Benefits of Using Skirted Pile Jacket Instead of Pile Through Leg Jacket in Persian Gulf

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Abstract
In current research two existing pile through leg jacket platforms of Forouzan oil and gas zone are modeled with skirt piles in SACS software to compare their structural behavior, weight, constructability, maintainability, removal costs and other parameters to find which design method is more beneficial for Forouzan oil and gas zone. Modeling and analysis are done based on original jackets design criteria and specification to reach more realistic results. Selecting design and fabrication method in offshore projects are closely related to contractors' equipment and experience and also each method has its own beneficial and advantageous points which can lead to use them in specific projects. These methods discussed comprehensively in current paper however for this particular site and its environment, the analyses indicate that using skirt pile method may result in more optimized and lighter structures which are easier to install and remove and more structural benefits and lower costs can be attained in this zone.

Keywords: Pile Through Leg, Skirt Pile, Fixed Platform, Deep Foundation

Introduction

Jackets (fixed platforms) are the most common offshore platforms designed for areas with low or middle water depth such as Persian Gulf. Foundation systems which are mainly used for this type of structure are piles through leg (pin piles) and skirted piles.

Piles are stabbed from top of the jacket to the required depth in soil at through leg method. In this method deck is installed on the piles, so piles carry the weight of deck directly. Pile and leg connection is provided by welding at top elevation of their connection area [1]. Also the gap between the inner diameter of leg and the outer diameter of pile can be filled with cement grout. In this kind of platform, the diameter of leg is dependent to the diameter of pile. In fact the inner diameter of leg should be larger than the outer diameter of pile plus gap between them [2].

Piles in the models designed with skirted pile method are connected to structure with skirt at little distance above sea bed (e.g. 10-12 meters above sea bed). The deck is installed on the legs at top of jacket and the forces resulted from deck are transferred across the legs to the piles via skirts. Designers should consider that the weight of deck is carried by legs; therefore the strength capacity of legs should be enough to bear design loads. Obviously in skirted pile systems, the diameter of leg is independent from the diameter of skirt pile. In some projects, designers could optimize leg size independent of pile to carry its assigned loads. Meanwhile piles are connected to the structure at the lower elevation. On the other hand by decreasing the quantity of steel materials, dead load is decreased and as a result the structure provides better behavior and preferable outcomes in different analysis.

Previous Studies

Nowadays more than 30% percent of world energy comes from offshore hydrocarbon resources. During past recent years extraction of oil and gas from offshore resources has grown rapidly which caused to utilize deep sea resources. Extraction from deep sea resources require bigger, straighter, heavier and complicated structures in order to withstand sea forces and heavy loads on their deck and these difficulties force engineers to recognize marine structures behavior more accurately and find a better way for fabrication and installation of them.

Due to the expensive cost of fabrication, installation and operation of offshore platforms, in the past recent years a number of researches and experiments devoted to recognize the behavior and improve design of these types of structures. By having a huge amount of oil and gas resources in Persian Gulf, Iranian scientist need to develop their design knowledge in this particular field.

Regarding Persian Gulf depth and environment, jacket platforms are widely used in oil and gas fields. Jacket platforms are the types of fixed platforms which are suitable for low to medium water depth and calm to moderate environmental condition. For these situations, jacket platforms are the most economical platforms and widely used. In these type of platforms, vertical loads of deck and horizontal loads from waves are transferred to soil by piles. Two major types of jacket foundation system which are commonly used in these jacket platforms are "pile through" and "skirt pile" types.

Pile through leg: In this method piles are inserted from top elevation of jacket to below seabed. Platforms load are transferred directly by the piles to soil and legs are just a template for piles. Pile legs are commonly long and legs diameter are determined by pile diameter. In some cases gap between pile and leg filled with grout which helps energy absorption.

Skirt pile: In this method a pile or group of piles surrounding each legs of jacket like cluster. Piles in this method are not continued in whole length of jacket legs and they are just joint with some parts of legs. In this method in contrast with previous method, legs play an important role in transferring deck load. Because of using clusters in foundation system, designers can reduce the number of legs or decrease piles length.

Each system has its advantages and disadvantages, which leads to use each of them in particular projects. In this paper specification of each method is completely discussed and after modeling of jackets in SACS, a comparison is done. All design procedures has been done in accordance with API-RP2A standard [3].

