Effect of near-fault vertical seismic excitation on the response of long-span continuous deck truss bridges

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Abstract:

Introduction/purpose: This study investigates the seismic response of long-span continuous deck truss bridges under the effect of near-fault vertical ground motions. The primary objective is to assess how near-fault vertical seismic excitation affects the structural safety and performance of these bridges.

By exploring the nuanced dynamics induced by near-fault vertical motions, the research aims to improve the understanding of the vulnerabilities and challenges faced by long-span continuous deck truss bridges during seismic events.

Methods: To achieve this objective, the truss bridge was subjected to a series of ground motions, representing natural seismic events. The seismic response of the bridge was investigated by applying the linear time history method to the 3D finite element model. This analysis focused specifically on the evaluation of base shear and displacement. The analysis was extended to include the seismic performance of truss structures. The comparison between the bridge responses with and without consideration of the vertical component of ground motion was made to clarify the effect of vertical excitation.

Results: The results show that there is a significant contribution of vertical excitation, particularly concerning the internal force in the truss elements, where it exceeded 60 % during a severe earthquake, and consequently increased the demand-to-capacity ratio in most elements of the truss bridge structure.

Conclusion: For structural engineers and designers, the results of this research suggest that neglecting to include the vertical ground motion component in the analytical assessments of this type of bridges can lead to a greater degree of uncertainty and risk, particularly in near-fault regions.

Key words: deck-truss bridge, vertical displacement, seismic performance, axial force, V/H ratio, D/C ratio.

Introduction

Truss bridges are ubiquitous in modern infrastructure, owing to their efficient use of materials and structural stability. However, the seismic response of long-span truss bridges to near-fault vertical ground motions poses an important research gap, as it can profoundly impact bridge safety and serviceability after seismic events. It is known that the vertical component of ground motion weakens faster than its horizontal counterparts, especially for bridges located in moderate to high seismic zones and in close proximity to active faults (less than 25 km). The vertical component of ground motion is often more significant and can cause damage alongside the horizontal components, by amplifying the demand on some of the bridge's structural elements, which could damage the entire bridge. The vertical acceleration depends on the earthquake magnitude, soil conditions, and the site-epicenter distance (Bhanu et al, 2018; Nouri et al, 2020). The incorporation of vertical excitation in seismic bridge design has been extensively studied. Research has shown that vertical earthquake loads impose excessive axial demands on reinforced concrete bridge columns (Saadeghvaziri & Foutch, 1988; Papazoglou & Elnashai, 1996; Elnashai & Papazoglou, 1997; Collier & Elnashai, 2001; Kunnath et al, 2008; Pollino & Bruneau, 2010; Kim et al, 2011a, 2011b; Di Sarno et al, 2011; Matsuzaki et al, 2012; Wilson et al, 2015; Li et al, 2017; Guo et al, 2023). Other works found that vertical excitation amplifies bending in bridge components, potentially causing structural failure. Veletzos et al. (2006) examined bridge segment joints subjected to concurrent vertical and horizontal seismic motions. The authors observed that vertical excitation amplified positive bending rotations by 400% and negative rotations by 90%. Recent numerical studies indicated that increased vertical acceleration heightens damage across bridge components (Li & Yao, 2020; Aryan & Ghassemieh, 2020). Predicting vertical earthquake intensity using the vertical-to-horizontal (V/H) acceleration ratio has been studied extensively. Though a V/H ratio of 2/3 was initially proposed, values exceeding 1.0 have been recorded in several major earthquakes (Newmark et al, 1973; Newmark & Hall, 1982). High V/H ratios above 1.5 have also occurred in near-fault zones (Bozorgnia et al, 1995; Papazoglou & Elnashai, 1996; Ambraseys & Douglas, 2003; Campbell, 2004).

As span length increases, truss bridges become more flexible and prone to vertical vibrations. Such vibrations can adversely affect stability and strength, consequently altering a seismic response (Saadeghvaziri & Foutch, 1988). Although prior research has focused predominantly on the effects of vertical excitation on bridge piers, such excitation may also detrimentally impact bridge decks, especially those incorporating truss girders. Further research is needed on the complex interplay between vertical excitations and the nonlinear response of long-span truss bridges.

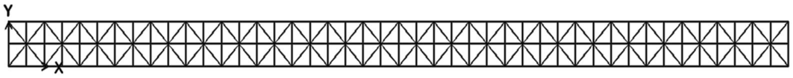
To address this gap, the current study utilizes analytical simulation to examine the seismic response of long-span truss bridges subjected to near-fault vertical ground motions, considering the influence of vertical-to-horizontal (V/H) acceleration ratios.

Using SAP 2000 software, spatial finite element models were generated for a 165-meter truss bridge. Time history analyses were conducted to evaluate the bridge behavior under vertical earthquake loads. A seismic response was assessed via bridge displacements, base shear, and axial forces. Additionally, the effects of varying V/H ratios on seismic performance were investigated through demand/capacity (D/C) ratios. Findings may hold important implications for seismic design modifications and retrofitting to enhance the earthquake resilience of long-span truss bridges.

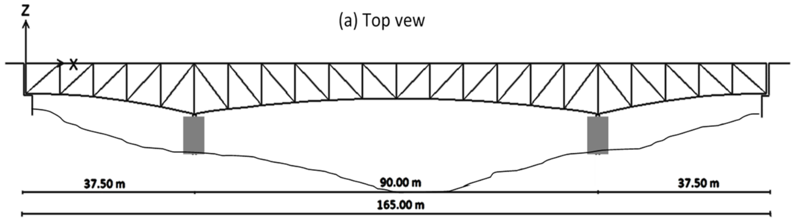
Materials and methods

Description of the bridge

The bridge under consideration in this study features a continuous 165 m long x 9.75 m wide steel truss deck with an upper slab that includes a center 90 m span flanked by two 37.5 m and 17.5 m side spans (Figure 1). Two longitudinal truss girders support the 200 mm thick reinforced concrete deck, with HEB300 sections serving as intermediate stiffeners and HE450B sections serving as outer girders. Transverse floor beams are joined to longitudinal deck beams at 3.75 m intervals by two 150 x 100 x 12 mm angle sections and bear on 120 x 80 x 12 mm angle seats.



