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NONLINEAR DYNAMIC ANALYSIS OF JACKET TYPE OFFSHORE STRUCTURES SUBJECTED TO EARTHQUAKE USING FIBER ELEMENTS

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SUMMARY

Jacket type offshore platforms in seismically active areas have been to meet two specific level of earthquake requirements named strength and ductility levels. Overall structural response of this type of platforms in the nonlinear range of deformation, greatly depends on the buckling mode, post buckling and hysteresis behavior of jacket braces as well as nonlinear behavior of jacket frame elements. In this paper the Fiber Beam-Column Post-Buckling Element has been formulated and implemented in the non-linear program DRAIN-3DX to predict Buckling, Post-buckling and hysteresis behavior of tubular Struts and Portals. In this element both material and geometric nonlinearities are considered. The element is applied to simulate nonlinear dynamic response of sample jacket type offshore structures subjected to earthquake time history. The predicted overall response matched well with the available experimental and other analytical results.

KEYWORDS

Buckling, Post buckling, Tubular struts, Fiber Beam-Column Post Buckling Elements, Jacket Type Offshore Structures

INTRODUCTION

In recent years experimental and analytical investigations have been directed toward evaluating inelastic behavior of jacket type offshore structures subjected to strong ground motions. Overall structural response of jacket-type offshore platforms greatly depends on the member nonlinear behavior. Jacket members have two types of behavior in the nonlinear range of deformations named portal and struts [1, 5 and 6], as shown in Fig. 1. Jacket legs act as portals and jacket braces behave as struts. In a jacket subjected to lateral loads, braces during compressive loading up to buckling point remain essentially straight and usually elastic (for the case of elastic buckling). After buckling of braces the load descends and the magnitude of axial load decreases with increasing lateral deflection at mid span. The strut thus loses strength in the post buckling range rapidly. In the load reversal, the strut returns to semi-elastic state, but because it is bent, its axial stiffness is much less than the initial elastic stiffness. At the second loading reversal the strut again unloads, regaining essentially its original elastic stiffness. Since residual lateral deflection remains in the mid span of buckled member, it does not however attain its previous compressive strength. During the lateral loading of jacket- type offshore platforms, legs and piles behave as portal in which plastic hinges due to combined action of axial force and bending moment occur in the nonlinear range of deformations. Several methods have been proposed for the modeling of portal and strut members in the nonlinear range of deformation [8,9 and 10]. In this paper a nonlinear fiber elements used for the modeling of both strut and portals.

FIBER BEAM-COLUMN POST BUCKLING ELEMENT

The fiber beam-column post-buckling element is implemented in DRAIN-3DX software, a general finite element program for "Dynamic Response Analysis of Inelastic Frame Structures" [2, 3 and 4]. The element is subdivided longitudinally into a number of segments, as shown in Fig. 2. The slice at the middle of each segment is then divided into a number of fibers. The geometric characteristics of a fiber are its location in the local y and z coordinate and the fiber sectional area Afib. [Fig. 3]. The main characteristics of the elements are as follows:

(a) The deformable part of the element is divided into a number of segments.
(b) The behavior is monitored at the center cross section (or slice) in each segment,
(c) The cross section properties are assumed to be constant within each segment, but can vary from segment to segment.
(d) Each cross section is either elastic or is divided into a number of fibers.
(e) The fiber can have nonlinear stress strain relationships.

The constitutive relation of each section is not specified explicitly, but it is derived by integrating the response of the fibers, which is based on uniaxial stress strain relation of the particular material [5]. Among all element types already implemented, element type E15 is a fiber beam-column element, which is incapable of accounting for buckling loads and post buckling behavior of struts. The new element is an inelastic fiber beam-column element capable of accounting for buckling and distributed inelasticity. This element has been implemented in DRAIN-3DX in this research work as element type E16, adopting specifications similar to element E15.
In this element, both the usual and geometric stiffness matrices are considered:

$$K = K_U + K_G \quad (1)$$

Since the degrees of freedom defined at both element ends, it allows a long, inelastic beam-column member to be modeled accurately using single elements. The method is based on varying the element shape function as the state of the element changes, without introducing additional nodes or elements [OMAE Paper 2002].

