Temporary Construction Barrier Implementation in Ontario

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Executive Summary

Over recent years, several Temporary Steel Barrier systems have been successfully crash tested in accordance with the AASHTO Manual for Assessing Safety Hardware and have demonstrated equivalent and in some cases superior performance to Temporary Concrete Barriers which have been traditionally used in Ontario. Temporary Steel Barriers have gained acceptance in Europe, Australia and other areas of North America and the construction industry in Ontario indicated an interest in using them on Ontario highway construction projects.

In response to this interest and the demonstrated functional equivalence of temporary steel and concrete barriers, the Ministry of Transportation, Ontario (MTO) sought to standardize the use of temporary steel barrier, which required a major re-write of its temporary barrier specification, shifting to the concept of a Temporary Construction Barrier. The Temporary Construction Barrier concept groups both concrete and steel barriers into four categories, based on their Dynamic Deflection when impacted under MASH TL-3 testing, with a corresponding tender item. Contractors are able to select from all systems that qualify for a given tender item. Most steel barriers require pinning into asphalt, and some have been crash tested with different pin spacings, with more frequent pin spacing resulting in a lower dynamic deflection. For three steel barrier systems, standard drawings were created for multiple pin spacing options which correspond to different Temporary Construction Barrier items.

The transition to Temporary Construction Barrier has been well received by the construction industry in Ontario and provides contractors with more flexibility and options for innovation on sites where temporary barrier is required. An added benefit of linking the appropriate tender item with dynamic deflection is higher quality designs as designers are required to consider available space behind barrier to excavations or fixed objects for a staging configuration.

Introduction

Temporary construction barriers are typically used to separate highway traffic from construction sites. They serve two purposes. First, they provide protection to construction personnel who would otherwise be exposed to live traffic on a roadway. Section 67 of Ontario Regulation 213/91 under the provincial Occupational Health and Safety Act requires the placement of a barrier, which is defined as “a device that provides a physical limitation through which a vehicle would not normally pass, and includes a concrete barrier” [1] for a project that meets the following criteria [2]:

- Is on a freeway
- Is not a mobile operation
- Is expected to require more than five days to complete

Temporary barriers also provide an equally important function in protecting motorists from roadside hazards created as a result of a construction site. These hazards include features such as: excavations, bridge drop-offs, water hazards, construction equipment and partially finished highway features. Barriers are commonly placed on non-freeway highways in Ontario to provide protection to workers and motorists in construction zones.

Although barriers often have the effect of channelizing traffic, their primary purpose is not for delineation. There are several effective methods of providing delineation and channelizing traffic which are detailed in Ontario Traffic Manual (OTM) Book 7 [3]. Barriers should also never be placed perpendicularly across a roadway or driveway to prohibit vehicular access as this creates a hazard to motorists and allows for an opportunity for a vehicle to impact at a high angle, contrary to the manner in which barriers are crash tested. Again, OTM Book 7 provides measures for safely closing roadways and entrances using appropriate devices.

Crash Testing of Barrier Systems

Currently, MTO specifies temporary construction barriers that have been crash tested in full scale according to the National Cooperative Highway Research Program (NCHRP) Report 350 [4] or the American Association of State Highway Transportation Officials’ (AASHTO) Manual for Assessing Safety Hardware (MASH) [5]. Temporary construction barriers are required to have been crash tested according to Test Level 3. According to both manuals, a barrier crash tested to this test level must be able to contain and redirect a small car and pickup truck at 100 km/h and an impact angle of 25 degrees. This represents approximately the 98^{th} percentile severity of real-life collisions with barrier. The vehicle must be redirected in a manner that it does not become a hazard to

other traffic and must not overturn, penetrate, vault over or snag on the barrier, nor may the barrier penetrate the vehicle in any manner or crush the passenger compartment excessively. Forces generated during the impact must be within specified limits in order to mitigate driver injury. One important outcome of a crash test is dynamic deflection which is defined as the total lateral displacement of the system during an impact. It is important to provide room equal to or greater than the as-tested dynamic deflection behind a temporary barrier to allow it to deflect during an impact. Failure to do so may cause the barrier to snag, overturn or behave otherwise unpredictably which may expose a vehicle occupant to increased risk of injury or death.

