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Effetcs of Near-Fault and Far-Fault Ground Motions on Cable-Stayed Bridges

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ABSTRACT

In this paper, the response of a long span cable-stayed bridge is investigated under the effect of near-fault and far-fault ground motions. Because cable-stayed bridges has been started to be used for center spans reaching to 1000 m it has become important to investigate the cable-stayed bridges under the effect of near-fault ground motions. Therefore, in this study a cable-stayed bridge is considered to determine the effects of near-fault and far-fault ground motions on the seismic responses of these types of bridges. Tatara Bridge constructed in Japan is chosen as a cable-stayed bridge model. Total length of the Tatara Bridge is 1480 m having a main span of 890 m. As near-fault and far-fault ground motions, 1995 Kobe, 1999 Chi-Chi, 1999 Kocaeli and 1999 Duzce strong ground motion records are used. Classifying near-fault ground motions as pulse type and none pulse type ground motions, the effect of near-fault ground motions on cable-stayed bridges has been investigated considerably. Bridge responses obtained from the near-fault and far-fault ground motion cases are compared with each other to emphasize the importance of earthquake ground motions on bridge responses. The results have underlined the remarkable effect of the pulse type near-fault ground motions on the dynamic responses of cable-stayed bridges.

Keywords: Cable-stayed bridges, near-fault ground motions, far-fault ground motions, pulse type ground motions.

1. INTRODUCTION

In the recently recorded earthquakes it has been observed that near fault ground motions show pulse type characteristics and transmit considerable seismic forces on structural systems at the initial phase of the ground motion.

Previously publishes papers revealed that pulse type near fault ground motions taking place close to the earthquake faults cause larger seismic demands on bridge type structural systems than those of the far fault ground motions [1-7]. Although there have been some studies investigating the effects of near fault ground motions on cable-supported bridges, there is still a lack of studies considering the detailed dynamic analysis of cable-stayed bridges under near fault ground motions showing pulse type characteristics. McCallen et al. [8] investigated the effects of long-period near-fault ground motions on suspension bridges. Yan and Lee [9] investigated steel arch bridges under near fault ground motions by considering the travelling wave effect with variable apparent velocities. Jia and Ou [10] studied the pulse effect of near-fault ground motions and its effects on cable-stayed bridges. Shrestha and Tuladhar [11] investigated the relative importance of the vertical ground motion on the response of a cable-stayed bridge which is located near to an active fault zone. Adanur et al. [12] compared the near-fault and far-fault ground motions effects on suspension bridges and underlined the importance of the near-fault ground motions on suspension bridges. Ismail et al. [13] investigated the near-fault seismic performance of an isolation system on a cable-stayed bridge model. Shrestha [14] presented an analytical investigation on the effect of the near fault vertical ground motions on seismic response of a long span cable-stayed bridge. Soyluk and Karaca [15] considered a cable-stayed bridge and a suspension bridge with closer main span lengths and compared the bridge responses obtained from the near-fault and far-

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fault uniform grounds to underline the relative importance of earthquake ground motions on the bridge responses.

Because cable-stayed bridges has been started to be used for larger center spans it has become necessary to investigate the bridge type to be used for center spans around 1000 m. Considering the differences of the seismic responses of long-span cable-stayed and suspension bridges it is important to be able to define the dynamic behavior of these bridges under earthquake excitations. Therefore, in this study a cable-stayed bridge is considered to determine the effects of near-fault and far-fault ground motions on the seismic responses of these types of bridges.

2. APPLIED GROUND MOTIONS

It is known that the pulse type characteristic is one of the most remarkable properties of near fault ground motions. This can be attributed to fact that near fault ground motions show pulse type characteristics at the initial phase of the ground motion. In this study recently recorded earthquakes Kobe 1995, Kocaeli 1999, Chi-Chi 1999 and Duzce 1999 are selected and these ground motions showing near fault characteristics are applied to the considered cable-stayed bridge model.

