NON LINEAR EARTHQUAKE ANALYSIS OF BAGHDAD TOWER FOR COMMUNCATIONS USING A THREE DIMENSIONAL FINITE ELEMENT METHOD

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ABSTRACT
This study analyzes Baghdad Tower for communications when subjected to earthquake excitation using an elasto-viscoplastic material modeling and a three-dimensional finite element method. The algorithm used in this research deals with nonlinear structural analysis. Newmark's method is employed to study the displacement response under El-Centro earthquake type of excitation

الخلاصة
يقوم البحث بتحليل برج بغداد للاتصالات إنشائيا في حال تعرضه لأحمال هزة أرضية، وذلك باستعمال طريقة العناصر المحددة لتمثيل البرج هندسيا بواسطة عناصر ثلاثية الأبعاد . كما تم تحوير البرنامج الخاص بالتحليل الديناميكي لهذا النوع من العناصر مع استعمال التحليل اللاخطي في هذا البرنامج لتحديد الازاحات تحت تاثير هزة ارضية من نوع السنترو.

KEY WORDS
finite element. earthquake, elasto-viscoplasticity, dynamics, Newmark integration.

INTRODUCTION
A tall building is usually one that possesses a ratio of total floor space to total site area built upon as being very high (ASCE, 1978). Generally, towers are vertical cantilevered beams. They must cope with the vertical forces of gravity and the horizontal forces below the ground. The lateral forces are the applied loads of most importance that affect tower structures. Due to the increase of height and change of properties of towers, the dynamic analysis of towers becomes more important (Gasib, M. 1998) According to the Iraqi seismic code (1997), it is specified that "A dynamic analysis is highly recommended for specific structures such as slender high-rise buildings and structures with irregularities of geometry or mass distribution or rigidity distribution"

EARTHQUAKES IN IRAQ
Iraq lies on the north – east border of the Arabian Plate which is a semi–continuous line of earthquake foci which forms part of the well known historical Himalayan Belt earthquake. Depending on the previous studies of the history of earthquakes in Iraq, there were more than 79 major earthquakes that took place during the period between 1260 BC and 1900 AC. In fact, the

start of organized recording of earthquakes started in the early years of the twentieth century. During the period between 1900 and 1976, the seismicity of the country was studied depending only on the records of the strong earthquakes by foreign earthquake monitoring centers. The studies showed that there were 90 earthquakes with foci centers in Iraq and some of these earthquakes had specific effects. They had a shallow focus depth and their magnitude ranged between 2 and 7 on the Richter scale. Also, their intensities varied in strength between regions as shown in **Figs. (1) and (2)** (Al-Taee. A.Y.Y 2001). It was found from the earthquake distribution map that the scale ranges between (5) and (9) according to the Modified Mercalli Scale.

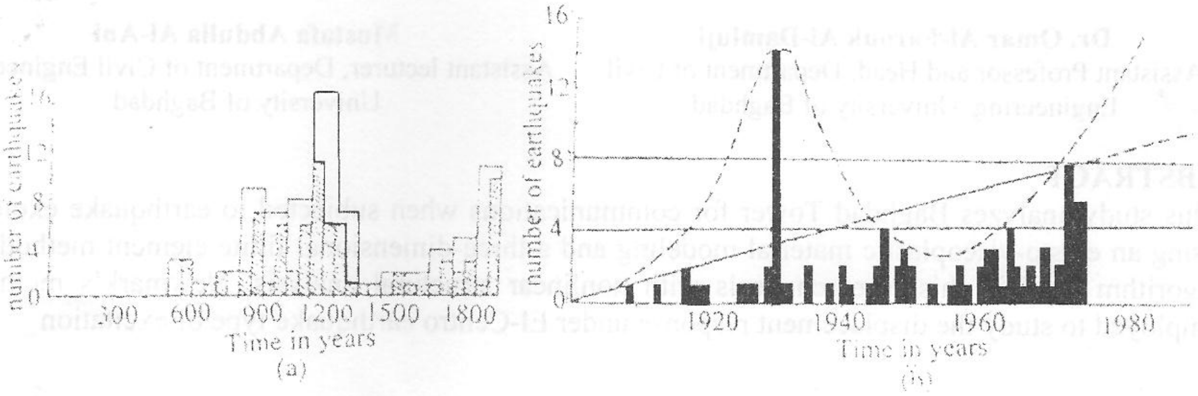

Fig. (1) Historical and Recent Earthquakes in Iraq
(a) Historic seismicity of Iraq
(b) Current seismicity of Iraq (Al-Taee, A.Y.Y 2001)

