DESIGN OF A TL-4 MEDIAN CABLE BARRIER FOR DEERFOOT TRAIL, CALGARY

Robyn V. McGregor, M.Sc., P.Eng.
Senior Transportation Engineer and Principal Consultant
EBA Engineering Consultants Ltd., Calgary

Masood Hassan, Ph.D., P.Eng.
Senior Transportation Engineer
EBA Engineering Consultants Ltd., Edmonton

Olivier Lahey, E.I.T.
Operations Engineer, Calgary District, Southern Region
Alberta Infrastructure and Transportation, Calgary

Paper prepared for the Session on

"Road Medians for Access Control and Separation"

2007 Annual Conference of the
Transportation Association of Canada
Saskatoon, Saskatchewan

ABSTRACT

This paper describes the preliminary engineering and design, by EBA Engineering Consultants Ltd. (EBA), of a National Cooperative Highway Program (NCHRP) 350: Test Level 4 (TL-4) high-tension (pre-stretched post-tensioned) cable barrier installed in May 2007 in the depressed median of an 11 km stretch of the Deerfoot Trail, an urban freeway in Calgary, Alberta, Canada.

The paper reports the results of the research regarding the available TL-4 cable barriers approved by the US Federal Highway Administration (FHWA), including discussions with FHWA officials, review of the recent experience in several US states, published reports, and face-to-face discussions with each of the three manufacturers (Brifen, Gibraltar and Trinity) who supply FHWA-approved TL-4 cable barriers. A summary comparison of the three products is also presented.

The paper discusses important design considerations, such as the post spacing and allowable maximum deflection of the cable barrier, the recent revisions to the AASHTO Roadside Design Guide with respect to placing of cable barriers on median slopes, and the pros and cons of placing the barrier at the edge of pavement, on the slope or in the median ditch.

For the Deerfoot Trail project, a design deflection of 2.4 m (8 ft) and a maximum post spacing of 6.1 m (20.0 ft) was specified, and it was recommended that the supplier should be selected in a competitive bidding process.

The median cable barrier was placed 4.0 m from the edge of the travel lane (the painted shoulder line). With the inside shoulder width being 2.43 m, this would place the cable barrier approximately 1.5 m from the edge of pavement, just below the top of the sideslope. This minimized the interaction with existing barrier systems, and allowed for emergency vehicles to park or pass on the inside shoulder.

The authors believe that the research and design of the high tension cable barrier described in this paper should be of interest to future similar projects in Canada.

PURPOSE AND SCOPE OF PAPER

This paper describes the preliminary engineering and design, by EBA, of a NCHRP 350: Test Level 4 (TL-4) high-tension (pre-stretched post-tensioned) cable barrier installed in the depressed median of an 11 km stretch of the Deerfoot Trail, an urban freeway in Calgary, Alberta, Canada (see Figure 1).

