MINISTRY OF EDUCATION AND TRAINNING

THE UNIVERSITY OF DANANG

TRAN VAN DUC

RESEARCH OF CABLE-STAYED BRIDGE VIBRATION SUBJECTED TO MOVING LOAD CONSIDERING THE VEHICLE VELOCITY AND BRAKING FORCE

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INTRODUCTION

1. Reason for selection topics

Bridge construction technology has developed rapidly during the recent two decades, particularly the technology built cable-stayed bridge (CSB) span is increasingly more complete. CSB Structure has been widely applied across the world, including Vietnam. The length of large span CSB usually have to use all types of materials with high strength, so the structure becomes more slender bridge and the weight significantly reduces itself. CSB structure has a long span and light self-weight will be very sensitive to the live load, as the load of the traffic on the bridge, the wind, rain, earthquakes, etc. So far, there were many studies of CSB oscillating under effect of the vehicle loading. Most of the findings focus on the interaction model vehicle - CSB ignored of the speed of change and braking force. In this thesis, the author continues the study of oscillations CSB under effect of vehicle loading into consideration the 3-axis variable speed and braking force, one of the research problem necessary, scientific significance and true reality.

2. Research objectives

Research objectives are vibration analysis and determination of dynamics of CSB under effect of vehicle loading considering the three-axle variable speed and braking force.

3. Subjects and scope of the study

Subjects research is vibration span of 02-span, 03-span CSB under effect of vehicle loading considering the three-axle variable speed and braking force.

Scope of the study is vibration in the vertical plane of the two-span and three-span CSB structure under effect of vehicle loading considering the three-axle variable speed and braking force.

4. Research Methods

Research methodology is a combination of theoretical study with experimental measurements. Research topic applied finite element method (FEM) for structural modeling and loading through using interaction model vehicle-CSB, application of the FEM and the numerical methods to solve the problem of interaction and analysis of CSB vibration under effect of vehicle loading considering the braking force. Analytical results theoretically be verified by the results of experimental measurements. Using the simulation program to analyze the vibration of CSB and predicted the risk areas for the bridge when subjected to vehicle loading considering effect of braking force.

5. The significance scientific and practical applications

CSB very high-slender structure and light self-weight so sensitive to dynamic loads, which vehicles loads of traffic on the bridge had a significant impact on the longevity of CSB. Until now there have been many studies of CSB vibration under effect of vehicle loading. Most of the work was done on the interaction model vehicle - CSB not considering the change of speed and braking force. The study of vibration CSB under effect of vehicle loading considering the change of speed and braking force is necessary. The topic: "***Research of Cable-Stayed bridge vibration subjected to moving load considering the vehicle velocity and braking force***" that is significance science and high practicality. This study used the simulation program to analyze the vibration of CSB and predict the unsafe risk areas for construction under effect of vehicle loading considering the braking force. Initial research results of the thesis significance scientific and practicality high.

6. Thesis structure

In addition to the introduction, table of contents, list of scientific works published by the author, reference list, the contents of the thesis consists of 04 chapters, the conclusion and appendices as follows:

- Chapter 1. Overview of bridges and CSB vibration under effect vehicle loading
- Chapter 2. Theoretical basis of analyze dynamic interaction between CSB and vehicle loading considering brake force.
- Chapter 3. Research theory and experiment of CSB vibration under the vehicle loading considering braking force.
- Chapter 4. Analytical applications of CSB vibration under the vehicle loading considering braking force.
- Conclusions and recommendations for follow-up studies.
- The appendix.

CHAPTER 1. OVERVIEW OF BRIDGES AND CSB VIBRATION UNDER EFFECT VEHICLE LOADING

After the railway bridge collapse incident in the state Cheshire Chester - England (05/1847), that has attracted the interest of many scientists around the world involved in research in the field of bridge vibrations under the influence vehicle loading. The authors studied the vibration of the bridge due to load of vehicles, often considered effects of factors such as vehicle speed, road surface condition, loading models, bridge modelling, the interaction of the bridge foundation and a few studies consider effect of vehicle braking force. In general, the study of interactions between bridge and CSB under effect of the vehicle loading tend to focus more on theory or experimentally, others tend to study combining both theoretical and experimentally.

1.1. Researching of bridge vibration under effect of vehicle loading more oriented to theory

The typical studies on construction vibration under effect of moving load include: R. Willis (1849), E. & O. Morh Winkler (1868), G. Stokes (1896), SAIliaxevic, AN Krulov (1905). Subsequently, S.P.Timoshenko (1922) studied the problem extended to the beam subject to vibration loading. Meizel (1930) solve the problem with the load model does not damping, no inciting force. Wen (1960) solved the problem for load moving on the uniform beam. Sundara & Jagadish (1970) have solved the problem with the model truck on the system of springs. In addition there are the relate studies as Barchenkov (1976), Tran Quang Vinh (1978), Green & Cebon (1995), Dongzhou, Wang Ton-Lo, Shahawy Mohsen (1995), Fafard & Bennur (1997), Do Xuan Tho (1996), Yang YB & Yau JD (1997), Wu YS & Yang YB & Yau JD (2001), Jalili & Esmailzadeh (2002), Zeng & Bert (2003), Zhai WM, CB Cai, Wang KY (2004), Ta Huu Vinh (2005), Lesław Kwasniewski (2006), Deng L. & Ca C.S. (2009), Nan Zhang (2010), Wu & Law (2011), Neves, Azevedo & Calcada (2012), Nan Zhang & He Xia (2013), Camara et al (2014), Saeed A., Mijia Y. & Two Z. (2015).