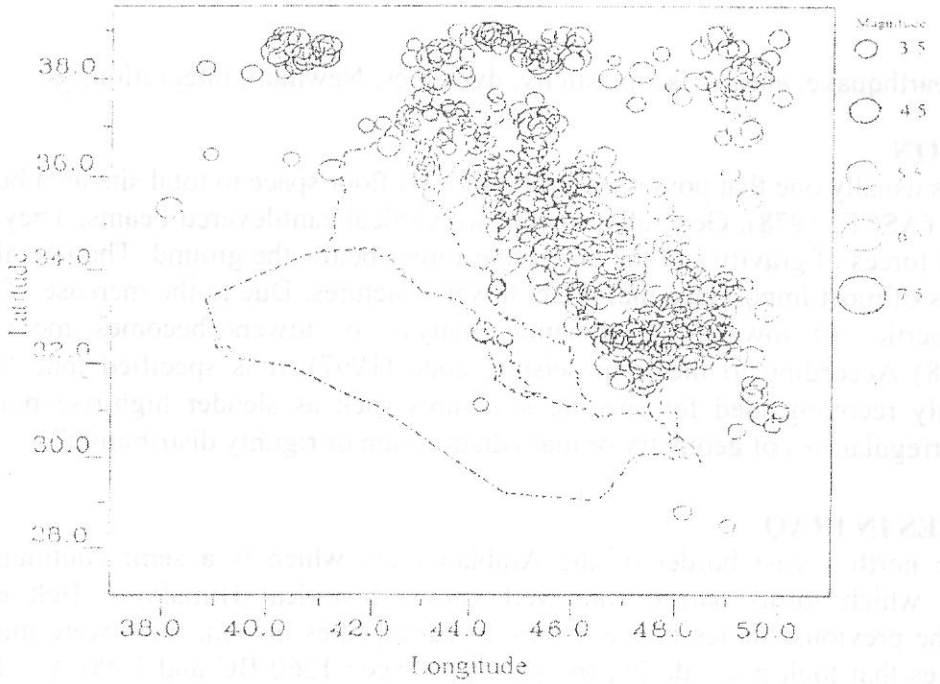

Fig. (2) Map of the Regions for the Earthquake Foci within the Geographical Boundaries of Iraq (1900-1989) (Al-Taee, A.Y.Y 2001).

EARTHQUAKE RESPONSE ANALYSIS

The earth's crust is not static, but rather it is subjected to constant motion. Since the foundation is the location of contact between the building and the earth, seismic motion acts on the building by shaking the foundation back and forth. An earthquake is defined as the ground vibration induced by a sudden release of energy accumulated in the crust and upper mantle. Due to the various types of mechanisms of energy release and to the complexity of the constitution of the ground, observed earthquakes on and near the ground surface show apparently random complicated motion (ASCE 1978).

GENERAL DESCRIPTION OF BAGHDAD TOWER FOR COMMUNICATIONS:

Baghdad tower for communications is located in al-Mamoon District. The tower is one of the most important structures built in Iraq in the last few years during the period of economic embargo (1990-2003). This is due to that it was designed and constructed by purely Iraqi experiences and expertise. The tower consists of two parts: first is a 120m high reinforced concrete shaft of circular cross section. of a constant inside diameter of 4.15m and a variable thickness. The second part is a 78.16m high tubular steel shaft with a variable circular cross section as shown in **Fig. (3).** The total height of the tower (both concrete and steel parts) is 203.5m. Without the antenna, it is 198.16m high from the ground level. **Fig (4)** shows a longitudinal section in the concrete shaft and its vertical reinforcement. From ground level to 20 m height, the shell thickness is 0.6 m. It starts to decrease linearly up to a height of 100m where the thickness becomes 0.32m at 10m height. This thickness remains unchanged for what is left of the height of the tower. Many openings of different sizes are encountered at various levels. **Fig (5)** shows the steel parts. Six communication platforms are placed at levels 102, 107 and 112 m of the concrete shaft, and at levels 147.43, 195.43 and 197.61 m of the steel frame (Gasib, M. 1998).

DYNAMIC EQUILIBRIUM EQUATION:

The equilibrium of transient dynamic systems with multi- degrees of freedom is (Hinton, F.1988)

$$\underline{M}\,\ddot{\underline{Y}} + \underline{C}\,\dot{\underline{Y}} + \underline{K}\,\underline{Y} = \underline{F} \quad (1)$$

Upon discretization using a Galerkin type of approximation [7]:

$$\underline{M}\,\underline{Y} + \underline{C}\,\underline{Y} + \underline{P}\left(\underline{Y},\underline{Y}\right) = \underline{F} \quad (2)$$

where

$\underline{Y}$ = vector of nodal displacements,

$\dot{\underline{Y}}$ = vector of nodal velocities,

$\ddot{\underline{Y}}$ = vector of nodal accelerations,

$\underline{M}$ = mass matrix,

$\underline{C}$ = damping matrix,

$\underline{P}\left(Y,Y\right)$ = vector of internal resisting forces, and

$\underline{F}$ = vector of external applied forces.