It is recognized that temporary (and permanent) barrier systems will not be able to contain and redirect every errant vehicle. Some collisions are more severe in speed and impact angle than the crash testing allows for. Additionally, temporary barriers are not designed to contain a vehicle larger than a pickup truck, minivan or SUV. This is mitigated by the fact that larger vehicles are typically commercial vehicles, driven by professional drivers with specialized licensing requirements. Statistics indicate that these vehicles are involved in collisions at lower rates than passenger vehicles [6] and thus provision of higher performance barriers in construction zones would not be cost effective.

The AASHTO MASH was issued in 2009 and updated in 2016. The sizes and weights of the sedan and pickup truck were increased from NCHRP Report 350 to reflect an increase in size and weight of typical cars in the North American fleet. A full comparison of test level requirements between the two documents is provided in Tables 1 and 2 below:[4][5]

Test Level	Test Vehicle Designation and Type			
		Vehicle Weight (kg)	Speed (km/h)	Angle (deg.)
1	820C (Passenger Car) 2,000P (Pickup Truck)	820 2,000	50 50	20 25
2	820C (Passenger Car) 2,000P (Pickup Truck)	820 2,000	70 70	20 25
3	820C (Passenger Car) 2,000P (Pickup Truck)	820 2,000	100 100	20 25
4	820C (Passenger Car) 2,000P (Pickup Truck) 8,000S (Single Unit Truck)	820 2,000 8,000	100 100 80	20 25 15
5	820C (Passenger Car) 2,000P (Pickup Truck) 36,000V (Tractor-Van Trailer)	820 2,000 36,000	100 100 80	20 25 15
6	820C (Passenger Car) 2,000P (Pickup Truck) 36,000T (Tractor-Tank Trailer)	820 2,000 36,000	100 100 80	20 25 15

Table 1: NCHRP Report 350 Test Level Matrix for Barrier Systems

Test Level	Test Vehicle Designation and Type			
		Vehicle Weight (kg)	Speed (km/h)	Angle (deg.)
1	1100C (Passenger Car) 2,270P (Pickup Truck)	1,100 2,270	50 50	25 25
2	1100C (Passenger Car) 2,270P (Pickup Truck)	1,100 2,270	70 70	25 25
3	1100C (Passenger Car) 2,270P (Pickup Truck)	1,100 2,270	100 100	25 25
4	1100C (Passenger Car) 2,270P (Pickup Truck) 10,000S (Single Unit Truck)	1,100 2,270 10,000	100 100 80	25 25 15
5	1100C (Passenger Car) 2,270P (Pickup Truck) 36,000V (Tractor-Van Trailer)	1,100 2,270 36,000	100 100 80	25 25 15
6	1100C (Passenger Car) 2,270P (Pickup Truck) 36,000T (Tractor-Tank Trailer)	1,100 2,270 36,000	100 100 80	25 25 15

Table 2: MASH Test Matrix for Barrier Systems

It is important that temporary construction barriers are constructed in the field in a manner that allows for errant vehicles to impact in a manner similar to the crash testing configuration. Essentially this requires barriers to be placed parallel to traffic with flaring being done at as shallow a rate as possible. The ministry achieves these standardized layouts through its designer guidance and standard layout drawing which contractors are required to adhere to.

Previous Temporary Concrete Barrier Specification System

As of the start of 2019, the Ministry of Transportation, Ontario had specified Temporary Concrete Barrier systems on its construction projects. A single generic tender item was provided in a contract for a barrier. The construction specification, Ontario Provincial Standard Specification 741, allowed for a contractor to select from four different systems:

-Type M barrier, a non-proprietary system developed at the Midwest Roadside Safety Facility in Nebraska. The system was crash tested in accordance with MASH TL-3 [7].

-Type T barrier, a proprietary system developed by Rockingham Precast of Harrisonburg Virginia. This system was crash tested in accordance with NCHRP Report 350 TL-3 and subsequently with MASH TL-3 with no modifications [8].

-Type J barrier, a proprietary system developed by Easi-Set Worldwide of Midland Virginia [9].

Figure 1 depicts a typical Type M temporary concrete barrier.

