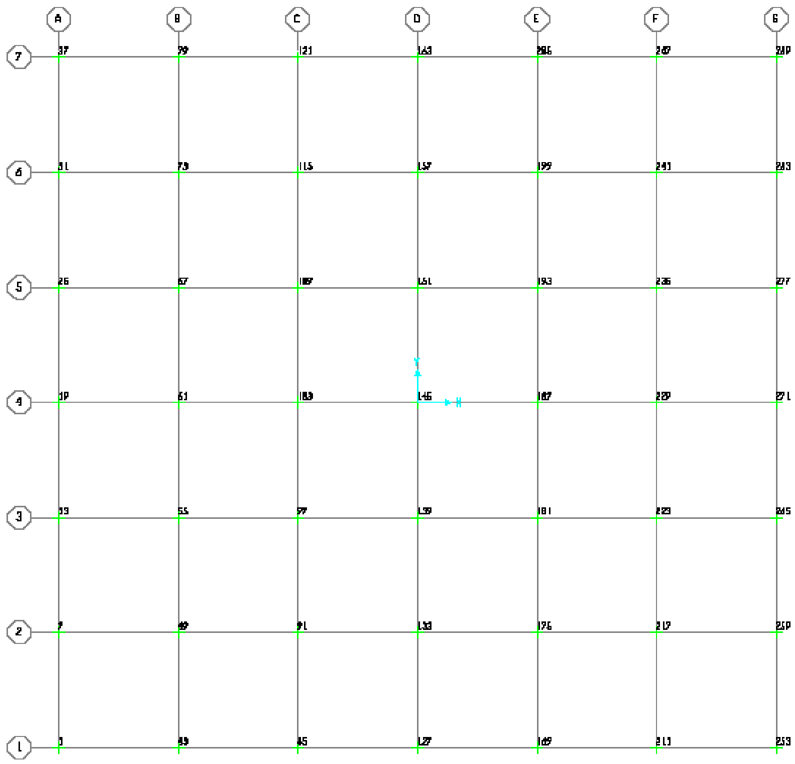
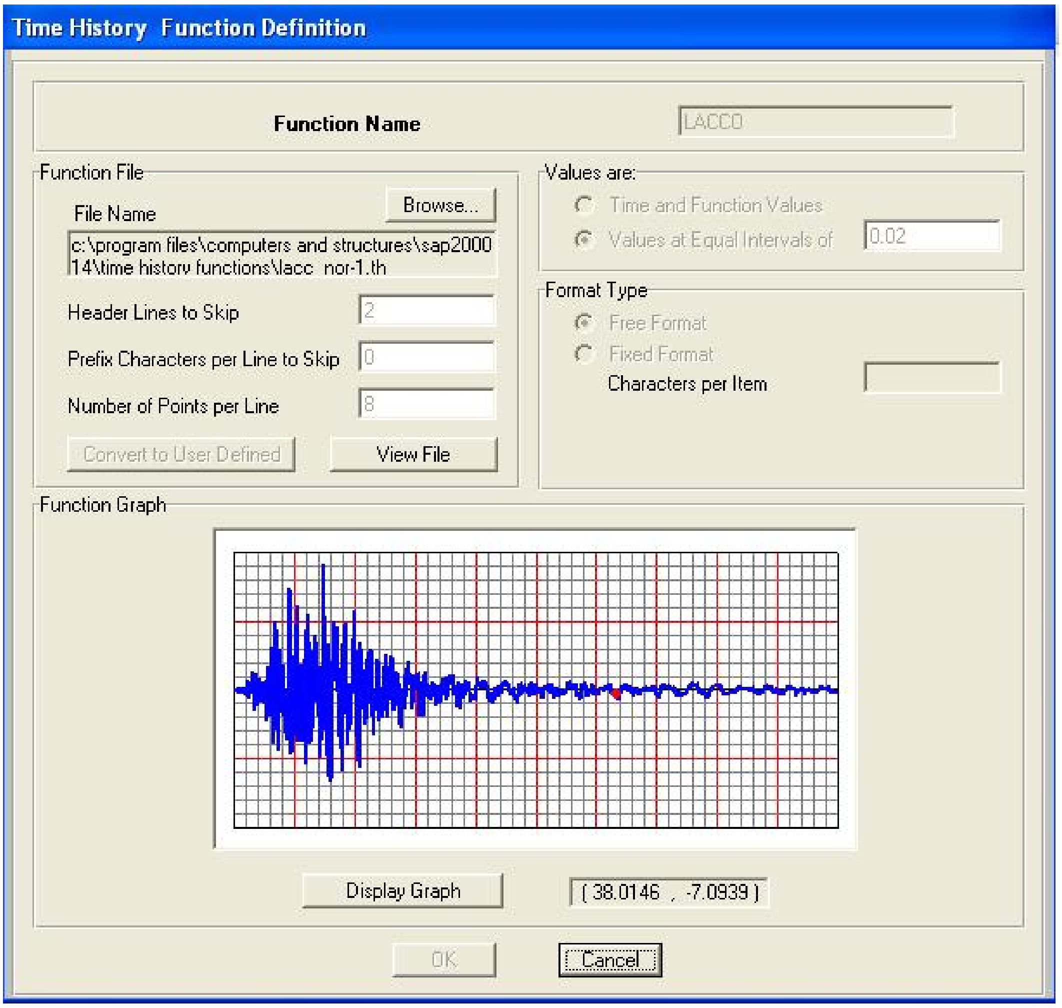


