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Seismic Behavior of Jacket Offshore Platform Subjected to Near and Far Field Ground Motions

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ABSTRACT: Offshore structures such as jacket platforms have to inevitably be designed against sever environmental actions. In seismically active areas these structures also become susceptible to earthquake excitations. Strong ground motions recorded in recent earthquakes, including the 1995 Kobe, Japan, 1999 Chi-chi, Taiwan and 1999 Kocaeli, Turkey earthquakes, revealed that the dynamic motions in near fields are dominated by a large, narrow band, long period pulse caused by rupture directivity effects. Sever damages have been reported with specific bridges, quay walls and multistory buildings near to the shaking fault. It was been noticed that the dynamic characteristics of these structures were close to the characteristics of the rupture directivity and felling pulses.This paper deals with the behavior of existing jacket platform under near field earthquake loading. As an example seismic assessment of the existing 4 legged service platform placed in Persian Gulf is presented. A finite element approach utilizing "Opensees" Standard software has been chosen for this study. A dynamic non-linear direct integration analysis method has been used. Seven, near and far fault records have been examined. In general it has been found that the far field excitations produce more critical consequence for the jacket offshore platform as compared with those from the corresponding near field excitations. It has been noticed that the correspondence between the dominant frequency of the record and the main natural frequency of the jacket structure can be used as a criteria to decide whether a far or near field Earthquake is more critical.

Keywords: *Earthquake; Far fault; Ground motion; Near fault; Rupture directivity*

INTRODUCTION

Ground motions close to a ruptured fault can be significantly different than those observed further away from the seismic source. The near – fault zone is typically assumed to be restricted to within a distance of about 25 km from the ruptured fault. In the near fault zone, ground motions at a particular site are significantly influenced by the rupture mechanism and slip direction relative to the site and by the permanent ground displacement at the site resulting from tectonic movement. Depending on the first two factors, ground motions in the near – fault zone can exhibit the dynamic consequences of forward – directivity, neutral – directivity, or backward – directivity. Depending on the last factor, ground motions close to the surface rupture may contain a significant permanent static displacement, which is termed fling – step. The estimation of ground motions for a project site close to an active fault should account for these special aspects of near – fault ground motions.

Pulse – type motions have been identified a critical issue in the design of structures in the near – fault zone, with the analysis of elastic and inelastic multiple degree of freedom systems indicating that the amplitude and period of the pulse in the velocity – time history are parameters that control the performance of structures (Abrahamson, 2001; Anderson and Bertero, 1987; Chopra and Chintanapakdee, 2001; Krawinkler and Alavi, 1998; Makris, 1997; Mylonakis and Reinhorn, 2001; Sasani and Bertero, 2000).

This paper deals with the behavior of existing jacket platform under near –fault ground motion Records, in the first part of the paper, the consequence of characteristic of near-fault

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ground motions are investigated by analysis of the seismic response of existing jacket platform, and in Next part, behavior of Far field ground motions records explain and compare with Near-fault Records. The finding from a comprehensive study of around 7 near fault and 7 far field ground motion records are presented in this paper.

MATERIAL AND METHODS

Generation of near-fault motions

The effects of forward-directivity are generated because the velocity of fault rupture is only slightly less than the shear wave propagation velocity. As the rupture front propagates from the hypocenter, a shear wave front is formed by the accumulation of the shear wave traveling ahead of the rupture front. When a site is located at one end of the fault and rupture initiates at the other end of the fault and travels towards the site, the arrival of the wave front is seen as a large pulse of motion (a shock wave effect) that occurs at the beginning of the record (Hall *et al*., 1995; Somerville *et al*., 1997).

To account for directivity effects, (Somerville *et al*., 1997) modified the average horizontal response spectra and the ratios of fault normal to fault parallel response spectra based on fault-site geometric parameters.

Pulse-like motions can also be generated by permanent ground displacement associated with surface fault rupture (i.e. fling-step). Pulses from fling-step have different characteristics than forward-directivity pulses. Whereas forward-directivity is a dynamic phenomenon that causes no permanent ground displacement and hence two-sided velocity pulses, fling-step is a result of a permanent ground displacement that generates one sided velocity pulses. Fling-step is observed as a discrete step in a displacement-time history that occurs parallel to the strike of the fault with strike-slip earthquake and in the dip direction for dip-slip events (i.e. in the direction of fault displacement). Given their different characteristics, it is desirable to treat the pulse motions originated from forward-directivity and fling-step slip effects separately. For strike-slip events, forward-directivity pulses are polarized principally in the strike-normal direction, whereas fling-step effects are polarized in the fault-parallel direction. For dip-slip events, forward-directivity and fling-step are both polarized in the fault-normal direction, and can be difficult to distinguish.

