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Life-Cycle Performance of a Bridge Subjected to Multiple Heavy Vehicle Impacts Maizuar Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia Department of Civil Engineering, University of Malikussaleh, Aceh, Indonesia Lihai Zhang Department of Infrastructure

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Engineering, The University of Melbourne, Melbourne, Australia Russell Thompson Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia Herman Fithra Department of Civil Engineering, University of Malikussaleh, Aceh, Indonesia Abstract Purpose � The purpose of this study is to develop a numerical framework to predict the time-dependent probability of failure of a bridge subjected to multiple vehicle impacts.

Specially, this study focuses on investigating the inter-relationship between changes in life-cycle parameters (e.g., damage size caused by v eh icl e i mp a ct , l o ss of i n i ti a l st r uc tu r a l c ap a ci t y , a n d t h r esh o ld in t er v en t i on) a n d b r id g es p r o b ab i l i t y of f ai lure. Design/Methodology/Approach � The numerical procedure using MATLAB program is developed to compute the probability failure of a bridge.

First, the importance and characteristics of life-cycle analysis is described. Then, model for damage accumulation and life cycle as a result of heavy vehicle impacts is discussed. Finally, the probability of failure of a bridge subjected to vehicle impacts as a result of change in life-cycle parameters is presented. Findings � The results of study show that damage size caused by both vehicle impacts and loss of initial structural capacity have a great impact on the long-term safety of bridges. In addition, the probability of failure of a bridge under different threshold limits indicates that the structural intervention (e.g.,

repair or maintenance) should be undertaken to extend the service life of a bridge. The ? rst author wishes to acknowledge Indonesian Endowment Fund for Education for the support. � Maizuar, Lihai Zhang, Russell Thompson, Herman Fithra. Published in the Emerald Reach Proceedings Series. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence.

Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode Life-Cycle Performance 13 Emerald Reach Proceedings Series Vol. 1 pp. 13 �18 E me ral d P ubli shi ng Li mi t ed 2516-2853 D OI 1 0. 110 8/ 9 78- 1- 78 75 6- 79 3- 1 - 00 003 Research Limitations/Implications � The damage sizes caused by heavy vehicle impacts are based on simple assumptions.

It is suggested that there would be a further study to estimate the magnitude of bridge damage as a result of vehicle impact using the full-scale impact test or computational simulation. Practical Implications � This will allow much better predictions for residual life of bridges which could potentially be used to support decisions on health and maintenance of bridges.

Originality/Value � The life-cycle performance for assessing the time-dependent probability of failure of bridges subjected to multiple vehicle impact has not been fully discussed so far. Keywords Life-cycle, vehicle impact, structural deterioration, bridge All papers within this proceedings volume have been peer reviewed by the scienti ? c committee of the Malikussaleh International Conference on Multidisciplinary Studies (MICoMS 2017). 1.

Introduction Bridges are critical transportation infrastructure networks and often are subjected to heavy traf?c

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loads, harsh environments, and accidental damage (Deco and Frangopol, 2013; Frangopol and Soliman, 2016). For example, some catastrophic failure of bridges occurs because of collision accidents between bridges and heavy vehicles (e.g., over 30 tons). As seen in Maitland Pedestrian Bridge, Australia, in 2009, the collision accident between a bridge and medium truck collapsed the bridge, four persons were injured, and the road was closed for four days (Greg, 2009).

The risk of damage caused by vehicle impacts can be more vulnerable for ageing bridges with an increased traf?c loading. Thus, the permanent degradation and frequent vehicle collision with bridge damage highlighted the importance of safety bridges and traf?c system in metropolitan areas. Life-cycle performance of a structure is directly affected by different deterioration mechanisms such as sudden damaging extreme events, progressive deterioration, or combination of both (Melchers et al., 2008; Iervolino et al., 2013).

Vehicle collision with bridge can be described as an extreme event that occur randomly in time and cause sudden damage to bridge structure (e.g., bridge pier). Therefore, the life-cycle performance of a bridge caused by heavy vehicle impacts can be modeled as shock degradation. In recent decades, extensive research has been performed to develop an analytical model for shock degradation (Nakagawa, 1976, 1985; Feldman, 1977; Barlow and Proschan, 1996). However, the majority of shock-based degradation and failure models developed mainly focus on earthquakes.

Such application related to earthquake damage of structures can be found in the study of Rackwitz et al. (2005) and S�nchez-Silva and Rackwitz (2004). In addition, the combined effect of multiple deterioration mechanisms on structures (e.g., shock and progressive deterioration) has also been investigated (Yang and Klutke, 2000; Sanchez- Silva et al., 2011). However, highway bridges could also be subjected to accidental heavy vehicle impacts and their effects on damage accumulation have not been fully discussed in the literature so far.

The purpose of this study is to develop a numerical framework to predict the time-dependent probability of failure of a bridge subjected to multiple vehicle impacts. 1.1. Life-cycle performance of a bridge subjected to vehicle impacts The performance of a bridge system or a component throughout its lifetime subjected to multiple vehicle impacts can be represented by a general life-cycle model as shown in Figure 1.

