**Analytical study of frame behavior of a crater under horizontal earthquake acceleration considering the effect of soil kinematic interaction**

**Abstract:**

Considering the interaction of soil and structure can lead to more accurate results of the dynamic response of the structure. Research shows that considering the interaction of soil and structure can cause changes in the forces and displacements of the structure. Often the interaction of soil and structure is done numerically and the results are valid for a specific numerical model. The research tries to investigate the effect of soil interaction on the frame of a crater by considering the geometric characteristics of the frame and the effect of horizontal acceleration.

For this purpose, the equations of motion of the system for a flexural frame structure of a two-dimensional span are written and the response of the system and the forces created in the frame for different values ​​of mass of structural components, stiffness and damping of structural components, soil density and shear wave velocity are obtained. Finally, it is concluded that the shear wave velocity in all structures is faster than the column and will occur with increasing degrees of maximum acceleration in the period of higher rotations. Also, by comparing the structures with different degrees of freedom, their effect on the acceleration of the structure has been investigated.

**key words:** Kinematic interaction, design spectrum, horizontal component, earthquake

**1. Introduction**

Soil-structure interaction is one of the main topics in the field of structural engineering, especially earthquake engineering, which has recently been especially for structures. Heavy and bulky structures such as nuclear power plants, offshore platforms, bridges and tall buildings have received international attention. Deformation of a structure during an earthquake under the influence of the interaction of three related systems of the structure, foundation and the characteristics of the following soil layers And around the foundation. Soil-structure interaction analysis evaluates the response of these systems to ground motion in the free field Gives.

In general, the structure is interacting with the surrounding soil, so the load on the soil environment around the structure, during Earthquake movments, must be considered. Compared to structures, soil has an infinite territory in which the wave propagation conditions must be in the model Be dynamic. In a general view, it can be said that considering the interaction of soil and structure causes the behavior of the structure to behavior Get closer to the real thing.

During an earthquake, the interactions of soil and structure are important, as the dynamic interaction between the response of the structure and the characteristics of the foundation. Commonly known as the effects of dynamic soil-structure interactions. Observing past earthquakes is well important Considering the effects of interaction on the seismic response clarifies the structure. These observations show that in general

the effect of the interaction phenomenon The seismic response of the structure in scale with the response of the structure on a rigid base may be increasing or decreasing depending on the properties of the soil. Most soil-structure interaction research has been performed numerically and the results have been validated for a specific numerical model. In this research,
In this research, the effect of soil interaction on the frame of a span is analyzed by considering the geometric characteristics of the frame and the effect of horizontal acceleration.

 If the equations of this system are solved in the frame for different values ​​of mass of structural components, hardness and damping of structural components, soil density And the shear wave velocity is obtained. By generalizing the results, an approximate analytical answer can be given to the behavior of multi-span structures with Obtained cinematic interaction.

**2. Concepts**

Earthquakes are one of the most devastating natural disasters that cause a lot of financial and human losses. On average, tens of thousands of people die each year from earthquakes and leaving financial losses of about billions of dollars. In this article, the general knowledge of the waves generated by the earthquake and how to create the vertical component of the earthquake and the destructive effects of the vertical component of the earthquake are presented in the form of images of damage to structures and the results of analysis.

**2.1.** **General knowledge of waves and components of earthquake acceleration**

Fault ruptures cause brittle fractures of the Earth's crust, which consume up to ten percent of the total plate tectonic energy in the form of depleted seismic waves. Earthquake movements are caused by two types of elastic seismic waves in the form of volumetric and surface waves. The volume that travels through the Earth's inner layers includes longitudinal or primary waves (known as P waves) and waves Are transverse or secondary (known as S-waves), also because P and S waves are initially felt in most earthquakes.