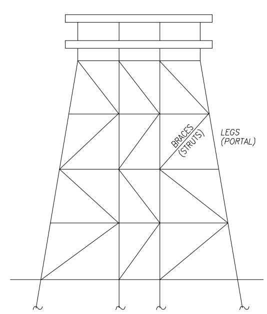


Fig. 1 Jacket Type Offshore Structure

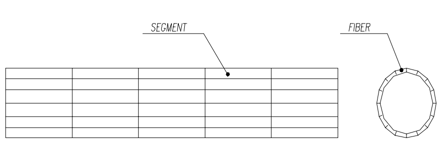


Fig. 2 Segments and Fibers in Tubular Section

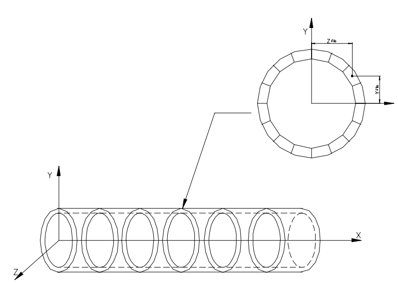


Fig. 3 Geometric Characteristic of the Element

APPLICATION OF FIBER BEAM COLUMN POST BUCKLING ELEMENT

In this section, the fiber beam column post-buckling element is applied to the dynamic time history response of one tested two dimensional and one typical sample jacket type of offshore platforms subjected to several earthquakes.

In order to verify the computer model developed, a comparison is made with the available results of tests and some other theoretical models. Figs. 4, 5 show two and three dimensional elevations of the analyzed platforms.

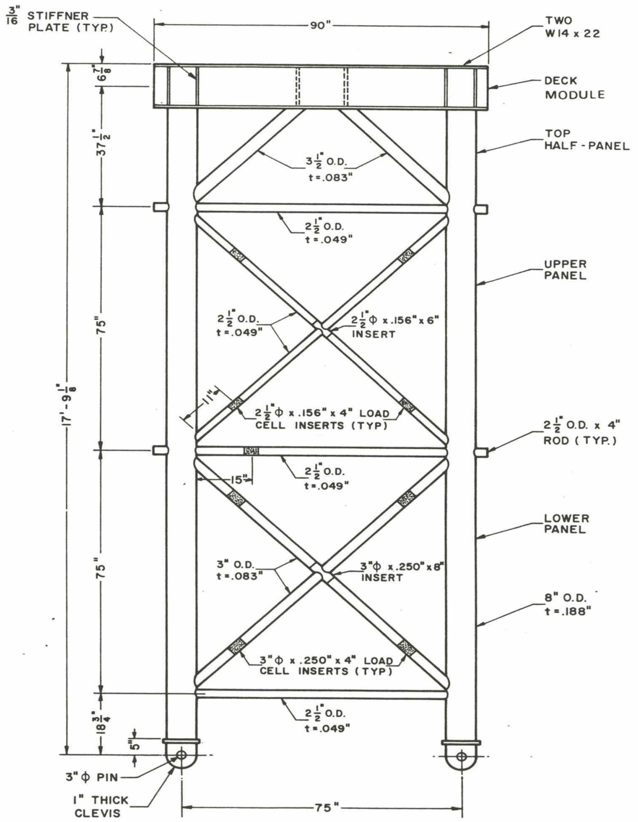


Fig. 4 Elevation of the tested Jacket [7]

