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Sensitivity Study On the Effect of Intermittent Expansion Joints on the Design of TL-5 Single-Slope Concrete Barrier-Deck Overhang System

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Abstract - This sensitivity study investigates the effect of intermittent construction joints on the moments, shear, and tensile forces on the barrier wall and deck slab overhang in slab-on-girder bridges due to transverse vehicle impact loads. This study used the three-dimensional finite-element modeling of a 30 m long, TL-5, single-slope concrete barrier mounted over a 1 m length deck overhang. Spacing between intermittent expansion joints was taken at 3, 4, 5, and 6 m compared to the continuous barrier wall that equals the overhang length in the direction of traffic. The results from this research are pivotal in formulating robust empirical design equations in the future, marking a significant advancement in engineering practices for reliable bridge design. Results show that intermittent expansion joints, with spacings from 3 to 6 meters, cause an increase in the transverse moment at the inner side of the barrier wall for interior loads. However, the presence of these joints does not significantly alter the shear force at the barrier base or the tensile force at the inner side of the barrier wall, indicating that the primary impact of expansion joints is on the moment rather than shear or tensile forces. At the barrier end location, the presence of intermittent expansion joints over 3 m to 6 m spacings has an insignificant effect on the transverse moment and tensile force in the deck overhang at the inner side of the barrier wall (except for the 3 m spacing) and the shear force at the barrier base at the barrier end due to transverse vehicle impact load.

Keywords: Bridge barrier, deck overhang, finite element model, construction joint, bridge analysis.

1. Introduction

In slab-on-girder bridges, shown in Fig. 1, the deck slab serves as a critical component that not only offers foundational support and transfers the dynamic loads to the primary load-bearing elements, such as the girders, but also gives a smooth riding surface for vehicular traffic. The deck slabs in such structures are oriented transversely, perpendicular to the direction of vehicular movement. Extending beyond the exterior girders, these slabs form overhangs that support barrier walls and contribute additional width to the bridge cross-section, thereby accommodating the necessary number of travel lanes and traffic shoulders. The traffic loads to design the deck slab overhang are specified in the Canadian Highway Bridge Design Code, CHBDC [1]. It includes transverse, vertical and longitudinal line loads resulting from vehicle impact to the barrier wall. The transverse load is shown to be the critical load to be used to determine the moment and tensile force to design the deck overhang [2].

CHBDC and AASHTO LRFD Bridge Design Specifications [3] mandate that the design of the deck slab overhang should account for distinct design scenarios: (i) the transverse and longitudinal forces arising from a vehicle's collision with the barrier and (ii) the vertical forces generated as a consequence of such a vehicular impact with the barrier. In their pivotal study, Azimi et al. [3] and Shaji et al. [4] conducted a thorough analysis of the deck slab overhang-barrier system to determine the factored transverse moment and the associated tensile forces required for the design of deck overhang when the barrier wall is subjected to transverse vehicle impact forces (F_t) at interior and end locations as depicted in Fig. 2. The insights gleaned from their analysis facilitated the development of empirical formulas for determining the moment and tensile forces imparted by transverse vehicle impacts, significantly contributing to the body of knowledge on deck slab overhang design and safety. Rosenbaugh et al. [5] furthered this by delving into the mechanics of load distribution on deck sections during impacts, formulating an equation to approximate load length at critical sections, and underscoring the necessity of considering the spatial distribution of impact forces in structural design. In addition to these studies, specifications from US Departments of Transportation, such as those from California, Indiana, and Minnesota, recommend increases in the design moments and associated tensile forces in deck slab overhang by 20-33% to ensure that the deck overhang will not fail before the concrete barrier in vehicle collisions [6, 7, 8].