The studies dynamic interaction between CSB and vehicle loading may include various authors: Wilson & Barbas, Meurthe-et-Moselle (1980), Rasoul (1981), Alessandri et al (1984), Brancaleoni, Petrangeli & Villatico (1987), Khalifa (1991), Wang & Huang (1992), Miyazaki et al (1993), Musharraf Z et al (1996), Yang F & Fonder G (1998), Karoumi R (1998). In Vietnam, there are authors Hoang Ha (1999), Nguyen Xuan Toan (2007), ... In addition, a few studies on the dynamic interaction between bridges and vehicle loading considering braking force such follows: Fry'ba (1974), Gupt & Trail-Nash (1980), Mulcahy (1983), Krylov (1996), Toth & Ruge (2001), Yang & Wu (2001), Law & Zhu (2005), Ju & Lin (2007), Hossein & ... (2013).

1.2. Researching of bridge vibration under effect of vehicle loading based on experimentally

The author Walther (1988), the authors Green M & Cebon D (1994), the authors Nowak & Kim (1997), Chowdhury and Ray (2003), Nguyen Xuan Toan (2007), Zhisong Z. & Nasim U. (2013). The studies had based on the result of experiments to determine the increasing in dynamics factor is usually denoted: dynamics impact factor IM or (1+ IM)

1.3. Method of determining the dynamic impact factor of bridge design code of some countries

According to the studies show that, the usual factor (1 + IM) in bridge design codes can be defined in two ways: based on the length determined or based on the frequency of span.

1.4. Conclusion of Chapter 1 and objective study of the doctoral dissertation

- Research interactions between CSB and vehicle loading into consideration the braking force by FEM with the four-mass model.
- Develop the KC05 program modules about CSB vibration analysis under effect of three-axle vehicle loading considering braking force.
- Conducting experiments to measure vibrations of some bridges aimed at adopting measures to verify the theoretical results.
- Compare the results of vibration analysis by theoretical and experimental measurements. Through compare the results to assess accuracy and reliability according to the theoretical calculation.
- Use Vibration Analysis Program (KC05) for assessment effect of braking force to CSB vibration.
- Apply the confidence interval theories to determine the dynamic impact factor of CSB considering braking force.

CHAPTER 2. THEORETICAL BASIS OF ANALYZE DYNAMIC INTERACTION BETWEEN CSB AND VEHICLE LOADING CONSIDERING BRAKING FORCE

2.1. General introduction

Chapter 02 will present the results using FEM methods for analyzing vibration CSB problems under effect of vehicle loading takes into account braking force.

2.2. Dynamic interaction model between three-axle vehicle and beam elements

Dynamic interaction model between three-axle vehicle and beam element take into account braking force is described as shown in Fig 2.2

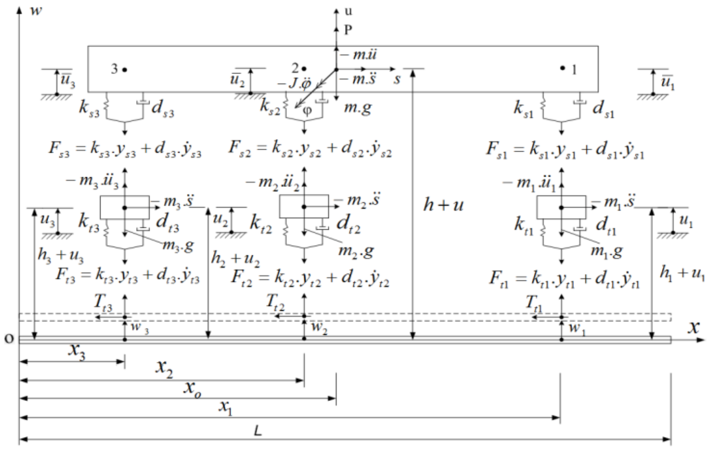

Fig. 2.2. Interaction between three-axle vehicle and element beam

2.3. The calculation assumptions

- Mass of the entire vehicle and goods except the mass of vehicle axles is transferred to the center of the system is equivalent to m and rotational inertia J. The mass of the i^{th} vehicle axles is m_i considered as a point with volume of concentrate of the i^{th} corresponding vehicle axles. The chassis is assumed stiff absolute and not deformed when vehicle moving. Beam material working in the linear elastic stage. Flat of bridge deck, the friction coefficient is uniformed over the deck. The braking force of the vehicle axles is assumed that occurs simultaneously.

2.4. Vibration differential equation considering braking force

2.4.1. The equations of three-axle vehicle loading balancing

$$\begin{cases} P - m\ddot{u} - \sum_{i=1}^{n} F_{si} - mg = 0 \\ F_{si} - F_{ti} - m_i.\ddot{u}_i - m_i g = 0 \\ \sum_{i=1}^{n} T_{ti} + (m + \sum_{i=1}^{n} m_i).\ddot{s} = 0 \end{cases}$$

$$(P - m.\ddot{u} - m.g).x_o + m.\ddot{s}.(h+u) - J.\ddot{\varphi} - \sum_{i=1}^{n}(m_i.\ddot{u}_i + m_i.g).x_i + \sum_{i=1}^{n} m_i.\ddot{s}.(h_i + u_i) + \sum_{i=1}^{n}(T_{ti}.w_i - F_{ti}.x_i) = 0$$

