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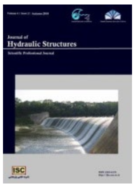

Dynamic response of offshore platforms installed on sloping seabed under actual seismic loading

Abbas Rezaeian[1]
Farhad Hosseinlou[2]
Abbas Ali Shnewer[1]

Abstract

This research numerically investigates the structure behavior of steel jacket platform stand on 20 degrees inclined seabed and exposed to the earthquake. Considering the inclined seabed, the effect of the main variables on the structural behavior of the steel jacket platform subjected to the four famous earthquakes are discussed. The most effective variables of the structural response contain stresses and displacement. The stresses and displacement of the main four legs and as well as at the top of jacket structure will be as indicator for the structural response. ABAQUS 6.14 is used to model and analyze. The research finds that the change in the mass location will generate torsion effects which vary according to the leg's location and its length. In the sloping seabed it is necessary to use a stiffer tubular section to resist the torsional effect.

Keywords: Offshore structures, steel jackets, inclined seabed, tubular section, seismic behavior

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1. Introduction

Jacket structures are among the simplest and most practical fixed offshore platforms. These structures are considered to accommodate the facilities and equipment needed for temporary or permanent operations in marine environments. Jacket structures have to be carefully designed and organized according to the operating environments. Extreme environmental force may cause seabed instability, especially if the seabed is weak.The seabed instability, manifested in movement of soil layers, exerts lateral forces that may cause damage in offshore structure. The induced damage may compromise the stability of the structure [1-3]. In offshore industries, jackets have been one of the first systems to be used as secure platforms for the extraction of oil and gas. Frame is a key feature of this structural system [4]. Unfit or unsuitable construction will lead to structural failure. Several analyzing techniques can be utilized for the jacket structures resting on severe

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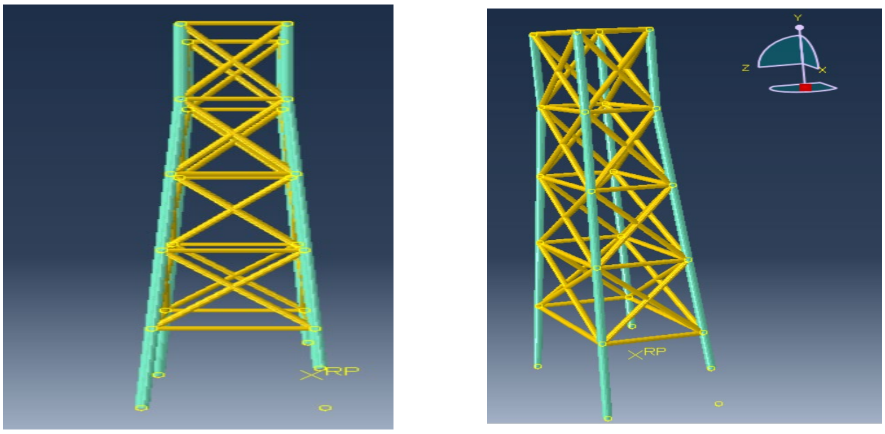
[1] Department of Civil Engineering, Faculty of civil Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran
[2] Department of Civil Engineering, Faculty of civil Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran. E-mail: F.hosseinlou@scu.ac.ir **(Corresponding author)**

sloping ground seismically effected [5]. But finite element approach is a very successful way of achieving the strength and response evaluation of the steel jacket structure. Therefore, the general purpose of this paper is to investigate the seismic performance of the platform structure built on a 20 degree slope.

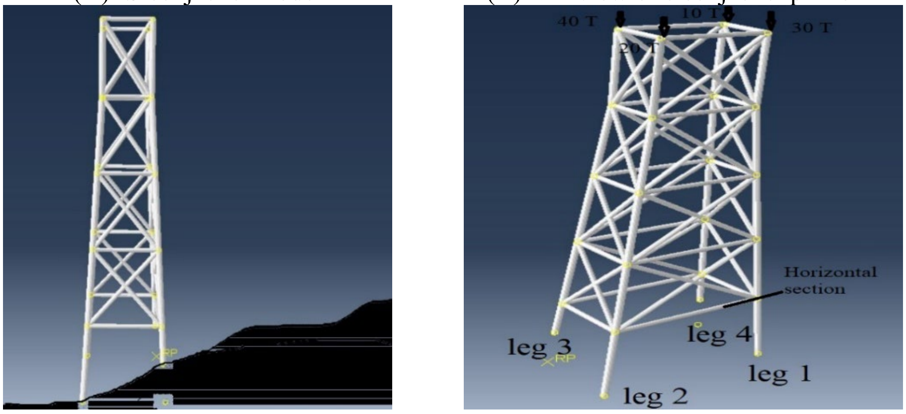
Ahemer and Mohamad Ali (2019) [6] discussed the behavior of offshore structure under seismic load (AL-Basra oil port (ABOP). The study has done by ABAQUS finite element program, and the Cam-clay model, a three-dimensional element used to depict the interaction between pile and soil, was utilized to simulate soil in two cases: elastic state model and elastoplastic state model. The results were shown that the natural frequency for fixed support is more than for structure with piling support and the responses are more influenced by the near in frequency between structure and seismic action. Mohamad Ali et al. (2016) [4] calculated the stability time of the steel frame during the consecutive loading. 7-story steel frame is thermally modeled and is subjected to the sudden removal of columns in different positions. The results show that the sudden removal of the column will have a great effect on the failure time of the structure and will increase the failure probability of the structure and reduce the failure and collapse time of the structure. The robustness index is also presented based on the probability of collapse time. Hasan et al. (2010) [7] provided an approach based on finite element and plastic node techniques for earthquake reaction analysis using three-dimensional frames of geometric and material nonlinearities. The suggested approach is used to investigate the seismic response of a jacket platform. This technique can also be used to analyze offshore structures under collision load, since they are not linear. Lotfollahi-Yaghin and Rezaei (2012) [8] developed the reliability evaluation tool for safety tests on the jacket platforms. Corrosion, fatigue and cracks are the causes that contribute to a resistance deterioration of the jacket platforms. A reliability evaluation approach would then be best suited to consider various resistances. In the work of Behnam (2019) [13], an appropriate time-dependent reliability model was proposed for the platform. In the work of Bai et al. (2016)[9], the object is reassessment of Jacket Structure have been built to outmoded standards. The analysis showed that, while the jacket structure is more influenced by the area of splash than the whole immersion zone, the whole immersion zone has 3.5 times the corrosion rate. This is because the complete immersion area comprises more structural components than the sprinkling area. Bai and Jin (2016) [10] studied the behavior of offshore structures under impact loads. Large plastic deformations may develop in offshore structures due to severe ship–platform collisions. The dynamic collision response of platforms should be analyzed at the design stage. In order to explain the consequences of high deformation, the plasticity or stress-stricken beam-column members and the principle of massive displacement analyzes and the plastic node system were merged. In the work of Hartnett and Mitchell (2000) [11], the FE scheme is considered to analyze the effects of leg-spacing on the response of jacket platforms. They found that the analysis of the response of the real platform to wave loads gives much more accurate estimates than the spectral response of an equivalent truss system. Ersdal (2005) [12] investigated the performance of four marine structures through probabilistic failure approaches. He also evaluated the impact of inspections and maintenance done at different time intervals in four inspection scenarios defined for this purpose. This research reported that with proper structural configuration and periodic inspections and maintenance, it would be possible to use the platforms beyond their initial design life. According to the previous studies, it can be stated that no study has been done on the seismic behavior of the platform legs located on the inclined seabed. Based on this, in the present study, the effects of bed slope on the seismic response of jacketed platforms are evaluated.

