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Responses of long-span rigid frame bridge under longitudinal excitation of near-field and far-field ground motion

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ABSTRACT

This paper set a typical long-span rigid frame bridge as a research object and established a finite element model for the long-span rigid frame bridge using finite element software MIDAS/CIVIL. The near-field and far-field ground motions from four stations were recorded to study the responses of the bridge under the longitudinal excitation of near-field pulse type ground motion, and they were compared with the responses under far-field ground motion excitation. It aims to analyze the response characteristics of long-span bridge under the two types of ground motions and investigate the response characteristics of the rigid frame bridge with taking the account of horizontal and three-dimensional ground motion effects. The results indicate that: The bridge response caused by near-field pulse type ground motion is greater than that caused by non-pulse type when at longitudinal input under the ground motion and recording the action at same accelerated speed peaks; under the excitation of near-field pulse type ground motion, there would be a great increase in bridge response. Different effects on different structural parts; PGV/PGA is a major parameter affecting structure response; attention must be paid to the impact from the medium and long cycle velocity pulse of near-field ground motion on long period and flexible structure; near-field pulse type ground motion also has significant impact on longitudinal displacement at mid-span and pier top. All these phenomena shall be considered during the aseismic design for near-field rigid frame bridge appropriately.

KEYWORDS

Near-fault pulse-like ground motion; Longitudinal excitation; Rigid frame bridge; Seismic response; Parameters of ground motion.

INTRODUCTION

Among long-span structures, rigid frame bridge is applicable to V-shaped canyons with overhanging cliff at both sides because of the high pier and big span and has been widely used in mountainous areas. Generally, continuous rigid frame bridge is as statically indeterminate structure due to continuous girder beam body and thin-walled pier consolidation. In frequent earthquake areas and high intensity areas, long-span bridge structure are confronted with threatens from near-field earthquake. In most cases, near-field earthquake is more complicated and has greater destructiveness to long-span bridge structure. It presents the characteristics [1] of near-field pulse type ground motion. However, there are few researches on near field pulse effects on long-span bridge at present. Researches on the impacts and rules[2-3] under the effects of near-field ground motion on long-span rigid frame bridge are of vital importance.

Port Hueneme, an earthquake engineer and seismologist begun to realize the pulse effects and destructiveness of ground motion in 1957. Housner et. al [4]proposed pulse effects of near-field ground motion after studied the record of the earthquake for the first time, and pointed out that near-field ground motion contains energy pulse and that this kind of ground motion still has strong destructiveness even under the circumstance of a relatively small moment magnitude and low peak ground acceleration. Bogdanoff et. al applied the traveling wave effects of ground motion into structural seismic analysis in 1965. Scholars conducted a large number of studies specifically on multiple-support excitation in 1980s and 1990s. Many research results have been introduced to some national and regional specifications correspondingly. Eurocode stipulates that space variation of seismic motion should be taken into consideration in the case of the length of a bridge is over 200m and with geological discontinuity or significantly different topographical features, or the length of a bridge is over 600m.

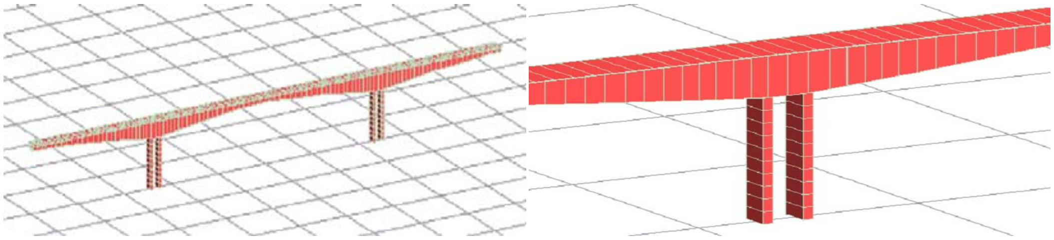
From studies of Button et. al [5], we can learn that vertical ground motion cannot be ignored on studies of pier axial force and bridge vertical shear. Liao et. al [6] compared the response characteristics of seismic isolated and non-seismic isolated three-span continuous girder bridge under near-field and far-field ground motion excitation taking 4 near-field and 12 far-field seismic records from a same station as input, and studied the relationship between near-field ground motion parameters and seismic isolated bridge responses. The research has shown that the reducing effect of seismic isolated bridge on pier bottom shear has been significantly decreased under the impact of near-field ground motion. The correlation between displacement of medium cycle, short cycle seismic isolated bridge, pier bottom shear, PGV/PGA and ground motion energy (E_i) is significant. PGV/PGA of near-field ground motion has significant impacts on bridge response.