(a) Top vew



(b) Side vew

Figure 1 – Truss bridge geometry: (a) Top view; (b) Side view

Analytical model of the truss bridge

To undertake a seismic study of the 165-meter-long truss bridge, a three-dimensional finite element model was created using Sap 2000. To effectively reflect structural behavior, the three-span deck truss was modeled utilizing truss components with hinged joints. Bridge bearings were modeled as one fixed and three moveable transversely fixed supports (Figure 2). There were 1670 nodes and 2180 elements in the finite element model. For all seismic events investigated, the accelerograms from earthquake recordings were input at the base in both horizontal directions, with the vertical component also added in the second phase. The model utilized the measured material properties for the bridge components (Table 1). This advanced numerical simulation enables an in-depth evaluation of the seismic response of long-span truss bridges to multi-axial earthquake excitations.

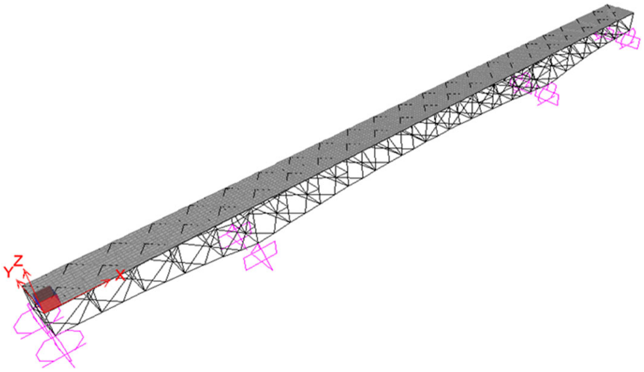


Figure 2 – Finite element model of the truss bridge

Table 1 – Mechanical properties of the materials

Material	Concrete	Steel
Young’s modulus/MPa	34500	210000
Poisson ratio	0.2	0.3
Yielding strength/MPa	/	345
Compression strength/MPa	28	/

Parameters and options considered in the seismic analysis

Input ground motions

Five significant near-fault earthquake records with magnitudes ranging from 6.8 to 7.3 were used to assess the effects of vertical stimulation on the bridge seismic response. The accelerations were measured in three directions (horizontal, transverse, and vertical). The records were chosen based on the comparable horizontal peak ground acceleration (PGA) values (Table 2), although the vertical PGA ranged from 0.24g to 1.34g. The vertical-to-horizontal (V/H) acceleration ratios ranged from 0.39 to 1.89 as a result. All data were obtained within 2 to15 kilometers of a fault.

Figure 3 shows the three-component accelerograms for the earthquake in Gazli, Uzbekistan. This collection of the near-fault movements allowed for the systematic evaluation of vertical shaking effects at different but realistic V/H ratios.

Table 2 – Earthquakes used in the time history analysis (PEER ground motion database, 2024)

No	Seismic event	Mw	Station	PGA-Long (g)	PGA-Tran (g)	PGA-Ver (g)	V/H
1	Gazli, Uzbekistan (1976)	6.8	Karakyr	0.71	0.63	1.34	1.89
2	Loma-Prieta, USA (1989)	6.9	LGPC	0.56	0.61	0.89	1.47
3	Landers, USA (1992)	7.3	Lucerne valley	0.72	0.79	0.82	1.04
4	Kobe, Japan (1995)	6.9	Nishi-Akashi	0.51	0.50	0.37	0.73
5	Kobe, Japan (1995)	6.9	JR Takatori	0.61	0.61	0.24	0.39

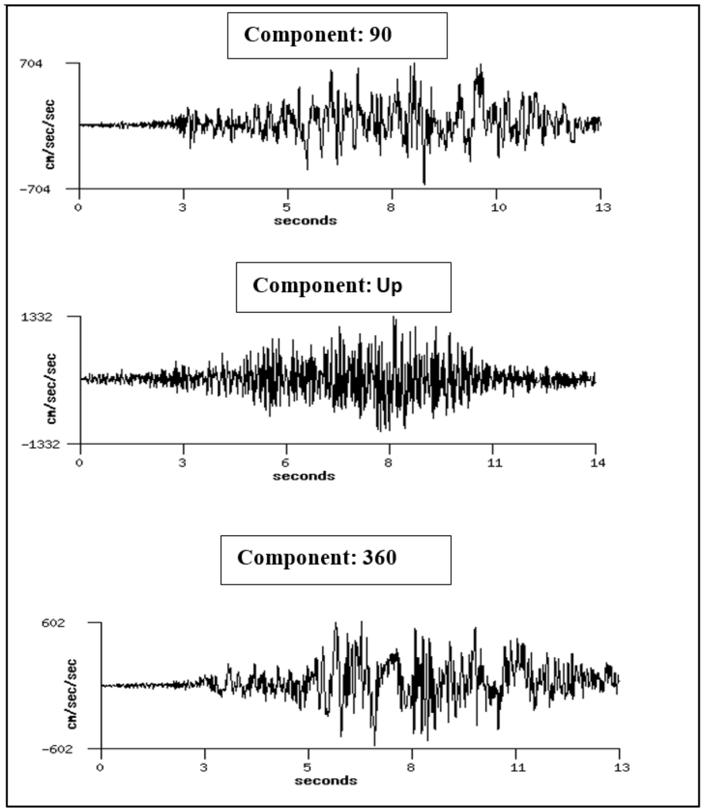


Figure 3 – Ground time-histories of the Gazli (Uzbekistan) earthquake in three directions

Modal analysis

A modal analysis was conducted to determine the dynamic properties of the bridge, which depend on structural mass and stiffness. The results can be utilized to calibrate the finite element model and evaluate structural damage. In this study, a modal analysis of the truss bridge was performed prior to a time history analysis to obtain fundamental vibration modes and frequencies. These dynamic characteristics provide insights into the bridge's seismic response and validate the numerical model's ability to realistically simulate dynamic behavior. The first six modal shapes and periods obtained from the analysis are presented. The comparison of the analytical and experimental modal properties enables model calibration and confirmation that the model accurately represents the inertia and flexibility of the actual bridge. This modal analysis provides the basis for the in-depth time history seismic evaluations described in the subsequent sections.