These waves are also called primary tremors. P waves as shown in the figure on the left (1-2) cause pressure and Intermittent tensions occur in the rock, so with the propagation of these waves, moderate expansion and contraction occur. They are similar to sound waves such as low magnitude and short periodicity and the ability to transmit in the atmosphere. P waves or Seismic waves They are low with relative damage potential. The propagation of S-waves by contraction, causes them to move side by side horizontally and vertically. Such waves They create shear stresses for the paths shown in Figure (1), so they are defined as a shear waves.The motions of these waves can be divided into two parts: horizontal component (SH) and vertical (SV), which both of them can cause significant damage. Shear waves similar to electromagnetic waves have high magnitude, long periodicity, and non-diffusion properties in fluids [Di sarno Elnashai, 2008] and [Datta, 2010]

Figure (1) Volumetric wave motion mechanism: primary waves (left) and secondary waves (right) [Di sarno Elnashai, 2008] and [Datta, 2010]

P and S volumetric waves are named according to their arrival time and are measured by seismographs at the scene. P-waves travel at a speed between 5.9 and 0 km / s faster than S-waves, while S-wave velocities are usually around 52 to 62% is the velocity of P waves. The actual velocity of volumetric waves depends on the density and elastic properties of the rock and soil through which they pass.(Di sarno Elnashai, 2008)

The velocity of volumetric waves can be explained by the Navier equation for an infinite, homogeneous, isotropic and elastic mediator in the absence of volumetric forces. The propagation velocities of P and S waves in an elastic isotropic mediator with density ρ are denoted by υp and υs in relations (2-1) and (2-2), are shown.

(2-1) $v\_{p}=\sqrt{\frac{E(1-v)}{p(1+v)(1-2v)}}$

(2-2) $v\_{s}=\sqrt{\frac{E}{2p(1+v)}}$

In which $υ$ is the Poisson's coefficient and E is the median Yang modulus of elasticity. The ratio of the velocities of the P and S waves is as a relation (3-2).

(3-2) $\frac{v\_{s}}{v\_{p}}\sqrt{\frac{(1-2v)}{2(1-v)}}$

And for the values ​​of $υ$ for different types of soil, for example, the range between 0.3 to 0.5, the relationship (4-2) is established.

(4-2) $0\leq v\_{s}\leq 0.53v\_{p}$

Surface waves propagate along the outer layers of the earth's crust, generated by the beneficial intervention of P-waves moving parallel to the earth's surface and the boundaries of the subsoil. Surface waves include Love waves (L or LQ waves) and Rayleigh waves (R or LR waves). In areas far from the source of the earthquake, these waves are most different. In shallow earthquakes, surface waves are the most present, while volumetric waves are equal in all earthquakes with different depths. Given the long duration of action of surface waves, it seems likely that these waves will cause severe damage to structural systems during an earthquake.[Di sarno Elnashai, 2008] and [Datta, 2010]

Low waves are generated by the beneficial intervention of SH volumetric waves, so they can not pass through fluids. Their motion, as shown schematically in the left figure (2), is in the horizontal direction and perpendicular to the direction of propagation of the wave, which is parallel to the earth's surface. Low waves have a large magnitude and long periodicity, which are also called long wave waves (60 to 300 seconds) called G waves, which travel at a speed of about 4 kilometers per second and are like a shock, Riley waves are generated by the beneficial intervention of volumetric waves such as P and SV. R-waves show large size and regular shapes and move more slowly than S-waves. By approximation, it can be assumed that the Rayleigh wave velocity $v\_{LR}$ is obtained from Equation (5-2) and for a solid layer, the Low-wavelength $v\_{LQ}$ generally follows Equation (6-2).

(5-2) $v\_{LR}≈0.92v\_{s}$

(6-2) $v\_{s1}\leq v\_{LQ}\leq v\_{s2}$

Where $v\_{s1}$ and $v\_{s2}$ are the velocities of S waves in the surface layers and deep layers, respectively.