Generally, the model experiment adopts partial analysis, such as experimental analysis on join node between bridge pier or pier and girder due to restricted by various conditions. Since the overall bridge interaction is ignored, sometimes the analysis results are not conform to actual seismic damage and the analysis results are subject to great limitations. Numerical simulation method can establish overall bridge numerical model. At present, some studies on impacts of pulse type ground motion on multi-span continuous bridges and cable-stayed bridge have been carried out at home and abroad, but few on impacts of near-field pulse effect on long-span rigid frame bridge. Rigid frame bridge has different structural features compared with multi-span continuous bridges and cable-stayed bridge. The other seismic responses have distinctive features as well.

The paper studied the responses of the reinforced concrete long-span rigid frame bridge under longitudinal excitation of far-field ground motion based on the near-field and far-field ground motions recorded by the four stations, compared which with the responses under far-field ground motion excitation, analyzed response characteristics of long-span bridge under the two types of ground motions and discussed the calculation results of the numerical example based on the comparison, which indicate that long cycle velocity pulse effects will cause large displacement impact on large-span bridge structure, thus attentions should be paid on impacts caused by medium and long cycle velocity pulse effects on long cycle and flexible structure.

FINITE ELEMENT MODEL

Finite element model



a) Full bridge structure b) bridge joint

Figure 1 Finite element model of the rigid bridge

The paper established three dimensional space finite element model with MIDAS/CIVIL finite element software according to bridge design data. In order to simulate bridge responses under the effect of ground motion more accurately, the piers of the large-span rigid frame bridge were established with space fiber beam elements, taking pier material nonlinearity into consideration but ignoring interaction of pile-soil structure. The overall bridge structure finite element calculation model of the rigid frame bridge is as shown in Figure 1a) and finite element partial model is as shown in Figure 1b).

FEATURES OF GROUND MOTION RECORDS

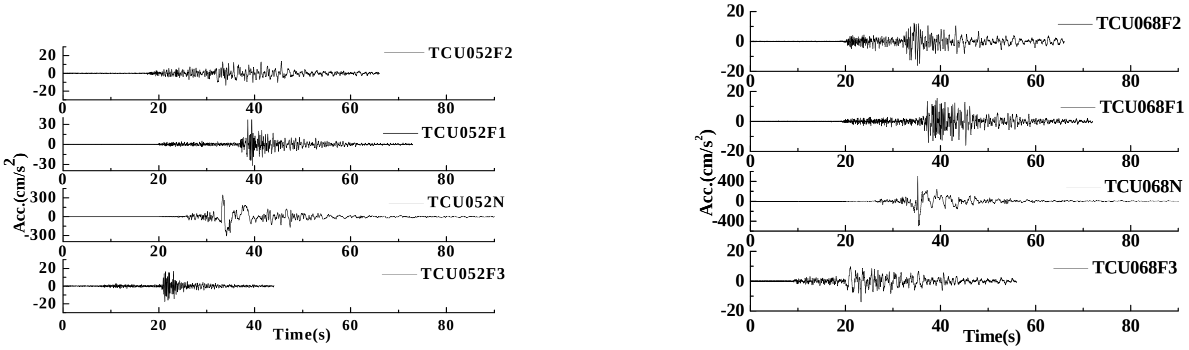
Took four records, from station TCU052, TCU068, TCU075 and TCU0102 respectively of Taiwan chi-chi earthquake (M_w=7.7) which happened in 1999 as near-field pulse type records. The ground motion parameters of each record are as shown in Table 1. For the convenience of comparison, took 12 far-field ground motion records [5] of other seismic events recorded by these four stations as well. The ground motion parameters of far-field ground motion records are as shown in Table 2. Figure 2 From the comparison between accelerated velocity time-history of near-field pulse type seismic record and that of far-field seismic record, we can see that the impulse waveform recorded by near-field accelerated velocity is relatively obvious.