Time history analysis by direct integration

Time-history analysis is a common technique for evaluating bridge seismic performance, as implemented in several prior studies, e.g. (Behnamfar & Velni, 2019, An & Lee, 2022). So, a linear time-history analysis can provide useful insights into fragility across damage levels and near-source seismic response (De Luca & Lombardi, 2017). In the current study, three-component earthquake ground motions obtained from the PEER database were input in the (x, y, and z) directions to the structural model (Figure 1). The seismic response history was computed using direct integration with Rayleigh proportional viscous damping, assigning the structure 5% critical damping ratio for the first two vibration modes. The average acceleration Newmark method was utilized for the dynamic time integration. The details of the time history analysis factors and settings are provided in Table 3. This rigorous numerical simulation method enables an in-depth evaluation of the truss bridge response under multidirectional seismic excitations.

Table 3 – Parameters input in the time-history analysis

Mass Coeff	Stiff Coeff	Frequency	Damping1	Frequency	Damping2	γ	β
1/Sec	Sec	Cyc/sec	Unitless	Cyc/sec	Unitless	Unitless	Unitless
1.122	0.0022	3.25	0.05	3.68	0.05	0.5	0.25

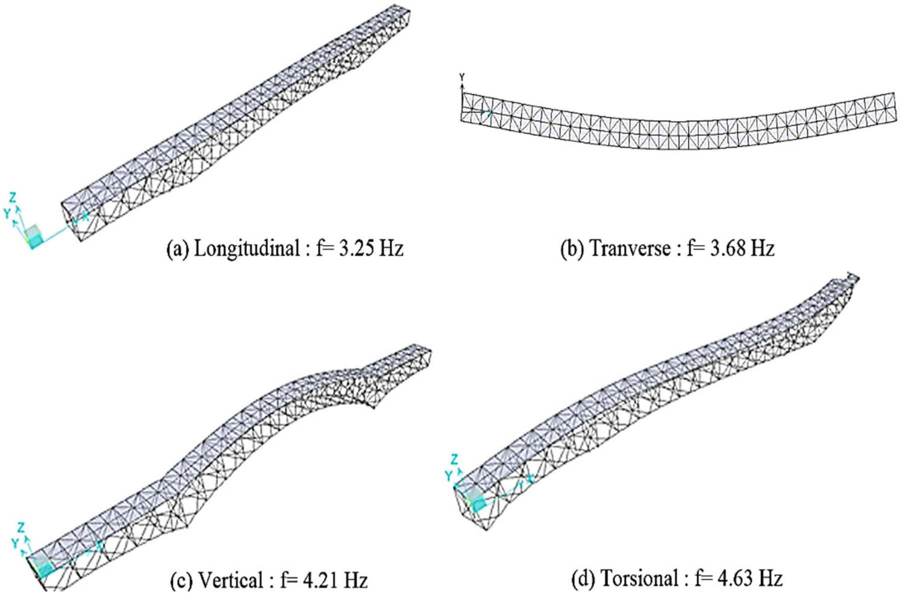
Analysis and discussion of the results

Natural vibration results

A modal analysis was first conducted to characterize the bridge's dynamic properties which are critical in determining a structural vibration response (Li et al, 2014; Fouché et al, 2017; Xin et al, 2019). The eigenvector method identified the natural frequencies and mode shapes.

Four primary mode types were observed (Figure 4): longitudinal, transverse, vertical bending, and torsional. The fundamental frequency was a longitudinal oscillation at 0.32 sec. The second mode was transverse at 0.24 sec, and the first vertical bending mode occurred at 0.22 sec. The torsional response did not appear until the fourth mode at 0.20 sec.

Nineteen natural modes were computed, accounting for over 90% mass participation in the longitudinal, transverse, and vertical directions. This meets recommended design code requirements, e.g. (Ministère des Travaux Publics Algérie, 2008; European Standard, 2011; AASHTO, 2017). The modal analysis provided essential insights into the bridge's dynamic characteristics governing its seismic response.


(a) Longitudinal : f= 3.25 Hz

(b) Tranverse : f= 3.68 Hz

(c) Vertical : f= 4.21 Hz

(d) Torsional : f= 4.63 Hz

Figure 4 – The four first analytical mode shapes: (a) Longitudinal: f= 3.25 Hz, (b) Tranverse: f = 3.68 Hz, (c) Vertical: f = 4.21 Hz, (d) Torsional: f = 4.63 Hz.

Time history results

The two horizontal components of the earthquake were the primary focus of this study's first phase, and the vertical component which is integrated with the two horizontal components was considered in the second phase. Equation (1) was utilized to determine the proposed earthquake amplification ratio (RHV) which was used to assess the contribution of the vertical component of ground motion to the bridge reaction. By incrementally introducing the vertical acceleration in the time history analysis, its specific impact on bridge seismic demands could be isolated and quantified through RHV (1).

$$RHV = \frac{RSP(DL + H + V)}{RSP(DL + H)} \qquad (1)$$

RHV: *The ratio of the bridge response due to combined dead load and earthquake loading with and without the vertical ground motion components.*

RSP(DL+H): *Response resulting from the two horizontal ground motion components and dead loads.*

RSP (DL + H + V): *The response resulting from the three components of ground motion and dead loads.*

Effect of vertical seismic excitation

A linear time-history analysis was performed on the truss bridge model using five near-fault earthquake records with three-directional components to evaluate the influence of vertical ground motion. The key response parameters examined were:

Vertical displacement

The peak vertical displacement at numerous nodes along the deck truss top chord was examined to quantify the role of vertical excitation to bridge deformation. There were three load situations studied: dead load only (DL), dead load plus horizontal motions (DL+H), and dead load plus horizontal and vertical motions (DL+H+V). Figure 5 depicts the peak drift profile along the top chord for the three load situations during the Karakyr earthquake. In all cases, the deck displayed a symmetric parabolic displacement form, with the greatest displacement at the midspan. Figure 6 depicts the temporal history of the Nishi-Akashi event's midspan displacement, demonstrating amplification after integrating vertical acceleration.