In a life-cycle model, the performance of a system is usually quanti?ed in terms of structural capacity (e.g., material resistance and drift). The structural lifetime is de?ned as the length of time required by a structure to reach a prede?ned performance threshold values (e.g., k* and s*). As shown in Figure 1, the threshold k* represents the minimum Proceedings of MICoMS 2017 14 structural performance level while the threshold s* denotes the ultimate structural capacity which refers to structural collapse.

In this study, the damage accumulation caused by heavy vehicle impacts and their occurrences was assumed to occur randomly over time with each truck impact resulting in a random reduction in structural capacity. Therefore, the structural damage of a bridge can be modeled using marked point process. Let us consider a structural system with an initial capacity V 0 as shown in Figure 1. If the shock size � Y v i � and the time interval between shocks X � D t v i are random variables, then the remaining capacity of the component at a particular time V v (t) can be computed as V v � t ☐ V 0 D v � t � s (1) where s* is the limit state design requirement of the bridge and D v (t) is the accumulated deterioration as a result of N heavy truck impacts given by D v �t ☐ X N i �0 Y v i (2) Then, the remaining structural capacity V v � t � can be rewritten as V v � t ☐ V 0 X N i � 0 Y v i s (3) If distribution of G v (y) describes the probability of the bridge reaching a certain damage level as a result of vehicle impacts, then the probability of failure at a given time P v � t � is given by P v � t 1 ☐ � V v �t � 0 G v �y � dy (4) Assuming that the inter-arrival time of shocks t v i and their sizes Y v i are independent and identically distributed (iid) as well as exponentially distributed, a numerical procedure using Figure 1.

Life-Cycle Model of a Structure Subjected to Shock Events (e.g., Vehicle Impacts) Life-Cycle Performance 15 MATLAB program was developed and the average values of the bridge probability of failure were computed after 100 simulations. 2. Case study The Montague Street Bridge located in South Melbourne, Australia, was used as a case study. This railway bridge has a length of 70 m and width of 7.5 m. Information on vehicle collision with bridges in Melbourne Australia was based on �Crash Stats Data� provided by Data Victoria.

Using exponential distribution, the inter-arrival heavy vehicle impacts was obtained statistically with the mean of 1.5 years. In this study, we assume the following: The initial structural capacity of the bridge V 0 is 100%. The threshold intervention s* (i.e., limit state) is 30%. The shock size (damage size) caused by a truck impact is exponentially distributed. The remaining structural capacity of the bridge V v � t � is exponentially distributed with a mean of 0.05.

Each vehicle impact on bridge is assumed to be statistically independent. 3. Results and discussion The effect of three different mean damage sizes of the bridge caused by heavy vehicle impacts � Y v i � (i.e., 2%, 3%, and 5%) on probability of failure of a bridge is shown in Figure 2. The results show that the increase in damage size caused by heavy vehicle impacts signi?cantly increases the probability of failure and led to the decrease in the remaining service life of the bridge.

Further, compared to the damage size of 2%, the damage sizes of 3% and 5% could result in around 32% and 50% reduction in residual life of a bridge, respectively. As deterioration increases, the structural capacity of a structure decreases. Figure 3 compares the probability of failure of the bridge under different initial structural capacities u 0 (i.e., 95%, 90%, and 85%). The results show that the loss of initial structural capacity could generally lead to the signi?cant decrease of the probability of failure of the bridge.

Figure 2. Probability of Failure of the Bridge under Different Damage Sizes Proceedings of MICoMS 2017 16 The threshold intervention s* describes the damage states of a bridge. Figure 4 shows the probability of failure of the bridge under different threshold intervention capacities (e.g., 2.5%, 10%, 30%, and 60%). The simulation results in Figure 4 show that the probability of failure of the bridge is larger for minor damage states and smaller for severe damages. 4.

Conclusion A life-cycle performance of a bridge subjected to multiple heavy vehicle impacts is presented. In particular, this study develops a numerical procedure for assessing the probability of failure of a bridge when both inter-arrival time of impacts and their sizes are random. First, the importance and characteristics of life cycle analysis is described. Then, model for damage accumulation and life cycle as a result of heavy vehicle impacts is Figure 3.

Probability of Failure of the Bridge Under Different Initial Structural Capacities Figure 4. Probability of Failure of the Bridge under Different Damage States Life-Cycle Performance 17 discussed. Finally, the probability of failure of a bridge subjected to vehicle impacts as a result of change in life-cycle parameters (e.g., damage size caused by vehicle impact and loss of initial structural capacity and threshold intervention) is presented.

The outcomes of the study show that damage size caused by both vehicle impacts and loss of initial structural capacity has a signi?cant effect on the residual life of bridges. In addition, the probability of failure of a bridge under different threshold limits is useful for making decisions related to structural maintenance or repair in the future. References Barlow, R.E. and Proschan, F. (1996).

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Probability in the Engineering and Informational Sciences, Vol. 14, No. 4, pp. 445� 460. Corresponding author Maizuar can be contacted at maizuar@unimal.ac.id Proceedings of MICoMS 2017 18