The ageing effect of mechanical joints on the tyre/joint noises monitored by a control vehicle method without traffic disturbance

Wong, C. K.; Lee, Y. Y.; Wong, J. C K; Lo, T. Y.; Leung, A. Y T; Wong, K. W.

Published in:
Advances in Mechanical Engineering

Published: 27/01/2015

Document Version:
Final Published version, also known as Publisher's PDF, Publisher’s Final version or Version of Record

License:
CC BY

Publication record in CityU Scholars:
Go to record

Published version (DOI):
10.1155/2013/454351

Publication details:
Wong, C. K., Lee, Y. Y., Wong, J. C. K., Lo, T. Y., Leung, A. Y. T., & Wong, K. W. (2015). The ageing effect of mechanical joints on the tyre/joint noises monitored by a control vehicle method without traffic disturbance. Advances in Mechanical Engineering, 2013, [454351]. https://doi.org/10.1155/2013/454351

Citing this paper
Please note that where the full-text provided on CityU Scholars is the Post-print version (also known as Accepted Author Manuscript, Peer-reviewed or Author Final version), it may differ from the Final Published version. When citing, ensure that you check and use the publisher's definitive version for pagination and other details.

General rights
Copyright for the publications made accessible via the CityU Scholars portal is retained by the author(s) and/or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights. Users may not further distribute the material or use it for any profit-making activity or commercial gain.

Publisher permission
Permission for previously published items are in accordance with publisher's copyright policies sourced from the SHERPA RoMEO database. Links to full text versions (either Published or Post-print) are only available if corresponding publishers allow open access.

Take down policy
Contact lbscholars@cityu.edu.hk if you believe that this document breaches copyright and provide us with details. We will remove access to the work immediately and investigate your claim.

Download date: 22/06/2020
Research Article

The Ageing Effect of Mechanical Joints on the Tyre/Joint Noises Monitored by a Control Vehicle Method without Traffic Disturbance

C. K. Wong, Y. Y. Lee, J. C. K. Wong, T. Y. Lo, A. Y. T. Leung, and K. W. Wong

Department of Civil and Architectural Engineering, City University of Hong Kong, Hong Kong Special Administrative Region, Hong Kong

Correspondence should be addressed to C. K. Wong; wongck@cityu.edu.hk

Received 22 July 2013; Accepted 3 November 2013

Academic Editor: Hirosi Noguchi

Copyright © 2013 C. K. Wong et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This paper studies the ageing effect of mechanical joints reflecting from the tyre/joint impacting noise by measuring the vehicle structure-borne noise change. Field data is collected applying two measurement methods suitable for newly installed and existing old expansion joints. The measurement methodology is improved by designing and applying a trailer for equipment installation. The main advantage of this method is not to disturb existing traffic by lane closure for measurement. Field measurements were conducted regularly for a study period up to 16 months after new joint replacement to monitor the variation of the structure-borne noise change inside a test vehicle while passing through mechanical joints. Empirical relationship is developed based on the field data of the roadside airborne noise change and the vehicle structure-borne noise change. The roadside tyre/joint noises could be converted using calibrated empirical formula. Key result findings include the following. (1) The vehicle structure-borne noise change is found smallest during the 3rd–6th months even lower than that measured when a new joint is installed. The structure-borne noise change then keeps increasing afterwards till the end of the study period. (2) Similar observations are found in all study cases incorporating various mechanical joint types and test vehicle types.

1. Introduction

Bridge joint performances and assessment methods have been an important research area [1, 2]. Noise generated due to traffic over different road surfaces was measured in site and studied [3, 4]. A pavement condition index was developed numerically relating the field-measured data for evaluating the structural integrity and operational condition of pavements [5]. Application of nondestructive infrared thermography for detecting airport pavement defects was proposed [6]. Falling weight deflectometer was also a non-destructive method for monitoring and assessing rigid pavement systems [7]. A mathematical model of a 3D automobile and the interaction between wheels and the road surface and the geometry of the road surface were developed to confirm that stability of moving automobiles on pavements was closely related to road surface conditions including depth of ruts [8]. Statistical relationships among noise and pavement surface texture and friction were established using field measured data [9]. Bendtsen et al. [10] promoted nondestructive acoustic approach for analyzing the aging trend and effect of road pavements so as to assist road administrators to develop maintenance policies and strategies for traffic noise reduction. Traffic noise due to installing traffic calming devices to promote safety driving and speed reduction could not be avoided but should be minimized [11]. More recently, Donavan and Rymer [12] conducted a study to relate the effects of aging to tire-pavement noise generation for concrete pavements. Murugan et al. [13] studied the ageing problem of wind turbines by monitoring the trend of power output. Kamaitis [14] investigated the deterioration of bridge deck with site survey and condition evaluation for movement joints. Asphalt plug joints were specifically investigated and found to be effective to connect pavement decks together in terms of gap plate width, thickness, and edge geometry to reduce tire/joint noise [15].