Forward rupture directivity effects occur when two conditions are met: the rupture front propagates toward the site, and the direction of slip on the fault is aligned with the site. The conditions for generating forward rupture directivity effects are readily met in strike-slip faulting, where the rupture propagates horizontally along strike either unilaterally or bilaterally, and the fault slip direction is oriented horizontally in the direction along the strike of the fault. However, not all near fault locations experience forward rupture directivity effects in a given event. Backward directivity effects, which occur when the rupture propagates away from the site, give rise to the opposite effect: long duration motions having low amplitudes at long periods. (Ghodrati *et al*., 2011; Somerville, 1998; Zhang and Ivan, 2002).

The conditions required for forward directivity are also met in dip-slip faulting. The alignment of both the rupture direction and the slip direction updip on the fault plane produces rupture directivity effects at sites located around the surface exposure of the fault (or its updip projection if it does not break the surface). Unlike the case for strike-slip faulting, where forward rupture directivity effects occur at all locations along the fault away from the hypocenter, dip-slip faulting produces directivity effects on the ground surface that are most concentrated in a limited region updip from the hypocenter (Somerville, 2002).

Description of the jacket platform

- ***General arrangement***

The south pars gas field is located approximately 100 km off the Iranian coast in the Persian Gulf. Phase 19 is located in this area and consist one wellhead platform, one Bridge between wellhead platform and intermediate bridge support platform and one bridge between bridge support platform and flare support platform. Our study is about the wellhead platform. Salient features of this jacket are given below (Fig. 1):

Four leg battered jacket (1/7) with four main piles to support wellhead production facilities. The dimensions between the legs are 24m x 13.716 m (at W.P elevation). The overall size of the deck is approximately 32.500m x 27.516 m. the topside is composed of upper deck, upper mezzanine deck, lower mezzanine deck, lower deck and a drain deck platform. Water depth is 64.7 m below LAT, and the foundation consist four grouted main piles. Total weight of deck is 3200 ton. Salient features of jacket legs and braces dimensions are given below (Table 1).

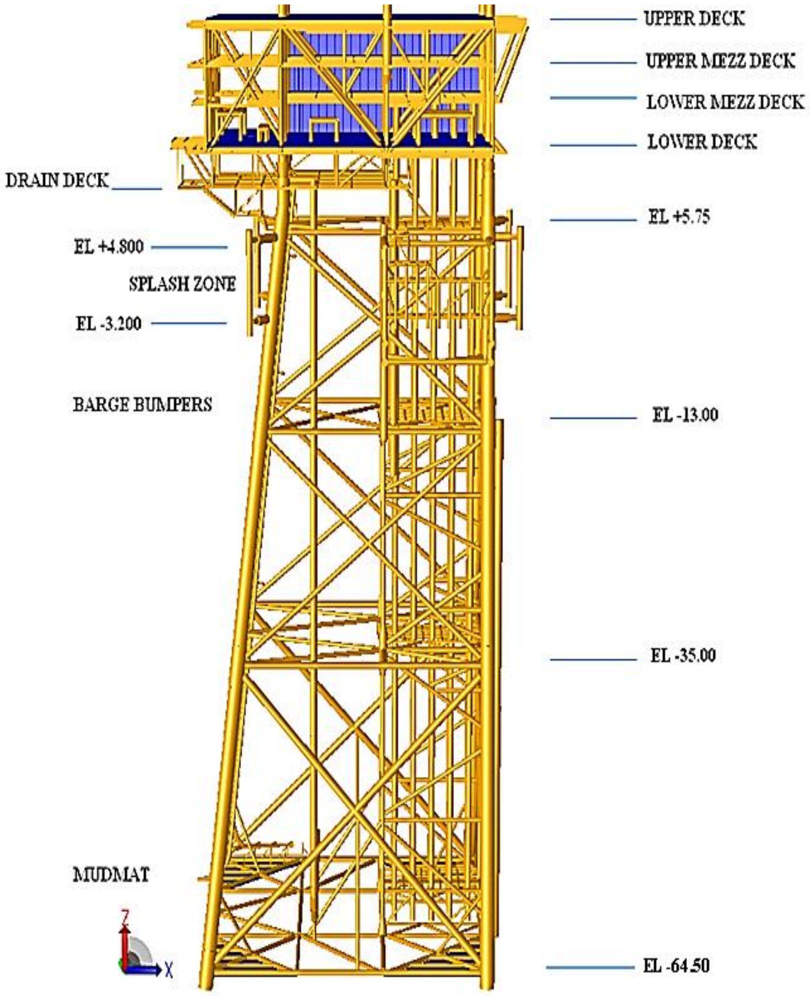


Fig. 1: Isometric view of SPD 19 Platform

Table 1: Dimension of members of Jacket

Element name	Dimensions(mm)
Leg part 1	1675 x 25
Leg part 2	1665 x 20
Leg part 3	1655 x 15
Leg part 4	1655 x 15
Brace part 1	762 x 12.70
Brace part 2	610 x 25.4
Brace part 3	610 x 19.05
Brace part 4	610 x 15.88

- ***Load cases***

For time history analysis of platform, a 'best fit' set of scaled, natural time histories is used provided the velocity spectrum values have been properly modulated to equal or exceed the Standard spectrum velocity values At specified periods (0.2 T to 1.5 T) as mentioned in international building code (Golafshani et al. 2006; IBC, 2000).