Figure (2) Surface wave motion mechanism: Love waves (left) and Rayleigh waves (right) [Di sarno Elnashai, 2008] and [Datta, 2010]

Surface waves are slower than volumetric waves, and generally Love waves are faster than Rayleigh waves. In addition, in the magnitude of the P and S wave values, the linear decrease of the magnitude value with increasing distance (x) is shown while the surface wave magnitude decreases with the inverse square root ratio of the distance (x), S-waves die faster than P-waves, which is the amount of damping obtained from the viscosity of the earth's crust.[Di sarno Elnashai, 2008]

The occurrence of a vertical seismic component associated with the arrival of vertical compressive P waves is propagated, while shear waves (S) are the main reason for the formation of horizontal components. The wavelength of P-waves is shorter than S-waves so vertical motion has higher frequencies than horizontal motion, It should also be noted that the magnitude of vertical motion has a faster reduction rate than horizontal motion. Also, the behavior of the horizontal and vertical components of seismicity is often determined by the ratio of the peak acceleration ratio of vertical to horizontal ground, ie $PGA\_{V}/PGA\_{V}.$[Di sarno Elnashai, 2008]

P-waves compared to S-waves which were attributed to the occurrence of vertical component and horizontal components of earthquake, respectively, can be said that during the excitation time of each earthquake, the vertical component in general in the initial seconds show more impact which in most The cases are in the form of impact movements that after a short time after the earthquake and the shear waves reach the site, the destructive effects of the horizontal components become more apparent.

**2.2. Soil-structure interaction**

According to a general perception, any analysis in which the structure and the soil are examined simultaneously, whether in static or dynamic conditions of the soil and structure applies to it. Accordingly, the static analysis of a nailed wall in which the nails and the surrounding soil environment are analyzed together is a kind of analysis of soil-structure interaction. But in a more specialized and accurate interpretation, this title is only dedicated to dynamic analysis in which the structure and the soil environment vibrate as an integrated system and the vibration modes affect each other. In this case, seismic waves are transmitted from the soil to the structure and vibrate the structure. On the other hand, the return of waves due to the vibration of the structure into the ground creates new seismic stresses in the soil.

In general, considering the interaction of soil and structure in the analysis of the dynamic response of structures has the following effects which are briefly mentioned below:

 ●a) change in the natural frequency and shape of the system modes; Thus, the rotation time is often increased by considering the interaction of soil and structures for structures built on soft ground. To clarify this point, we can refer to a runner running on soft ground which will take longer to cover a fixed distance compared to hard ground.

●B) In most buildings, the amount of base cut decreases with the interaction and the displacement of the floors increases.

●C) change in the acceleration response and consequently the response spectrum which, depending on the characteristics of the structure and soil, may reduce or intensify the acceleration.

●D) The attenuation of the soil and structure system is often greater than the attenuation of the grounded state.

Soil-structure interaction causes two important changes in the factors affecting the behavior of the structure in the earthquake. The first is related to the change in the effective stimulus applied to the foot of the structure, which means that the stimulus that the structure experiences is different from the stimulus recorded at the surface of soil free of the structure and foundation (untouched soil). This work is called cinematic action. The second is the change in the dynamic conditions of the system, such as its effective period and damping. Considering soil and structure as a dynamic system, the period and damping of this system will be different from the structure located on a rigid bed and, consequently, the performance of the structure in this system will also be different. This effect is called inertial action. Basically, the effect of soil-structure interaction is important when large or hard structures such as nuclear reactors or dams are placed on relatively soft soil.

As mentioned, the effects of soil-structure interaction are divided into two effects: kinematic interaction and inertial interaction. When the mass of the foundation is not considered, due to the rigidity of the foundation relative to the soil and the inability of the soil to adapt to the free field motion, the foundation experiences an average of the free field motion of the soil, which is changed to this movement. It is said that this event is derived from the cinematic effect of the interaction of soil and structure. In the action of inertia, it appears despite the mass of the structure and the foundation, which the vibration of the structure and the resulting inertial force will cause a new movement. These two effects cause the motion of the foundation during an earthquake to be completely different from the response due to the movement of the free field of the soil. Studies show that the effect of inertial action is more important than kinematic interaction.[A.Veletsos, 1993]