The common practice in barrier-deck overhang construction is that the barrier wall is continuous and equal to the length of the supporting deck overhang. However, a few bridge owners, such as the Texas Department of Transportation (DOT) and the Ministry of Transportation of Quebec (MTQ), use intermittent expansion joints over the length of the barrier wall to reduce shrinkage cracks. Figure 3 shows images of the intermittent construction joints in the barrier wall of constructed bridges. The paper investigates the effect of the intermittent construction joints on the applied moment and tensile force in the deck overhang and the moment and shear in the barrier wall resulting from transverse vehicle impact load. The three-dimensional finite element modeling was used to model the barrier-deck overhang system under transverse vehicle impact at interior and end locations. Results from this sensitivity study were discussed, followed by conclusions and recommendations for further research.

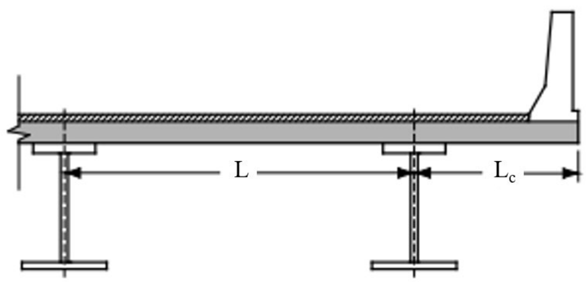


Fig. 1: Cross-section on slab-on-girder bridge showing the concrete barrier and deck overhang.

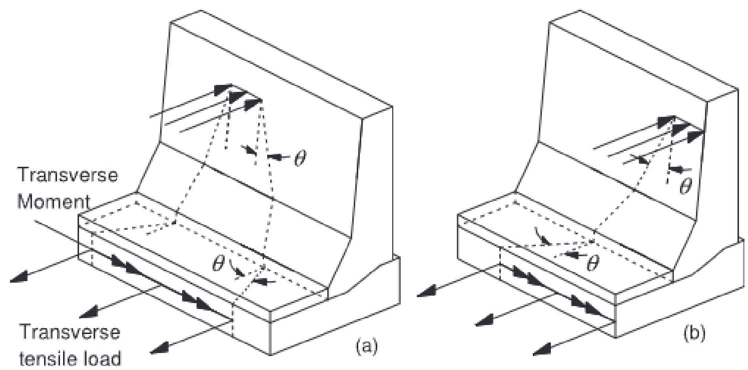


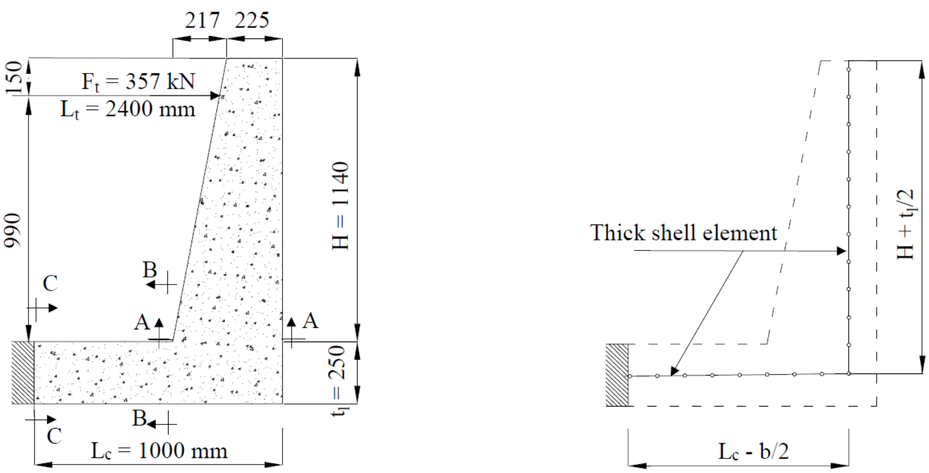
Fig. 2: Load dispersal of transverse load (a) internal portion and (b) end of barrier wall.

(a) (b)

Fig. 3: Views of the intermittent construction joints in the barrier wall of a constructed bridge.