The global mass and damping matrices are:

$$\underline{M} = \int \underline{N}^{t} \rho \underline{N} dV \tag{3}$$

$$\underline{C} = \int \underline{N}^{t} c \underline{N} dV \tag{4}$$

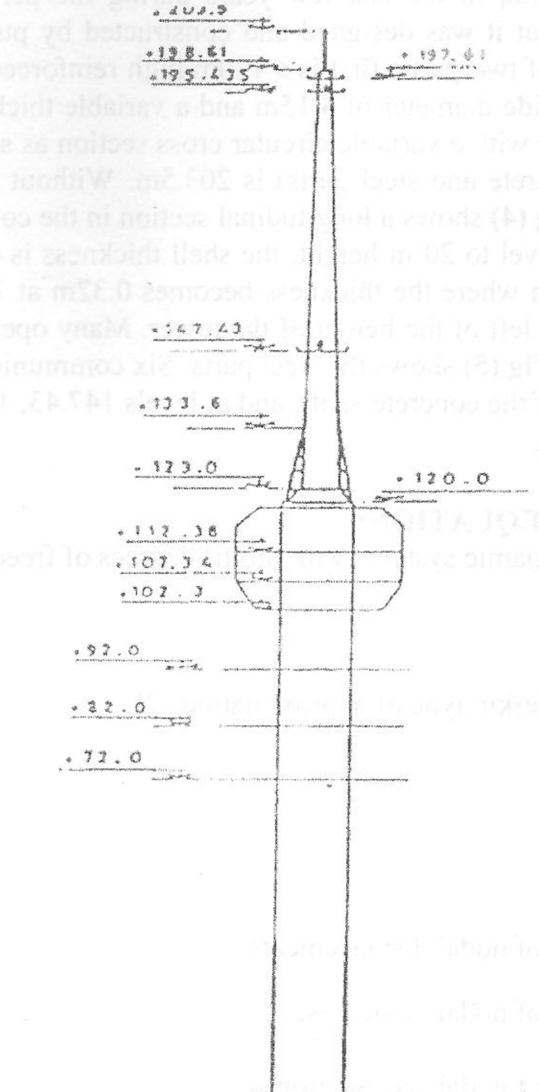

Fig. (3) Longitudinal Section of Baghdad Tower for Communications (Gasib, M.1998)