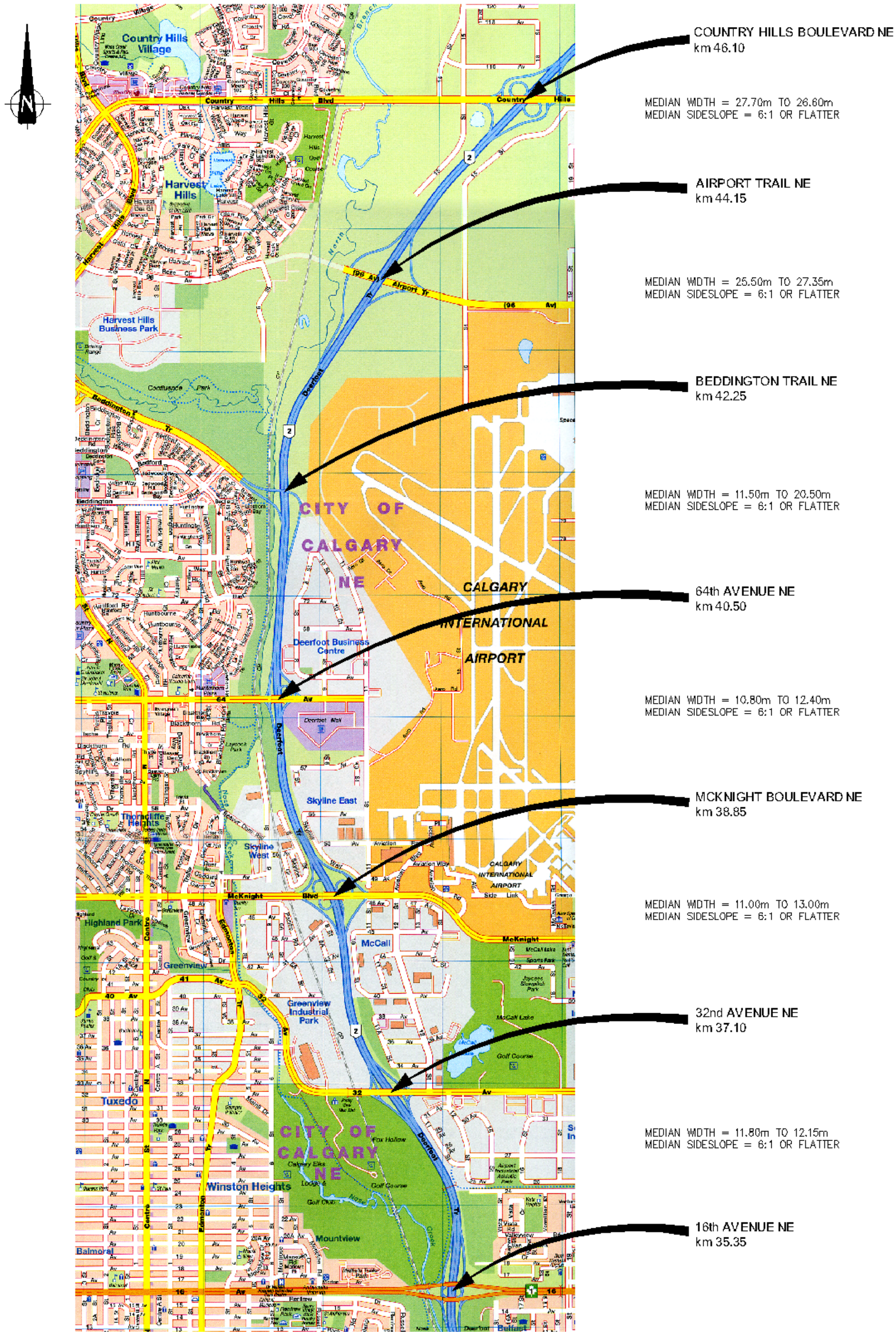

Figure 1 – Location Plan of Project Limits

The installation, completed in May 2007, is believed to be the largest median cable guardrail project in Canada to date. A 3-km high-tension median cable barrier was installed on Highway 1 through Chilliwack, BC, in the spring of 2007 (Luymes, 2007).

The paper reports the results of the research regarding the available TL-4 cable barriers approved by the FHWA, including discussions with FHWA officials, review of the recent experience in several US states, published reports, and face-to-face discussions with each of the three manufacturers (Brifen, Gibraltar and Trinity) who supply FHWA-approved TL-4 cable barriers. A summary comparison of the three products is also presented.

The paper also discusses important design considerations, such as the post spacing and allowable maximum deflection of the cable barrier, the recent revisions to the AASHTO Roadside Design Guide with respect to placing of cable barriers on median slopes, and the pros and cons of placing the barrier at the edge of pavement, on the slope or in the median ditch.

BACKGROUND INFORMATION ABOUT THE DEERFOOT TRAIL PROJECT

Deerfoot Trail (Highway 2:15) is a major north-south corridor through the City of Calgary. Authority for this multilane urban freeway, built in the late 1970's, was transferred from the City of Calgary to the Province of Alberta [Alberta Infrastructure and Transportation (AIT)] in July 2000. Deerfoot Trail forms part of the CANAMEX Trade Corridor. Traffic volumes along the 37 kilometres within the Calgary City Limits range from 45,120 vehicles per day to 154,050 vehicles per day (2006 AADT). The highway supports free flow traffic movements with cross traffic accommodated through interchanges. For the most part, the posted speed limit is 100 km/h and the speed limit increases to 110 km/hr for a short distance near the Calgary north city limits.

South of 17th Avenue SE, the freeway has an urban cross section with a narrow median and concrete barrier (Figure 2).

Figure 2 – Southbound Deerfoot Trail, South of 17th Avenue SE

Between 17th Avenue SE and 16th Avenue NE the cross section has a depressed grass median, with W-Beam median barrier, (Figure 3).

Figure 3 – Southbound Deerfoot Trail, North of 17th Avenue SE

The Bridge piers at 16th Avenue NE have large steel beam sand filled barriers, which date back to early designs or perhaps as early as the original construction of Deerfoot Trail (Figure 4).