In Hong Kong, there are over 580,000 licensed vehicles running along 2,000 kilometers of roads with 15 major
tunnels, nearly 1,300 flyovers, and bridges. Lots of highway bridges were built and put into services in the past few decades of ages up to 40–50 years. Movement expansion joints are generally installed for connecting different sections of bridge decks over supporting piers. Riding qualities of movement joints on those highway bridges, especially noise nuisance generated by moving vehicles, are one major source of complaints received by the authority concerned in Hong Kong. In view of the close proximity of bridges to residential blocks due to the special situations in crowded cities like Hong Kong, such noise nuisance problem generated from traffic running on bridges becomes a severe environmental problem leading to frequent public complaints. Such issue becomes controversial as local residents are very subjective to make their complaints without scientific justification. Over 20,000 complaints were received in 1999 by the Environmental Protection Department (EPD). Among them, over 1/3 of them was noise related [16]. On average, the annual budget in the Highways Department of Hong Kong for road maintenance work is around HK$1.0 billion [17].

There are two main kinds of traffic noise which are bridge related: the tyre/pavement noise and the tyre/joint noise. The tyre/pavement noise refers to the noise created while the tyres of vehicles run on the pavement of bridges. Skid resistance representing the pavement surface condition has been measured adjacent to the joint noise to refer to the pavement condition as given in Figure 1. Indirect relationship was established between tyre/pavement noise and skid resistance value. The tyre/joint noise refers to the noise created while the tyres of vehicles collide with the mechanical joints on bridges. Many previous studies have focused on the former while fewer studies on the latter. In this paper, the study will focus on tyre/joint noise.

In UK, Transport for London (TfL) also realized that deck expansion joints are important bridge component to ensure road user safety, bridge durability, and riding quality and should be maintained in good condition. Inside the “inspection guidance for bridge expansion joints” [18], it is highly recommended to keep a full inspection record for each movement joint including the entire history of defects, repair items, and methods to monitor the performance and working condition of each joint. Recommended inspection intervals are also specified as given in Table 1.

Table 1: Lifespan and recommended inspection interval for 7 common expansion joints.

| Joint type                  | Expected lifespan | Inspection interval                                      |
|-----------------------------|-------------------|----------------------------------------------------------|
| Buried joint                | 10–12 years       | 6 years or every 2 years after end of service life        |
| Asphaltic plug joint        | 5 years           | Every 2 years                                             |
| Nosing joint                | 5 years           | Every 2 years                                             |
| Reinforced elastomeric      | 6 years           | 2 years or annually after end of service life             |
| Elastomeric in metal runners| Up to 20 years    | 6 years or every 2 years after end of service life        |
| Cantilever comb or tooth    | 25 years          | 6 years or every 2 years after end of service life        |

Figure 1: Field measurement of skid resistance by the first author.
Advances in Mechanical Engineering

2. Methodology

2.1. Measurement Using a Control Vehicle. A previous study has been carried out using Acoustic-box-in-vehicle methodology [4]. A microphone placed on roadside and another microphone placed in a control vehicle will capture the changes of the noise levels measured while the test vehicle approaches, pass through, and leave a joint. The roadside microphone and the in-vehicle microphone will measure different natures of the noise generated. The microphone on the roadside is used to measure the airborne noise change while the control vehicle is passing through the joint, that is, the tyre/joint noise. The microphone in the control vehicle is used to measure the structure-borne noise change of the test vehicle while the test vehicle is passing over the joint. An acoustic box, which is mounted rigidly in the control vehicle, is used to envelope the microphone to facilitate the measurement of the structure-borne noise change. In the proposed methodology, the airborne noise change and vibration change are focused and measured. It is because the tyre/joint noise is induced within the short time when the control vehicle passing a joint. The instruments capture the sound and vibration responses before and after the control vehicle passing through the movement joint. Hence, the airborne noise and vibration due to other sources should be eliminated. The roadside airborne noise change and the vehicle structure-borne noise change are calculated by (1) and (2).