In this study near fault ground motions are considered as excitations where the distance between the stations and earthquake fault is less than 10 km, the velocity-time history plots have pulse durations larger than 2 s and the ratio of the peak ground velocity to the peak ground acceleration (PGV/PGA) is larger than 0.1 s. For proper comparison of the bridge responses obtained from near fault and far fault ground motions, horizontal, longitudinal and vertical components of the earthquakes are scaled to 0.35g, 0.35g and 0.20g for Chi-Chi earthquake, 0.40g, 0.35g and 0.20g for Duzce earthquake, 0.55g, 0.50g and 0.40g for Kobe earthquake, 0.20g, 0.30g and 0.20g for Kocaeli earthquake, respectively. Detailed properties of the selected ground motions are given in Table 1 to Table 4.

Table 1. Near-fault and far-fault ground motion characteristics for Chi-Chi earthquake

Record	Ground Motion	Mw	d (km)	PGA (g)	PGV (cm/s)	PGV/PGA (s)	Tp (s)
TCU050, EW	Near-fault with Pulse	7.62	9.49	0.14	36.67	0.27	7.7
TCU050, NS	Near-fault with Pulse	7.62	9.49	0.13	43.28	0.34	7.8
TCU050, V	Near-fault with Pulse	7.62	9.49	0.09	42.14	0.48	4.7
TCU054, EW	Near-fault with Pulse	7.62	5.28	0.15	46	0.31	9.2
TCU054, NS	Near-fault with Pulse	7.62	5.28	0.19	41.4	0.22	5.8
TCU054, V	Near-fault with Pulse	7.62	5.28	0.13	30.13	0.24	5.7
TCU089, EW	Near-fault without Pulse	7.62	9	0.35	34.97	0.1	No Pulse
TCU089, NS	Near-fault without Pulse	7.62	9	0.23	33.13	0.15	No Pulse
TCU089, V	Near-fault without Pulse	7.62	9	0.19	21.02	0.11	No Pulse
HWA032, EW	Far-fault	7.62	47.31	0.15	8.2	0.06	No Pulse
HWA032, NS	Far-fault	7.62	47.31	0.11	8.17	0.08	No Pulse
HWA032, W	Far-fault	7.62	47.31	0.09	8.71	0.1	No Pulse

Table 2. Near-fault and far-fault ground motion characteristics for Duzce earthquake

Record	Ground Motion	Mw	d (km)	PGA (g)	PGV (cm/s)	PGV/PGA (s)	Tp (s)
1058, NS	Near-fault with Pulse	7.14	0.21	0.08	14.28	0.18	6.1
1058, EW	Near-fault with Pulse	7.14	0.21	0.11	15.81	0.15	2.9
1058, V	Near-fault with Pulse	7.14	0.21	0.07	15.21	0.22	3.7
531, NS	Near-fault with Pulse	7.14	8.03	0.16	10.87	0.07	4.8
531, EW	Near-fault with Pulse	7.14	8.03	0.12	13.4	0.11	2.7
531, V	Near-fault with Pulse	7.14	8.03	0.06	8.84	0.15	7.1
498, NS	Near-fault without Pulse	7.14	3.58	0.4	24.15	0.06	No Pulse
498, EW	Near-fault without Pulse	7.14	3.58	0.35	25.22	0.07	No Pulse
498, V	Near-fault without Pulse	7.14	3.58	0.18	17.69	0.1	No Pulse
BOLU, NS	Far-fault	7.14	12.04	0.74	55.9	0.08	No Pulse
BOLU, EW	Far-fault	7.14	12.04	0.8	65.85	0.08	No Pulse
BOLU, V	Far-fault	7.14	12.04	0.2	23.46	0.12	No Pulse

Table 3. Near-fault and far-fault ground motion characteristics for Kobe earthquake

