# Evaluation of DIAGRID and TUBE structural systems in bionic high-rise buildings

**Mohsen Rostami[1*], Fatemeh Gorji sinaki[2], Abdolreza S.Moghadam[3]**

1-master of structure engineering, faculty of technical, Islamic Azad university south Tehran branch , Tehran , Iran
2-master of earthquake engineering, faculty of technical , Islamic Azad university south Tehran branch , Tehran , Iran
3-International institute of Earthquake and seismology, department of civil engineering ,Tehran, Iran

st_m_rostami@azad.ac.ir

st_f_gorji@azad.ac.ir

**abstract**

The most important issue in the design of high-rise building is the lateral load system that accordingly, the selection of a structural systems that can ductility, stiffness, and sufficient resistance based on valid regulations provide is the most important principle in the field of high-rise building because the parameters of stiffness, ductility and structural resistance will change with variation the type of lateral load systems a relatively large amount. therefore, in this study, two structural systems tube and diagrid in similar structures (in plan, height, loading, etc) with 30 and 38 floors has been modelled in software ABAQUS and after the calculation of earthquake factors on structures mentioned (by program written in MATLAB based on 2800 regulation). Analysis of static and liner dynamic and nonlinear static (pushover), respectively is done on structures 30 and 38 floors of the diagrid and 30 and 38 floors of the tube and finally after analysing of 4 structure studied, the advantages and disadvantages and relative superiority of the two systems lateral load in structures mentioned based on stiffness parameters, relative displacement, ductility and resistance compared with each other. the importance of this comparison is that based on its finding can be determined the system suitable lateral load based on the seismic hazard at the site of construction. The results of the above analysis show that the diagrid structures, have stiffness higher than the tube structures but its plasticity is lower than that the tube system.

Keywords: Bionic high-rise structures, lateral load system, tube system, diagrid system.

## I. INTRODUCTION

The rapid growths of urban population and consequent pressure on limited space have considerably influenced the residential development of city. Increase cost of land, the desire to avoid a continuous urban sprawl, and the need to preserve important agricultural production have all contributed to drive residential high-rise buildings upward. As the height of building increase, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads.

**Introduction high-rise building systems**

**Introduction of TUBE structures building**

One of resistant systems in the high-rise building that has been developed by Mr. Fazlur khan is a tube system. [1] In this structural system, peripheral columns with relatively close distance ( 3 to 6.1 meters) around the building in witch they are by beams with high depth (between 0.9 to 1.5 meters) are connected to each other , and connecting beam and columns in the peripheral frame is fixed and all lateral forces are tolerated by this peripheral frame . and internal columns place with relatively high distance relative from one another and are designed only to counter the gravitational forces and all the internal beams and columns connections are type of the joints. Tube systems behavior under effect of lateral loads such as bending of a tress hollow in witch in effect it , axis against lateral forces have been short and the axis lateral forces is long.[5]
The system lateral stiffness and torsional resistance is high but due to non-uniform distribution of force in the flange columns ( perpendicular to lateral load ) will have shear torque . the effect of shear torque is framed tube , using the maximum stiffness and structural strength limit and resistance torque and rigidity bending ( rigidity )in the figure 1 overview this structure of the system is described.[5]

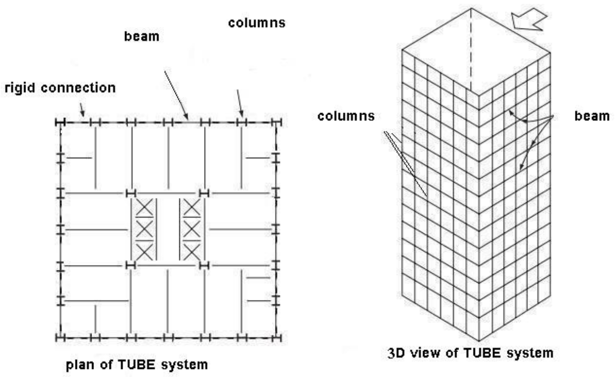



**Figure1 : tube system [1]**

**Introduction of diagrid structure systems**

Diagrd systems that has emerged with the development of the theory of tube structures . diagrid systems if formed of crossing diagonal and horizontal members . diagonal members in the diagrid structure can be gravity forces and lateral forces tolerate because of their structural and triangular grid position .

Diagrid is a particular form of space truss. It consists of perimeter grid made up of a series of triangulated truss system. Diagrid is formed by intersecting the diagonal and horizontal

components. The diagonal members in Diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration.[5]
angel diagonal members ( diagonal columns) plays a key role in the structures with diagrid systems That mean of the optimum angle in the structures with diagrid systems in the angle for witch a minimum of material used in structure and also lateral displacement is lower . According to studies by researchers , this optimum angle of about 60 to 70 degrees.[6]

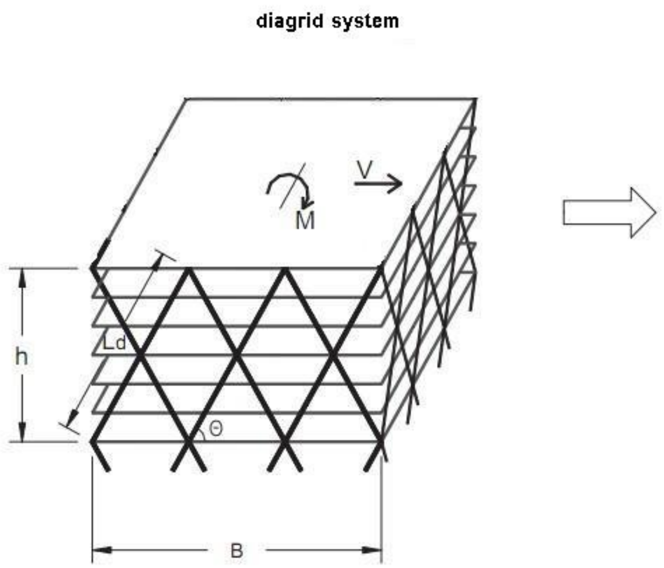



**Figure 2 : Diagrid system[5]**

## Modeling and design and analysis of structural systems

In this study , we will examine and compare two systems of diagrid and tube structure with quite similar the geometric dimensions and loading in the software ( ABAQUS) It should be noted that in all the models assume that the distance between the walls and the beams and columns of structure is such the effect of infill to be removed Also skeleton of all structures are steel . in table 1 , the dimensions and specifications of structures modeled are brought .[9]

**Table 1 : properties of structures**

| Type of structure | Number of story | Height of each story ( m ) | Total height (m) | Leangth of plan (m) | Width of plan (m) |
|---|---|---|---|---|---|
| Diagrid system( 30 story) | 30 | 3.8 | 114 | 32 | 32 |
| Tube system(30 story) | 30 | 3.8 | 114 | 32 | 32 |
| Diagrid system(38 story) | 38 | 3.8 | 144.4 | 32 | 32 |
| Tube system(38 story) | 38 | 3.8 | 144.4 | 32 | 32 |

## loading

for better comparison , systems of diagrid and tube , loading them on the table … and to is done quite similar .