2. Finite Element Modelling

Figure 4 shows the dimensioning of the TL-5 single-slope concrete barrier mounted over a deck slab overhang. The deck slab overhang was considered 1 m in this study, while the continuous barrier length was 30 m, which is the length of the deck overhang in the direction of traffic. This research used thick-shell elements in the SAP2000 software [9] to model the barrier and deck slab overhang, as depicted in Fig. 4. Figure 5 shows SAP2000 finite element modelling of the barrier-overhang system with transverse load at an interior location. The barrier wall was subjected to a transverse impact force, F_t, of 357 kN, distributed over a span of 2400 mm and at a height of 990 mm per CHBDC. Four different spacings of intermittent construction joints were considered in this study, namely 3, 4, 5, and 6 m. Intermittent expansion joints were introduced in the barrier wall at 6, 4, 5, and 3 m spacings by introducing a gap of 25 mm between the shell elements forming the barrier wall at each expansion joint. The transverse impact load locations were selected, as shown in in Fig. 6, for 6 m spacing of intermittent construction joints to obtain the most significant moment and tensile force for comparison. The transverse load was located at the end of the barrier wall, while for load at interior segments, six loading case locations were selected, as depicted in Figure 4. Some of these six loading locations included the center of the transverse vehicle impact load at the center and end of the interior barrier segments between construction joints and being centered at the construction joint. The first set of interior locations was selected at or close to the mid-length of the 30 m-long barrier-overhang system, see cases 1 through 3 in Fig. 6. On the other hand, the second set of interior locations was selected to be at the end segment of the barrier, as depicted in cases 4 through 6 in Fig. 6. Instead of obtaining results at a point, the maximum bending moments, tensile forces, and shear forces were obtained from the modeling using the "section cut" option in SAP2000 software to obtain average values within 1 m width at the maximum moment location. The only exception was the maximum horizontal moment in the barrier obtained at a point due to a large variation of their values over the 1140 mm barrier height.



a) Barrier geometry and applied loading b) Finite element model of barrier and overhang

Fig. 4. TL-5 single-slope barrier geometry, CHBDC traffic load, and the finite element model

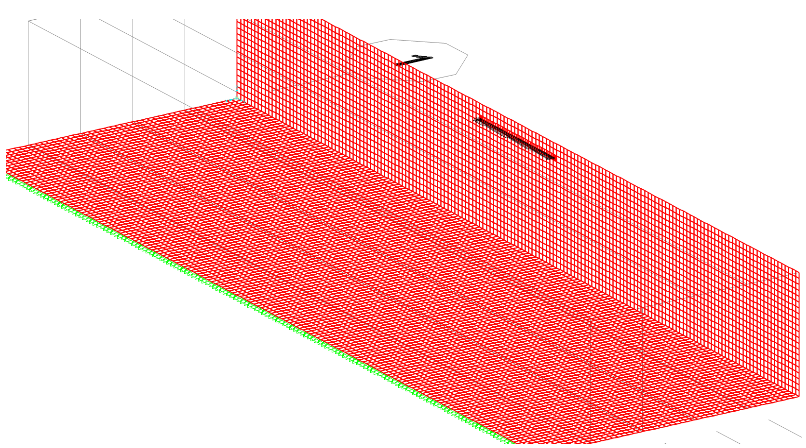


Fig. 5. Image of SAP2000 FEA modeling of barrier-overhang system with transverse load at interior location

