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Evaluation of Seismic Behavior of Damaged Offshore Jacket Platform under the Environmental Conditions

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ABSTRACT

Most of the fixed offshore platforms in the Persian Gulf have survived more than 25-year design life and have suffered from significant damages in this period. Seismic acceleration modifications and changes in seismic criteria of API-2EQ-2014 increase the importance of seismic assessment of the offshore platforms in the Persian Gulf. This paper presents a case study for modeling and evaluating the seismic behavior of an existing damaged fixed offshore platform in the Persian Gulf with consideration of actual structural damages as per provided subsea inspection reports and comparing with the intact condition of the platform to obtain the effect of assessment initiators like; actual damages and increased spectral acceleration as per API2EQ 2014 in the structural integrity of the fixed offshore platforms under the seismic loads in the Persian gulf. Following the actual jacket inspection reports, Excessive corrosion, flooding of some members, marine growth, and anode wastage are the significant damages on this platform. Spectral nonlinear and static-dynamic analysis with SACS12.00 software considering the pile-soil interaction in the three following scenarios has been performed to verify structural seismic assessment. The first scenario contains a damaged platform with a lighter topside, the second scenario is a damaged platform with a heavier topside, and the third one includes the intact platform with initial design assumptions and criteria. The evaluation of the structure in three parts of the jacket members, joints, and piles has been done under the ALE & ELE earthquake levels. According to the results, jacket legs have a significant effect on the structural seismic strength. In the abnormal level earthquake, the first plasticization occurs in the deck legs which are connected to the topside and the piles below the seabed. The comparison of the RSR values indicates that the initial assumption in platform design criteria has been stringent and uneconomical in the past. Also, the actual presented damages do not have much effect on the seismic strength of the structure. A Comparison of the Joint and member capacity illustrates a more significant impact of uniform corrosion on joint capacity than member strength. Finally; buckling in the deck legs at the splash zone and yielding in the Piles near the sea bed causes the global collapse of the structure.

1. Introduction

Jacket fixed offshore platforms are the most common structures in the Persian Gulf. The offshore platform construction process began in 1960 in Iran. Increasing the service life and occurring the damages such as corrosion, denting, fatigue, and other cases during the operation are the assessment initiators and lead to the reassessment of the structure [1].

The high cost and downtime of the platform during the construction and replacement of the new platform with the damaged platform have made owners and clients more willing to repair and modify the existing platform instead of replacing it [1]. Before the 22nd revision of the API code, the Persian Gulf was located in the seismic zone no.1 and the offshore structures did not need to be evaluated at two levels of SLE and DLE [2]. However, the earthquake spectrum of the API 22nd follows the ISO 19002 regulation. As per the latest API code, the earthquake has been divided into abnormal and extreme levels [3]. Regarding the revised seismic acceleration for the Middle East in ISO19902, the Persian Gulf is categorized in the no.3 seismic zone. Accordingly, the evaluation of the seismic behavior of the offshore structures under the two levels of ALE and ELE is required [4]. In previous revisions, the seismic design was based on the seismicity of zones. Though in the 22nd revision, the seismic design procedure has changed and it depends on the exposure category of the platform. Spectral linear dynamic or time history methods shall be considered to evaluate the seismic behavior of the platforms at ELE events [4]. Also, nonlinear pushover methods or time history analysis shall be utilized at the ALE level. Limitations like utilizing at least four earthquake records in the time history method. Also, acceptable accuracy and spending less time and cost on the pushover analysis make it more prevalent [4]. The static push-over analysis provides insight into the loadbearing performance of the platform. The ultimate lateral loadbearing capacity of the structure is expressed in terms of the “Reserve Strength Ratio” (RSR). RSR is a measure to ensure the immediate and future structural integrity of the structures to check their fit for purpose during the intended design life or beyond [1].

In 1974, the pushover method was conducted to evaluate the reliability of offshore platforms, including identification of applied loads, modeling of the superstructure, soil modeling, investigation of soil-structure dynamics, and model analysis [5]. In 1984, it was determined that in the evaluation of offshore structures, the entire platform system should be converted into different parts of the deck, jacket, and foundation. Also, the minimum strength of each part is considered as a measure of platform strength [6]. Comparison of different loading scenarios and different dimensions of members in pushover analysis showed a significant effect of wave height and member dimensions on the platform strength resulting from 100 years of wave nonlinear static analysis [7]. Comparing the intact and damaged platform, illustrated that removing several diagonal and longitudinal members does not significantly affect the integrity of the structure. Also, strengthening the damaged platform is much more cost-effective than constructing a new platform. [8]. Member removal under the 100-year wave load indicates that increasing the gravity load on each element increases the impact of damages on them. Moreover, damages in the lower part of the platform will have a more negligible effect on the reliability of the structure [9]. To achieve the coefficient of seismic strength of offshore structures with the purpose of seismic assessment, modal, seismic, and nonlinear static analyzes are necessary [10]. Modifications in pile yield stress, member thickness and member properties indicate that the failure mode of the structure strongly influences the RSR value in the reliability analysis. Also, it was observed that the type of bracing does not have a significant effect on the jacket seismic design considering the soil-structure interaction [11]. CMR, RSR, and ductility coefficients are decisive in the seismic evaluation of the structure. The CMR coefficient of the structure is strongly influenced by RSR resulting from pushover analysis and ductility coefficient. Also, increasing the strength and ductility coefficient leads to an increase in CMR. However, increasing the ductility coefficient to increase CMR is not economical [12]. In 2017, a tornado approach was conducted to identify variables that affect on RSR value. Regarding results, the drag coefficient C_d has the most significant variable which affects RSR. Also, the effect of the Modulus of Elasticity (E) and Inertia Coefficient (C_m) can be ignored in investigating the ultimate behavior of structures [13]. Platform behavior was evaluated using the finite element method with pushover analysis in 2019. Regarding the results, the mentioned method is more accurate than other conventional methods. Also, utilizing the frame elements instead of shell elements greatly reduces the analysis costs [14]. The integrity of the structures in the Gulf of Mexico has been carried out by inplace, Seismic, Fatigue and Pushover analysis [15, 16].

2. Platform Descriptions

The presented structure is an 8-leg drilling platform with four skirt piles with L_1 exposure categories in the Persian Gulf. The mentioned platform was built in 1960 and has suffered from several damages during Iran/Iraq war. Subsea Jacket structural inspection was carried out in 2001 and 2013. Also, the topside weight was reduced to 2000 tons by removing the drilling rig in 2013 as an SMR operation method. Figure 1 illustrates a general view of the drilling platform.

Figure 1. General View of the Drilling Platform

Regarding actual subsea inspection reports, several structural members are suffering from excessive corrosion, flooding, marine growth effects, and anode wastage. No fractures or dents were observed in the members and welds [17]. Figure 2 shows the general condition of the jacket members in the splash zone.

Table 1, Table 2, and Table 3 illustrate structure design specifications, marine growth inspection reports and member corrosion rates based on subsea inspection, respectively. To easier reporting, each elevation of the jacket has been named separately, as shown in Figure 3.

Figure 2. General Condition of Members in Splash zone

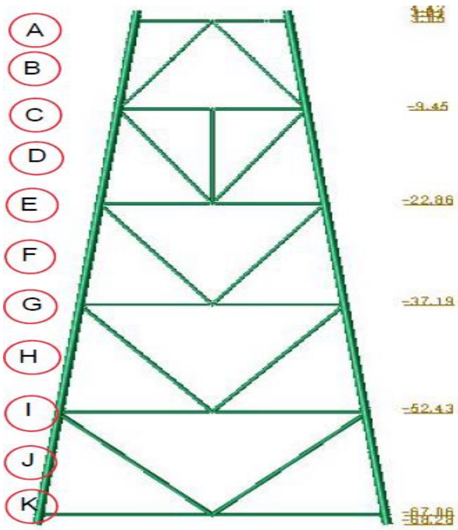


Figure 3. Tag Name of the Each Elevation on DP [17]

Table 1 Structure Design Specifications [18]

height (m)	Description
4.4	**W.P. level**
67.05	**MUDMAT level**
67.75	**Water depth at MSL level**

Table 2 . Marine Growth Inspection Report [17]

Effective thickness (mm)	Diameter (mm)	Level	High level (m)	Low level (m)
45.9	863.6	B	70.07	57.94
44.9	914.4	C	57.94	57.57
40.1	863.6	D	57.57	44.22
36.4	914.4	E	44.22	44.16
31.8	863.6	F	44.16	29.90
24.2	914.4	G	29.90	29.84
17.8	863.6	H	29.84	14.66
13.6	914.4	J	14.66	14.60
5	863.6	K	14.60	0

Table 3 . Member Corrosion Rate of Platform [17]

Inspection thickness (mm)	Initial thickness (mm)	Level	Element
7.3	9.525	C	MC71
8	9.271	C	MC32
8	9.271	C	MC72
Note: All braces in levels H and K are corroded by **1** millimeter.			

