INVESTIGATION OF THE BRIDGE'S DESIGN CODES THROUGH NEAR FAULT'SEARTHQUAKES

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ABSTRACT

viewpoints of various design codes about vertical component of ground motions is reviewed. Design codes that have been reviewed in this study are: Iranian codes for seismic design of roads and railway's bridges, Caltrans, Euro Code8, AASHTO , AASHTO Seismic Isolation Guide Specifications , AASHTO LRFD Bridge Design Specifications, ASCE ,IBC2012 and UBC97. Then a database consists of 31 near fault earthquake records is gathered and individual and mean and mean +/- standard deviation response spectra plotted for selected 31 earthquakes and by comparison with standard spectra's is showed that usual assumption that vertical component spectrum equal to 2/3 horizontal spectrum isn't correct in short period regions.

INTRODUCTION

Previous researches presents that effects of vertical component of earthquakes on key structural elements of bridges is very noticeable in near fault seismic events.Vertical component of earthquakes have unique properties that distinct it from horizontal component. In the near distances of source (D<10 to 15 km) response spectrum of vertical component has a great peak in short periods regions. for vertical motions recent observations suggest that the commonly adopted vertical- to- horizontal response spectral ratio of (2/3) (Newmark and Hall , 1978) may be significantly exceeded at short periods in the near-source distance range. Most bridges design office analyses that are performed on bridges are based on linear elastic model using the response spectrum method. Very rarely is the vertical component included in such analyses. Bridge codes to date haven't provided load multipliers or specific vertical response spectra that allow for the impact of the vertical motions to be rationally included. The bridges linear elastic analyses results that bridges with greatest percentage of modal mass associated with periods near the peak of vertical response spectrum experience the greatest impact from the vertical seismic motions. Thus for some force response quantities of such bridges , for accounting effect of vertical motions , response from dead loading must multiply by 2 (Button et al., 2002).

LITERATURE REVIEW

Saadeghvaziri and Foutch completed the first major analytical study into the effects of vertical acceleration on bridges. They reported that san Fernando 's vertical peak acceleration in Pacoima dam station was 0.7g and fault peak displacement was 6 ft in vertical direction. Peak acceleration in Elasnam earthquake (10 octobr 1980) is estimated to be 1g in vertical direction and 0.25g in horizontal direction. They used a finite element code capable of modelling the inelastic behaviour ofreinfoercd concrete columns under combined horizontal and vertical deformations. With three dimensional finite element model of eight bridges. They show that varying axial force in the columns results in pinched hysteresis that causes larger horizontal displacements and fluctuation in shear capacity of the columns.The study concluded that for earthquake motions with effective peak acceleration (EPA) of 0.4g or less , the additional damage caused by the vertical component is minimal while for earthquakes motions with EPA of 0.7g , the addition of the vertical component resulted in considerably more damage (Saadeghvaziri and Foutch, 1998).

Broekhuizen and Yu conducted parametric studies into the effects of vertical acceleration on bridges (Broekhuizen and Yu, 1997). AlsoYu similarly studied the effects of vertical component of earthquakes on bridges (Yu et al., 1997). Both studies concentrated on three overpass of the SR14/15 interchange location about 15 km north of the epicentre of the 1994 Northridge earthquake. Two of these bridges partially collapsed during that earthquake. Broekhuizen investigated effects of vertical acceleration on pre-stressed concrete bridges. By assuming a 1g upward acceleration it was found that allowable tensile stresses in deck could be exceeded (Broekhuizen, 1996). Yu analyzed forces in all piers of three overpasses using a 3D linear Models with Sylmar hospital (Northridge) record as an input motion. The study found a 21% increase in axial force and a 7% change in longitudinal moment due the addition of the vertical component. Yu analyzed the effects of the vertical of earthquake motions on bridge foundations , hinges and bearings. Soil stiffness was varied for spread footing and friction –pile foundation. The maximum response was found to increase as the shear-wave velocity of the soil increased, approaching the limiting values obtained with rigid base (Yu et al., 1997). Yu and Gloyd presented criteria used in design of 60 pre-stressed box-girder bridges that considered the effects of vertical ground motion (Yu and Gloyd,1997).Sheng and Kunnath studied effects of vertical components on 2 highway bridges with low periods is greater (Sheng and Kunnath, 2008) . Kunnath considered variation of axial loads effects due vertical components on ordinary highway bridges and represented that vertical acceleration can considerably increase tension stresses in deck and decrease flexural &shear capacity in piers (Kunnath et al., 2008).