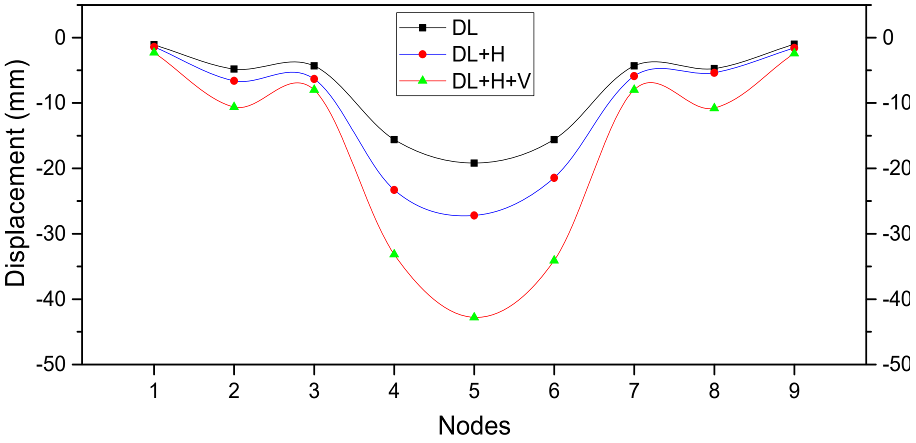


Figure 5 – Vertical deck truss deformations due to the Karakyr seismic event and the dead load

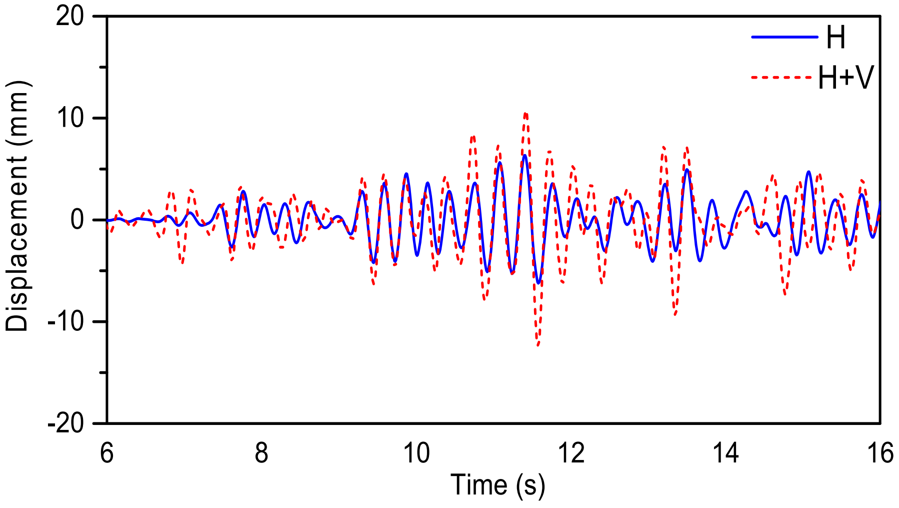


Figure 6 – Mid-span deck vertical displacement history for the Nishi-Akashi ground motion

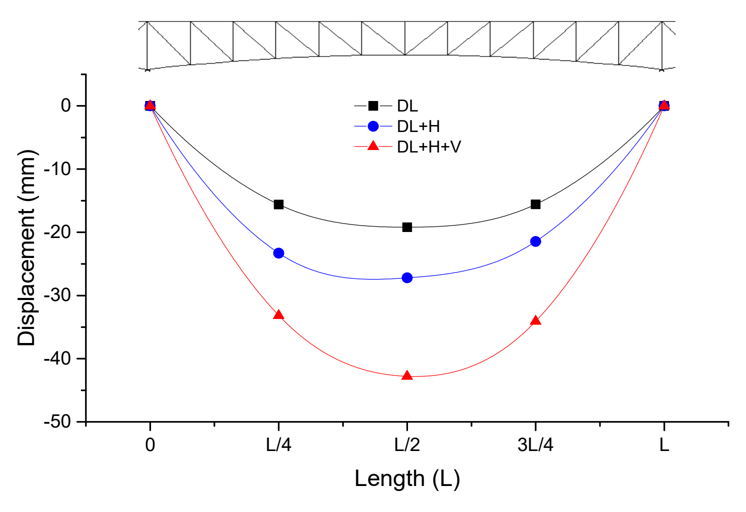
Figure 7 compares the midspan vertical displacement for the Gazli and J-R Takatori events.

Table 4 summarizes the peak midspan displacements across the five earthquakes for each load case. With only dead load (DL), the displacement was 19 mm. Adding horizontal excitation (DL+H) increased this moderately to 23-29 mm. Incorporating vertical acceleration (DL+H+V) substantially amplified displacements by 57-66%.

