ISSN : 0974 - 7435 Volume 10 Issue 24

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(24), 2014 [15290-15295]

Effects of near-field and far-field ground motion on seismic response to long-span rigid frame bridge

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ABSTRACT

The near-field and far-field ground motions recorded by four stations is adopted to study the response of reinforced concrete long-span rigid frame bridge at transversal excitation of far-field ground motion and near-fault pulse-like ground motion. The correlation between parameters of these two ground motion and seismic response (including pier top displacement, mid-span transversal displacement, pier bottom bending moment, mid-span bending moment and pier bottom shear force) were analyzed and compared. The results show that there is strong correlation between parameters of these two ground motion and seismic response. The seismic response caused by near-fault pulse-like ground motion is more apparent than that caused by far-field ground motion at the effect of the same peak acceleration of ground motion records. All the seismic response is greatly increased with excitation of near-fault pulse-like ground motion. The impact rule to different structure positions is similar. The parameters of ground motion for estimating destruction degree of long-span rigid frame bridge are given.

KEYWORDS

Far-field ground motion; Near-fault pulse-like ground motion; Seismic response; Long-span rigid frame bridge.

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INTRODUCTION

The issue of destructive effect of ground motion to bridge structure always draws attention of anti-seismic research and design staffs. Especially the near-field earthquake appears the characteristic of near-fault pulse-like ground motion which is more complicated and has greater destruction effect to engineering structure. In the industry the parameters such as magnitude, intensity, peak value acceleration, peak value velocity, peak value displacement, maximum increment velocity, maximum increment displacement are usually adopted to estimate and compare the damage potential of ground motion [1-3]. The response of structure in seism is greatly related to ground motion. Therefore, the response of structure at near-fault pulse-like ground motion can be very different from far-field ground motion. At present, the research to this difference mainly aims at seismic motion itself. Although some scholars [4-6] researched the structure, the studies were not enough. Researching the response of reinforced concrete long-span rigid frame bridge at transversal excitation of far-field ground motion and near-fault pulse-like ground motion shall be in favor of improving bridge anti-seism design level and disaster prevention and mitigation capacity.

Through Port Hueneme seism in 1957, the engineers and seismologists started to realize the pulse effect and destruction capability of near-field ground motion. After researching the seismic record, Housner, etc [7] firstly proposed the pulse effect of near-field ground motion, and pointed out that near-field ground motion contained energy pulse, and this seismic motion has fairly strong destructiveness even at fairly small seismic magnitude and low acceleration peak value.

At present researching impact of pulse-like ground motion to bridge structure mainly adopts model test and value simulation method. Orozco, etc [8] adopted scale model test to research impact of velocity pulse to reinforced concrete bridge pier, and deemed that general impact of velocity pulse to bridge pier is fairly small. Michael and Wilson[9] researched the effectiveness of cable stayed bridge seismic isolation technology at near-field ground motion effect.

Liao, etc [10] researched and compared the dynamic response of five span continuous beam bridge which respectively undertake near field seism and far field seism, and found that ductility demand and base shear coefficient at the effect of near-fault ground motion exceeds the demand at far-field seismic effect.

In this paper, Chongqing Guangyangdao Bridge is taken as an example to adopt 12 far-field seismic motions (three logs respectively for each station) recorded by 4 stations of Chi-Chi earthquake to research the response characteristic of long-span rigid frame bridge structure at near-fault pulse-like ground motion and far-field ground motion effect. The correlation of near-fault pulse-like ground motion characteristic parameter and long-span rigid frame bridge structure response via five aspects as structure mid-span transversal displacement, pier top displacement, pier bottom bending moment, mid-span bending moment and base shear, were analyzed and compared. In order to reflect characteristic of different seismic motions, amplitude of inputted seismic motion log is not adjusted. The full transient analysis method is also adopted, with consideration of transversal seismic motion input only.