Record	Ground Motion	Mw	d (km)	PGA (g)	PGV (cm/s)	PGV/PGA (s)	Tp (s)
PRI, NS	Near-fault with Pulse	6.9	3.31	0.35	90.62	0.26	2.2
PRI, EW	Near-fault with Pulse	6.9	3.31	0.29	51.11	0.18	2.7
PRI, V	Near-fault with Pulse	6.9	3.31	0.57	62.08	0.11	2.3
KBU, NS	Near-fault with Pulse	6.9	0.92	0.27	55.27	0.21	2.4
KBU, EW	Near-fault with Pulse	6.9	0.92	0.31	30.87	0.1	2.2
KBU, V	Near-fault with Pulse	6.9	0.92	0.45	18.57	0.04	1.7
NIS, NS	Near-fault without Pulse	6.9	7.08	0.48	46.8	0.1	No Pulse
NIS, EW	Near-fault without Pulse	6.9	7.08	0.46	38.24	0.08	No Pulse
NIS, V	Near-fault without Pulse	6.9	7.08	0.49	24.61	0.06	No Pulse
CHY, NS	Far-fault	6.9	49.91	0.09	5.32	0.06	No Pulse
CHY, EW	Far-fault	6.9	49.91	0.11	4.12	0.04	No Pulse
CHY, V	Far-fault	6.9	49.91	0.07	2.43	0.04	No Pulse

Table 4. Near-fault and far-fault ground motion characteristics for Kocaeli earthquake

Record	Ground Motion	Mw	d (km)	PGA (g)	PGV (cm/s)	PGV/PGA (s)	Tp (s)
YPT, NS	Near-fault with Pulse	7.51	4.83	0.23	69.68	0.31	4.4
YPT, EW	Near-fault with Pulse	7.51	4.83	0.32	71.85	0.23	4.7
YPT, V	Near-fault with Pulse	7.51	4.83	0.24	30.76	0.13	4.3
IZT, NS	Near-fault with Pulse	7.51	7.21	0.16	22.32	0.14	3.2
IZT, EW	Near-fault with Pulse	7.51	7.21	0.23	38.27	0.17	4.7
IZT, V	Near-fault with Pulse	7.51	7.21	0.14	12.38	0.09	3.1
ERG, NS	Far-fault	7.51	142.29	0.09	16.63	0.19	No Pulse
ERG, EW	Far-fault	7.51	142.29	0.1	10.91	0.11	No Pulse
ERG, V	Far-fault	7.51	142.29	0.06	3.98	0.07	No Pulse

Near fault ground motion components of PRI and KBU which show pulse type characteristics, near fault ground motion component without pulse effect NIS and far fault ground motion component CHY of Kobe earthquake are shown in Figure 1. As can be observed from the figures pulse duration in the near fault ground motions with pulse type characteristics are larger than 2.0 s.