**Table 2 : details of loading**

| Live load for roof ( kg/m2) | Dead load for roof (kg/m2) | Live load ( kg / m2) | Dead load ( kg/m2) |
|---|---|---|---|
| 150 | 300 | 200 | 650 |
| Load of peripheral wall for roof (kg /m) | | Load of peripheral wall (kg /m ) | |
| 300 | | 600 | |

## Design and analysis structural models

For the process modeling , analysis and design of diagrid and tube structures from the process following view is used .

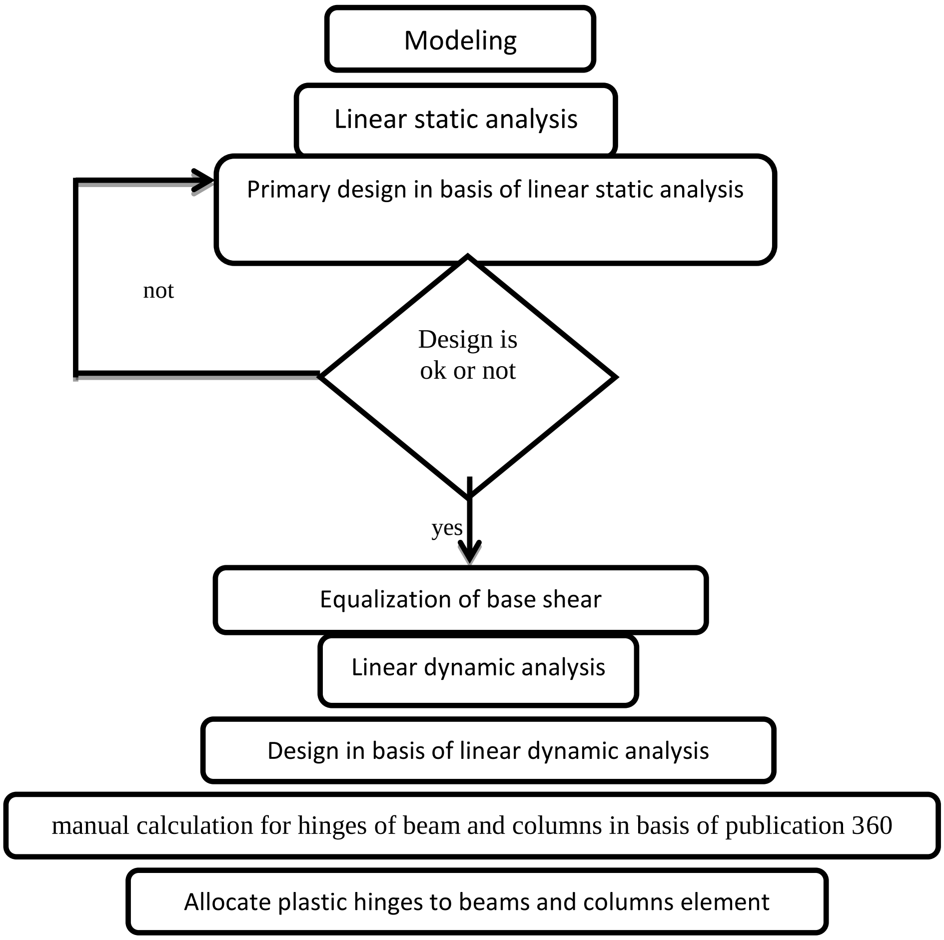



**Figure 3 : chart of modeling**

After modeling and analysis and design of 30 floors of diagrid and tube structures based on items listed have been studied to compare the results of analysis mentioned structures In the figure. the images of modeled structures, is visible.