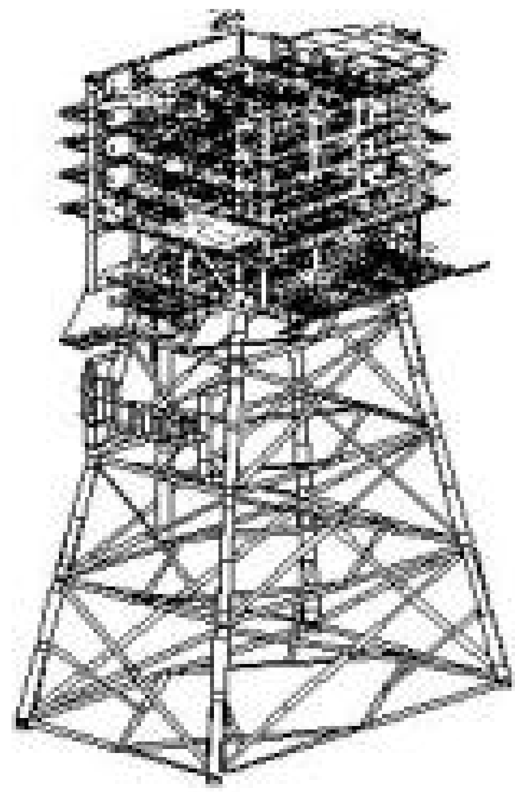


Fig. 5 Three dimensional elevation of the platform

DYNAMIC TIME HISTORY RESPONSE OF TESTED JACKET

Ray Clough and Yousof Ghanaat [7] have studied the dynamic elastic and inelastic behavior of one 5/48 scaled model of an X-braced offshore platform made of tubular members (Fig. 4). This platform in which represented a 5/8 scaled model of a jacket tested by Zayas et al. at UC Berkeley [8,9,10] designed for the southern California according to API guidelines. The platforms subjected to three levels of ground motion: (1) Strength Level Earthquake (SLE); (2) Ductility Level Earthquake (DLE); and Maximum Credible Earthquake (MCE). Earthquake motions used for jacket shaking were modified records using El Centro and Taft recording earthquakes. Linear and nonlinear analyses of the test structure on the shaking table were performed using Fiber Beam-Column Post Buckling Element. In this model the member is divided into 10 segments of equal length. Each of the slices cross section is then subdivided into 16 fibers. A bilinear kinematics hardening material with 5% strain hardening is considered. Because of tested jacket and shacking table interaction, explicit model of the shaking table was developed [7] as shown in Fig. 6. Table 1 compares frequencies of the system for the three levels of deformations in the jacket. A hinge connection model also has been developed and the results for the frequencies presented in the table for comparison. It is observed that the frequencies predicted accurately for the system using Fiber Beam-Column Post Buckling Element. It means that the element used tracked the stiffness degradation of the system due to buckling of the bracings.

Figs. 7, 8 and 9 show experimental and analytical results for the deck displacement time histories for the SLE, DLE and MCE. It is observed that the responses are similar in nature and the peak deck displacements predicted accurately.

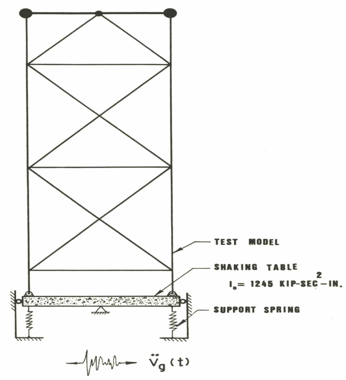
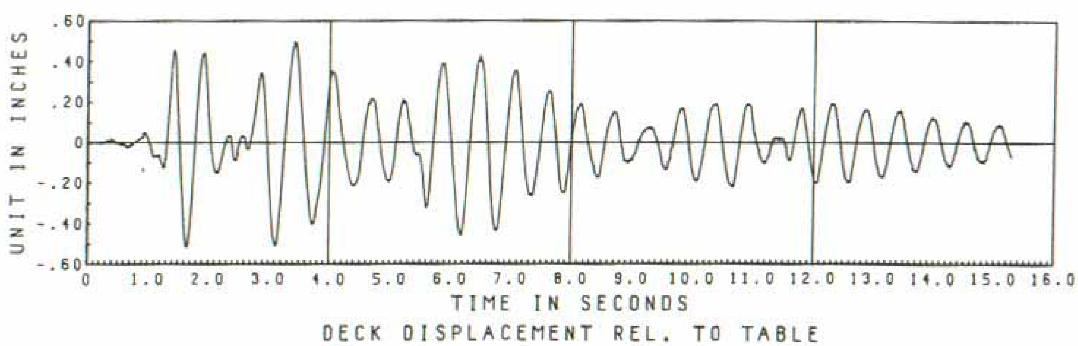