Figure 4 – Southbound Deerfoot Trail, at 16th Avenue NE

Between 16th Avenue NE and Country Hills Boulevard (Calgary North City Limits) there is no median barrier. The highway is a rural cross section with a depressed grass median, which ranges in width from 16.05 m to 30.46 m (including 2.43 m paved shoulders in each direction). Based on available design and record drawings, the median sideslopes are considered to be 6:1 or flatter. (Figures 5 and 6)

Figure 5 – 16.05 m Median just north of 16th Avenue NE

Figure 6 – 30.46 m Median Width just south of Country Hills Boulevard

Hazards in the median (i.e., overhead sign structures, power poles, bridge piers) either have no barrier system or have varying types of barrier systems including W-Beam weak post, W-Beam strong post or steel sand filled barriers as noted above.

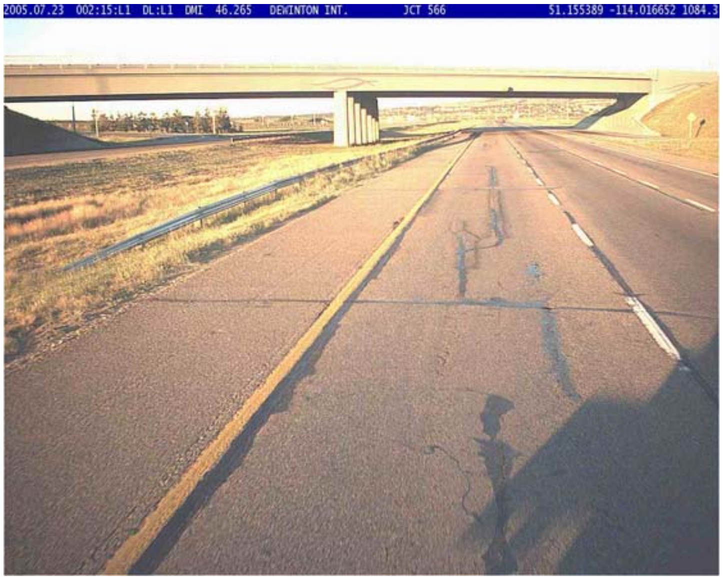

Figure 7 – W-Beam Weak Post Barrier System at Country Hills Boulevard

Figure 8 – W-Beam Strong Post System at Overhead Sign Structure

As a result of public concern over fatal collisions resulting from vehicles crossing the median, in 2005, AIT commissioned a consultant study titled "In-Service Road Safety Review: Highway 2:15 Deerfoot Trail Median 16 Avenue to North City Limit, Calgary" (Hamilton-Finn, 2005). The study, a summary of which was presented at the 2006 Transportation Association of Canada Annual Conference (Zein, S. et al, 2006), analyzed the crossover collision record on Deerfoot Trail, compared the advantages and disadvantages and economics of various barrier types, and recommended that a cable-and-post median barrier system be installed along the 6.8 km section between 16 Avenue NE and Beddington Trail.

AIT accepted the recommendation, but increased the length of the median cable barrier installation to 10.8 km, from 16 Avenue NE to Country Hills Blvd. In early 2006, AIT retained EBA to research the available approved Test Level 4 (TL-4) median cable barriers (see below for an explanation of the "test levels"), conduct the preliminary engineering, design, tender package preparation and construction administration for the installation of the 10.8 km median cable barrier project.

The limits of the median cable guardrail project described in this paper are from 16 Avenue NE to Country Hills Blvd, a distance of 10.8 km six-lane divided freeway.

SELECTION OF FHWA-APPROVED TL-4 MEDIAN CABLE BARRIERS

This section briefly defines the various test levels for longitudinal barriers, and summarizes the main features of the TL-4 cable barriers that were available for the Deerfoot Trail project.

Explanation of Test Levels for Longitudinal Barriers

The "NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features" (Ross, H. et al, 1993) published by the US Transportation Research Board's NCHRP is the authoritative "manual" of procedures for conducting vehicle crash tests and in-service evaluation of roadside safety features and appurtenances, including longitudinal barriers such as bridge rails, guardrails, median barriers, transitions, and terminals.

The NCHRP Report 350 describes and prescribes the procedures for six test levels (TL) for longitudinal highway barriers (beam, cable or other types):

- TL-1, TL-2, and TL-3 tests involve two test vehicles, an 820 kg car impacting a barrier at 20 degrees and a 2,000 kg pickup truck impacting a barrier at 25 degrees, at speeds of 50 km/h for TL-1, 70 km/h for TL-2, and 100 km/h for TL-3.
- TL-4 adds a third vehicle, an 8,000 kg single-unit truck impacting a barrier at 15 degrees and 80 km/h, to the TL-3 matrix.
- TL-5 substitutes a 36,000 kg tractor/van for the 8,000 kg single-unit truck in the TL-4 test.
- TL-6 substitutes a 36,000 kg tractor/tank trailer for the 8,000 kg single-unit truck in the TL-4 test.