To consider the effect of soil-structure interaction, soil properties in each layer are presented in Table 4. More details are provided in the attachment.

Table 4. Site Soil Layering [19]

Unit	Description	Top of Unit	Thickness
1	Very soft	0.0	1.6
2	Clayey	1.6	1.3
3	Firm to stiff	2.9	43.1
4	Fine to medium sand	46	2.5
5	Very stiff	48.5	>31.5

3. Analytical Method

3.1. Introduction & Assumptions

The previous studies on seismic assessment of offshore platforms were conducted as per API 2007. As mentioned before, the seismic assessment of the jackets in the Persian Gulf was negligible due to low seismic acceleration in this area. Also, the seismic analysis was performed under the Gulf of Mexico design spectrum and the implemented damages were assumed and there were not any actual inspection reports.

In this paper, the seismic assessment of a damaged fixed offshore platform has been conducted as per the 22^{nd} revision of the APIRP2EQ 2014, and the response spectrum of the earthquake has been calculated as per seismic acceleration and the equations related to the Persian Gulf with consideration of site soil coefficient. Also, the actual damages as per the latest jacket structural inspection report have implemented to the structure to obtain the effect of structural damages on the seismic behavior of the platform in three scenarios. A three-dimensional model was conducted in three following scenarios:

1. Damaged jacket with a new deck weighing 2000 tons.
2. Damaged jacket with an old deck weighing 3000 tons. (Present condition)
3. Intact jacket considering the initial criteria and assumptions like annual corrosion rates, etc. weighing 3000 tons.

The model incorporates all primary and secondary steel structural members in the topside and jacket, such as legs, vertical and horizontal bracings, piles, and topside truss members. All vertical loads (dead weight, operational loads, and %75 of the live loads with appropriate load contingency) are implemented as gravitational load cases.

In the first and second scenarios, damages and corrosion have implemented to the members based on the jacket inspection report in 2001. Also, corrosion values from 2001 to 2021 have been incorporated according to the annual corrosion rate, which was calculated in the inspection report [17]. In the third scenario, the corrosion rate has been implemented in the structure according to the estimated initial corrosion rate [18]. It is noted that the effect of corrosion of the members has been defined by reducing the diameter and thickness of the corroded members.

The mass of the structure used for the dynamic analysis is simulated based on a consistent mass assumption. The mass model comprises the structural mass, displaced water (added) mass calculated automatically by SACS software, contained mass and marine growth mass.

To consider the effect of pile interaction, the soil stiffness matrix has been obtained from the PSI module of the SACS software. The water depth is taken at the Mean Sea Level (MSL). All members below this water depth have an added mass value. All submerged parts of the legs are considered as flooded, while all other members, except otherwise reported in the underwater survey document, are assumed non-flooded. The equivalent seismic load is calculated as per section 3.3. To achieve the natural period of the structure, Modal, and spectral dynamic analyses have been performed at two ALE and ELE levels. The imposed load under the extreme earthquake is based on the natural period of the structure in each mode shape and their combination by the CQC method in each direction. Also, the responses in different directions have been combined by the SRSS method as per API regulations.

The member, pile and joint check were carried out under the ELE, respectively. The abnormal earthquake effect is implemented to the structure as an equivalent static load is obtained from the earthquake spectrum by considering the vibration modes of the structure in the longitudinal, transverse, and diagonal directions.[15]. Before performing the push-over analysis, the gravitational loads are implemented to the structure in the first load step.

A series of analyses have been performed with the aforementioned above procedure for all directions to achieve critical RSR of the structure. Figure 4 and Figure 5 illustrate topside and jacket modeling in SACS software, respectively. It is noted that, as per API2EQ 2014, No other environmental load is assumed to act concurrently with the seismic loads.

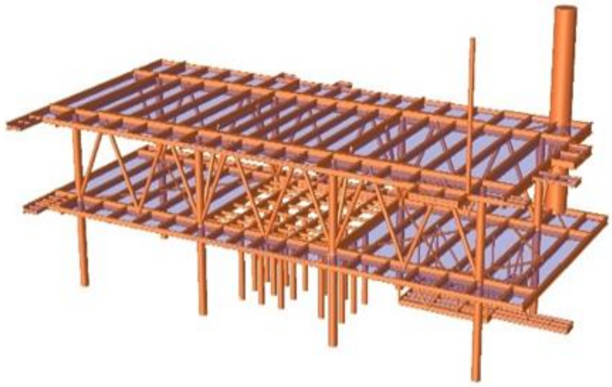


Figure 4. Topside Modeling in SACS Software

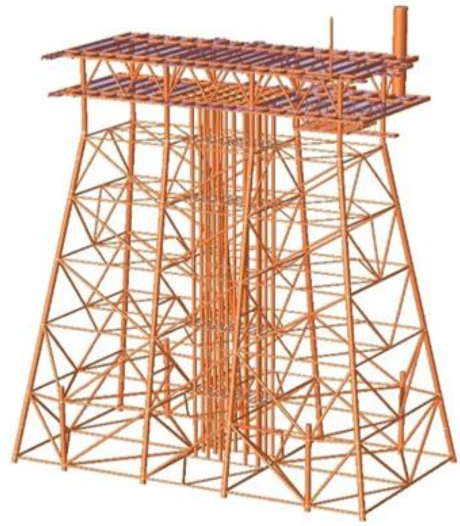


Figure 5. Jacket Modeling in SACS Software

3.2 Pile Soil Interactions

It is reiterated that for the dynamic Linear Global Analysis, the non-linear soil-pile springs are not explicitly modeled. The soil-pile system of the jacket foundation is replaced by a linear foundation model obtained through Pile Soil Interaction (PSI) analysis.

To consider the effect of pile-soil interaction, the soil stiffness matrix has been obtained from the PSI module of the SACS software. The coupled stiffness matrix is generated for each pile based on the average displacement of the pile and P-Y, T-Z & Q-Z curves, which are presented in the attachment and obtained from the actual geotechnical survey of the site from superelement analysis [19],[20]. The foundation is modeled using uncoupled non-linear soil springs acting along the pile's length. PILEHEAD is assigned to each pile joint at mud-line EL. (-) 67.06m for the interaction with the non-linear pile soil resistance.

3.3 Earthquake Force

To determine the magnitude of the earthquake spectrum at the two levels of ALE and ELE, the design spectrum of API-RP2EQ-2014 with a 5% damping ratio is calculated according to Figure 6 and, Eq. 1, 2 and, 3 [2].

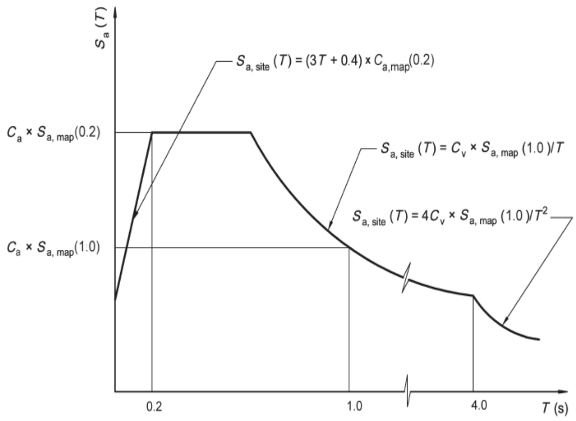


Figure 6. Earthquake Spectrum of API2014 Code [2]

$$
sa,site = \begin{cases} (3T + 0.4) \times Ca\ map \times Sa,map(0.2) & \textbf{(1)} \quad T \le 0.2 \\ Cv \times \dfrac{Sa,map(1.0)}{T}\ \text{except} \le Ca \times Sa,map(0.2) & 0.2< T< 4 \quad \textbf{(2)} \\ 4Cv \times Sa,map\ (1.0)/T\hat{}\ 2 & \textbf{(3)} \quad 4 < T \end{cases}
$$

Site coefficients (C_a and C_v) are obtained from Table 5. $S_{a,map}$ (0.2) and $S_{a,map}$ (1.0) are 0.3 and, 0.75, respectively[2].