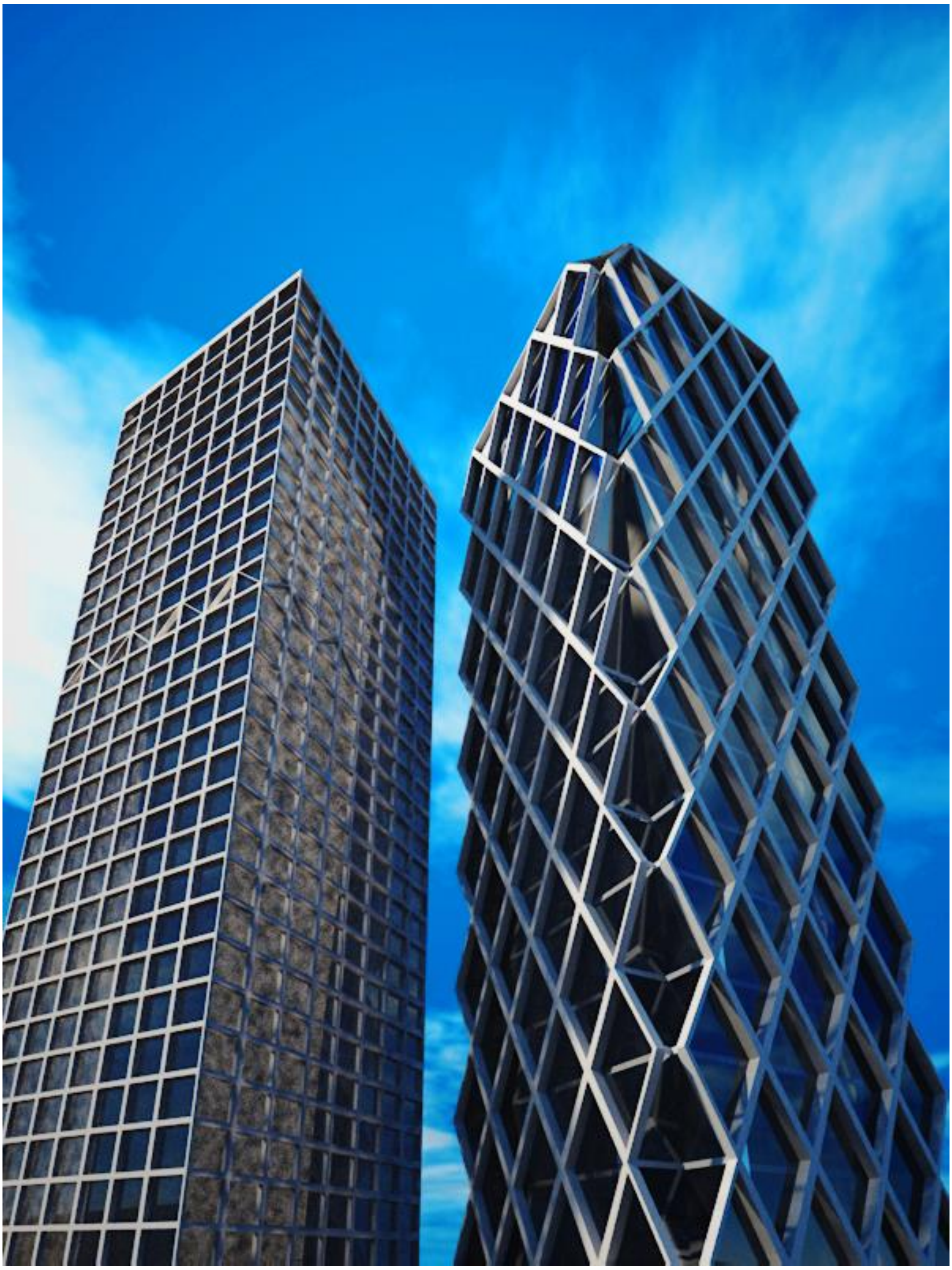


**Figure 4 : modeling Diagrid and Tube structural systems in 3D MAX software**

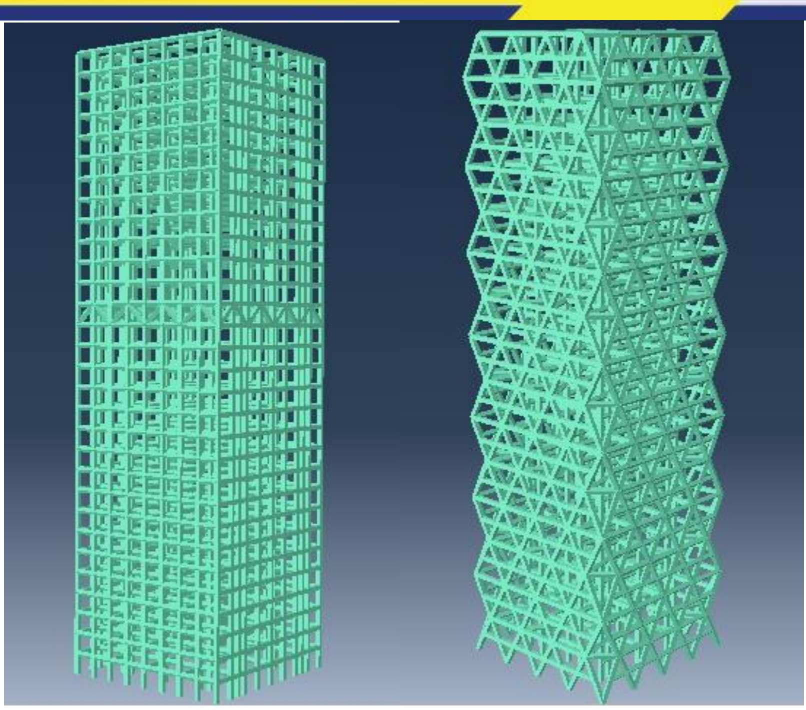


**figure 5 : Diagrid structures modeled in software ABAQUS ( right image) and the image of 30 floors tube structure( left image)**

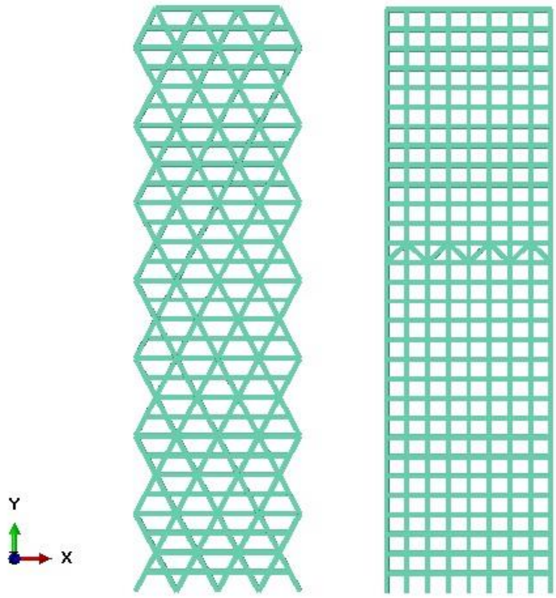



**figure 6: Diagrid structures 30 floors (left image) and the image of 30 floors tube structure (right image).**

In high-rise structures, an important criteria of design is that maximum displacement is within the allowable range. that is this study , allowable range is equal (1/400 total height of structure) which for structures 30 floors above that have the height of 114 meters , this allowable displacement is equal 28 meters that according to the diagram1 , 30 floors of diagrid and tube structures studied have displacement of less than allowable range .

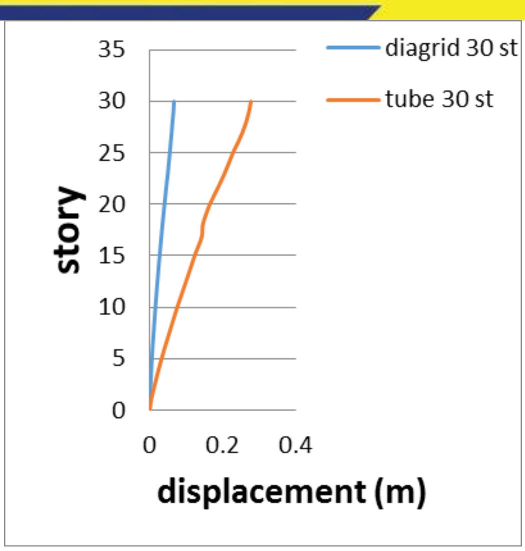



**Diagram 1**

By studying the diagram 1 is determined that the displacement of 30 floors diagrid structure is about 6.5 cm and displacement of 30 floors tube structure is 27 cm . In the other words drift of 30 floors diagrid structure is about 76 precent less than the drift of 30 floors tube structure.

