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Topology Optimization of Fixed Offshore Platform under Earthquake Loading in Gulf of Suez

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Abstract: *Jacket-type offshore platforms play an important role in oil and gas industry in shallow and intermediate water depths. The reliability and cost are the most concerned problems in the design, manufacture and installation. In order to design reliable and high cost-benefit platforms, optimization technique is extremely important. Importance of optimization of such important and costly structures increased in the recent years specially with lowering in oil and gas prices. In this paper, a new topologically optimized shape of a standard jacket platform located in the Gulf of Suez is investigated under seismic loads by using proposed automated method. The seismic loading is considered because the Gulf of Suez is considered seismically active zone. A finite element linear time history analysis (Extreme Level Earthquake, ELE) was performed as per the earthquake offshore standard API-2EQ. PEER ground motion database was used for selection and scaling of applied earthquake records. One set of three earthquake components (two horizontal and vertical) of acceleration time history records was considered. Each earthquake component applied in one direction considering gravity, buoyancy and hydrostatic pressure loads. Buckling is not considered in this study.*

Keywords: *Finite element, time history analysis, jacket platform, Gulf of Suez, API-2EQ, scaling, topology optimization.*

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Nomenclature

ALE	Abnormal Level Earthquakes	MSE	Mean Square Error
B.C.	Boundary Condition	M.W.L	Mean Water Level
dir.	Direction	PEER	Pacific Earthquake Engineering Research
EL	Elevation	PGMD	PEER Ground Motion Database
ELE	Extreme Level Earthquake	*O.D.*	Outer Diameter
EP	Existing Platform	*SO*	Structural Optimization
Freq.	Frequency	S.R.	Stress Ratio
GA	Genetic Algorithm	TH	Time History analysis
H1	Earthquake Horizontal-1 acceleration component	T.O.	Topology Optimization
H2	Earthquake Horizontal-2 acceleration component	WSNDP	Winning Shape of New Design Platform
J.	Jacket	*W.T.*	Wall Thickness
[K]	Stiffness matrix	α	Mass proportional damping
L.	Leg	β	Stiffness proportional damping
[M]	Mass matrix	Φ_i	Mode shape i
MAX.	Maximum	ω_i	Natural circular frequency of mode i

I. Introduction

Many researches on offshore structures which studied dynamic response due to wave and earthquake loading were performed. Elshafey et al. [1] investigated dynamic response under random wave loads of a scaled model of a jacket offshore structure theoretically and experimentally. Bargi et al. [2] conducted nonlinear dynamic analysis of a typical Jacket-Type platform under simultaneously wave and earthquake loading by using recorded earthquake time history-displacement involving three records with different energy levels. Some researchers have evaluated offshore structures due to earthquake loading per offshore standards. Chang et al. [3] conducted comparison of seismic design guidelines ISO19901-2 [4] and API-2EQ [5] using three existing offshore platforms. Peng et al. [6] conducted nonlinear soil-pile-structure interaction analysis of a deep-water platform.

Offshore man-hour overall cost is approximately five times that of an onshore man-hour and the expenses of offshore platforms has substantial influence on feasibility of offshore development, because it is an early capital expenditure. The expected ratios of installation, fabrication, material and equipment and engineering costs of an offshore platform are 40%, 28%, 24% and 8%, respectively (Sleg) [7]. The decrease in weight not only decreases material costs, but also it reduces the size of naval equipment needed for towing and installation, such as derrick barges, cranes … etc. Traditionally, engineers perform structural optimization by trial and error. This is a very costly and time-consuming approach. Currently, the modern approach is a mathematical design optimization method by using numerical software that simultaneously analyzes and optimizes the design. This approach streamlines the optimization process by automating the analysis and design iterations, therefore decreasing the time and the cost, in addition to increasing the solution efficiency.

In real applications, structural optimization under dynamic loading faces many challenges in comparison with the optimum design of structures under static loads. Implementation of an approach of displacement-based finite element to transform earthquake loading into equivalent static loads with using optimization technique based on mathematical method was proposed to perform efficient structural shape optimization under earthquake loadings by Akbari and Sadoughi [8]. Lagaros et al. [9] presented seismic design evaluation based on European seismic design code for three-dimensional frame structures using methodologies of structural optimization. It is concluded that the optimized design combined with better seismic performance are obtained from nonlinear time-history analysis.

Martens [10] utilized Genetic Algorithm (GA) for topology optimization of an offshore wind turbine jacket structure subjected to turbine power output, wind and wave loading. He used initial random design shape in the beginning of the optimization process. This idea is utilized in this paper.

Dahy [11] conducted a study on seismicity and tectonic setting in the Northeastern part of Egypt. It aimed to point out the fact that the Gulf of Suez is seismically active associated with earthquake risk. A platform is located in area that is determined to be seismically active, seismic forces are considered in the platform design [4], [5] and [12]. Abou El-Makarem et al. present an assessment of an existing platform in the Gulf of Suez [13]. According of that and as a continuing of the authors' previous work seismic loading is chosen to be studied in this paper.

II. Description of The Existing Platform

Four-legged K and diagonal bracing jacket-type platform installed in the Gulf of Suez in approximate water depth of 33.7 m as shown in **Fig.1**. The platform is braced by 6 horizontal bracing. Jacket legs are battered 1:10 in the two transverse directions. Jacket legs are sized to accommodate 30” outer diameter piles. The platform has three deck levels "main, mezzanine and cellar deck" and one boat landing.

III. Finite Element Modeling

A detailed 3D model including jacket, decks and piles above sea bed were conducted to perform the seismic analysis and the optimization by using ANSYS APDL software.

All members were modeled as 3D elements that are rigidly connected to each other with six degrees of freedom at each joint. The piles, jacket legs and bracing were modeled using PIPE289 element which take into consideration the hydrodynamic effects. Marine growth was modeled as pipe insulation. PIPE289 element was also used for modeling deck legs and braces in addition to other tubular elements (such as hangers). BEAM188 element was used to model the deck beams. No hydrodynamic effect is taken for deck members as they are above mean water level. All jacket appurtenances like boat landing, risers, conductors and different deck loads, e.g. plating/grating, equipment loads, vessels and etc., were modelled as point masses applied at legs by using MASS21 element.

