ASPS Conference Proceedings 1: 537-543 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

A Review on the Combined Effects of Seismic and Vehicular Vibrations on Long Span Bridges

Meera Jacob [1, *], S. D. Balakrishnan [2]

[1] Department of Civil Engineering, Ph.D. scholar, Cochin University of Science and Technology, Cochin 682 022, India
[2] Department of Civil Engineering, Professor, Cochin University of Science and Technology, Cochin 682 022, India

Paper ID - 050368

Abstract

Long span bridges are massive structures which are subjected to combined loadings. The increase in span length of long span bridges will result in decrease of their natural frequencies that renders them very susceptible to the actions of various combined dynamic forces. Dynamic loads such as vehicular movement and seismic excitations have greater potential in causing increased vibrations in long span bridges. The vehicular loading is highly variable and depends on type of vehicle, number of lane, behaviour of vehicle such as lane changing, traffic congestions and so on. Further, seismic excitations are characterized by its spatial variability parameters such as incoherence effect, wave passage effect and site response effects. From detailed review, it was found that fewer researches have been carried out in the field of dynamic effects of long span arch bridges and thus the study aims in determining the combined effects of seismic and vehicular vibrations on long span arch bridges

Keywords: Long Span, Arch Bridge, Combined Loading, Multi- support seismic excitations, Dynamic Effects, Vehicular vibrations

1. Introduction

Transportation infrastructures are vital for human life and economy. Bridges play an important role in the construction of highway and railway transportation system. Bridges has been categorized in many ways. They have been categorized by their principal use as highway, railroad, pedestrian, pipeline, etc; by the construction material used as stone, timber, wrought iron, steel, concrete, and prestressed concrete; by their structural form as girder, box-girder, moveable, truss, arch, suspension, and cable-stayed; by structural behaviour as simple span, continuous, and cantilever; and by their span dimension as short, intermediate, and long-span. Any bridge can be designated as a long span bridge if its span exceeds 120m. Today, the longest span bridge in the world is the Akashi Kayiko Bridge in Japan (Fig.1). It is a suspension bridge with a total span of 3911m with longest central span of 1991m. Long span bridges are slender structures and thus they are more susceptible to vibrations under dynamic loading. The effect of dynamic forces on long span bridges were instigated after the collapse of the famous Tacoma Bridge in USA. Zhiwei Chen et.al [26] pointed out that for long span bridges subjected to multiple loadings, a number of loading combinations should be simulated in assessment of its behaviour. Further, it was reported that validation of numerical simulations with data measured using structural health monitoring system makes the safety assessment more reliable for these types of structures. Vehicle movement (both highway and railway) over bridge are variable in nature and need to be properly accounted for. Also, consideration of seismic excitations along with vehicular forces makes the dynamic loading even more complex. Li, Y.et.al [27] described that a vehicle moving on a bridge during an earthquake is acted upon by dual excitations (ie, one due to earthquake and the other due to bridge vibration), which decreases the lateral driving stability of vehicles.

A number of researches have been carried out in the past decades to clearly determine the effect of seismic and vehicular forces on long span bridges. Ren, W.-X et.al [29] described that effect of dead load needs to be considered in the seismic analysis of long span cable stayed bridges such that the linear and non-linear seismic analysis of bridge should start with the deformed state of bridge due to dead load. Li Y et.al [28] revealed that the lateral and vertical component of seismic excitations has considerable effect on the vibrations of the bridge and vehicle and thus it is very essential to consider three dimensional effects of earthquake to determine the actual performance of vehicle and bridge under seismic excitations. Frýba, L.et.al [30] revealed that increase in train speed increases the dynamic behaviour of bridge particularly near the supports. Similarly, various researches outlined that the effect of ground motion is more pronounced at the bottom of the bridge tower [31,32]. Thus, it can be interpreted that the proper care should be taken in the analysis and design of foundation structures of long span bridges. Further, the effects of seismic excitation on long

*Corresponding author. Tel: +917034108861; E-mail address: mjmeera53@gmail.com

Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India | 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.545

Fig.1 The Akashi Kayiko Bridge in Japan

span bridges are greatly affected by the geological condition of the site. It affects the propagation and thus the intensity of seismic forces reaching the bridge support locations [33, 34].