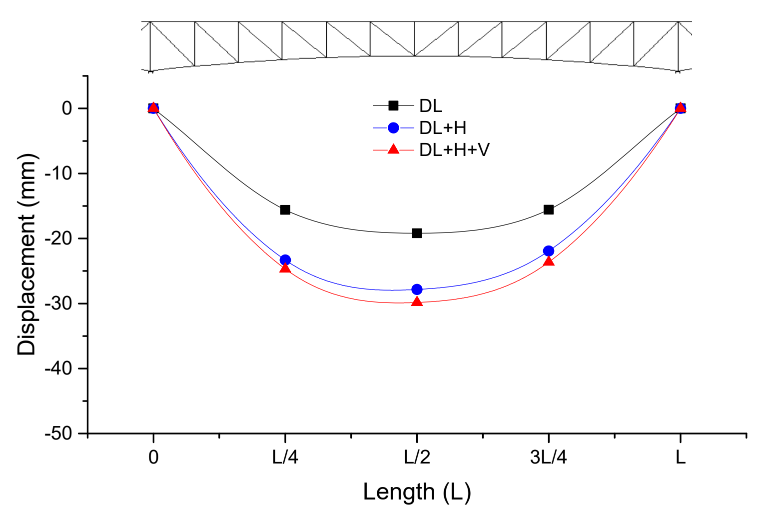
Table 4 – Peak displacement at the middle point of the main span of the deck truss under tow load cases

Seismic events	Load cases	U1 (mm)	U2 (mm)	U3 (mm)
Karakyr	DL+H	13.35	21.33	27.22
	DL+H+V	11.54	21.33	42.80
	RHV	0.86	1.00	1.57
LGPC	DL+H	15.03	14.85	29.10
	DL+H+V	15.97	14.84	34.26
	RHV	1.06	1.00	1.18
Lucerne valley	DL+H	7.02	21.31	23.23
	DL+H+V	9.22	21.30	38.49
	RHV	1.31	1.00	**1.66**
Nishi-Akashi	DL+H	12.18	8.65	25.40
	DL+H+V	13.37	8.64	31.56
	RHV	1.10	1.00	1.24
J R Takatori	DL+H	13.88	25.31	27.84
	DL+H+V	13.67	25.32	29.86
	RHV	0.98	1.00	1.07

The vertical motion caused the highest displacement amplification for the Karakyr event (RHV = 1.57). The lowest amplification occurred for the J-R Takatori (RHV = 1.07). In most cases, RHV increased proportionally with the V/H ratio (Figure 8).



(a) Gazli seismic events



(b) J R Takatori seismic events

Figure 7 – Peak vertical displacement of the main span for seismic and dead load: (a) Gazli seismic events; (b) J R Takatori seismic events

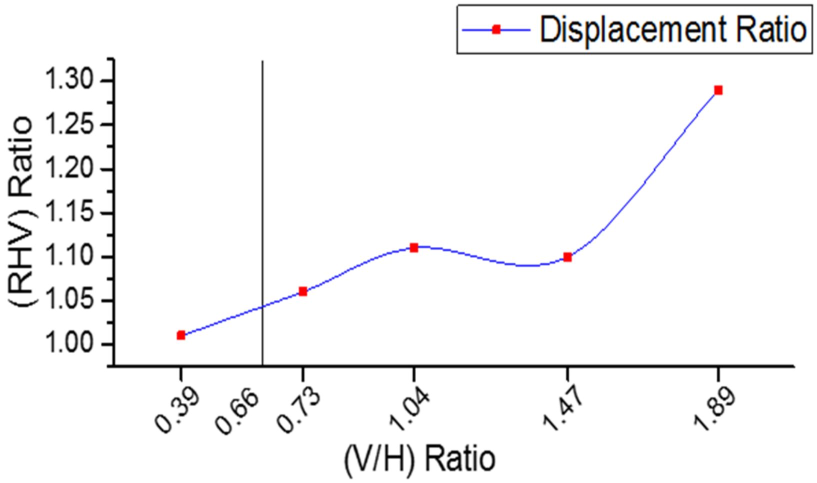


Figure 8 – Variation in the RHV ratio at the midpoint of the main span with the increase in the V/H ratio

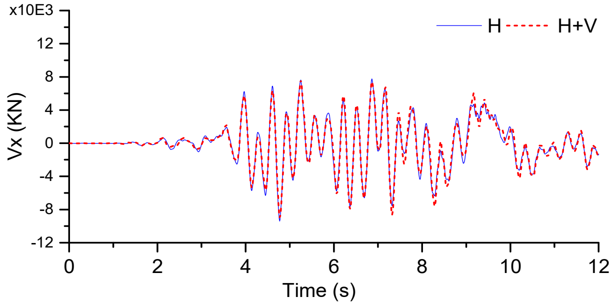
Horizontal displacement

Table 4 shows that the DL condition did not result in any displacement in the horizontal direction. In contrast, Case 2, which involved the introduction of both horizontal components, showed an increase in displacements in the longitudinal direction that were almost identical in magnitude. Nevertheless, the longitudinal displacement estimates for each of the five earthquakes changed dramatically when the vertical component of ground motion was included, where it also somewhat decreased for certain ground motions, like in the case of the Karakyr ground motion, but it grew greatly for some other ground motions (e.g. the Lucerne valley).

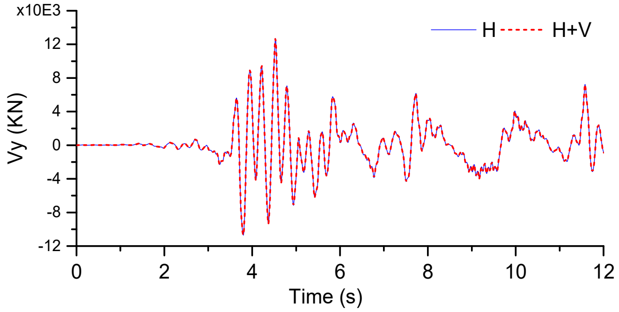
This demonstrates that the vertical component can substantially influence the bridge response in the longitudinal direction. However, its effect on transverse displacement was negligible. Compared to dead load alone, horizontal excitation notably increased vertical displacement by up to 53%, likely due to the large span and light weight of this truss bridge type. Overall, the analyses highlighted the potential for vertical ground motion to alter longitudinal seismic demands on long-span truss bridges.

The time-history analysis results demonstrate the vertical ground motion component considerably influences vertical deformation of the bridge deck at the mid-span. However, horizontal deck displacement was less susceptible to vertical excitation, aligning with the past findings by Shrestha (Shrestha, 2015) for a long-span cable-stayed bridge.