The finite element model is also considered some well-known parts/connections in fixed offshore platforms (**Fig.1**) such as Joint Can, Wishbone which was simulated in this model by two nodes in the same location, one of them for jacket leg and another node for pile, with coupled degree of freedom in the lateral translations degree of freedom (local nodal X and Y directions) and welding of pile to top of jacket leg (Crown Shim plates)was simulated in this study by modeling both pile and jacket members rigidly framing to one joint.

Model global coordinate system has the origin at the center of the jacket legs and lies at the M.W.L elevation. Nodal coordinate system for wishbone was rotated according to jacket legs batter. The structure is fixed at four piles' nodes at mud-line as shown in **Fig.1**.

In order to initiate the optimization process, modeling of an initial random jacket topology was carried out. A random shape of jacket was chosen as a first generation by using the simulation of the existing deck and jacket, then adding random vertical and horizontal bracing as illustrated in **Fig.2**. The new bracings in the 3D model were generated by representing unique cross section definitions**.**

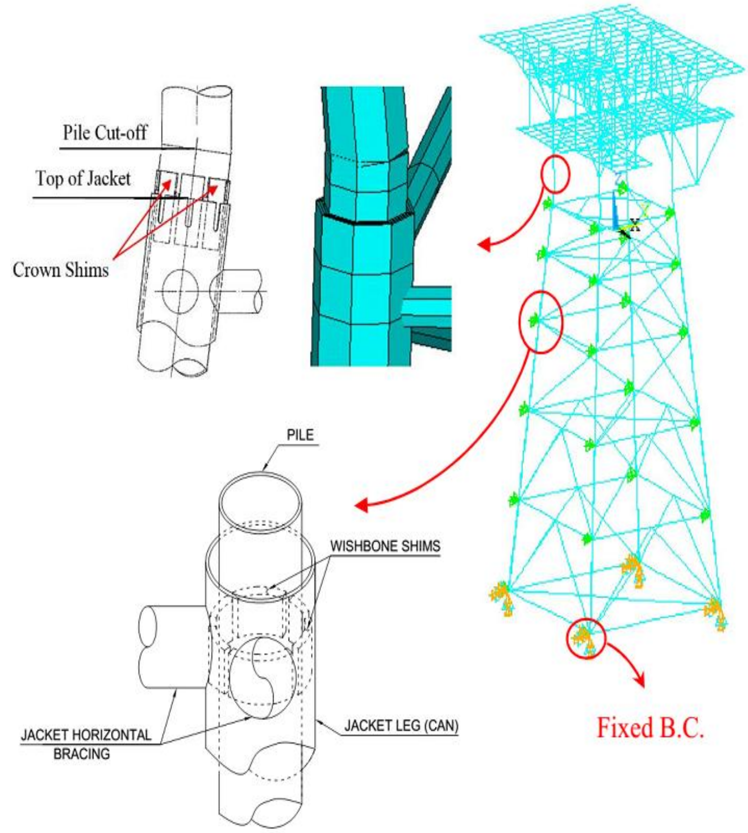


Fig.1: Schematic Model of Existing Jacket Platform

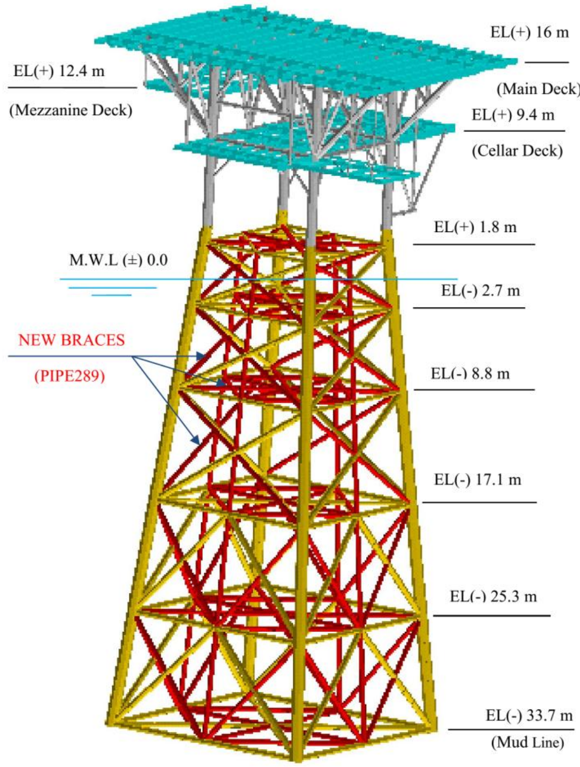


Fig.2: 3D Simulation Model of 1st Generation of New Shape of Jacket Platform

IV. Dynamic Properties

The mass used in this study as per API2AWSD-2014 [12] as it contains structure mass including gravity loading, entrapped water mass in the structure and hydrodynamic added mass which is considered in motion transverse to the longitudinal axis of the individual structural element. The total masses of the existing structure in the three principle directions are 1680 MT in the X-direction and Y-direction and 1613MT in the Z-direction. The total masses of the 1st generation new shape are 1939 MT in the X-direction, 1941 MT in the Y-direction and 1874 MT in the Z-direction.

Modal analysis of the structure is performed using Block LANCZOS method [14] to provide information about the structure's dynamic behavior to perform the time history analysis. The lowest and the highest dominant mode frequencies of the existing platform were used in this study for calculation of Rayleigh damping constants α (mass proportional damping) and β (stiffness proportional damping) [14] and [15], calculating suitable Newmark integration time step [14] and [15] and for scaling of earthquake records. The same values of these factors were used in the assessment of the existing platform and the optimization study because the generated shapes during the optimization process have different dynamic properties making the solution more complicated. The basic equation solved in a typical un-damped modal analysis is the classical Eigen value problem:

$$[K]\{\Phi_i\} = \omega_i^2 [M]\{\Phi_i\} \qquad (1)$$

Plots of X, Y and Z direction mode and torsion mode shapes and their corresponding natural frequencies of the existing platform and the 1st generation new shape are illustrated in **Fig.3** and **Fig.4**, respectively. The mode frequencies of the 1st generation new shape are higher than those of the existing shape as they are affected by the increase of the stiffness due to the new added braces in spite of the increase of the masses.