The airborne noise level change captured by microphone on the roadside is

$$\Delta L_{\text{air}} = 10 \log \left( \frac{\langle P_a^2 \rangle_{\text{avg}}}{\langle P_{\text{ref},a}^2 \rangle_{\text{avg}}} \right),$$  (1)

where $\Delta L_{\text{air}} = \text{Airborne Noise Level Change}$, $P_a$ is the sound pressure captured by the roadside microphone just before the control vehicle passing through the joint, $P_{\text{ref},a}$ is the sound pressure captured by the roadside microphone when the control vehicle is passing over the joint, and $\langle \rangle_{\text{avg}}$ is the temporal average for the duration when the tyres of the control vehicle passing over the joint.

The structure-borne noise level change captured by the microphone inside the acoustic box is

$$\Delta L_{\text{stru}} = 10 \log \left( \frac{\langle P_s^2 \rangle_{\text{avg}}}{\langle P_{\text{ref},s}^2 \rangle_{\text{avg}}} \right),$$  (2)

where $\Delta L_{\text{stru}} = \text{Structure-borne Noise Level Change}$, $P_s$ is the sound pressure captured by the microphone inside the acoustic box just before the test vehicle passing over the joint, $P_{\text{ref},s}$ is the sound pressure captured by the microphone inside the acoustic box when the test vehicle passing over the joint, and $\langle \rangle_{\text{avg}}$ is temporal average for the duration when the tyres of the test vehicle passing over the joint.

From a previous study, statistics show that the vehicle structure-borne noise change is linearly proportional to the roadside airborne noise change. Therefore, the vehicle structure-borne noise change can be used as an indicator to show the noise performance of mechanical joints, including joint types with noise reduction performance. Acoustic-box-in-vehicle methodology without using the trailer has been used for noise measurement on Bridges A and B.

2.2. Enhanced Measurement Using a Trailer. Damping system of a test vehicle would affect the structure-borne noise received by the microphone installed inside the acoustic box. The previous measurement method is thus modified. A trailer without damping system, as shown in Figures 2 and 3, is used to carry the acoustic box for conducting practical field measurement. Figure 4 shows a schematic overview of A–D, are scheduled for on-site field tests. Two joints of two different types with noise-reduction design have been newly installed on Bridges A and B. Site tests were conducted periodically nearly 1.5-year to continuously monitor their noise performances using a test vehicle without the trailer. Another 4 existing joints of two different types on Bridges C and D were also tested periodically for about 6 months to keep monitoring their noise performances by the measurement method using the trailer.
Table 2: Summary of the measurement and test results.

| Test | Bridge/joint type | A (see Figure 5) | B (see Figure 6) | C (see Figure 7) | D (see Figure 8) |
|------|------------------|------------------|------------------|------------------|------------------|
| Joint no. | A | B | C1, C2 | D1, D2 |
| Methodology | Without trailer | Without trailer | Trailer | Trailer |
| Average speed of the test vehicle (km/h) | 64 | 45 | 15 | 15 |
| Speed limit (km/h) | 70 | 50 | 50 | 70 |
| No. of measurement | 5 | 5 | 3 | 3 |
| Joint replacement within monitoring period | An existing old joint is replaced with a new joint | An existing old joint is replaced with a new joint | Nil | Nil |
| Joint maintenance within monitoring period | Nil | Nil | Nil | Joint nosing is renovated |

the modified methodology. The frame of the trailer is self-manufactured using galvanized iron angles and galvanized iron bars. The junctions of the frame are connected by metal arc welding. A piece of hardwood is employed to form a deck for the placement of the acoustic box. The axle, wheels, and tyres of the trailer are detached from a sedan with the removal of its original damping system. There are no powered moving parts on the trailer with bearings and wheels only. The trailer itself is a rigid body.

Having no damping system, the trailer cannot travel at high speed level as proven from trial tests. Cases were reported that the trailer would “fly through” the joints instead of passing over the joints with direct contact. With experiences on testing mechanical joints along the high traffic volume highways in Hong Kong, it is recommended that the maximum traveling speed for conducting meaningful measurements with the trailer is around 15 km/hr.

The proposed methodology using the trailer has been used on Bridges C and D. The structure-borne noise change captured by the microphone inside the acoustic box is calculated by (2).