Figure 1: Type M Temporary Concrete Barrier (MTO File Photo)

Proprietary barrier systems are manufactured in Ontario through licensing agreements with the patent holders. Non-proprietary systems may be manufactured by any pre-casting facility according to the ministry's specifications. The MTO requires pre-casting facility which manufactures temporary concrete barriers to prequalify on the MTO's Designated Sources of Materials (DSM) list by submitting a Product Evaluation Report

demonstrating the ability of a plant's products to meet ministry requirements for material strength and durability as well as indicating an adequate quality control process. Plants that are listed on the DSM are assigned a unique plant identification code which is required to be displayed on the top of the barrier either embossed or using indelible ink. This allows an inspector to quickly confirm on site that a barrier unit originates from an approved plant.

An additional non-proprietary temporary concrete barrier system, the I-Lock, was also included in the Temporary Concrete Barrier construction specification. This barrier was a legacy system that had been permitted since the 1990's however it had not been crash tested in accordance with NCHRP Report 350 or AASHTO MASH and would likely not have passed a TL-3 test according to either criteria. In 2013 the construction specification was modified to restrict the use of I-Lock barrier to highways with posted speeds of less than 70 km/h in order to limit its exposure to high speed traffic while at the same time allowing the construction industry to make use of its remaining stock of this type of barrier. This system was removed from the construction specification in 2019 with the transition to Temporary Construction Barrier.

In constrained work zones where limited space was available, modified Type M temporary concrete barrier has been crash tested with various restraint systems [10][11]. These systems include the following:

-Pinned through holes in the barrier through asphalt pavement

-Strapped using steel straps and anchors located at the pin-and-loop connection between barriers to concrete pavement or bridge deck. An alternate configuration is also available for strapping to a bridge deck through waterproofing and asphalt pavement

-Bolted through bridge deck.

Figure 2 shows the restraint system for a Type M barrier strapped to a concrete surface. For these configurations, specific standard drawings are provided and minimum offsets to fixed objects as well as bridge drop-off or excavations are provided depending on dynamic deflection. Figure 3 depicts the standard drawing for a Type M temporary concrete barrier strapped to concrete indicating drop off to excavation and offset to fixed object such as scaffolding, roadway protection or sign support. Prior to May 2019 a Temporary Concrete Barrier Restraint System tender item was included which covered the costs of the restraint systems when these systems were required in addition to the Temporary Concrete Barrier tender item which covered only the cost of the barriers.

Figure 2: Type M Temporary Concrete Barrier Strapped to Concrete (MTO File Photo)

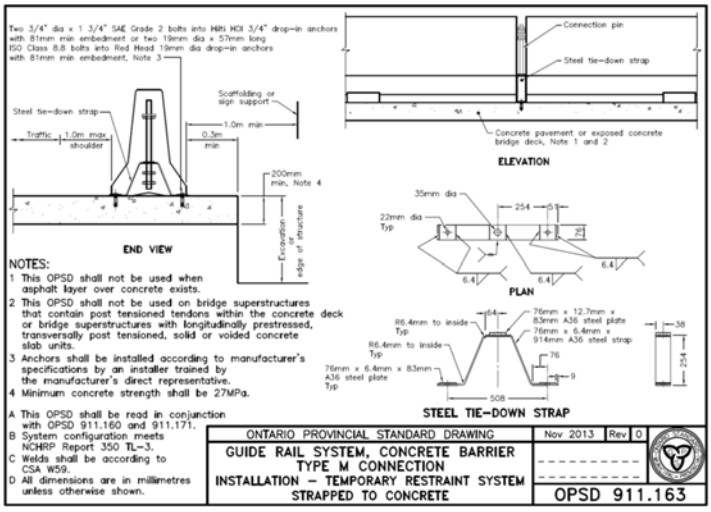


Figure 3: Standard Construction Drawing Type M Barrier Strapped to Concrete

An additional temporary concrete barrier was made available in 2016? called Type X. This system is the non-proprietary Texas DOT X-low deflection X-bolt barrier which was crash tested according to MASH TL-3 by the Texas Transportation Institution for the Texas Department of Transportation [12]. This barrier system has a significantly lower dynamic deflection value than other freestanding temporary concrete barriers and in addition was crash tested at an offset of 600mm from the rear of the barrier to the top of an excavation. Correspondingly a new tender item was created for this barrier called Temporary Concrete Barrier – Low Deflection.