Hosseinzadestudied effects of vertical components reinforced concrete piers of bridges. He selected two concrete piers of a bridge and analyzed this piers under tabas earthquake records with different horizontal PGA and 50% of horizontal PGA as vertical component PGA. He found that by applying vertical component width of cracks increase 60% and cracking mechanism change from flexural to shearing (Hosseinzade, 2008).

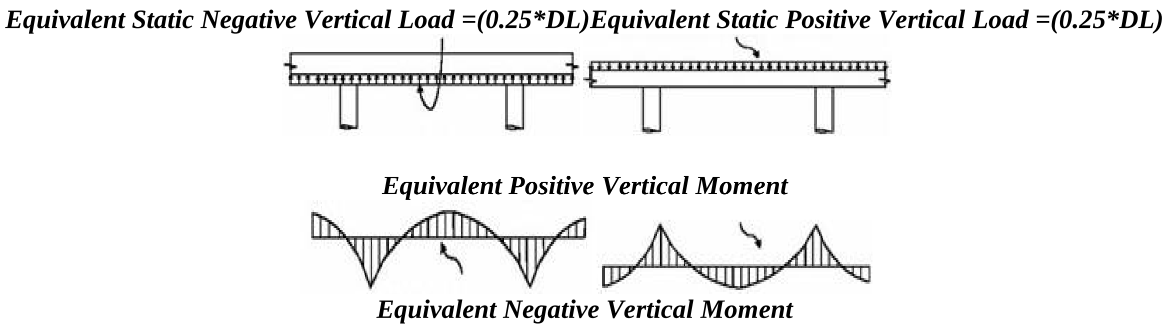
Few studies can be found concerning seismic performances of masonry bridges.Armstrong evaluated dynamic properties of two stone bridges by field studies (Armstrong et al., 1995). Brencich measured dynamic properties of a multi-span masonry bridge and compared this results by finite element modelling results(Brencich et al., 2010). Bayraktar modelled a two span masonry bridge analytically based on results obtained from modal tests updated the analytical model(Bayraktar et al., 2010). Ozdencaglayan calibrated two masonry arch bridge based on results obtained from ambient vibration test and finite element modelling and calculated seismic response of bridges (Ozdencaglayan et al., 2010). Marefat estimated damping ratios for two unreinforced concrete arch bridges based on modal properties resulted from vibration test and finite element modelling(Marefat et al., 2004). Luca Pella studied effectiveness of nonlinear static analysis methods for evaluating of seismic performance a three arch's masonry arch bridge based on comparison responses obtained from nonlinear static analysis method by those obtained from nonlinear dynamic analysis method(Luca Pela et al., 2010).

EARTHQUAKE VERTICAL COMPONENT THROUGH BRIDGE DESIGN CODES

It seems reviewing viewpoints of various design codes about vertical component of ground motions is essential. Design codes that have been reviewed in this study are: Iranian Codes for Seismic Design of Roads and Railway's bridges,Caltrans,EuroCode, AASHTO LRFD Bridge Design Specification's, AASHTO, AASHTO Seismic Isolation Guide Specifications, ASCE,IBC2012 and UBC97.

Iranian Codes for Seismic Design of Roads and Rail ways bridges respects only horizontal components and ignores vertical component effects,recommends only amount of design forces for deck support bolts(Iranian Codes for Seismic Design of Roads and Railway's Bridges).

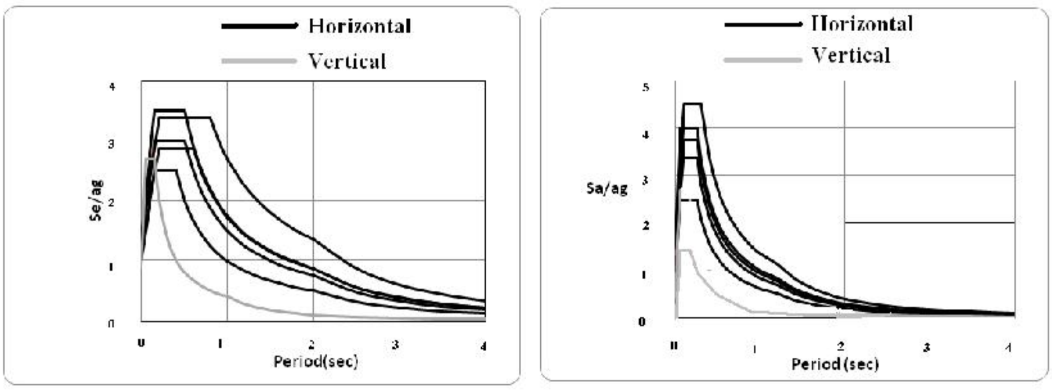
Caltrans applies a vertical load in ordinary and standard bridges that their site's PGA exceeds from 0.6g and recommends sitestudy for evaluation effects of vertical component in important and complicated bridges. In bridges with above conditions, a uniform vertical load which is equivalent to one forth of the deck dead load, is applying to the deck in upward and downward directions. This is shown in Figure 1 (Caltrans).