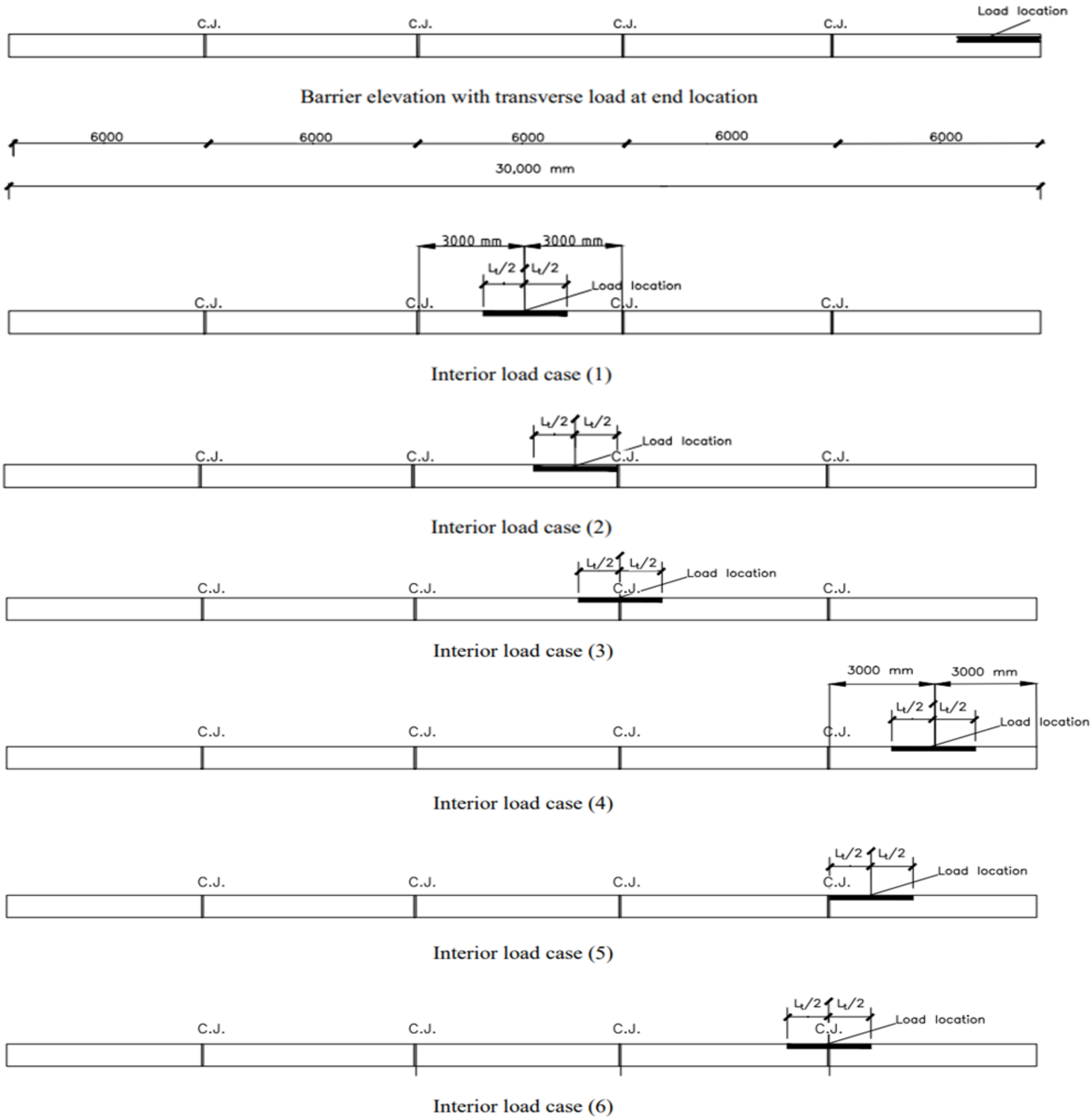


Fig. 6: Intermittent construction joints spaced at 6-meter intervals under CHBDC traffic load cases