Notably, the contribution of vertical motion to vertical displacement does not necessarily correlate directly with the peak ground acceleration ratio (V/H). This contribution can also depend on soil conditions, ground motion characteristics (Tonyali et al, 2019), the closest distance to the fault (Button et al, 2002), and earthquake duration.

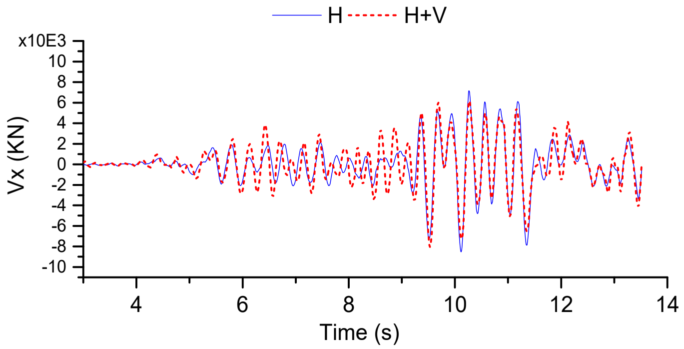


(a) longitudinal direction

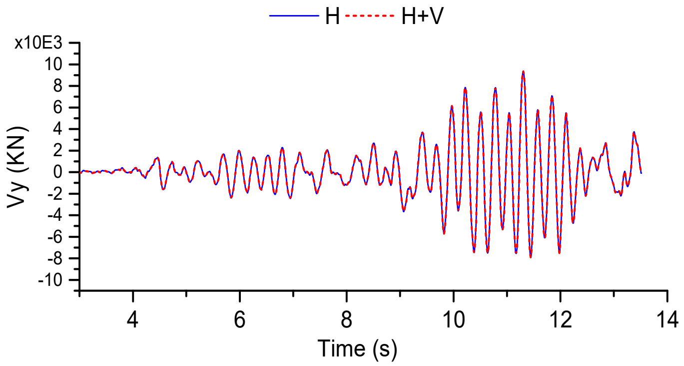


(b) transverse direction

Figure 9 – Base shear force history during the JR Takatori seismic events



(a) longitudinal direction



(b) transverse direction

Figure 10 – Base shear force history during the Karakyr seismic events.

Base shear

Figures 9 and 10 present the examples of the base shear force time histories with and without vertical motion for the JR Takatori and Karakyr events, in longitudinal (V_x) and transverse (V_y) directions. The deck response appears identical for both load cases over the vibration duration. Table 5 compares the base shear amplification ratios (RHV) and the amplification percent (Amp %) with and without vertical excitation for the five earthquakes. The results show the vertical component has a negligible effect, increasing base shear by no more than 2% and 0% in some cases.

This demonstrates the vertical ground motion does not meaningfully contribute to base shear force in the deck truss bridge.

Table 5 – Amplification ratio with and without the vertical ground motion of the base shear force

Ground motion	V/H	Base shear			
		Vx		Vy	
		RHV	Amp %	RHV	Amp %
Karakyr	1.89	1.00	0%	1.01	1%
LGPC	1.47	1.00	0%	1.00	0%
Lucerne valley	1.04	1.00	0%	1.00	0%
Nishi-Akashi	0.73	1.02	2%	1.02	2%
J R Takatori	0.39	1.00	0%	1.00	0%

Structure performance

Axial frame force

Figures 11-14 compare the axial force time histories with and without vertical motion for four critical members on the intermediate pier under the Lander seismic events. Including vertical acceleration dramatically increased axial forces, exceeding 64% in diagonal members. Table 6 summarizes the axial force amplification from the vertical component for the members on the intermediate support across the five earthquakes. The signs (-) and (+) represent the compression and tension in an element, respectively. The results show that the effect was independent of the V/H ratio and most significant in vertical and diagonal members versus top and bottom chords. The table indicates that the effect of the vertical ground motion component was independent of the V/H ratio.

Table 6 – Amplification ratio (RHV) for internal axial force of the members situated on the intermediate support

Element		Column (-)		Brace (+)		Bottom chord (-)		Top chord (+)	
Ground motion	V/H	RHV	Amp %	RHV	Amp %	RHV	Amp %	RHV	Amp %
Karakyr	1.89	1.33	33%	1.44	44%	1.61	61%	0.94	-6%
LGPC	1.47	1.10	10%	1.20	20%	1.31	31%	1.05	5%
Lucerne valley	1.04	1.18	18%	1.64	64%	1.64	64%	1.01	1%
Nishi-Akashi	0.73	1.09	9%	1.19	19%	1.17	17%	1.08	8%
J R Takatori	0.39	1.03	3%	1.10	10%	1.12	12%	1.02	2%

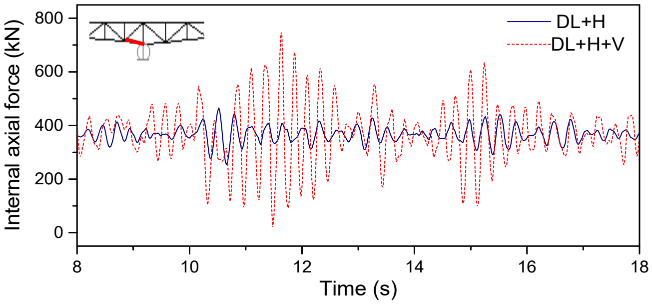


Figure 11 – Axial frame force history under the Landers seismic events combined with the dead load for the bottom chord

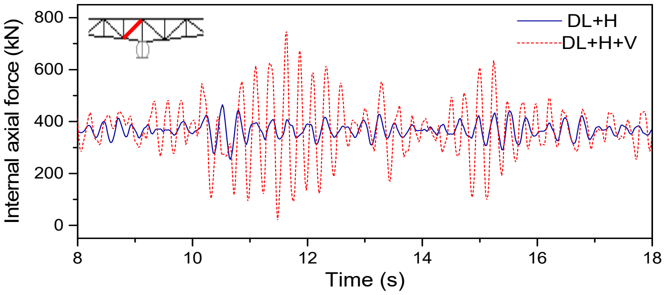


Figure 12 – Axial frame force history under the Landers seismic events combined with the dead load for the brace