Development of analytical model

- ***Frame modeling***

Analytical model were created using the open source finite element platform, Opensees. This program is useful for modeling of jacket platform structures because of its capability of modeling the post-buckling behavior of tubular members, soil-pile-structure interaction etc. (Opensees, 2005). A two-dimensional model of a single frame is developed for a structure. A force-based nonlinear beam-column element (utilizing a layered fiber section) is used to model all components of the frame. Steel material is modeled using a bilinear stress-strain curve with 0.3% Post-yield hardening. initial imperfections in the struts are accounted for, with a value of 0.001L where L is the length of the member. this idea is useful for modeling the post-buckling behavior of the strut members.

- ***Pile/soil modeling***

The mathematical model of the pile/soil system consists of the following sets of element (Fig.2):
a. pile elements, modeled by a number of nonlinear beam-column elements.
b. Near-field elements that connect the piles to the soil, vertically and horizontally. The strength And stiffness of this elements depend on the state of the far-field soil and the relative motion of the pile and far-field soil.
The interface between the pile and surrounding soil is modeled using P-y, t-z, q-z nonlinear spring elements (fig. 2). Hysteretic and radiation damping are considered in using these elements. group effects are not considered for the piles. The input motion is applied to the fixed nodes at the bottom of soil column. The seismic record at the bedrock is found from input motion at the surface.
c. Far-field soil model representing the free-field motion of the soil column, vertically and horizontally that is unaffected by the pile motions. The soil is modeled using elastic quad elements. The nodes that are at the same depth are constrained.

- ***API standard***

The collapse of structure is defined by its lack of ability to withstand the load. The collapse load is defined as the maximum load the structure can withstand, before the load-displacement curve start a negative tend (Ersdal 2005). The deck displacement at the collapse point of the jacket is 1.35 meter.

- ***Incremental Dynamic Analysis (IDA)***

Incremental dynamic analysis (IDA) is a parametric analysis method that has recently emerged in several different forms to estimate more thoroughly structural performance under seismic loads. It involves subjecting a structural models to one or more ground motion records, each scaled to multiple levels of intensity, thus producing one or more curves of response parameterized versus intensity level. To establish a common frame of reference, the fundamental concepts are analyzed, a unified terminology is proposed, suitable algorithms are presented, and Properties of the IDA curve are looked into for both single-degree of freedom (SDOF) and multi-degree of freedom (MDOF) structures. IDA Diagram consist three stage of damage measure, which is shown in (Fig. 3). In this paper, the output of the opensees program transferred to (IDA) diagram, which vertical axis is peak ground acceleration (PGA) and horizontal axis is a maximum drift (Fig. 3).

Ground motion database

As discussed, two sets of Near-fault and Far-fault records were selected and provided in (Table 2) and (Table 3). The first set includes seven near-fault ground motion records and second set also contains seven far-fault ground motion records. in next part, the diagrams of near and far fault records have been shown then, after scaling the far-fault record with near- fault records, comparing diagrams with together.

- ***FEMA recommendation***

Performance based design (PBD) has been fully described in the guidelines published by FEMA and ATC. These documents do not have the force of codes but provide details of best practice for the evaluation and strengthening of existing buildings. These are continuing to be expanded as PBD become more widespread. In these standards a criterion such as drift is applied indirectly when the elements are assessed (FEMA-356, 2000; FEMA-440, 2005).