Movable Temporary Concrete Barrier

A separate tender item called Movable Temporary Concrete Barrier exists and is specified where temporary concrete barrier is required in a construction zone and lane

closures are only permitted during off-peak times. This is most frequently the case on freeways in the Greater Toronto Area where all lanes must be kept open during rush hour. One system is currently available, the Quickchange Movable Barrier system. It has been crash tested according to NCHRP Report 350 TL-3 [13]. A specialized Barrier Transfer Machine is designed for this system and is able to shift the barrier back and forth to open and close a lane as required. This item was kept as it was with the change to Temporary Construction Barrier as it serves a niche purpose.

Catalyst for Change

In the years leading up to 2019 there was an increased interest on the part of Ontario's construction companies to supply and install temporary steel barrier systems. Several temporary steel barrier systems were crash tested according to MASH TL-3 in 2017 and 2018 and received FHWA funding eligibility letters. All currently available steel barrier systems are proprietary. Steel barrier systems which MTO has accepted for use on its highways include the following systems: [14][15][16][17][18]:

-Barrier Guard 800 manufactured by Laura Metaal (Netherlands)

-SafeZone manufactured by Laura Metaal (Netherlands)

-Defender manufactured by Safe Barriers (Australia)

-ZoneGuard manufactured by Hill and Smith (United States)

-HV2 manufactured by Safe Roads (Australia)

These barriers have been used extensively in Europe, Australia, New Zealand and some American states and Canadian provinces. Prior to 2019 MTO had permitted steel barriers on contracts via change orders at the contractor's request when appropriate in place of temporary concrete barrier that was specified. A temporary steel barrier system was also used on the Ambassador Bridge in Windsor / Detroit as part of a short-notice rehabilitation contract where weight restrictions prohibited the use of concrete barriers. Figure 4 shows a ZoneGuard temporary steel barrier system.

Figure 4: ZoneGuard Temporary Steel Barrier Installation [19]

Temporary steel barriers are functionally equivalent to concrete and have some advantages. They are significantly lighter than concrete barriers which allows for more length to be loaded on a truck. This allows for savings on shipping costs, particularly for remote sites. This also allows for more barrier to be stacked per unit area, potentially reducing storage requirements. They also provide some flexibility on bridges with load restrictions. Disadvantages include a higher initial cost (however this may be offset by longer lifespan than concrete barriers), as well as the fact that most barrier systems require anchorage to achieve dynamic deflections similar to several freestanding concrete systems.

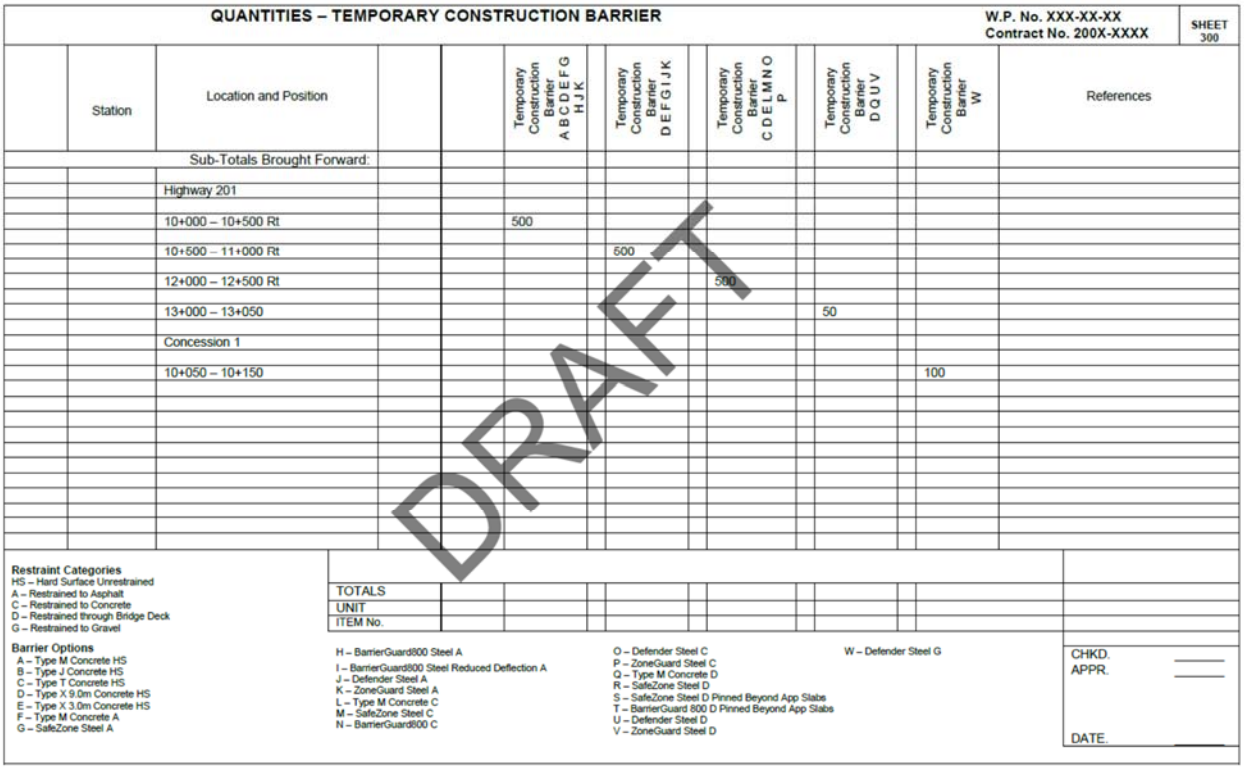
MTO supported the standardization of the use of temporary steel barriers and in 2018 examined possible ways to allow for their use at contractors' discretion in construction zones on Ontario highways.