2. Studied jacket platform

In this work, a model is proposed for a platform with a four-legged tubular installation with a diameter of 80 cm and the other parts of a pipe section with a diameter of 40 cm. The platform has a variation in the height of the legs as it is supported on a sloping ground and has a total height of 100 meters. The front legs of the oil platform have an estimated height of 100 meters, while the rear legs have a height equivalent to 90 meters. Suppose the platform is submerged in water to a height equivalent to 90 meters and 10 meters is a free non-submersible field. The first model was represented using the AutoCAD program, and then it was linked to the well-known program ABAQUS for simulation and analysis purposes. Figure (1) and Figure (2) show proposed steel jacket oil platform model.



(A)- Steel jacket model (B)- 3D view of steel jacket platform



(C)- platform rest on slope ground (D)- Loads pattern on steel jacket

Figure 1. 3D view of steel jacket platform

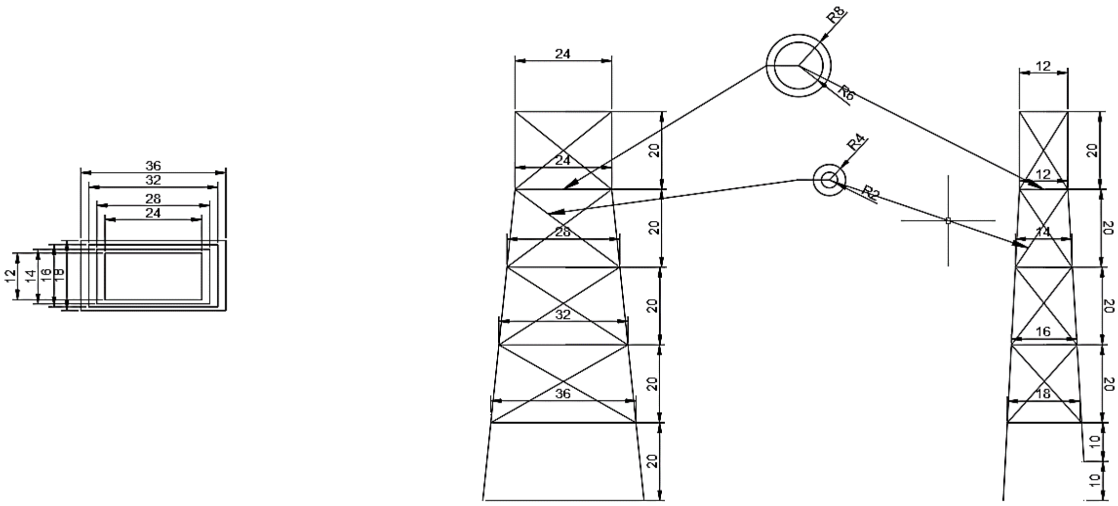


Figure 2. Steel platform geometry

Material and characteristic of steel Jacket listed in Table 1. Table 1 shows all the specifications and details of structural members. The joint and connection models to represent as ideal joint without any gap between the vertical and horizontal section.

Table 1. Material and characteristic of steel jacket

Item	Section	Detail	Properties
1	Main leg	(100 – 90) m Height, 80 cm diameter, 8 mm wall thickness, tubular section.	Density 7282 kg/m3 Modulus of elasticity = 200 GPA Poisson Ratio = 0.33
2	Horizontal section	40 cm diameter, 8 mm wall thickness, tubular section.	Density 7282 kg/m3 Modulus of elasticity = 200 GPA Poisson Ratio = 0.33
3	Bracing section	40 cm diameter, 8 mm wall thickness, tubular section.	Density 7282 kg/m3 Modulus of elasticity = 200 GPA Poisson Ratio = 0.33
4	type of foundation	massless, fixed	Rested on sloping ground

3. FE model

Generally, finite element method is very wide used to solve the structural problem. In this regard, features such as stresses, strain and displacement are very important in the modeling of structural components [10]. Steel jacket platform is conceptualized as a collection of subdivisions (components) interconnected by a finite number of nodal points. Steel jackets are made using a monolithic tie technique. The joints are hinged to produce a full monolithic structure. In reality, the kinds of isoperimetric solid and shell elements are well suited for arch steel jacket platform analysis. The linear eight nodes solid element needs very finer meshing to accommodate the same displacement of the shell element [13-14].

The isoperimetric family of finite elements is used to analyze steel jacket platforms because both element coordinates and element displacements are defined using the same (ISO) parameters or interpolation functions. Interpolation functions that are easily specified in the natural coordinate system are used to transform the elements [15]. A linear-displacement isoperimetric element, the typical eight-node solid element was designed by [14]. For superior bending behavior, this element employs opposite deformation modes. Material properties can be stated in both isotropic and orthotropic forms. This component is used to represent the foundation rock or a thick portion of steel jacket platform. By assuming higher order interpolation functions and describing them in terms of an adequately increased number of nodal points, it may be extended to more refined elements (A 3-D shell element is an example of this). It's a 16-node curved solid element with quadratic displacement and geometry interpolation on two faces and linear interpolation through the thickness. Inappropriate deformation modes are also included in the element to improve bending behavior and therefore accuracy. This element has proven to be highly useful in the research of steel jacket platforms, but it necessitates the use of a high-quality and unique computer device. The most important step in simulation is the meshing process. This option providing wide facilities to make unique meshing for complex body as shown in Figure 3. The S4R element was employed for steel parts and plates. After modeling the jacket with mesh dimensions of 55, 45, 35, and 25 (mm), sensitivity analysis was performed. The results showed that the best convergence and analysis time is obtained with 35 mesh. The model was manufactured of stainless steel (ST304) pipes welded together to ensure proper load transfer. The time step is 0.1 s in the dynamic solution.

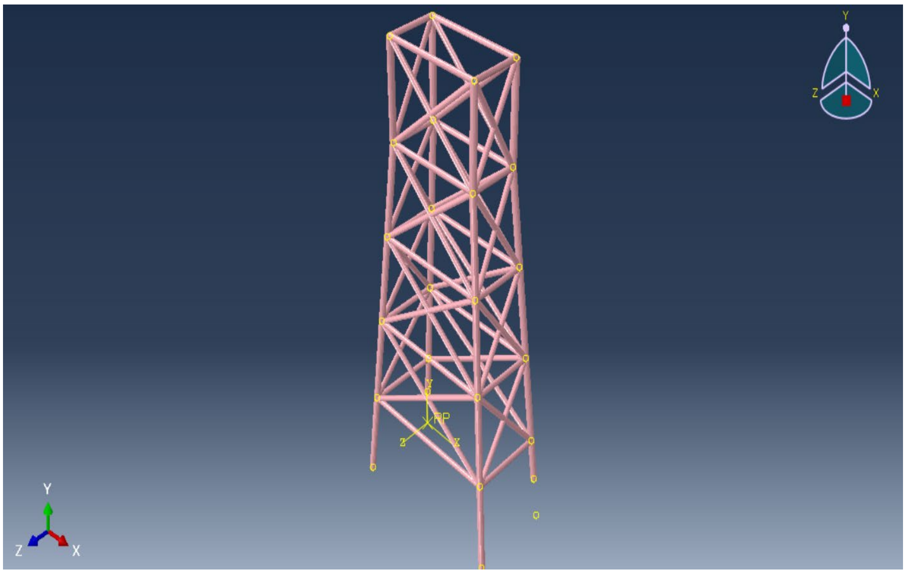


Figure 3. Meshed finite element model of jacket structure

3.1. Earthquake Loads

Four earthquake records are considered for nonlinear analysis. The specifications of the earthquake records applied to the platform legs are shown in Figures 4 to 7.The Maximum value of acceleration amplitudes listed in Table 2.