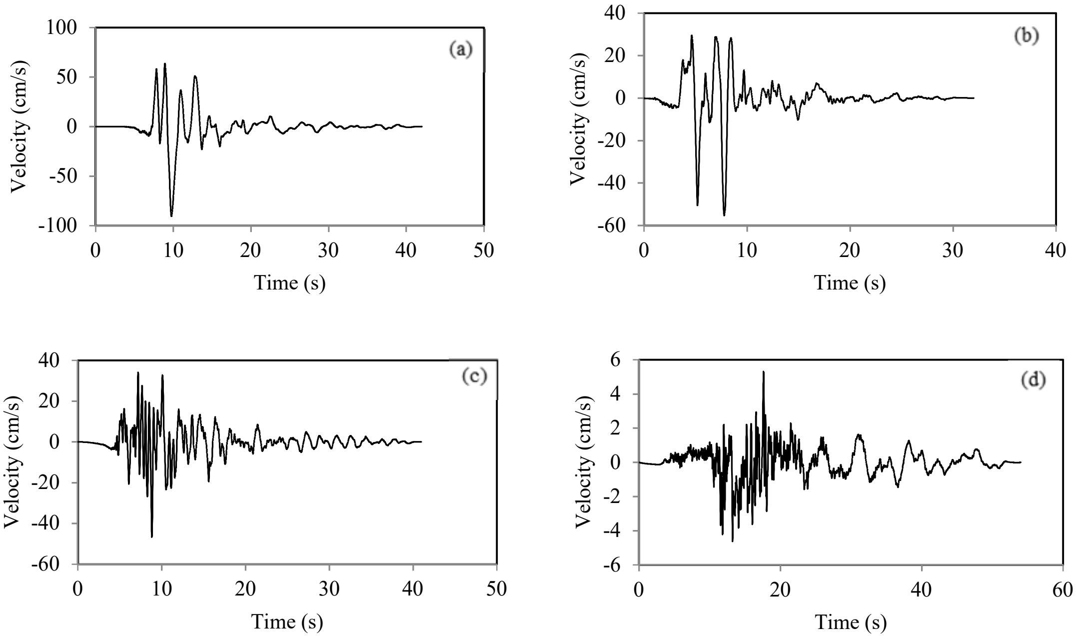


Figure 1. Velocity-time history recordings of (a) PRI-NS; (b) KBU-NS; (c) NIS-NS; (d) CHY-NS

3. FINITE ELEMENT MODEL OF TATARA BRIDGE

Tatara Bridge has a total length of 1480 m having a main span of 890 m, and side spans of 270 m and 320 m. As the deck section is mostly steel along the bridge length (1312 m), prestressed concrete is used at each end of side span sections to prevent negative reaction. The main tower is 220 m high and designed as an inverted Y shape. It has a cross-shaped section with corners cut for higher wind stability. Cables installed in 21 levels are two-plane multi-fan cables [16].

3D analytical model is considered for the response calculations (Figure 2). 450 nodal points, 283 beam elements, 168 truss elements, and 168 rigid-link elements are used in this model. While the deck of the bridge and towers are defined as beam elements, the cables are defined as truss elements. The box girder deck is represented by an equivalent beam element passing through the centre line of the deck. Two rigid links are placed horizontally at 90° to the longitudinal axis of the deck at each cable location to achieve the proper offset of the cables from the centreline of the deck. The cables are connected to the outer ends of the rigid links. The equivalent beam elements and rigid links are defined as having zero mass, as their primary function is to provide stiffness. The mass of the deck is lumped at the end of each rigid link. Link elements are also used at the points where deck frame elements and tower frame elements intersect. These link elements are vertically and horizontally constant and have a stiffness of 20000 kN/m in the longitudinal direction. The nonlinearity of the cables is included with an equivalent modulus of elasticity.

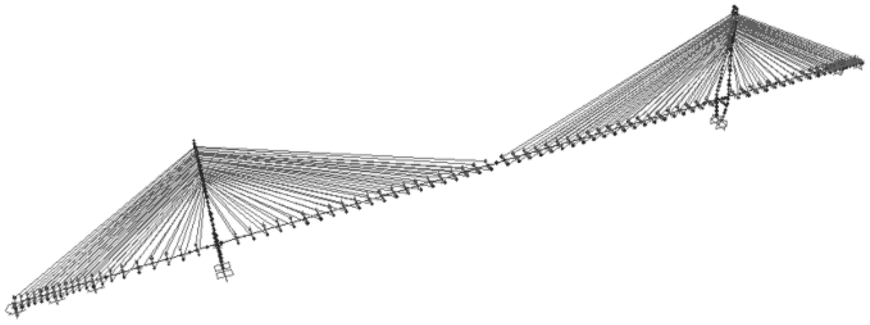


Figure 2. 3D finite element model of Tatara Bridge

4. NUMERICAL SOLUTIONS

To emphasize the importance of the near-fault and far-fault ground motions on cable-stayed bridge responses, Chi-Chi, Duzce, Kobe and Kocaeli earthquakes are considered and the resulting deck displacements and bending moments are compared with each other.

Vertical deck displacements obtained for Chi-Chi earthquake are shown in Figure 3a. It can be observed that TCU050 and TCU054 ground motion components which show pulse type characteristics caused considerable larger displacements than those of the near fault ground motion component without pulse effect TCU089 and far fault ground motion component HWA032. TCU050 pulse type ground motion component caused larger displacements than those of the other pulse type ground motion component TCU054. This difference can be attributed to the fact that TCU050 ground motion component has larger PGV/PGA ratio. From the figure it can also be noticed that near fault ground motion component without pulse effect TCU089 caused larger displacements than those of the far fault ground motion component HWA032. Bending moments calculated at the bridge deck shows the same variation obtained for the deck displacements (Figure 3b).