The barrier manufacturers must get the crash impact tests of their proprietary barriers done by independent testing facilities according to the NCHRP 350 requirements and guidelines, and submit the detailed test results to the FHWA. On the basis of the test results, FHWA issues letters of approval indicating the maximum barrier deflection, post spacing and other conditions, guidelines and caveats under which the approved barriers can be used. The letters of approval for cable and other barrier types are available on the FHWA website for longitudinal barrier http://safety.fhwa.dot.gov/roadway_dept/road_hardware/longbarriers.htm.

Available FHWA-Approved TL-4 Cable Barriers

Until about 2004, TL-3 was the highest level of cable barrier used by the US State Departments of Transportation on Interstate and other major highways. Since then, several dozen installations of the TL-4 cable barrier have been completed in several states, with Texas perhaps being in the forefront (Hassan, 2006). It appears that no cable barriers have yet been tested at the TL-5 and TL-6 levels for FHWA approval. The lower speed TL-1 and TL-2 tests are apparently no longer relevant.

For the Deerfoot Trail project, AIT prescribed that the median cable guardrail barrier must be an approved TL-4 design for the longitudinal section, thus capable of stopping an 8,000 kg single-unit truck, as well as, of course, cars and pickup trucks. An approved TL-3 design was designated for the end treatments.

The available TL-3 and TL-4 cable barriers for highway use consist of three or four cables of pre-stretched steel ropes strung on weak steel posts. The cables are tensioned after installation (post tensioned). The posts can be driven into the ground or placed in sockets in concrete foundations, depending upon the manufacturer's specifications and FHWA approvals.

Contact with FHWA officials in early 2006 indicated that the following were the only three manufacturers of FHWA-approved TL-4 pre-stretched, post-tensioned cable barriers. These three and other manufacturers also supply approved TL-3 cable barriers.

1. Brifen Canada
   15521 Marine Drive
   White Rock, BC V4B 1C9 Canada
   www.brifencanada.com

2. Gibraltar
   320 Southland Road
   Burnet, Texas 78611 USA
   www.gibraltartx.com

3. Trinity Highway Safety Products
   2525 North Stemmons Freeway
   Dallas, Texas 75207 USA
   www.highway-safety.com

It should be noted that, although the physics/dynamics involved in the workings of all cable barriers is similar, the actual designs are proprietary, thus differing in, for example, the design and dimensions of the cables, tension, post height, post cross-section, lock plates/pins holding the cable to the posts, end treatments/anchors, etc. The parts are not interchangeable between products. Therefore, if the highway designers elect to specify a design deflection rather than a particular product, they must specify that a given installation of a cable barrier must use components from the same manufacturer.

Table 1 shows selective test data, including the maximum deflection at given post spacing, for the Brifen, Gibraltar and Trinity cable barriers meeting the TL-3 and TL-4 test criteria. The notes to the table provide additional relevant explanation. The data are summarized from the FHWA approval letters and test reports provided by the manufacturers.

Table 1
Selective Data for Three FHWA Approved TL-4 and TL-3 Cable Barrier Systems as of Spring 2006

Cable Barrier	TL-4 TEST			TL-3 TEST		
	Brifen	Gibraltar	Trinity	Brifen	Gibraltar	Trinity
Date of FHWA-Approval Letter	Mar 27, 2005	Sept 9, 2005	Nov 17, 2005	Apr 10, 2001	Jun 13, 2005	Nov 17, 2005
Post Spacing, m	3.2 (10.5 ft)	4.27 (14.0 ft) See Note 3.	6.1 (20.0 ft)	3.2 (10.5 ft)	4.58 (15.0 ft)	6.1 (20.0 ft)
Deflection, m (8,000 kg Single Unit Truck; 80 km/h, 15 Deg. angle)	2.21 (7.25 ft)	2.13 m (7.0 ft)	2.205 (7.23 ft)	-	-	-
Deflection, m (2,000 kg Pickup Truck; 100 km/h, 25 Deg. angle)	See Notes 1 and 3.	See Notes1 and 3.	See Notes 1 and 3.	2.4 (7.9 ft)	2.59 (8.5 ft) See Note 3.	2.35 (7.7 ft)
Deflection, m (820 kg Car; 100 km/h, 20 Deg. angle)	1.35 (4.4 ft) See Note 2.	Not tested. See Note 2.	Not tested. See Note 2.	1.04 (3.4 ft)	0.762 (2.5 ft)	? See Note 2.
Cable Height, m Top Cable Middle Cable 4th Cable Bottom Cable	 0.930 0.780 0.630 0.480	 0.991 0.762 - 0.508	 0.965 0.749 - 0.533	 0.720 0.675 0.675 0.510	 0.762 0.635 - 0.508	 0.749 0.640 - 0.533
FHWA- Approved End Treatment	TL-3, TL-4	TL-3	TL-3	TL-3	TL-3	TL-3