Fig. 6 Tested jacket numerical model considering shaking table interaction

Table 1, Frequency comparison of excremental and analytical model

Test ID	Test Freq. (Hz)	Fiber El. Freq. Considering Table Interaction Effects	Fiber El. Freq. Considering Hinge Connection at Supports
Static	2.75	2.75	2.60
Initial strength	2.125	2.03	2.04
Post strength	1.875	1.788	1.75



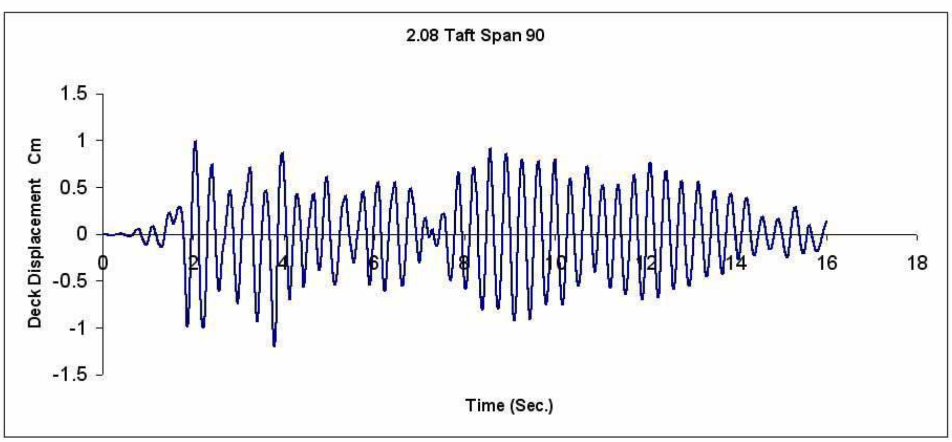


Fig. 7, Experimental and analytical results for the deck displacement time histories for the SLE