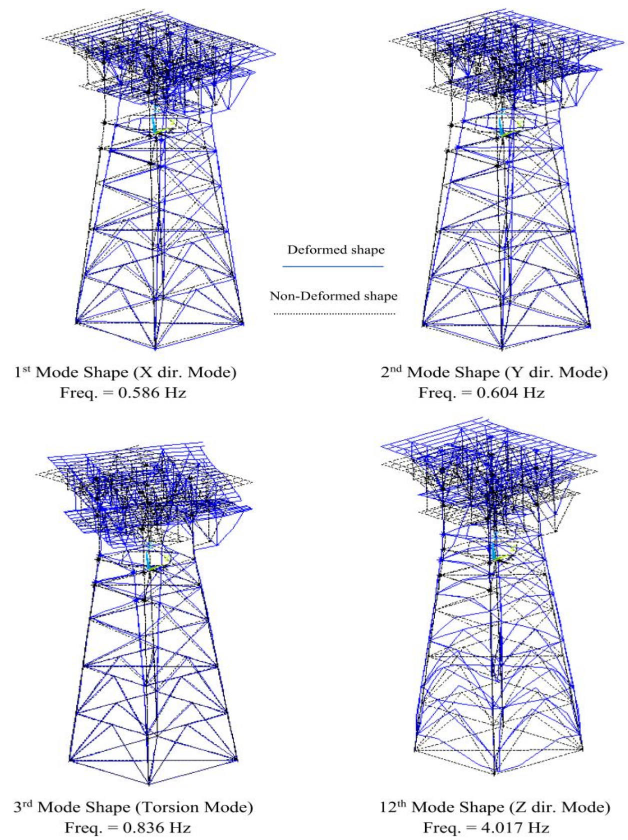


Fig.3: Dominate Mode Shapes and Natural Frequencies of Existing Platform

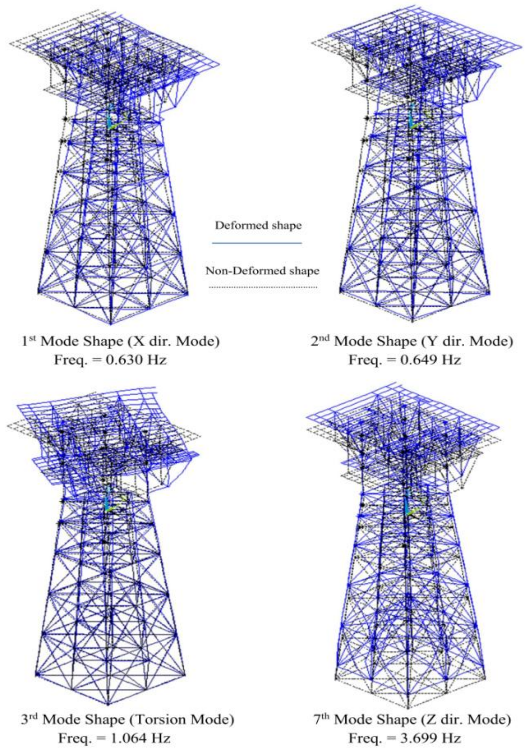


Fig.4: Dominate Mode Shapes and Natural Frequencies of 1st Generation Random New Shape

V. Earthquake Time History Analysis

From the structural engineering point of view, it is possible to design an offshore jacket structure to withstand the strongest earthquake without yielding, but it would not be economical. On the other hand, it may be impractical to ignore the consideration of the stronger earthquakes, even though they occur very infrequently [6]. Seismic design guides [4] and [5] have adopted the dual approach design philosophy where it is stated that structures located in areas which are seismically active shall be designed for extreme level earthquakes (ELE) using the ultimate limit state, and the abnormal level earthquakes (ALE) using accidental limit state.

5.1 Seismic Analysis as per API RP 2EQ

In this study, linear time history analysis "Extreme Level Earthquake-ELE" was performed after selection and scaling of a set of earthquake time history records as per API-2EQ [5] for the assessment of the existing platform and the new optimized shape approach. Only one set is chosen for simplification purpose. The time history records selected and scaled such that they represent the dominating ELE event and match its elastic design spectrum for 5% damping ratio (**Fig.5**) determined as per API-2EQ for Gulf of Suez seismic region. Generic seismic maps of spectral accelerations for the Middle East offshore areas with the simplified seismic action procedure were adopted.