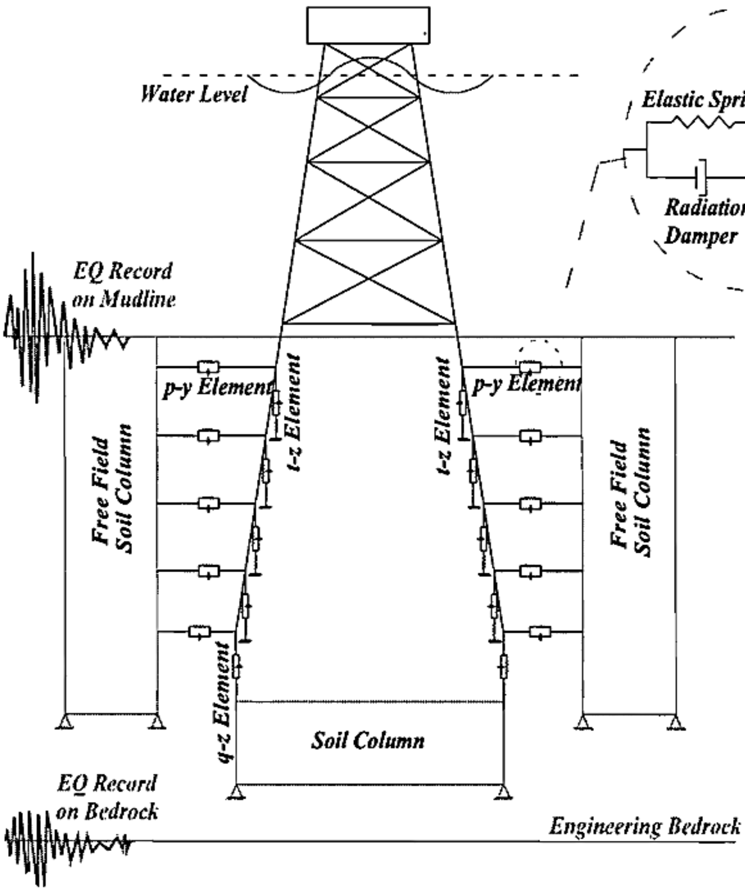


Fig. 2: Modeling of soil-pile structure interaction

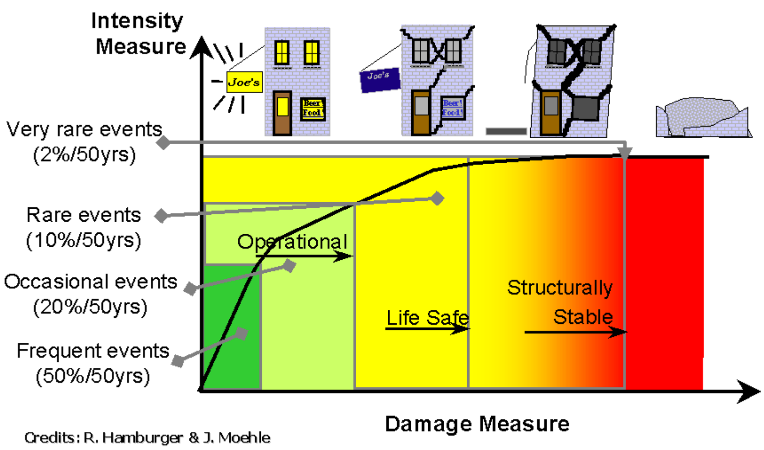


Fig. 3: Boundary behavior of IDA diagram in structure

Table 2: Near fault Ground motions database

Near –fault records						
No	Year	Earthquake	Closest to fault rupture (km)	PGA(g)	PGV(cm/s)	PGD(cm)
1	1999	Chichi	11.14	0.484	74.4	66.92
2	1979	Imperial valley	23	0.238	26	12.06
3	1995	Kobe	15.5	0.243	37.8	8.54
4	1989	Loma prieta	28	0.247	38.5	17.83
5	1994	Northridge	23	0.242	29.8	4.74
6	1971	San fernando	21.2	0.21	18.9	12.4
7	1978	Tabas	26	0.089	18	18.27

Table 3: Far fault Ground motions database

Far –fault records						
No	Year	Earthquake	Closest to fault rupture(km)	PGA(g)	PGV(cm/s)	PGD(cm)
1	1999	Chichi	130.5	0.04	11.7	8.58
2	1979	Imperial valley	54.1	0.167	8.3	1.05
3	1995	Kobe	157.2	0.042	5.3	2.08
4	1989	Loma prieta	85.1	0.233	38.1	11.45
5	1994	Northridge	146.5	0.099	7.7	1.56
6	1971	San fernando	136	0.047	2.6	0.33
7	1978	Tabas	121.2	0.067	5.7	10.03

Four levels of building performance consist of operational (O), Immediate occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) in increasing levels of damage is considered in FEMA. The Immediate Occupancy (IO) performance level requires that the building remain essentially functional during and immediately after the earthquake. The last performance level, Collapse Prevention (CP) will result in a building on the point of collapse and probably economically irreparable. The Life Safety level (LS) is the level usually implicit in codes and may also result in a building which is not economic to repair. The rehabilitation objectives are formed of combinations of earthquake hazard and building performance. (Table. 4)

This allowable values for this jacket have been shown for example in chichi record (Fig. 4).as it marked in figure 4 ,Immediate occupancy region (IO) equal (0.005×70) and for collapse prevention (CP) allowable value Is (0.015×70). this quantities show that performance of jacket is proper and this jacket has suitable performance in duration of operation.