2.4.2. The equation for bending and longitudinal vibration of beam element subject to vehicle loading

$$EJ_d.\left(\frac{\partial^4 w}{\partial x^4} + \theta.\frac{\partial^5 w}{\partial x^4.\partial t}\right) + \rho F_d.\frac{\partial^2 w}{\partial t^2} + \beta.\frac{\partial w}{\partial t} = \sum_{i=1}^{n} p_i(x,z,t)$$

$$EF_d.\frac{\partial^2 u_x}{\partial x^4} + \rho F_d.\frac{\partial^2 u_x}{\partial t^2} + \beta.\frac{\partial u_x}{\partial t} = q(x,z,t) = \tau.\sum_{i=1}^{n} p_i(x,z,t)$$

$$J.\ddot{\varphi} + \sum_{i=1}^{n} d_{si}(x_i - x_o)^2.\dot{\varphi} + \sum_{i=1}^{n} d_{si}(x_i - x_o).\dot{u} - \sum_{i=1}^{n} d_{si}(x_i - x_o)\dot{u}_i + \sum_{i=1}^{n} k_{si}(x_i - x_o)^2.\varphi$$
$$+ [\sum_{i=1}^{n} k_{si}(x_i - x_o) - m.\ddot{s}].u - \sum_{i=1}^{n}[k_{si}(x_i - x_o) + m_i.\ddot{s}].u_i - \sum_{i=1}^{n} T_{ti}.w_i - (m.h + \sum_{i=1}^{n} m_i.h_i).\ddot{s} = 0$$

$$m.\ddot{u} + \sum_{i=1}^{n} d_{si}(x_i - x_o).\dot{\varphi} + \sum_{i=1}^{n} d_{si}.\dot{u} - \sum_{i=1}^{n} d_{si}.\dot{u}_i + \sum_{i=1}^{n} k_{si}(x_i - x_o).\varphi + \sum_{i=1}^{n} k_{si}.u - \sum_{i=1}^{n} k_{si}.u_i - P + m.g = 0$$

$$m_i.\ddot{u}_i - d_{si}(x_i - x_o).\dot{\varphi} - d_{si}.\dot{u} + (d_{si} + d_{ti}).\dot{u}_i - k_{si}(x_i - x_o).\varphi - k_{si}.u$$
$$+ (k_{si} + k_{ti}).u_i - d_{ti}.\dot{w}_i - k_{ti}.w_i + m_i.g = 0$$

$$\ddot{s} = -g.\tau$$

$$p_i(x,z,t) = \xi(x_i).F_{ti}.\delta(x - x_i) = \xi(x_i).[-m_i.\ddot{u}_i + d_{si}(x_i - x_o).\dot{\varphi} + d_{si}.\dot{u} - d_{si}.\dot{u}_i$$
$$+ k_{si}(x_i - x_o).\varphi + k_{si}.u - k_{si}.u_i - m_i.g].\delta(x - x_i)$$

with $\xi(x_i) = \begin{cases} 1 & khi \quad 0 \le x_i \le L \\ 0 & khi \quad x_i < 0 \ \& \ x_i > L \end{cases}$: the signal control function logic

$\delta(x - x_i)$ is Delta-Dirac function; n=3; i= 1,2,3

2.4.3. Transformation the differential equations variation in matrix form

Using the Galerkin method combined with Green theory, each part integrating for each element and taken as matrix form:

$$M_e.\ddot{q}+C_e.\dot{q}+K_e.q=f_e$$

$\ddot{q},\dot{q},q,\ f_e$ - acceleration vector, velocity vector, displacement vector, the vector of the entire system, respectively.

M_e, C_e, K_e – mass matrix, damping matrix, stiffness matrix of the entire system, respectively.

$$M_e=\begin{bmatrix} M_{ww} & M_{wz} \\ M_{zw} & M_{zz} \end{bmatrix};\ C_e=\begin{bmatrix} C_{ww} & C_{wz} \\ C_{zw} & C_{zz} \end{bmatrix};\ K_e=\begin{bmatrix} K_{ww} & K_{wz} \\ K_{zw} & K_{zz} \end{bmatrix}$$

M_{ww},C_{ww},K_{ww} - mass matrix, damping matrix, stiffness matrix of the beam elements, respectively.

2.4.4. The differential equations vibration of cable element:

Based on studies of Shimada (1994), Zui Hiroshi et al (1996), N.X.Toan (2007), we get the differential equations of the cables element vibration taking into account stiffness and weight of cable components.

2.5. Application algorithms and establish analysis modules for interactive dynamics of CSB and three-axle vehicle loading considering brake force

2.5.1. General algorithm of CSB vibration analysis program under effect of three-axle vehicle loading considering brake force

Analysis program is written in Delphi algorithm is described as a flowchart as shown in Figure 2.5:

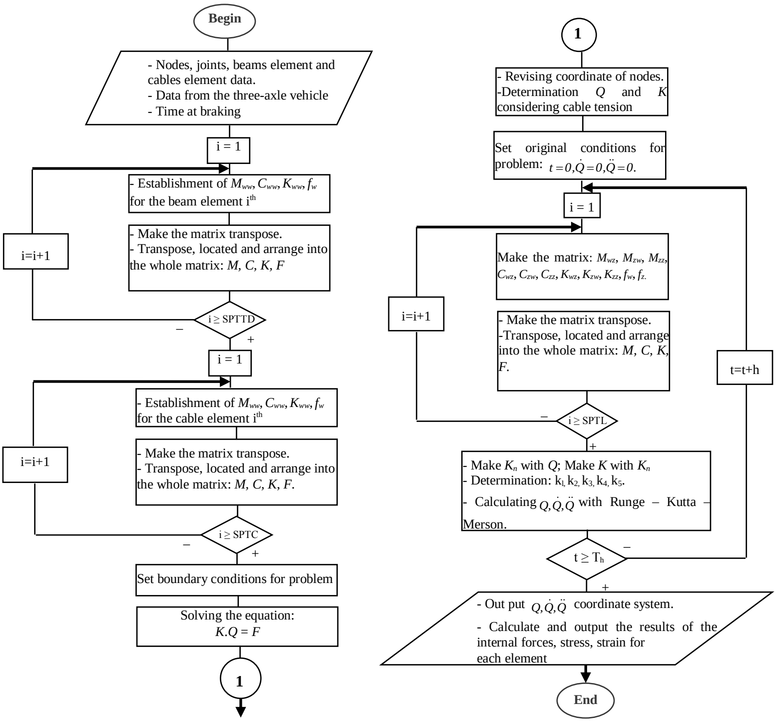

Figure 2.5. The algorithm of CSB vibration analysis program

2.5.2. Build modular of static analysis and vibration of CSB under effect of three-axle vehicle loading considering braking force

The main interface of the KC05 program developed when adding modules as shown in Figure 2.6. On the main interface of the software have items: Input the structure model, enter the technical parameters of structures and vehicles, input the parameters related to the analysis step, acceleration vehicle when braking, static analysis, dynamic analysis, printing the analysis results.

Figure 2.6. The KC05 software interface after developed module

2.5.3. Assessment results of KC05 program for bridge and CSB vibration analysis subject to vehicle loading considering braking force

The author selected Hoa Xuan bridge, Da Nang (continuous girder bridge) to verify theory results. The difference between experimental measurements and theoretical results was 5.9%, quite reasonable.

2.6. Conclusions of Chapter 2

The author has established computational models of beam element under the three-axle vehicle loading considering braking force. Build of vibration equations and applications FEM analysis of CSB vibration under vehicle loading considering the braking force. Base on the program KC05, build additional modules of CSB vibration analysis considering the braking force. Simultaneously, the author has carried out experimental measurement for Hoa Xuan bridge to verification of results theoretical analysis.

CHAPTER 3. RESEARCH THEORY AND EXPERIMENT OF CSB VIBRATION UNDER VEHICLE LOADING CONSIDERING BRAKING FORCE

3.1. General introduction

For a basis for evaluating the rationality of the results of FEM analysis, the author has carried out experiment to measure reality vibration of Pho Nam bridge in Da Nang.

3.2. Experimental measurement at Pho Nam bridge, Da Nang

3.2.1. Introduction of Pho Nam bridge

Pho Nam bridge is a cable-stayed bridge across the Cude river, Hoa Bac commune, Hoa Vang district, Da Nang.

3.2.2. Technical parameters of Pho Nam bridge and vehicle testing

3.2.2.1. Technical parameters of Pho Nam bridge

Bridge span: 35,7m +80m+ 35,7m, with steel girder 2xI600, bridge tower: I700&I500. Technical parameters of the beam: $E=2,1x10^8 T/m^2$; $J_d=0,001702m^4$; $F_d=0,02568m^2$;$q_y=\rho F_d= 2,035T/m$; $g=9,81m/s^2$;

3.2.2.2. Technical parameters of vehicle testing

Technical parameters of KAMAZ-5111: $m=8,56T$;$m_1=0,06T$; $m_2=0,11T$; $m_3=0,11T$;$P=0$;$b_1=2,09m$;$b_2=0,39m$;$b_3=2,07m$;$h=0,95m$; $h_1=h_2=h_3=0,51m$;$k_{1s}=120T/m$;$k_{1t}=220T/m$;$k_{2s}=k_{3s}=160T/m$;$k_{2t}=k_{3t}=32 T/m$; $d_{1s}=0,734Ts/m$;$d_{1t}=0,367Ts/m$;$d_{2s}=d_{3s}=0,4Ts/m$; $d_{2t}=d_{3t}=0,8 Ts/m$.

3.2.3. Order of experiments

Order of experiments: Collect data, determine the loading parameters, installation location surveying of equipment, moving from 10 km/h ÷ 40 km/h.

3.2.4. Results of experimental measurement at the Pho Nam bridge

There are 02 transducers of the beam at position 1 and 2, while the remaining 02 transducers will measuring displacement of the cable at position 3 and 4, as shown in Figure 3.8.

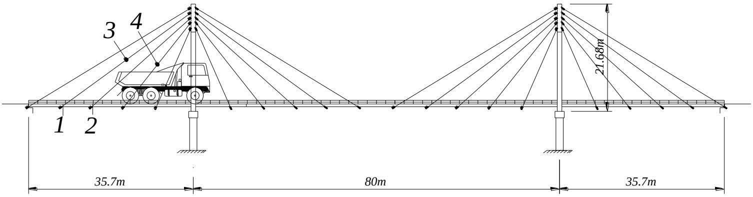

Figure 3.8. Installation of the measuring equipment on the Pho Nam bridge

3.2.4.1. Results of measurement of the dynamic impact factor when variety of vehicle speed and brake positions:

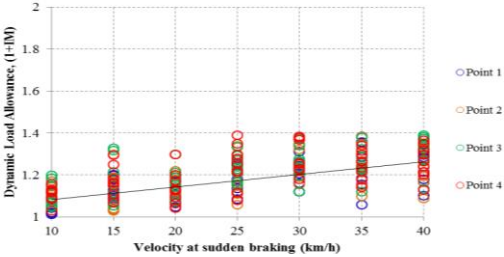

Figure 3.13. (1+IM) at the position 1, 2, 3, 4

3.2.4.2. Results of measurement of the dynamic impact factor depend on braking position when constant velocity:

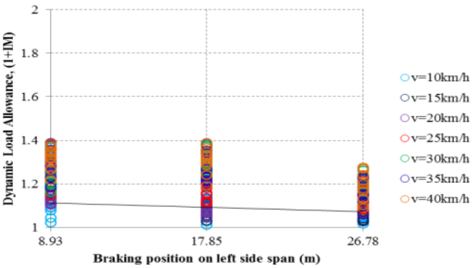

Figure 3.21. (1+IM) at the positions when the speed v=10÷40km/h

3.3. Comparison of the calculated results of dynamic impact factor in theory and experimentally

3.3.2. Some experimental measurements at Pho Nam bridge

The vehicle speed of 20km/h and 25km/h, and braking at 1/4 and 1/2 of span is received from experiment equipment as shown Fig. 3:22.