Table 2. Phase Three, Maximum Amplitude of Earthquake Data (PEER)

Earthquake	Acceleration CAP 090	Acceleration CAP 000	Acceleration CAP -UP
Imperial valley	0.313g	0.215g	0.205g
Northridge	0.344g	0.308g	0.552g
Loma Prieta	0.443g	0.529g	0.541g
Kobe	0.694g	0.693g	0.433g

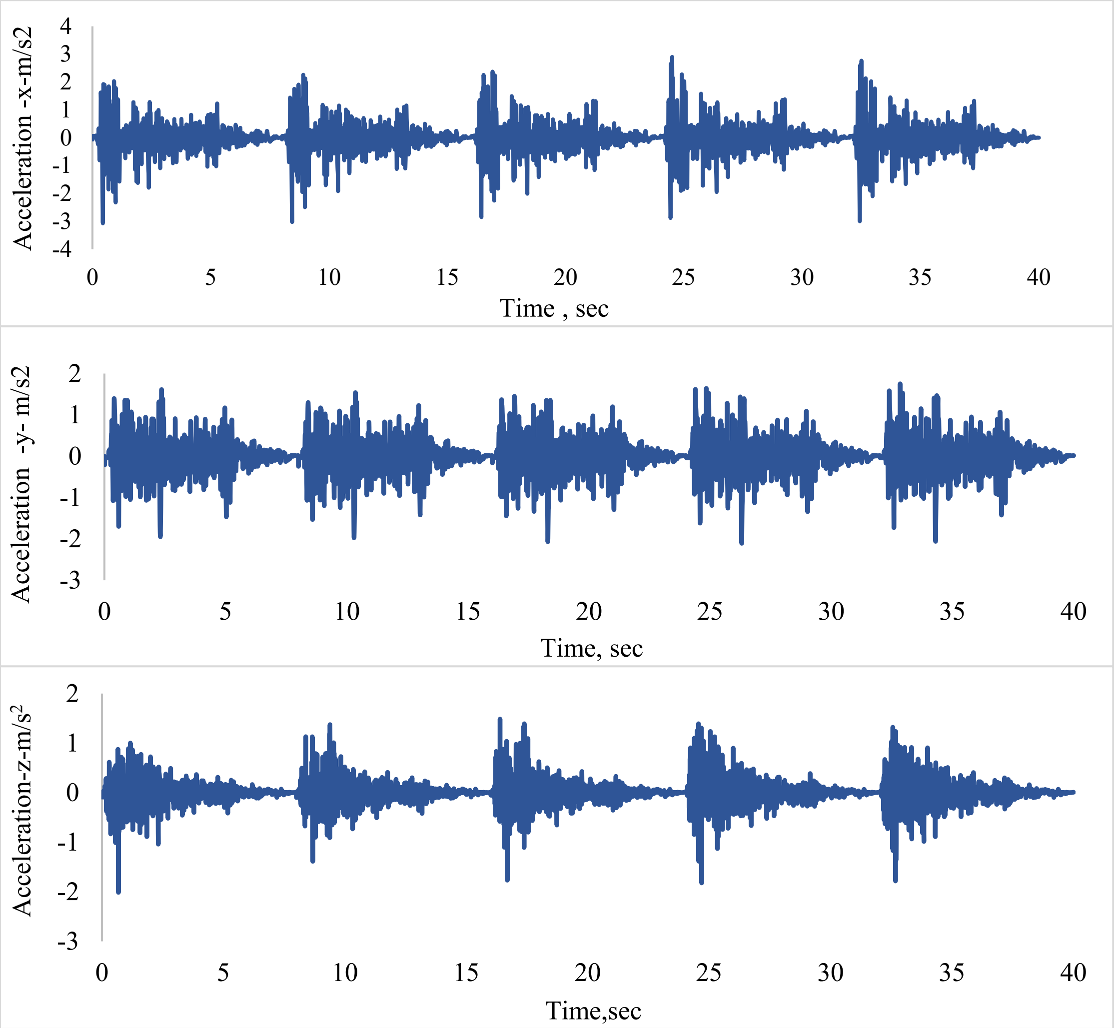


Figure 4. Earthquake Data: Imperial valley

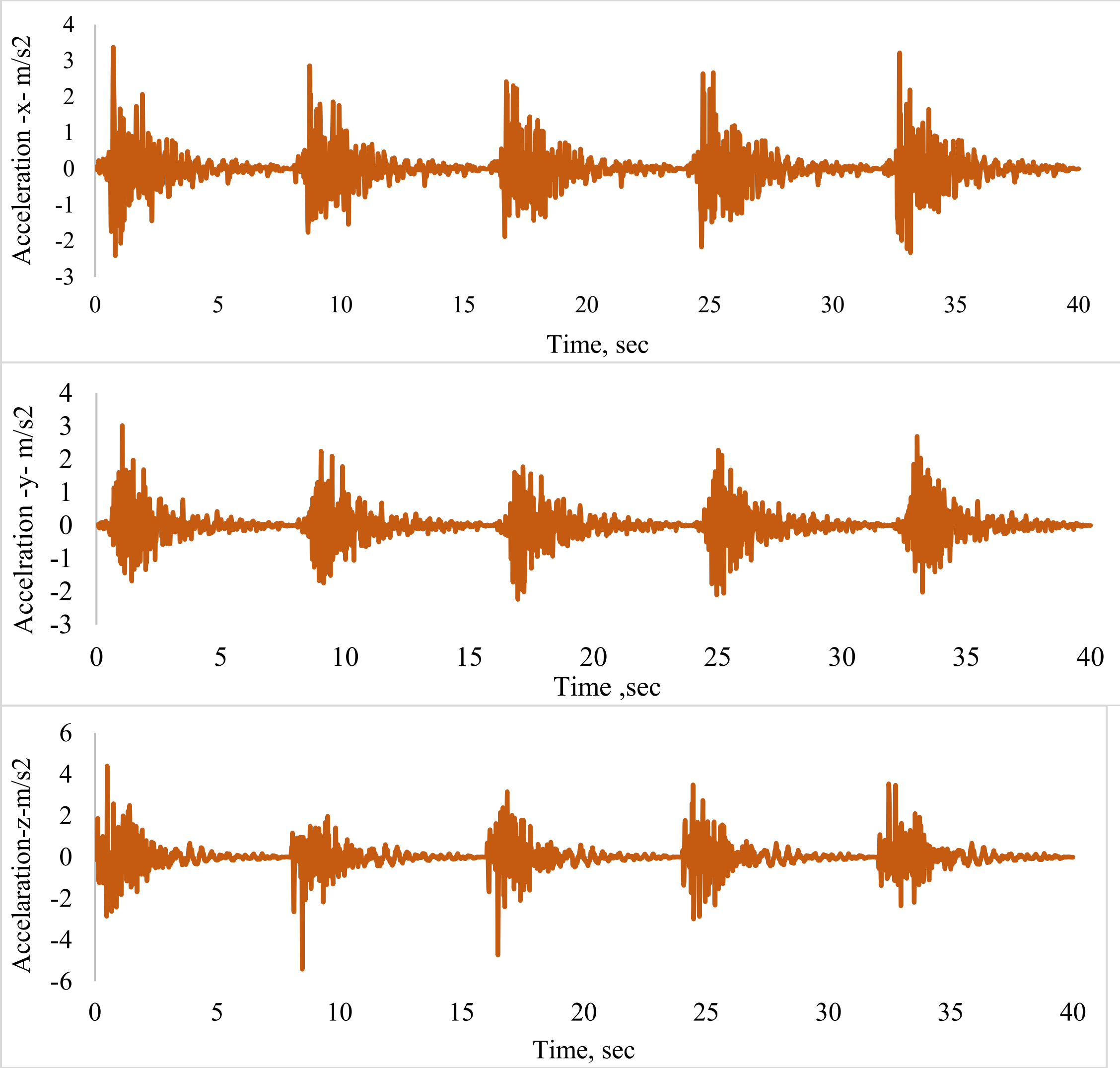
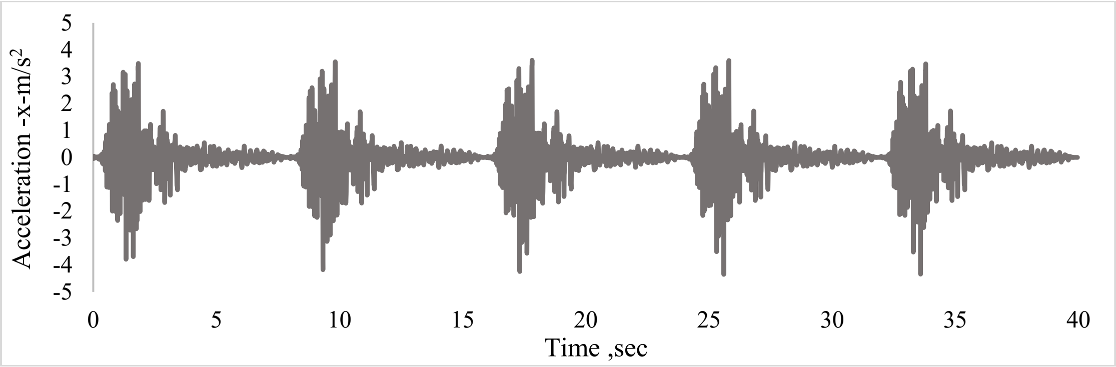