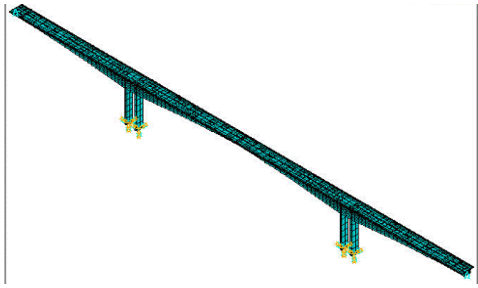
PROJECT OVERVIEW AND FINITE ELEMENT MODEL

Main bridge of Chongqing Guangyangdao Bridge adopts continuous rigid frame system, and its main bridge length is 441m, span combination is 115.5+210+115.5m. The main bridge adopts single box and single room beam whose width is 12.5m, box bottom width is 6.0m, and single side cantilever width is 3.25m. The box beam mid-span beam height is 3.5m, pier top root beam height is 11.0m, and single T box beam height is of half cubic parabola variation; The slab thickness of box beam mid-span bottom is 32cm, pier top bottom slab root thickness is 120cm, bottom slab thickness variation is of two times' parabola. One end of main bridge is connected with abutment, the other end adopts three span simply supported beam as approach bridge of 120m long. The main pier adopts double-rib flexible thin wall pier, clear distance of two ribs is 6.0m, pier body bridge transversal direction width is the same as main bridge box beam bottom slab, and they are both 6.0m, the pier body along-bridge direction width is 2.0m.

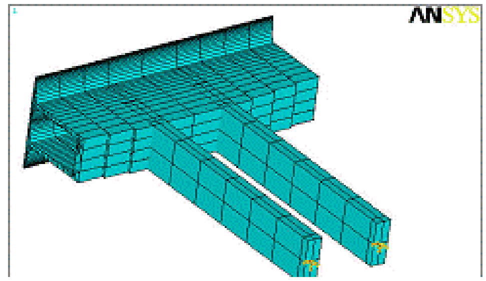
This paper adopts ANASYS finite element software to establish main span finite element model to analyze time history. In this paper, the approach bridge pier of the other end is cancelled when establishing finite element model, and it is simplified into symmetrical structure (two ends of main beam are both bridge abutment), the pier beam is concreted and only restricts vertical displacement of two ends of main beam, pier height is all taken as 40m restricting all freedom degree of pier bottom.

The main beam and bridge pier both adopt spatial beam unit beam 44, total bridge has 149 nodes, 148 units. The beam length is 441m, in total 108 units; double rib thin wall pier height is 40m, each rib has 10 units, bridge pier totally has 40 units. During calculation each section mass and moment of inertia of superstructure is taken as mean value of neighboring section, impact of pipe to section characteristic is omitted, and gross section is taken for calculation.

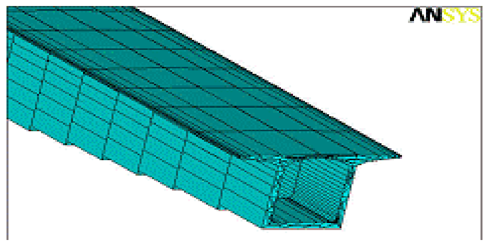
Full bridge structure finite element calculation model is shown in Figure 1a), finite element partial model is shown in Figure 1 b) and c).



a) Full bridge structure



b) The pier and beam



c）Part of the box girder section

Figure 1 Finite element model of the rigid bridge

THE GROUND MOTION RECORDS

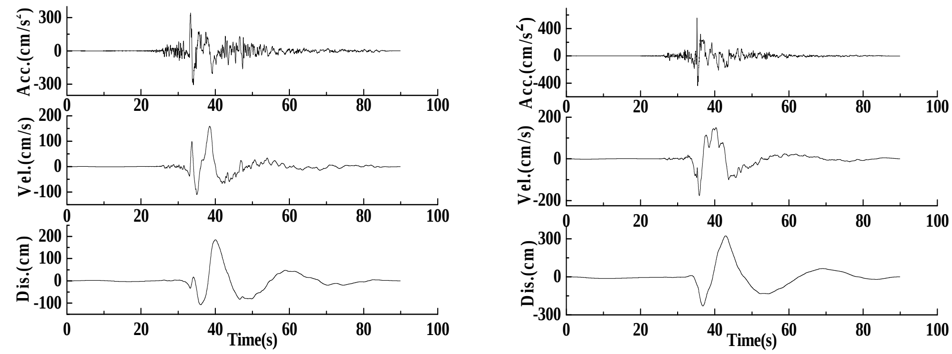
Fours logs recorded during 1999 Taiwan Chi-Chi earthquake are adopted as near field pulse log, these four logs respectively come from four stations TCU052, TCU068, TCU075 and TCU0102. Each recorded ground motion parameter is shown in TABLE 1. In the paper TCU052N presents near field log of TCU052 station, TCU052F1, TCU052F2, TCU052F3 respectively present three far field logs of TCU052 station. The indication of near and far field seismic motion of other stations is of the same. For the convenience of comparison, 12 far field seismic motion logs recorded by these four stations at other seismic event are taken; ground motion parameter of far field seismic motion log is shown in TABLE 2. Figure 2 provides time history of four near field seismic motion logs.