2. Need for Study

Long-span bridges have always held a fascination for engineers as well as public. They are characterized by their comparatively higher span length. This increase in span length of long span bridges will result in decrease of their natural frequencies that renders long span bridges very susceptible to the actions of various combined dynamic forces.The vibration and dynamic characteristics of a long span bridge are mostly contributed by vehicle loading, seismic loading and wind forces.

One of the most important engineering challenges of long span bridges is their dynamic behaviour under the effect of differential earthquake ground motions. There is a pronounced effect of non-synchronous excitation which needs to be considered in the analysis and design of long span bridges [1]. Traditional analysis methods and research experience could not be fit for the judgment of the performance of long span bridge under non-synchronous seismic excitations. The seismic excitations on long span bridges should be analyzed in terms of incoherency effect, wave passage effect, site-response effect and attenuation effect [2].A key factor which influences the effect of seismic motions on structures is the kinematic soil structure interaction. Soil properties may vary at each and every point in a site. The variation in properties of soil strictly affects the response of structure to seismic excitations. Although quite large amount of research has been done in this scenario, real time modeling and analysis of long span bridge subjected to multi-support seismic excitations are still an area of research.

Fig.2 Failure of Tacoma Narrow Bridge

Vehicle loads are one of the most important types of live load which needs to be considered for the bridge design. The vehicular loading is highly variable and is itself a topic of research. The most variable type of loading is the highway loading as it may contain different types of vehicles moving at a time. The simulation of highway traffic mainly consists of type of vehicle, number of lane, behavior of vehicle such as lane changing, traffic congestions and so on. This state of highway traffic can be simulated to a small extent using a technique known as Cellular Automata [3,4]. However, more work needs to be carried out in this field to simulate the actual realistic highway traffic.

The combined loading of vehicle as well as seismic forces will have pronounced effect on long span bridges which needs to be accurately analyzed and designed for. Underestimation or overestimation of behaviour of a long span bridge under dynamic loading may lead to failure or even collapse of the structure. Many such failures have been reported in the past centuries. As the action of combined forces may prove detrimental to the structure, it very crucial to analyze the various components of the structure accurately and design them in order to withstand the effect of combined loads. Research works have been going on in this field in the recent years and the behavior of long span bridges under the combined action of dynamic forces is yet to be determined.

3. Overview Of Literatures

Many researches have been carried out in the field of long span bridges from the past decades. This section discusses certain relevant literatures related to effects of various loadings on long span bridges.

3.1. Seismic Loading

Nazmy A. S. [5] studied the dynamic and earthquake response characteristics of long span arch bridges subjected to uniform and no-uniform seismic excitations. The study mainly included 3-D finite element models of three different types of arch bridge structures namely tied arch bridge, half-tied arch bridge and deck type arch bridge. The time history seismic records were applied in uniform manner as well as multi-support excitation to the models. It was concluded from the study that there is strong coupling between in-plane and out-of-plane motions of the arch ribs and the deck. Further, consideration of three orthogonal components of earthquake motions simultaneously acting at all points of the bridge is essential to obtain the realistic earthquake quantities for design purposes.

Álvarez, J. J.et.al [6] determined the effect of seismic force on the axial force fluctuation of a long span arch bridge. The study was conducted by developing a FEM model of a long span arch bridge using SAP2000 software. Ten three component scaled seismic ground motion was adopted as seismic input. Time history analysis method was considered for the study. The main conclusion drawn from the study was that the Peak Ground Velocity (PGV) can be considered as a hazard measure the predict the seismic response of long period structures as the displacements and rotational demands of structural elements occurred for earthquake with largest peak ground velocity(PGV). Further, it was found that the variation in axial forces reduces the energy dissipation of the bridge and also affects the flexural capacity of section.