Figure 5. Earthquake Data: Northridge



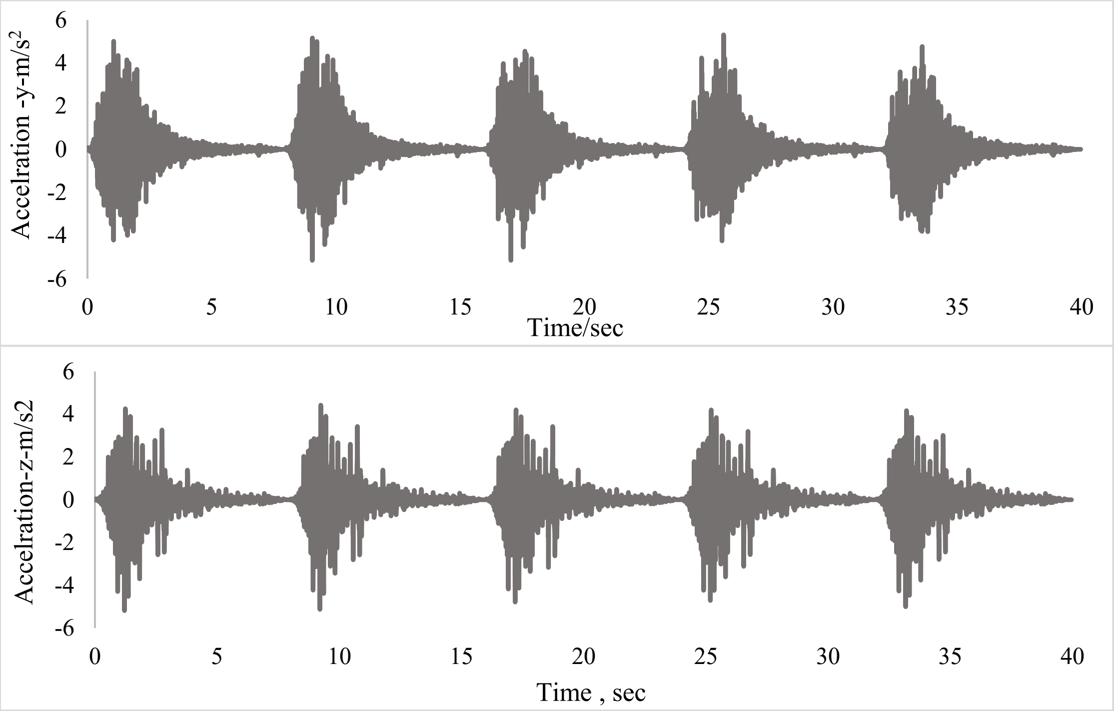
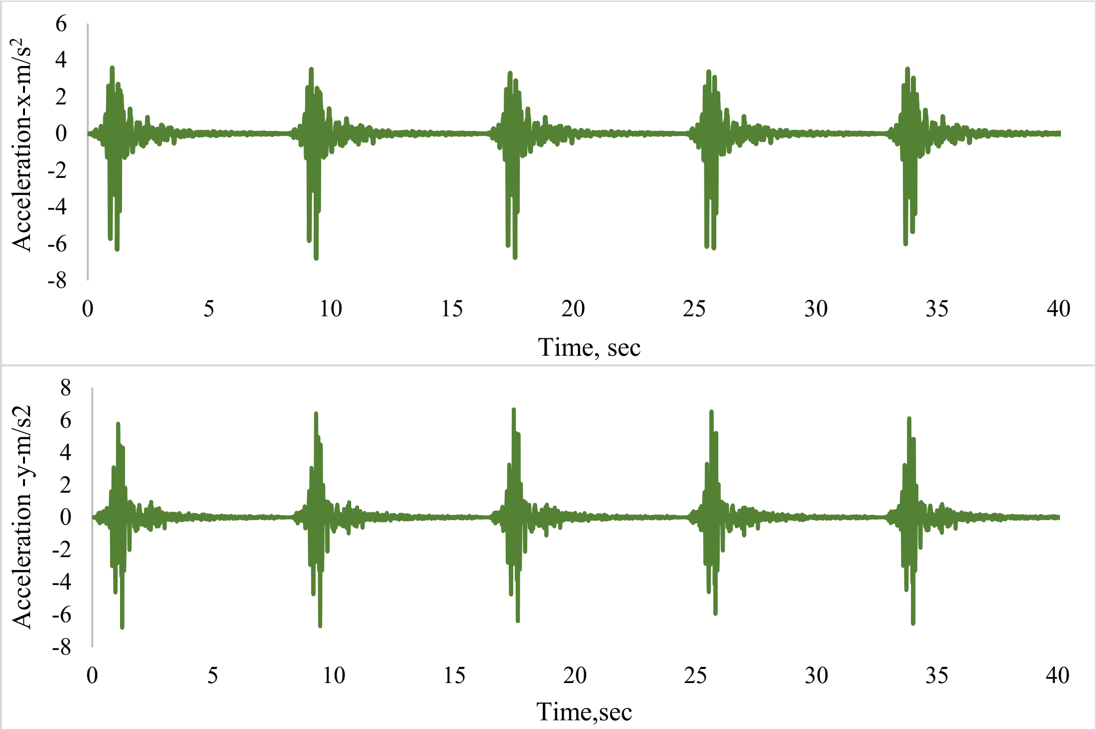


Figure 6. Earthquake Data: Loma Priet



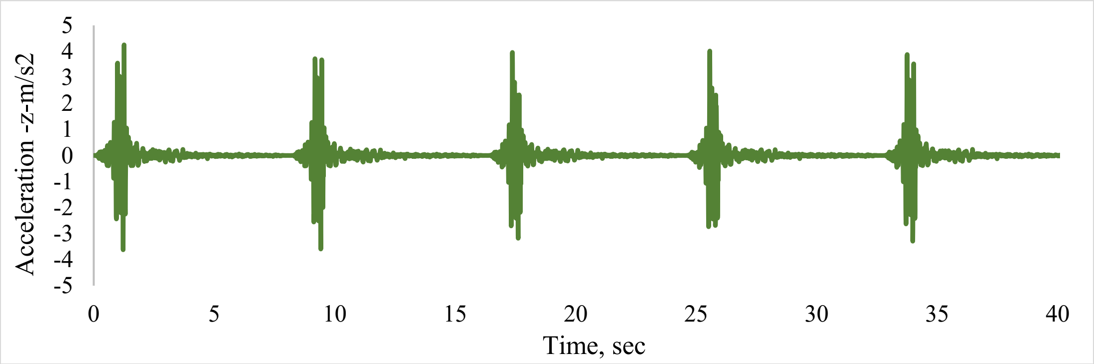


Figure 7. Earthquake Data: Kobe

4. Results and Discussion

Considering the inclined seabed effect, the results section discuss the effect of the main variables on the structural behavior of the steel jacket platform subjected to the four famous earthquakes.