 Therefore, considering the soil-structure interaction, it can be divided into two stages: the first stage is the correction of the free field motion of the soil, which results in input stimulation, and the second stage is the replacement of the structure with a soil-structure system. Considers the effect of soil presence in dynamic analysis. In this way, the resulting soil-structure system can be stimulated at the input and then analyzed. In order to clarify the kinematic action and the inertial interaction qualitatively, an example is given in Figure 2-3. Assuming that the waves reaching the boat are in fact the same as the waves reaching the foundation, the boat will represent the foundation and the person standing in it will represent the structure. Boat swing It will represent the average of the waves reaching the hull and will fluctuate inside the boat as a result of the oscillation. If one's weight is ignored, the oscillations created in the boat are the same as the kinematic effect (KI) and are similar to the input stimulation. Where as in terms of a person's weight, when a person oscillates, due to his mass and according to Newton's first law, wherever he goes, he strikes a blow at the end of his oscillation, which itself changes the oscillation Has been turned. This part of the oscillation is the same as inertia (II).



**Figure (3): Kinematic interaction and inertial interaction**

**3. Research Methods**

In numerical analysis ( Numerical Analysis) (RungeKutta Methods) (also called RungeKutta Methods) are a family of Explicit and Implicit Methods. One of these methods, the first-order Rang Kota, is also known as the Euler method and is very popular. Rang Kota methods for (Temporal Discretization) are used to estimate solutions (Ordinary Differential Equations). These methods were developed around 1900 by two German mathematicians named Carl Runge and Wilhelm Kutta. he most well-known method of the Rang Kota family of methods is the RK4, the classic Rang Kota method, or the fourth-order Rang Kota method, which is abbreviated to the Rang Kota method. In this paper, equilibrium equations are written for the fourth time with the help of Rang Kota.

**4. data analysis**

In the present study, three models of two degrees, three degrees and four degrees have been studied in eight, nineteen and fifteen states with an earthquake record, respectively, the specifications of which are given in the following tables.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Earthquake Magnitude | EpiD (km) | PGA (g) | Station Name | Earthquake Name |
| 6.19 | 40.26 | 0.293446 | Temblor pre-1969 | Parkfield |

**Table (4-1): Acceleration mapping characteristics used for structural analysis in MATLAB**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mf(kg) | Ms(kg) | Vs(m/s) |
| 1 | 15000 | 30000 | 310 |
| 2 | 15000 | 30000 | 160 |
| 3 | 15000 | 30000 | 700 |
| 4 | 15000 | 10000 | 310 |
| 5 | 15000 | 100000 | 310 |
| 6 | 32000 | 30000 | 310 |
| 7 | 8000 | 30000 | 310 |
| 8 | 16000 | 30000 | 310 |

**Table (4-2): Different values ​​of the two-degree freedom model**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | M1(kg) | M2(kg) | Mb(kg) | Mf(kg) | Vs(m/s) | alpha | beta |
| 1 | 5000 | 5000 | 25000 | 16000 | 310 | 1 | 1 |
| 2 | 5000 | 5000 | 25000 | 16000 | 160 | 1 | 1 |
| 3 | 5000 | 5000 | 25000 | 16000 | 700 | 1 | 1 |
| 4 | 5000 | 5000 | 25000 | 16000 | 310 | 0.2 | 1 |
| 5 | 5000 | 5000 | 25000 | 16000 | 310 | 0.5 | 1 |
| 6 | 5000 | 5000 | 25000 | 16000 | 310 | 1 | 0.2 |
| 7 | 5000 | 5000 | 25000 | 16000 | 310 | 1 | 0.5 |
| 8 | 5000 | 5000 | 25000 | 16000 | 310 | 0.2 | 0.5 |
| 9 | 5000 | 5000 | 25000 | 16000 | 310 | 0.5 | 0.5 |
| 10 | 5000 | 5000 | 25000 | 16000 | 310 | 1 | 0.7 |
| 11 | 5000 | 5000 | 5000 | 16000 | 310 | 1 | 1 |
| 12 | 5000 | 5000 | 10000 | 16000 | 310 | 1 | 1 |
| 13 | 5000 | 5000 | 25000 | 8000 | 310 | 1 | 1 |
| 14 | 5000 | 5000 | 25000 | 32000 | 310 | 1 | 1 |
| 15 | 5000 | 5000 | 25000 | 160000 | 310 | 1 | 1 |
| 16 | 25000 | 5000 | 25000 | 16000 | 310 | 1 | 1 |
|  17 | 50000 | 5000 | 25000 | 16000 | 310 | 1 | 1 |
| 18 | 100000 | 5000 | 25000 | 16000 | 310 | 1 | 1 |