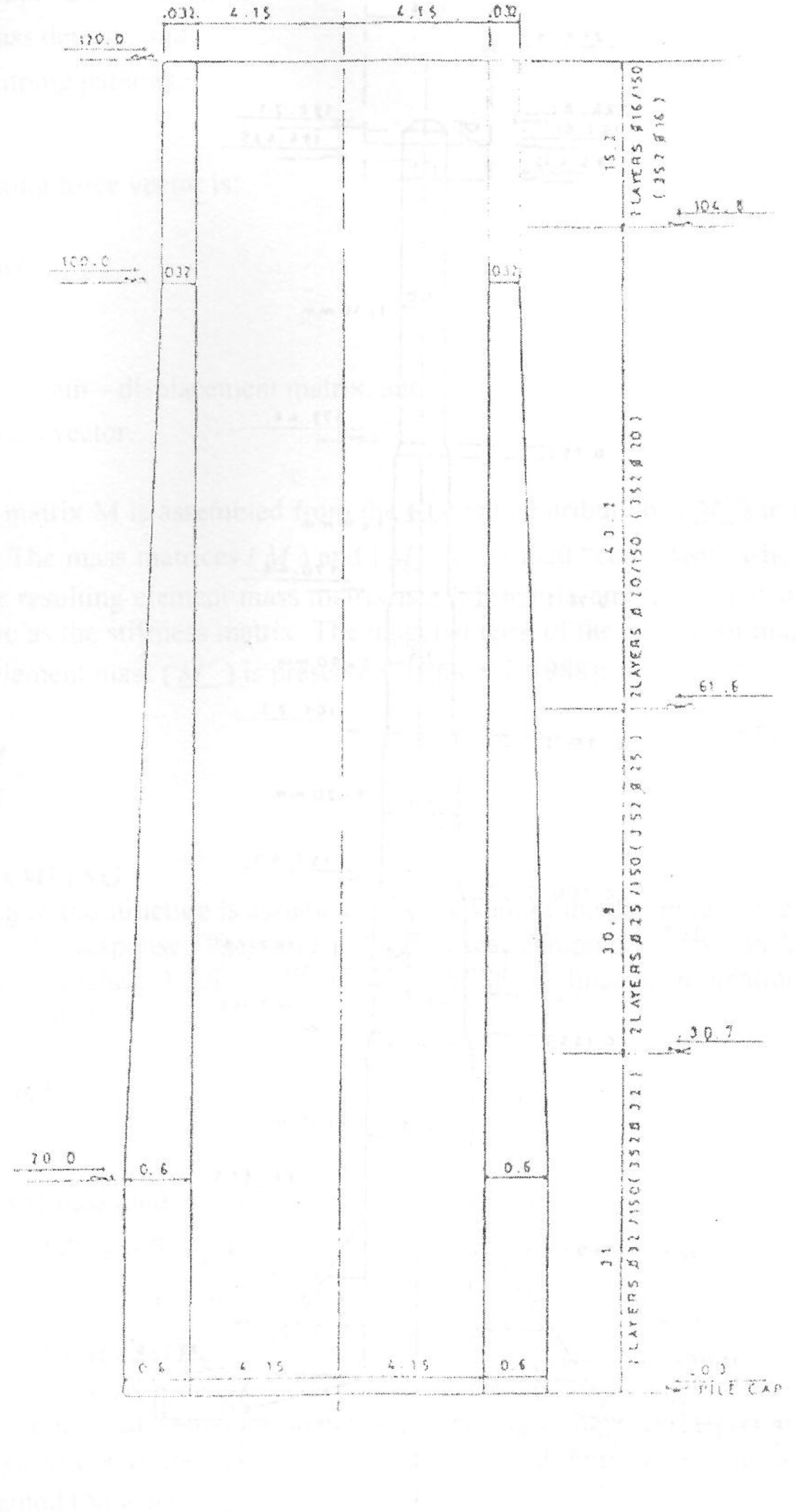

Fig. (4) Reinforced Concrete Shaft (Gasib, M.1998)

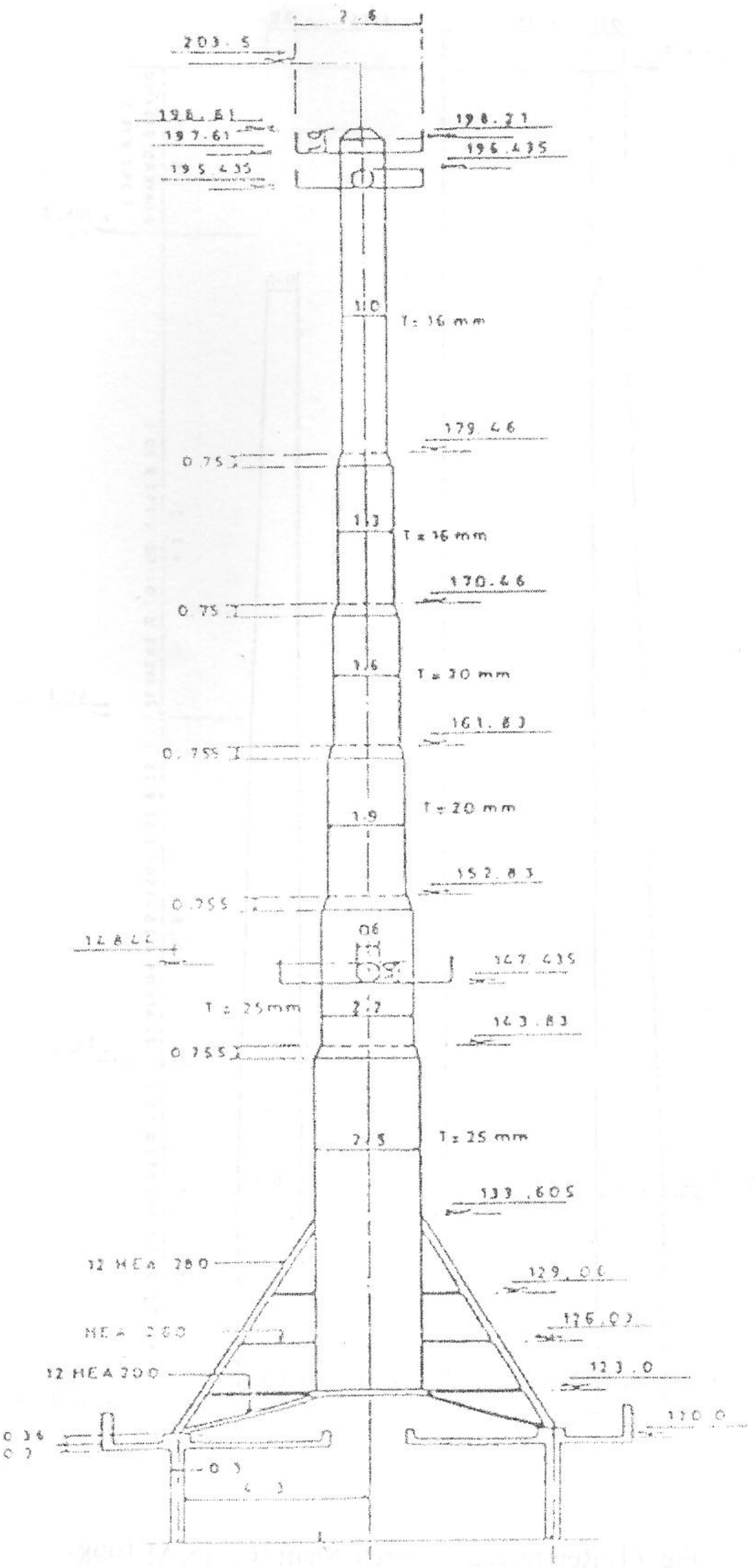

Fig. (5) Steel Tower (Gasib, M.1998)

where

$\underline{N}$ = shape function matrix,

$\underline{\rho}$ = mass density, and

c = damping parameter.