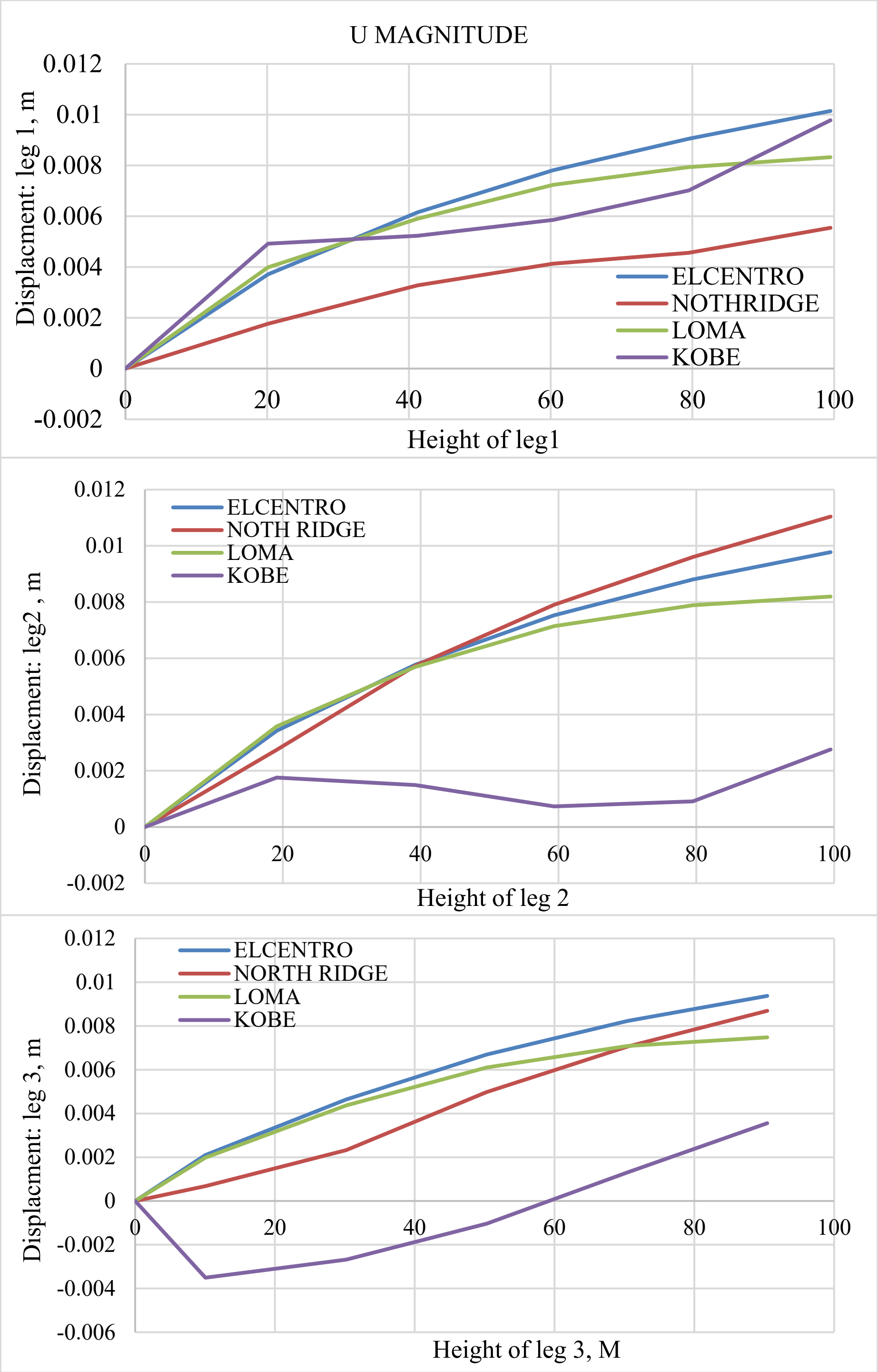
The most effective variables of the steel jacket platform structural response contain stresses and displacement for the four phases of nonlinear analysis under the effect of loads combination. The stresses and displacement of the main four legs and as well as at the top of jacket structure will be as indicator for the structural response. The structural response will be evaluated based on the following: a) Irregularity of the configuration, b) Irregularity of the loading, c) bed slope, d) Seismic loading under different earthquake records. In addition, the mass change in the platform deck has been investigated as a variable.

4.1. Seismic response

In this work, results are extracted for four stress paths along four legs of the platform under the influence of static and dynamic loads, where the results of the response of the platform under each loading condition presented as follows.

4.1.1. Displacement of the legs

A series of node was taken in the form of a longitudinal path from the foundations to the highest point in the structure to express the response of the legs under the effects of applied loads. Figure 8 shows the displacement response of legs under the effect of seismic load.


U MAGNITUDE
Displacment: leg 1, m
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
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20
40
60
80
100
Height of leg1
ELCENTRO
NOTHRIDGE
LOMA
KOBE
Displacment: leg2 , m
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
0
20
40
60
80
100
Height of leg 2
ELCENTRO
NOTH RIDGE
LOMA
KOBE
Displacment: leg 3, m
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
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Height of leg 3, M
ELCENTRO
NORTH RIDGE
LOMA
KOBE

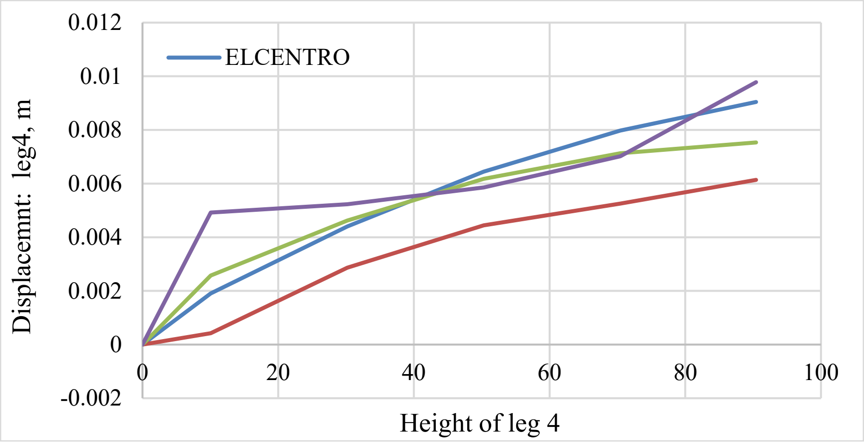
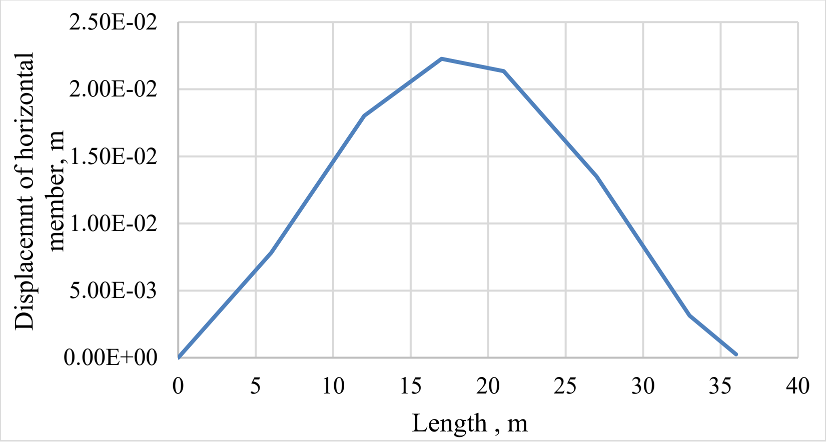