 **Table (4-3): Different values ​​of the three degrees of freedom model**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | M1(kg) | M2(kg) | Mb(kg) | Mf(kg) | Mff(kg) | V(m/s) | alpha | beta |
| 1 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 1 | 1 |
| 2 | 5000 | 5000 | 25000 | 8000 | 8000 | 160 | 1 | 1 |
| 3 | 5000 | 5000 | 25000 | 8000 | 8000 | 700 | 1 | 1 |
| 4 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 0.2 | 1 |
| 5 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 0.5 | 1 |
| 6 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 0.5 | 0.2 |
| 7 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 0.5 | 0.5 |
| 8 | 5000 | 5000 | 25000 | 8000 | 8000 | 310 | 1 | 0.5 |
| 9 | 5000 | 5000 | 5000 | 8000 | 8000 | 310 | 1 | 1 |
| 10 | 5000 | 5000 | 250000 | 8000 | 8000 | 310 | 1 | 1 |
| 11 | 5000 | 10000 | 25000 | 8000 | 8000 | 310 | 1 | 1 |
| 12 | 5000 | 100000 | 25000 | 8000 | 8000 | 310 | 1 | 1 |
| 13 | 5000 | 5000 | 25000 | 80000 | 8000 | 310 | 1 | 1 |
| 14 | 5000 | 5000 | 25000 | 800000 | 8000 | 310 | 1 | 1 |

**Table (4-4): Different values ​​of the four-degree freedom model**

In the codes written in MATLAB software, the damping constant value is assumed to be 5% and alpha and beta in the above tables have nothing to do with the Rayleigh method.

To obtain the stiffness ratio of the beam and column, the stiffness ratio of one of the columns is calculated and with the help of alpha and beta coefficients, the stiffness ratio of the other beam and column will be calculated based on the original column that has been calculated. In a 4 degree structure, a radius equivalent to 0.5 is considered.

**4.1. Comparison of one-degree and two-degree models**



Figure (4.1) Investigation of changes in the acceleration ratio of a structure of one degree to two degrees by changing the weight of the foundation of a structure of two degrees of freedom

According to Figure (4.1) and by examining the changes in the acceleration ratio of the structure one degree to two degrees with the change of the weight of the foundation of the structure is considered two degrees. One degree, the acceleration applied to the structure of one degree is about 2.5 and 2 times the structure of two degrees and its value is about half for 50 ton and 500 ton structures, over time due to the predominance of the ratio of structure stiffness to the weight of the structure column. All models are the same, reduced and fixed at about 0.15.

**4.2. Comparison of two-degree and three-degree models**

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Figure (4.2) Investigation of changes in the acceleration ratio of a structure two degrees to three degrees by changing the weight of one of the columns of a structure three degrees of freedom.

Following the results obtained from Figure (4.2) by examining the changes in the acceleration ratio of the structure two degrees to three degrees and considering that in matrix A of the Kunga equation, the ratio of column weight to damping has a greater effect in less periods by changing the weight of one column. Of three-degree structures, at the beginning of the graph and in periods less than about 0.7 structures with a column weight of 5 tons, the ratio of acceleration of the structure of two degrees to three degrees shows this ratio more, but from 0.5 onwards, all 4 structures between 0/3 and oscillate.

**4.3. Compare three-degree and four-degree models**

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Figure (4.3) Investigation of changes in the acceleration ratio of a structure of three degrees to four degrees by changing the weight of one of the foundations of a structure of four degrees of freedom.

According to Figure (4.3) and by examining the changes in the acceleration ratio of the structure three degrees to four degrees by changing the weight of one of the foundations of the four degrees structure, the ratio of changes in the structure of 8 and 5 tons is almost the same and increases with increasing periodicity, Shows more and then shows less. The structure with a weight of 800 tons shows approximately the same behavior as the two structures of 5 and 8 tons with a lower ratio.