After modeling and analysis and design of 38 floors diagrid and tube structure based on items listed have been studied to compare the result of analysis of mentioned structures.

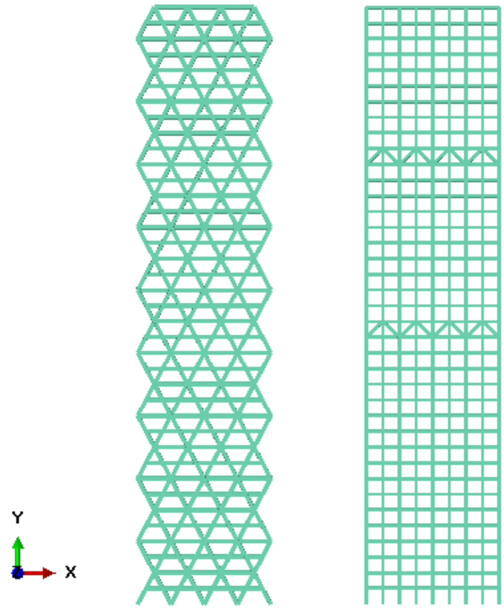



**figure 7 : 38 floors diagrid structure ( left image) and 38 floors tube structure (right image) in the tube structure due to prevent excessive displacement of structure is used two belt truss.**

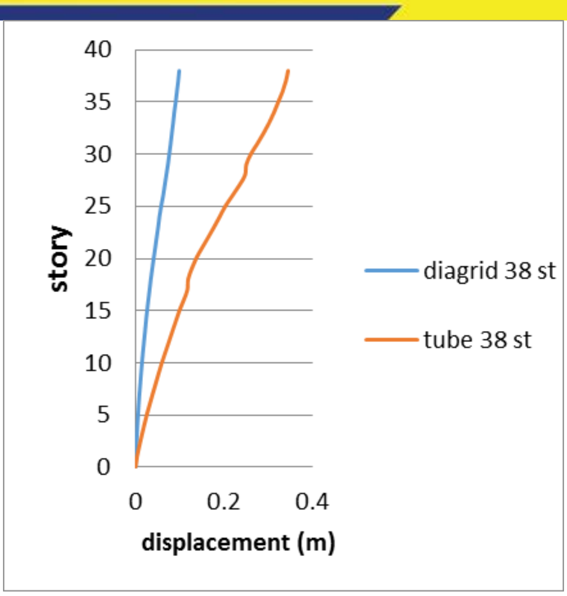



**Diagram 2**

By studing the diagram 2 is determined that displacement of 38 floors diagrid structure is about 10 cm and displacement of 38 floors tube structure is 34 cm in the other words drift of 38 floors diagrid structure is about 71 percent less than the drift of 30 floors tube structure.

**Comparison of weight and the base shear**

By studying the diagram 3 it’s observed that in both cases the total weight of the diagrid structure is less than tube structure that the weight loss is about 6 percent , also by studying diagram4 it’s observed that the base shear In the diagrid structure is less than the tube structure . also reduction of the base shear in diagrid structure than the tube structure is about 6 percent.