Seismic response evaluation of studied jacket

- ***Near –fault records diagram***

For drawing the below diagrams, at the beginning with period of jacket structure (T=2.94), different amplitude according to (g) being considered, then under the using record, structural analysis has been done and standard failure which here is a maximum relative displacement is Computed. Then harmonic stimulated amplitude increased and maximum relative displacement of jacket computed again. This increasing of amplitude continuing till the structure of jacket reaches to dynamic instability. Incidentally for an ordinary structure with nonlinear behavior, IDA diagram finally tend to horizontal mood. This tendency to horizontal mood of IDA diagram explaining the intensity of unbounded response which structure produce (Fig. 5).

As explained in last part (part 5), the region of (IO) and (LS) have been shown in (IDA) diagram of Chichi Earthquake. As it clear in diagram, after (PGA=2g) curved line tendency to horizontal mood, which is The sign of start of dynamic instability in structure. furthermore the structure until (PGA=0.8 g) is in (IO) boundary and has a reasonable performance. In this area, the behavior of structure is linear.

6.2 . Far –fault records diagram The diagram of Far-fault record, like Near-fault Records (same method) has been drawing. It should be noted that all the records have been Scaled to 0.35g before being applied to the Analytical models (Fig. 6).

Comparing near- fault and far- fault records

in last part, the diagram of near-fault and far-fault has been shown separately. in this part ,both of them inserted in one diagram to compare together (Fig. 7)

Table 4: Allowable value for relative displacement in structure (FEMA-356, 2000)

Region	IO	LS	CP
displacement elative	0.005 H	0.015 H	0.02 H

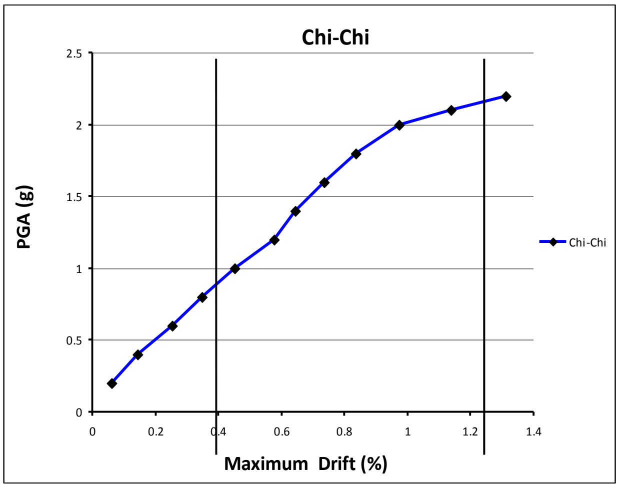
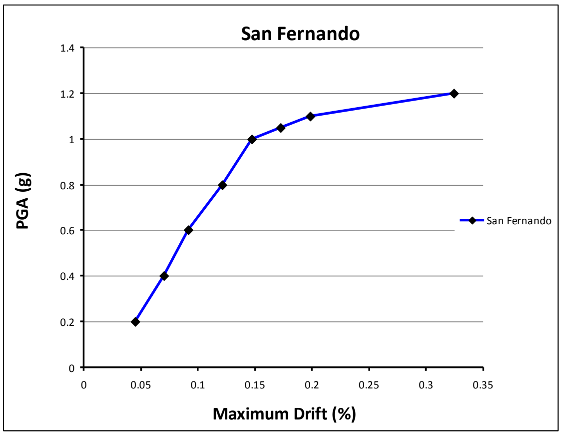
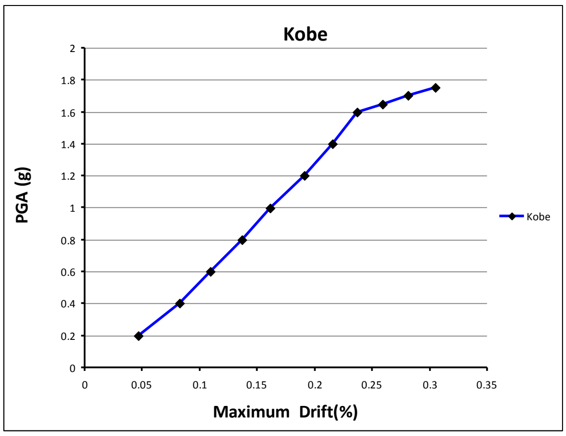