Zhang, N.et.al [7] describes a method to simulate the dynamic behavior of train bridge interactions under seismic excitations. In the study, train vehicle was modeled by rigid body dynamics method while the bridge was modeled by FEM. The seismic acceleration history was incorporated by large mass method to ensure that bridge foundations have their specific dynamic status. It was concluded from the study that contribution of seismic excitation is more than that of contribution of track irregularity in vehicle bridge interaction. Further, seismic excitations affect the bridge vibrations more in lateral direction than in vertical directions. It was also concluded that the derailment factor and offloading factors increased with seismic intensity due to which the trains should reduce speed or even stop when higher intensity EQ occurs.

Betti, R. et.al [8] investigated the kinematic soil-structure interaction for long span cable supported bridges. The study considered the effect of long span bridges under seismic excitation considering the effect of spatial variability of ground motion as well as the complex soil-structure interaction. Mainly four types of seismic waves were considered namely, SV waves, SH waves, P waves and Rayleigh waves. Various responses due to the waves considering their inclination were adopted and the responses in vertical, longitudinal and transverse directions were determined. It was concluded that the anti-symmetric modes of bridge vibration would be excited by the non-uniform ground motion. Further, soil structure interaction affects the response of the structure by increasing the response amplitude, excitation of more vibration modes and participation of higher modes. It was also concluded that embedment of bridge foundation should be considered for soil-foundation system analysis.

Lin, J. et.al [9] studied the need of considering spatial effects of earthquake motion for long span bridges. Conventional response spectrum method which is recommended in many standard codes neglects the spatial effects of ground motion leading to incorrect outputs which facilitated the study. The study suggest a new method known as pseudo excitation method which includes the wave passage effects, incoherence effects and cross-correlation terms between the participating nodes and excitations. The above suggested method was validated using the FEM model of a real time bridge- Jin Ma Bridge situated in Southern China, which is a cable stayed bridge. The numerical results obtained using the pseudo excitation method was compared with that of conventional methods namely, response spectrum method and time history method. It was concluded from the study that response spectrum cannot take into account the wave passage effect and thus the results generated are not reliable. Further,time history method can take into account the wave passage effect but the computational time is so large that it becomes inconvenient to implement. Also, pseudo excitation method based random vibration method is an easy and efficient method to deal with seismic analysis of long span bridge.

Shaban, N., & Caner, A. [10] conducted shake table tests of different seismic isolation systems on a large scale structure subjected to low to moderate earthquakes. Mainly three types of isolation systems were considered for the study namely Ball Rubber Bearing (BRB) isolation system, Lead Rubber Bearing (LRB) system and Elastomeric Bearing system. The main focus of the study was to determine the performance of BRB system in comparison with the other two systems by conducting a series of shake table tests at low and moderate earthquakes further. Further, shake table test was also conducted on a short span bridge of 12m length and 3.5m with concrete deck supported on steel girders to determine the effectiveness of isolation systems. It was concluded from the study that LRB and BRB dampened the system and resulted in considerable reduction of deck acceleration and displacements when compared with elastomeric bearings. It was also found from the shake tests that the damping characteristics of LRB and BRB were three times than that of elastomeric bearings. Further, in all the shake table tests conducted, BRB resulted in higher reduction in peak deck acceleration in comparison with the LRB.

Shen, X.,.et.al [11] investigated the seismic performance of transverse steel damper seismic system for long span bridges. Transverse Steel Dampers (TSD) is a new seismic system which can be used along with the fixed or sliding bearing of the bridge structure, as the fixed or sliding bearing is vulnerable to failure if the design seismic load exceeds. A TSD consists of several triangular steel plates outfitted with steel hemispheres at their upper vertices. The steel hemispheres allow free movement of the superstructure with respect to piers in the longitudinal direction as well as they also provide reliable load path in the transverse direction. Quasi-static tests were conducted on two scaled and two prototype specimens of TSD to determine their seismic behavior and the results shows excellent performance in energy dissipation, large displacements and synchronization of triangular plates under complex contact conditions. Further, the load-displacement constitutive model of TSD was established using ABAQUS software which was calibrated using test data and a design method for TSD seismic system was proposed. The application of TSD was demonstrated by considering a long span cable stayed bridge in China as a case study. It was concluded that TSD has the capability of balancing transverse girder-pier relative displacements and forces of substructures under seismic excitations. Further, for combination of TSD and fixed or sliding bearing system, TSD contributes to most of the energy dissipation capacities while the contributions of sliding bearings are negligible. Also, TSDs are insensitive to ground motion magnitudes (PGA) while conventional sliding systems are sensitive to them.