New Temporary Construction Barrier Specification System

Early consensus was that the Temporary Concrete Barrier items would be converted to a more generic Temporary Construction Barrier item. Two potential methods of implementing this were developed and discussed internally.

The first possible solution involved the creation of a single Temporary Construction Barrier item, with an assignment of letter codes when implemented in a contract. Each barrier system would be assigned a unique letter code, corresponding to a legend that would be created in a standardized quantity sheet in a contract. The designer would be required to assign letter codes to a specific segment of Temporary Construction Barrier indicating which systems and variations would be acceptable based on available width, pavement structure and bridge attributes if applicable. This proposed system was based on the existing method of specifying allowable materials for non-structural culverts. A

sample proposed quantity sheet for a hypothetical contract using Temporary Construction Barrier is shown in Figure 5



QUANTITIES – TEMPORARY CONSTRUCTION BARRIER

W.P. No. XXX-XX-XX
Contract No. 200X-XXXX

SHEET 300

Station	Location and Position	Temporary Construction Barrier A B C D E F G H J K	Temporary Construction Barrier D E F G I J K	Temporary Construction Barrier C D E L M N O P	Temporary Construction Barrier D Q U V	Temporary Construction Barrier W	References
	Sub-Totals Brought Forward:						
	Highway 201						
	10+000 – 10+500 Rt	500					
	10+500 – 11+000 Rt		500				
	12+000 – 12+500 Rt			500			
	13+000 – 13+050				50		
	Concession 1						
	10+050 – 10+150					100	
	TOTALS						
	UNIT						
	ITEM No.						

DRAFT

Restraint Categories
HS – Hard Surface Unrestrained
A – Restrained to Asphalt
C – Restrained to Concrete
D – Restrained through Bridge Deck
G – Restrained to Gravel

Barrier Options
A – Type M Concrete HS
B – Type J Concrete HS
C – Type T Concrete HS
D – Type X 9.0m Concrete HS
E – Type X 3.0m Concrete HS
F – Type M Concrete A
G – SafeZone Steel A
H – BarrierGuard800 Steel A
I – BarrierGuard800 Steel Reduced Deflection A
J – Defender Steel A
K – ZoneGuard Steel A
L – Type M Concrete C
M – SafeZone Steel C
N – BarrierGuard800 C
O – Defender Steel C
P – ZoneGuard Steel C
Q – Type M Concrete D
R – SafeZone Steel D
S – SafeZone Steel D Pinned Beyond App Slabs
T – BarrierGuard 800 D Pinned Beyond App Slabs
U – Defender Steel D
V – ZoneGuard Steel D
W – Defender Steel G

CHKD. _____
APPR. _____
DATE. _____

Figure 5 – Proposed Temporary Construction Barrier Letter Codes Quantity Sheet

While this system provided the greatest level of control in specifying allowable barrier types, there were several challenges identified. One concern was the level of effort required to create a new quantity sheet template and the amount of effort to modify it whenever a new barrier system or variation were to be added. Another concern was that the use of a single tender item would make cost tracking difficult as the item cost would be only an average of the cost of all barriers.