a)b)

Figure1. equivalent static loads in up and down direction & moments (Caltrans)

Euro code8 considers vertical earthquake motion effects explicitly during design procedure and offers vertical response spectrum for different soil types. Figure 2 & 3 represents Type I & Type II Response Spectrum for Vertical and horizontal components according Euro Code8(Euro Code8).



a) TypeI b)Type II

Figure2: Response Spectrum for Vertical and horizontal components(Euro Code)

AASHTO do not have a direct method for applying vertical component on bridges but instead AASHTO Seismic Isolation guide specification uses +/- 20% of dead load (i.e. load factors of 1.2 and 0.8) in the testing requirements to represent vertical effects, irrespective of earthquake magnitude, fault distance and soil type(AASHTO Seismic Isolation Guide Specifications).

AASHTO LRFD Bridge Design Specifications denotes for short period motions in the near fault environment the ratio of vertical to horizontal ground motions increase. if site is located within 6 mi of an active fault , intermediate to long periods ground motion pulses that are characteristics of near source time histories should be included if this types of ground motion characteristics could significantly influence structural response. Similarly the high short –period spectral content of near source vertical ground motions should be considered (AASHTO LRFD Bridge Design Specifications).IBC2012 denotes every structures and portion thereof , including non-structural components that are permanently attached to structures and their supports and attachments shall be designed and constructed to resist the effects of earthquake motions in accordance ASCE 7 and don't present's any un dependent instruction about vertical component effects(International Building Code 2012).

In UBC97 structures shall be designed for ground motion producing structural response and seismic forces in any horizontal direction , the following earthquake loads shall be used in load combination :

$$E = \rho.\ E_h + E_v$$

That E is the earthquake load on an element of structure resulting from combination of horizontal component E_h, and the vertical component E_v. $E_v$the load effect resulting from vertical component of earthquake ground motion and is equal to an addition of 0/5. C_a.*I*.*D* to dead load effect, D For strength design and may be taken to as zero for allowable stress design. Maximum values of 0/5.C_a.I product according table's presented in code is 81% .the vertical component of ground motion may be defined by scaling corresponding horizontal acceleration by a factor of two thirds. Alternative factors may be used when substantiated by site specific data. Where the near source factor ,$N_a$is greater than 1 , site specific vertical response spectra shall be used in lieu of the factor of two-thirds (Uniform Building Code 97).

In ASCE7-10 vertical seismic load effect E_v shall be determined in accordance with following equation: E_v= $0.2S_{DS}.D$

That S_{DS} is design spectral response acceleration parameter at short periods and D is effect of dead load(ASCE /SEI 7-10) .

DESIGN CODES AND STATISTICAL VERTICAL RESPONSE SPECTRUM'S

In later stage of this study a database consists of 31 nearfault earthquake records is gathered. These database consists61 horizontal and 31 vertical components of 31 worldwide earthquakes . (reported by PEER-NGA database). Table 1 represents specifications of 31 ground motion that is used in this study.