TABLE 1 Properties of near-fault ground motions used in this study

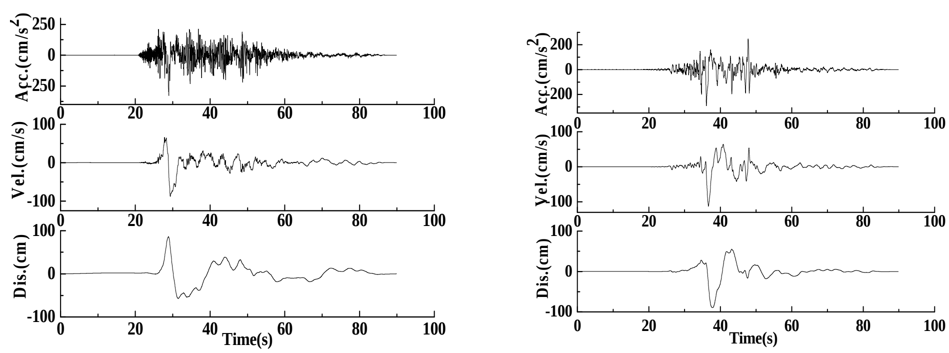
Logs	fault displacement (km)	magnitude (M_w)	PGA (cm/s^2)	PGV (cm/s)	PGV/PGA (s)	pulse duration (s)	the type of site
TCU052N	1.84	7.7	348.9	181.8	0.521	5.54	C
TCU068N	3.01	7.7	501.9	280.2	0.558	3.85	C
TCU075N	3.38	7.7	325.6	116.5	0.358	3.08	C
TCU0102N	1.19	7.7	298.6	86.5	0.290	7.69	C

TABLE 2 Properties of far-fault ground motions used in this study

Logs	fault displacement	magnitude	PGA	PGV	PGV/PGA	the type of site
TCU052F1	152.7	5.83	37.3	2.39	0.064	C
TCU052F2	104.5	6.50	13.5	2.07	0.153	C
TCU052F3	108.3	5.56	17.5	1.90	0.109	C
TCU068F1	157.8	5.83	16.1	1.31	0.081	C
TCU068F2	98.5	6.50	16.0	2.03	0.127	C
TCU068F3	93.9	5.77	13.9	1.86	0.134	C
TCU075F1	119.8	5.58	22.6	0.82	0.036	C
TCU075F2	140.4	5.83	36.8	1.24	0.034	C
TCU075F3	107.4	5.53	23.0	0.51	0.022	C
TCU102F1	98.3	5.77	12.1	2.21	0.183	C
TCU102F2	103.9	6.50	22.1	1.92	0.087	C
TCU102F3	112.4	5.56	7.7	0.37	0.048	C



a) TCU052 b) TCU068



c) TCU075 d) TCU102

Figure 2 Acceleration, velocity and displacement time histories of near-fault ground motions

CORRELATION BETWEEN SEISMIC MOTION CHARACTERISTIC PARAMETER AND BRIDGE STRUCTURE RESPONSE

Since excitation direction of straight line bridge is clear, force-bearing is simple, the definite research factor is seismic motion characteristic (far field log and near field pulse log) impact, therefore other factors are accordingly simplified: The foundation is of concretion without considering mutual effect of pile earth; traveling wave effect is provisionally not considered; the excitation direction shall only consider the transversal direction. This paper selects seismic motion characteristic parameters as peak value (peak ground acceleration PGA, peak ground velocity PGV, peak ground displacement PGD), peak ratio (PGV/PGA、PGD/PGV) increment velocity and pulse duration, etc to inspect the correlation with large span rigid frame bridge frame effect (pier top displacement, mid-span transversal displacement, pier bottom bending moment, mid-span bending moment and pier bottom shear).