Fig.(5) Location of (Nllink)System for Building With Base Isolation.

6.1 Load Time History Analysis:

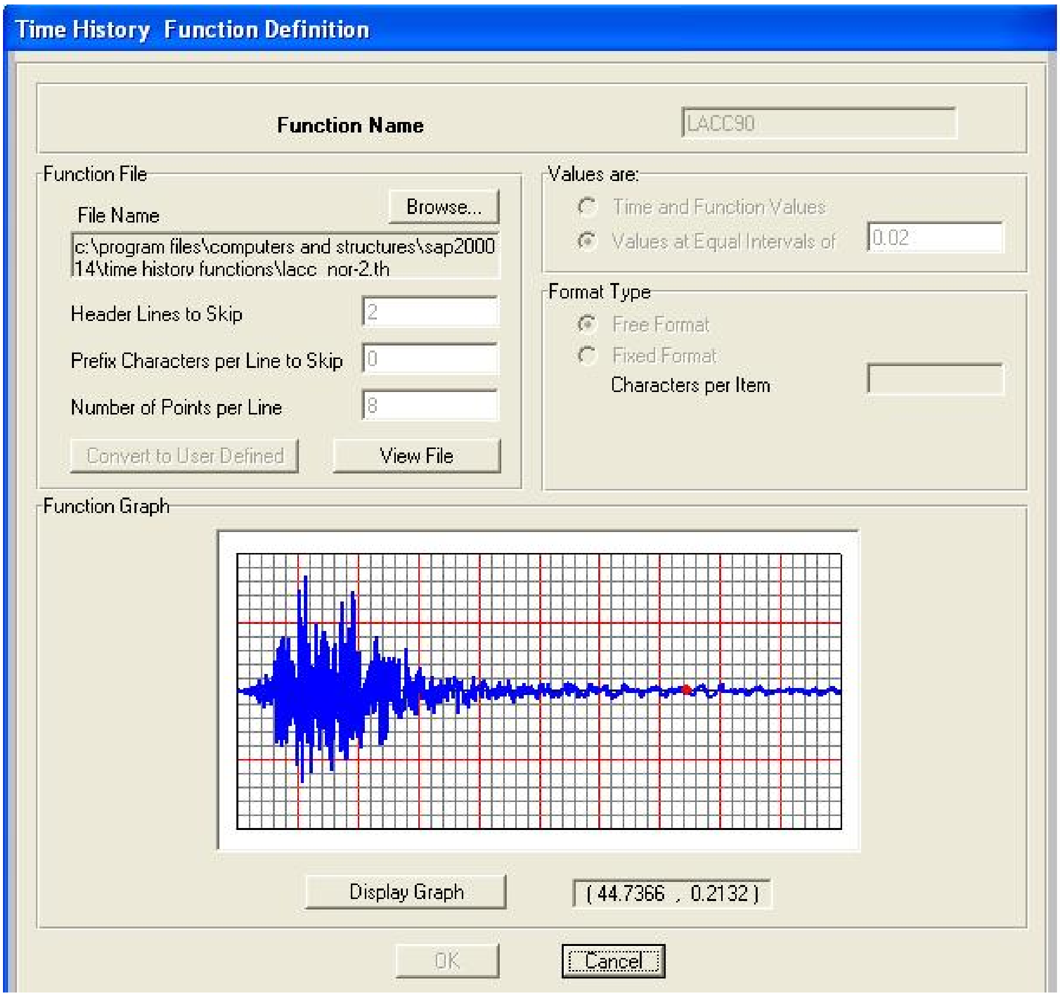
The analysis was done by using the nonlinear analysis of load time history that available in SAP2000 PROGRAM for the two cases of the building base isolation.

In this study the dynamic analysis was done by using records of the two load time histories available in program. The analysis was done to explain effect of the base isolation in decreasing building response to seismic loads. The **Fig.(6)** shows load time history for the two records (LACC_NOR-1.TH) and (LACC_NOR-2.TH), respectively.