3.2. Vehicular Loading

Xia, H.et.al [12] investigated the dynamic interaction of long span suspension bridges with running trains. Suspension bridge was modelled as a 3-D FE model while the train vehicle was modelled as a 27 degree of freedom dynamic system. The train vehicle consists of eight passenger coaches each of which has two identical bogies, supported by two identical wheel-sets. The study also computed the derail factor and offload factor related to the train running safety. It was concluded from the study that responses of bridge was high when the train travels over the main span while the bridge response was quite small when the train travels over the left-side span as well as right-side span. Also, maximum lateral displacement response of bridge decreases with increase in train speed.

Law, S. S., & Zhu, X. Q.[13] studied the dynamic response of a bridge due to road roughness effect and vehicular motion. The main objective of study was the dynamic behavior of multi span non-uniform continuous bridge under a moving vehicle by considering the effect of interaction between the bridge, road surface roughness and the vehicle. Numerical as well as experimental study was conducted. The bridge was modeled as multi-span Bernoulli-Euler beam having non-uniform cross-section. The vehicle was modeled as a group of moving loads with specific spacing. The dynamic responses of single span bridge and two span bridges were considered for simulation and experimental study. It was concluded from the study that vehicles with lower speed created higher dynamic response of bridge and dynamic response of first span is smaller than other span due to smaller initial conditions of vehicle at the entry of first span. As well as suspension system of vehicle has significant effect on the response especially during vehicle braking at top of structure.

Schadschneider, A. [14] described the various cellular automata models that can be adopted for highway traffic. A detailed description of NaSch model of cellular automation is described. Further, the in course of work, description about a new model namely VDR model (Velocity Dependent Randomization) developed by including the features which are not incorporated in NaSch model such as metastable states, synchronized phase, human desire for comfortable driving etc, was given. The work concludes by summarizing the advantages as well as shortcomings in different models.

Li, X.-G. et.al [15] developed a realistic two lane cellular automata model considering the aggressive lane-changing behavior of fast vehicle. The study also investigated the effect of different lane-changing probability. The new model was developed by introducing new lane changing rules to the basic NaSch model. The lane changing can be symmetric or asymmetric depending on the lanes and vehicles. Symmetric two lane model was the one which was considered for the study. The lane changing rules adopted by the author Chowdhary et al [4], which was named as symmetric two lane cellular automata (STCA) was modified and introduced to develop the new model. Further in study, the analysis using new model was compared with STCA model. It was concluded that the introduction of aggressive lane changing rules for fast vehicles has enhanced the flux of mixed traffic system in the intermediate density range. Also, as the ping-pang behavior is greatly depressed, the lane change becomes much more effective in the new model. On comparing the new model with STCA model, the lane changing frequency of new model was found to be much smaller.

An, L. et.al [16] developed a seven degree of freedom vehicle model and the potential energy of vehicle space system was deduced. Using a self-compiled Fortran program and bridge engineering, the dynamic response of long span continuous girder bridge under vehicular loading was analyzed and studied. The study also included the determination of vehicle impact coefficient, evaluation of vibration comfort and analysis of dynamic response parameters. It was concluded that maximum dynamic displacement, acceleration and impact coefficient of single lane under vehicular action is smaller than that of three lanes under the same vehicular loading. Also, by effectively controlling the vibration of vehicle-bridge system, driver safety and comfort are expected to improve as per the study.

Yuan Gao. et.al [17] carried out the analysis of coupled vehicle bridge vibrations of a long span cable stayed bridge using multi-scale modeling. The study establishes the principles and methods of universal multiscale modeling and further verifies the model sing a case study. Vibration equations for vehicle bridge system were developed for the study and programs for analyzing two-axle vehicle-bridge coupled vibration based on Newmark-□ method were developed using MATLAB and ANSYS software. It was concluded that stress histories at specific parts of same cross section can be obtained using the proposed multi-scale modeling technique and the method is useful for anti-fatigue design of long span cable stayed bridges. Further, serious increase in road roughness of pavement and vehicle speed above 100 km/hr drastically increased the impact coefficient thus indicating the reduction in service life of bridges.