Table 5. Site Soil Coefficients [2]

Site class	C_a	C_V
A/B	1	**0.8**
C	1	**1**
D	1	**1.2**
E	1	**1.8**
F	Site study	**Site study**

$$S_{a,ALE}(T) = N_{ALE} \times S_{a,Site}(T) \quad \textbf{(4)}$$

$$S_{a,ELE}(T) = S_{a,ALE}(T)/C_r \quad \textbf{(5)}$$

$$RSR = Q_u/Q_d \quad \textbf{(6)}$$

The N_{ALE} value in Eq. 4, is equal to 1.6. The value of Cr is obtained from Table 3. Determining the exact C_r has a significant effect on cost. So, it is necessary to meet both economical and regulations for seismic design procedures [2].

3.4 Calculated Design Spectrum:

Following the actual geotechnical survey reports, the site soil class is categorized in level E and the Ca and, Cv coefficients are equal to 1 and 1.8, respectively [19]. The calculated spectra for two earthquake levels are presented in Figure 7:

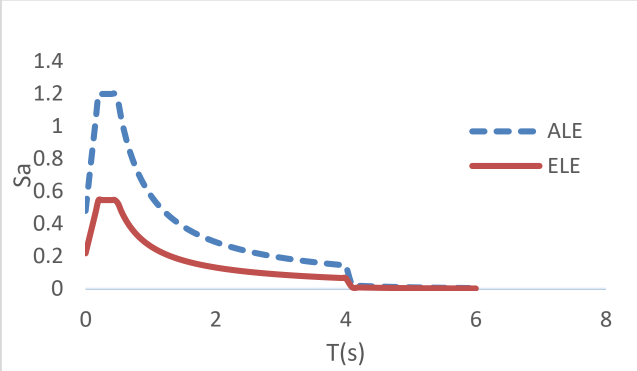


Figure 7. ALE and ELE Level Design Spectrum

4. Results and Discussion

4.1 Modal Analysis Results:

A total of 50 modes were extracted to obtain a cumulative mass participation factor of more than 90% in all directions. As shown in Figure (8), damages and defects have no significant effect on the natural period of the structure. Although, load reduction of the structure by 16% make decrease the natural period by 0.5 seconds. According to Figure (9), the natural periods of the structure are identical in all three cases from the fourth mode onwards. The vibrational modes of the structure are similar in all three modes and have not been affected by weight loss and damage. Figure (10) illustrates the first three modes of the platform in all three scenarios.

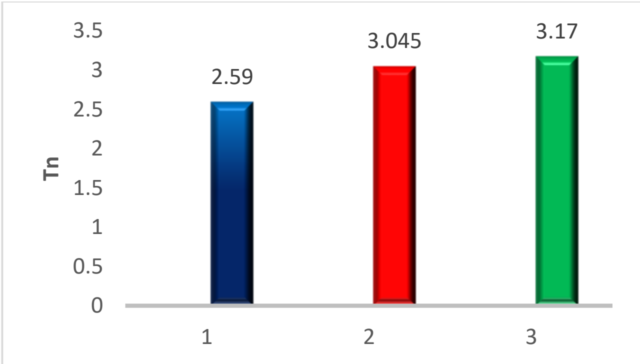


Figure 8. Comparison Diagram of the Natural Period of the Structure in all Three Scenarios

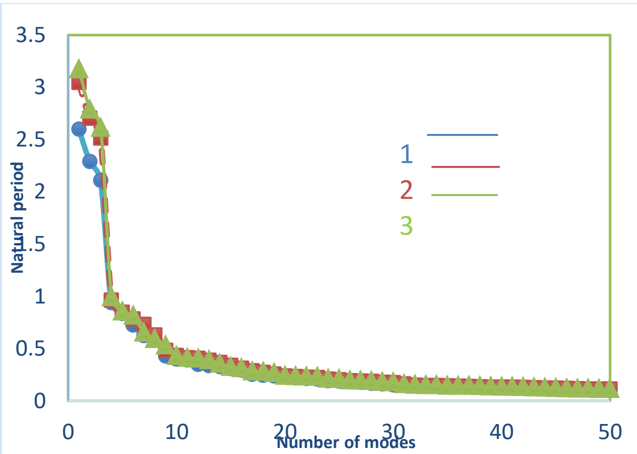


Figure 9. Comparison of Natural Period of Structure in all Three Scenarios

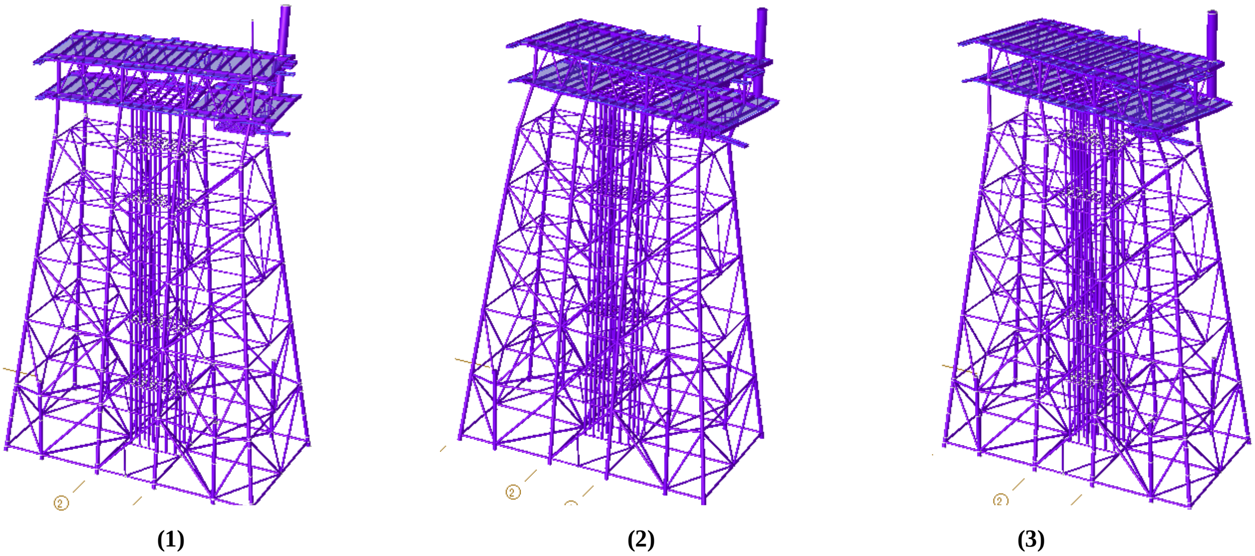


Figure 10. First Three Modes of the Structure in Three Scenarios

4.2 Base Shear

The result of base shear checks along two directions in all three scenarios has shown in Figure (11). Increasing Weight due to flooding of some members has no significant effect on the structure's weight. However, weight reduction of the topside by 16% decreases the base shear by 5%.

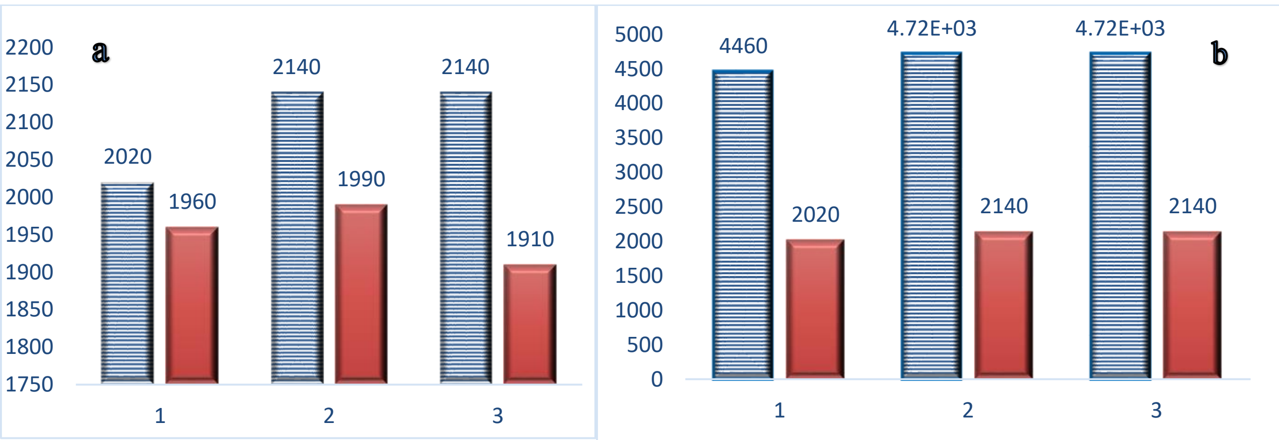


Figure 11. Base Shear Results in Extreme (a) and Abnormal (b) Levels for All Three Scenarios