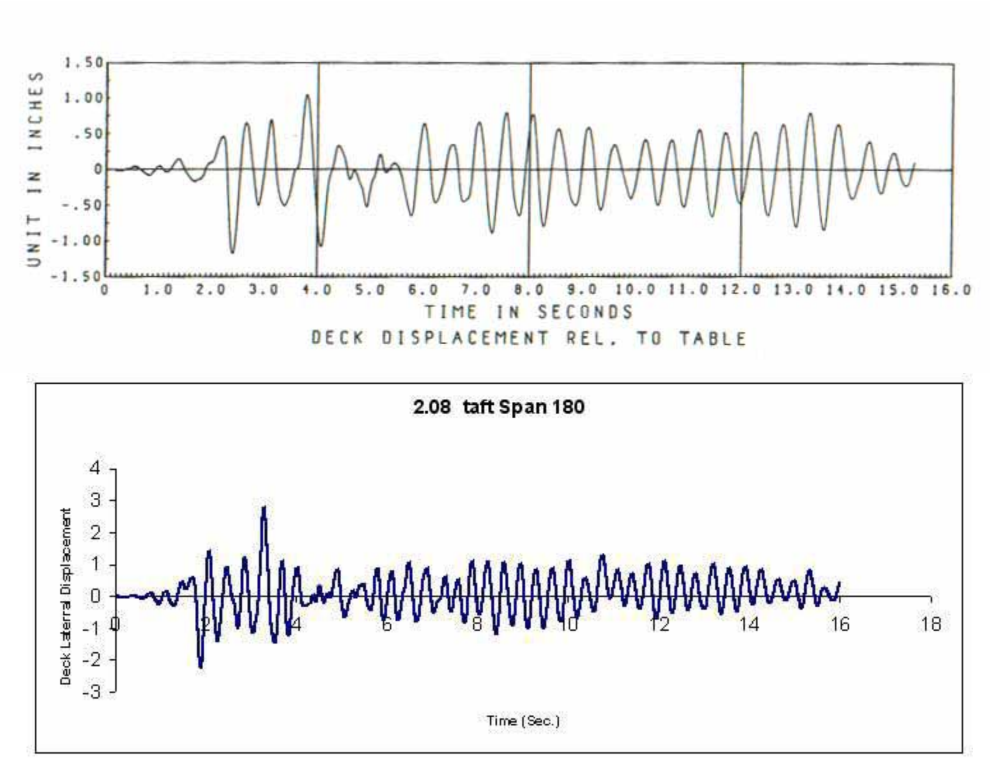


Fig. 8, Experimental and analytical results for the deck displacement time histories for the DLE

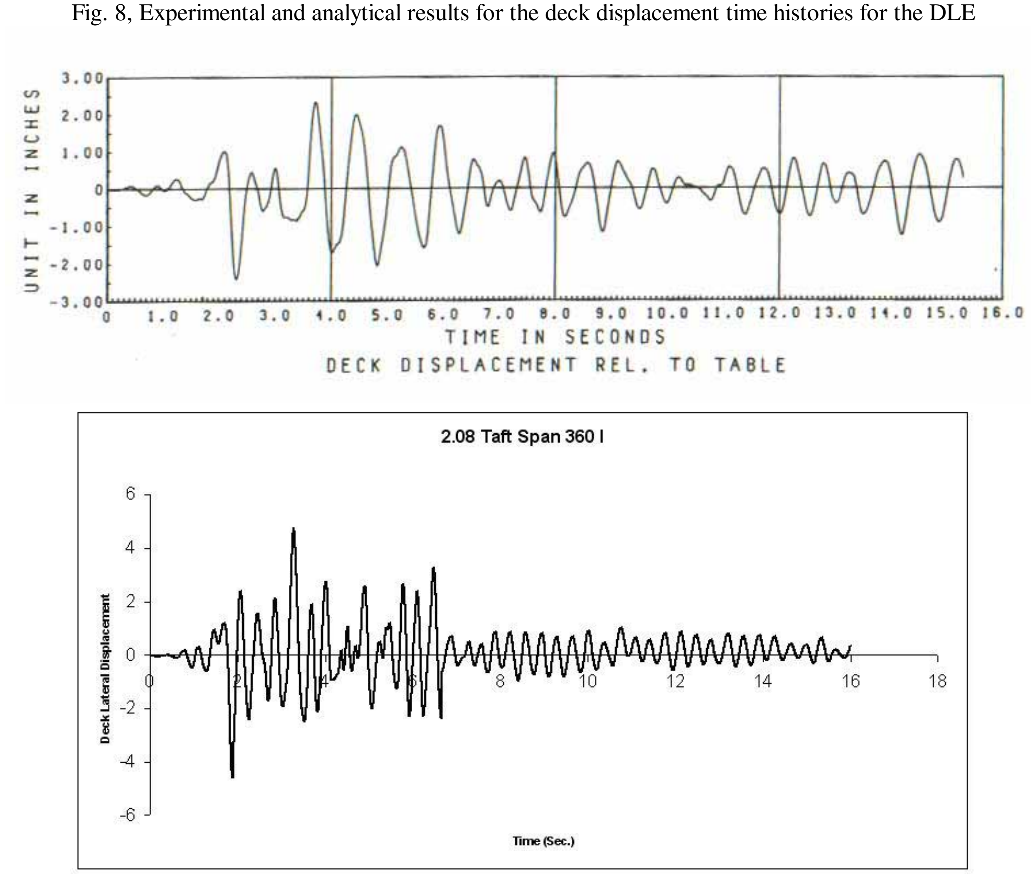


Fig. 9, Experimental and analytical results for the deck displacement time histories for the MCE

DYNAMIC TIME HISTORY RESPONSE OF TYPICAL SAMPLE PLATFORM IN PERSIAN GULF

Nonlinear dynamic analysis of one sample platform in Persian Gulf subjected to several earthquake time histories was performed using Fiber Beam-Column Post Buckling Element. An integrated model of the jacket and the topside was considered for structural analysis. Jacket member were modeled using nonlinear fiber elements and topside members were modeled using elastic beam element (El. No. 17). The effect of pile below the jacket legs is replaced by an equivalent pile stub. The mass of the structure used for the dynamic analysis is simulated on the basis of consistent mass assumption according to table 2. The jacket installed at the Persian Gulf in 40.0 m water depth. No environmental load is assumed to act along with seismic load.