In order to research the relation between seismic motion parameter and large span rigid frame bridge structure destruction, Pearson correlation coefficient is introduced in. Correlation coefficient (taken as absolute value) of random variables is calculated by formula (1).

$$\rho_{XY} = \frac{\operatorname{cov}(X,Y)}{\sqrt{D(X)}\sqrt{D(Y)}} \qquad (1)$$

Correlation between far field seismic motion parameter and bridge response

In order to research correlation between far field seismic motion parameter and large span rigid frame bridge response, 117 (15 times' seism at 1952-1999) far field seismic logs are selected. The selected seismic motion logs respectively come from USA Berkeley Pacific Seismic Engineering Research Center (PEER) database website http://peer.berkeley.edu/smcat, China Seismological Bureau Engineering Mechanics Research Institute (IEM) strong seism database website http://www.iem.cn/eeev and Chi-Chi earthquake Log data in references [11].

Elasticity dynamic analysis is conducted to structure of Chongqing Guangyang Bridge, and calculation results as pier bottom shear, pier bottom bending moment, pier top displacement, mid-span displacement, mid-span bending moment response, etc of the bridge structure are extracted, through a large number of time history analysis, correlation coefficient is calculated via formula (1), as shown in table 3.

TABLE 3 Correlation coefficients between the parameters of far-fault ground motions and the response of bridge

Parameters of ground motions	Pounding bottom shear	Pounding bottom bending moment	Displacement of pier crown	Displacement of the midspan	Bending moment of the midspan
PGA	0.396	0.405	0.419	0.317	0.421
PGV	0.720	0.724	0.728	0.692	0.735
PGD	0.478	0.476	0.472	0.516	0.463
PGV/PGA	0.333	0.330	0.323	0.391	0.323
PGD/PGV	0.177	0.173	0.167	0.219	0.148

Table 3 shows that, correlation among PGA, PGV, PGD and PGV/PGA and bridge response is all very apparent. Correlation between PGV and bridge response is fairly strong, and is stronger than correlation between PGA and bridge response; in turn is correlation among PGD, PGV/PGA and bridge response; correlation among PGD/PGV and bridge response is relatively weak. The correlation of same seismic motion parameter and different bridge response is consistent.

It is worth noting that PGA is usually adopt to evaluate seismic hazard at present. In this paper, correlation between PGV and bridge response is apparently stronger than correlation between PGA and bridge response. It is suggested that this conclusion shall draw attention.

Correlation between near field seismic motion parameter and bridge response

In order to research correlation between near field seismic motion parameter and large span rigid frame bridge, 137 (17 times seism from 1966 to 1999) near field seismic motion logs are selected. The selected seismic motion logs respectively come from USA Berkeley Pacific Seismic Engineering Research Center (PEER) database website, China Seismological Bureau Engineering Mechanics Research Institute (IEM) strong seism database website.

In addition to five seismic characteristic parameters which are same as that of far field seismic motion, near field seismic motion is also introduced in by pulse duration and increment velocity. The near field pulse seismic motion log time duration usually contains apparent pulse, therefore pulse duration is deemed as specific parameter of near field pulse seismic motion for investigation. Increment velocity is specific parameter of near field seismic motion.

Elasticity dynamic analysis is conducted to structure of Chongqing Guangyang Bridge, and calculation results as pier bottom shear, pier bottom bending moment, pier top displacement, mid-span displacement, mid-span bending moment response, etc of the bridge structure are extracted, through a large number of time history analysis, correlation coefficient is calculated via formula (1), as shown in TABLE 4.

Table 4 shows that, correlation between same seismic motion parameter and different bridge response is consistent. Correlation among PGA, PGV, PGD, PGV/PGA, PGD/PGV, and velocity increment and bridge response is all very apparent. Correlation between PGV and bridge response is best; in turn is correlation between near field pulse seismic motion typical characteristic PGV/PGA and bridge response; correlation among PGD, PGD/PGV and bridge response is relatively weak. There is no correlation between pulse time duration and bridge response.