(a) For (LACC_NOR-1.TH).

Fig.(6) Load Time History of the Two Records Implemented in Sap2000 Program.



(b) For (LACC_NOR-2.TH).

Fig.(6) (Continued)

In this study the following two load cases were used in the analysis:

1- GRAV:

In this case apply the static load (dead and live load) were applied to the building by using the linear time history function (linear) increasing as (ramp) found given in the program.

2- LACC:

In this case acceleration of seismic loads was considered. Results of the 1st case consider the initial condition of analysis. The value of damping was taken as 5% for the non isolated building case and 2% for the isolated building case.

The figures below show the analysis cases.

6.2 Dynamic Response of Building (Isolated and Non-Isolated Cases):

The dynamic response of structures was then evaluated for both cases (isolated and non isolated ones). The response includes value of the maximum translation at each story, and value of base shear. The maximum values at every story were evaluated at some point from the same story. The maximum values from these points at same location for each of the two cases are given in **Table (1).**

Table(1) Response Values under Seismic Load for the Non isolated and the Isolated Buildings.

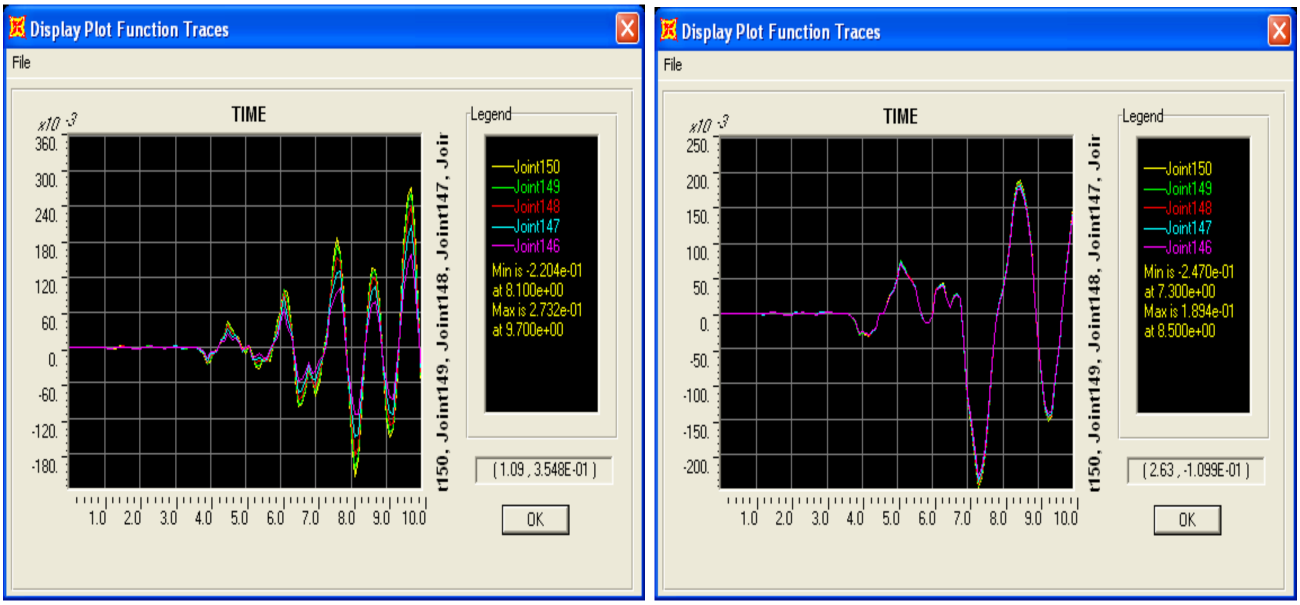
item	unit	Story No.	Before isolate	After isolate
Maximum floor displacement (X)*	cm	Base	0	27.33
		1st	17.16	29.99
		2nd	24.53	30.62
		3rd	29.51	31.02
		4th	32.83	31.28
		Roof	34.59	31.43
Base shear in (X)	Ton		4443	435
Base Moment (X)	Ton.m		21830	2053
Maximum floor displacement (Y) *	mm	base	0	20.39
		1st	15.92	23.25
		2nd	20.82	23.85
		3rd	24.13	24.25
		4th	26.25	24.53
		Roof	27.32	24.67
Base shear in (Y)	Ton		1702	399.8
Base Moment (Y)	Ton.m		44160	3048

- **X- and Y- directions are with reference to Fig.(4).**

Evaluation of the performances of the two buildings were determined by selecting the central point (one node per each level) and plot the relationship between time as abscissa and displacement as ordinate as shown in **Fig.(7)** for the two cases of base isolation. One node of number (146) at the building base was then selected to evaluate the base shear and shown in **Fig.(8).**