Note 1

The design deflection of longitudinal barrier systems is based by the FHWA on the ~2,000 kg Pickup Truck. As the above table shows, the test deflection of the Pickup Truck in the TL-3 test is always higher than the test deflection of the ~8,000 kg Single Unit Truck in the TL-4 test. Since the FHWA is selecting the higher deflection value as the design value, it waived the requirement to test a Pickup Truck for all three manufacturers; the applicable wording about the Pickup Truck deflections in the FHWA TL-4 approval letters is as follows:

Brifen — "Presumably, deflection with the pickup truck would be similar to that noted in your earlier TL-3 test and thus may be assumed to be approximately 2.4 m."

Gibraltar — "Since the bottom cable remained at the same height as the TL-3 design, we agreed beforehand that tests with the small car and the pickup truck would be waived."

Trinity — "Since the design deflection of longitudinal barriers is based on the pickup truck test, which was waived for the CASS TL-4, its dynamic deflection can be assumed to be the same as the CASS TL-3, i.e., 7.7 feet."

Note 2

Small car deflections are nearly half of the Pickup deflections, and don't therefore affect the design deflection.

Note 3

Brifen has not tested its cable barrier at any post spacing other than 3.2 m (10.5 ft) shown in the table. In January 2006, Gibraltar conducted tests with a pickup truck on its TL-4 cable barrier at 3.05 m (10 ft) post spacing resulting in a 2.0 m (6.8 ft) deflection; and at 9.15 m (30 ft) post spacing resulting in a 2.8 m (9.3 ft) deflection. Gibraltar has interpolated the 10 ft and 30 ft post spacing tests and states that the design pickup truck deflection for its TL-4 cable barrier at 20 ft (6.1 m) post spacing would be 8 ft (2.44 m). The FHWA has since accepted Gibraltar's interpolation, and has approved the Gibraltar cable barrier as having an 8 ft maximum deflection at 20 ft post spacing.

Trinity has FHWA approval, as shown in the table, for a design deflection of 7.7 ft (2.35 m) at 20 ft (6.1 mm) post spacing for its TL-4 cable barrier.

It should be noted that a TL-4 cable barrier is designed to stop an 820 kg car, a 2,000 kg pickup truck, or an 8,000 kg single-unit truck without exceeding the tested maximum deflection of the barrier. As Table 1 shows, the test deflection of the 2,000 kg pickup truck in the TL-3 test is always greater than the test deflection of the 8,000 kg single unit truck in the TL-4 test, presumably because of the higher speed and steeper angle of impact of the 2,000 kg pickup truck in the TL-3 test. The FHWA approvals for the TL-4 cable barrier therefore base the design deflection of the cable barriers on the 2,000 kg pickup truck. Since the FHWA is selecting the higher deflection value as the design value, it waived the requirement to test a pickup truck for the TL-4 test for all three manufacturers, and accepted the TL-3/pickup truck deflections as the design values. The applicable wording in the FHWA TL-4 approval letters is shown in Note 1 of the Table 1.

Other points to note in Table 1 include:

- Brifen is a four-cable design, while Gibraltar and Trinity use three cables.
- The top cable height in the TL-4 design is higher than the TL-3 design, for the obvious reason that the TL-4 barrier is designed to stop a taller vehicle: an 8,000 kg single-unit truck as compared to a 2,000 kg pickup truck.
- The FHWA allows the TL-4 cable barriers to use a TL-3 end treatment/anchor. Brifen is the only one of the three manufacturers with an approved TL-4 end treatment.
- All three barriers have a design deflection of 2.4 m (8 ft) or less, with post spacing varying from 3.2 m (10.5 ft) to 6.1 m (20.0 ft).

Discussions with Cable Barrier Manufacturers

To gain additional insights into the characteristics of the three TL-4 cable barriers, the representatives of the three manufacturers (Brifen, Gibraltar and Trinity) were invited to Calgary on March 13, 2006 to make individual presentations about their respective cable barrier product to the staff from AIT and EBA. Staff from the private contractor responsible for the maintenance of Deerfoot Trail also attended the presentation. Through the presentations, the manufacturers provided input into the conceptual design for the placement of the median cable barrier and also provided insight from their experience with other similar installations.