TABLE 4 Correlation coefficients between the parameters of near -fault ground motions and the response of bridge

Parameters of ground motions	Pounding bottom shear	Pounding bottom bending moment	Displacement of pier crown	Displacement of the midspan	Bending moment of the midspan
PGA	0.406	0.417	0.419	0.394	0.446
PGV	0.838	0.835	0.826	0.851	0.867
PGD	0.432	0.429	0.443	0.460	0.432
PGV/PGA	0.687	0.679	0.655	0.678	0.614
PGD/PGV	0.451	0.427	0.404	0.426	0.435
pulse duration	-0.086	-0.091	-0.071	-0.054	-0.088
speed increment	0.806	0.814	0.821	0.813	0.822

It is worth noting that PGA is usually adopted to evaluate seismic hazard at present. In this paper, correlation between PGV, PGV/PGA, velocity increment, etc and bridge response is apparently stronger than correlation between PGA and bridge response. This shall appropriately draw attention, nevertheless, basic cycle of bridge structure in this paper is 4s, the structure with shorter cycle and longer structure shall be further researched.

Comparison on seismic motion parameter and bridge response correlation

Comparison on seismic motion parameter and bridge response correlation coefficient mean value is shown in table 5. Table 5 presents that, correlation between near field pulse seismic motion PGV/PGA, PGD/PGV and bridge response is far above correlation between far field related parameter and bridge response. Especially correlation between PGV/PGA and bridge response is only next to correlation between PGV and velocity increment and bridge response. Therefore, PGV/PGA can really in some extent reflect the destruction capability of near field pulse seismic motion to large span bridge. Considering of correlation with bridge response, PGV/PGA is adopted to judge destruction trend of seismic motion. Furthermore, PGV/PGA is deemed as critical parameter of near field pulse seismic motion, because response spectrum of such type of seismic motion apparently differs from ordinary near field response spectrum.

TABLE 5 Comparison of mean Correlation coefficients between parameters of near-fault ground motions and the response of bridge

Ground motion type	PGA	PGV	PGD	PGV/PGA	PGD/PGV
far-field	0.392	0.720	0.481	0.34	0.177
near-field	0.416	0.843	0.439	0.663	0.4286

Table 5 also shows that correlation coefficient of near field pulse seismic motion peak velocity PGV and bridge response is far above correlation coefficient between far field seismic motion and bridge response; correlation between near field pulse seismic motion peak displacement PGD and ground acceleration peak PGA and bridge response is similar with far field seismic motion. Some researchers deem that, under effect of high intensity seism, vertical seismic motion and pulse seismic motion shall apparently increase destruction to bridge pier, and seismic response is not proportional to PGA.

CONCLUSIONS

This paper mainly analyzes the correlation among far field seismic motion parameter, near field pulse seismic parameter and bridge response (pier top displacement, mid-span transversal displacement, pier bottom bending moment, mid-span bending moment and pier bottom shear), together with analysis and comparison, to derive following conclusions:

● It is not appropriate to adopt pulse cycle to estimate near field pulse seismic motion, because: (1) pulse cycle has no correlation with bridge response; (2) It is not easy to determine pulse cycle; (3) Cycle value distribution scope is very wide, with very great discreteness.

● At seismic motion log effect of same acceleration peak value, during transversal input, bridge response caused by near field pulse seismic motion is more apparent that bridge response caused by far field seismic motion.

● During seismic hazard evaluation at present, correlation coefficient between peak value parameter PGA and large span rigid frame bridge structure response is usually adopted, irrespective of whether it is at near field pulse seismic motion environment or far field seismic motion environment. Nevertheless, it is apparently lower than correlation coefficient between PGV and bridge response, and this shall draw attention.

● The peak velocity PGV, velocity increment, peak velocity versus peak acceleration (PGV/PGA) can preferably present the parameter of near field pulse seismic motion to large span bridge destruction trend. PGV can preferably present the destruction trend of far-field ground motion to large span bridge.

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