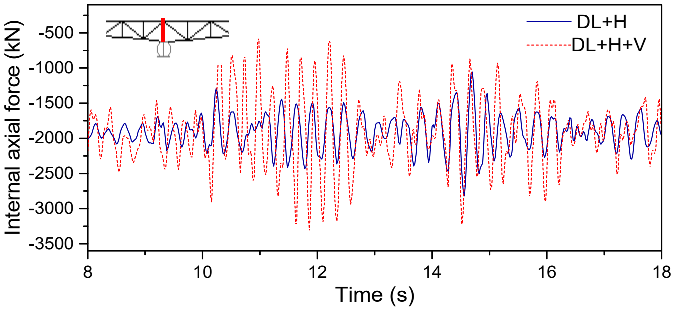


Figure 13 – Axial frame force history under the Landers seismic events combined with the dead load for the column

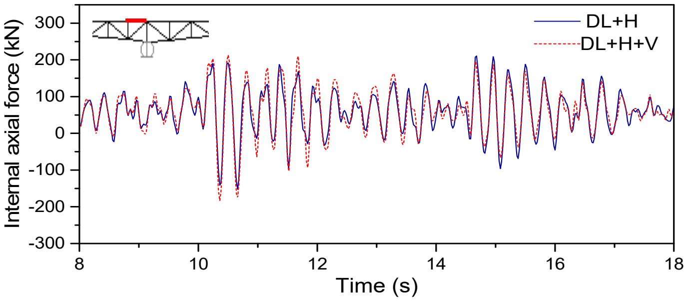


Figure 14 – Axial frame force history under the Landers seismic events combined with the dead load for the top chord

The time history analysis performed on the truss bridge using five natural recordings of earthquakes with different V/H ratios revealed that the vertical component contributed significantly to the internal axial force; however, its effect was greatest in the vertical and diagonal brace members and least in the upper and lower chord members. It should be noted that the contribution of the vertical ground motion component to vertical displacement does not necessarily change proportionally to the change in the ratio of the PGA value (V/H), which is due to variations in seismic and soil characteristics and could be the closest distance to the fault.

Demand to capacity ratio

Seismic evaluation in terms of the demand-to-capacity (D/C) ratio is a standard approach used in structural engineering to analyze a building's or structure's seismic performance. The (D/C) ratio is computed by dividing an element's capacity to withstand seismic forces by the demand for seismic forces predicted during an earthquake. The (D/C) ratio is a valuable measure of a structure's capacity to withstand seismic force.

A (D/C) ratio more than once has shown that the element's ability to resist seismic pressures is greater than the demand it is anticipated to face during an earthquake, which is a desired outcome. A (D/C) ratio less than one indicates that the structure's capacity may be insufficient to resist the expected seismic forces, and further strengthening may be necessary.

Table 7 – Amplification ratio (RHV) for the maximal demand of the members situated on the intermediate support

Element	Ground motion	Karakyr	LGPC	Lucerne valley	Nishi-Akashi	J R Takatori
	V/H	1.89	1.47	1.04	0.73	0.39
Column	Ratio	1.29	1.09	1.24	1.09	1.02
	Amp %	29%	9%	24%	9%	2%
Brace	Ratio	1.48	1.27	1.61	1.22	1.07
	Amp %	48%	27%	61%	22%	7%
Bottom chord	Ratio	1.42	1.2	1.4	1.14	1.08
	Amp %	42%	20%	40%	14%	8%
Top chord	Ratio	1.27	1.22	1.41	1.19	1.05
	Amp %	27%	22%	41%	19%	5%

The seismic performance was evaluated through the demand-to-capacity (D/C) ratios by comparing the member seismic demand to capacity. Table 7 presents the D/C ratio amplification (RHV) for the four most affected members on the intermediate support. The D/C ratios differed substantially between the load cases with and without vertical excitation. For example, the D/C ratio for the vertical member at Pier C increased from 0.78 (DL+H) to 0.89 (DL+H+V) under the Lucern event, an amplification of 24%. For the Karakaty, it increased from 0.77 to 0.99, with an amplification of 29%.

In summary, the vertical component significantly impacted the truss member seismic performance, especially for the members near the supports. This highlights the importance of incorporating vertical excitation in analysis models to accurately evaluate seismic responses.

Conclusions

The effects of vertical ground motion on the seismic response of a long-span truss bridge under near-fault excitations were evaluated using numerical simulation in this study. The time history analysis revealed the following major trends in the dynamic response:

- Vertical acceleration primarily affects vertical deck displacement, with a lesser but still significant impact on longitudinal deformation. However, the lateral response is minimally influenced.

- Inclusion of the vertical component does not alter base shear forces.
- Axial forces in truss members, especially near supports, are substantially amplified by the vertical motion.
- Vertical excitation heightens member demand beyond capacity limits in some cases.
- Applying the vertical component markedly increases vertical deformation and demand-to-capacity ratios compared to horizontal excitation alone.
- The three-directional analysis provides a greater insight into seismic behavior than the one with one or two components.
- Maximum vertical acceleration does not necessarily govern response amplification.
- Vertical effects are more pronounced for V/H ratios exceeding 1.0 versus the 2/3 ratio in codes.

The results demonstrate that vertical excitation significantly impacts deck trusses, not just bridge piers. Considering all three ground motion components is critical for accurate seismic evaluation of near-fault truss bridges. These findings can guide engineers toward improved design and assessment of truss bridges in seismic regions.

Additional research on different truss arrangements could lead to more thorough findings about their seismic performance under vertical excitation.