The internal resisting force vector is:

$$P = \int B^t \sigma \, dv \qquad (5)$$

where

$\underline{B}$ = the strain – displacement matrix, and

$\underline{\sigma}$ = stress vector.

The global mass matrix M is assembled from the element contributions ($\underline{M^e}$) in the standard finite element manner. The mass matrices ($\underline{M}$) and ($\underline{M^e}$) are called "consistent" when calculated using equation (3). The resulting element mass matrix is a full matrix and the global stiffness matrix has the same structure as the stiffness matrix. The diagonal term of the consistent mass matrix is scaled so that the total element mass ($\underline{M^e}$) is preserved (Hinton, F.1988):

$$M_i = \frac{M_{ii} M^e}{\sum M_{ii}} \qquad (6)$$

EFFECT OF DAMPING

The total damping in the structure is assumed to be the sum of the damping of the individual masses present in the system response. Therefore, the numerical damping matrix can be expressed using Rayleigh damping (Hughes, T.J.R. 1987) which considers a linear combination of the mass and stiffness matrices so that:

$$\underline{C} = a_o \underline{M} + a_1 \underline{K} \qquad (7)$$

where

$\underline{K}$ = stiffness matrix, and

a_o, a_1 = damping constants.

TIME –STEP INTEGRATION

The equation of motion (1) is integrated using a numerical step –by-step procedure. The direct integration method is used using implicit integration algorithms, in which equilibrium at time $(t + \Delta t)$ is imposed to obtain the corresponding solution. The implicit scheme used in this work is the Newmark method (Newmark, N. M. 1959).

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The Newmark Method

The Newmark method used is an extension of the linear acceleration method. The final form of the equation of motion is linearized and written at time (t_{n+1}) as:

$$\underline{M}\ddot{\underline{Y}}_{n+1}+\underline{C}\dot{\underline{Y}}_{n+1}+\underline{K}\underline{Y}_{n+1}=\underline{F}_{n+1} \quad (8)$$

Using a typical time step, the nodal displacement and velocity can be written as [7]:

$$\underline{Y}_{n+1}=\underline{Y}_{n}+\Delta t\dot{\underline{Y}}_{n+1}+\frac{\Delta t^2}{2}\left[(1-2\beta)\ddot{\underline{Y}}_{n+1}+2\beta\ddot{\underline{Y}}_{n+1}\right] \quad (9)$$

$$\dot{\underline{Y}}_{n+1}=\dot{\underline{Y}}_{n}+\Delta t\left[(1-\gamma)\ddot{\underline{Y}}_{n}+\gamma\ddot{\underline{Y}}_{n+1}\right] \quad (10)$$

where

$\underline{Y}_n$ = vector of nodal displacement at time (t),

$\dot{\underline{Y}}_n$ = vector of nodal velocity at time (t),

$\ddot{\underline{Y}}_n$ = vector of nodal acceleration at time (t), and

γ,β = parameters which control the stability and accuracy of the method.

TYPE OF ELEMENT

An eight-node hexahedron brick element is used in this work as shown in **Fig. (6)** (Hinton, F.1988).

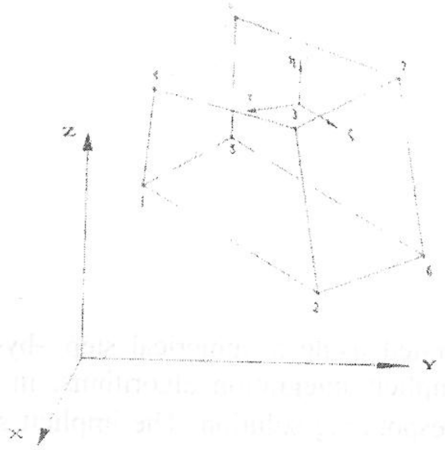


Fig. (6) Typical eight-nodded element

MATERIAL PROPERTIES OF STEEL AND CONCRETE

An elasto-viscoplastic model that includes strain –rate sensitivity and progressive degradation strength is adopted in this work. The total strain ε and strain rate $\dot{\varepsilon}$ are decomposed into elastic and viscoplastic parts as:

$$\underline{\varepsilon} = \underline{\varepsilon}_e + \underline{\varepsilon}_{vp} \quad (11)$$

$$\dot{\underline{\varepsilon}} = \dot{\underline{\varepsilon}}_e + \dot{\underline{\varepsilon}}_{vp} \quad (12)$$

The stress rate is given by:

$$\dot{\underline{\sigma}} = \underline{D}\dot{\underline{\varepsilon}} \quad (13)$$

where $\underline{D}$ is the elasticity matrix.

