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PTI M-10 Barrier Cable TG Meeting Agenda
Update on Publication Action Items

October 21, 2020 12:00 PM – 2:00 PM Eastern
Virtual Convention Meeting via Zoom

Task Group Members **Present** (**X** of 15):

Todd Stevens – TG Lead
Tim Christle – PTI Staff
Rashid Ahmed
Carlos Banchik
Langston Bates
Asit Baxi
Muhammad Cheema
Baruch Gedalia
Dawn Kori
Thomas Matthews
Andrew Micklus
Doug Schlegel
Pete Scoppa
Eric Tegner
Dan Williams
Michael Williams

Short Span Barrier Cable Sub-Task Group Members **Present** (**X** of 8):

Fabrice Brugere – Sub-TG Lead
Tim Christle – PTI Staff
Todd Stevens
Rashid Ahmed
Don Kline
Carol Hayek
Carlos Banchik
Muhammad Cheema
Eric Tegner

The purpose of this meeting will be to discuss the status of each action item listed below as they pertain to PTI publications associated with this Task Group. The goal will be to establish a clear plan, member assignments and due dates which would facilitate completion of these action items.

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STATUS OF DOCUMENTS ASSIGNED TO THIS TASK GROUP

(New notes from this meeting will be added in red)

1. **PTI M10.7-XX Guide for Barrier Cable Maintenance and Repair**
    a. **180831-Ballot M-10-1803-M10.7-xx Guide for Barrier Cable M&R.pdf is attached**
    b. This ballot closed on October 7, 2018
    c. Was there ever a M-10 web meeting held to resolve negatives on this ballot? I don't believe so based upon the information I've reviewed.
    d. ACTION ITEM 1.1: M-10 web meeting needs to be scheduled as soon as possible to resolve this ballot
    e. ACTION ITEM 1.2: After ballot resolution, final edited document needs to be sent to TAB
    f. Determine if ballot can be resolved by this TG or if it has to be sent back up to M-10 for re-ballot or resolution.
    g. Can this group clean it up and resolve it and then send it up to M-10?
    h. Tim will follow up with Miroslav on ruling.

2. **Barrier Cable Specification**
    a. 8/31/17 Web Meeting states: Assemble small TG to finalize – Todd and Fabrice to draft prior to Cancun
    b. 10/4/17 Cancun M-10 Meeting minutes state: Barrier cable specifications will be completed and sent to PTI staff by 11/1/17
    c. 5/8/18 Minneapolis M-10 Meeting minutes state: Some specs required re-tightening option. Maybe, screw anchors should be used on one side. ASTM is close to finalizing new spec for galvanized strand; if available, it should be referenced.
    d. 9/26/18 Colorado Springs M-10 Meeting minutes state: Some specs required re-tightening option. Maybe, screw anchors should be used on one side. ASTM is close to finalizing new spec for galvanized strand; if available, it should be referenced.
    e. Were these specification revisions ever completed and advanced? I don't believe so based upon the information I've reviewed.
    f. ACTION ITEM 2.1: Complete all revisions needed and send to PTI staff as soon as possible
    g. Revisions were waiting on resolution to TN 14 and short span issue.
    h. Needed to finish revisions and then submit M10.4 to M10 so it could then be balloted.
    i. Was waiting on ASTM as well maybe.
    j. Todd will look for his latest draft version of document.

3. **Technical Note 14 Revision**
    a. Or as I've been considering it, a brand new technical note with updated information that will replace existing TN 14.
    b. 8/31/17 Web Meeting states: Todd to review progress with Asit and coordinate with drafting of PT Manual update
    c. 10/4/17 Cancun M-10 Meeting minutes state: Technical note #14 is still under review. Asit Baxi needs to give some input.

d. 5/8/18 Minneapolis M-10 Meeting minutes state: Technical Note #14 revision; Based on the above items, revisions to the TN can be finalized. ("above items" referenced here were the other barrier cable action items covered during that meeting)
e. 9/26/18 Colorado Springs M-10 Meeting minutes state: Technical Note #14 revision; Based on the above items, revisions to the TN can be finalized. ("above items" referenced here were the other barrier cable action items covered during that meeting)
f. **161116-TN 14 Revision Proposal.docx is attached**. This is the most recent revised version of TN 14 I could find.
g. My understanding is that the issues with the short span barrier cable calculation method were the only remaining thing holding up final revisions to this TN 14. Is that the only thing standing in the way of making revisions to this technical note final?
h. ACTION ITEM 3.1: Make final edits to this TN 14 incorporating the decisions that were made regarding design approach for short span barrier cable
i. ACTION ITEM 3.2: Forward this updated TN to PTI staff so it can be balloted by M-10 as soon as possible
j. Fabrice restated that the short span calculation method has been resolved. Short span document will be incorporated into TN 14.
k. Fabrice will send proposed edits to TN 14 with short span info to TG before the end of June 2020.
    i. See 10/21/20 agenda exhibit for updated draft from Fabrice with proposed edits from Asit as well
l. Revisions should include reference to maintenance and repair as well.

