Dynamic Inelastic Behavior of Fixed Offshore Platforms

Pile-Leg Interaction Numerical Modeling

Campaign 1 (Portal elements)

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Abstract

Increasingly offshore operators of steel jacket structures are requiring reappraisal of existing installations. This may be in the light of revised design recommendations based on a better knowledge of structural performance. Many jackets have foundation piles through each main leg which are welded to the structure at deck level. The annulus between the pile and leg might be filled with cement grout as a means of reducing horizontal deflections, inhibiting corrosion, and increasing energy absorption capacity.

This paper aims at discussing an approach which can be used to demonstrate enhanced structural performance due to both the presence and lack of grouted piles. In this study, nonlinear fiber element will be used. Therefore, different behavior of grouted and ungrouted jackets and the relative different pile-leg interaction is investigated. The experimental results of two frames of the same geometries filled with a standard offshore cement grout in their pile-leg gap under lateral deck displacement-controlled load, together with the two similar frames without any grout, are ongoing and will be presented in near future. However, this paper presents an important comparison between the general behaviors of grouted and un-grouted offshore frames in an area where there are many existing jacket-type platforms.

1- Introduction

Offshore platforms in seismically active areas should be designed to survive rare and unusually intense earthquake motions of ductility level, allowing for local damages, without global failure. The inelastic dynamic response of a structure subjected to severe seismic excitation can be studied, either analytically or experimentally, by applying real time history earthquake acceleration records scaled to produce the desired intensity of ground shaking. An alternative approach as was utilized in this investigation is to impose quasi-static load or deformation histories on the specimen to verify specific aspects of the models [5]. In this case, same displacement history is imposed on all specimens. This way the differences in behavior can be compared and related to differences in the specimens. In this study, nonlinear fiber element for "simulation of buckling, post-buckling and hysteretic responses of tubular struts and nonlinear behavior of portals, formulated in DRAIN-3DX [2]", is introduced; Finally the different behavioral aspects of grouted and un-grouted jackets including different pile-leg interaction are investigated.

Under cyclic excitations, tubular members respond either as portals or as struts. Jacket legs act as portals with nearly constant axial forces but variable lateral displacements. However jacket braces behave as struts with more or less constant lateral forces, but variable axial displacements[3]. Two of most useful applicable numerical models, presented in recent years, for nonlinear dynamic analysis of offshore platforms elements and jacket frames can be summarized as:

I) In Kayvani and Barzegar efforts (1993), based on the engineering beam theory and appropriate provisions for plasticity and large displacements, typical tubular members are successfully modeled and analyzed using the general-purpose FE Program, ANSYS [3].

II) Nonlinear fiber element for simulation of buckling, post-buckling and hysteretic responses of tubular struts and nonlinear behavior of portals, has been formulated and implemented in the nonlinear program DRAIN-3DX by [Asgarian] in [2002] [1,2].

2- Portal Elements & Composite Behavior

In this research, only portal elements are focused on, in order to see the effect of grout on the lateral hysteretic nonlinear behavior and the pile-leg interaction in jacket type platforms, either in grouted or un-grouted cases. The portal behavior of a jacket leg under lateral forces results in a relatively small bending moment at the mid-height of the leg segment between any two adjacent horizontal bracing levels [3]. Moreover, since the axial force of the leg segment does not vary significantly, in many efforts, half of the leg segment used to be modeled by a cantilever under a constant axial force P, and a variable lateral force Q. In this research, however, the sample portal element was modeled completely. Here, two kinds of portal sections are described herein below:

Ungrouted Sections:

Most designers model a jacket leg and the pile within it as two parallel but separate members rigidly connected at the top of the jacket and linked by "wishbone" elements at other major joints. Considering that the annulus, separating the two is very small compared to the length, lateral interaction is possible and its effect on the lateral stability of the pile should not be ignored. For now, assume the annulus separating the two columns to be nearly zero. The pile and jacket leg can be analyzed as one column of composite cross section whose moment of inertia is the sum of the moments of inertia of the pile and jacket, or $I_p + I_j$, a property of concentric circles.

Grouted Sections:

In jacket structures where piles pass through the main legs and are welded to the jacket at deck level the vertical loading from the deck is shared between the piles and the jacket structure. In a global structural analysis, piles within the leg may be modeled as members parallel to the leg and with equivalent support stiffness. Tubular joint forces along the leg are then checked against conventional design formulae capacities allowing for local can thickness. Ultimate load tests have indicated that where piles are grouted there can be considerable enhancements in joint strength and fatigue performance due to composite action between the leg, the grout and the pile. It is concluded that where existing structures are un-grouted or incompletely grouted, grouting can be used as a relatively inexpensive method of improving strength and structural performance.