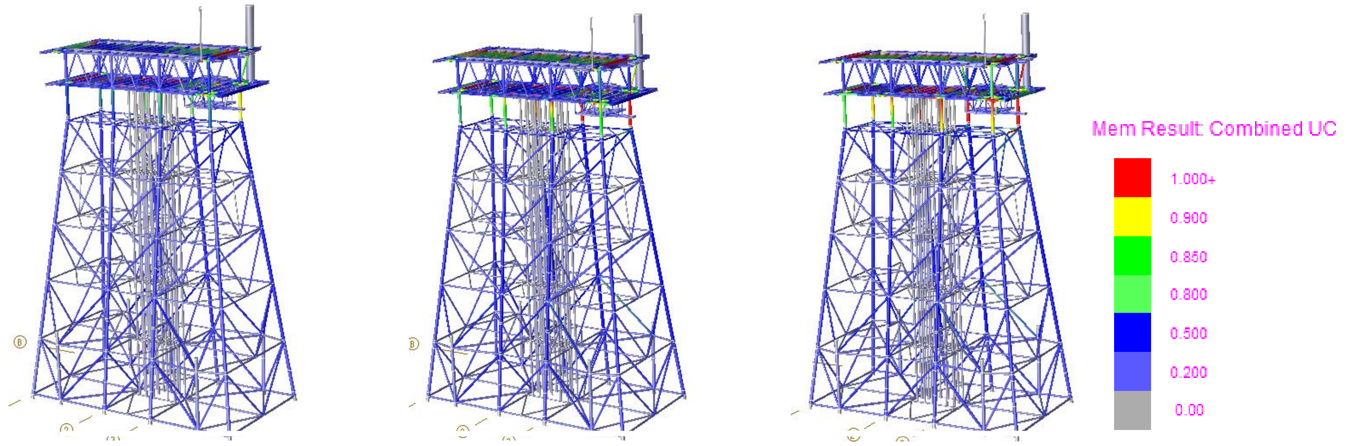
4.3 ELE Member Check

The jacket members which are located above the seabed have checked for all three scenarios.

Regarding the results of linear seismic analysis, the legs in the splash zone between the working point to the deck legs are in the critical range of unity check. UC of mentioned legs is decreased along the members from up to downward. Most of the braces are in the UC range between 0.1 and 0.3. Also, horizontal members with UC 0.1 to 0.5 are in acceptable condition. Implemented damages like; flooding the members and corrosion have no significant effect on UC. The UC ranges in the second scenario are similar to the first one. Increasing the topside weight in the second scenario has led to an actual stress increase in deck legs. However, these mentioned increased stresses did not affect on strength of bracing members.

The UC values are higher than the two previous cases in the third scenario. Also, the number of members has nonlinear behavior. Regarding the results of the third scenario, the initial design criteria and the assumed corrosion rate are conservative and the structure has less corrosion rate in its present condition. Also, considered damages in the initial design have never occurred for the platform until 2020. The nonlinearity of the braces in all three cases indicates their design criteria following a more robust force such as wave force. By controlling the members above the soil surface, it was determined that the most critical members under the earthquake force in all three cases are the jacket legs connected to the deck. There are 0, 5 and, 7 members with critical UC in the first, second and, the third scenarios, respectively.

Figure (12) illustrates the UC range of jacket members which are located above the seabed.



(1) (2) (3)

Figure (12). UC range of Members in first (1), second (2) and Third (3) Scenarios

4.4 ELE Joint Check

Tubular connection joints of the jacket have been checked as per API 22nd Edition criteria in both tensile and compression forces. The results show that most of the tubular joints are in an acceptable condition in all three scenarios. As illustrated in Figure (13), some of the joints located in the splash zone and other elevations with excessive corrosion rates are in critical condition and do not pass the API requirements.

As shown in Table (6), most of the overstressed joints are located at levels -37 meters and -52 meters with UC values greater than unity. However, these mentioned joints do not lead to non-linearization and collapse of the structure due to multiple load transfer paths and redundancy degree of structure. Regarding ELE analysis results, uniform corrosion has more effect on the joint strength of the corroded members than the strength of the exact members. The overall performance of the jacket structure, almost in all analyses, depends on the assumed corrosion rates for the members in the splash zone.

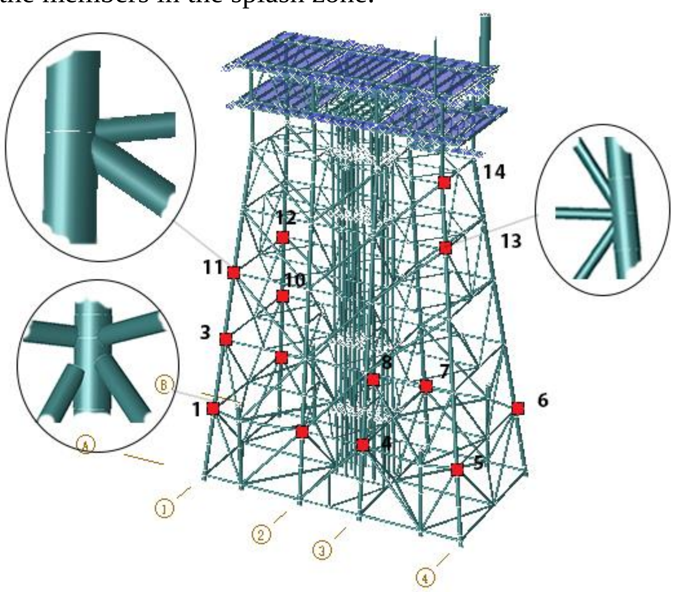


Figure (13). Jacket Critical joints

Table 6. Strength UC of the Joints in All Three Scenarios

JOINT	STRN U.C 1	STRN U.C 2	STRN U.C 3
1	1.61	1.75	1.745
2	1.003	1.003	0.817
3	1.577	1.702	1.702
4	1.554	1.657	1.656
5	1.547	1.65	1.652
6	1.542	1.658	1.652
7	1.532	1.651	1.65
8	1.508	1.611	1.612
9	1.504	1.597	1.593
10	1.406	1.991	4.463
11	1.311	1.313	1.313
12	1.309	1.312	1.311
13	1.309	1.311	1.311
14	1.309	1.311	1.311

4.5 Pile control

The foundation assessment is carried out using the soil pile interaction with maximum combined static and seismic loads for all three scenarios. The foundation is presented by a linear foundation stiffness matrix. As shown in Table 7, all 12 piles below the seabed are in normal condition with UC lower than unity under the linear seismic analysis. Also, no nonlinearity occurred in any of the piles under both tensile and compressive forces. The UC value of all piles under the compression loads is more than tension in the same condition. Also, pile UC in the second and third scenarios are close due to the same weight of the topside. However, implemented damages on the members which are located above the mudmat have no significant effect on the load transfer path. Regarding below table, the pile with ID '206L' has the most UC due to the existing crane weight as a concentrated load on the topside. Reducing the concentrated loads or implementing them as a distributed load is a useful SMR method for the overloaded piles.

Table 7. UC Values of Piles below the Mudline under Extreme Earthquake

PILE	LOAD	U.C1	U.C2	U.C3
201L	1TEN	0.238	0.312	0.316
	2COM	0.444	0.539	0.53
202L	1TEN	0.423	0.655	0.575
	2COM	0.574	0.803	0.805
203L	1TEN	0.372	0.493	0.491
	2COM	0.522	0.665	0.654
204L	1TEN	0.306	0.401	0.4
	2COM	0.508	0.626	0.616
205L	1TEN	0.287	0.438	0.348
	2COM	0.457	0.559	0.551
206L	1TEN	0.464	0.613	0.616
	2COM	0.714	0.9	0.897
207L	1TEN	0.425	0.548	0.542
	2COM	0.576	0.758	0.74
208L	1TEN	0.385	0.487	0.483
	2COM	0.596	0.819	0.738
JS21	1TEN	0.183	0.196	0.212
	2COM	0.233	0.323	0.266
JS24	1TEN	0.106	0.207	0.207
	2COM	0.106	0.264	0.26
JS22	1TEN	0.193	0.228	0.215
	2COM	0.238	0.281	0.006
JS23	1TEN	0.281	0.237	0.236
	2COM	0.297	0.297	0.292

4.6 ALE Member Check

The seismic linear ELE analysis results show that 0, 5, and 7 jacket members are in critical condition in the first, second, and third scenario, respectively. Most of the members mentioned above are located in the splash zone. Moreover, there are 14 joints with U.C greater than unity. A number of inelastic Pushover analyses has been performed to achieve RSR for all scenarios and verify the fracture mechanism and ability of the side members of the critical members to sustain and transfer the loads. During the pushover analysis, the gravity load has been implemented into the structure before inducing the lateral load. Due to the symmetrically of the platform, the earthquake load has been implemented to the structure as an equivalent static load in four longitude, latitude, and diagonal directions. Figure (14) is presented the selected direction of the equivalent seismic loads. As shown in Table (8), the reserve strength ratios in the first direction are less than other in all three scenarios. The RSR values in all three scenarios and four directions are close to each others due to the design methodology of the jackets and designing the jacket based on the metocean loads to achieve the integrity of the structure against different load cases.