**5. Conclusion**

In this section, by considering those results, they are analyzed and concluded. By analyzing the results, the behavior of the effective parameters in the soil-structure interaction as well as the effect of change in the degrees of structural freedom will be described. At the end, a summary of the work done and the results are stated.

**5.1. Two-degree structure**

In a two-degree structure, the spectral acceleration of a column with a shear wave velocity of 100 provides more acceleration to the structure than 700, 310 and 160 meters per second, and its acceleration changes are less than those of the other three structures. At three shear wave velocities of 700, 310 and 160 m / s in the low periodicity period less and with increasing periodicity of the column spectral acceleration also increases until after T = 0.7 the amount of shear wave velocity is uniform. Following the spectral acceleration of the foundation decreases with increasing shear wave velocity and shear wave velocity 100 is very different from the other three shear wave velocities, which indicates the need to apply shear wave velocity in soft soils. it shows that The shear wave velocity only affects soft soil with a velocity of 100 and shows a different behavior, and in the other three velocities in the displacement spectrum for the column has no significant effect and have almost the same behavior. Subsequently, the value of the displacement spectrum of the foundation decreases slightly with increasing shear wave velocity, only the velocity of 100 to the periodicity represents a relatively higher value.

Increasing the weight of the column results in more acceleration, which increases with time up to about 0.4 seconds. Spectral acceleration of columns of different weights will be obtained. In column displacement in periods of less than 0.4 seconds with increasing column weight, the displacement spectrum increases and from 0.4 seconds to 0.7, the results are reversed and the column with less weight achieves less displacement spectrum and from 0.7 seconds does not have much effect. Observing the changes in the acceleration of the foundation with the change of weight, it was observed that with increasing the weight of the foundation, the spectral acceleration of the foundation also increases and the difference between the spectral acceleration of the foundation increases from T = 0.7 upwards but has no effect on higher spectral acceleration. As the weight of the foundation increases, the displacement changes of the 2-degree structure also increase, and the greatest amount of change occurs at the beginning of the graph.

**5.2. Three-degree structure**

By examining the changes in the acceleration of the three-degree structural column, it was observed that the spectral acceleration of the column at 100 velocity shows a different behavior compared to the other three velocities and shows more displacement except in the range of 1.25 to 1.5 have almost the same behavior. and from T = 0.7 to T =1 shear wave velocity of 160 m / s, the column spectral acceleration is less than 310 and 700 m / s. After 1T = s, all three spectral accelerations of the column increase to about T = 1.4 and then decrease. Examination of changes in column displacement shows that the spectral acceleration of the foundation decreases with increasing shear wave velocity, and the velocity of 100 differs greatly from the other three velocities and tolerates an acceleration of approximately 4 times.The displacement changes of the column show that the shear wave velocity shows a higher value of 100 to T=1.2, then the displacement spectra of the two velocities 100 and 160 have approximately the same displacement and the two velocities 310 and 700 show the same displacement.

Examination of changes in column acceleration by changing the stiffness ratio of a 3 degree structural column shows that by increasing the stiffness ratio from 0.2 to 1, the structure behaves similarly, with the difference that the maximum value will occur in more periodic periods. Displacement changes by changing the stiffness ratio of the structural column of three degrees of freedom with increasing the beam stiffness ratio from 0.2 to 1 when reaching the maximum displacement point increases and the remarkable point is that the maximum value of the stiffness ratio is 0.5 more than other ratios. A small time difference is obtained in the amount of displacement.