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

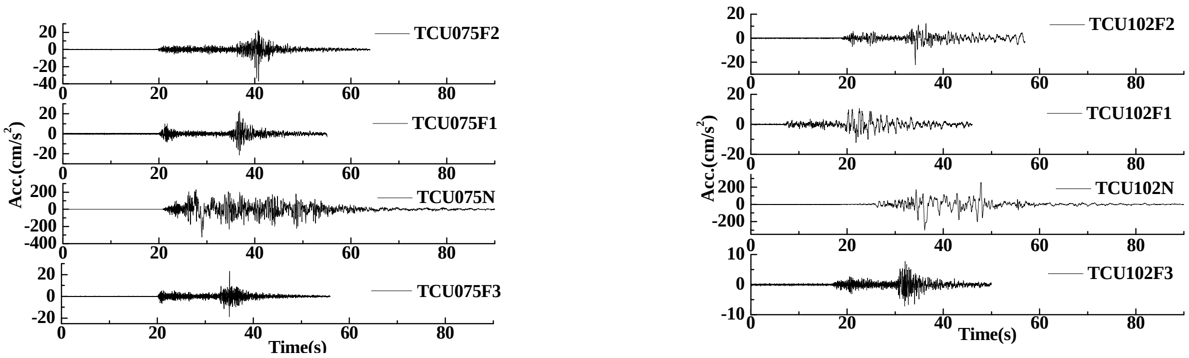
Logs	fault displacement （km）	magnitude （M_w）	PGA （cm/s^2）	PGV （cm/s）	PGV/PGA （s）	pulse duration （s）	the type of site
TCU052N	1.84	7.7	348.9	181.8	0.521	5.54	C
TCU068N	3.01	7.7	501.9	280.2	0.558	3.85	C
TCU075N	3.38	7.7	325.6	116.5	0.358	3.08	C
TCU0102N	1.19	7.7	298.6	86.5	0.290	7.69	C

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

Logs	fault displacement （km）	magnitude （M_w）	PGA （cm/s^2）	PGV （cm/s）	PGV/PGA （s）	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 Comparison of acceleration time histories between near-fault and far-fault ground motions

BRIDGE RESPONSE COMPARISON UNDER NEAR-FIELD AND FAR-FIELD GROUND MOTION

Since the excitation direction of straight line bridge is clear, stress is simple, and effects of ground motion characteristics are set forth study factors (far-field records and near-field pulse type records), the other factors can be simplified correspondingly: the foundation takes consolidation, ignoring pile soil interaction; temporarily not considering traveling wave effect; only taking longitudinal excitation into consideration.

Generally the Max. internal force response value of long-span continuous rigid frame bridge's main girder is located at the middle section of mid-span, sidespan or main girder root section under the action of earthquake; the Max. internal force response value of pier body usually occurs at pier top or pier bottom cross-section; the Max. displacement value usually occurs at pier top or main girder. Consequently, the paper mainly studied the cross section responses at seismic analysis.

Impact on beams

Table 3 indicated the Max. value of box beam longitudinal displacement, mid-span moment under longitudinal excitation of near-field ground motion TCU052N, TCU068N, TCU075N and TCU102N respectively, and indicated the average of the Max. response under excitation from 3 different far-field ground motion records of a station as well.