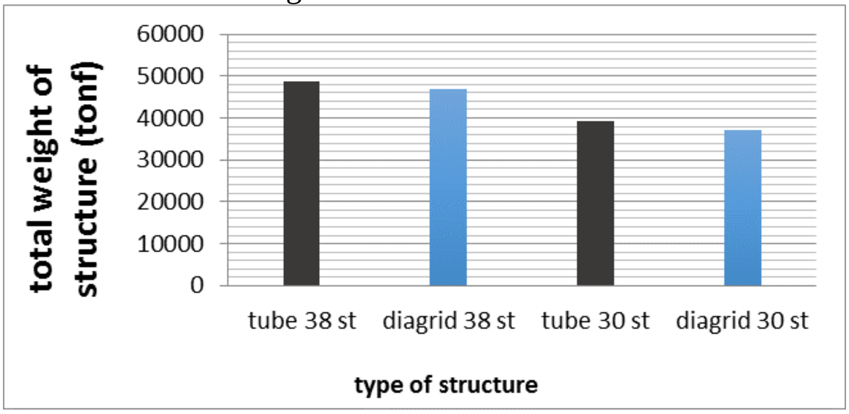



**Diagram 3 : total weight of structures**

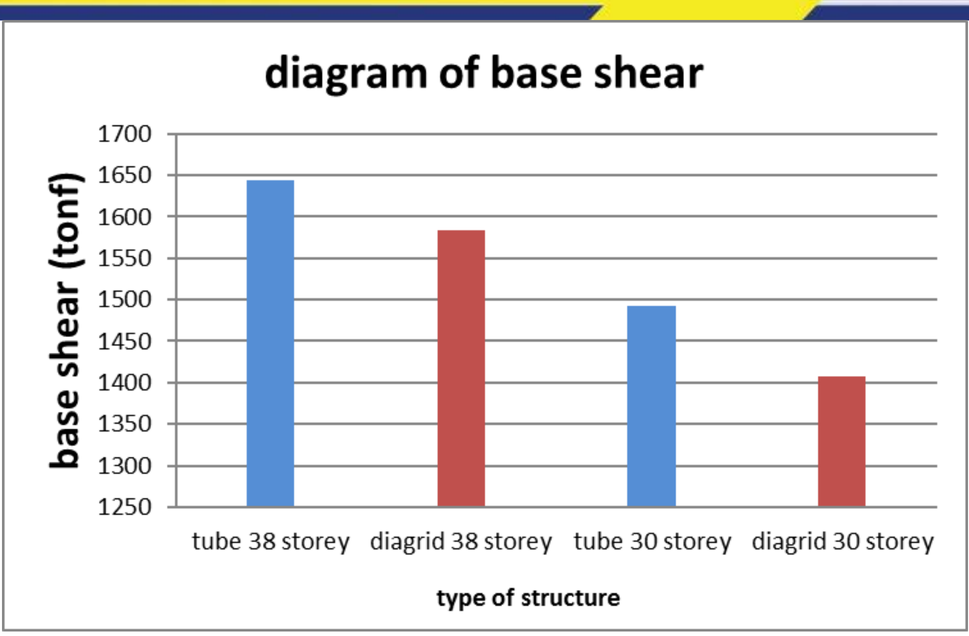



**Diagram 4**

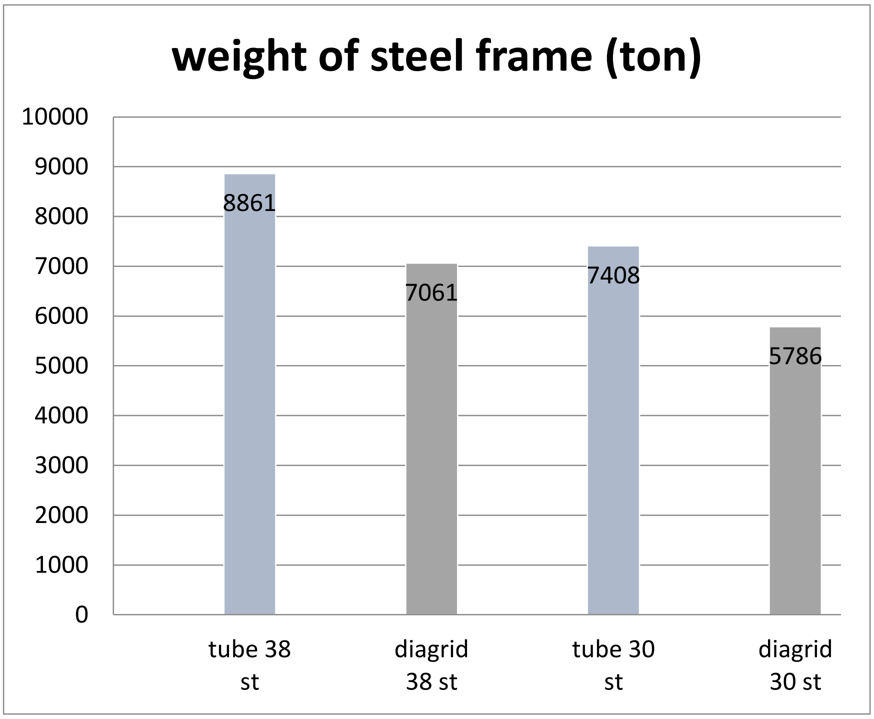
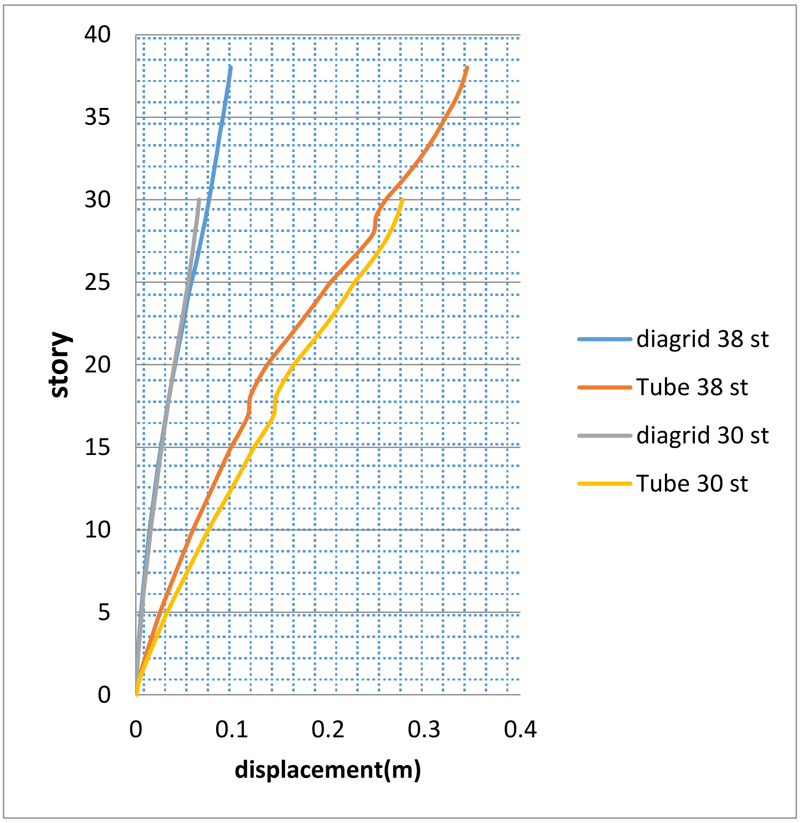



**Diagram 5**

by studying diagram 5 we conclude that 30 floors steel frame diagrid structure is lighter than 30 floors tube structure .This means that 30 floors steel frame diagrid structure is 28 percent lighter than 30 floors steel frame tube structure , also 38 floors steel frame diagrid structure 25 percent is lighter than 38 floors tube structure with closer examination of the diagram5 can be seen that even 38 floors skeleton diagrid structure is lighter than 30 floors skeleton tube structure .

by the investigation of diagram 6 can be seen relative displacement in diagrid structure is very lower than tube structure .(Lateral displacement of the diagrid structure according to graph is about 30 percent lateral displacement of the tube structure)




Digram 6

**PUSHOVER ANALYSIS PROCEDURE [5]**

Pushover analysis is a static nonlinear procedure in which the magnitude of the lateral load is increased monotonically maintaining a predefined distribution pattern along the height of the Structure. Structure is displaced till the „control node" reaches „target displacement" or structure collapses.**[5]**

The sequence of cracking, plastic hinging and failure of the structural components throughout the procedure is observed.The relation between base shear and control nodedisplacement is plotted for all the pushover analysis.

Response characteristics that can be obtained from the pushover analysis are summarised as follows:**[5]**

a) Estimates force and displacement capacities of the structure. Sequence of the member yielding and the progress of the overall capacity curve.

b) Estimates force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.

c) Estimates global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.

d) Sequences of the failure of elements and the consequent effect on the overall structural stability.

e) Identification of the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in plan or in elevation) of the building.