Conclusions Regarding Design Deflection and Cable Barrier Choice

As mentioned above, until about 2004, TL-3 was the highest level of cable barrier used by the US State DOTS. EBA talked to State DOT officials in Texas, Iowa, and Ohio (Hassan, 2006), and the indication was that the various approved TL-3 barrier installations (there had not yet been enough experience with the TL-4 barriers) had performed according to expectations, and the officials did not express a preference of one manufacturer’s product over another’s. It was indicated that the selection of the particular cable barrier product among the approved ones had been based on competitive bids.

Based on the research about available TL-4 cable barriers, contacts with the FHWA staff and staff of the Transportation Departments in selective US States, and the inability within the Alberta Provincial contracting regulations to specify a single manufacturer where there are others that meet the minimum design criteria (i.e., TL-4), a design deflection of 2.4 m (8 ft) and a maximum post spacing of 6.1 m (20.0 ft) was specified by EBA, and it was recommended that the supplier would be selected in a competitive bidding process.

MAJOR DESIGN ISSUES

This section presents the major design issues and how they were dealt with. They include general design parameters and considerations that apply to cable barrier projects in general, as well as the specific issues that arose during the design of the Deerfoot Trail project.

Lateral Placement of Median Cable Barrier

Chapter 6 of the AASHTO Roadside Design Guide (AASHTO, 2002) provides guidelines and criteria pertaining to median barriers. A revised Chapter 6 was issued by AASHTO in 2006 which includes a new section on High Tension Cable Barrier Systems and guidance on the placement of median cable barriers (AASHTO, 2006). The following summary is based on the revised AASHTO guidance, discussion with FHWA officials, and cable barrier manufacturers.

1. TL-4 cable barriers can be installed in the median ditch, or on the median sideslopes that are 6:1 or flatter.

2. A cable barrier should not be placed on a 6:1 slope beyond a ditch unless the barrier is within one foot (0.3 m) of the ditch bottom or beyond 8 feet (2.4 m). The reason is that some cars have been known to penetrate through cable barriers installed on the median sideslope when the cable barrier was offset from a ditch bottom in a median with 6:1 sideslopes. It appears that the cars left the roadway at angles greater than 25 degrees and experienced suspension compression as the vehicles "hit" the ditch bottom. These factors allowed the bumper of the car to scrape along the ground as the vehicle climbed the back slope, thus getting under the bottom cable and continuing across the median. Computer analysis and limited testing by FHWA replicated this type of penetration when the barrier was offset 4 feet from the ditch bottom. In the tests, containment and redirection of the vehicle was obtained when the cable barrier was offset only one foot from the ditch bottom. Hence the not-within-one-to-eight-feet guideline stated above.

3. Since the clearance distance between the ground and the bottom cable is a crucial factor in the effectiveness of a cable barrier, the ground under the barrier must be stable and free from obstructions or depressions that may affect the stability of an errant vehicle.

The above constraints on the lateral placement of the cable barrier would mean that the cable barrier can be placed in the ditch, or on the sideslope within 0.3m to 2.4 m of the ditch.

EBA's research showed that in general the ditch in the centre of the median may not be a suitable location for a cable barrier because of: the potential softening of the ground from deliberate use of the ditch for drainage or from run off accumulation; part of all of the in-ditch barrier covered by snow; and frequent presence, as in the case of the Deerfoot Trail project, of longitudinally placed utilities and cables.

For the Deerfoot Trail project, EBA decided to place the median cable barrier 4.0 m from the edge of the travel lane (the painted shoulder line). With the inside shoulder width being 2.43 m, this would place the cable barrier approximately 1.5 m from the edge of pavement, just below the top of the sideslope. (Figure 9**.** This minimized the interaction with existing barrier systems, and allowed for emergency vehicles to park or pass on the inside shoulder in the northbound direction.

Figure 9 – Alignment of Cable Barrier Installation

<u>Where to Place the Cable Barrier: Northbound or Southbound?</u>

Placing of the cable barrier near the edge of pavement on one side of the median required a decision whether it should be placed on northbound side or the southbound side of Deerfoot Trail. Testing of barriers is done with short straight sections, and little to no information was available from the provincial and state agencies that were contacted as to the criteria for choosing one side of the median over the other. Ultimately, the decision as to which side of the median to place the barrier on was based on horizontal geometry. The horizontal curves on Deerfoot Trail are of a large enough radii that the installation of the cable barrier (i.e., the post tensioning) was not impacted by the alignment. Although not verified through testing, it was considered during the design process that a vehicle would be best to contact the cable barrier on the inside of a curve. Where this could not be accommodated, then the barrier should be placed such that a vehicle leaving the roadway from the opposite direction that enters the median has an opportunity to stop before hitting the barrier on the opposite side of the median.

There are approximately nine horizontal curves within the project limits, seven of which result in northbound vehicles being on the inside of the curve. The better placement of the barrier was considered to be closer to the northbound travel lanes.