3. Case Study and Measurement Results

Six movement joints installing in 4 different bridges, denoted as Bridges A, B, C, and D, are selected for measurement tests. Each joint consists of a series of measurements which are carried out on a regular basis. The structure-borne change as time goes can then be monitored.

Table 2 shows the summary of all the tests. Acoustic-box-in-vehicle methodology is used for all the measurements. The trailer is absent in the tests on Bridge A and Bridge B. In contrast, the trailer is employed for the tests on Bridge C and Bridge D. The speed limits of Bridge A, Bridge B, Bridge C, and Bridge D are 70, 50, 70, and 70 km/h, respectively.

The speed of the control vehicle is maintained above 90% of the speed limit when it runs across the joints on Bridge A and Bridge B. The speed of the trailer is maintained at 15 km/h when it runs across the joints on Bridge C and Bridge D.

Old joints are selected, respectively, from Bridge A and Bridge B. Both old joints have been installed and used for more than 5 years. A measurement is firstly carried out to measure the structure-borne noise change of the old joints.

After that, the old joints are replaced with the new joints with noise-reduction design. A series of monitoring measurements is then carried out on a regular basis up to 16 months after the joint replacement. Two more joints are selected, respectively, from Bridge C and Bridge D. These joints are relatively new joints which have been installed and used for about 2 years. No joint replacement work has been carried out during the monitoring period; however, maintenance work has been carried out to repair the joint nosing on Bridge D after the second monitoring measurement.

For all the monitoring measurements carried out on Bridge A and Bridge B, the respective highest structure-borne noise change is found in the measurements which are carried out before the joint replacement. This is reasonable as both joints are old joints with more than 5 service years. After joint replacement, structure-borne noise change keeps decreasing to reach a minimum noise level and then increases again. For the monitoring measurements carried out on Bridge C and Bridge D, the respective structure-borne noise change increases generally as the joints age. The structure-borne noise change of the joints on Bridge C increases along with the joints age. The structure-borne noise change of the joints on Bridge D has increased and then decreased. The decrease
Table 3: Average structure-borne noise change on Bridge A.

| Monitoring period (month after joint replacement) | Average vehicle structure-borne noise change (error range), dB; see Figure 5 for the time history |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Before replacement                                | 11.3 (±2.4)                                                                                     |
| 3rd                                              | 8.7 (±1.0)                                                                                      |
| 6th                                              | 6.6 (±0.2)                                                                                      |
| 13th                                             | 6.9 (±0.4)                                                                                      |
| 16th                                             | 9.0 (±0.5)                                                                                      |

Table 4: Average structure-borne noise change on Bridge B.

| Monitoring period (month after joint replacement) | Average vehicle structure-borne noise change (error range), dB; see Figure 6 for the time history |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Before replacement                                | 6.8 (±0.7)                                                                                     |
| 3rd                                              | 5.3 (±1.1)                                                                                      |
| 6th                                              | 4.5 (±0.1)                                                                                      |
| 10th                                             | 4.9 (±0.2)                                                                                      |
| 13th                                             | 5.1 (±0.9)                                                                                      |

Bridge D is planned to be tested with the trailer. However, an extra measurement has been carried out on Bridge D. The structure-borne noise change captured by Acoustic-box-in-vehicle methodology with the trailer is plotted against the structure-borne noise change captured by the Acoustic-box-in-vehicle methodology without using the trailer. The
Table 5: Average structure-borne noise change on Bridge C.

| Monitoring period (month after joint replacement) | Average vehicle structure-borne noise change (error range), dB; see Figure 7 for the time history of C1 |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Joint C1                                          | Joint C2                                                                                           |
| Start                                             | 4.8 (±0.3)                                                                                         |
| 3rd                                               | 5.5 (±0.3)                                                                                         |
| 6th                                               | 6.1 (±1.4)                                                                                         |

Table 6: Average structure-borne noise change on Bridge D.

| Monitoring period (month after joint replacement) | Average vehicle structure-borne noise change (error range), dB; see Figure 8 for the time history of D1 |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Joint D1                                          | Joint D2                                                                                           |
| Start                                             | 5.2 (±1.0)                                                                                         |
| 3rd                                               | 6.0 (±0.4)                                                                                         |
| 6th                                               | 5.4 (±1.2)                                                                                         |

Note: Maintenance work has been carried out in the fourth month of the monitoring period. The nosing of Joint D1 and Joint D2 have been repaired.