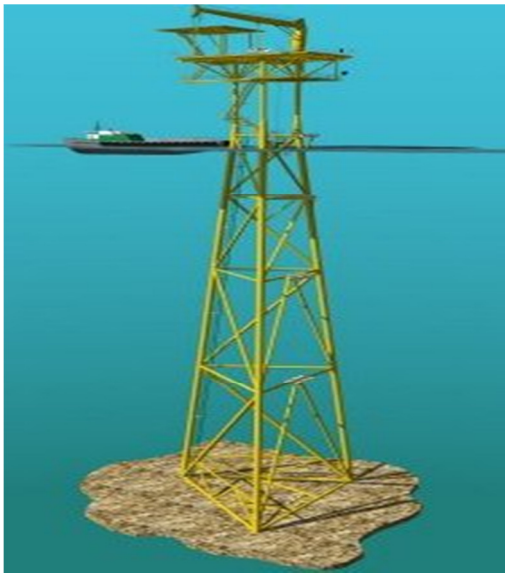

Figure 1: Pile through leg jacket platform

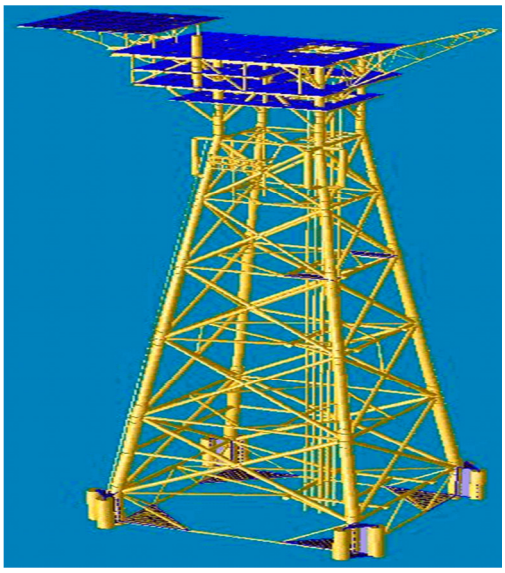

Figure 2: Skirt pile jacket platform

Palmer and his partners [4] made a similar research for design of four leg jacket platform 205-A in Gulf of Mexico. The depth of water was 134m and due to deck loads and environmental forces 84 inch pile was needed based on skirt pile which is smaller than diameter of pile based on pile through leg method. Designing jacket with skirt piles helped to reduce structure weight in legs and steel consumption, make installation easier by using lift operation instead of launch operation which is possible by lighter weight of skirt pile jacket platform.

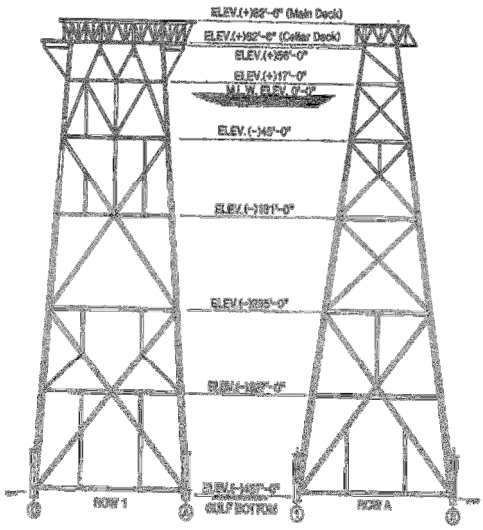

Figure 3: 205-A Jacket platform

Sleeves were used for connection of skirt piles to the legs. Note that his method prior was used in North Sea jackets to reduce steel quantity. In Iran a number of platforms such as SPP1 and SPQ1 were designed and constructed by skirt pile method due to their heavy weight.