Connection to or Separation from the Existing Barriers Systems and Other Hazards

As mentioned earlier, the project had several barrier systems protecting bridge piers and some overhead sign posts in the median. There were also several unprotected overhead sign posts and other obstructions in the median.

All three manufacturers of TL-4 cable barriers have proprietary or other suggested products for connecting the high-tension cable barrier to existing beam barriers. However, the existing barrier systems were not originally designed to be subject to tension, and connections to the new cable barrier system would require extensive modifications. Rather than consider a design where existing and new barrier systems functioned together, EBA's design was based on separate barrier systems providing for separate needs. The median cable barrier would function to prevent errant vehicles from crossing the median and entering into opposing travel lanes. Other barrier systems such as existing W-Beam and steel sand filled barriers at overhead sign structures and bridge piers or new installations of Modified Thrie-Beam would function to prevent errant vehicles from colliding with hazards in the median.

At locations where existing barriers were in place, the median cable barrier was installed between the barrier and the northbound travel lanes. Two criteria for minimum separation of barrier systems were employed. All existing barrier systems on Deerfoot Trail have either turndown buried end terminals or energy absorbing end terminals in the face of approaching traffic. Where the median cable barrier system passes the end terminal, the separation between the two barrier systems must be 2.5 m or greater. This separation, being greater than the specified maximum deflection of the median cable barrier would prevent an errant northbound vehicle from travelling along the cable barrier and being directed into the end treatment of the more rigid barrier system. Where the median cable barrier system passes the hazard (i.e., the bridge pier or the overhead sign structure), the minimum separation between the two barrier systems must be 0.9 to 1.0 m. Should a northbound vehicle leave the roadway at this point, the median cable barrier system is not expected to function as there is obviously insufficient room for deflection, but the minimum separation of 0.9 to 1.0 m between the systems, allows for the weak posts of the median cable barrier system sufficient room to bend or lay down, and the vehicle is protected from hitting the hazard by the existing, more rigid barrier system. In this manner the two systems function separately and in the intended manner. One does not impede the function of the other and additional or more significant hazards are not created. (Figure 10)

Figure 10 – Cable Barrier System installation near bridge pier.

In all locations along Deerfoot Trail, the median cable barrier was installed to meet this minimum separation of barrier systems without encroaching on the previously identified design criteria of installation a minimum of 4.0 m from the northbound painted shoulder line.

Existing Hazards in the Median without Barriers

In some instances, particularly near the north end of the project limits where the median is wider, overhead sign structures or power poles existed in the median without barriers, prior to the installation of the cable barrier system. In the northbound direction, all existing hazards without barriers are located more than 2.4 m from the design alignment for the median cable barrier. The cable barrier then also functions as a barrier that will prevent an errant vehicle from hitting the hazard.

In the southbound direction, hazards that did not have existing barrier were reviewed for available clear zone distance. In most cases, the hazards were determined to be within the clear zone for the appropriate design speed. Designs were prepared for installation of Modified Thrie-Beam Guardrail at these locations. Since the existing median sideslopes are steeper than 10:1, rather than undertake localized grading at these locations to flatten the sideslopes and provide for flaring of the guardrail, the guardrail was installed along the edge of pavement. This also facilitated the appropriate alignment for the specified proprietary FLEAT 350 energy absorbing end treatment.

Emergency Cross-overs

There were two median cross-overs for emergency vehicles within the project limits. Retaining the cross-overs would have meant ending the cable barrier at either end thus requiring end treatments and leaving gaps in the barrier. AIT determined that the median cross-overs were not a critical requirement for emergency response. The cross-overs were removed, and the sideslopes of the median graded to allow for continuous installation of the median cable barrier.

End Treatments/Terminals

The median cable barrier includes two continuous installations. The first from 16th Avenue NE to south of Airport Trail and the second between Airport Trail and Country Hills Boulevard. Minimizing the number of end treatments is important as they pose a hazard to vehicles. The two end treatments that are upstream from the flow of traffic are only required to be anchor end treatments and not crashworthy. The end treatment at the start of the median cable barrier, just north of Airport Trail is also not crashworthy. At this location, Deerfoot Trail goes over Airport Trail via two bridge structures. On either end of the structures is W-Beam bridge rail. On the north side of the bridge structure, the starting end of the median cable barrier is behind the existing W-Beam bridge rail such that it is not exposed to the oncoming traffic. (Figure 11)

Figure 11 – Non- Crashworthy End Treatment Installation

At the southern most end of the project at 16th Street North, the end treatment is specified as crashworthy and approved at the TL-3 level.