Table 1: specifications of 31 ground motion

Earthquake Name	Station name	PGA(g)	PGV (inch/sec)	PGD (inch)	Mag	Dis(mil)
Baja California	Cerro prieto	1.26	21.96	3.83	5.5	2.29
Cape Mendocino	Cape mendicono	1.3	34.81	10.62	7.01	4.32
Chi-chi Taiwan	Chy080	0.82	34.33	11.02	7.62	1.67
Chi-chi Taiwan	Tcu071	0.62	23.89	15.20	7.62	3.3
Chi-chi Taiwan-06	Tcu080	0.58	11.18	1.91	6.30	6.34
Coalinga-01	Pleasant valley pp	0.57	17.75	2.71	6.36	5.23
Gazli, ussr	karakyr	0.65	24.43	8.41	6.8	3.39
Imperial valley-06	Bonds corner	0.68	21.15	5.05	6.53	1.67
Imperial valley-06	El centro array #8	0.54	22.36	12.99	6.53	2.40
Landers	Lucerne	0.73	42.83	74.94	7.28	1.36
Loma prieta	Corralitos	0.52	16.35	4.17	6.93	2.39
Loma prieta	Lgpc	0.78	30.37	16.8	6.93	2.41
Northridge-01	Pacoimadam (up le)	1.4	31.11	5.55	6.69	4.36
Northridge-01	Rinaldi receiving	0.63	43.01	11.13	6.69	4.04
Northridge-01	Tarzana-cedar hill	1.67	37.68	13.5	6.69	9.69
Sanfernando	Pacoima dam up le	1.23	34.62	10.15	6.61	1.12
San Salvador	Geotech investing	0.65	18.65	4.75	5.8	3.91
Imperial valley-06	Agragias	0.29	13.33	3.73	6.53	0.4
Imperial valley-06	El Centro Dif-array	0.43	21.78	13.01	6.53	3.16
Imperial valley-06	El Centro Array #6	0.43	32.73	17.69	6.53	0.84
Imperial valley-06	El Centro Array #7	0.42	31.57	16.15	6.53	0.35
Loma Prieta	Capitola	0.48	13.59	2.81	6.93	9.46
Mammoth Lakes 01	Convict Creek	0.43	9.55	1.99	6.06	4.12
Morgan Hill	Gilroy Array #2	0.19	3.37	0.68	6.19	8.51
Morgan Hill	Gilroy Array #3	0.19	4.95	1.12	6.19	8.09
Morgan Hill	Gilroy Array #4	0.28	6.65	1.42	6.19	7.17
Northridge-01	Arleta-nordhof-fi-st	0.33	12.11	5.02	6.69	5.37
Superstition Hills-02	WildLiquef.Array	0.19	12.68	8.11	6.54	14.82
Tabas	Tabas	0.688	17.95	6.71	7.40	
Bam	Bam	0.88	36.82	11.12	6.6	
Manjil	Abbar	0.58	15	4.17	7.7	

These earthquakes have very close distance to fault and great magnitude. Then individual and mean and mean +/- standard deviation response spectra plotted for selected 31 earthquakes. Figure 3 represents mean and mean +/- standard deviation response spectrum for vertical component and response spectrum according Euro Code8.

This figure shows that mean spectrum of 31 records is approximately two times greater than Euro Code's spectrum in short periods regions. Thus usual assumption that vertical component spectrum equal to 2/3 horizontal spectrum isn't correct in short period regions. .Figure 4-5 shows mean and mean +/- standard deviation horizontal response spectrum for parallel and normal directions to fault prolongation respectively beside response spectrum according Iranian code of 2800 for Type II soils. This figure shows trend of mean spectrum and code's spectra are approximately accommodate and difference of this two spectrum is not large as large for vertical component.

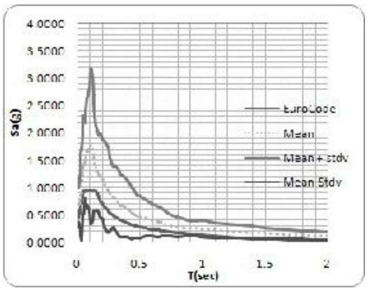


Fig3: vertical response spectrum

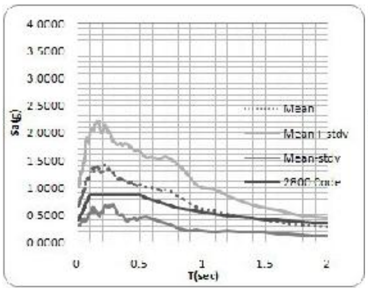


Fig4:parallel response spectrum

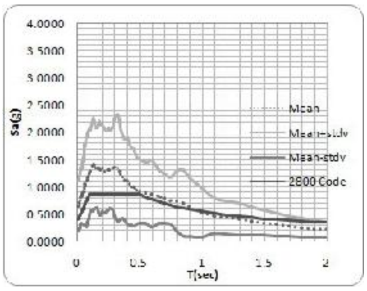


Fig5: normal response spectrum

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