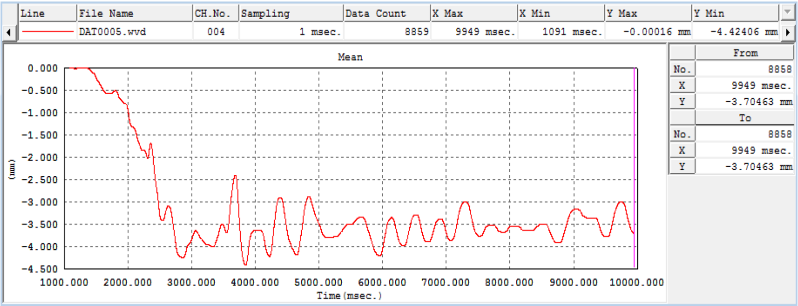

Figure 3.22. Deflection at node 02 when braking at the 1/4 span (v=20km/h)

3.3.2. Modeling and application FEM methods for Pho Nam bridge vibration analysis

Dyamic interaction model between CSB and vehicle loading considering the braking force is described as shown Fig. 3.30:

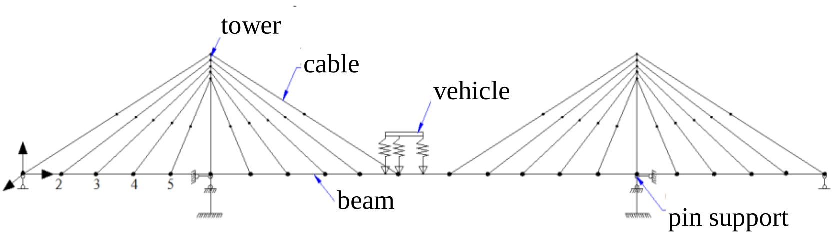

Fig 3.30. Dyamic interaction model between CSB and vehicle

3.3.3. Comparing the results of theoretical analysis and experimental measurement Pho Nam bridge, Da Nang

Table 3.3. The comparison of dynamic impact factor when analyzing in theory and experiment

Def. position	Braking position	Speed of braking (km/h)	Theory results		Experimental results		Difference between theory and experimentally	
			q_d (mm)	1+IM	q_d (mm)	1+IM	Δq_d (%)	ΔIM (%)
Node 2	1/4 L	20	4.918	1.227	4.424	1.164	11.2	5.4
Node 3	1/4 L	20	5.293	1.154	4.529	1.105	16.9	4.5
Node 2	1/2 L	20	4.711	1.175	4.048	1.079	16.4	8.9
Node 3	1/2 L	20	6.048	1.225	5.393	1.135	12.1	7.9
Node 2	1/4 L	25	5.292	1.320	4.770	1.255	10.9	5.2
Node 3	1/4 L	25	5.831	1.206	5.395	1.148	8.1	5.1
Node 2	1/2 L	25	5.092	1.260	4.508	1.156	13.0	9.0
Node 3	1/2 L	25	5.780	1.163	5.279	1.111	9.5	4.6

3.4. Conclusions of chapter 3

- The author has carried out experiments in the field to determine reality dynamic impact factor of Pho Nam bridge, Da Nang. After comparing reality measurements and theoretical analysis showed dynamic impact factor according to theoretical analysis quite matching the experiment. The greatest difference between these two results for Pho Nam is 9.0%. Thus, the dynamic impact factor result when analyzing in theory be trusted. Experimental results measuring dynamic impact factor at Pho Nam bridge with vehicle speed from 10km/h to 40km/h with maximum value is 1,389.

- Based on the trend line on the chart experiment measurements when moving at speeds between 10÷40km/h showed (1+IM) tends to increase as the vehicle speed increase at braking when braking position as far as bearing the (1+IM) tends to decrease.

CHAPTER 4. ANALYTICAL APPLICATIONS OF CSB VIBRATION UNDER THE VEHICLE LOADING CONSIDERING BRAKING FORCE

4.1. General introduction

In this chapter will present contents of using the program KC05 after the upgraded to analyze dynamic interaction between 02-span, 03-span CSB and three-axle vehicle considering braking force.

4.2. Vibration investigation of CSB subject to vehicle loading with variety velocity considering braking force

4.2.1. Vibration investigation of Pho Nam bridge, in Da nang

Conducting a investigation of (1+IM) at nodes: 4, 7, 8, 9 24, 29, 39, 40 as shown in Fig. 4.1.

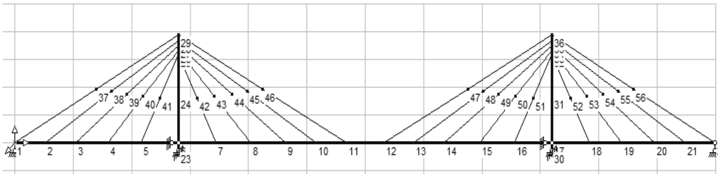

Figure 4.1. Pho Nam bridge, Da Nang

Vehicles derived from the left end of the bridge, running with the speed of 5÷50 m/s and put the brakes at nodes:4, 5, 6, 7, 8 respectively.