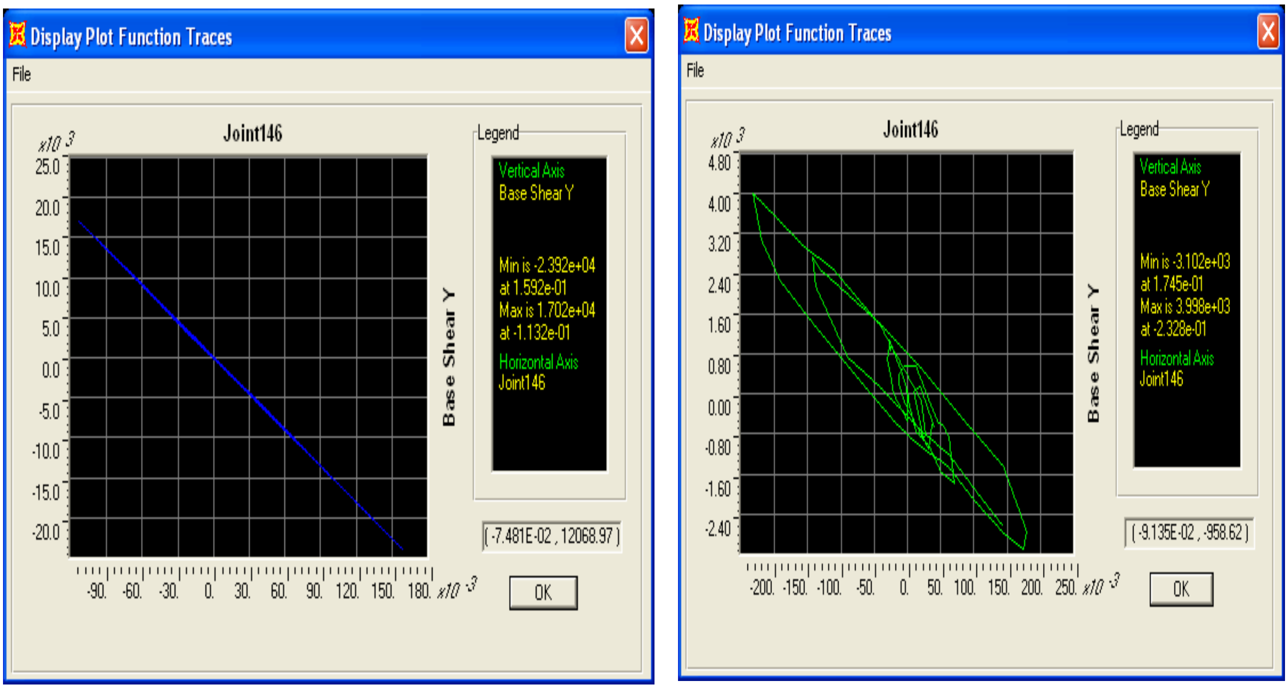
The response of the structure under those load effects due to shear and moment are shown in **Figs.(9&10)**, were behavior of the building is the same in the two orthogonal directions.

Also effects of these loads on the slabs were determine by selecting the shell option in the program for each building case for which the maximum stresses are shown in **Fig.(11).**Finally the moment relation with time is selected for one part and shown in **Fig.(12).**