Viscoplastic flow occurs for positive values of the scalar yield function:

$$F_\circ(\underline{\sigma}) = f(\underline{\sigma}) - \sigma_\circ(k) \quad (14)$$

where

σ = a value defining the position of the yield surface, and
k = hardening (or softening) parameters.

The viscoplastic strain rate is given by Perzyan (Perzyan, P. 1966).

$$\dot{\underline{\varepsilon}}_{vp} = \gamma\langle\phi(F_\circ)\rangle\frac{\partial f}{\partial\underline{\sigma}} \quad (15)$$

where:

γ = fluidity parameter,
$\langle\phi(F_\circ)\rangle = \phi(F_\circ)$ for a positive value of F_0 otherwise
= 0, and
$\frac{\partial f}{\partial\underline{\sigma}}$ = a vector normal to the potential surface and it defines the direction of viscoplastic flow.

The flow function is defined as:

$$\phi(F) = \frac{F_\circ}{\sigma_\circ} = \frac{f(\underline{\sigma}) - \sigma_\circ}{\sigma_\circ} \quad (16)$$

A strain rate sensitive elasto/viscoplastic model is adapted for concrete (Hinton, F.1988).

EARTHQUAKE MAGNITUDE

Richter has correlated modified Mercalli intensity with Richter's earthquake magnitude as follows (Al-Taee, A.Y.Y 2001):

Table –1- Modified Mercalli Intensity

Magnitude	Maximum modified Mercalli Intensity
2	I-II
3	III
4	V
5	VI–VII
6	VII-VIII
7	IX-X
8	X

Baghdad can be considered to lie in Zone 4 with an acceleration intensity of 0.15 of the gravity acceleration. EL-Centro earthquake record which hit the Imperial Valley in California, U.S.A. in 18 May, 1940 has been selected to be applied to the structure under consideration herein. A complete record of this earthquake is given in reference .

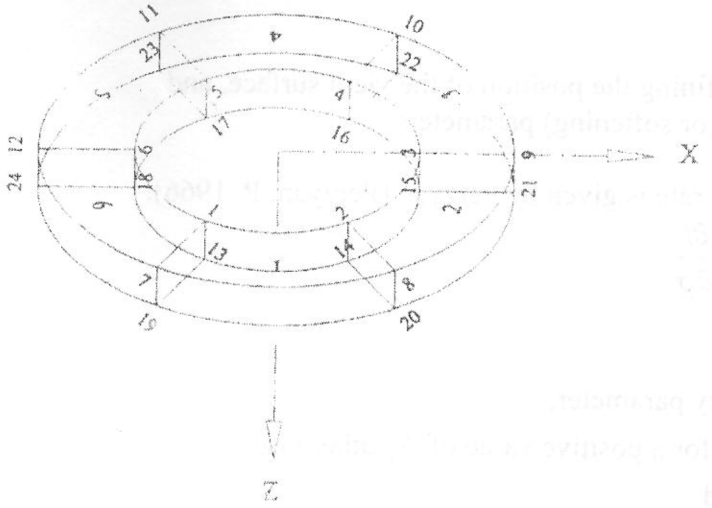


Fig. (7) Typical Ring Element

MODELING OF BAGHDAD TOWER FOR COMMUNICATION

Using the 8 nodal hexahedron isoparametric brick element **Fig. (6)**, the tower is divided into 126 elements with a total number of 260 nodes. **Fig. (7)** shows a typical ring from the tower consisting of six elements. It is assumed that the earthquake excitation is in the direction shown in **Fig. (8).** The base of the tower is assumed to be fully fixed in all directions. The finite element mesh of the tower is shown in **Fig. (9).**