TABLE 3 Comparison of mid-span response of girder subjected to near-fault and far-fault ground motions

Logs	Max. of mid-span longitudinal displacement（m）		Max. of mid-span moment（N·m）	
	Average of far-field	near-field	Average of far-field	near-field
TCU052	0.107	0.626	6.74E8	6.75E8
TCU068	0.131	0.462	6.74E8	6.75E8
TCU075	0.014	0.430	6.74E8	6.75E8
TCU102	0.157	0.481	6.74E8	6.75E8

It can be seen from Table 3 that:

- The impact caused by near-field pulse type ground motion on mid-span longitudinal displacement is significant. The average response of 3 far-field ground motion records from stations is 3%~33% of near-field pulse type ground motion record response from the same station.
- Compared with impacts on mid-span moment from far-field ground motion, that from near-field pulse type ground motion is not obvious. Bridge mid-span moment (Bending moment refers to mid-span moment within beam plane M_y. Longitudinal displacement has few impact on mid-span moment at this direction due to symmetrical structure) is not sensitive to ground motion type.

Impact on piers

Table 4 indicated the Max. value of longitudinal displacement at pier top, bending moment at pier bottom and pier bottom shear under longitudinal excitation of near-field ground motion TCU052N, TCU068N, TCU075N and TCU102N respectively, and indicated the average of the Max. response under excitation from 3 different far-field ground motion records of a station as well.

TABLE 4 Comparison of the maximum response of pier subjected to near-fault and far-fault ground motions

Logs	Vertical displacement of pier crown (m)		bending moment of pounding bottom (N·m)		Shear of pounding bottom (N)	
	Average of far-field	near-field	Average of far-field	near-field	Average of far-field	near-field
TCU052	0.225	0.748	3.70E8	6.35E8	3.75E7	4.89E7
TCU068	0.234	0.557	3.74E8	5.38E8	3.81E7	4.54E7
TCU075	0.132	0.551	3.22E8	5.35E8	3.55E7	4.30E7
TCU102	0.270	0.602	3.92E8	5.61E8	3.85E7	4.57E7

It can be seen from Table 4 that:

- The impact on longitudinal displacement from near-field pulse type ground motion at pier top is relatively significant. The average response of 3 far-field ground motion records from stations is 20%~50% of near-field pulse type ground motion record response from the same station.
- The impact on bending moment at pier bottom from near-field pulse type ground motion is greater than that from far-field ground motion. The average response of far-field ground motion records from stations is 50%~70% of near-field pulse type ground motion record response from the same station.
- The impact on pier bottom shear from near-field pulse type ground motion is not significant. The average response of far-field ground motion records from stations is 70%~ 90% of near-field pulse type ground motion record response from the same station.

Near-field pulse type ground motion has a biggest impact on longitudinal displacement at pier top, medium impact on bending moment at pier bottom and smallest impact on pier bottom shear. It can be seen that longitudinal displacement at pier top is quite sensitive to longitudinal excitation of near-field pulse type ground motion, while pier bottom shear is not sensitive to near-field pulse type ground motion.

CONCLUSIONS

This paper set near-field pulse type ground motion as starting point, and conducted studies on responses of large span reinforced concrete rigid frame structure under longitudinal excitation of near-field pulse type ground motion. Conclusions are as follows:

- The bridge response caused by near-field pulse type ground motion is greater than that caused by non-pulse type at longitudinal input under the ground motion recording action of a same peak accelerated speed.
- Under the excitation of near-field pulse type ground motion, there will be a great increase in bridge response. Different effects for different structural parts; near-field pulse type ground motion has the biggest impact on displacement at mid-span and pier top of main beam (The average response of 3 far-field ground motion records from stations is 20%~50% of near-field pulse type ground motion record response from the same station), medium impact on bending moment at pier bottom (The average response of far-field ground motion records from stations is 60%~70% of near-field pulse type ground motion record response from the same station.), and smallest impact on pier bottom shear.
- Under the condition of an equal PGA, structural seismic response caused by PGV/PGA>0.2s pulse type ground motion records are obviously greater than that caused by PGV/PGA<0.2s non-pulse type ground motion records, which indicates that PGV/PGA is a major parameter affecting structure response.
- Long cycle velocity pulse effects will cause large displacement impact on large-span bridge structure.
- Near-field pulse type ground motion also has significant impact on longitudinal displacement at mid-span and pier top which shall be considered during the aseismic design for near-field rigid frame bridge appropriately.

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