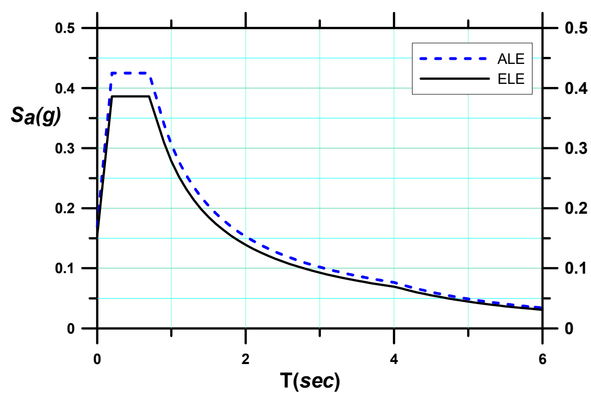


Fig.5: ALE and ELE Seismic Acceleration Spectrum for 5% Damping

5.2 Selection and Scaling of Real Earthquake Records

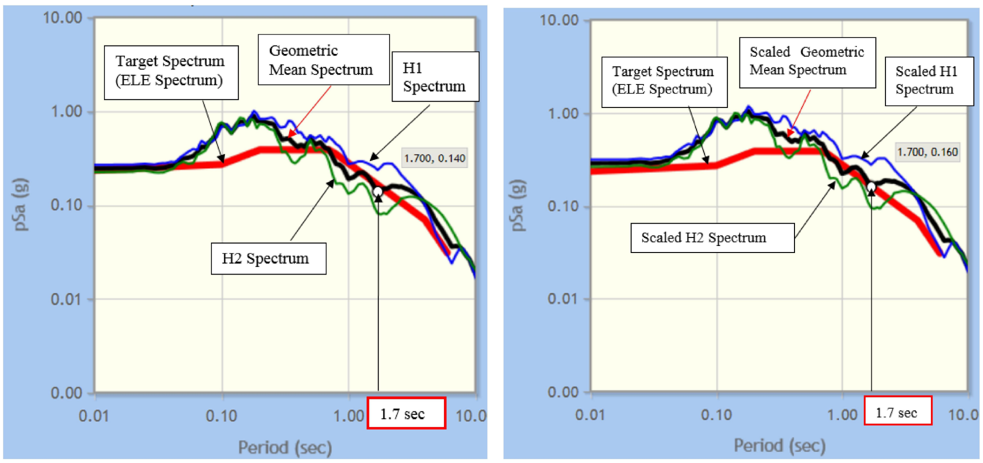
The selection of acceleration time histories is one of the crucial issues of time history analysis to satisfy design code requirements and site condition, fault type, distance to fault and other seismological parameters. Synthetic records compatible with design response spectrum or obtained from seismological models and real accelerograms recorded during earthquakes are three sources of acceleration time histories. Using and scaling really recorded accelerograms is becoming one of the latest recent research trends in this field, because of the increase of available strong ground motion database. Several studies addressed the selection and scaling of real earthquake accelerograms, Yasin M. FAHJAN [16].

According to API-2EQ [5], records scaling will be required to match the level of ELE/ALE response spectrum. Simple scaling is mentioned as a scaling option in which the average response spectrum due to the two horizontal components matches the horizontal ELE/ALE response spectrum at the dominant period of the structure. In this work, real earthquake records were used and scaled to match ELE response spectrum as per API-2EQ. The selection and scaling of real earthquake records were conducted by using the Pacific Earthquake Engineering Research (PEER) Center, NGA strong motion data base [17]. A basic criterion of selection of acceleration time series used by the PEER Ground Motion Database (PGMD) is that the time series spectrum provides a good match to the target spectrum (e.g. ELE spectrum) over the spectral period range of interest. The evaluation of the degree of conformity of time series to the target spectrum is conducted by using the mean squared error (MSE) of the difference between the spectral accelerations of the record and the target spectrum. Records are searched to satisfy general acceptance criteria provided and then ranked in order of increasing MSE. The best-matching records having the lowest MSE.

In this study, the PGMD web-based tool was used to search the database for records that provide a "good match" of the average response spectrum (geometric mean) due to the two horizontal components scaled to the target spectrum (ELE response spectrum) at the dominant period of the structure (1st mode shape period is 1.7 *sec* from **Fig.3**) and then ranked the records in order of increasing MSE.

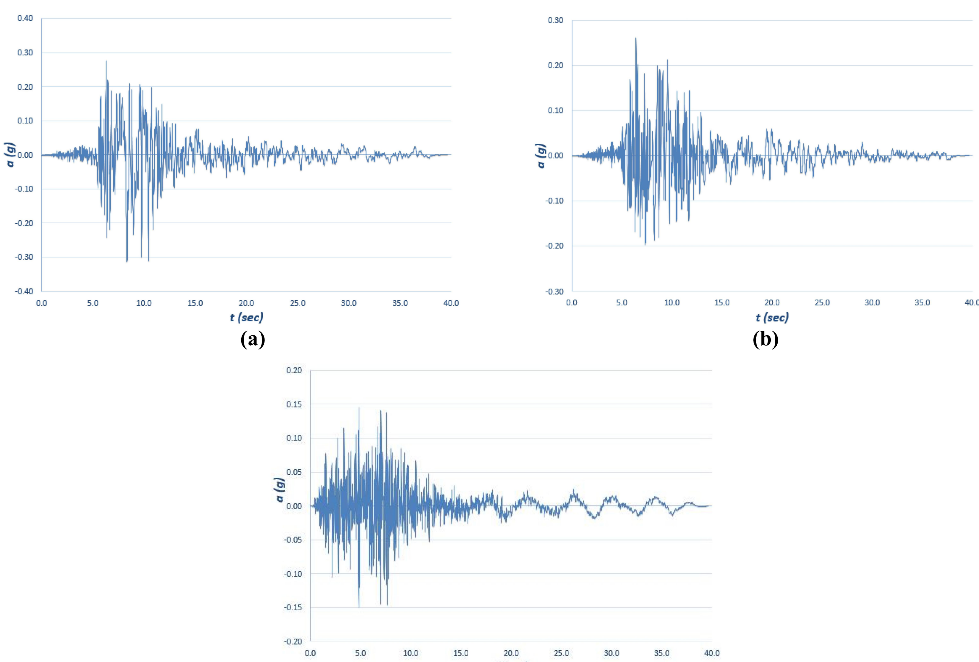
As a result of PGMD search, 1979 Imperial Valley-06, El Centro Array #3 was chosen as a suitable set of earthquake records. It is scaled at period 1.7 *sec* by scaling factor equal to 1.173. It has MSE of 0.200 of the difference between the ELE target spectrum and the average spectral accelerations of the two horizontal components records.

Small Scaling factor and low value of MSE indicate that the mean spectrum of the two-horizontal component (H1 and H2) is a good match to the ELE spectrum at period 1.7 *sec* even though without scaling as shown in the plots at **Fig.6**. This scaling factor is multiplied by the three-acceleration time history of El Centro records (two horizontal and vertical) as illustrated in **Fig.7**. It is also noticed from **Fig.6** that the mean spectra of the two horizontal components (H1 and H2) is in good agreement with the ELE spectrum at periods range from 1 *sec* to 2 *sec*. Therefore, same earthquake loading (scaled records) could be used in this study for the existing platform and new platform in the optimization approach because the mode natural period is changing during optimization process and the natural period of first mode of the generated shapes are not out these period's range.



(a) (b)

Fig.6: Panel (a) Un-Scaled El Centro Spectra and Target Spectrum-ELE (Log-Log Scale), Panel (b) Scaled El Centro Spectra and Target Spectrum-ELE (Log-Log Scale)



(a) (b)

(c)

Fig.7:Panel (a) Scaled Horizontal-1 Acceleration Component, Panel (b) Scaled Horizontal-2 Acceleration Component, Panel (c) Scaled Vertical Acceleration Component

5.3 Initial Condition and Loading Direction

As per API2AWSD-2014 [12], earthquake loads and other simultaneous loads such as gravity, buoyancy, and hydrostatic pressure should be combined. So that gravity, buoyancy and hydrostatic pressure loads are considered in the analysis by include pre-stressing effects in a full transient dynamic analysis by applying the gravity, buoyancy and hydrostatic pressure loads in preliminary static load steps before performing the full dynamic transient analysis.