Vertical deck displacements obtained for Duzce earthquake are compared in Figure 4a. It is observed that near fault ground motion component with pulse type characteristics 1058 caused much larger displacements than those of the near fault ground motion component with pulse type characteristics 531, near fault ground motion component without pulse effect 498 and far fault ground motion component BOLU. Bending moments are compared in Figure 4b and observed the same variation obtained for the vertical deck displacements.

Vertical deck displacements obtained for Kobe earthquake are compared in Figure 5a. It can be noticed that near fault ground motion component with pulse type characteristics PRI caused the largest deck displacements and the for the remaining ground motion components of KBU with pulse type characteristics, NIS without pulse effect and CHY far fault ground motion very close and small responses are obtained. Bending moments throughout the length of the bridge deck are compared in Figure 5b. It is observed that PRI ground motion component with pulse type characteristics caused considerable larger bending moments than those of the near fault ground motion component without pulse effect and far fault ground motion. Opposite to the previous observations, near fault ground motion component without pulse type characteristics NIS caused larger bending moments than those of the near fault ground motion component with pulse type characteristics KBU. Bending moments obtained for far fault ground motions remained very small.

For the dynamic analysis of the cable-stayed bridge when subjected to the Kocaeli earthquake, near fault ground motion components with pulse type characteristics YPT and IZT are used with the far fault ground motion component ERG. The resulting deck displacements and bending moments are compared in Figure 6a and Figure 6b. It is generally observed that YPT ground motion component with pulse type characteristics caused larger responses than those of the near fault ground motion component with pulse type characteristics IZT and far fault ground motion component ERG. Near fault effect of the Kocaeli earthquake on the dynamic response of the cable-stayed bridge is clearly observed. On the other hand the near fault ground motion component with pulse type characteristics IZT and far fault ground motion component ERG resulted generally close responses.

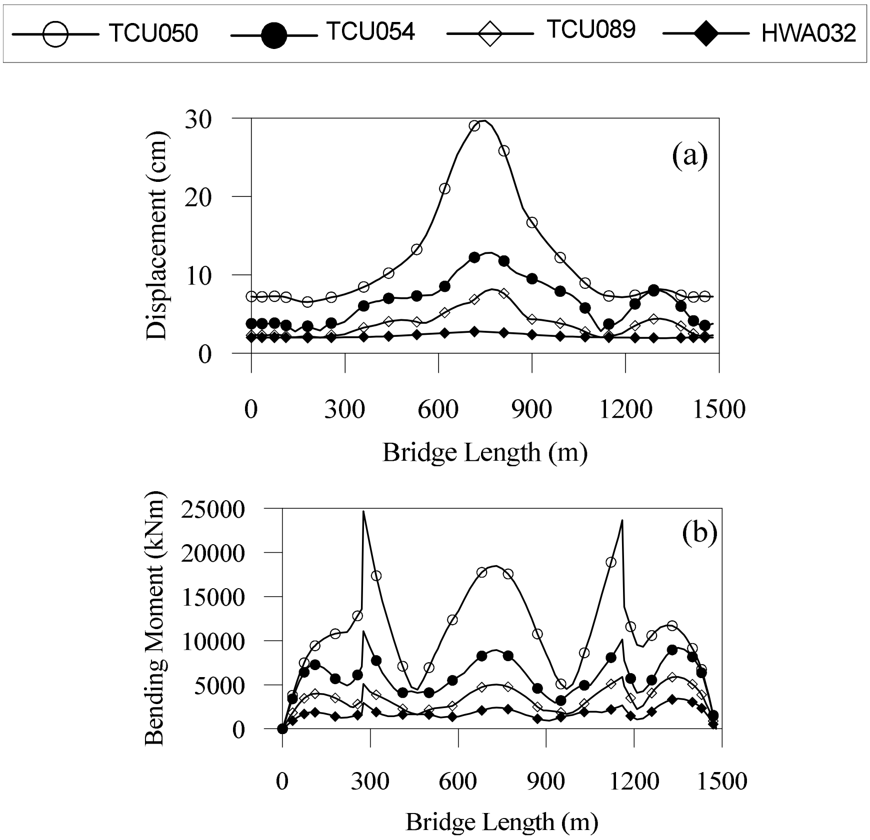
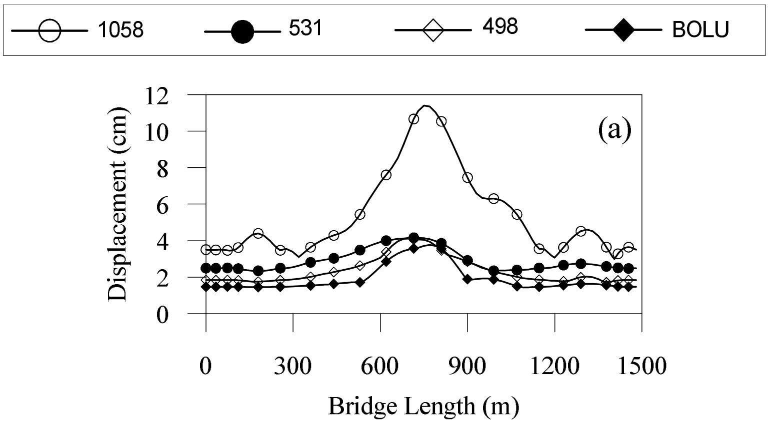