Kong X. et.al [18] developed a new strategy of substructure method to model long span hybrid cable stayed bridges under vehicle-induced vibration. The routine way of using substructure method is to refine a specific part and condense it into a super-element that is then embedded and used to replace the original part in the whole structure. In spite of the routine way, the present study involves condensation of all the other parts but the important joint part into super-elements. All the parts including the joint are then assembled into a complete bridge model. Further, the method was validated against finite element (FE) method and Mixed Dimensional Coupling (MDC) method. The new method was then used to determine the vehicle induced dynamic responses on the Jingyue Yangtze River Bridge which is a hybrid steel concrete cable stayed bridge. From the analysis results, it was concluded that the concrete steel joint worked well and the transition between the steel girders and concrete beams were very smooth. Also, the study proved that the computational effort using the new method was much less compared to other conventional methods.

3.3. Combined Loading

Zhou, Y., & Chen, S. [19] discussed about the effects of vehicles and other extreme loads on the behavior of long span bridges. In the study, a general simulation platform was established to investigate the dynamic performance of long span bridge under the effect of moving vehicles and extreme loadings. Major findings of the study were that when earthquake ground motions are considered, the dynamic displacements of bridge and vehicles are dominated by seismic excitations in both vertical and lateral directions. It was also proved from the study that the presence of traffic along with the earthquake will suppress the lateral bridge displacement while it considerably increases the vertical bridge displacement.

Chen, S. R., & Wu, J. [20] discussed about the coupled system of bridge-vehicle-wind interaction studies in predicting the dynamic behaviour of long span bridge. In the study, a semideterministic bridge model is considered for analyzing its dynamic behavior. From the study it was determined that the mean value of the bridge displacement at the midpoint increases with wind speed and vehicle occupancy. Larger stress level happens at the midpoint of bridge. A stronger wind will reinforce fluctuations of stress along with impacts from traffic flow.

C.S. Cai & Chen S.R [21] developed a framework for the dynamic analysis of vehicle-bridge-wind system. Vehicle was modelled as a combination of several rigid bodies connected by axle mass blocks, springs and damping devices. The bridge was modelled using beam and truss elements available in finite element software. Strong wind forces and road surface roughness were the external excitations. Dynamic performance of the bridge and vehicle were studied by considering the effect of different driving speeds along with wind forces. It was concluded from the study that for high wind speeds, vehicle responses are contributed by the bridge response while for low wind speeds, vehicles responses are contributed by road roughness. Also, vehicle responses are amplified when the vehicle approaches the midspan of bridge for strong wind forces. In addition, eccentric gravity of vehicles on bridge reduced the dynamic response of bridge under high winds.

Zhang, W. et.al [22] discussed the fatigue problems induced on a long span bridge due to combined vehicle loads and wind loads. For the study, modelling of a cable stayed bridge was done using equivalent orthotropic material modelling scheme (EOMM). Vehicle-Bridge-wind dynamic interaction system was developed and the stochastic loading was introduced to carry out the fatigue analysis. The main conclusion from the study was that combined dynamic effects from winds and vehicle might cause serious fatigue damage accumulations for long span bridges while the traffic or wind loads alone are not able to induce any serious fatigue problems. Further, it was concluded that the dynamic stress ranges and number of cycles increase with wind velocity.

Liu, M.-F.et.al [23] investigated the interactive behavior due to vehicular loads and vertical seismic excitations in a suspension bridge. Initially, two coupled cable beam equations which are integro-differential equations were developed to describe the dynamic characteristics of cable and the roadbed respectively. The dynamic effect of vehicles were incorporated by modeling the vehicles as a row of equidistant moving forces and the earthquake motion was simulated as vertical oscillatory motions at the supports. The above proposed methodology was further validated using a real time bridge – The Messina Bridge – the largest suspension bridge in the world with a central span of 3.3km. The bridge was modeled numerically with equidistant vehicles and the seismic excitations applied were that of the modified Kobe Earthquake of 1995. It was concluded from the study that the oscillation produced by the deformation of cable is higher than that of beam since the material property of cable is more flexible than that of beam. In addition, the response of long span suspension bridge gets amplified due to vehicular motion and seismic excitations at the vicinity of end supports.