**Calculate the target displacement**

According to the 360 publication , for calculate the target displacement should use equation 1 in the equation (1 ) is equal vibration period of the structure that is obtained after structure

analysis. After parameters of equation (1) explained in 360 publication that because of the brevity we refused to mention them .**[11]**
In the table3 the target displacement is calculated for the structures studied

$$\delta = C_0 C_1 C_2 C_3 S_a \frac{T_e^{\,2}}{4\pi^2} g$$

**Equation 1**

**Traget displacement**

In the following figure7 , place of creation the plastic hinges is seen in both structures. Is clearly visible that in the diagrid system, only members of the first class under pressure is damaged. How ever , the plastic hinges have been formed a greater number in the tube structure

**Table 3 : Target displacement for structures**

| Type of structure | Target displacement ( m) |
|---|---|
| Tube 30 story | 3.2 |
| Diagrid 30 story | ۱,۶ |
| Tube 38 story | ۴.1 |
| Diagrid 38 story | ۲,۷۸ |

Therefore, more energy by tube structure the effect of loads is absorbed than the diagrid structure and as a result tube structure, has more plasticity than the diagrid structure
The results show that the displacement of the diagrid structures was very less than the displacement of the tube structures. and as a results, the stiffness of diagrid structures is higher than the tube structures.

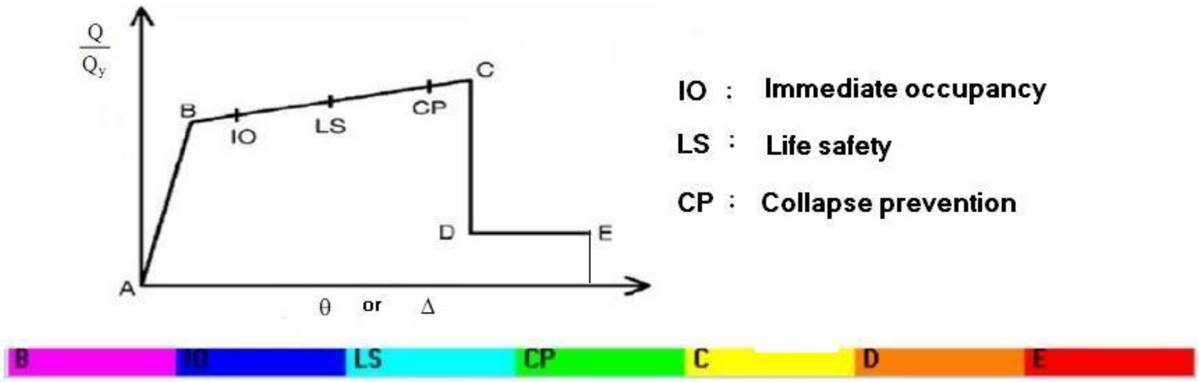



**Figure 8: force – deformation curve for steel elements**

According to figure 8 and 9 After the analysis and design of diagrid structure system clearly is determined that the axial force of the side columns inward decreases Also this axial force decreases with increasing height of the upper columns due to this subject , in the design of diagrid structures lateral columns of the external frame should be stronger than the middle column in addition , distribution of the axial force in the diagrid structures system is more uniform than the tube structures and contrary the tube system . all the columns of the diagrid structure tolerated the axial force.

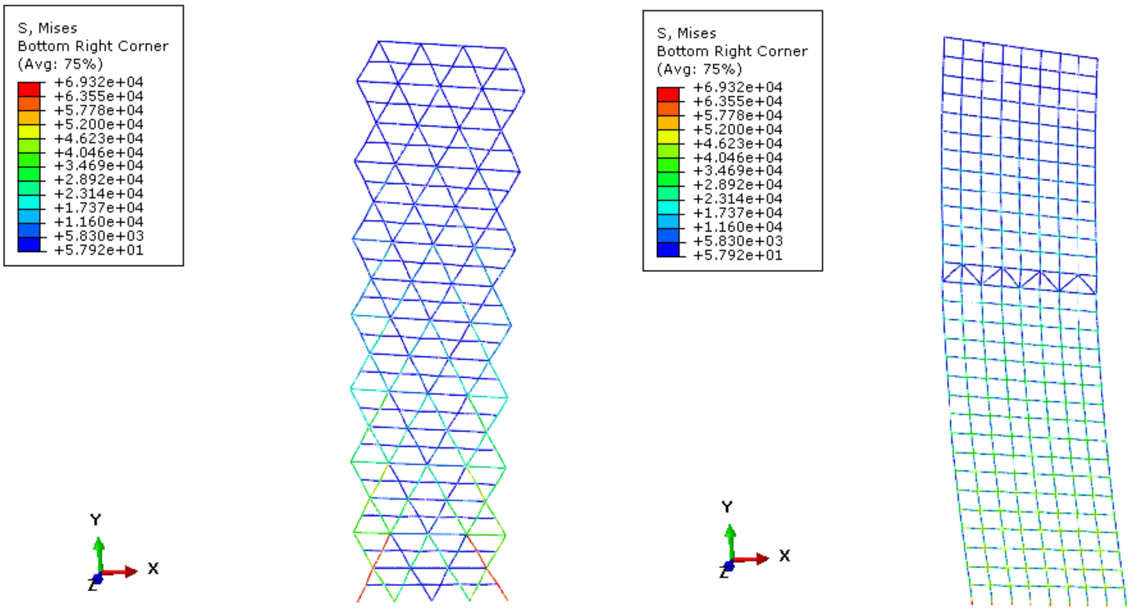



**Figure 8 :axial forces in columns of structures**

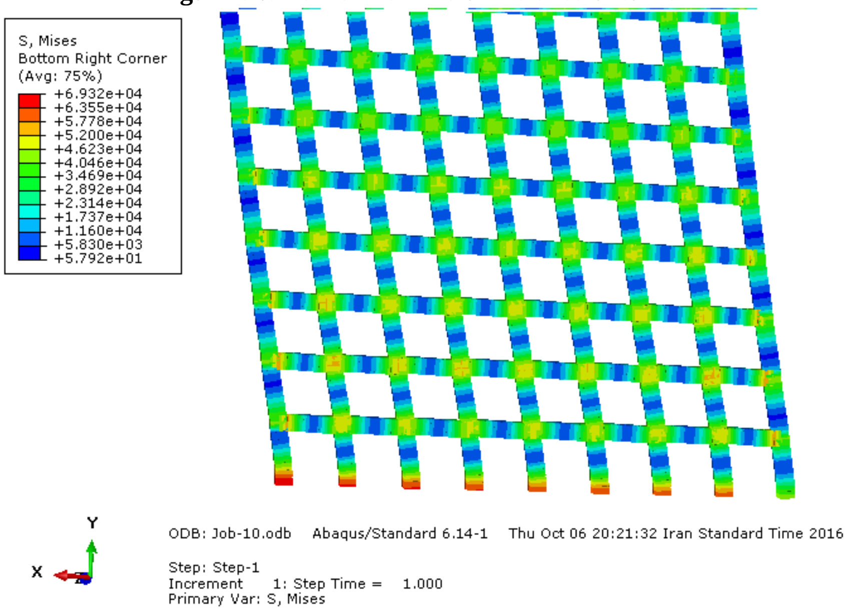



**figure 9 : axial forces in columns of tube structure**

**Comparison of ductility between TUBE system and DIAGRID system**

as in the figure 10 is seen in the diagrid structure is made law joints it also in columns but in 38 floors tube structures has been established much more plastic hinges it also in the beams of the structure. and this represents that the tube systems have higher ductility than the diagrid systems.