The base shear in the first direction is higher than in other directions. The structural collapse of the jacket in the diagonal direction can be due to the behavior of the foundation. However, in this structure, the presence of skirt piles have led to the strengthening of the foundation against the diagonal forces.

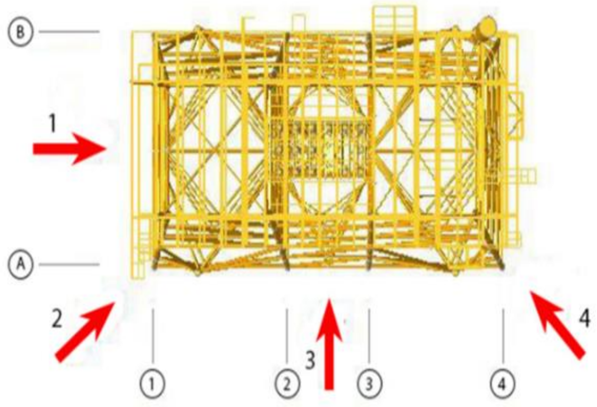


Figure 14: Directions of Implemented Forces in Pushover Analysis

Regarding investigation of the fracture mechanism of the structures in all three scenarios, the first yield has occurred on deck legs. Although, mentioned members as the main members whose resistance against the compressive loads are more sensitive to damages. As per RSR checks in all four directions and three scenarios, the reserve strength ratio in the first direction is more critical than other conditions. So, the fracture mechanism of the structure has been controlled in the first direction in all three scenarios.

Table 8: RSR Value of the Structure in Different Scenarios and Directions

Scenario	RSR 1	RSR 2	RSR 3

direction			
1	3.8	3.32	3.08
2	4.23	3.8	3.56
3	4.28	3.56	3.32
4	4.52	4.16	3.56

4.6.1 First Scenario:

Regarding capacity diagram of the structure in the first scenario under abnormal level earthquake forces in direction No.1, Diagonal members are buckled and plastic hinges have occurred to develop in the deck legs. The first plasticization with a 16% rate occurred in the legs which connected to the deck at a load factor of 1.88. This mentioned plasticization has no significant effect on the behavior of the damaged structure.

While the loading process continues at a load factor of 2.84, the structure begins to yield and reduce stiffness. Plasticization of skirt piles and some horizontal members begin at the highest level of the jacket at a load factor of 3.08. Plasticization of the other horizontal members of the seadeck is stared at load factor 3.32. The first yield has occurred on the deck legs in the splash zone due to corrosion and lack of diagonal braces in this elevation. A plastic joint on the deck legs with in load factor of 3.56 has led to a change in the transmission of force from the legs to the horizontal members and VDM braces. Finally, 100% plasticization of deck legs and piles in the soil leads to the collapse of the structure at a load factor of 3.8. Figure (15) shows the displacement - load coefficient of the structure under gravity and lateral loads. The load factor from 0 to 1 is related to gravity loads. During the pushover analysis in the first scenario, no punching occurred in the piles and the soil has sufficient strength under the abnormal earthquakes up to a load factor of 3.8.

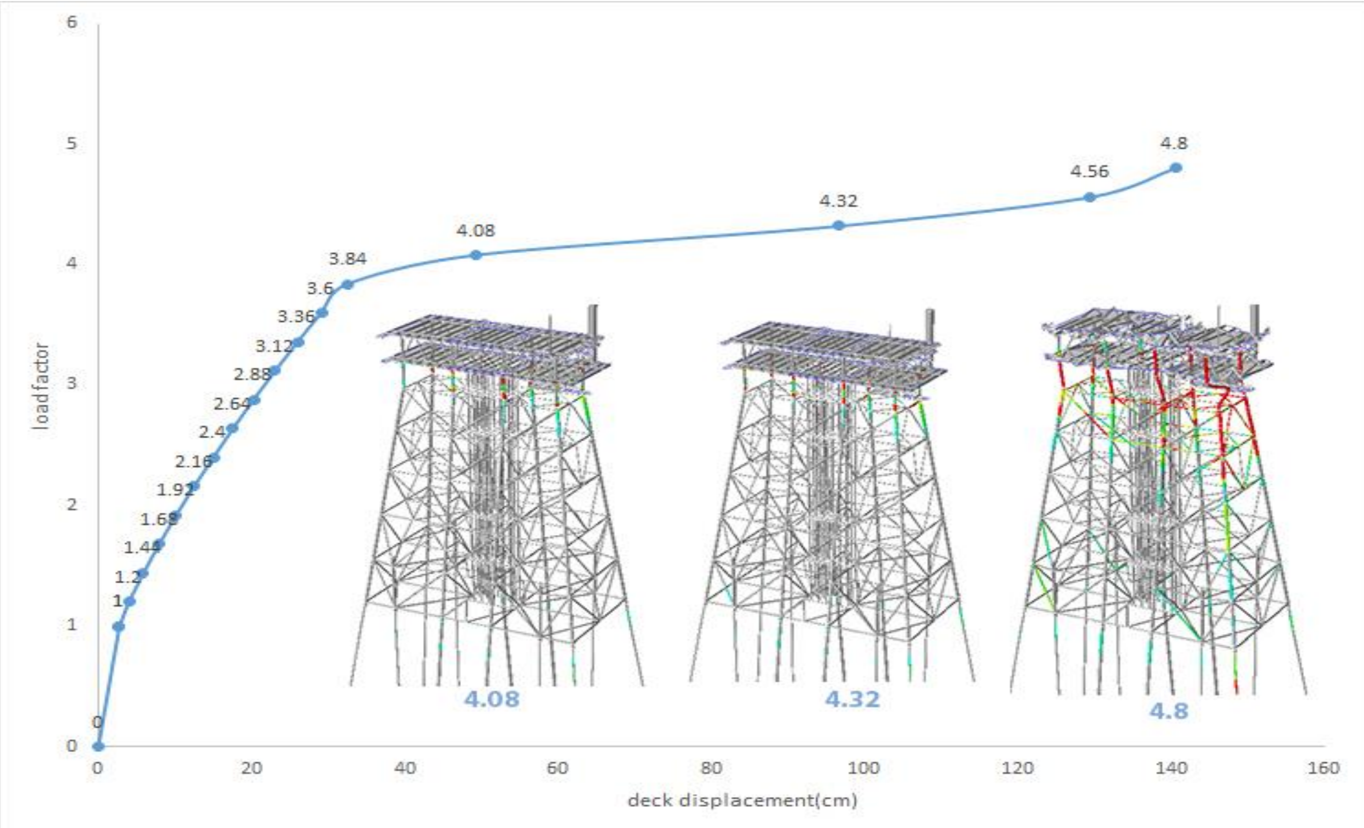


Figure 15. Capacity and Plasticization Rate of the Structure in the First Case

4.6.2 Second Scenario

The second scenario represents the actual condition of the structure. In the current scenario, due to the increase of the deck's weight, the members' plasticization occurred at a lower load factor with a higher percentage of yield. However, this increased weight has no significant effect on the fracture mechanism of the structure. The leg of the jacket and the diagonal braces have considerable roles against seismic load, respectively. No punching has occurred on the piles below the mudline. Also, plasticization of the piles has decreased along the piles from up to downward. The first yield has occurred in the deck leg, which is located below the crane. Although, plasticity is developed, platform failure is not happening and conforms to the ALE requirement. The structural leg elements are allowed to behave plastically developing the reserve strength of the cross-section, and making use of ductility and energy dissipation to resist ALE factors. Figure (16) illustrates the capacity diagram of the structure.