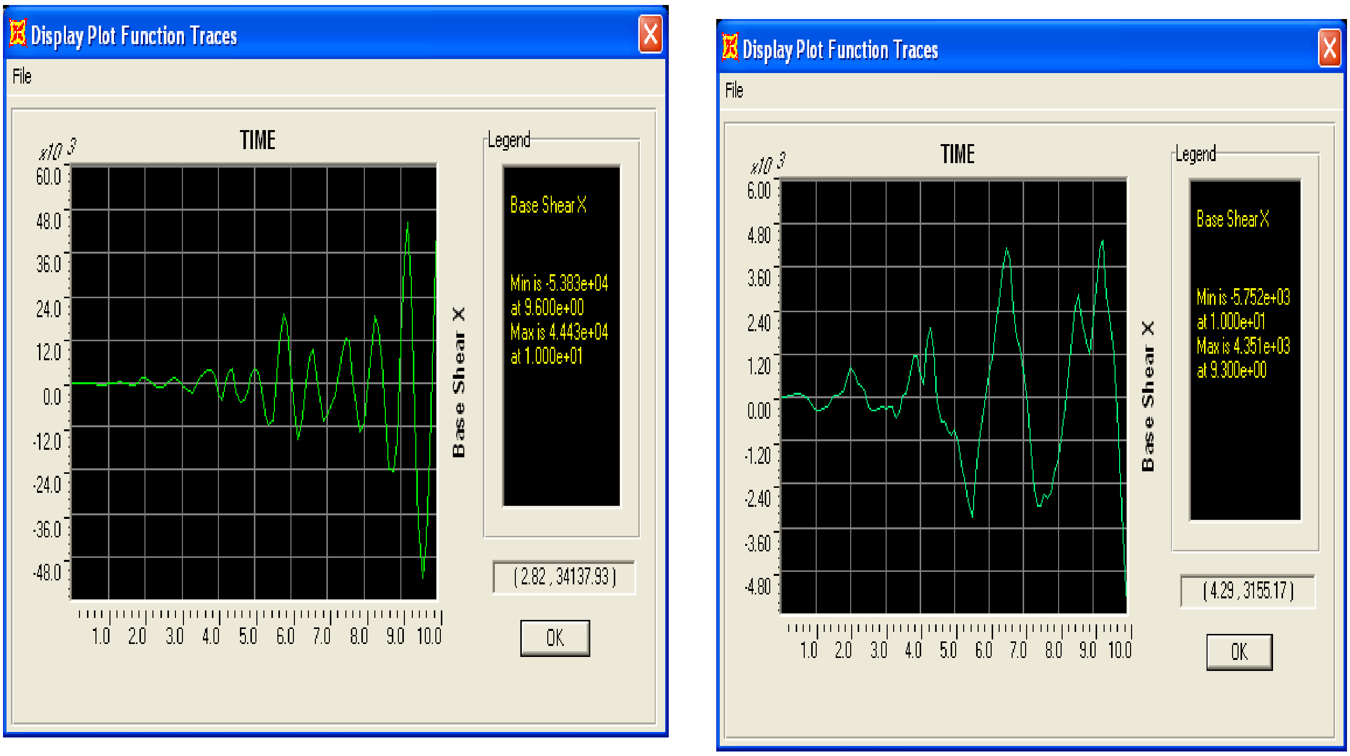
(a) Without Base Isolation **(b) With Base Isolation**

Fig.(7) Displacement-Time History of All Floors.



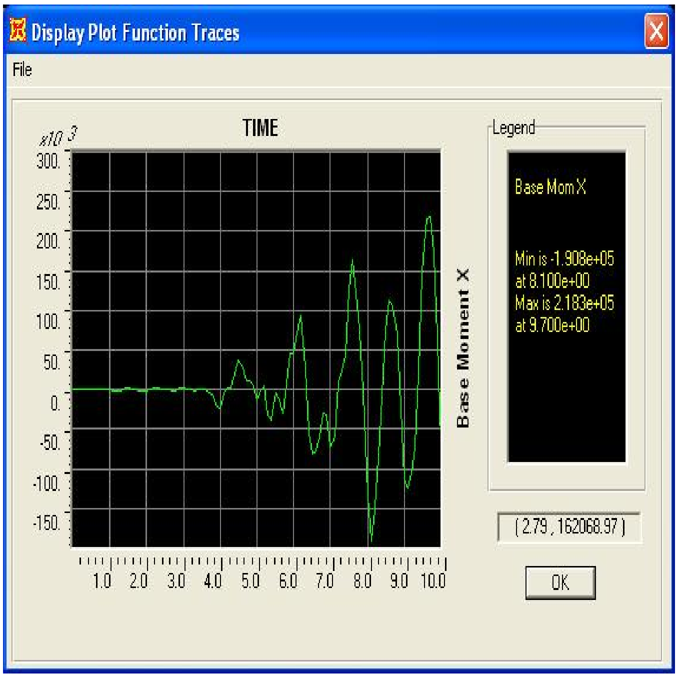
(a) Without Base Isolation **(b) With Base Isolation**

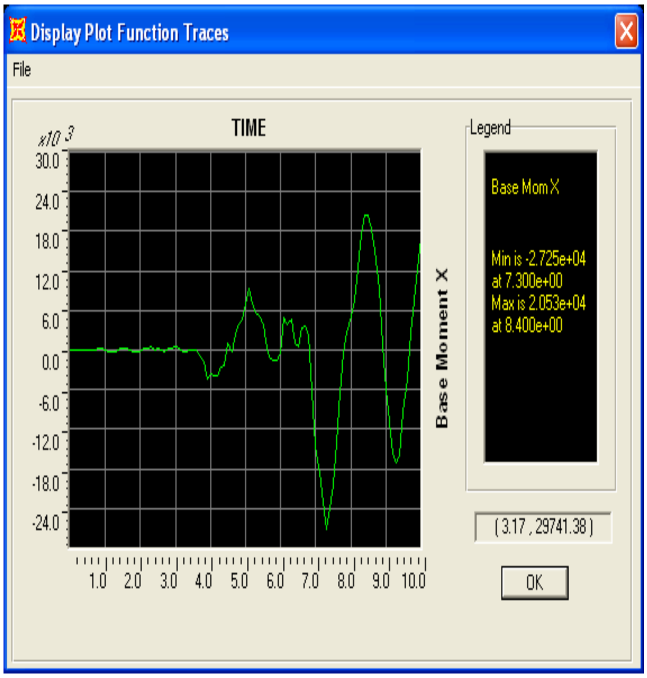
Fig.(8) Base Shear at joint (146) of Building.