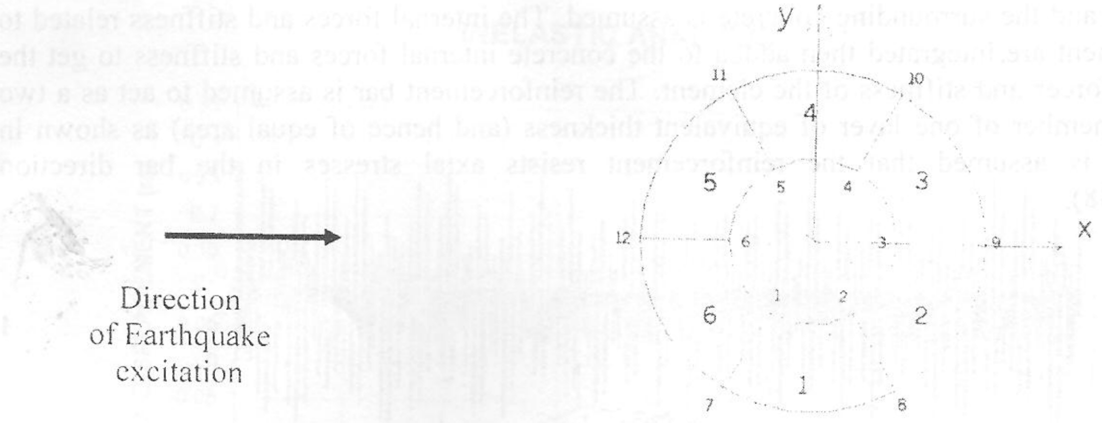


Fig. (8) Direction of Earthquake

Fig. (9) Finite Element Mesh of Baghdad tower

REINFORCEMENT REPRESENTATION

Concrete and reinforcement are represented within a single element. Perfect bond between the reinforcement and the surrounding concrete is assumed. The internal forces and stiffness related to the reinforcement are integrated then added to the concrete internal forces and stiffness to get the total internal forces and stiffness of the element. The reinforcement bar is assumed to act as a two dimensional member of one layer of equivalent thickness (and hence of equal area) as shown in **Fig. (10)**. It is assumed that the reinforcement resists axial stresses in the bar direction (Hinton, F.1988).

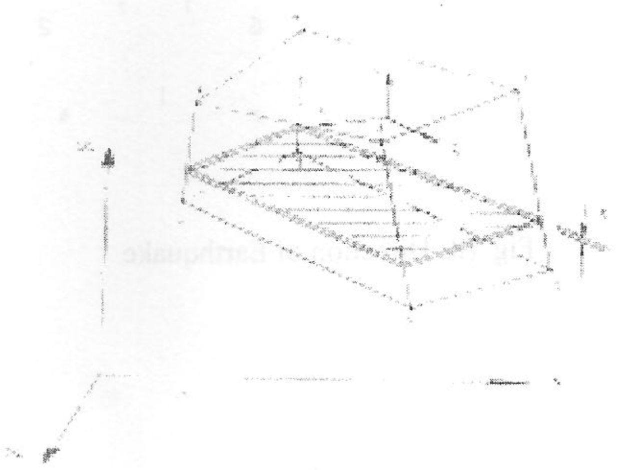
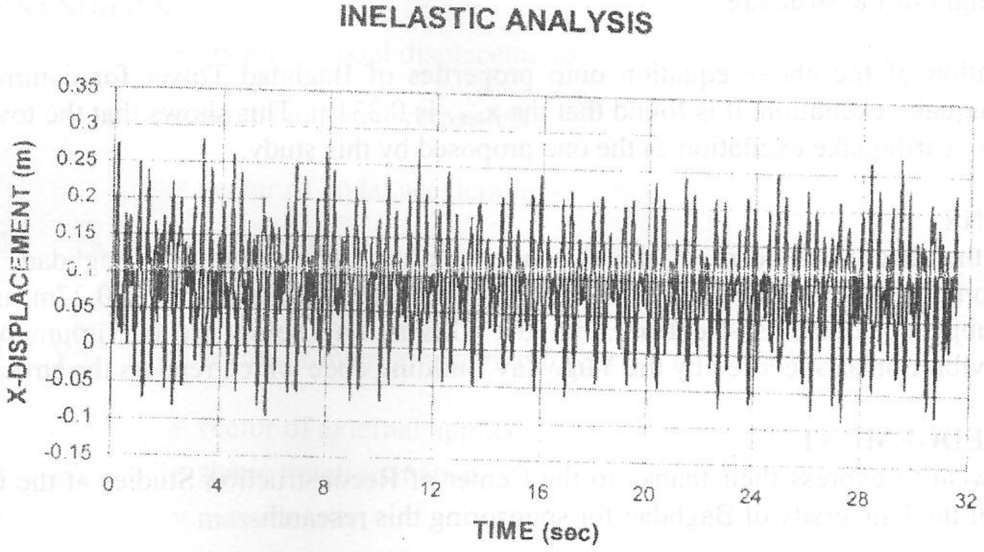


Fig. (10) Typical eight-nodded reinforced concrete brick element of DARC3 programm (Hinton, F.1988).

RESULTS AND DISCUSION

The theory presented in this study for the analysis of reinforced concrete structures in 3-dimensions under dynamic loads is used herein through the developed numerical algorithm. The displacement response of the top node of Baghdad tower for communications at different time intervals is obtained. **Fig. (11)** presents the x- and y- displacements for the top node under the El-Centro earthquake. It is shown that the maximum top horizontal displacement reaches a value of almost 0.27m in extension and –0.1m in compression. As for the y-displacement the maximum deflection including the weight of structure, is in the order of 0.16m in extension and –0.22m in compression. As the major components of excitation are horizontal, the maximum deflection is found to be in the horizontal direction. The results shown in **Fig. (11)** are for the case when no damping is assumed. That is why that the amplitude of vibration remains at almost a steady state as exemplified in **Fig. (11)**.