The second proposed alternative which was ultimately accepted and implemented involved the creation of four new Temporary Construction Barrier items, categorized by rigidity or dynamic deflection. Individual barrier systems were assigned into categories based on their dynamic deflections as follows:

-Category I: > 1,500 mm dynamic deflection

-Category II: 1,000 mm to 1,500 mm dynamic deflection

-Category III: 500 mm to 999 mm dynamic deflection

-Category IV: < 500 mm dynamic deflection

This system addresses the shortcomings of the alternative described above in that the creation of 4 items allows for their immediate implementation in the existing MTO Contract Preparation System where quantity sheets are generated, using existing formatting. Barrier categories are specified in the construction specification, MTO Special Provision 741S03, according to Table 3 below. Sone steel barrier systems have been crash tested with various spacings of restraint systems. As such, where applicable these variations are listed as separate systems and each has a corresponding standard construction drawing for installation.

Type	System	Hard Surface, Unrestrained	HMA, Restrained	Concrete, Restrained	Bolted to Bridge Deck	Gravel, Restrained
Temporary Concrete Barrier	Type M	II	III	III	IV	-
	Type J	I	-	-	-	-
	Type T	II	-	-	-	-
	Type QMB	II	-	-	-	-
	Type X, 9.0m	III	-	-	-	-
	Type X, 6.0m	III	-	-	-	-
	Type X, 3.0m	III	-	-	-	-
Temporary Steel Barrier	ZoneGuard	I	-	-	-	-
	ZoneGuard MDS	-	IV	IV	IV	-
	BarrierGuard 800	I	-	-	-	-
	BarrierGuard800 LDS	-	III	III	III	-
	BarrierGuard800 MDS	-	IV	IV	IV	-
	SafeZone	I	-	-	-	-
	SafeZone LDS	-	III	III	III	-
	Defender LDS	-	III	III	IV	I
	HV2	I	-	-	-	-

Table 3: Temporary Construction Barrier Deflection Categories

Updating the construction specification as new systems are added requires significantly less effort than updating a quantity sheet template. Cost tracking is much easier with this system as higher performance barriers corresponding to lower deflection categories are more expensive to install. This is expected to be reflected in the unit costs for each

category which will allow for more accurate estimation. At the time of preparation of this paper there is insufficient costing information to completely corroborate this assumption due to the limited amount of time these items have been in effect. An example of a quantity sheet using to the “deflection categories” system for the same hypothetical contract using Temporary Construction Barrier as was shown in Figure 5 is shown in Figure 6

QUANTITIES – TEMPORARY CONSTRUCTION BARRIER

W.P. No. XXX-XX-XX
Contract No. 200X-XXXX

SHEET 300

Station	Location and Position	Temporary Construction Barrier – Category I	Temporary Construction Barrier – Category III	Temporary Construction Barrier – Category II	Temporary Construction Barrier – Category III	Temporary Construction Barrier – Category I	References
	Sub-Totals Brought Forward:						
	Highway 201						
	10+000 – 10+500 Rt	500					
	10+500 – 11+000 Rt		500				
	12+000 – 12+500 Rt			500			
	13+000 – 13+050				50		
	Concession 1						
	10+050 – 10+150					100	
	TOTALS						
	UNIT						
	ITEM No.						

CHKD.
APPR.

DATE.

Figure 6: Hypothetical Temporary Construction Barrier Deflection Categories Quantity Sheet

The Contract Design, Estimation and Detailing guide was updated to provide designers with guidance on how to specify the correct item in a contract. Most importantly, designers are required to be aware of the amount of available space that will be present behind a temporary construction barrier as this is the primary element that informs the selection of the appropriate item. Designers are instructed to assume a base width of 600 mm for a temporary barrier as most barriers have a base width equal or close to 600 mm.

Implementation, Feedback and Lessons Learned

Consultation with the consulting and construction industry was conducted in early 2019 leading up to the implementation of the new Temporary Construction Barrier system. Industry was supportive of the direction taken by the ministry.