Only one case of earthquake loading was considered in the assessment of existing platform and optimization process considering the initial condition effect. Horizontal-1 acceleration component (**Fig.7** (**a**)) was applied in the global X direction, the scaled horizontal-2 acceleration component (**Fig.7** (**b**)) was applied in the global Y direction and the scaled vertical acceleration component (**Fig.7** (**c**)) was applied in the global Z direction. The scaled earthquake acceleration records were applied at the supporting nodes.

VI. Topology Optimization of New Design Platform

A topology optimization of new design platform was performed to have a safe structure during earthquake event with minimum total weight. To initiate the intended optimization process, a first generation of random jacket topology was carried out. Existing platform model was used as a basis of the model of the first random shape. New random braces with unique tubular cross section size ($12.75''$ outer diameter $x\ 0.875''$ wall thickness) were added to the existing jacket model as shown in **Fig.2**.

Structural optimization (SO) can be expressed as [18]:

$$(SO) = \begin{cases} minimize\ f(x,y)\ with\ respect\ to\ x\ and\ y \\ subject\ to \begin{cases} behavior\ constraints\ on\ y \\ design\ constraints\ on\ x \\ equilibrium\ constraint. \end{cases} \end{cases} \tag{2}$$

In this paper, proposed automated iterative method of gradually topology optimization of jacket bracing was performed by using programing capability of ANSYS APDL. The objective function is the total weight of jacket and piles. The design variable, x, is the topology of the jacket braces and is modified during the optimization process. The state variable, *y*, is chosen to be Von Mises stress of jacket and piles elements.

6.1 Element Death Option

Element deactivation or "Death" [19] option in ANSYS was used in the optimization process to kill jacket bracing elements. Von Mises stress is the criteria used to eliminate unneeded element. Deactivation is performed by multiplying the stiffness by a severe reduction factor ”1.0E-6 by default”.

Mass, damping and strain of element, element loads, and other such effects are set to zero for deactivated elements. Their mass and energy are not included in the summations in the overall model. The full Newton-Raphson option was used in this study as it often yields good results when using the death option.

Nodes not connected to any active elements may "float," or pick up stray degree-of-freedom (DOF) responses. To overcome that, artificial constraint of inactive DOFs was performed in this study to reduce the number of equations to be solved and to avoid ill-conditioning during optimization iterations. As the study is global analysis not local, less meshing was done to decrease the probability of generating floating members during optimization process.

6.2 Gradually Iterative Optimization Methodology

The entire topology optimization process utilized in this paper is overviewed in the flowchart in **Fig.8**. After finishing modeling and analyses "static and full transient dynamic", arrays are constructed from the results contained maximum Von Mises stresses of all jacket and pile elements. After that, gradually deactivation process for jacket bracing is performed under optimization constraints. Override of stresses values in arrays is conducted in every iteration. Optimization process will continue until one of the members is yielded or the maximum number of iterations is reached.

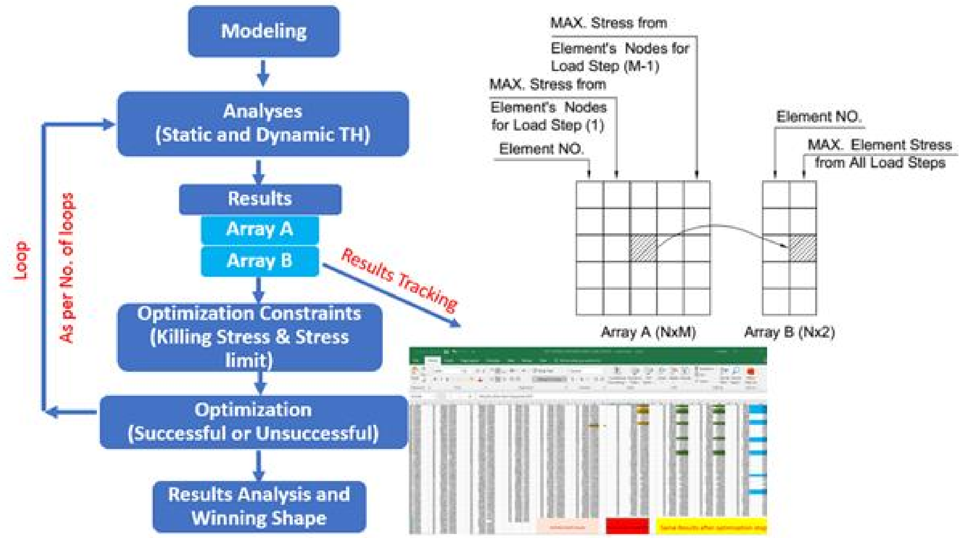


Fig.8: Flowchart of Optimization Process

6.3 Optimization Procures and Programing
To generate an automated iterative optimization process, a comprehensive ANSYS APDL script was written.

6.3.1 Arrays A and B

Arrays A and B play the main role in the optimization process which are constructed after the analysis stage in every iteration. In addition, they are utilized in screening and tracking the results of the analysis and optimization process. **Fig.8** illustrates the main idea of the arrays A and B.

Array A is an array N x M, where N is rows number and it is equal to the total number of the selected elements.M is columns number and is equal to the total number of load steps + 1, the first column is specified for selected element numbers and the rest of columns for maximum Von Mises stress values from element's nodes resulted from load step where every load step has its own column.

Array B is constructed from Array A, N x 2. It has only two columns the first is for selected element numbers and the second is for element maximum Von Mises stress values from all load steps "from critical load step".

6.3.2 Optimization Process Constraints

Von Mises Stress was chosen as a state variable which constrains the optimization process. The “killing stress” is the stress limit specified to deactivate the jacket bracing element. In the used method, number of iterations and killing stress are constraining the optimization process. It was found in this study that killing stress step of 2.5% of bracing yield stress was suitable for the gradually optimization process.

Optimization process changes the load path and accordingly changing stresses in the platform elements. The first-generation new shape has big number of bracing elements. That gives freedom to noticeable changing in the load path, so that stress in bracing element is significantly changing up and down during the optimization process. Some casualties of bracing members were overstressed in the first loops. After conducting some optimization steps, the stress became lower until they were killed. Accordingly, and due to the capability of changing element cross section size, generally, no stress limit or optimization constraint for the jacket bracing was used.