By examining the changes in acceleration by changing the stiffness ratio of the beam and the column, three degrees of freedom are observed. By increasing the stiffness ratio of the beam from 0.7 to a spectral acceleration value, they will behave almost similarly. Exits and increases the value less than other modes. In the case where the stiffness of one column and the stiffness of the beam is half the stiffness of the other column, the maximum spectral acceleration will occur and with increasing the stiffness ratio of the column, the maximum T value will increase. Examination of displacement changes by changing the stiffness ratio of the beam and the structural column of three degrees of freedom shows that by increasing the stiffness ratio of the beam from 0.5 to 1, not much change in the displacement rate is observed. By reducing the stiffness of the beam to 0.2 until T=1.1 , the graph shows a fixed number of 0.04 and then increases with an almost constant slope. By changing the stiffness ratio of one of the columns from 0.2 to 0.5 in addition to increasing the time required for Achieving maximum displacement, The amount of maximum displacement also increases. Changes in the acceleration spectrum of a 3-degree structural column with an increase in the weight of the beam from 5000 to 25000 kg, in addition to increasing the maximum acceleration, the maximum acceleration will be delayed by about 0.5 seconds. With a very large increase in the weight of the beam, the amount of acceleration also changes and increases slightly with almost linear behavior. By increasing the weight of the beam from 5000 to 25000, in addition to increasing the amount of maximum displacement, the amount of time reached to the maximum displacement also increases, and like acceleration, displacement increases slightly by increasing the weight of the beam almost linearly. Also, the study of changes in the acceleration of the column by changing the weight of the foundation of the structure by 3 degrees shows that there is not much change in the amount of acceleration; only with a very large increase in the weight of the foundation, the amount of acceleration increases significantly.

In the study of changes in column displacement by changing the foundation weight of the structure 3 degrees is observed that, like acceleration changes, the displacement increases with the foundation weight only when the foundation weight increases too much, and in other cases the displacement changes behave similarly.

As the weight of the foundation increases, the spectral acceleration of the foundation also increases and the amount of spectral acceleration is constant for up to 0.6 seconds, then it increases and reaches the peak point in about one second and then decreases with a slight decrease. Displacement also increases significantly. In structures with a weight of 160 tons, the graph is constant for about 0.8 seconds, and from 0.8 onwards, in contrast to other structures, the amount of displacement decreases. In foundation displacement changes, with increasing the weight of the foundation, except for a very large increase in the weight of the foundation, it increases slightly, and the change in the displacement of the foundation over time is small, with a very large increase in the weight of the foundation. In this case, the minimum value will occur in about T=1 in this range.

Changes in the acceleration spectrum of the column show that by changing the weight of the column from high values, ie more column weight, less acceleration spectrum is obtained, which increases the time to reach the maximum value by increasing the weight of the column. Also, with decreasing the weight of the column, the amount of displacement has increased, except that the weight of the column has increased a lot, in which case the maximum value will occur at the end of the graph.

**5.3. 4 degree structure**

The spectral acceleration of the column at two shear wave velocities of 700 and 310 m / s has almost the same behavior and the 160 velocity has almost the same behavior but with less acceleration but 100 velocity withstands almost constant acceleration with less value. In spectral acceleration, the amount of acceleration increases with decreasing shear wave velocity, so that velocity 100 will withstand the maximum acceleration. The amount of acceleration difference between different velocities decreases with increasing periodicity. Column displacement changes indicate similar behavior with changes in shear wave velocities of 310, 700, and 160, except that velocity 160 indicates a lower maximum value. Speed ​​100 shows almost constant displacement with a value less than other speeds.

Examination of the displacement spectrum of the foundation shows that the value of the displacement spectrum of the foundation decreases with increasing shear wave velocity from 100 to 310, but the two velocities of 310 and 700 show almost the same displacement. Examination of changes in column acceleration by changing the column stiffness ratio shows that by increasing the stiffness ratio from 0.2 to 1, the structure behaves similarly, with the difference that with increasing stiffness, the amount of acceleration with delay will be less than the amount of acceleration. Examination of acceleration changes by changing the stiffness ratio of beams and columns of the structure shows that by decreasing the stiffness ratio of beams and columns of the structure, the time to reach each acceleration increases, but the maximum value in 4 cases is almost equal. In the study of displacement changes by changing the stiffness ratio of the column, it is observed that by increasing the stiffness ratio of the beam from 0.2 to 1, the time to reach each displacement increases and the remarkable point in this diagram is less than the maximum hardness ratio of 0.2 than other ratios.

Displacement changes by changing the stiffness ratio of the beam and column Expresses that by changing the stiffness ratio of the beam and column, the time to reach the maximum value will change and the maximum value is approximately equal.