Results are shown in Figure 13 and Table 7. A strong linear relationship is observed for Joints D1 and D2.

4. Discussions and Recommendations

Intensities of tyre/joint noise level measured on Bridges A and B are found to keep decreasing during the first 6 months after joint replacement work. The reason is that contractors for joint replacement work do intend to allow some level difference between the nosing of two bridge decks in the joint installation. Such level difference starts to diminish after opening to traffic where vertical wheel loadings are applying on the joint and it results in decreasing the tyre/joint noise. An increasing trend of tyre/joint noise is then found on Bridges A and B after the noise level has reached lowest values. Similar trend has also been found on Bridges C and D, regardless of the third measurement carried out on Bridge D as prior maintenance work has been completed. This trend is normal due to the inherent ageing effects of the
Table 7: Structure-borne noise change captured by Acoustic-box-in-vehicle method with and that without using the trailer on Bridge D.

| Trial | Measurement without using the trailer | Measurement using the trailer |
|-------|--------------------------------------|-------------------------------|
|       | Joint D1 | Joint D2 | Joint D1 | Joint D2 |
| 1     | 2.4      | 2.6      | 5.7      | 6.3      |
| 2     | 2.5      | 3.2      | 5.9      | 7.0      |
| 3     | 3.1      | 3.6      | 6.4      | 7.2      |

Figure 12: Average structure-borne noise change on Bridge D (joint nosing of respective joints has been renovated after the third month of the monitoring period).

The design of the joint should consider facilitating joint replacement operation, improvement of nosing/bitumen interface, and reinforcement details. A typical design of the currently used joint type as shown in Figure 15 has top rebars (in blue color) extending from the pavement to cross the rebars (in green color) of the nosing and bending vertically as shear reinforcement (in blue color) of the joint. Such complex overlapping of reinforcement causes difficulty and will be timeconsuming in joint replacement. A better finger-type zigzag design for the nosing/bitumen interface and reconnecting the cut top reinforcement to the preinstalled coupler (in blue and green colors) is proposed to replace the current joint design, as given in Figure 16.

One of the main features for noise reduction joint design is the finger-type design that the noise reduction plates can effectively reduce the angle of transition with the vehicle wheels. As vehicle tyres while traveling across the interface of two surfacing materials will generate noise, adopting the new zigzag joint design to the nosing/bitumen interface can further enhance the noise reduction at joint by reducing the angle of transition at the nosing/bitumen interface. The proposed zigzag nosing/bitumen interface is a design with steps of width 75 mm and pitch spacing at 150 mm (in Figures 16 and 17). The shape of the stud can maintain the necessary strength of concrete pavement for vehicle wheel load and limits the contact length of vehicle tyre across the mechanical joints. Damages, such as cracks at the nosing of the joint as shown in Figure 14, can be detected accordingly and confirmed by visual inspection.

It is recommended that noise levels on mechanical joints should be monitored at least once a year in Hong Kong by an approved monitoring and measurement method. The noise reduction capability of joints may probably be degraded to an unacceptable level if the noise level is found to exceed a threshold when vehicles run over a movement joint. Inspectors should report this to the authority concerned for seeking appropriate follow-up actions, such as noise measurement, maintenance work, or joint replacement. Once a mechanical joint is detected with abnormal noise problems and decided for replacement, contractors should pay attentions to the following areas.

1. A reasonable minimum curing time for concrete hardening should be provided.
2. Never install different types of joints across different lanes along a road section.
3. Level difference between the nosing of two consecutive bridge decks near the movement joint should be restricted to within +3 mm.

Movement joints with finger type design and noise reduction capability features should be used whenever possible.
nosing/bitumen interface to be 75 mm. The introduction of angle of transition provides a phasing in design for the vehicle so that tyre contact would reduce from line contact to point contact across the nosing/bitumen interface.

5. Conclusions

In general, the tyre/joint noise increases as the age of the mechanical joint grows due to normal deterioration. According to the nondestructive measurement results in the present study, this general trend is also matched for joints with noise-reduction design on four studied bridges. It is found that the tyre/joint noise levels of new installed mechanical joints will first reach a certain level and then drop in the next 6 months right after joint installation works. Percentage of such drop in the tyre/joint noise is around the average range of 10–30% for the 4 studied bridges. After this tyre/joint noise reduction period, the noise level will then be increased steadily and linearly with the time line. It can be concluded that either joint replacement or standard maintenance works can be carried out to help reduce the tyre/joint noise level. In order to keep a bridge joint in good condition for traffic based on the measured noise level, regular joint replacement work must be conducted.