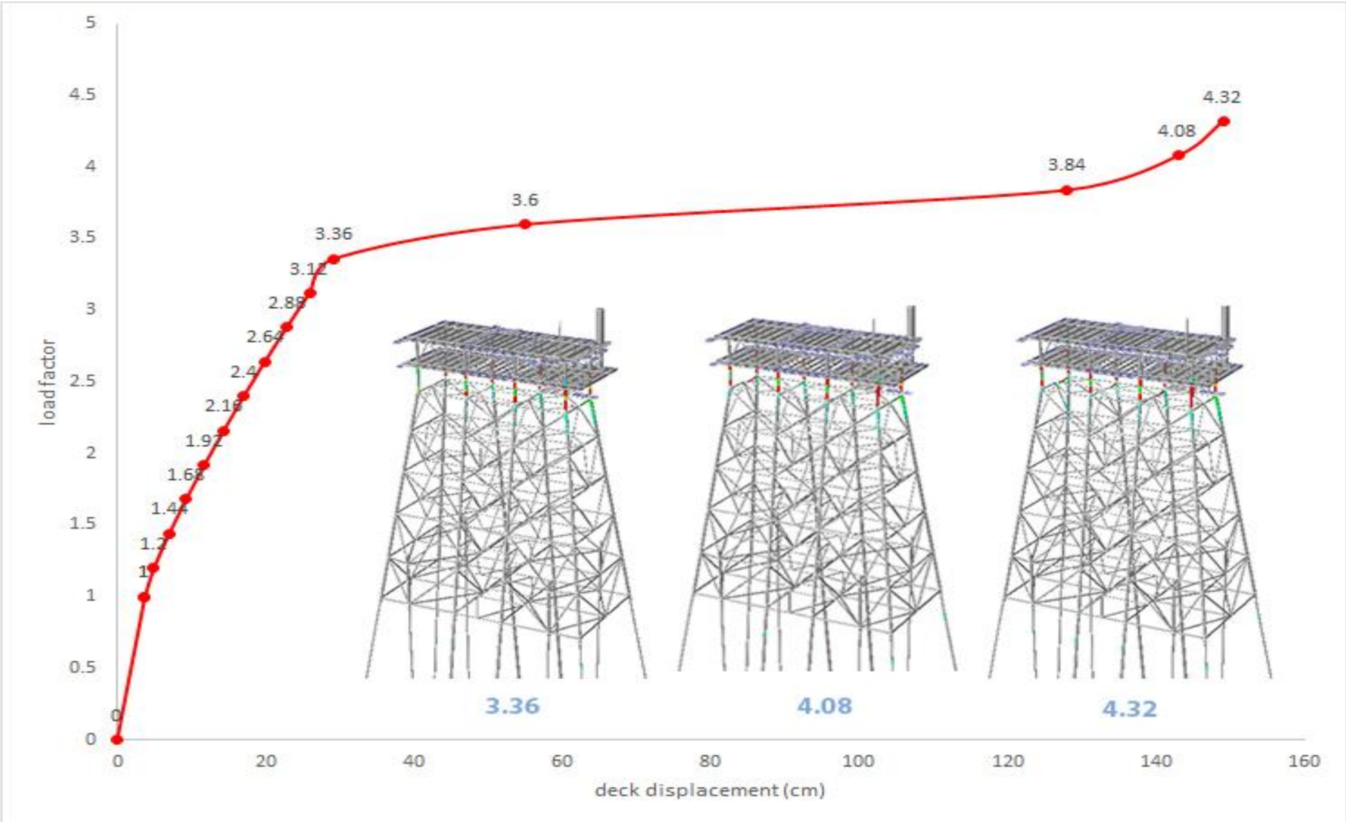


Figure 16. Capacity and Plasticization Rate of the Structure in the Second Case

4.6.3 Third Scenario

The behavior of the structure in the third case is similar to the two other scenarios. However, the strict criteria and the considered damages in the initial design criteria of the structure have not happened properly. Although, damages in the initial design basis are more conservative than in other cases, and the actual condition of the platform and led to the collapse of the structure at a lower load factor than the other two cases. The 8% difference in the Strength ratio between the second and third scenarios indicates the effect of damages like corrosion on the RSR of the structure. The bending has occurred on the deck legs below the heavy crane. Also, diagonal braces which are located near the crane are near to buckle. The result of the global inelastic seismic analysis of the structure indicates that the structure has suffered damages consisting of the buckling of some diagonal braces in the splash zone and the yielding of deck legs during the abnormal earthquake. So, the platform has a minimum RSR of 3.32 under a 1,000-year return period earthquake event. It is concluded that despite the poor performance and condition of some members and joints, especially in the splash zone and deck legs, the platform can fulfill API for the structural assessment against seismic loads.

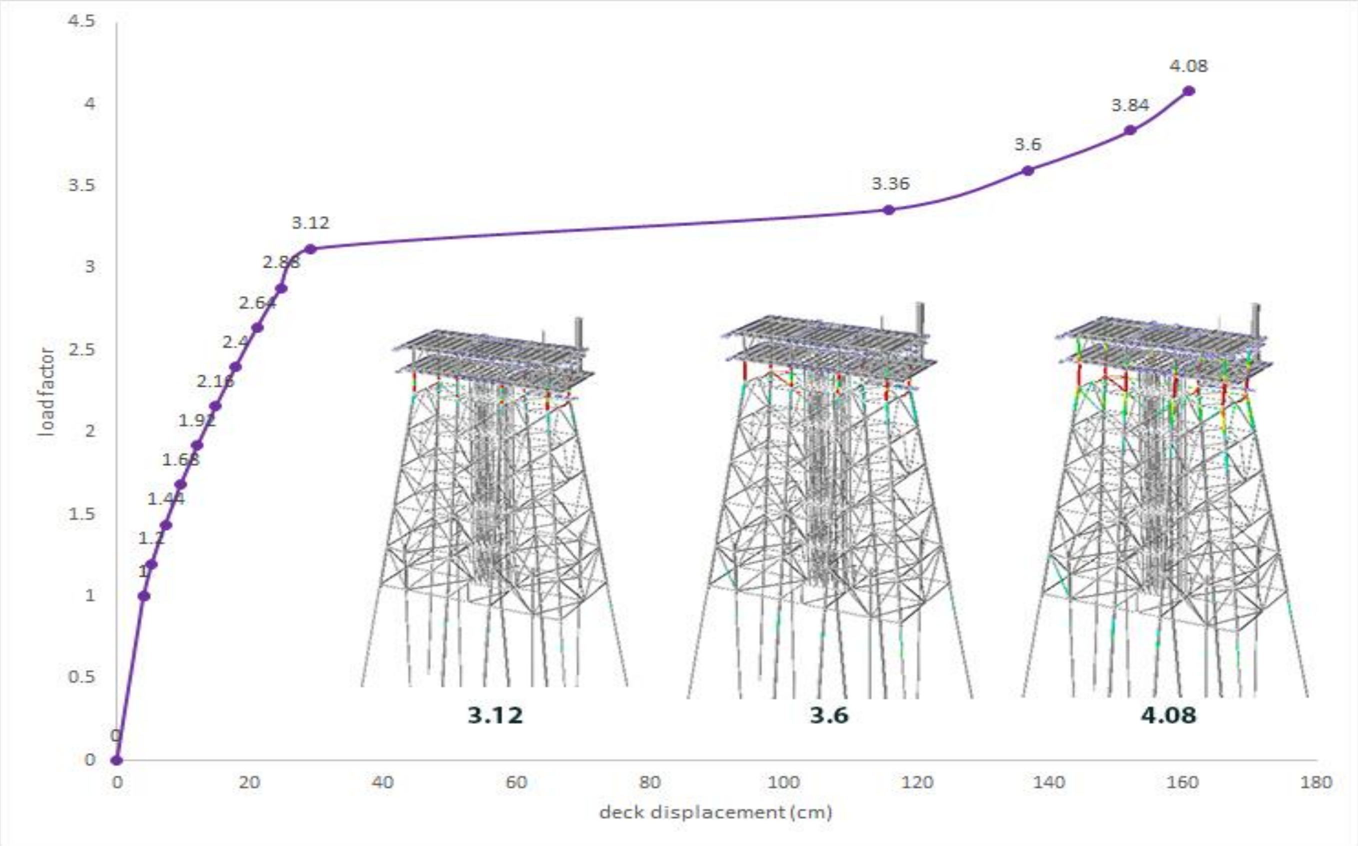


Figure 17. Capacity and Plasticization Rate of the Structure in the Third Case

5. Conclusions

This paper is presented the seismic assessment of a damaged fixed offshore platform which is located in the Persian Gulf with consideration of pile soil interaction according to the actual inspection report of the structure in two linear and nonlinear methods in three scenarios to obtain the effect of damages and increased seismic acceleration of the Persian Gulf region on seismic behavior and integrity of the jacket during the abnormal earthquake respectively. The results are as follows:

1. Despite excessive corrosion, flooding of some members, marine growth, and regulation changes, the mentioned platform remains stable under the earthquake forces and there is no need to do SMR operation for the damaged jacket.

2. At each stage of pushover analysis, the plasticization of several members above the soil surface of the jacket has a direct effect on increasing the plasticization rate of piles in the soil due to the direct connection of piles from the working point to the deck legs.