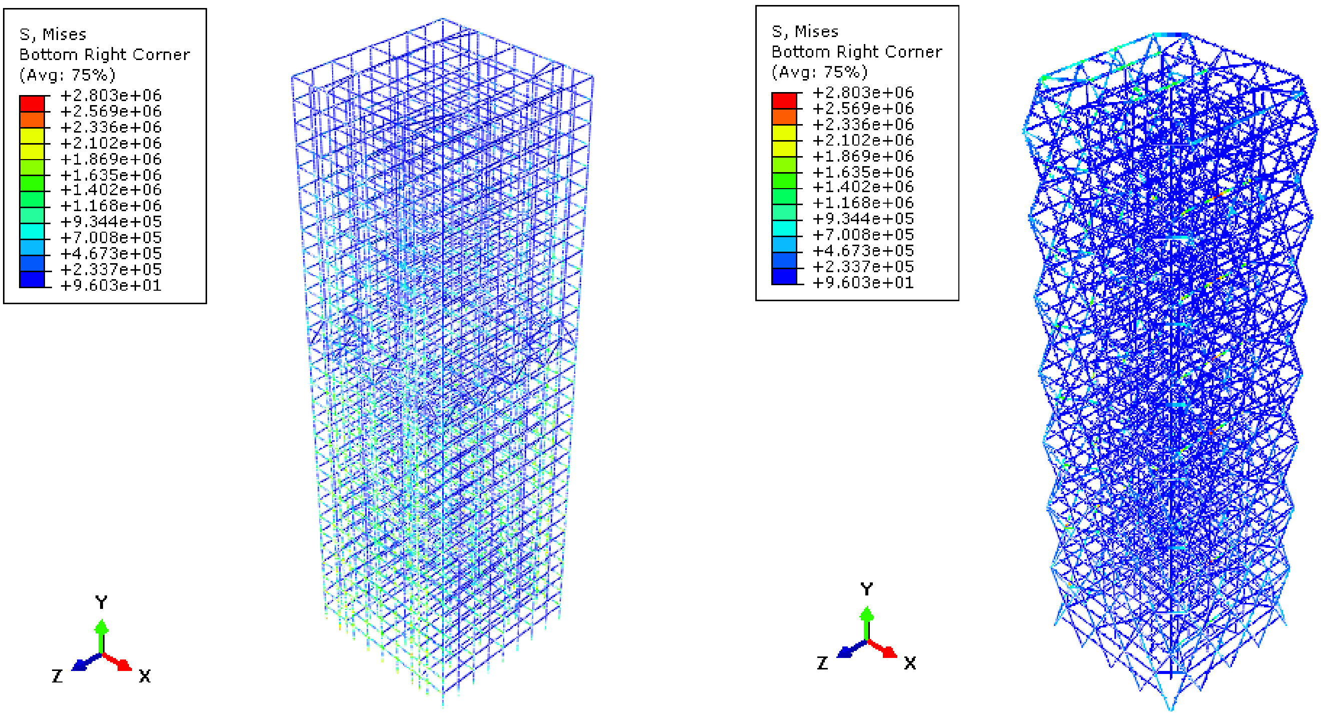



**Figure10 : plastic hinges in tube structure ( left image ) and diagrid structure ( right image)**

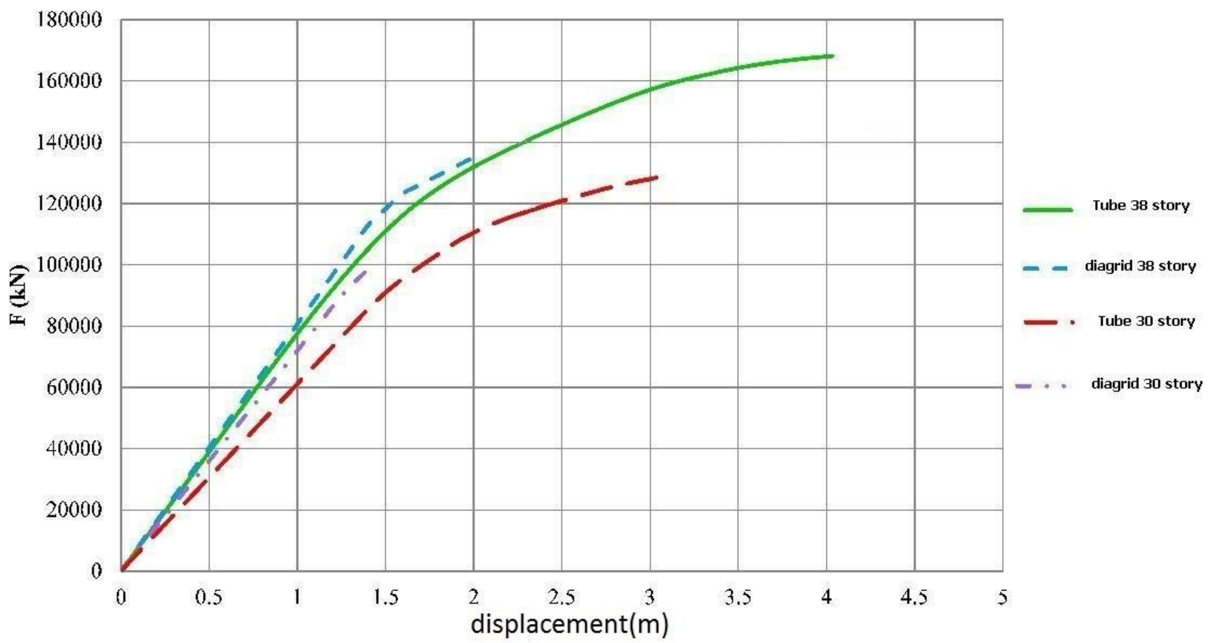



**Diagram 7 : Comparison of capacity curves for the "Pushover" load case**

According diagram 7 ductility of 38 story tube structure is bigger than 30 story tube structure also ductility of 30 story tube structure is bigger than 38 story diagrid structure, thus ductility of 30 story diagrid structure is less than other structures.