3. Results and discussions

Results are presented in different sections A, B, and C, as shown in Fig. 4. The applied vertical moment and shear force force were obtained at section A for the base of the barrier wall. The applied transverse moment and tensile force in the deck deck overhang were obtained for sections B and C at the inner side of the barrier wall and the fixed end of the overhang, respectively. Table 1 summarizes the results at the end of the barrier wall due to transverse loading at the same location. One One may observe that the applied moments at the barrier base and in the overhang at the inner side of the barrier wall for construction joint spacings between 4 and 6 m have insignificant changes from the case of a continuous barrier. At the same time, it increases by 7% and 9.5%, respectively, for the case of 3 m spacing between the construction joints. Although the applied moment at the fixed end of the overhang increases with the decrease in construction joint spacing from 6 m to 3 m, its value is less than that at the inner side of the barrier wall, so it does not govern design. One may also observe that the shear force at the barrier base and tensile force in the deck overhang have insignificant changes with the presence of the construction joints, irrespective of the spacing between them, with differences of less than 3%.

Table 1: Applied moment, shear, and tensile force due to transverse vehicle loading at the end location of TL-5 single-slope barrier-deck system with a 1 m overhang length and different spacings of the intermittent expansion joints

Barrier type	Vertical moment at bottom of barrier (kN.m/m)	Overhang moment at inner side of barrier wall (kN.m/m)	Overhang moment at fixed end of barrier (kN.m/m)	Shear at bottom of barrier wall (kN/m)	Overhang tension force at barrier inner side, (kN/m)	Tension at fixed end of barrier (kN/m)	Max. horizontal moment in barrier (kN.m/m)
Continuous	100.5	94.4	81.8	141.4	148.9	148.8	13.9
L_b = 6 m	99.6	95.9	87.4	141.0	146.6	145.0	14.1
L_b = 5 m	99.4	96.6	89.4	140.6	146.0	144.6	14.0
L_b = 4 m	100.8	98.3	91.2	140.6	146.5	146.2	13.3
L_b = 3 m	107.8	103.4	92.9	144.9	152.8	152.7	11.2

Table 2: Applied moment, shear, and tensile force due to transverse vehicle loading at interior locations of TL-5 single-slope barrier-deck system with a 1 m overhang length and intermittent expansion joints every 6 m length

Load location	Vertical moment at bottom of barrier wall, (kN.m/m)	Overhang moment at inner side of barrier wall, (kN.m/m)	Overhang moment at fixed end of barrier wall, (kN.m/m)	Shear at bottom of barrier wall, (kN/m)	Overhang tension force at inner side of barrier, (kN/m)	Tension at fixed end of barrier, (kN/m)	Max. horizontal moment in barrier wall (kN.m/m)
Cont.* (case 1)	77.0	59.4	35.3	132.9	146.5	152.2	19.6
Cont.* (case 2)	74.1	58.2	35.8	124.6	137.3	143.3	19.7
Cont.* (case 3)	77.0	59.4	35.3	132.9	146.5	152.2	19.6
Cont.* (case 4)	82.1	68.4	48.1	132.9	144.4	148.1	18.3
Cont.* (case 5)	75.0	60.5	39.7	123.8	135.5	140.5	19.5
Cont.* (case 6)	77.4	60.3	36.9	132.8	145.9	150.9	19.3
Int.** (case 1)	79.5	62.1	37.3	132.7	146.5	152.6	18.8
Int.** (case 2)	75.8	65.3	40.6	126.4	135.8	140.0	16.4
Int.** (case 3)	70.3	61.8	54.8	140.8	160.4	157.2	16.0
Int.** (case 4)	83.2	69.9	50.0	132.8	144.2	148.2	17.9
Int.** (case 5)	77.2	67.4	43.2	126.5	135.6	139.5	16.0
Int.** (case 6)	70.7	62.3	55.2	140.8	160.0	156.6	15.9

* Cont.: Continuous barrier with interior loading cases shown in Fig. 5.