Acknowledgment

This research was supported by a research Grant (SRG 7002569) from the City University of Hong Kong.

References

[1] P. Park, S. El-Tawil, S.-Y. Park, and A. E. Naaman, “Behavior of bridge asphalt plug joints under thermal and traffic loads,” Journal of Bridge Engineering, vol. 15, no. 3, pp. 250–259, 2010.
[2] B. K. Bramel, C. W. Dolan, J. A. Puckett, and K. Ksaibati, “Asphalt plug joints: refined material tests and design guidelines,” Transportation Research Record, no. 1740, pp. 126–134, 2000.
[3] U. Sandberg, “Review and evaluation of the low-noise road surface programme for low-speed roads in Hong Kong,” Tech. Rep. Project No. AN 06-004, Hong Kong Environmental Protection Department, 2008.
[4] K. W. Wong, A. Y. T. Leung, R. Y. Y. Lee et al., “A new methodology of measuring tyre/joint noise in Hong Kong,” in Proceedings of the 4th Symposium on Environmental Vibration “Environment Vibrations, Prediction, Monitoring, Mitigation and Evaluation”, vol. 1, pp. 599–604, 2009.
[5] H. Shahnazari, M. A. Tutunchian, and M. Mashayekhi, “Application of soft computing for prediction of pavement condition index,” Journal of Transportation Engineering, vol. 138, no. 12, pp. 1495–1506, 2012.
[6] A. Moropoulou, N. P. Avdelidis, M. Koui, and K. Kakaras, “An application of thermography for detection of delaminations in airport pavements,” NDT and E International, vol. 34, no. 5, pp. 329–335, 2001.
[7] J. N. Karadelis, “Numerical model for the computation of concrete pavement moduli: a non-destructive testing and assessment method,” NDT and E International, vol. 33, no. 2, pp. 77–84, 2000.
[8] V. Vansauskas and M. Bogdevičius, “Investigation into the stability of driving an automobile on the road pavement with ruts,” *Transport*, vol. 24, no. 2, pp. 170–179, 2009.

[9] M. A. Ahammed and S. L. Tighe, “Pavement surface friction and noise: integration into the pavement management system,” *Canadian Journal of Civil Engineering*, vol. 37, no. 10, pp. 1331–1340, 2010.

[10] H. Bendtsen, E. Kohler, Q. Lu, and B. Rymer, “California-Denmark study on acoustic aging of road pavements,” *Transportation Research Record*, vol. 2158, pp. 122–128, 2010.

[11] A. García, A. T. Moreno, and M. A. Romero, “Development and validation of speed kidney, a new traffic-calming device,” *Transportation Research Record*, vol. 2223, pp. 43–53, 2011.

[12] P. R. Donavan and B. Rymer, “Effects of aging on tire-pavement noise generation for concrete pavements of different textures,” *Transportation Research Record*, vol. 2233, pp. 152–160, 2011.

[13] N. Murugan, M. Umamaheswari, S. I. Yimal, and P. Sivashanmugam, “Experimental investigation on power output in aged wind turbines,” *Advances in Mechanical Engineering*, vol. 2012, Article ID 380986, 7 pages, 2012.

[14] Z. Kamaitis, “Deterioration of bridge deck roadway members part I: site investigations,” *The Baltic Journal of Road and Bridge Engineering*, vol. 1, no. 4, pp. 177–184, 2006.

[15] P. Park, S. El-Tawil, and S.-Y. Park, “Improved geometric design of bridge asphalt plug joints,” *Journal of Bridge Engineering*, vol. 16, no. 1, pp. 158–165, 2011.

[16] EPD, *Environment Hong Kong 2000 Resource Materials*, 2000.

[17] Highways Department, *Hong Kong: The Facts*, The HKSAR, 2010.

[18] TfL, *Inspection Guidance for Bridge Expansion Joints Part 1—Reference Guide*, Transport for London, Surface Transport, 2011.

[19] J. A. Prozzi, *Modeling pavement performance by combining field and experimental data [Ph.D. thesis]*, University of California, Berkeley, Calif, USA, 2001.