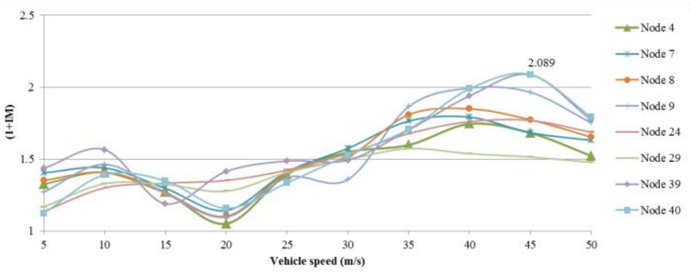

Figure 4.2. Dynamic impact factors of axial displacement when braking at position is 13m away from the left bearing

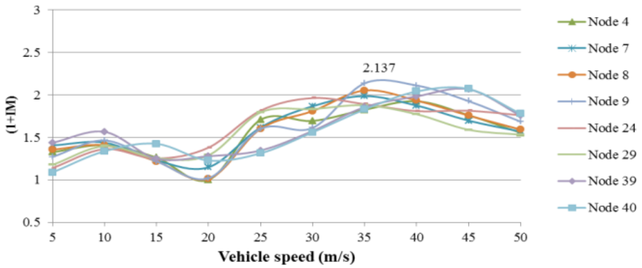

Figure 4.2. Dynamic impact factors of axial displacement when braking at position is 20m away from the left bearing

Fig. 4.2 and Fig. 4.5 describe the variety of dynamic impact factors when vehicle speed from 5 to 50m/s, maximum value is 2.089 and 2,137 with speed 45m/s and 35m/s, using the brake. Similar to other results.

4.2.2. Vibration investigation of Nhat Le_02 bridge, Quang Binh

Conducting a investigation of (1+IM) at nodes: 2, 4, 6, 8, 10, 17, 19, 21 as shown in Fig. 4.26.

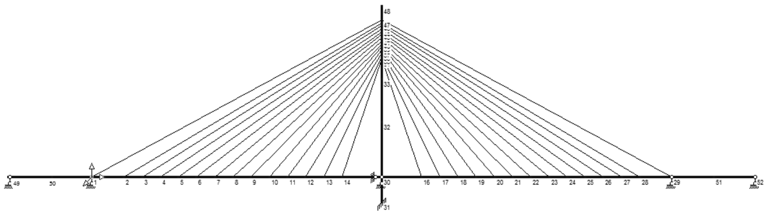

Figure 4.1. Nhat Le_02 bridge, Quang Binh

Vehicles derived from the left end of the bridge, running with the speed of 5÷80 m/s and put the brakes at nodes: 2, 6, 10, 14, 18, 22.

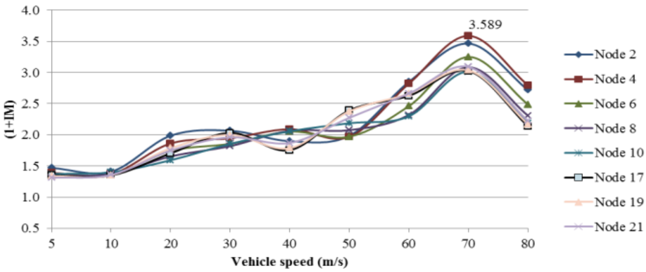

Figure 4.27. Dynamic impact factors of axial displacement when braking at position is 16,6m away from the left bearing

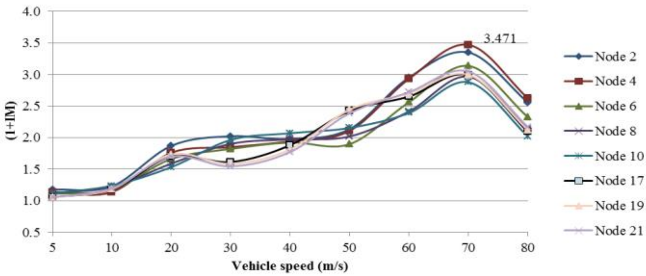

Figure 4.30. Dynamic impact factors of axial displacement when braking at position is 54,2m away from the left bearing

Fig. 4.27 and Fig. 4.30 describe the variety of dynamic impact factors when vehicle speed from 5 to 80m/s, maximum value is 3,589 and 3,471 with speed 70m/s, using the brake

4.3. Vibration investigation of CSB subject to vehicle loading with variety velocity considering braking position

4.3.1. Vibration investigation of Pho Nam bridge, in Da Nang

Conducting a investigation of (1+IM) for Pho Nam bridge subject to the KAMAZ-5111 dumper truck, using brake at positions is 13m to 108,5m away from the left bearing.

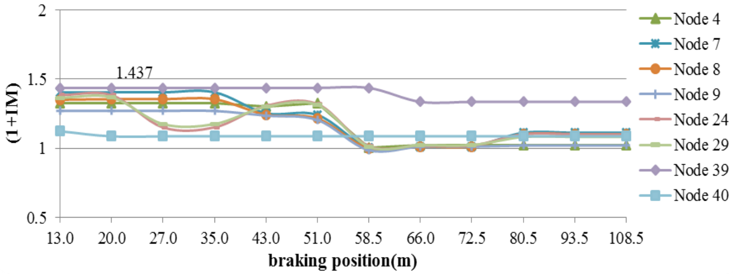

Figure 4.45. Dynamic impact factors of axial displacement when v=5m/s

Fig. 4.45 describes the variety of dynamic impact factors when vehicle speed of 5m/s and brake at nodes: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

4.3.2. Vibration investigation of Nhat Le_02 bridge, Quang Binh

Conducting a investigation of (1+IM) for Nhat Le_02 bridge subject to the ASIA dumper truck, using brake at positions are 16,6m, 54,2m, 91,8m, 189,4m, 227m, 264,6m away from the left bearing..