Pipinato, A et.al [24] discussed about the fatigue damage in steel bridge girder due to the vehicle traffic and seismic loading based on linear elastic fracture mechanics(LEFM). The study is reliability based approach and assumes that along with the traffic loading, at least one seismic event will occur during the service life of the structure. The study was carried out in two parts. In the first part, the fatigue damage computed on the basis of traffic loads produced by heavy trucks and the second part is dealing with the fatigue caused due to seismic loading. For the study the damage of bridge due to both cases are analyzed using LEFM principles and the time required for first crack propagation is calculated. It was concluded that although the structure is not seriously damaged by EQ, its residual fatigue life could greatly reduce. Further, seismic loading along with traffic loading will seriously damage the structure rather than traffic loading alone as seismic loading causes the occurrence and propagation of cracks thus increasing damage accumulation.

Z.W.Chen et.al [25] investigated the dynamic effect of different types of loadings such as road vehicle loading, train loading and wind loading on long span bridges. A dynamic stress analysis framework of long span suspension bridge considering train, road vehicle and wind loading was developed. The train, road vehicle and bridge were modeled using finite element method. The connection between the train and bridge was established by the wheel rail contact condition while the connection between road vehicle and bridge was established using tire-road surface contact condition. The wind force was simulated as spatial distribution of buffeting force and self-exciting forces. The proposed model was validated by comparing it with a real time suspension bridge- Tsing Ma Bridge situated in Hong Kong. The information obtained from WASHMS of Tsing Ma Bridge was utilized for computation and comparison was made between the measured and computed results. The comparison was done mainly between the time histories (stress-time results) and amplitude spectra (stress-amplitude results). It was concluded from the study that the time history results as well as the amplitude spectra results were found to be similar for computed and measured ones, thus validating the framework. Also, the dynamic effect of running train on long span bridge is much pronounced in comparison with the effect of running road vehicle and wind.

4. Conclusions

From the extensive literature review conducted, it has been concluded that the most important parameters that need to be considered for seismic loading are the spatial variability effects namely, incoherence effect, wave passage effect and site response effect. In the case of vehicular loading the parameters to be considered are the number and type of vehicles, number of lanes, lane loading, direction of movement, eccentric loading and braking effect. Further, numerous researches were conducted to determine the combined action of seismic and vehicular effect on long span suspension and cable stayed bridges but studies on effect of dynamic parameters on long span arch bridges are less prevalent.