Unlike piles and jacket legs, optimization stress constraint for piles and jacket legs is mandatory to obtain feasible and effective optimized shape. There were few pile elements in the 1st generation shape before conducting any optimization have stresses more than yield stress, so that stress value equal to 1.1 of yield stress was taken as pile stress limitation to constrain the optimization process. While yield stress was taken as stress limitation of jacket leg elements to constrain the optimization process. After ending the optimization, redesign of these overstressed members can be done to get it back to safe stresses by changing element cross section size.

VII.Optimized Shape and Results

7.1 Earthquake Assessment of Existing Platform

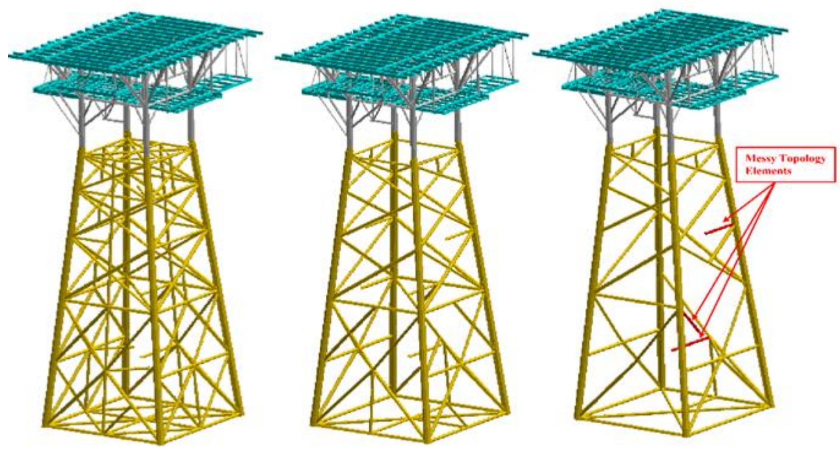
Assessment of the existing platform was performed to compare the results between this platform and the new one generated after the optimization. Static analysis was performed before the full transient earthquake analysis as discussed before. It resulted that the maximum pile stress is at tip (crown piece) and it is very close to pile material yield stress.

7.2 Winning Jacket Topology of New Design Platform

Starting deactivation stress was chosen to be 5% of bracing yield stress for the first and second iteration and increasing of 2.5% of the yield stress was chosen for the subsequent every two loops.

Fig.9 (**a & b**) illustrate sample of generated optimized shapes which were generated after optimization conducted in 6th and 13th loop, respectively. During the optimization process, there were missy topology members generated. They were usually killed in the next loop but sometimes they remain. Final required optimization was conducted in the 21st loop resulted to topology optimization winning shape with three messy topology elements (see **Fig.9(c)**). After two manual modifications were performed on the required optimized shape, the final **Wining Shape of New Design Platform, WSNDP**, is achieved (**Fig. 10**). The first manual modification was disregarding the messy topology element. Stress in a bracing element and two pile elements at top end exceeded yield stress. Therefore, second modification was resizing of bracing elements to be 12.75" $O.D.$ x 0.875" $W.T.$ instead of 16" $O.D.\ x$ 0.375" $W.T.$ and resizing of wall thickness of pile section to be 1" (2.54 cm) instead of 7/8" (2.23 cm). These modifications were done not only in over stressed elements but also in few other conjugated elements to be more practically.

20% of weight saving in jacket bracing is successfully achieved by the proposed optimization method compared to the original weight of the existing jacket bracing. This weight reduction reduces the weight of the whole jacket and piles above mud line by **8%**.



(a) **(b)** **(c)**

Fig.9: Panel (a) New Shape Generated after T.O. Resulted at 6th ITR. Loop, Panel (b) New Shape Generated after T.O. Resulted at 13th ITR. Loop, Panel (c) WSNDP with Messy Topology

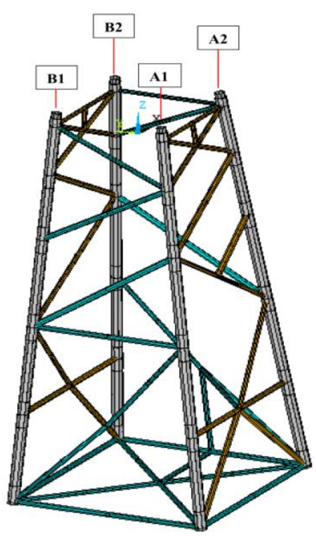


Fig. 10: Jacket Faces of WSNDP

It is noticed in the generated winning shape that, braces parallel to Y direction are more exposed to be lost during optimization process than which are parallel to X direction as illustrated in **Fig. 10**. That attributes to braces parallel to Y direction are lower stressed. It is also noticed that the horizontal braces are more susceptible to loss than the vertical braces. The winning shape is not symmetric as there is no symmetry constraint in the proposed optimization method and it may be due to the consideration of only one loading direction for each component of earthquake.

Curves in **Fig.11** to **Fig.14** illustrate change in maximum Von Mises stress ratio with respect to element yield stress of piles, jacket legs and bracing during the optimization process, in addition to number of causalities during the process. In the first iteration and before any deactivation process, the maximum stress of pile element is bigger than its yield stress (**Fig.11**), so that stress value equal to 1.1 of yield stress was taken as pile stress limitation to constrain the optimization process in this case study. From the figures, it is noticed that there is an optimization step at every iteration loop. From figures **Fig.11**, **Fig.12** and **Fig.13**, maximum stress on pile and jacket leg elements are increasing and decreasing during the optimization process without significant change except after optimization done in the fourteenth loop and the twenty first loop, after generation of the winning shape, stress at jacket leg was significantly increased.

Load path is changing during the optimization process. In the beginning and before conducting any optimization step there were four overstressed pile elements exceeded the yield stress and after optimization done in the 6th iteration, there weren't any overstressed pile element and after that the stress exceeded the yield stress again (**Fig.11**). During optimization process, stress of bracing elements is significantly changed during optimization process as shown in **Fig.14**. Some casualties of bracing members had been overstressed in the first loops. After conducting some optimization steps, the stress became lower until they were killed as shown in **Fig.15**. Therefore, no stress limit or optimization constraint for the jacket bracing was used in the new design platform optimization process.