Changes in the column acceleration spectrum show that by increasing the weight of the beam from 5000 to 25000 kg in periods of less than 1, the amount of acceleration of the structure with the weight of the beam shows more, but from one onwards the structure with a weight of 5000 kg shows more. With a very large increase in the weight of the beam, the amount of acceleration also changes and increases slightly with a slight slope.

Increasing the weight of the beam from 5000 to 25000 The amount of maximum displacement increases slightly and the time to reach the maximum displacement also increases and the amount of displacement with a very large increase in the weight of the beam shows an almost constant number of 0.04. The changes in the acceleration spectrum of the column are approximately equal to the structure by changing the weight of the column from 5 tons to 10 tons, but the time to reach each acceleration at 10 tons is about 0.2 seconds less and the maximum acceleration is slightly higher, with a very large increase in column weight. Both peak time and maximum acceleration are significantly reduced. By examining the changes in column displacement by changing the column weight, the displacement of the structure with a column weight of 10 tons is up to 1.4 seconds more than the structure with a column weight of 5 tons, but from this time onwards, the displacement of the structure with a column weight of 5 tons is higher. A very large increase in the weight of the column up to 100 tons of the structure will change the behavior and the maximum amount of displacement will occur in the period of low rotations and the beginning of the graph.

As the weight of the foundation increases, the spectral acceleration of the foundation also increases first and then decreases to about 2 with the unusual increase in weight, which over time shows a nearly constant number of graphs. Also, with increasing weight, the spectral acceleration of the column increases. The two structures with a weight of 8 tons and 80 tons have almost the same behavior, with the difference that at any moment the acceleration of 80 tons is slightly higher. The structure with a weight of 800 tons has almost Experiences constant acceleration.

Changes in the displacement of the foundation As the weight of the foundation changes by 4 degrees, as the weight of the foundation increases, the amount of displacement will increase, but over time it will show an almost constant value.

**5.4.Investigation of changes in the acceleration ratio of a structure of one degree to two degrees by changing the weight of the foundation of a structure of two degrees**

By examining the changes in the acceleration ratio of the structure one degree to two degrees, by changing the weight of the foundation of the structure, two degrees are observed. 50 ton and 500 ton structures are about half. Over time, due to the predominance of the ratio of structure stiffness to the weight of the structural column, the ratio of all models is the same, decreases and is fixed at about 0.15.

**5.5. Investigation of changes in the acceleration ratio of two degrees to three degrees by changing the weight of one of the columns of a three degree structure**

By examining the changes in the acceleration ratio of the structure of two degrees to three degrees and considering that in matrix A of the Kanga equation, the ratio of column weight to damping has a greater effect in less periods by changing the weight of one of the columns of the three degree structure at the beginning of the diagram and in Periods less than about 0.7 structures with a column weight of 5 tons, the ratio of the acceleration of the structure two degrees to three degrees shows this ratio more, but from 0.5 onwards, all 4 structures fluctuate between 0.3 and one.

**5.6.Investigation of changes in the acceleration ratio of a three-degree to four-degree structure by changing the weight of one of the foundations of a four-degree structure**

By examining the changes in the acceleration ratio of the structure three degrees to four degrees, by changing the weight of one of the foundations of the four degrees structure, the ratio of changes in the structure of 8 and 5 tons is almost the same and increases with increasing periodicity, but in the eighty ton structure Shows less. The structure with a weight of 800 tons shows approximately the same behavior as the two structures of 5 and 8 tons with a lower ratio.

**5.7. the final conclusion**

In a general conclusion, the following can be mentioned:

●The effect of shear wave velocity on the foundation is greater in all structures than the column.

●With increasing degree of freedom, maximum acceleration will occur in the period of higher rotations.

●By observing the change of the parameters of the structures, it is observed that the major changes in the behavior of the structures occur in the period of low periodicities.

●In a 4-degree structure, unlike other structures, increasing the shear wave velocity increases the acceleration and displacement of the column and decreases the acceleration and displacement of the foundation.

 **5.8. Suggestions for further research**

●Investigate and add the effect of height on equilibrium equations

●Check the frame in 3D

●Impact of vertical earthquake component on equilibrium equations

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