(a) Without Base Isolation **(b) With Base Isolation**

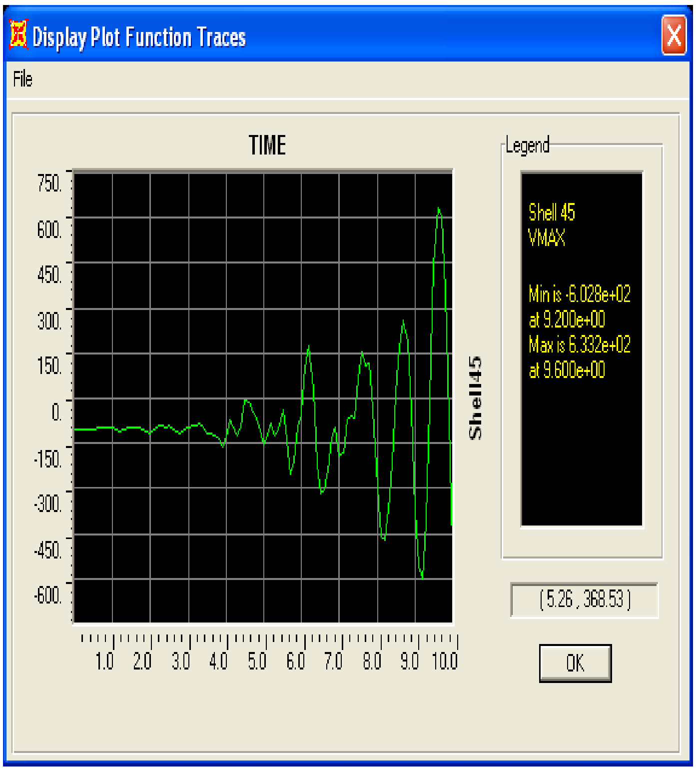
Fig.(9) Base Shear-Time History of Building in X-Direction.