Twenty-three loops were chosen. As mentioned, the iteration loop starts with the analyses then results stage and finally the optimization stage. Shape generated in the twenty first iteration was chosen to be the winning shape. Results of this winning shape were obtained in the next loop in the twenty second loop. This last intended optimization step was conducted by deactivating braces had stresses lower than 30% of bracing yield stress. Eliminating missy topology members and resizing of the cross section of limited pile and bracing elements which exceeded the yield stress were conducted to obtain the final wining shape with safe stresses as shown in **Fig.11** and **Fig.14**.

Optimization was done in the twenty second iteration. It is unneeded optimization as stress was increasing in more bracing and pile elements at different positions which exceeded the yield stress but not exceed the optimization stress limit. Last optimization was done in the twenty third iteration getting the stress in jacket leg element exceeded the jacket leg optimization stress limit which is its yield stress. No optimization could be done if number of loops is more than the chosen twenty-three loops.

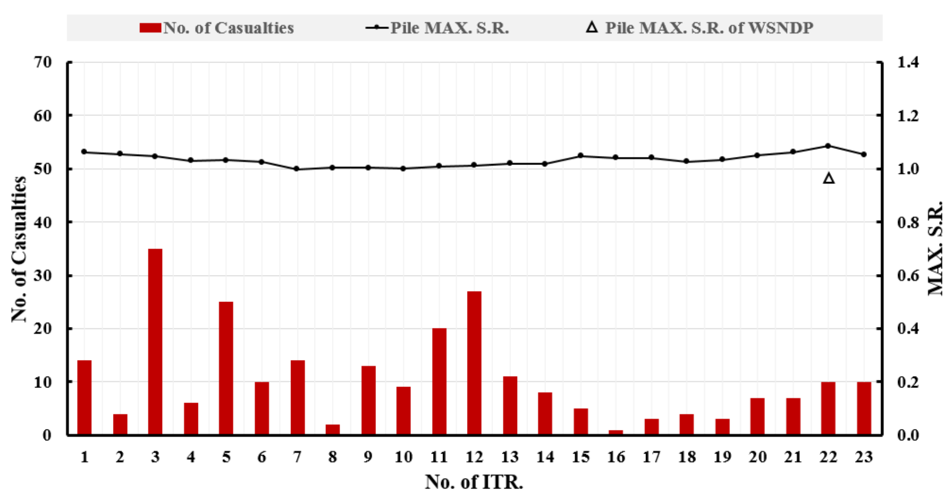


Fig.11: No. of Casualties and MAX. Stress Ratio of Pile Elements

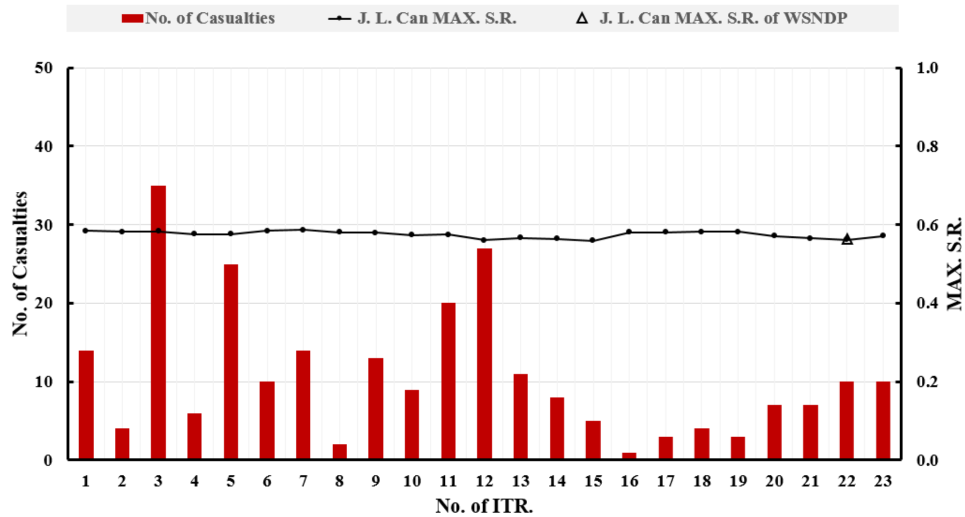


Fig.12: No. of Casualties and MAX. Stress Ratio of J.L. Can Elements

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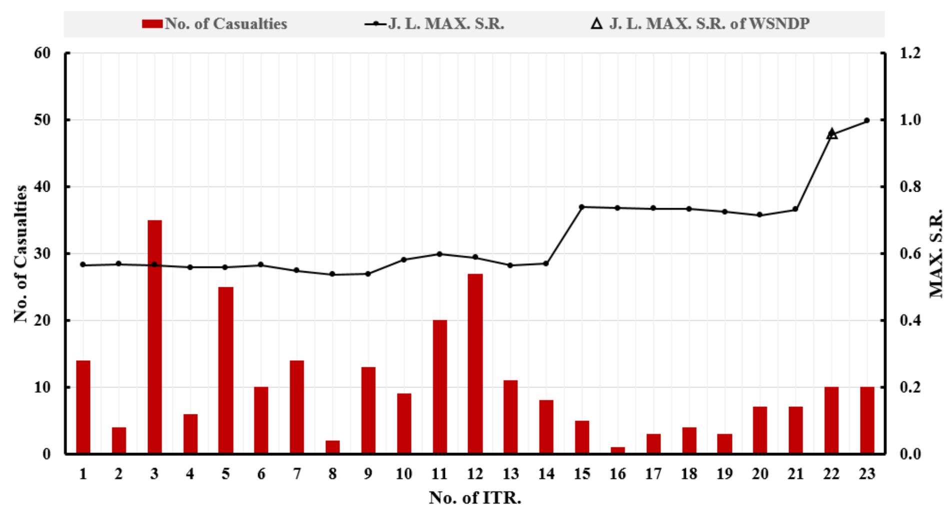