The Potential for Southbound Vehicles to be Trapped Between Barrier Systems

An independent Road Safety Audit was conducted near the end of the design stage **(**Morrall, et al, 2006**).** One of the few issues that were identified in the audit report was the potential for a southbound vehicle to enter the median and be trapped between a W-Beam or Modified Thrie-Beam installation and the median cable barrier; potentially colliding with the hazard.

With a view to finding a solution for this issue, EBA perused some of the cable barrier test reports submitted to FHWA (KARCO, 2006 and Exponent, 2005)**.** The documented test results for the cable barrier systems indicate that after making contact with the cable barrier, the vehicles traveled along the longitudinal alignment of the barrier and were not redirected. The resulting transverse position of the vehicle was equal to the deflection distance of the barrier. Each location on the Deerfoot Trail project where a southbound vehicle could potentially be trapped between the cable barrier and another barrier system was reviewed for spacing between the cable barrier and the hazard. For locations where the spacing was sufficient for a southbound vehicle to continue between the hazard and the cable barrier after making contact with the cable barrier, no design modifications were made.

The test results also indicated the distance that a vehicle traveled after making contact with the cable barrier before coming to a stop. For those locations reviewed above, where space was not available for a vehicle to pass the hazard after making contact with the cable barrier (in most cases, these were bridge pier locations), it was determined that sufficient distance should be available after the vehicle makes contact with the cable barrier for the vehicle to come to a stop before colliding with the hazard. Based on the documented test results, this distance could be between 70 and 110 m depending on the vehicle, the travel speed, the angle of departure from the roadway, and the travel surface. Only two locations were of concern under this scenario: the existing bridge pier and barrier system at 16th Street NE, and the elevated opening between the two bridge structures over Airport Trail. At 16th Street NE, it was recommended that the existing barrier system be extended by approximately 50 m to increase the protective envelope for southbound vehicles. At Airport Trail, the existing W-Beam bridge rail would need to be extended to a total length of 250 to 275 m. As this is not likely efficient, it was recommended that a short length of transverse Modified Thrie-Beam be installed across the median opening.

THE INSTALLED MEDIAN CABLE BARRIER

The supply and installation of the median cable barrier on Deerfoot Trail was publically tendered. The successful contractor was Volker Stevin Contractors with Gibraltar supplying the TL-4 high-tension cable barrier. At the time of writing this paper, installation was underway.

REFERENCES

AASHTO (2002). Roadside Design Guide, 3rd Edition, Association of State Highway and Transportation Officials, Washington, D.C.

AASHTO (2006). Roadside Design Guide, Chapter Six Update. Association of State Highway and Transportation Officials, Washington, D.C.

Exponent, (2005), NCHRP Report 350 Test 4-12 of the Gibraltar Longitudinal Cable Barrier System PH09688. Report prepared for Gibraltar. Exponent Failure Analysis Associates, Phoenix, Arizona, August 5, 2006.

Federal Highway Administration, (2007) Internet site for longitudinal barriers, (FHWA), Washington, D.C. http://safety.fhwa.dot.gov/roadway_dept/road_hardware/longbarriers.htm

Hamilton-Finn, (2005), In-Service Road Safety Review: Highway 2:15 Deerfoot Trail Median 16 Avenue to North City Limit, Calgary. Report prepared for Alberta Infrastructure and Transportation. Hamilton-Finn Road Safety Consultants Ltd., Calgary, Alberta, September, 2005.

Hassan, M., (2006). Telephone communications with various officials of the State Departments of Transportation in Iowa, Ohio and Texas. February-April, 2006.

KARCO Engineering, (2006), Crash Test Report TL-4 Cable Barrier System, Posts on 30 FT Centers. Report prepared for Gibraltar. KARCO Engineering L.L.C., Automotive Research Center, Adelanto, CA, January 6, 2006.

Luymes, G, (2007), Wire barrier to be installed on Highway 1 through Chilliwack. *Fraser Valley Reporter,* March 29, 2007.

Morrall, J., de Leur, P., and Ho, G., (2006), Road Safety Audit, Highway 2:15, Deerfoot Trail, Median Cable Barrier System. Report prepared for Alberta Infrastructure and Transportation. Canadian Highways Institute, Calgary, AB, June 2006.

Ross, H., Sicking, D., Zimmer, R. and Michie, J., (1993), National Cooperative Highway Research Program (NCHRP) Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features. Transportation Research Board, Washington, DC.

Zein, S.R., Wilson, C., and Dilgir, R., (2006). To separate or not to separate?: the Deerfoot Trail case study. Proceedings of the Transportation Association of Canada Annual Conference, Charlottetown, PEI, September 2006.