The same problem is re-analyzed once again but taking the effect of damping into consideration. The damping parameters a_0 and a_1 in equation (7) are taken as (1.539) and (0.971), respectively. **Fig. (12)** shows the results for this case. From the trend of the results, it is obvious that the amplitude attenuates with time. This depicts damping in the analysis. For this case, it is apparent that the maximum x-displacement attained is almost the same as that for the undamped case which



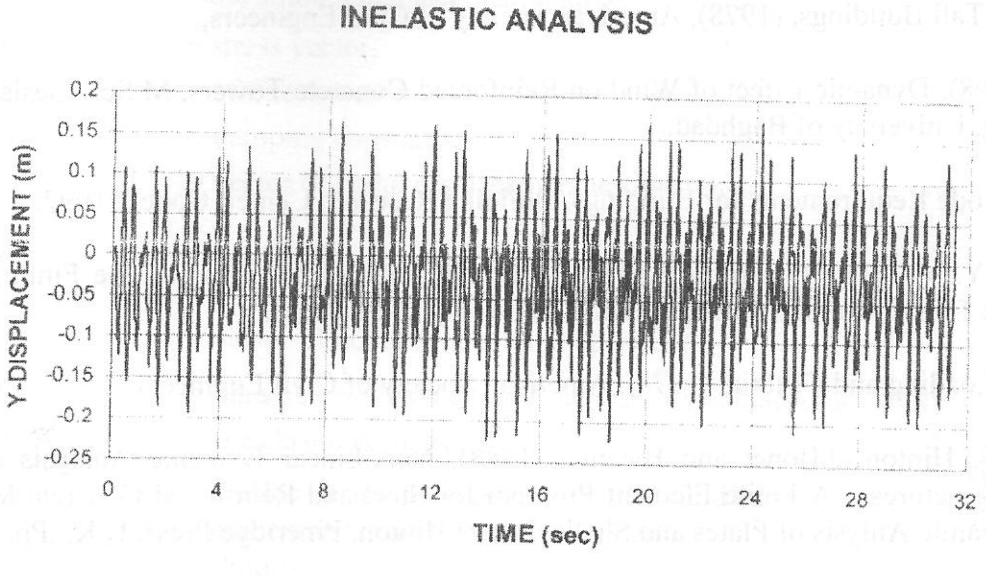


Fig. (11) Time Displacement Diagram for Inelastic Undamped Case where:

x_{max} = maximum allowed displacement, and

H = height of the structure.

Upon application of the above equation onto properties of Baghdad Tower for communications under an earthquake excitation, it is found that the x_{max} is 0.331m. This shows that the tower will be stable under an earthquake excitation as the one proposed by this study.

CONLUSIONS

Upon using the discritized form of the dynamic equilibrium equation on Baghdad Tower for communications, it is seen that the maximum amplitude for displacement is 0.27m and 0.16m, when it is subjected to the EL-Centro excitation. This is way below the maximum permissible amplitude of vibration as specified by the Yugoslav Building code which renders the structure safe.

ACKNOWLEDGEMENT

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LIST OF SYMBOLS

$\underline{Y}$ = vector of nodal displacements,

$\dot{\underline{Y}}$ = vector of nodal velocities,

$\ddot{\underline{Y}}$ = vector of nodal accelerations,

$\underline{M}$ = mass matrix,

$\underline{C}$ = damping matrix,

$\underline{P}\left(Y, \dot{Y}\right)$ = vector of internal resisting forces,

$\underline{F}$ = vector of external applied forces,

$\underline{N}$ = shape function matrix,

ρ = mass density,

C = damping parameter,

$\underline{\beta}$ = the strain – displacement matrix,

$\underline{\sigma}$ = stress vector,

$\underline{K}$ = stiffness matrix,

a_o, a_1 = damping constants,

$\underline{Y}_n$ = vector of nodal displacement at time (t),

$\dot{\underline{Y}}_n$ = vector of nodal velocity at time (t),

$\ddot{\underline{Y}}_n$ = vector of nodal acceleration at time (t),

γ, β = parameters which control the stability and accuracy of the method,

$\underline{D}$ = the elasticity matrix

σ = a value defining the position of the yield surface,

K = hardening (or softening) parameters,

γ = fluidity parameter,

$\langle \phi\ (F_o) \rangle$ = $\phi\ (F_o)$ for a positive value of F_0 otherwise = 0,

$\frac{\partial f}{\partial \underline{\sigma}}$ = vector normal to the potential surface and it defines the direction of viscoplastic flow,

x_{max} = maximum allowed displacement, and

H = height of the structure.

ABBREVIATIONS

ACI = American Code Institute.

ASCE = American Society of Civil Engineering

DARC3 = Dynamic Analysis of Reinforced Concrete Structures in 3-dimensions