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Efecto de la excitación sísmica vertical cercana a la falla en la respuesta de puentes de celosía de tablero continuo de largo alcance

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Resumen:

Introducción/objetivo: Este estudio investiga la respuesta sísmica de puentes de celosía de cubierta continua de largo alcances bajo el efecto de movimientos verticales del terreno cercanos a la falla. El objetivo principal es evaluar cómo la excitación sísmica vertical cercana a la falla afecta la seguridad estructural y el desempeño de estos puentes. Al explorar la dinámica matizada inducida por los movimientos verticales cercanos a la falla, la investigación tiene como objetivo mejorar la comprensión de las vulnerabilidades y los desafíos que enfrentan los puentes de celosía de cubierta continua de largo alcance durante eventos sísmicos.

Métodos: Para lograr este objetivo, el puente de celosía fue sometido a una serie de movimientos del suelo, que representan eventos sísmicos naturales. La respuesta sísmica del puente se investigó aplicando el método de historia del tiempo lineal al modelo de elementos finitos 3D. Este análisis se centró específicamente en la evaluación del corte y desplazamiento de la base. El análisis se amplió para incluir el comportamiento sísmico de las estructuras de celosía. La comparación entre las respuestas del puente con y sin consideración del componente vertical del movimiento del suelo se realizó para aclarar el efecto de la excitación vertical.

Resultados: Los resultados muestran que existe una contribución significativa de la excitación vertical, particularmente en lo que respecta a la fuerza interna en los elementos de la armadura, donde superó el 60 % durante un terremoto severo, y en consecuencia aumentó la relación demanda-capacidad en la mayoría de los elementos de la estructura del puente de celosía.

Conclusión: Para los ingenieros y diseñadores estructurales, los resultados de esta investigación sugieren que no incluir el componente de movimiento *vertical del suelo en las evaluaciones analíticas de este tipo de puentes puede generar un mayor grado de incertidumbre y riesgo, particularmente en regiones cercanas a la falla.*

Palabras claves: puente tablero-armazón, desplazamiento vertical, comportamiento sísmico, fuerza axil, relación V/H, relación D/C.

Влияние вертикального сейсмического возбуждения вблизи разлома на отклик большепролетных неразрезных ферменных мостов

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РУБРИКА ГРНТИ: 67.21.00 Инженерные изыскания в строительстве
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данном исследовании изучается сейсмическая реакция большепролетных неразрезных ферменных мостов на воздействие вертикальных подвижек грунта вблизи разлома. Основная цель статьи заключается в оценке того, как вертикальное сейсмическое возбуждение вблизи разлома влияет на безопасность конструкции и эксплуатационные характеристики этих мостов. Исследуя тонкую динамику, вызванную вертикальными смещениями вблизи разлома, появляется лучшее понимание уязвимостей большепролетных неразрезных ферменных мостов во время сейсмических событий.

Методы: Для достижения этой цели ферменный мост подвергался серии колебаний грунта, представляющих естественные сейсмические явления. Сейсмическая реакция моста была исследована с помощью метода линейного течения времени с использованием трехмерной конечно-элементной модели. Этот анализ был сосредоточен, в частности, на оценке сдвига и смещения основания. Анализ был расширен, учитывая сейсмические характеристики ферменных конструкций. Сравнение откликов моста с учетом и без учета вертикальной *составляющей движения грунта было проведено в целях выяснения влияния вертикального возбуждения.*

Результаты: Результаты исследования показали значительное влияние вертикального возбуждения, особенно в отношении внутреннего усилия в элементах фермы, где оно превышало 60% во время сильного землетрясения и, следовательно, увеличило соотношение нагрузки и пропускной способности в большинстве элементов конструкции моста.

Вывод: На основании результатов данного исследования инженеры-строители и проектировщики должны убедиться в том, что игнорирование вертикального движения грунта при аналитических оценках мостов подобного типа может привести к большей степени неопределенности и риска, особенно вблизи разломов.

Ключевые слова: палубно-ферменный мост, вертикальное смещение, сейсмические характеристики, осевое усилие, соотношение вертикального и горизонтального ускорений, соотношение требований и возможностей.

Утицај вертикалног сеизмичког кретања у близини раседа на одговор гредних континуалних мостова решеткасте конструкције и већег распона

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ОБЛАСТ: материјали, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овој студији испитује се сеизмички одговор гредних континуалних мостова решеткасте конструкције и већег распона на вертикална померања тла у близини раседа. Основни циљ јесте да се процени како вертикално померање тла услед земљотреса у близини раседа утиче на сигурност конструкције и перформансе ових мостова.

Истраживање танане динамике проузроковане вертикалним померањем тла у близини раседа има за циљ да прошири сазнања о слабостима гредних континуалних мостова решеткасте конструкције и великог распона и указује на изазове којима су изложени током сеизмичких догађаја.

Методе: У ту сврху, решеткасти мост подвргнут је серији померања тла, што је представљало природне сеизмичке догађаје. Сеизмички одговор моста испитиван је применом методе линеарног протока времена на тродимензионални модел коначних елемената. Ова анализа се фокусира нарочито на смицање и померање базе, али је и проширена како би укључила сеизмичке перформансе решеткастих конструкција мостова. Одговор моста са узимањем у обзир вертикалне компоненте померања тла упоређен је са одговором без узимања у обзир дате компоненте како би се разјаснио утицај вертикалне ексцитације.

Резултати: Резултати показују да постоји значајан допринос вертикалне ексцитације, нарочито када је реч о унутрашњој сили у решеткастим елементима, где она прелази 60% током јаких земљотреса и има за последицу повећање односа захтева и капацитета у већини елемената решеткасте конструкције моста.

Закључак: Резултати овог истраживања показују да занемаривање укључивања компоненте вертикалног померања тла у аналитичке процене ове врсте моста може да доведе до већег степена неизвесности и ризика, нарочито у подручјима са раседима.

Кључне речи: гредни мост решеткасте конструкције, вертикално померање, сеизмичке перформансе, аксијална сила, однос вертикалног и хоризонталног убрзања, однос захтева и капацитета.

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