3- Fiber Elements

In this regard, nonlinear fiber element for simulation of buckling, post-buckling and hysteretic responses of tubular struts and nonlinear behavior of portals, has been formulated and implemented in the nonlinear program DRAIN-3DX by [Asgarian-Aghakuchak-Bea] in [2002]. The new element proposed in that effort, was an inelastic fiber beam-column element capable of accounting for buckling and distributed inelasticity. In this element both material and geometric non-linearities were considered. That method had the advantages of FE method but was much faster. Using this type of element, in conjunction with some other types of elements, the hysteretic response of jacket type offshore structure under cyclic loading or dynamic loading could be simulated. The new element was an inelastic fiber beam-column element capable of accounting for buckling and distributed inelasticity. This element was implemented in DRAIN-3DX in that research work as element type E 16, adopting specifications similar to element E 15 as shown in Fig. 1:

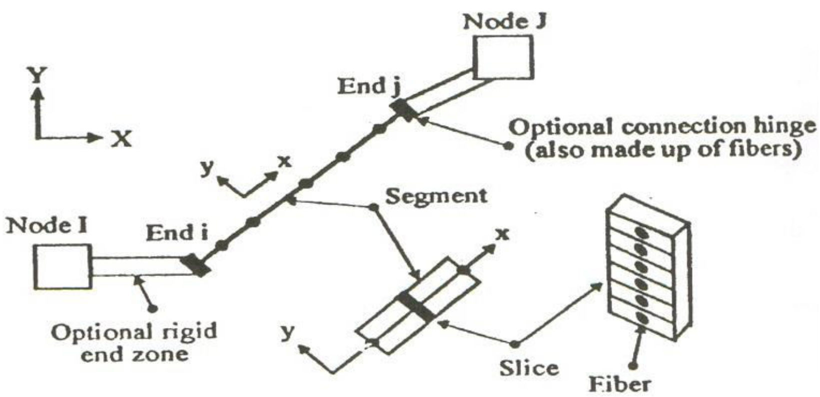
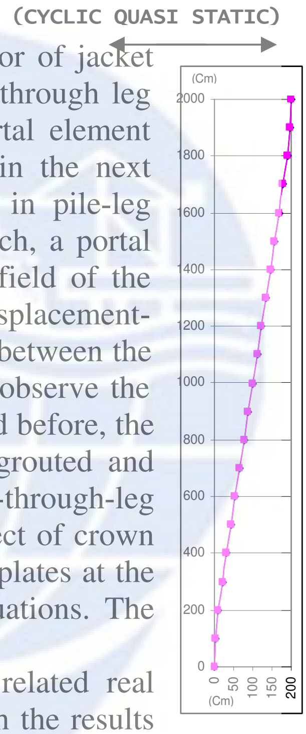


Fig. 1 Element E16 (Post-Buckling Inelastic Fiber Beam-Column Element)

The deformable part of the element is divided into a number of segments. The cross section properties are assumed to be constant within each segment, but can vary from segment to segment. The fiber can have nonlinear stress strain relationships.

4- Proposed Model and Analysis Results



In this research the effect of grout on the lateral inelastic hysteresis behavior of jacket portal elements and the modeling method of pile-leg interaction in the pile through leg types of jackets, are both investigated. In the first campaign, only the portal element behavior is analyzed, both in grouted and un-grouted cases. Then later, in the next campaign, the overall behavior of jacket frames and the effect of grout in pile-leg interaction are going to be investigated. In the first campaign of this research, a portal element of a sample platform by the name of SPD10 (in South Pars gas field of the Persian Gulf in Iran) is numerically modeled and analyzed under the cyclic displacement-controlled increasing lateral loadings, either in case of using grout in the gap between the leg and the pile passed through in the leg, or in case of ungrouted piles, to observe the effect of grout on the behavior of such these composite sections. As mentioned before, the gap fiber post-buckling element in DRAIN software can model both the grouted and ungrouted composite sections and also the exact pile-leg interaction in pile-through-leg types of jackets: Top of the pile-leg are completely restrained due to the effect of crown shim plates of connection joint, on the load transfer rout. The effect of shim plates at the elevation of horizontal braces is considered with the related constraint equations. The bottom of pile is also restrained, simulating the effect of pile fixity in soil.

Some sample grout cubes (made exactly out of the real materials with related real proportions), are tested under the compression, as a parallel activity of which the results may also be used in the second campaign of this project. The 5x5x5 Cm^3 cube samples are made of seawater and cement type II (with Water/Cement weight ratio of 39% which is a common mix proportion for offshore grout purposes with 1.98 t/m^3 density). Three of the cubes were cured in the wet normal open condition, while other three in the entrapped close condition to simulate the entrapped gap space between the pile and leg where no air circulation would exist. The cubes and the resulted load curve are shown hereunder:

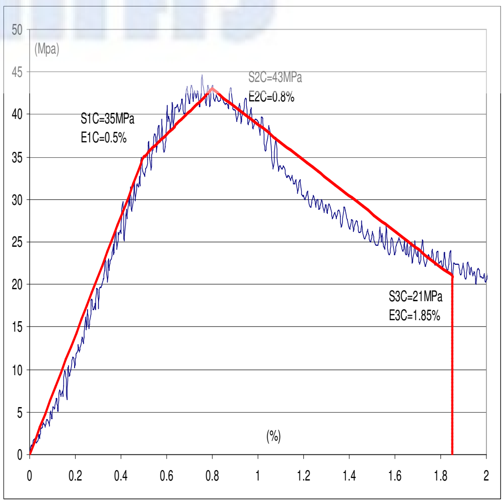


Fig.2 Grout Sample Cubes (3 Were Cured in an Entrapped Space)

Fig.3 Adjusted σ-E Curve of Grout in DRAIN

The measured σ-E curve of grout is used for grouted portal element as the input data of fibers between pile and leg. However overlapping joints are defined along the portal element for un-grouted case, between which, gap elements are modeled to simulate the probable situation where the relative deformation exceeds the gap distance. According to the analysis done by DRAIN software, following results are given.

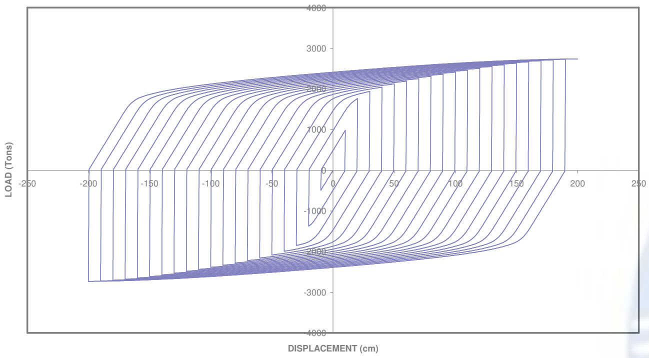


Fig.4 Hysteretic Loop – Ungroute Pile&Leg Interaction With Gap Element

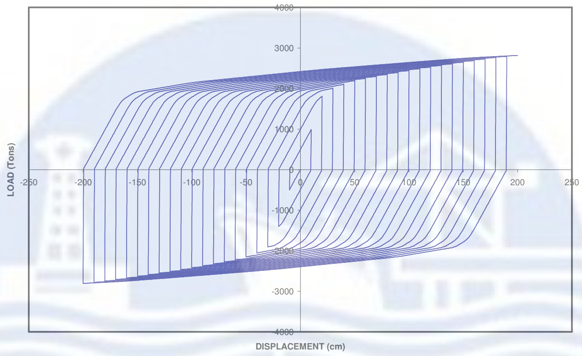


Fig.5 Hysteretic Loop – Grouted Leg

5- Conclusions and Recommendations

1- As shown in Fig. 4&5, it is obvious that hysteric behavior curves of a simple portal element in a jacket-type offshore structure for the grout or non-grout cases, do not depict considerable differences, though as it was expected, grouted one has a little more lateral stiffness. In this effort both cases were exactly modeled numerically (i.e. using fiber element for grouted portal element, and gap element for un-grouted). However the resulted forces, when applying a similar displacement-controlled load, showed only a negligible difference. That seems to be because of the zero stiffness of grout in tension which happens in one side of neutral cord of the element section, while working in bending moment. In the other hand, this difference in behavior must be more and considerable when a frame is being laterally loaded. Since there, this bending moment will be changed to a couple of tension force in one leg-pile and compression in the other, due to the effect of braces. This will be proved/checked in the 2nd campaign, where physical and numerical models of jacket frames are generated, either grouted or not. Furthermore, the effect of crown pieces in connection joint and shim plates and the way how to model them, were investigated and using the presented method, frame of jackets can be easily modeled.

2- In this study, the best method of modeling the pile-leg interaction is presented and would be used in 2nd campaign where a jacket frame dynamic inelastic behavior will be physically and numerically modeled. In un-grouted case, the probable contact between pile and leg was modeled using gap elements with zero stiffness before 5cm relative displacement and rigid behavior in after. This contact is not possible in small deformations due to the effect of shim plates in horizontal braces elevations but is in such these large deformation ultimate capacities studies in which buckling may occur. In grouted composite portals, the effect of grout was modeled using post-buckling fiber elements in DRAIN software, which needs the stress-strain curve of grout behavior. It means that composite behavior of pile-grout-leg is to be modeled in one section, since even in large deflections, the friction potential in walls between steel and grout is much more than produced shear flow, knowing that the effect of shim-plates inside of the legs can be added to this skin friction.

However ANSYS (Keyvani-Barzegar 's method) seems not to be able to model the exact pile-leg interaction, neither in grouted sections nor in un-grouted ones. In the other hand, gap elements (for un-grouted) and composite elements (for grouted) can not easily be modeled in ANSYS for dynamic inelastic studies.

3- The axial compression stress-strain curve of grout was derived, presented and will be also used in 2nd campaign, since there, exactly this mix ratio and material will be used. The grout between pile-leg, being entrapped in between, can not be cured completely; therefore, an average of normal cured and un-cured samples results was obtained.

7- References

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