Arch type bridges, compared to other types possess several advantages such as structural stability, composite nature etc. Earlier most arch bridges required complicated design and was mostly restricted to short spans. The development in modern technology has enabled the possibility of using arch structure for long span bridges with minimal maintenance and constructional ease. Also, in the Indian scenario, the longest span required may vary between 500m to 600m for which the arch bridge type may be the most suitable and economical one. But, an extensive amount of study needs to be carried out to determine the behavior of long span arch bridges under combined seismic and vehicular loading which can be considered an area of further research.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. Abdel Ghaffar, A. M., & Nazmy, A. S. (1991). 3D Nonlinear Seismic Behavior of Cable Stayed Bridges. Journal of Structural Engineering, 117(11), 3456–3476.
2. Kiureghian, A. D. (1996). A Coherency Model for Spatially Varying Ground Motions. Earthquake Engineering & Structural Dynamics, 25(1), 99–111.
3. Li, X.-G., Jia, B., Gao, Z.-Y., & Jiang, R. (2006). A realistic two-lane cellular automata traffic model considering aggressive lane-changing behavior of fast vehicle. Physica A: Statistical Mechanics and Its Applications, 367, 479–486
4. Chowdhury, D., Wolf, D. E., & Schreckenberg, M. (1997). Particle hopping models for two-lane traffic with two kinds of vehicles: Effects of lane-changing rules. Physica A: Statistical Mechanics and Its Applications, 235(3-4), 417–439.
5. Nazmy A. S. (1996). Earthquake-response characteristics of long span arch bridges. Proceedings of the 11th World Conference on Earthquake Engineering, Acapulco, Paper No. 1309
6. Álvarez, J. J., Aparicio, A. C., Jara, J. M., & Jara, M. (2012). Seismic assessment of a long-span arch bridge considering the variation in axial forces induced by earthquakes. Engineering Structures, 34, 69–80.
7. Zhang, N., Xia, H., & De Roeck, G. (2010). Dynamic analysis of a train-bridge system under multi-support seismic excitations. Journal of Mechanical Science and Technology, 24(11), 2181–2188.
8. Betti, R., Abdel-Ghaffar, A. M., & Niazy, A. S. (1993). Kinematic soil–structure interaction for long-span cable-supported bridges. Earthquake Engineering & Structural Dynamics, 22(5), 415–430.
9. Lin, J. ., Zhang, Y. ., Li, Q. ., & Williams, F. (2004). Seismic spatial effects for long-span bridges, using the pseudo excitation method. Engineering Structures, 26(9), 1207–1216.
10. Shaban, N., & Caner, A. (2018). Shake table tests of different seismic isolation systems on a large scale structure subjected to low to moderate earthquakes. Journal of Traffic and Transportation Engineering (English Edition), 5(6), 480–490
11. Shen, X., Wang, X., Ye, Q., & Ye, A. (2017). Seismic performance of Transverse Steel Damper seismic system for long span bridges. Engineering Structures, 141, 14–28.
12. Xia, H., Xu, Y. L., & CHAN, T. H. T. (2000). Dynamic Interaction Of Long Suspension Bridges With Running Trains. Journal of Sound and Vibration, 237(2), 263–280
13. Law, S. S., & Zhu, X. Q. (2005). Bridge dynamic responses due to road surface roughness and braking of vehicle. Journal of Sound and Vibration, 282(3-5), 805–830
14. Schadschneider, A. (2006), Cellular automata models of highway traffic. Physica A: Statistical Mechanics and Its Applications, 372(1), 142–150.
15. Li, X.-G., Jia, B., Gao, Z.-Y., & Jiang, R. (2006). A realistic two-lane cellular automata traffic model considering aggressive lane-changing behavior of fast vehicle. Physica A: Statistical Mechanics and Its Applications, 367, 479–486.
16. An, L., Li, D., Yu, P., & Yuan, P. (2016). Numerical analysis of dynamic response of vehicle–bridge coupled system on long-span continuous girder bridge. Theoretical and Applied Mechanics Letters, 6(4), 186–194.
17. Yuan Gao , Hong-hai Zhang , Ben-jun Jiang (2014). Analysis on vehicle bridge coupled vibrations of long span cable stayed bridge based on multi-scale modeling, Journal of Vibroengineering,17(1) , 402-410

18. Kong, X., Wu, D. J., Cai, C. S., & Liu, Y. Q. (2012). New strategy of substructure method to model long-span hybrid cable-stayed bridges under vehicle-induced vibration. Engineering Structures, 34, 421–435

19. Zhou, Y., & Chen, S. (2015). Dynamic Simulation of a Long-Span Bridge-Traffic System Subjected to Combined Service and Extreme Loads. Journal of Structural Engineering, 141(9), (04014215) 1-18

20. Chen, S. R., & Wu, J. (2010). Dynamic Performance Simulation of Long-Span Bridge under Combined Loads of Stochastic Traffic and Wind. Journal of Bridge Engineering, 15(3), 219–230.

21. C.S. Cai & Chen S.R (2004), Framework of vehicle-bridge-wind dynamic analysis, Journal of Wind Engineering and Industrial Aerodynamics 92, 579–607

22. Zhang, W., Cai, C. S., & Pan, F. (2013). Fatigue Reliability Assessment for Long-Span Bridges under Combined Dynamic Loads from Winds and Vehicles. Journal of Bridge Engineering, 18(8), 735–747.