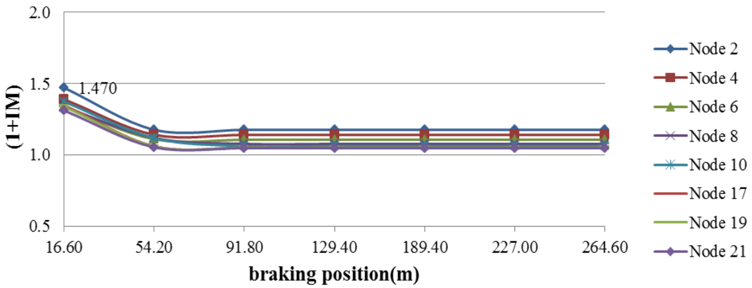

Figure 4.75. Dynamic impact factors of axial displacement when v=5m/s

Fig. 4.75 describes the variety of dynamic impact factors when vehicle speed of 5m/s and brake at nodes: 2, 4, 6, 8, 10, 17, 19, 21.

4.4. Analysis of dynamic impact factor results based on confidence intervals

Author application probability theory to analyze statistical (1+IM) data as calculated by the FEM based on confidence. In this case, the sample is a random set of (1+IM) at each node when moving at different speeds and braking at different positions on the bridge

4.4.1. Determining (1+IM) in the confidence interval theory

Results (1+IM) of the Pho Nam bridge according to the 90%, 95%, 99% and 99,99% confidence interval of the axial displacement, vertical displacement and angular displacement at nodes 4, 7 , 8, 9, 24, 29, 39, 40. they already make valuation of the dynamic impact factor is clearly and more reasonable than the average value.

4.4.2. Investigation of dynamic impact factor in the velocity range from 5m/s to 30m/s in the confidence interval for Pho Nam bridge

Investigation results of (1+IM) at nodes 4, 7, 8, 9, 24, 29, 39, 40 in velocity range from 5m/s to 30m/s (18km/h to 108km/h) and vehicle braking at multiple locations on the bridge as shown in Tab. 4.2 to Tab. 4.4:

Tab. 4.2. Dynamic impact factor of axial displacement as determined by the confidence interval of vehicle speed from 5m/s to 30m/s

Node	Average value of (1+IM)	s	Amplitude of error with confidence intervals (%)				Dynamic Impact factor, (1+IM) with confidence intervals							
			90	95	99	99,99	90%		95%		99%		99,99%	
							min	max	min	max	min	max	min	max
4	1.30	0.215	0.04	0.05	0.07	0.10	1.26	1.34	1.25	1.35	1.23	1.37	1.20	1.40
7	1.27	0.166	0.03	0.04	0.05	0.08	1.23	1.30	1.23	1.30	1.21	1.32	1.18	1.35
8	1.32	0.232	0.05	0.05	0.07	0.11	1.27	1.36	1.26	1.37	1.25	1.39	1.21	1.43
9	1.29	0.215	0.04	0.05	0.07	0.10	1.25	1.33	1.24	1.34	1.22	1.36	1.18	1.39
24	1.39	0.242	0.05	0.06	0.08	0.12	1.34	1.44	1.34	1.45	1.32	1.47	1.27	1.51
29	1.35	0.230	0.05	0.05	0.07	0.11	1.31	1.40	1.30	1.41	1.28	1.42	1.24	1.46
39	1.41	0.173	0.03	0.04	0.05	0.08	1.37	1.44	1.36	1.45	1.35	1.46	1.32	1.49
40	1.35	0.167	0.03	0.04	0.05	0.08	1.31	1.38	1.31	1.39	1.29	1.40	1.27	1.43

Tab. 4.3. Dynamic impact factor of vertical displacement as determined by the confidence interval of vehicle speed from 5m/s to 30m/s

Node	Average value of (1+IM)	s	Amplitude of error with confidence intervals (%)				Dynamic Impact factor, (1+IM) with confidence intervals							
			90	95	99	99,99	90%		95%		99%		99,99%	
							min	max	min	max	min	max	min	max
4	1.43	0.213	0.04	0.05	0.07	0.10	1.39	1.48	1.38	1.48	1.37	1.50	1.33	1.54
7	1.27	0.179	0.04	0.04	0.06	0.09	1.23	1.30	1.22	1.31	1.21	1.32	1.18	1.35
8	1.27	0.183	0.04	0.04	0.06	0.09	1.24	1.31	1.23	1.32	1.22	1.33	1.19	1.36
9	1.24	0.188	0.04	0.04	0.06	0.09	1.21	1.28	1.20	1.29	1.19	1.30	1.15	1.34
24	1.47	0.227	0.04	0.05	0.07	0.11	1.42	1.51	1.41	1.52	1.40	1.54	1.36	1.58
29	1.32	0.272	0.05	0.06	0.08	0.13	1.27	1.38	1.26	1.39	1.24	1.41	1.19	1.46
39	1.39	0.208	0.04	0.05	0.06	0.10	1.35	1.43	1.34	1.44	1.32	1.45	1.29	1.49
40	1.54	0.278	0.05	0.07	0.09	0.14	1.49	1.60	1.48	1.61	1.46	1.63	1.41	1.68