Fig. 10 shows analytical analysis result (displacement time history) for top of the jacket when the platform subjected to El Centro earthquake with a scale factor of 1.0 for acceleration. Fig. 11 compare analytical analysis result (displacement time history) for top of the jacket when the platform subjected to El Centro earthquake with a scale factor of 10.0 for acceleration. This analysis is performed only for showing the ability of the element for considering buckling and post buckling behavior of the jacket vertical bracings. Fig. 12 shows damaged jacket members when it was subjected to El Centro time history with an acceleration factor of 10.0 (just for showing the ability and comparison).

Table 2, Platform Masses Modeling

Item	Description	Weigth KN
1	Plate Elements	2054.75
2	Member Elements	10624.619
3	Member Element Normal Added Mass	3910.919
4	Flouded Member Element Entrapped Fluid	1928.691
5	Load Cases Converted to Weigth	16177.717
6	Summation	34696.696
6	Summation	34696.696

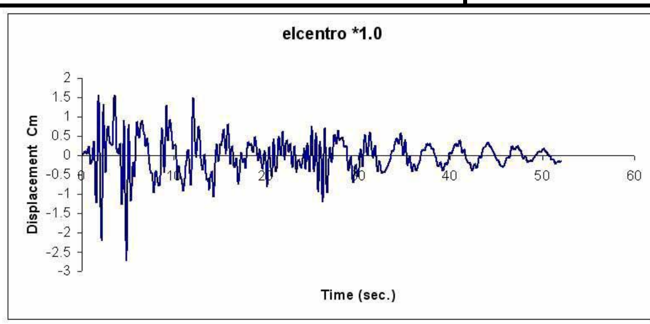


Fig. 10, Analytical results for the top of the jacket displacement for the El Centro Earthquake with a scale factor of 1.0 for acceleration

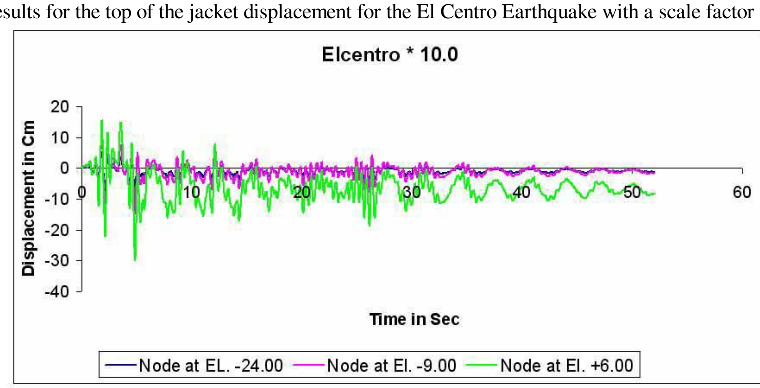


Fig. 11, Analytical results for the jacket elevations displacement for the El Centro Earthquake with a scale factor of 10.0 for acceleration