Figure 3. a) Vertical deck displacements b) Deck bending moments, for Chi-Chi Earthquake



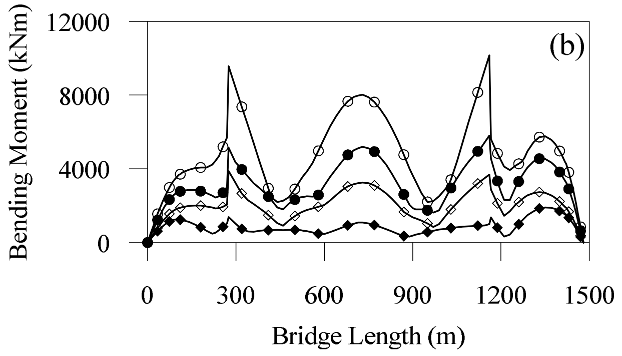


Figure 4. a) Vertical deck displacements b) Deck bending moments, for Duzce Earthquake

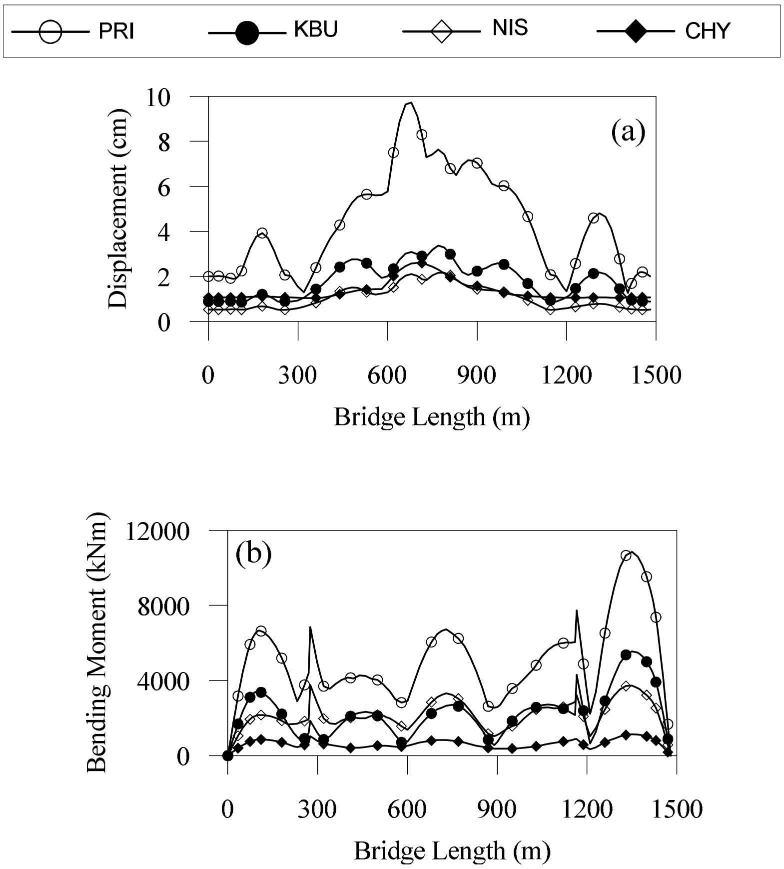


Figure 5. a) Vertical deck displacements b) Deck bending moments, for Kobe Earthquake

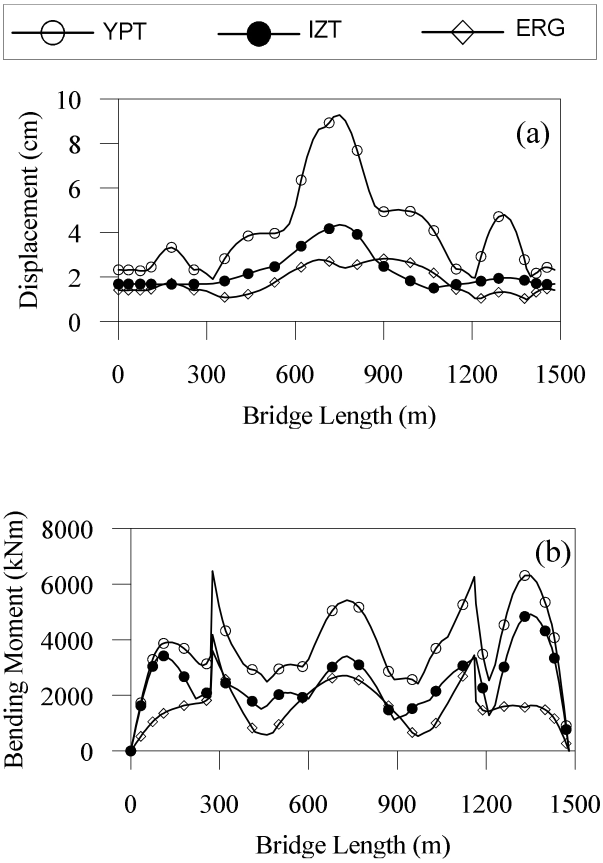


Figure 6. a) Vertical deck displacements b) Deck bending moments, for Kocaeli Earthquake

5. CONCLUSIONS

In this paper, the response of a long span cable-stayed bridge is investigated under the effect of near-fault and far-fault ground motions. Considered ground motions are classified as near fault ground motion with pulse type characteristics, near fault ground motion without pulse effect and far fault ground motions. For each ground motion component separate analysis are performed and obtained bridge responses are compared with each other. It is observed that nearly for all the considered earthquakes (Chi-Chi, Duzce, Kocaeli and Kobe), ground motion components which show pulse type characteristics caused larger responses than those of the near fault ground motion components without pulse effect and far fault ground motions. On the other hand for each earthquake motion (Chi-Chi, Duzce, Kocaeli and Kobe) two different near fault ground motions with pulse type characteristics are considered and the bridge responses are compared to underline the effect of the pulse type near fault ground motions. These analyses results revealed that the main parameter influencing the effect of the near fault ground motion on the bridge responses is the PGV/PGA ratio. It is also observed that generally ground motion components without pulse effects resulted larger responses than those of the responses obtained from far fault ground motions. The results mainly underline the remarkable effect of the pulse type near-fault ground motions on the dynamic responses of cable-stayed bridges.

This study shows that cable-stayed bridges with center spans reaching to 1000 m and hence having larger vibration periods have the potential to show larger seismic responses when subjected to the near fault ground motions with pulse type characteristics. The results suggest that for the reliable design of cable-stayed bridges near fault ground motions should be taken into account.

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