Figure 8. Displacement of the legs under seismic load

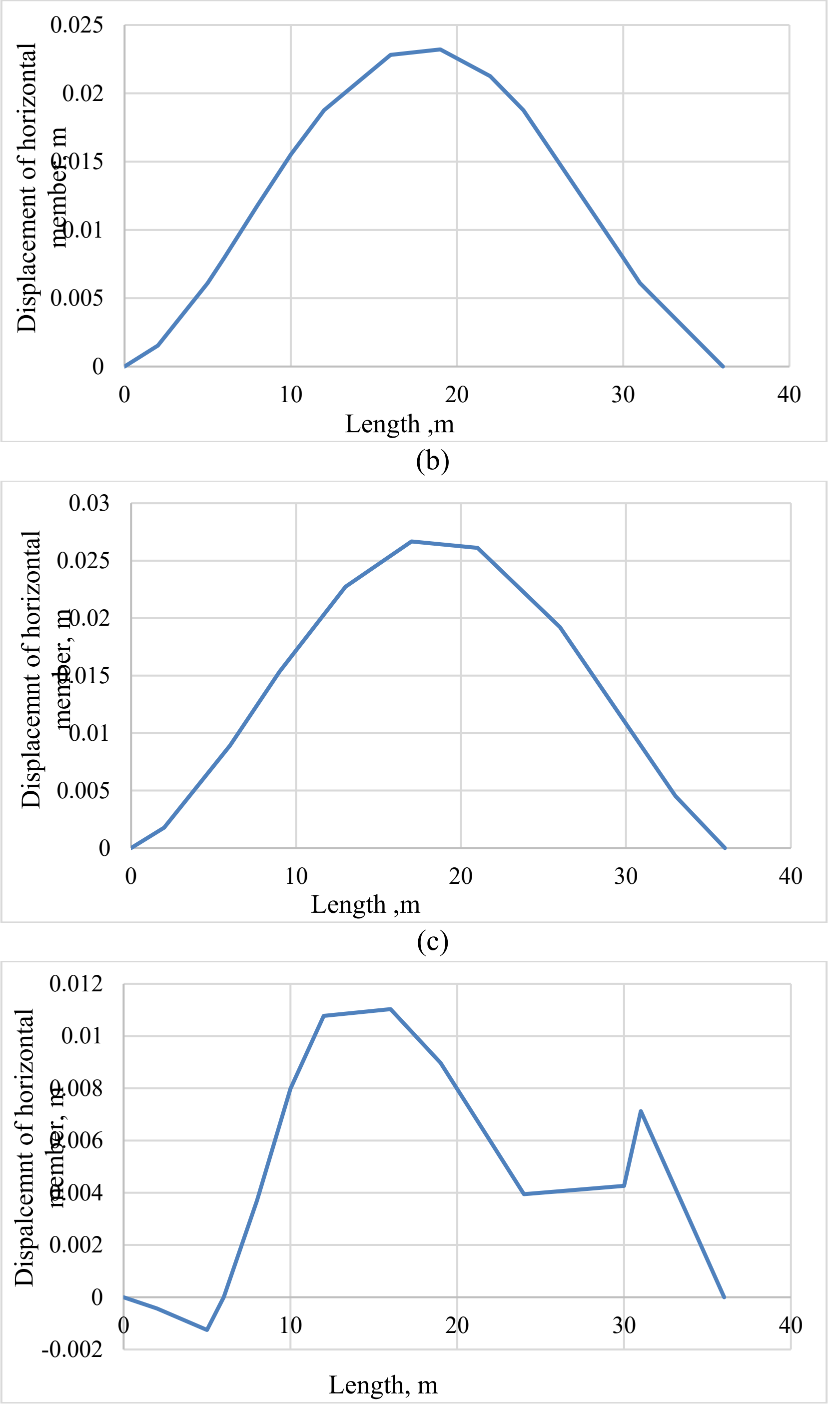
The results showed that the lowest displacement value occurred under the Northridge earthquake (for legs 1, 2 and 4). The displacement of leg 1 under the Elcentro, Loma, Kobe earthquakes is greater than the displacement of leg 1 under the Northridge earthquake (about 45.3%, 33% and 43.3 %, respectively), as shown in figure 8. While the displacement of leg 2 under Kobe earthquake is less than the displacement of leg 2 under another earthquakes (about 71.6%, 75.2% and 66%), as shown in figure 8. Also, the displacement of leg 3 under Kobe earthquake is less than the displacement of leg 2 under another earthquakes (about 62 %, 59 %, and 52%). The displacement of leg 4 under the Kobe earthquakes is greater than the displacement of leg 4 under the Elcentro, Loma and Northridge earthquakes (about 7.55%, 29.9%, and 37.7%, respectively).

4.1.2. Displacement of the horizontal member

To evaluate the seismic behavior of the structure, the horizontal member is one of the most important elements for this purpose. The displacement of the horizontal elements under the four earthquake are presented in figure 9. The results show that the maximum displacement for the horizontal member occur under the Loma earthquakes (about 16.5%, 12.9%, 58% more than other earthquakes).



(a)



(b)

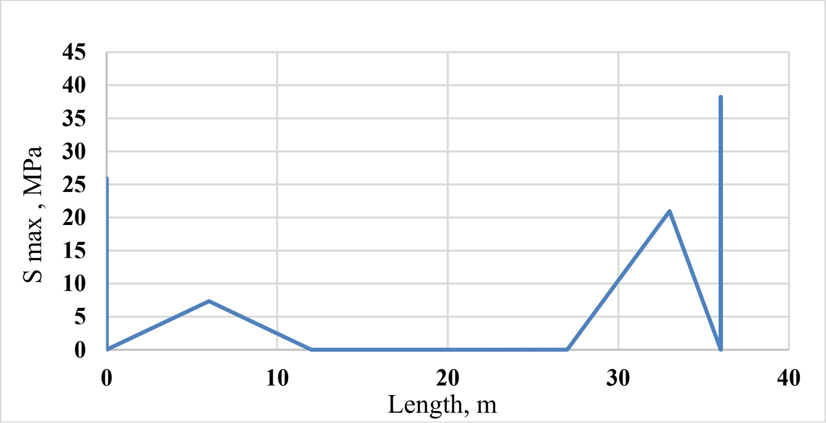
(c)

(d)

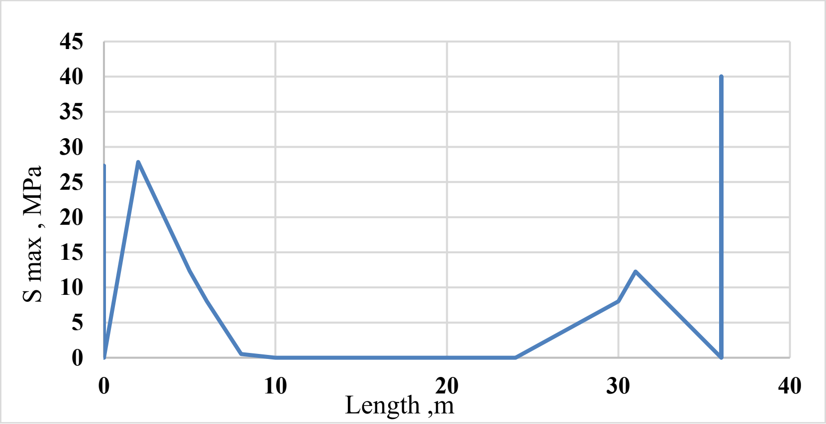
Figure 9. Displacement of the horizontal member under seismic load: (a) under effect of Elcentro, (b) Northridge, (c) Loma and (d) Kobe.