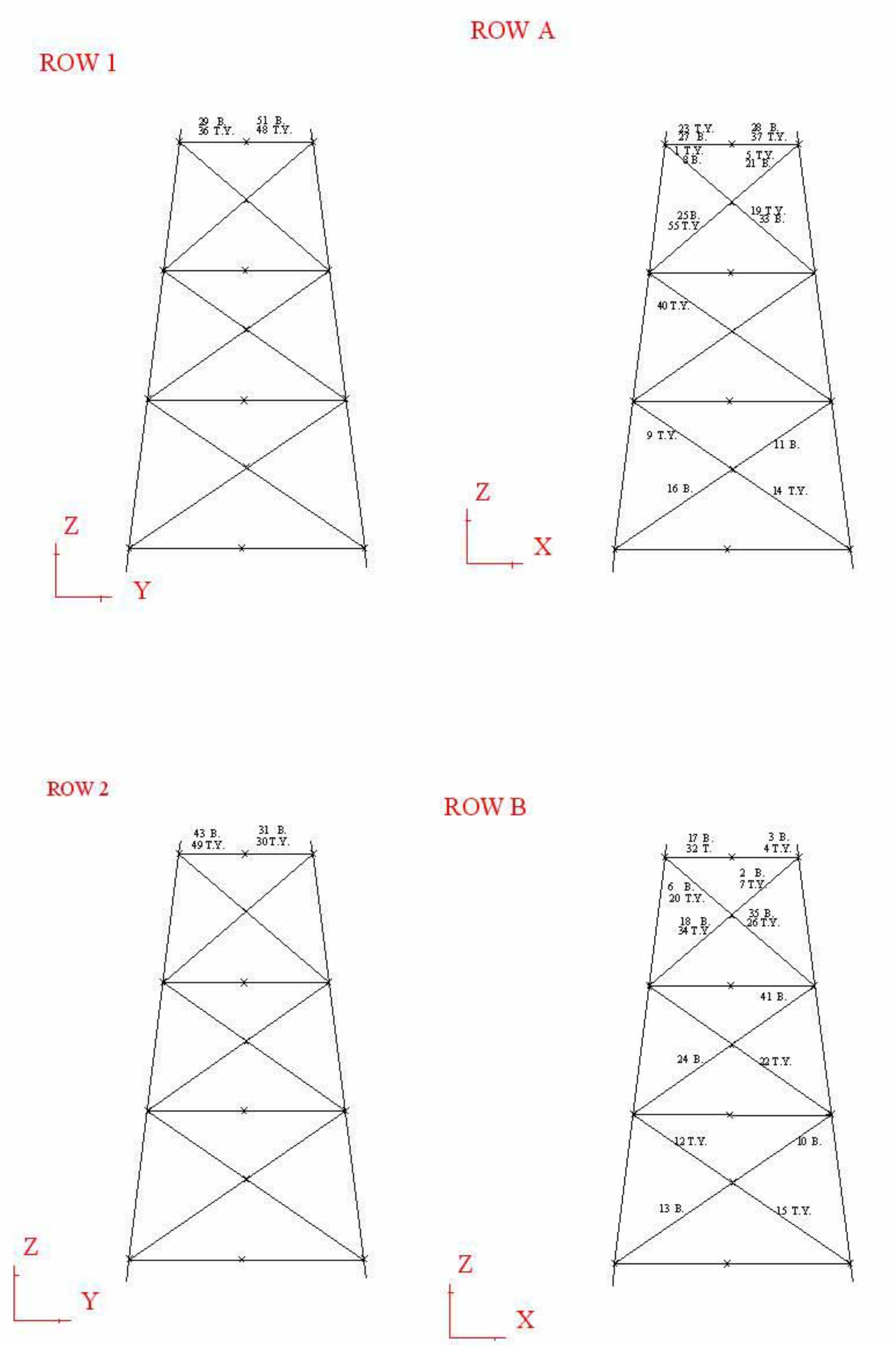


Fig. 11, damaged members of the jacket for the El Centro Earthquake with a scale factor of 10.0 for acceleration (T.Y. = Yield in Tension, B. = Buckling)

CONCLUSION

The nonlinear dynamic responses of a tested tubular frame and jacket type offshore platform in Persian Gulf have been studied using a new fiber element implemented in computer program DRAIN-3DX. This element is capable of accounting for buckling load and post buckling behavior of tubular struts. For nonlinear study of braced frames (especially for the jacket type offshore structures) behavior, this element can be used. This element predicts the overall behavior accurately. This model may also be used for the nonlinear dynamic analysis of braced steel structures.

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