Fig. 4: Near-fault record- chichi IDA diagram





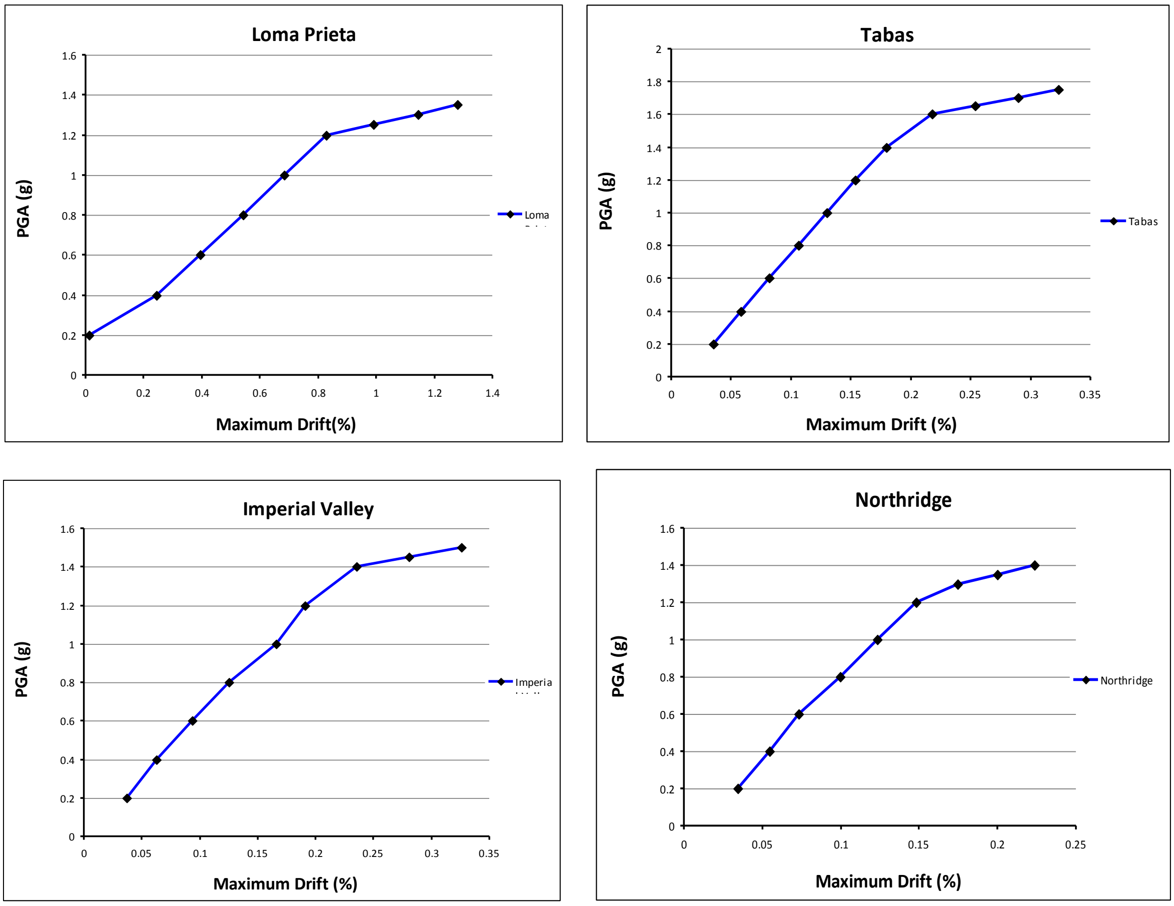
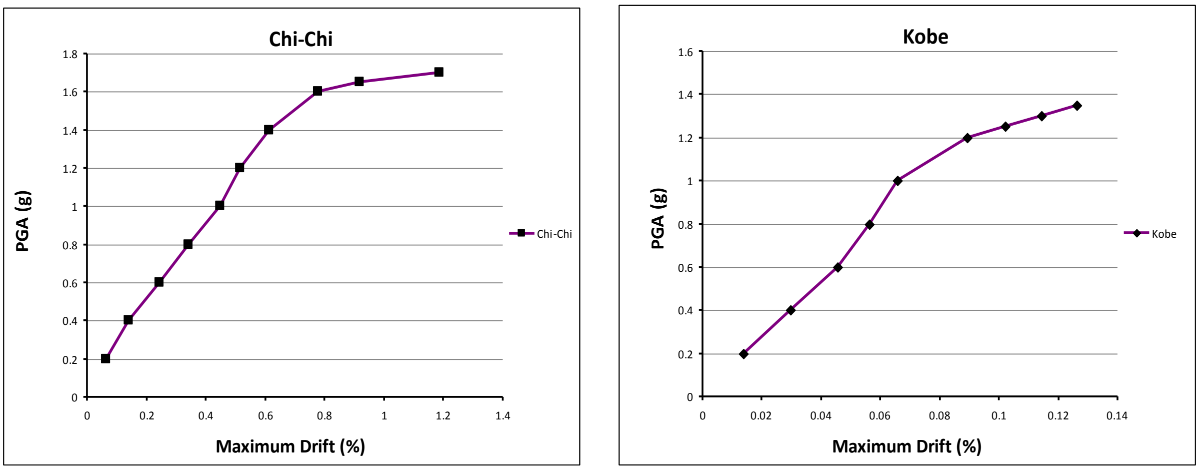