4.1.3. Maximum and Minimum Principal Stresses

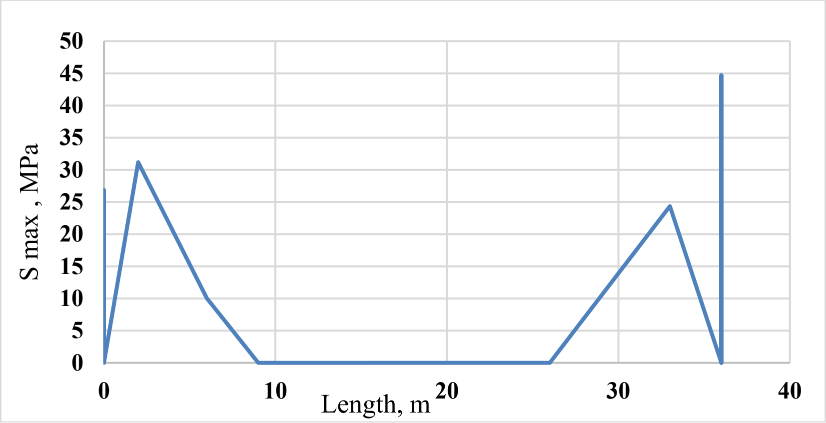
The other indication of structural response is the maximum and minimum principal stress of the horizontal element. Figure 5.3 (a, b, c, d) for maximum principal stress and (e, f, g, h) for minimum principal stress response under the (Elcentro, Northridge, Loma, Kobe) earthquake.



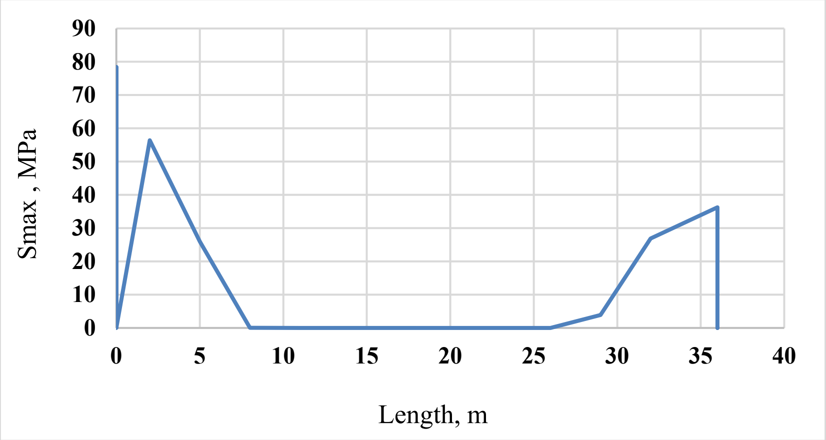
(a)



(b)

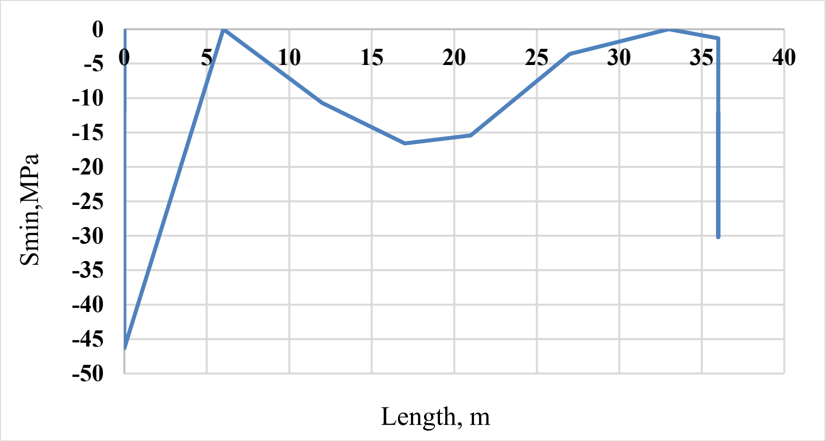


(c)

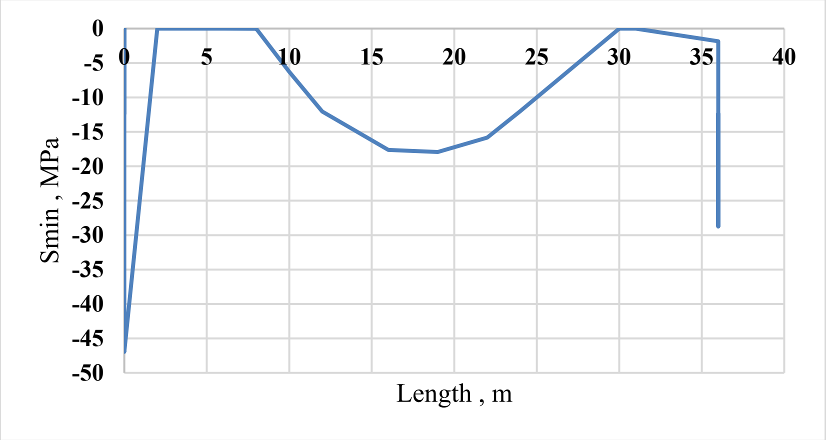


(d)

Figure 10. Maximum principal stress of the horizontal member under seismic load: (a) under effect of Elcentro, (b) Northridge, (c) Loma and (d) Kobe.



(a)



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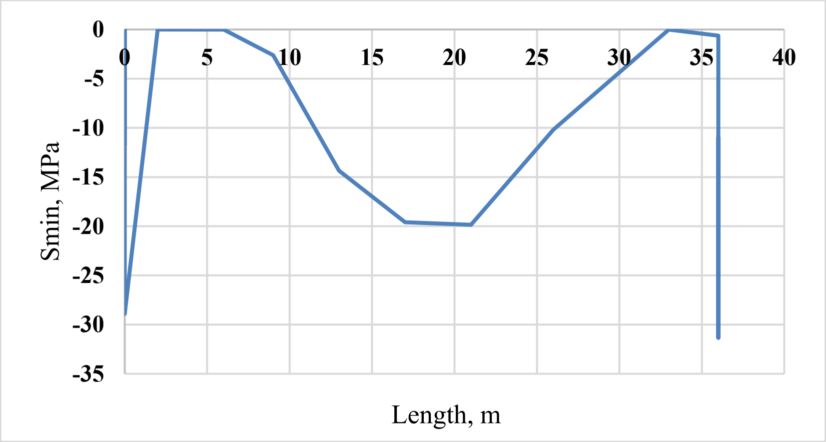