3. The first plasticization of the abnormal earthquake occurred in the deck legs and piles below the Mudline due to transferring the base shear force from below the mudline to the top of the piles near the working point. Although, these mentioned members have the most crucial role in the seismic strength of structures. Damages like denting and corrosion on these members have a more significant effect on the seismic strength of the structure than on other members.

4. The maximum displacement in the jacket legs is observed in the upper level due to the absence of VDM brace members.

5. Load reduction of the topside does not lead to a significant change in the UC of the diagonal braces. Although, in VDM braces, other SMR methods which increased the allowable stress of the damaged members are more effective than load reduction.

6. According to Figure 18, the implemented damages have no considerable effect on the structure's integrity. Also, reducing or increasing the weight of the topside has led to changes in the RSR and the percentage of plasticization of critical members.

7. Deck legs have suffered from bending and diagonal braces suffered from buckling under the seismic loads.

8. Buckling in the deck legs at the splash zone and yielding in the Piles near the seabed causes global structural collapse under the ALE pushover analysis.

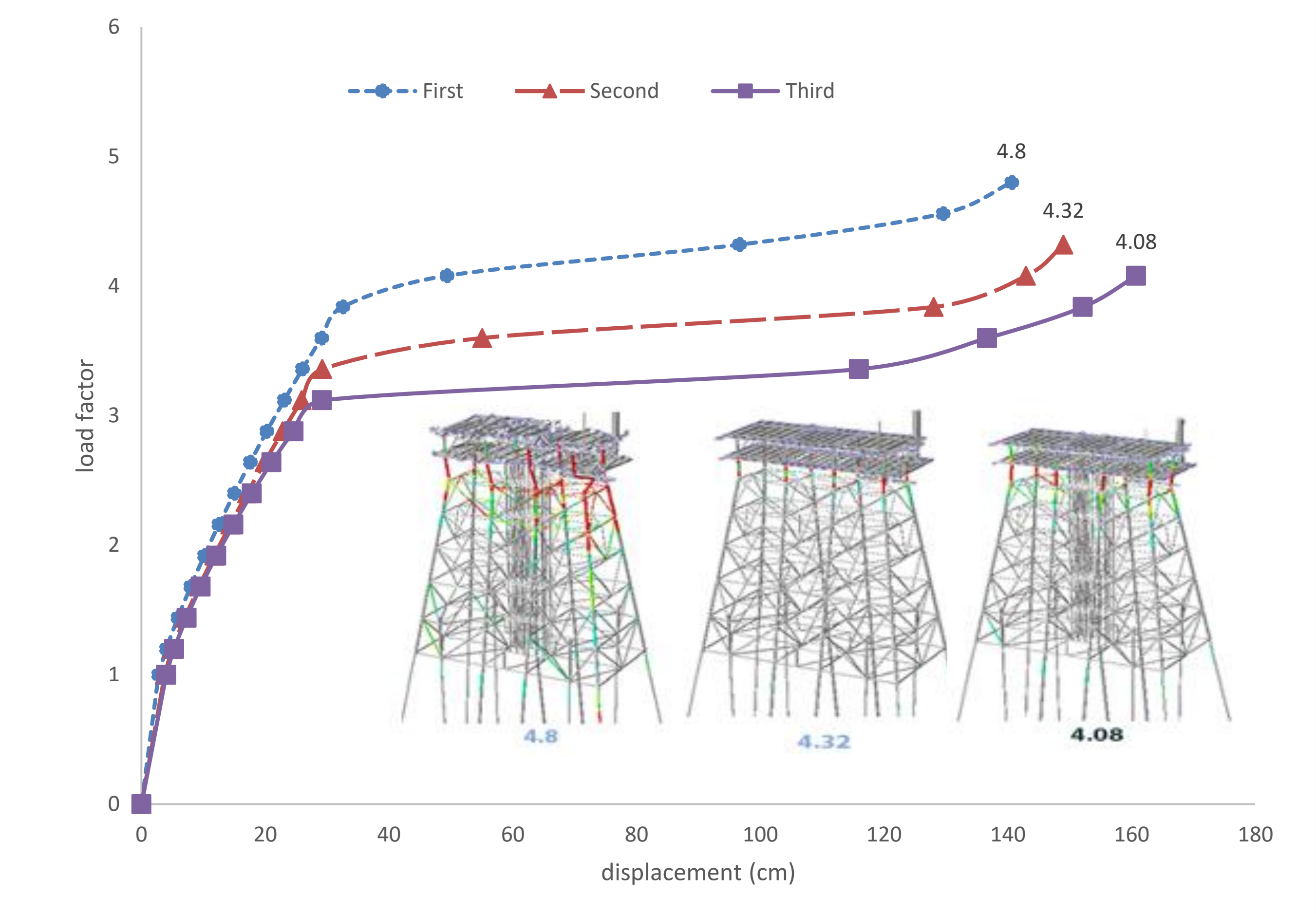


Figure 18. Comparison of Capacity Diagrams in Three Scenarios

Acknowledgment

The authors would like to thank Dr. Motevasel in the Iranian offshore oil company (IOOC) for his kind help and valuable tips.

List of Symbols (Optional)

ALE	Abnormal Level Earthquake
ELE	Extreme Level Earthquake
SLE	Strength Level Earthquake
DLE	Ductile Level Earthquake
API	American petroleum institute
C_a	Site coefficient
C_v	Site coefficient
S_a	Spectrum acceleration
CQC	Complete Quadratic Combination
SRSS	Square Root of the Sum of the Squares
UC	Unity Check
WP	Working Point
CMR	Collapse Margin Ratio
SMR	Strengthening, Modification and Repair
C_d	Drag Coefficient
Cm	Inertia Coefficient
RSR	Reserve Strength Ratio
Tn	Natural Period

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ATTACHMENTS

1. Soil data

   Following table presents the P-Y, T-Z & Q-Z of the site soil as per latest geotechnical survey on December 2004: [19]

depth [m]	soil type	t/c	t1	z1	t2	z2	t3	z3	t4	z4	t5	z5	t6	z6
.0	clay	t	.001	2.0	.001	3.8	.002	6.9	.003	9.8	.003	12.2	.002	24.4
		c	.001	2.0	.001	3.8	.002	6.9	.003	9.8	.003	12.2	.002	24.4
.8	clay	t	.003	2.0	.004	3.8	.006	6.9	.008	9.8	.008	12.2	.006	24.4
		c	.003	2.0	.004	3.8	.006	6.9	.008	9.8	.008	12.2	.006	24.4
1.0	clay	t	.003	2.0	.005	3.8	.008	6.9	.009	9.8	.010	12.2	.007	24.4
		c	.003	2.0	.005	3.8	.008	6.9	.009	9.8	.010	12.2	.007	24.4
1.0	sand	t	.001	.5	.002	1.0	.003	1.5	.004	2.0	.004	2.5	.004	5.1
		c	.001	.5	.002	1.0	.003	1.5	.004	2.0	.004	2.5	.004	5.1
2.9	sand	t	.003	.5	.006	1.0	.009	1.5	.012	2.0	.014	2.5	.014	5.1
		c	.003	.5	.006	1.0	.009	1.5	.012	2.0	.014	2.5	.014	5.1
2.9	clay	t	.030	2.0	.050	3.8	.075	6.9	.090	9.8	.100	12.2	.070	24.4
		c	.030	2.0	.050	3.8	.075	6.9	.090	9.8	.100	12.2	.070	24.4
9.9	clay	t	.046	2.0	.077	3.8	.115	6.9	.138	9.8	.153	12.2	.107	24.4
		c	.046	2.0	.077	3.8	.115	6.9	.138	9.8	.153	12.2	.107	24.4
9.9	clay	t	.046	2.0	.077	3.8	.116	6.9	.139	9.8	.154	12.2	.108	24.4
		c	.046	2.0	.077	3.8	.116	6.9	.139	9.8	.154	12.2	.108	24.4
10.0	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
10.1	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
10.4	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
10.4	clay	t	.048	2.0	.079	3.8	.119	6.9	.143	9.8	.159	12.2	.111	24.4
		c	.048	2.0	.079	3.8	.119	6.9	.143	9.8	.159	12.2	.111	24.4
14.7	clay	t	.058	2.0	.097	3.8	.146	6.9	.175	9.8	.194	12.2	.136	24.4
		c	.058	2.0	.097	3.8	.146	6.9	.175	9.8	.194	12.2	.136	24.4
14.7	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
15.7	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
15.7	clay	t	.061	2.0	.101	3.8	.152	6.9	.182	9.8	.202	12.2	.142	24.4
		c	.061	2.0	.101	3.8	.152	6.9	.182	9.8	.202	12.2	.142	24.4
21.5	clay	t	.073	2.0	.122	3.8	.183	6.9	.219	9.8	.243	12.2	.170	24.4
		c	.073	2.0	.122	3.8	.183	6.9	.219	9.8	.243	12.2	.170	24.4
21.5	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
22.0	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
22.0	clay	t	.074	2.0	.124	3.8	.185	6.9	.223	9.8	.247	12.2	.173	24.4
		c	.074	2.0	.124	3.8	.185	6.9	.223	9.8	.247	12.2	.173	24.4
23.7	clay	t	.079	2.0	.131	3.8	.197	6.9	.237	9.8	.263	12.2	.184	24.4
		c	.079	2.0	.131	3.8	.197	6.9	.237	9.8	.263	12.2	.184	24.4