In early May 2019, two videoconference information sessions were hosted by Design and Contract Standards Office for designers and project managers in the regional offices to provide a background on temporary steel barriers, alert staff to the pending transition and provide guidance on how to use the new tender items as well as answer questions. After the implementation of the Temporary Construction Barrier items on May 9, 2019 several questions were received from staff who were unable to attend one of the sessions or were simply unsure how to proceed however no significant issues were encountered.

The most significant challenge identified with the Temporary Construction Barrier system as implemented has been cases where designers wish to restrict the available barrier systems to non-restrained ones, mainly on bridge decks. Currently designers are instructed to modify the table shown in Table 3 to remove all restrained systems or variations corresponding to the Temporary Construction Barrier item specified. This is not considered a desirable long-term solution however and options are currently being considered to rectify this. One potential solution may be to provide an additional set of items which do not allow for restraints however internal conversations are ongoing.

Conclusion

The addition of temporary steel barriers for use on Ontario highway construction projects provides contractors with more flexible options and makes the market more competitive, providing value for taxpayers and the motoring public. The conversion from specifying Temporary Concrete Barrier to Temporary Construction Barrier allows for the standardized use of temporary steel barriers in Ontario in parallel with temporary concrete barriers which remain an important component of work zone protection.

References

1. O Reg 213/91, s 67(1)
2. O Reg 213/91, s 67(7)
3. Ministry of Transportation, Ontario Highway Standards Branch (2014). *Ontario Traffic Manual Book 7, Temporary Conditions*. St Catharines
4. Ross, H. E. Jr, Sicking, D., Zimmer, R. A., Michie, J. D. (1993). *National Cooperative Highway Research Program Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Washington DC, National Academy Press
5. American Association of State Highway Transportation Officials (2016). *Manual for Assessing Safety Hardware*. AASHTO.
6. Ministry of Transportation Ontario, Road Safety Research Office (2016). *Ontario Road Safety Annual Report*. Retrieved from http://www.mto.gov.on.ca/english/publications/pdfs/ontario-road-safety-annual-report-2016.pdf
7. Federal Highway Administration (2011), *Eligibility Letter B-215: Free Standing F-Shape Temporary Concrete Barrier System*, Washington DC
8. Federal Highway Administration (2009), *Eligibility Letter B-42B: 12-Foot T-LOC F-Shape Portable Concrete Barrier*, Washington DC
9. Federal Highway Administration (2018), *Eligibility Letter B-307: 12" J-J Hooks Freestanding 19-8 114ft barrier*. Washington DC
10. Bielenburg, R. W., Asselin, N. M., Faller, R. K. (2019). *MASH TL-3 Evaluation of Concrete and Asphalt Tied-Down Anchorage for Portable Concrete Barrier* (Report No. TRP-03-386-19). Midwest Roadside Safety Facility, Lincoln, Nebraska
11. Polivka, K. A., Faller, R. K., Rhode, J. R., Holloway, J. C., Bielenburg, B. W., Sicking, D. L. (2002). *Development of a Tie-Down System for Temporary Concrete Barriers* (Report No. TRP 03-115-02). Midwest Roadside Safety Facility, Lincoln, Nebraska
12. Silvestri-Dobrovolny, C., Shi, S., Brennan, A., Bligh, R., Sheikh, N (2019). *Synthesis of the Performance of Portable Concrete Barrier Systems*. College Station, Texas, Texas A&M Transportation Institute
13. Federal Highway Administration (2000). *Eligibility Letter B-63: Quickchange Movable Barrier (QMB)*. Washington DC
14. Federal Highway Administration (2018). *Eligibility Letter B-303: BarrierGuard 800 MASH TL-3 Standard.* Washington DC
15. Federal Highway Administration (2018) *Eligibility Letter B-292: SafeZone MASH TL-3 Limited Deflection.* Washington DC
16. Federal Highway Administration (2018) *Eligibility Letter B-296: Defender Barrier 100 FS.* Washington DC

17. Federal Highway Administration (2008) *Eligibility Letter B-176A: Zoneguard MASH.* Washington DC
18. Federal Highway Administration (2018) *Eligibility Letter B-308: HV2 Barrier.* Washington DC
19. Hill and Smith (Accessed April 29, 2020). *Barrier Solution for Battle Creek Bridge.* hillandsmith.com/case_study/barrier-solution-for-battle-creek-bridge/