** Int.: Intermittent construction joints at 6 m spacing in barrier with interior loading cases shown in Fig. 5.

Table 3: Applied moment, shear, and tensile force due to transverse vehicle loading at interior locations of TL-5 single-slope barrier-deck system with a 1 m overhang length and different spacings of the intermittent expansion joints

Intermittent barrier length, L_b (m)	Load location	TL-5 single-slope barrier: L_c = 1 m						
		Vertical moment at bottom of barrier wall, (kN.m/m)	Overhang moment at inner side of barrier wall, (kN.m/m)	Overhang moment at fixed end of barrier wall, (kN.m/m)	Shear at bottom of barrier wall, (kN/m)	Overhang tension force at inner side of barrier, (kN/m)	Tension at fixed end of barrier, (kN/m)	Max. horizontal moment in barrier wall (kN.m/m)
L_b = 6 m	(case 1)	79.5	62.1	37.3	132.7	146.5	152.6	18.8
	(case 2)	75.8	65.3	40.6	126.4	135.8	140.0	16.4
	(case 3)	70.3	61.8	54.8	140.8	160.4	157.2	16.0
	(case 4)	83.2	69.9	50.0	132.8	144.2	148.2	17.9
	(case 5)	77.2	67.4	43.2	126.5	135.6	139.5	16.0
	(case 6)	70.7	62.3	55.2	140.8	160.0	156.6	15.9
L_b = 5 m	(case 1)	82.0	64.2	38.2	133.5	147.1	152.7	18.2
	(case 2)	82.9	65.9	41.2	126.4	135.6	139.8	16.3
	(case 3)	69.5	62.0	57.0	140.6	160.1	156.3	16.1
	(case 4)	86.9	75.4	56.8	133.9	144.9	148.6	16.9
	(case 5)	85.9	70.8	47.8	126.5	135.3	138.8	15.5
	(case 6)	70.6	63.2	57.8	140.5	159.3	155.3	15.7
L_b = 4 m	(case 1)	89.6	68.3	40.9	138.7	143.4	150.9	15.9
	(case 2)	84.9	67.6	42.2	127.1	136.2	140.1	15.8
	(case 3)	68.7	62.5	59.6	140.1	160.0	156.2	16.1
	(case 4)	93.4	84.0	67.0	137.5	148.2	150.6	15.5
	(case 5)	89.6	78.1	58.8	125.6	134.2	137.7	14.3
	(case 6)	71.4	65.4	61.5	139.9	158.2	154.0	15.2
L_b = 3 m	(case 1)	94.0	73.4	45.6	141.0	148.2	149.2	13.7
	(case 2)	92.7	72.7	45.7	136.4	143.1	144.2	14.0
	(case 3)	69.4	64.1	62.2	139.0	160.4	157.7	15.6
	(case 4)	106.1	97.6	82.2	145.1	154.1	153.1	12.7
	(case 5)	98.2	94.8	85.5	131.2	138.9	135.6	12.5
	(case 6)	75.2	70.7	67.8	138.7	156.6	153.6	13.8

Table 2 summarizes the results due to transverse loading at different locations noted in cases 1 through 6 in Fig. 6 for the case on continuous barrier and the case of 6 m spacing between construction joints. While Table 3 summarizes similar results for each of the joint spacings. One may observe that loading cases 1, 2, and 3 were close to the mid-length of the 30 m-long barrier, while loading cases 4, 5, and 6 were close to the end of the barrier. It can be observed that for both the continuous and intermittent barriers, the applied moment at the barrier base and an overhang at the interior segment increases when the applied load is close to the end of the barrier, as depicted in the results of case 4 compared to cases 1, 2, and 3.

It can be observed that the maximum vertical moment at the barrier base increases by 1.3%, 5.8%, 13.8%, and 29.2% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier. Also, the maximum transverse moment at the inner side of the barrier wall increases by 2.1%, 10.2%, 22.8%, and 42.7% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier. The results in Tables 2 and 3 show that the maximum shear force at the barrier base increases by 5.9%, 5.8%, 5.4%, and 9.1% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier. Also, the maximum tensile force at the inner side of the barrier wall increases by 9.4%, 9.2%, 9.2%, and 9.4% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier.