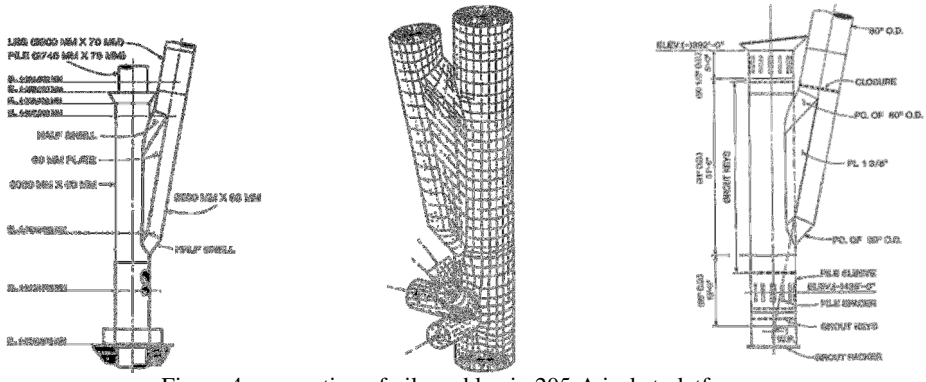

Figure 4: connection of pile and leg in 205-A jacket platform

If the design loads due to heavier equipment of deck or soft soils at the site plan makes impossible to use one pile on each leg, skirt pile method has an advantage to connect two or more piles on each legs. In these cases interaction between piles should be considered. In order to find out exact influence and interaction of piles, different studies were done such as Geoffrey Watson research on interaction between piles in skirt pile jacket platforms. The research was done by using finite element method [5]. Some different researches are done to understand effect and strength of cement grout in connection of pile to legs, different types of pile sleeve connection and different arrangement of piles when two or more piles on each legs connected[6, 7].

Comparison of Pile through leg method versus Skirt Pile

In skirt pile jacket platforms, unlike pile through leg method, leg design is independent from pile required diameter and also in soft soils requires using greater pile diameters for resisting loads. Reducing leg diameter due to independence from pile diameter and design load for applied force could make it lighter with different diameter in length and also by elimination of in leg pile length structure weight reduces significantly. By reducing leg diameter, especially in the first 10 meters from sea water level which is subjected to sea and wave forces, horizontal forces acting on jacket platforms will be reduced. At least by composing two positive effects of reduction in structure weight and reduction in environmental forces which are related together and reduces due to reduction in other parameters, designing jacket platforms by skirt pile method can help designer to plan more beneficially. Another advantage of skirt pile method is easier removal due to its lighter weight and easier cutting of hollow leg instead of leg with pile and grout inside it.

Pile through leg method also has its own advantages such as easier pile installation and more experience available about this method. It has more beneficial points in impact energy observation and ship collision due to great moment inertia of its combined pile and leg section. As a result of elimination of pile inside leg and reduction of leg diameter, the center of gravity will be moved lower level and structures weight will reduces, both of them help to perform better in earthquake analysis.

Modeling

Modeling of jacket platforms are done in SACS software by made a similar model of existing jacket platforms FY-A and FZ-A then made a new model with similar loads and environment but with skirt piles and design of jacket legs based on their loads and independent from pile size.

Jacket platforms specifications are:

FY-A:

FY-A is a living quarter platform. Platform north is oriented 45° from true North towards East.

FY-A is designed with Deck leg spacing of 17.5m in both the direction and it is supported over 4 legged Jacket.

FY-A Jacket structural design is a 4-piled substructure with all the four legs battered. All jacket legs have apparent batter of 1:10 and true batter at 1:7.071.

Two Launch trusses spaced at 12.192 m are provided perpendicular to Row 1 to allow the jacket installation by a launching operation.

FY-A jacket is designed with four horizontal bracing levels at the following Elevations, referred to LAT:

- El. (+) 6.40 m
- El. (-) 8.8 m
- El. (-) 26.5m
- El. (-) 46.9 m

The jacket has four separate mud-mats at the bottom of each leg. Configuration of mud-mats should be such that it does not project beyond launch truss bottom tubular, so that there is no hindrance during load out.

FY- A Deck consists of six floors; levels are as follow, with reference to LAT:

- Helideck at EL. (+) 35.550 m (TOS)
- Roof Deck at EL. (+) 31.550 m (TOS)
- LQ QB Level at EL. (+) 27.550 m (TOS)
- LQ QA Level at EL. (+) 23.550 m (TOS)
- LQ Main Deck at EL. (+) 18.550 m (TOS)

Cellar Deck at EL. (+) 12.300 m (TOS)

FZ-A:

FZ-A is a Process platform, oriented platform north 45° from true north towards east, with six number of Deck legs supported on six legged vertical jacket with main pile of 60” diameter.

FZ-A jacket is designed with 4 horizontal bracing levels at the following Elevations referred to LAT:

- El. (+) 6.40 m
- El. (-) 8.5 m
- El. (-) 27.45m
- El. (-) 46.4 m

Two Launch trusses spaced at 18m are provided perpendicular to Row 1 to allow the jacket installation by a launching operation.

The jacket has 4nos. separate mud-mats at the bottom of each corner leg. Configuration of mud mat should be such that it does not project beyond launch truss bottom tubular, so that there is no hindrance during load out.

In addition to the above, boat access to be provided at NW corner to permit vessels to approach and moored head into prevailing waves, wind and tide (Prevailing wind and wave are from NW).