Tab. 4.4. Dynamic impact factor of angular displacement as determined by the confidence interval of vehicle speed from 5m/s to 30m/s

Node	Average value of (1+IM)	s	Amplitude of error with confidence intervals (%)				Dynamic Impact factor, (1+IM) with confidence intervals							
			90	95	99	99,99	90%		95%		99%		99,99%	
							min	max	min	max	min	max	min	max
4	1.33	0.164	0.03	0.04	0.05	0.08	1.30	1.36	1.29	1.37	1.28	1.38	1.25	1.41
7	1.23	0.198	0.04	0.05	0.06	0.10	1.19	1.27	1.19	1.28	1.17	1.29	1.14	1.33
8	1.25	0.154	0.03	0.04	0.05	0.07	1.22	1.28	1.21	1.28	1.20	1.30	1.17	1.32
9	1.26	0.306	0.06	0.07	0.10	0.15	1.20	1.32	1.19	1.33	1.17	1.36	1.11	1.41
24	1.42	0.269	0.05	0.06	0.08	0.13	1.36	1.47	1.35	1.48	1.33	1.50	1.28	1.55
29	1.34	0.220	0.04	0.05	0.07	0.11	1.30	1.38	1.29	1.39	1.27	1.41	1.23	1.45
39	1.32	0.267	0.05	0.06	0.08	0.13	1.27	1.38	1.26	1.39	1.24	1.41	1.19	1.45
40	1.58	0.297	0.06	0.07	0.09	0.14	1.52	1.64	1.51	1.65	1.49	1.67	1.44	1.73

4.5. Conclusions of chapter 4

Braking force significantly affect to vibration of structural CSB. Compared with case of not braking, the increase in dynamic impact factor to change significantly:

+ For Pho Nam bridge is a 03-span CSB, the increase in the largest average value of dynamic impact factor is 20,8% for the axial displacement; 22,6% for vertical displacement; 21,4% for angular displacement. Including a number node of the element could be reached increasing to 29,7%, larger than the 25% value is measured by experimental research of Zhisong Zhao and Nasim Uddin (2013).

+ For Nhat Le 02 bridge is a 02-span CSB, the increase in the largest average value of dynamic impact factor is 25,2% for the axial displacement; 23% for vertical displacement; 22,7% for angular displacement. Including a number node of the element could be reached increasing to 29,74%, larger than the 25% value is measured by experimental research of Zhisong Zhao and Nasim Uddin (2013).

- Within the vehicle speed smaller than allow speed (108km/h), the largest average value of dynamic impact factor for Pho Nam bridge is 1,367, for Nhat Le 02 bridge is 1,448.

- For finding the resonance domain for Pho Nam bridge and Nhat Le 02 bridge, the author continued to investigate the vehicle speed is higher than the speed allowed. Results showed that for the domain resonant speed of Pho Nam bridge is 126km/h ÷ 162km/h, the domain resonance speed Nhat Le 02 bridge is 216km / h ÷ 252km / h.

CONCLUSIONS

Through the research content in the doctoral dissertation, the author summarizes some of the results already achieved by the following:

1. Build the new calculating models and vibration equations for dynamic interaction between the beam element and the three-axle vehicle considering braking force. Beam element model is considered simultaneously for bending and axial vibration under effect of vehicle load. The vehicle loading is a four-mass model with vertical displacement and inertial forces caused by braking force.

2. Additional algorithms and developing program modules for analysis of CSB vibration under effect of a three-axle vehicle considering braking force that is based on the finite element method (FEM) algorithm. Also, this study was conducted the tests to verify FEM results for the Hoa Xuan bridge and the Pho Nam bridge in Danang city. The difference between theory and experiment is about 9%.

3. The findings of this study provide the field test results on the Pho Nam under effect of the KAMAZ vehicle to speed from 10km/h to 40km/h with using sudden braking on the bridge. The dynamic impact factor tends to increase as the speed at brake. The dynamic impact factor tends to decrease when the braking location as far as bearing support.

4. The FEM results were applied for the Pho Nam bridge in Danang city and Nhat Le_02 bridge in Quang Binh province under the three-axle vehicle loading considering braking force. The dynamic impact factor of braking effect is often greater than without

braking. The biggest value added of dynamic impact factor is about 30%. In addition, the results of this study were showed that the KAMAZ vehicle speed domain can occur resonance for the Pho Nam CSB is 126km/h ÷ 162km/h, the ASIA vehicle speed domain can occur resonance for the Nhat Le_02 CSB is 216km/h ÷ 252km/h.

5. Application theory of confidence interval to determine the dynamic impact factor for Pho Nam bridge under three-axle vehicle considering braking force taking into account the allow speed domain. This study has achieved initial results compared to the value of the dynamic impact factor in 22TCN-272-05 standard as follows:

- With the 90% confidence interval, the dynamic impact factor increase of 15,2% ÷ 31,2%.
- With 95% confidence interval, the dynamic impact factor increase of 16,0% ÷ 32,0%.
- With the 99% confidence interval, the dynamic impact factor increase of 17,6% ÷ 33,6%.
- With the 99,99% confidence interval, the dynamic impact factor increase of 20,8% ÷ 38,4%.

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7. Toan X. N., Duc V. T. (2015), "Vehicle-Cable stayed bridge Dynamic Interaction considering the vehicle braking effects using the Finite Element Method", *Proceeding of The 16th Asian Pacific Vibration Conference*, Ha noi, Vietnam, p.260-267 / DOI: 10.15625/vap.2016.000044