Fig.13: No. of Casualties and MAX. Stress Ratio of J.L. Elements

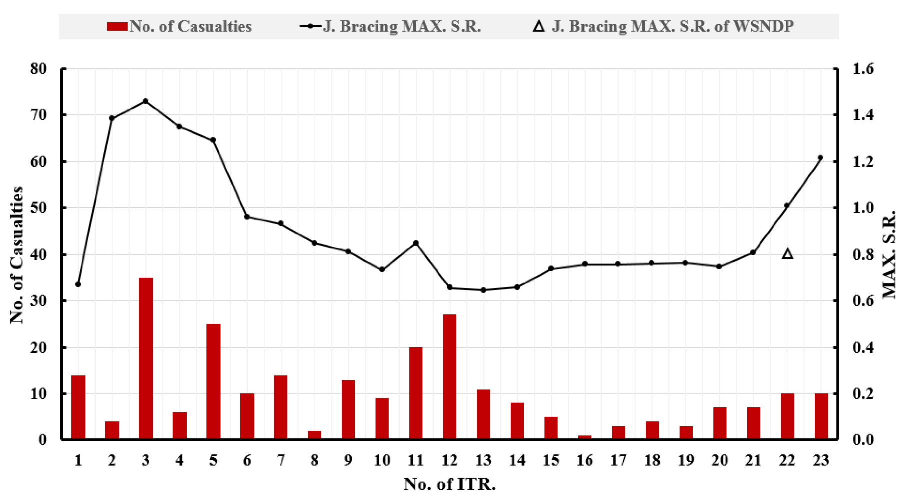

Fig.14: No. of Casualties and MAX. Stress Ratio of J. Bracing Elements

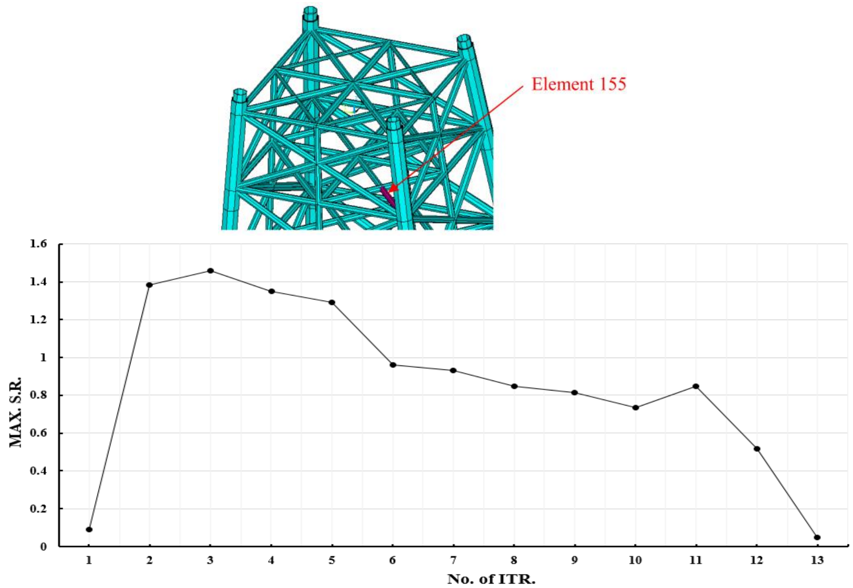

Fig.15: Change of MAX. Stress Ratio of Bracing Element 155

7.3 Comparison between EP and WSNDP

Table 1 illustrates weight comparison between existing platform (EP) and wining shape of new design platform (WSNDP). Weight saving in jacket bracing is successfully achieved by the proposed optimization method compared to the original weight of the existing jacket bracing.

20% weight saving in jacket bracing or 8% weight saving in whole jacket and piles above mud line is achieved in the wining shape of new design platform. Weight reduction decreases direct costs such as material and manufacturing costs and indirect costs such as using marine equipment and cranes with lower capacity. This leads to saving in overall costs. Not only could weight reduction be achieved by optimizing jacket bracing but also reduction of number of anodes which is used for cathodic protection. Marine growth accumulation on the jacket platform is also reduced leading to subsequent reduction in wave and current loadings.

Table 1: Weight Comparison between EP and WSNDP

	Weight of Jacket Bracing (Tonne)	Weight of Jacket and Piles above Mud Line (Tonne)
EP	74.5	189.2
WSNDP	59.9	174.9

Table 2 illustrates comparison of maximum drift at top deck node. **Table 3** illustrates comparison of maximum total reaction forces.

Table 2: Comparison of MAX. Drift between EP and WSNDP

	Drift at X dir. (m)	Drift at Y dir. (m)
EP	0.226	0.085
WSNDP	0.211	0.147

Table 3: Comparison of MAX. Total Reaction Forces between EP and WSNDP

	Total Base Shear at X dir. (kN)	Total Base Shear at Y dir. (kN)	Total Vertical Forces at Z dir. (kN)
EP	-5003	1936	14902
WSNDP	-4562	1589	14800

VIII.Conclusion

The authors' goal in this research is to advance of application of the proposed topology optimization method to jacket platform located in the Gulf of Suez. Earthquake loading as per API-2EQ of Extreme Level Earthquake, ELE, event is considered in this study. Three components (two horizontal and vertical) of 1979 Imperial Valley-06, El Centro Array #3 earthquake is chosen as a set of earthquake records for the time history analysis. Selecting and scaling are performed by using PEER Ground Motion Database.

By implementing this optimization method, winning topology optimized shape is achieved with considerable weight reduction compared to the original weight of the existing platform. The proposed topology optimization method distributes braces with feasible shape without induced sudden increasing in stresses, significant decreasing of stiffness or significant sudden change in the load path. This method has the capability to identify redundant elements in the design space. This approach streamlines the optimization process by automating the analysis and design iterations, therefore decreasing the time and the cost, in addition to increasing the solution efficiency.

In this optimization approach, manual modification may be needed to disregard missy topology elements or resize of member cross section after final required optimization step. There is no constraint to maximum response displacement so that it needs to be checked after obtaining the optimized winning shape.

More earthquake loading directions and buckling assessment are needed to be considered to obtain results more practical. Other types of pre-service, in-services loading such as environmental loading and fatigue damage are needs to be studied. In addition to, nonlinear with soil structure interaction is needed to be studied to evaluate Abnormal Level Earthquakes (ALE) according to API-2EQ.

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