depth [m]	soil type	t/c	t1	z1	t2	z2	t3	z3	t4	z4	t5	z5	t6	z6
23.7	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
24.2	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
24.2	clay	t	.080	2.0	.133	3.8	.200	6.9	.240	9.8	.267	12.2	.187	24.4
		c	.080	2.0	.133	3.8	.200	6.9	.240	9.8	.267	12.2	.187	24.4
24.7	clay	t	.081	2.0	.134	3.8	.202	6.9	.242	9.8	.269	12.2	.188	24.4
		c	.081	2.0	.134	3.8	.202	6.9	.242	9.8	.269	12.2	.188	24.4
24.7	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
25.8	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
25.8	clay	t	.083	2.0	.138	3.8	.207	6.9	.248	9.8	.276	12.2	.193	24.4
		c	.083	2.0	.138	3.8	.207	6.9	.248	9.8	.276	12.2	.193	24.4
26.8	clay	t	.084	2.0	.140	3.8	.210	6.9	.252	9.8	.280	12.2	.196	24.4
		c	.084	2.0	.140	3.8	.210	6.9	.252	9.8	.280	12.2	.196	24.4
26.8	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
27.2	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
27.2	clay	t	.087	2.0	.145	3.8	.218	6.9	.262	9.8	.291	12.2	.203	24.4
		c	.087	2.0	.145	3.8	.218	6.9	.262	9.8	.291	12.2	.203	24.4
46.0	clay	t	.124	2.0	.207	3.8	.310	6.9	.372	9.8	.414	12.2	.290	24.4
		c	.124	2.0	.207	3.8	.310	6.9	.372	9.8	.414	12.2	.290	24.4
46.0	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
48.5	sand	t	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
		c	.011	.5	.023	1.0	.034	1.5	.046	2.0	.057	2.5	.057	5.1
48.5	clay	t	.165	2.0	.275	3.8	.413	6.9	.495	9.8	.550	12.2	.385	24.4
		c	.165	2.0	.275	3.8	.413	6.9	.495	9.8	.550	12.2	.385	24.4
80.0	clay	t	.214	2.0	.357	3.8	.536	6.9	.643	9.8	.714	12.2	.500	24.4
		c	.214	2.0	.357	3.8	.536	6.9	.643	9.8	.714	12.2	.500	24.4

depth [m]	soil type	p1	y1	p2	y2	p3	y3	p4	y4
.0	clay	.003	10.1	.005	45.7	.007	137.2	.009	365.8
1.0	clay	.008	10.1	.013	45.7	.019	137.2	.027	365.8
1.0	sand	.020	3.7	.045	12.0	.051	20.3	.052	45.7
2.0	sand	.044	4.2	.096	12.2	.112	20.3	.117	45.7
2.9	sand	.053	3.5	.123	11.9	.138	20.3	.141	45.7
2.9	clay	.100	6.7	.166	30.5	.240	91.4	.333	243.8
4.0	clay	.112	6.7	.185	30.5	.267	91.4	.370	243.8
6.0	clay	.133	6.7	.221	30.5	.318	91.4	.442	243.8
8.0	clay	.156	6.7	.258	30.5	.372	91.4	.515	243.8
10.0	clay	.179	6.7	.296	30.5	.427	91.4	.592	243.8
10.0	sand	.405	2.6	1.017	11.4	1.074	20.3	1.078	45.7
10.4	sand	.437	2.7	1.089	11.5	1.157	20.3	1.163	45.7
10.4	clay	.182	6.7	.302	30.5	.436	91.4	.604	243.8
12.0	clay	.201	6.7	.333	30.5	.480	91.4	.665	243.8
14.0	clay	.224	6.7	.372	30.5	.536	91.4	.744	243.8
14.7	clay	.233	6.7	.386	30.5	.556	91.4	.772	243.8
14.7	sand	.787	3.4	1.847	11.9	2.058	20.3	2.095	45.7
15.7	sand	.845	3.4	1.979	11.9	2.209	20.3	2.249	45.7
15.7	clay	.243	6.7	.402	30.5	.580	91.4	.804	243.8
16.0	clay	.246	6.7	.408	30.5	.588	91.4	.815	243.8
18.0	clay	.269	6.7	.446	30.5	.644	91.4	.893	243.8
20.0	clay	.293	6.7	.486	30.5	.701	91.4	.972	243.8
21.5	clay	.298	6.7	.494	30.5	.712	91.4	.988	243.8
21.5	sand	1.164	3.4	2.438	11.9	2.438	20.3	2.438	45.7
22.0	sand	1.193	3.4	2.438	11.9	2.438	20.3	2.438	45.7
22.0	clay	.298	6.7	.494	30.5	.712	91.4	.988	243.8
23.7	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
23.7	sand	1.286	3.4	2.438	11.9	2.438	20.3	2.438	45.7
24.0	sand	1.304	3.4	2.438	11.9	2.438	20.3	2.438	45.7
24.2	sand	1.315	3.4	2.438	11.9	2.438	20.3	2.438	45.7
24.2	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
24.7	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
24.7	sand	1.343	3.4	2.438	11.9	2.438	20.3	2.438	45.7
25.8	sand	1.407	3.4	2.438	11.9	2.438	20.3	2.438	45.7
25.8	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
26.0	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
26.8	clay	.315	6.7	.521	30.5	.752	91.4	1.042	243.8
26.8	sand	1.462	3.5	2.438	11.9	2.438	20.3	2.438	45.7
27.2	sand	1.485	3.5	2.438	11.9	2.438	20.3	2.438	45.7
27.2	clay	.331	6.7	.549	30.5	.791	91.4	1.097	243.8
28.0	clay	.334	6.7	.553	30.5	.798	91.4	1.107	243.8
30.0	clay	.341	6.7	.565	30.5	.815	91.4	1.130	243.8
32.0	clay	.348	6.7	.577	30.5	.832	91.4	1.153	243.8
34.0	clay	.355	6.7	.588	30.5	.848	91.4	1.177	243.8
36.0	clay	.362	6.7	.600	30.5	.865	91.4	1.200	243.8
38.0	clay	.369	6.7	.612	30.5	.882	91.4	1.223	243.8
40.0	clay	.376	6.7	.623	30.5	.899	91.4	1.247	243.8
42.0	clay	.383	6.7	.635	30.5	.916	91.4	1.270	243.8

depth [m]	soil type	tip con	q1	z1	q2	z2	q3	z3	q4	z4	q5	z5
40.0	clay	p	.30	2.4	.60	15.8	.90	51.2	1.07	89.0	1.19	121.9
42.0	clay	p	.30	2.4	.61	15.8	.91	51.2	1.09	89.0	1.22	121.9
44.0	clay	p	.31	2.4	.62	15.8	.93	51.2	1.11	89.0	1.24	121.9
46.0	sand	p	.67	2.4	1.13	15.8	1.70	51.2	2.03	89.0	2.26	121.9
48.0	sand	p	.53	2.4	1.07	15.8	1.60	51.2	1.92	89.0	2.13	121.9
48.5	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
50.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
52.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
54.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
56.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
58.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
60.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
62.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
64.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
66.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
68.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
70.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
72.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
74.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
76.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
78.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9
80.0	clay	p	.53	2.4	1.05	15.8	1.58	51.2	1.89	89.0	2.10	121.9

depth [m]	soil type	p1	y1	p2	y2	p3	y3	p4	y4
44.0	clay	.390	6.7	.647	30.5	.933	91.4	1.293	243.8
46.0	clay	.397	6.7	.658	30.5	.949	91.4	1.317	243.8
46.0	sand	2.438	3.2	2.438	11.9	2.438	20.3	2.438	45.7
48.0	sand	2.438	3.1	2.438	11.9	2.438	20.3	2.438	45.7
48.5	sand	2.438	3.0	2.438	11.9	2.438	20.3	2.438	45.7
48.5	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
50.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
52.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
54.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
56.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
58.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8
60.0	clay	.662	6.7	1.097	30.5	1.582	91.4	2.195	243.8