23. Liu, M.-F., Chang, T.-P., & Zeng, D.-Y. (2011). The interactive vibration behavior in a suspension bridge system under moving vehicle loads and vertical seismic excitations. Applied Mathematical Modelling, 35(1), 398–411.

24. Pipinato, A., Pellegrino, C., & Modena, C. (2011). Fatigue assessment of highway steel bridges in presence of seismic loading. Engineering Structures, 33(1), 202–209.

25. Chen, Z. W., Xu, Y. L., Li, Q., & Wu, D. J. (2011). Dynamic Stress Analysis of Long Suspension Bridges under Wind, Railway, and Highway Loadings. Journal of Bridge Engineering, 16(3), 383–391.

26. Zhiwei Chen, Bo Chen (2014), Recent Research and Applications of Numerical Simulation for Dynamic Response of Long-Span Bridges Subjected to Multiple Loads, The Scientific World Journal, 2014, 1-17

27. Li, Y., Chen, N., Zhao, K., & Liao, H. (2012). Seismic response analysis of road vehicle-bridge system for continuous rigid frame bridges with high piers. Earthquake Engineering and Engineering Vibration, 11(4), 593–602

28. Li, Y., Zhu, S., Cai, C. S., Yang, C., & Qiang, S. (2016). Dynamic Response of Railway Vehicles Running on Long-Span Cable-Stayed Bridge Under Uniform Seismic Excitations. International Journal of Structural Stability and Dynamics, 16(05), (1550005) 1-25.

29. Ren, W.-X., & Obata, M. (1999). Elastic-Plastic Seismic Behavior of Long Span Cable-Stayed Bridges. Journal of Bridge Engineering, 4(3), 194–203

30. Frýba, L., & Yau, J.-D. (2009). Suspended bridges subjected to moving loads and support motions due to earthquake. Journal of Sound and Vibration, 319(1-2), 218–227

31. Wang, B., & Yuan, W. (2009). Risk- and Performance-Based Seismic Analysis for Long-Span Cable-Stayed Bridges. Technical Council on Lifeline Earthquake Engineering Conference (TCLEE) 2009:Lifeline Earthquake Engineering in a Multihazard Environment, 59-70

32. Konstantakopoulos, T. G., Raftoyiannis, I. G., & Michaltsos, G. T. (2012). Suspended bridges subjected to earthquake and moving loads. Engineering Structures, 45, 223–237.

33. Dumanogluid, A. A., & Soyluk, K. (2003). A stochastic analysis of long span structures subjected to spatially varying ground motions including the site-response effect. Engineering Structures, 25(10), 1301–1310

34. Wang, J., Hu, S., & Wei, X. (1999). Effects of engineering geological condition on response of suspension bridges. Soil Dynamics and Earthquake Engineering, 18(4), 297–304

35. Xiao, L., Li, C., & Qiang, S. (2010). Influence of Soil-Pile-Structure Interaction on Seismic Response of Long Span Suspension Bridge. ICCTP 2010

36. Huang, D., & Wang, T.-L. (1992). Impact analysis of cable-stayed bridges. Computers & Structures, 43(5), 897–908.

37. Weiab, H., Wang, Z., & Feng, Q. (2011). Seismic Analysis and Design of Minpu Double-Deck Cable-Stayed Bridge. Procedia Engineering, 14, 1501–1509

38. Li, Z. X., Zhou, T. Q., Chan, T. H. T., & Yu, Y. (2007). Multi-scale numerical analysis on dynamic response and local damage in long-span bridges. Engineering Structures, 29(7), 1507–1524

39. Boroschek, R. L., Moroni, M. O., & Sarrazin, M. (2003). Dynamic characteristics of a long span seismic isolated bridge. Engineering Structures, 25(12), 1479–1490.

40. Li, Z. X., Zhou, T. Q., Chan, T. H. T., & Yu, Y. (2007). Multi-scale numerical analysis on dynamic response and local damage in long-span bridges. Engineering Structures, 29(7), 1507–1524