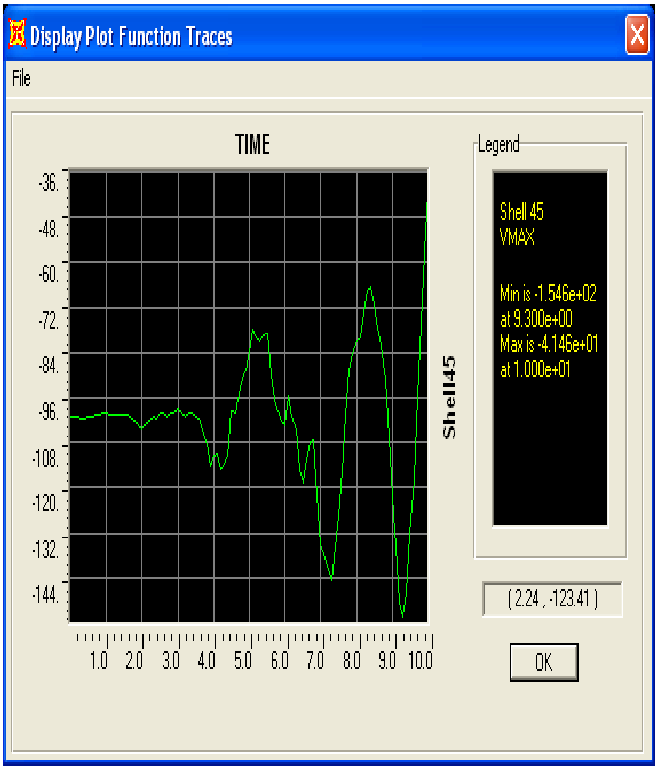




(a) Without Base Isolation **(b) With Base Isolation**

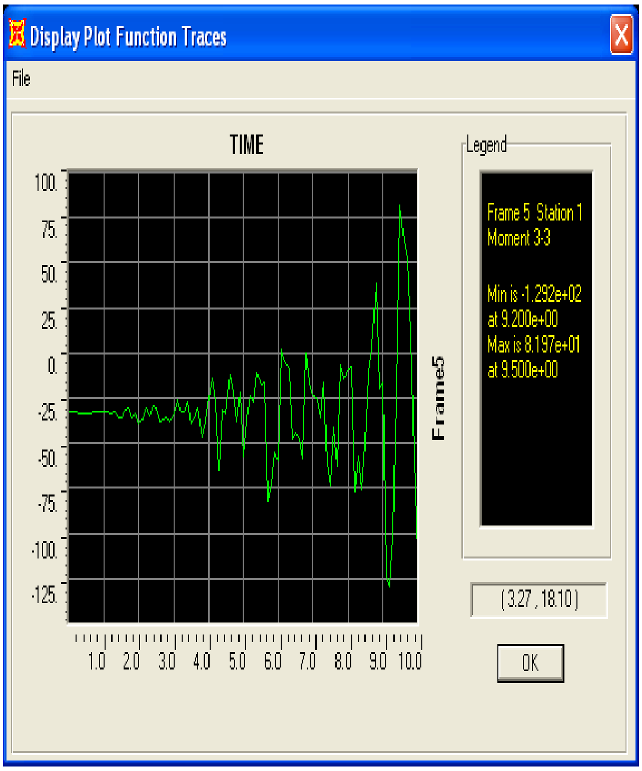
Fig.(10) Base Moment-Time History of Building in X-Direction.

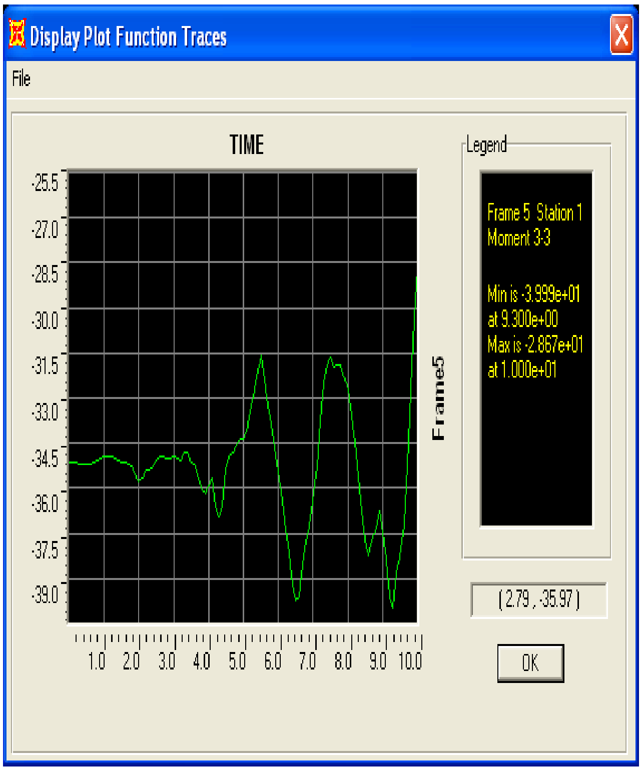




(a) Without Base Isolation **(b) With Base Isolation**

Fig.(11) Base Shear-Time History for Slab of Building.