Fig. 5: Near-fault records-IDA diagrams at different sites



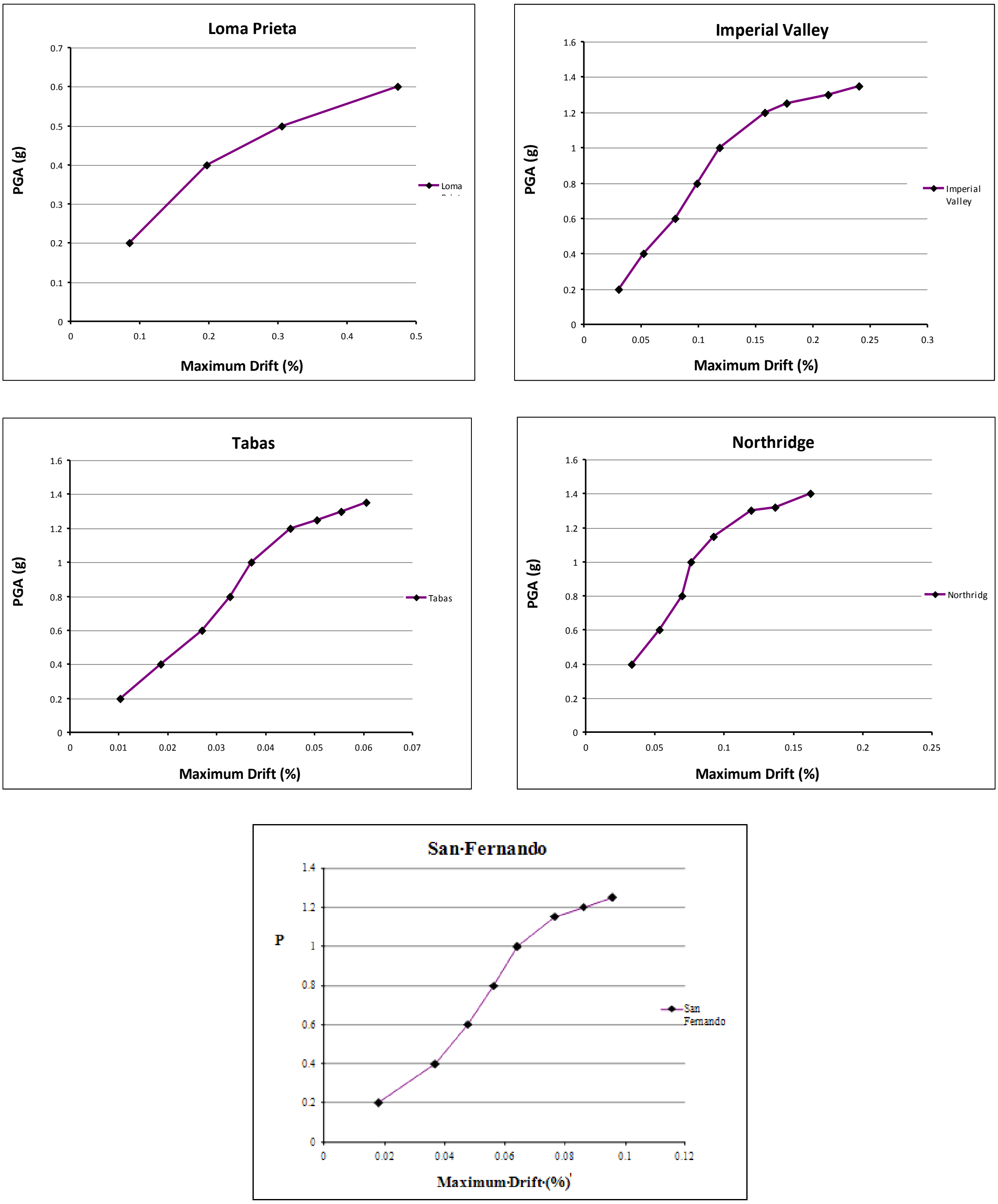


Fig. 6: Far-fault records-IDA diagram at different sites

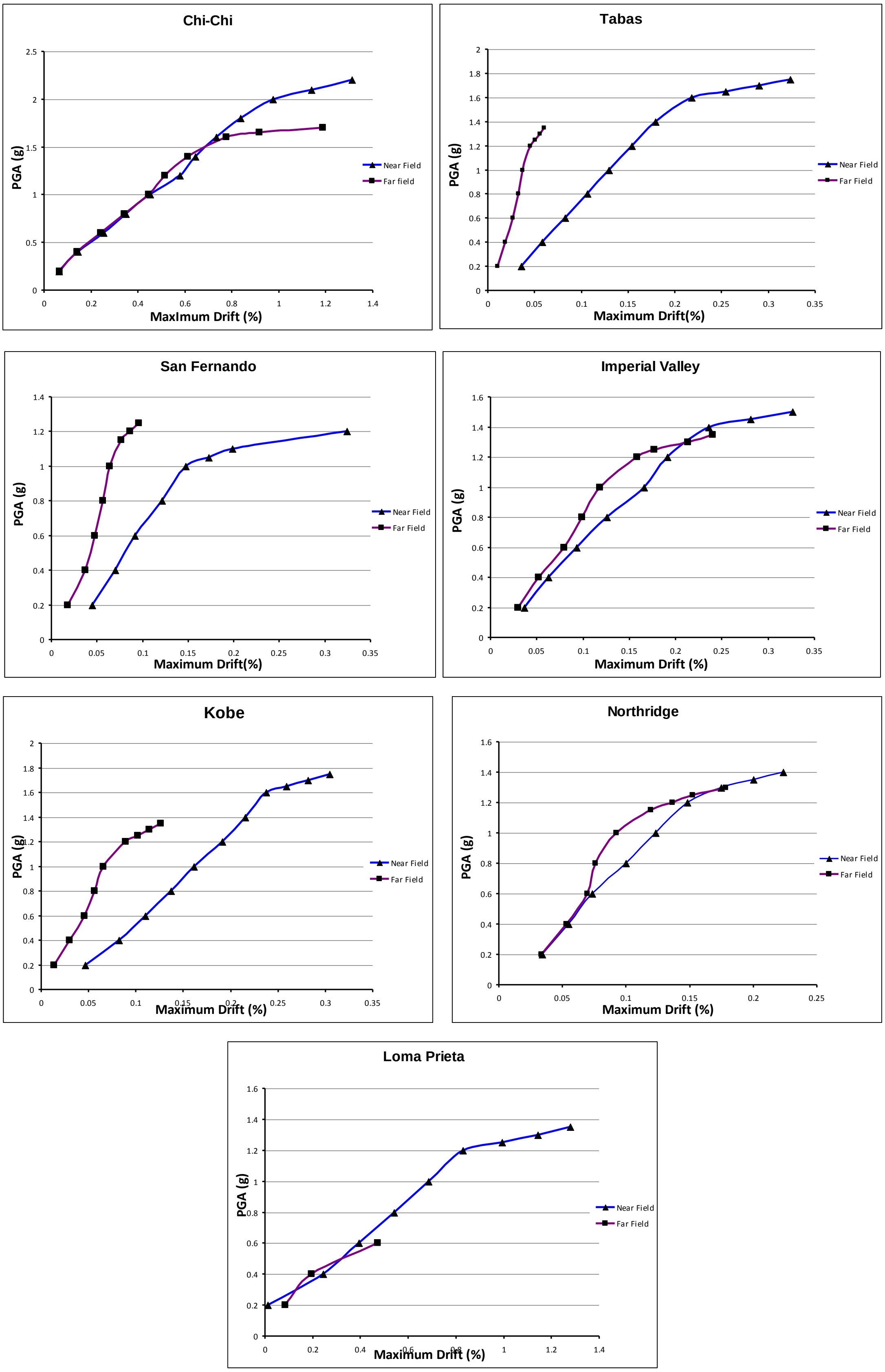


Fig 7: Near & Far- fault comparing IDA diagram at different sites

As it shown in upper diagrams (Fig. 7), in majority of cases (5 of 7 earthquake records) include: Kobe, Imperial, Chichi, Tabas and Loma, Far-Fault earthquake is critical and more dangerous and sooner than the Near-Fault record entered the nonlinear region. Also in one earthquake (Northridge), near-fault earthquake is critical and dominated and in one earthquake (San Fernando) both of near-fault and far-fault earthquake have a same behavior and the velocity of them for entering to nonlinear region is identical. With concentration on value of period of near –fault and far-fault earthquake clearly observed that the period of Far-fault earthquake is bigger than the near-fault earthquake and it is near to main period of jacket structure. Hence it could be expected the far-fault earthquake because of bigger period and near to main period of structure be more critical in relation near –fault earthquake.

CONCLUSIONS

The results of analyses revealed that reaction of jacket structure against the far-fault and near-fault Earthquake depend on kind and period of earthquake and other items and in some operational boundary Far-fault earthquake possible to prevail and in some cases near-fault earthquake. From presented diagrams and subjects in last parts final results express that far fault earthquake often times is more critical in comparison with near fault earthquake and exception cases also with accurate defining of confined behavior, to be deleted and for all jackets, far fault earthquake will be dominate .the reason of this Phenomenon, up value of marine platforms period and vicinity of platform period to far fault earthquake period in comparison with near fault earthquake.

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