All above items are located on the inside of the structure.

FZ-A Topside Deck is a six-legged structure designed with the following 5no floor levels:

- Above Upper Deck at EL. (+) 35.450 m (TOS)
- Upper Deck at EL. (+) 26.550 m (TOS)
- Main Deck at EL. (+) 18.550 m (TOS)
- Cellar Deck at EL. (+) 13.050 m (TOS)
- Below cellar deck at EL. (+) 10.500 m (TOS)

All levels given above are with reference to LAT.

And environmental data are:

Water depth: 47.9m

The water depth values refer to Chart Datum (CD). As the difference between CD and LAT is small, the water depths will be taken as LAT in the current design.

Wave, Tidal and Current:

All water levels are referenced to Lowest Astronomical Tide (LAT). The wave and current design data is omni-directional:

Tabele1: Wave, Tidal and Current

Design Data	Units	1Year	100Year
Significant wave height	m	3.5	6.3
Max.wave height	m	6.5	11.7
Period of maximum wave	s	8.1	11.5
Storm surge + Total Tide	m	2.0	2.9
Surface current	m/s	0.75	1.3
Bottom current	m/s	0.3	0.4
Profile		1/7 power law	1/7 power law

Wind Data
The prevailing wind direction is from the North-West.
Wind speeds at other elevations will be calculated in accordance with API RP 2A, Ref.2.3.
The maximum wind speed at 10 m above LAT is given in the table below.

Tabele2: Wind Data

Return Period	1 year	100 year
1 Hour	22 m/s	26 m/s
1 Minute	25 m/s	31 m/s
3 Second Gust	29 m/s	35 m/s

Marine Growth
In the calculations the density of the marine growth is taken as 1.4 t/m3.

Tabele3: Marine Growth

Marine Growth (H = height relative to LAT m)	Radial thickness (mm)
H > +2.5	0
-2.5 < H < 2.5	50
H < -2.5	25

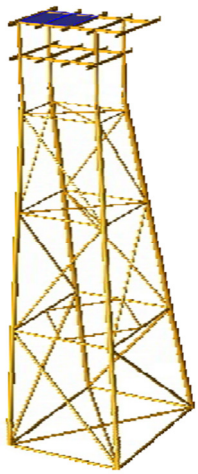

Figure 5: 3D view of original 4 leg pile through leg jacket platform FY-A

In skirt pile jackets leg diameter is reduced in sections from mud line to top level of jacket. This optimization was done due to the decreases of the loads in the legs from bottom to top. The skirt pile models are the same as original

models and just leg diameter is reduced with original model leg thickness to avoid punching shear. In selection of legs sections, ASME standard used to select real sections.

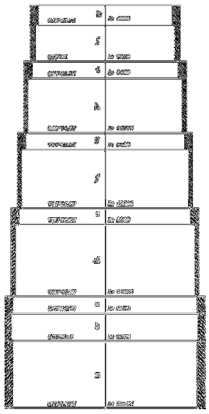

Figure 6: Reducing leg section from bottom to top in skirt pile jacket

Results and Discussion

In skirt pile jackets unity check increases due to decrease in leg diameter which leads to more economical design. In skirt pile jacket platforms due to decrease in environmental forces, the displacement at top of the jacket also decreases. Pile length in skirt pile jacket platforms decreased significantly from 60m below sea bed to 34m below sea bed with the same pile diameter, which is caused from lighter super structure and smaller environmental forces as a result of decrease in leg diameter.

By using grout in both type of jacket platforms energy absorption increased and especially in pile through leg jacket platform, stress decreased. Furthermore in skirt pile jacket platform which utilized grout, installation and connection is much easier by eliminating underwater welding operations.

On the other hand, construction of light weight jacket platforms is more straightforward and makes it easier to transfer from yard to sea. Also lifting operation can be done undemanding due to the crane capacity which is faster and safer in accordance with lunching operation.

Conclusions

Results show that fixed offshore platforms designed with skirt pile foundation show better performance in structural behavior such as "In-Place" and "Earthquake" analysis in comparison with platforms designed by pin piles. By means of using skirted pile, quantity of steel used for piles and jacket structure is reduced which results more optimized and economical design. Also, displacements in connection area of jacket and deck decrease significantly in comparison to pin pile foundation. Due to decreased weight and added mass of structure which is as a result of reduced leg diameter, earthquake force is also diminished.

Implicit studies about using grout in both type of foundation were done and showed that structural behavior and energy dissipation improved and it has more beneficial effects in pin pile foundation type.

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