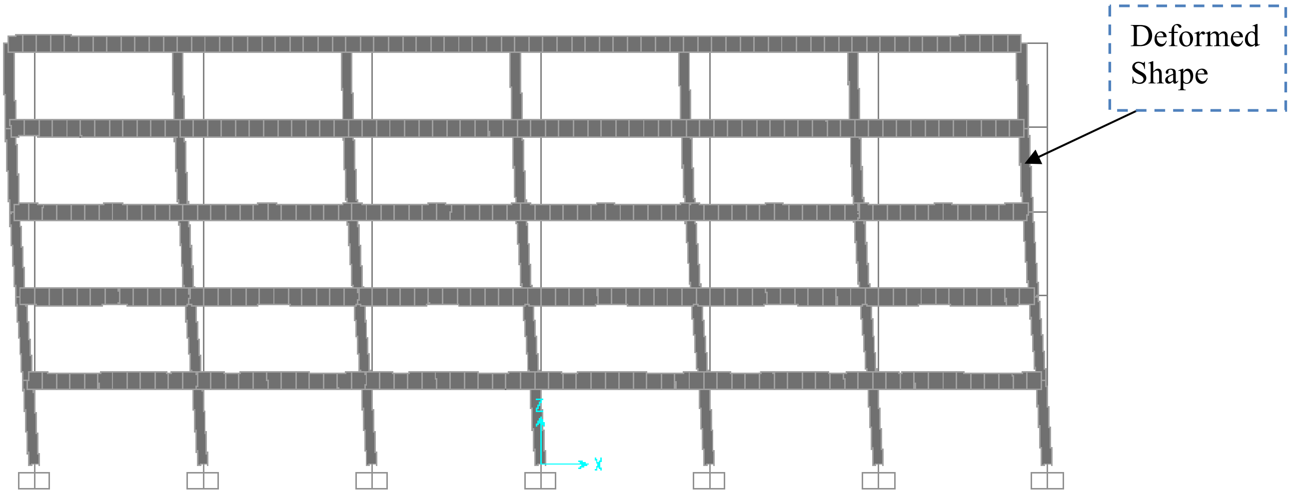


(a)Without Base Isolation **(b) With Base Isolation**

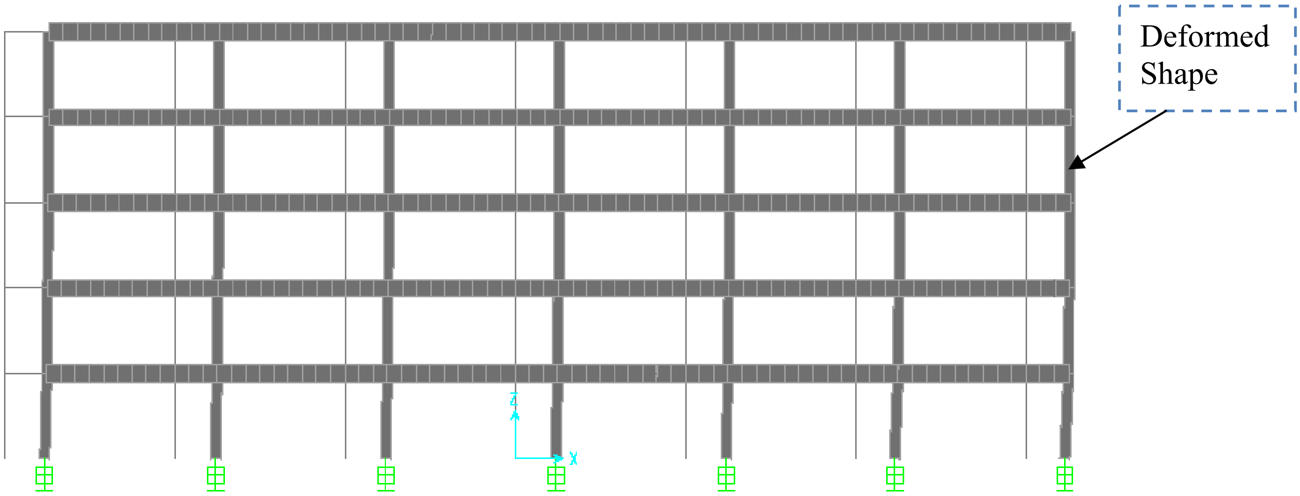
Fig.(12) Moment-Time History for Member No.(5) of Building

6.3 Deformed Shape of Building (Isolated and non-Isolated cases):

The deformed shape of the building took the maximum value at time of 3.4 second as shown in **Fig.(13).** From this figure it can be noticed that the building without base isolation that moved in the same direction but with different values of displacement in three directions. This lead to collapse of the building when subjected to seismic earthquake forces (because of the inertia forces), on the other hand using of the base isolation (i.e. NL link system) lead to movement in the same direction at different levels. The base isolation is more effective when used due to reduction of the displacement, acceleration and base shear at floor of building. This is attributed to the ability of dispersal of the energy of shock of earthquake loading.



(a) **Building Without with Base Isolation.**



(b) **Building with Base Isolation.**

Fig.(13) Deformed Shape of Building without and with Base Isolation at time (3.4 sec).

7. Conclusions:

From previous table and curve that used to evaluate the response of building under seismic load for the two studied building cases (i.e., without or with base isolation), the major drawn conclusions are as follows:-

1. Increase of the flexibility of the building in the horizontal plane at level of isolation led to reduction the values of absolute maximum acceleration of floors in the isolated building by about 95% (i.e. decrease inertia forces). Therefore the content of building

(with base isolation) and instrument become safer under the damage of earthquake force.

2. Using of rubber bearing pad under base of building gives more efficiency under seismic force (when used to isolate building).
3. Using of seismic base isolation as one method of protection of structure against seismic force led to decrease of the relative translation by about 85% in average.
4. The story translation, reduction values in relative translation, base shear and base moment as considered measurement for efficiency of isolator in reduction the damage of all parts of structures are as shown below:
   - When the base isolator were used the reduction values in base shear at both horizontal directions equal to 90.20% in X- direction and 76.5% in Y- direction.
   - Values of reduction in base moment are equal to 90.5% in X- direction and 93.1% in Y- direction.
   - The reductions in the maximum displacement values of all stories are equal to 9.14% in X- direction and equal to 9.69% in Y-direction.
5. The base shear stresses vibrated for building without base isolation rapidly during short time duration with large capacity. In the isolated building case the shear stress vibration became deceleration during long time period and small capacity. This led to reduction of the danger of breakdown those results from fatigued stresses.

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