# CONCLUSIONS

The diagonal members in Diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagonal members.

Compared with conventional framed tubular structures without diagonals, Diagrid structures are more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while conventional framed tubular structures carry shear by the bending of the vertical columns.

relative displacement (drift) of the diagrid structures was very less than the relative displacement of the tube structures

ductility of diagrid structure is very lower than tube structure and diagrid structure is not good for area with high seismic hazard.

skeleton diagrid structure is 25 percent lighter than skeleton tube structure

# References

[1]. “siesmic performance of twisted diagrid building” , jinko kim , international journal of High-rise building September 2012,vol3,no3,222-230

[2]. Pushover Analysis of Diagrid Structure, Ravi K Revankar, International Journal of Engineering and Innovative Technology,Volume 4, Issue 3, September 2014

[3]. Numerical Analysis Using MATLAB, Karris, 2014

[4]. “Seismic Performance of Diagrid Steel Structures Using Single and Double Friction Mass Dampers “Garlan Ramadhan for the degree of Master of Science in Civil Engineering, Oregon State University, 2013

[5]. Guidelines for performance-based seismic design of tall buildings, Pacific Earthquake Engineering Research Center ( PEER) , November 2010

[6].”Seismic Performance Evaluation of Diagrid System Buildings” , J. Kim, Y. Jun and Y.-Ho Lee Department of Architectural Engineering, Sungkyunkwan University, Suwon, Korea,2010

[7]. “Design and Construction of Steel Diagrid Structures” , K. Moon ,School of Architecture, Yale University, New Haven, USA , 2009

[8].” DIAGRID STRUCTURAL SYSTEMS FOR TALL BUILDINGS:CHARACTERISTICS AND METHODOLOGY FOR PRELIMINARYDESIGN, JOHN E. FERNANDEZ, Department of Architecture, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA , 2008

[9]. ABAQUS USER’S manual V.14.2

[۱۰]. publication 360 , iran

[11] . 2800 regulation , iran

# Appendix
# All of programs was written by Mohsen Rostami in MATLAB

## Earthquake program

```
% % % This program was written by MOHSEN ROSTAMI % % %
clc
clear all
H=input('please enter the height of the structure in meter :  ')
Type_of_soil=input('please enter the Type of soil : ')
Type_of_structure=input('please enter for steel number 1 & for concrete number 2 & other number 3   : ')
R=input( 'please enter the value of R in 2800 code : ')
I=input('please enter importance factor of building in 2800 code : ')
siesmic_hazard=input('if seismic hazard is very high input 1 & if seismic hazard is high input 2 & if seismic hazard is medium
input 3& IF seismic hazard is low input 4  : ')
if Type_of_structure==1
T=0.08*(H^(3/4));
end
if Type_of_structure==2
T=0.07*(H^(3/4));
end
if Type_of_structure==3
T=0.05*(H^(3/4));
end

if Type_of_soil==1
T0=0.1;
Ts=0.4;
s=1.5
end
if Type_of_soil==2
T0=0.1;
Ts=0.5;
s=1.5
end
if Type_of_soil==3
T0=0.15;
Ts=0.7;
s=1.75;
end
if Type_of_soil==4;
T0=0.15;
Ts=1;
s=2.25;
end
if T>=0 && T<T0
B=1+(s*(T/T0));
end
if T>=T0 && T<=Ts
B=1+s;
end
if T>Ts
B=(1+s)*((Ts/T)^(2/3));
end
if siesmic_hazard==1
A=0.35;
end
if siesmic_hazard==2
A=0.3;
```

```
end
if siesmic_hazard==3
A=0.25;
end
if siesmic_hazard==4
A=0.2;
end
A
B
I
R
C=(A*B*I)/(R)
disp(' this program was written by MOHSEN ROSTAMI ')
```

**spectrum of soil program**

```
clc
clear all
type_of_soil = input ( ' please enter type of soil :   ' )   % press 1 or 2 or 3 or 4
hazard_zone = input ( ' please enter hazad of zone :     ' ) % press 1 or 2 or 3 or 4

%%%% hazard zone %%%%%
if hazard_zone == 1
A=0.35 ;
end
if    hazard_zone == 2
A=0.3 ;
end
if hazard_zone == 3
A= 0.25 ;
end
if     hazard_zone == 4
A = 0.2 ;
end

%%%%%% type_of_soil %%%%
if type_of_soil==1
s=1.5  ;
T0=0.1 ;
Ts=0.4 ;
end
if type_of_soil ==2
s=1.5 ;
T0=0.1;
Ts=0.5 ;
end
if type_of_soil == 3
s=1.75 ;
T0=0.15 ;
Ts=0.7 ;
end
if type_of_soil == 4 && hazard_zone  <= 2
s=1.75 ;
T0=0.15 ;
Ts=1 ;
else  type_of_soil == 4 && hazard_zone >= 3
s=2.25 ;
T0=0.15 ;
Ts=1 ;
end
n = 10 ;
T = 20 ;
for Ti =0 : 50
Tj(Ti+1,1)= Ti/n ;
if  Tj ( Ti+1,1) < T0 ;
Saj(Ti+1,1)=A*(1+s*(Tj(Ti+1,1)/T0));
elseif T0 <= Tj(Ti+1,1) && Tj(Ti+1,1)< Ts ;
Saj(Ti+1,1)=A*(s+1)
elseif Ts <= Tj(Ti+1,1)
Saj(Ti+1,1)=A*(s+1)*((Ts/Tj(Ti+1,1))^(2/3))
elseif Ts > Tj(Ti+1,1) ;
Saj(Ti+1,1) = A*(s+1)*((Ts/Tj(Ti+1,1))^(2/3))*(16/Tj(Ti+1,1)^2);
end
```

```
end
plot (Tj , Saj , 'color' , ' red ' )
hold on
grid on
xlabel(' period T in senconds ' )
ylabel('spectural accelaration Sa    m/s^2' )
title ( ' response spectrum acceleration ' )
```