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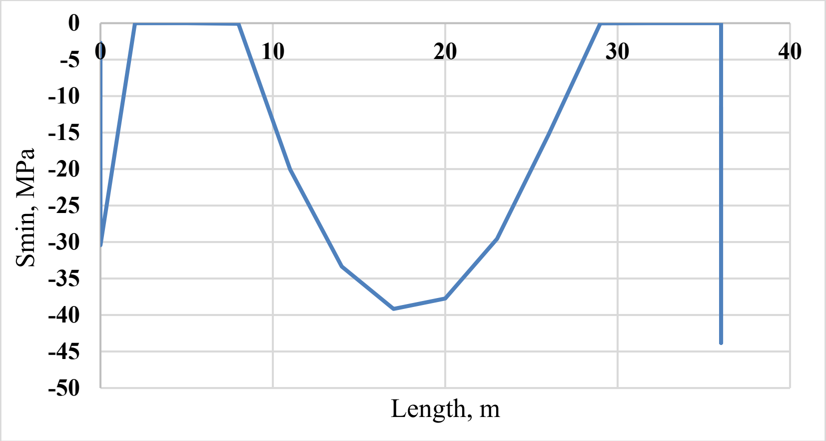


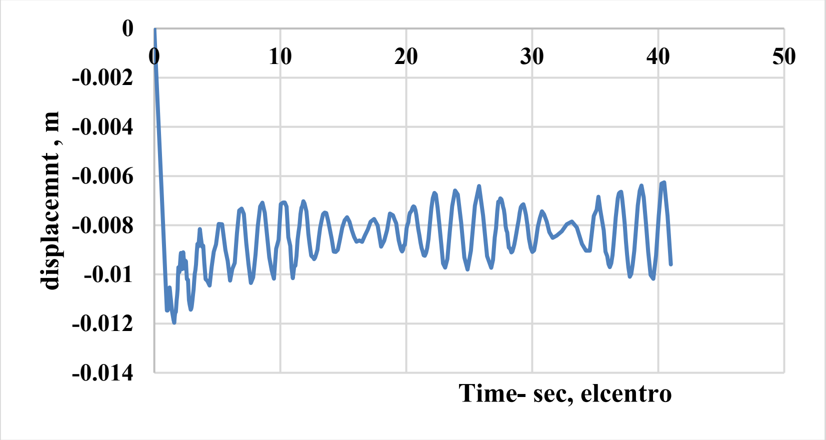
(d)

Figure 11. Minimum principal stress of the horizontal member under seismic load: (a) under effect of Elcentro, (b) Northridge, (c) Loma and (d) Kobe.

The results show that the maximum principal stress occur in horizontal member when the steel jacket platform under the effect of Loma earthquake while the minimum principal stresses under effect of Northridge earthquake.

4.1.4. Nodal Displacement at top of steel jacket platform

Nodal displacement at top of steel jacket platform is another structural indicator to assess the seismic behavior of the structure. The finding shows that the maximum value of nodal displacement at top of steel jacket platform occur when the structure is under the effect of Northridge as shown in figure 12.


0
-0.002
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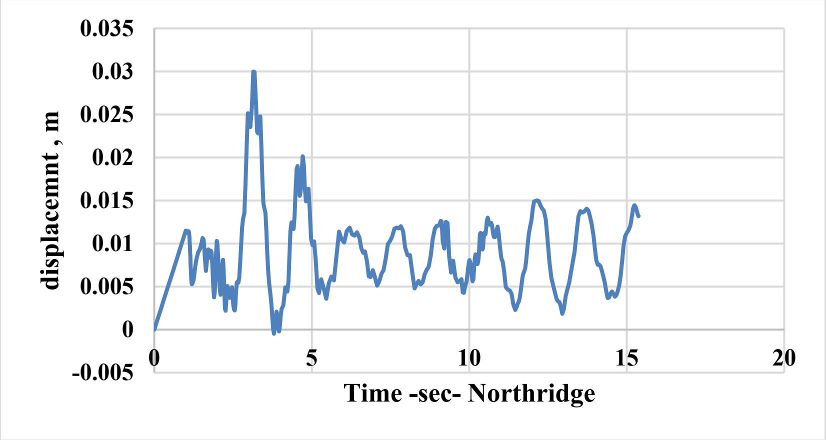
30
40
50
displacemnt , m
Time- sec, elcentro

(a)


0.035
0.03
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0.02
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0.005
0
-0.005
0
5
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15
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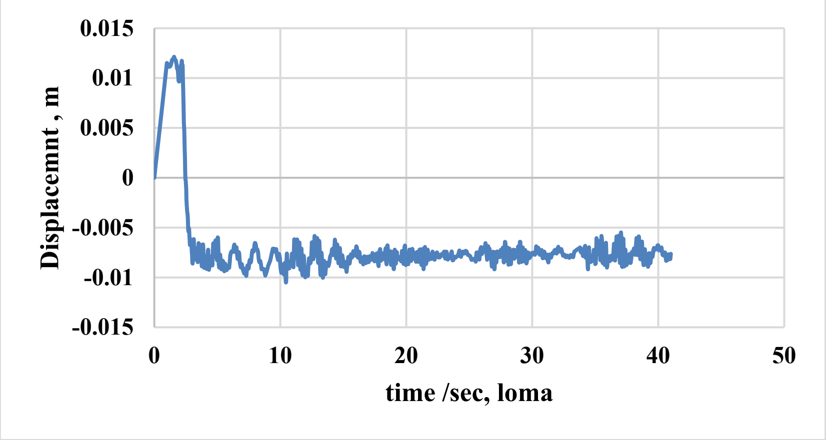
displacemnt , m
Time -sec- Northridge

(b)


0.015
0.01
0.005
0
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-0.01
-0.015
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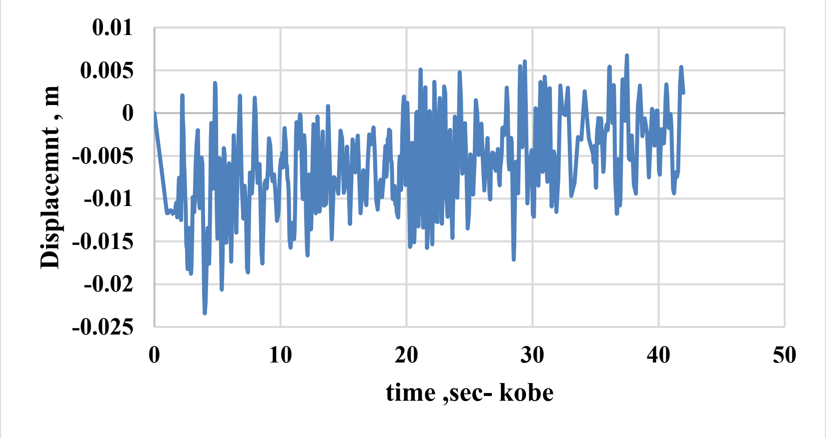
Displacemnt , m
time /sec, loma

(c)



(d)

Figure 12. Nodal displacement history of the deck

5. Conclusion

In the current paper, the effects of bed slope on the seismic response of platforms legs are estimated. The most effective variables of the structural response contain stresses and displacement. The stresses and displacement of the main four legs and as well as at the top of jacket structure will be as indicator for the structural response. In the investigation of the seismic response of the platform logs, it was found that the largest displacement is related to the short logs. Also, the horizontal element that connects two legs (short and long) is a critical element. In addition, it was found that the stress in the areas near the connection of the horizontal member to the logs is higher than the other areas of the member. As a result, these areas of the member must be strengthened. The research finds that the change in the mass location will generate torsion affects which vary according to the legs location and its length. In the sloping seabed it is necessary to use a stiffer tubular section to resist the torsional effect.

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