4. Conclusions

A sensitivity study investigated the effect of intermittent construction joints on the moments, shear, and tensile forces on the barrier wall and deck slab overhang in slab-on-girder bridges due to transverse vehicle impact loads. Based on the results from this study, the following conclusions were drawn.

1. For both the continuous and intermittent barriers, the applied moment at the barrier base and overhang at the interior segment increases when the applied load is close to the end of the barrier, as depicted in the results of case 4 compared to cases 1, 2, and 3.
2. The maximum vertical moment at the barrier base at the interior location increases by 1.3%, 5.8%, 13.8%, and 29.2% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier. Also, the maximum transverse moment on the inner side of the barrier wall increases by 2.1%, 10.2%, 22.8%, and 42.7% for joint spacings of 6, 5, 4, and 3 m, respectively, when compared to the continuous barrier.
3. The maximum shear force at the barrier base at the interior location increases by 5.9%, 5.8%, 5.4%, and 9.1% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier. Also, the maximum tensile force at the inner side of the barrier wall increases by 9.4%, 9.2%, 9.2%, and 9.4% for joint spacings of 6, 5, 4, and 3 m, respectively, compared to the continuous barrier.
4. For transverse vehicle impact load at the end location, intermittent expansion joints over 3 m to 6 m spacings have an insignificant effect on the shear force at the barrier base and tensile force in the deck overhang at the inner side of the barrier wall. Also, the applied moments at the barrier base and in the overhang at the inner side of the barrier wall for construction joint spacings between 4 and 6 m have insignificant change from the case of a continuous barrier. At the same time, it increases by 7% and 9.5%, respectively, for the case of 3 m spacing between the construction joints. Although the applied moment at the fixed end of the overhang increases with the decrease in construction joint spacing from 6 m to 3 m, its value is less than that at the inner side of the barrier wall, so it does not govern design.
5. For transverse vehicle impact load at the end location, the shear force at the barrier base and tensile force in the deck overhang have insignificant changes with the presence of the construction joints, irrespective of the spacing between them, with differences of less than 3%.

References

[1] CSA. (2019). Canadian Highway Bridge Design Code (CHBDC), CAN/CSA-S6:19. Canadian Standard Association, Toronto, Ontario, Canada.
[2] Azimi, H., Sennah, K., Tropynina, E., Goremykin, S., Lucic, S., and Lam, M. (2014). Anchorage Capacity of Concrete Bridge Barriers Reinforced with GFRP Bars with Headed Ends. ASCE Journal of Bridge Engineering, 19(9): 1-15.
[3] AASHTO. (2020). AASHTO LRFD Bridge Design Specifications, 9th Edition. American Association of State Highway and Transportation Officials, Washington, D.C.
[4] Shaji, C. S. (2022). Investigation of live load moment and tension force in bridge deck slab overhang due to AASHTO truck loading and transverse vehicle impact (Master's thesis). Ryerson University, Toronto, Ontario, Canada.
[5] Rosenbaugh, S., Rasmussen, J., Faller, R. (2020) Development and Testing of a Test Level 4 Concrete Bridge Rail and Deck Overhang, Journal of Transportation Research Record, Lincoln, NE
[6] Caltrans. (2017). Memo to Designers 10-20: Deck and Soffit Slab. California Department of Transportation, Caltrans, California, USA, December 2017.
[7] INDOT. (2013). Indiana Design Manual. Indian Department of Transportation, INDOT, Indiana, USA.
[8] MnDOT. (2017). LRFD Bridge Design Manual. Minnesota Department of Transportation, MnDOT, Minnesota, USA.
[9] CSI. (2020). SAP2000 Software Integrated Finite Element Analysis and Design of Structures. Computers and Structures Inc., Berkeley, USA.