4. **Short Span Barrier Cable Calculations**
    a. The Sub-TG noted above was tasked with determining the recommended design method for the short span condition, due to the large discrepancy between results found using the energy method versus the static method. The appropriate factor of safety needed to be agreed upon as well.
    b. Several meeting notes refer to this item as another technical note. It was my understanding rather that the final recommendations for short span calculation method would instead be incorporated into the revised TN 14. Do we really want to have a second barrier cable design tech note just for short span cables?
    c. 8/31/17 Web Meeting states: Send Todd contact information for Eric Tegner – Todd will contact and inquire on status and offer to help. Carlos and Amy will help with calculations.
    d. 10/4/17 Cancun M-10 Meeting minutes state: Short span technical note will be completed and sent to PTI staff by 11/1/17
    e. 5/8/18 Minneapolis M-10 Meeting minutes state: For short barrier cable runs, there is a big difference in results, depending on what method is used. This will go to TAB to get direction; staff will forward to TAB to get the specific question answered.
    f. 5/31/18 Web Meeting minutes state: TAB committee doesn't have the needed barrier cable design expertise at this time. Expand this Sub-TG to include specific DC-20 members with barrier cable design expertise. Survey PTI professional members to determine how they approach short span design.
    g. 8/9/18 Web Meeting minutes state: Survey results all over the place. Consider load testing and research to validate results? Further discussion at TG meeting in Colorado.
    h. 9/26/18 Colorado Springs M-10 Meeting minutes state: For short barrier cable runs, there is a big difference in results, depending on what method is used. A Sub TG (Lead

Fabrice Brugere) is working on this issue. This will be also discussed at the TAB meeting on 9/27/18. Fabrice will forward report notes to Chair.

i. 9/26/18 Colorado Springs TG Meeting minutes state: Consensus was to not pursue testing and research, but rather to go with more conservative energy method, clean up the information, show minimum length span, define L and l values, use factor of safety of 1.6, cutoff length for what is considered short is 23 feet.

j. **Short Span Barrier Cable PTI M10 Task Group- FAB REVISED for 1.6 safety coefficient – 9-26-18.docx and IBC 2015-Vehicle Barrier code requirements.pdf are attached**. These files were sent out to the TG for review and comment on 9/28/18, but to date no comments have been received.

k. ACTION ITEM 4.1: Sub-TG members review and comment on the documents produced by Fabrice as soon as possible, then reach a final consensus on the calculation example and recommendations that will be included in the TN 14 update. Hold a web meeting along with primary M-10 TG-Barrier Cable members to finalize action if needed.

l. Fabrice restated that the short span calculation method has been resolved. Short span document will be incorporated into TN 14.

m. Fabrice will send proposed edits to TN 14 with short span info to TG before the end of June 2020.
    i. See 10/21/20 agenda exhibit for updated draft from Fabrice with proposed edits from Asit as well

5. **PT Manual 7th Edition Update – Chapter 16, Design of Prestressed Barrier Cable Systems**
    a. The existing PT Manual 6th Edition Chapter 16 is being updated along with all other chapters to be part of the new 7th Edition
    b. Asit Baxi is the primary author of this chapter update
    c. The work of this Task Group related to TN 14 and the Short Span design issue needs to be completed in order for that information to be updated in Chapter 16 and be compatible
    d. ACTION ITEM 5.1: Task Group needs to finalize the items noted above as soon as possible so Asit can finish his update of the chapter
    e. ACTION ITEM 5.2: Asit to complete his update to Chapter 16 as soon as possible and forward to PTI staff so it can be made ready for TAB balloting
    f. Asit will incorporate TN 14 information from Fabrice available at the end of June.
    g. Manual is being updated to IBC 2018 code as well.
    h. Information in new TN 14 should echo into Chapter 16.
    i. Fig. 16.2 needs to have updated information. Pete Scoppa will ask around as well to see what numbers he can find out. This diagram will need to be updated in TN 14 too.
        i. I received a couple of responses (not as many as I was hoping) from concrete frame contractors.
        ii. Galvanized Barrier Cable – One guy gave me $22 per running foot and another gave me $36 per running foot that included some stub columns.
        iii. Masonry/Block Walls – Two different contractors gave me $63 and $70 per running foot.
        iv. Cast in Place concrete bumper walls – I got a $112 and a $58 per running foot. I have to think that the parameters are different for these two costs. The higher number did specify a 42” tall x 8” thick wall.
    j. Incorporate Tech Note 20 information and BC inspection as well into the revised chapter.

k. Asit to send copy of IBC 2018 barrier cable section to Fabrice.
l. Asit to add language in chapter about deflection control.

6. **Draft Guide for Design of Barrier Cables**
    a. 5/8/18 Minneapolis M-10 Meeting minutes state: The TG should draft a Design Guide after all the other documents are completed.
    b. 9/26/18 Colorado Springs M-10 Meeting minutes state: The TG should draft a Design Guide after all the other documents are completed.
    c. Would this design guide ultimately be issued as a DC-20 committee document?
    d. Wasn't there some discussion about merging design guide information with PTI M10.4-07 information to create a singular publication that covers all aspects of barrier cable?
    e. ACTION ITEM 6.1: Need to create a smaller Sub-TG (5 person max.) to work on the creation of this document, but as stated, only after all the other primary TG documents are completed. A mix of M-10 and DC-20 experts would seem appropriate.
    f. Need to revisit this item later to determine if it should even be pursued. On hold for now.
    g. May not be ideal considering all the other documents that are being updated.

7. **New Business**
    a. Maybe we need to have a separate FAQ document that deals with lots of the issues people are encountering.
    b. Eric mentioned there might be consideration for certification for barrier cable inspectors. Several inspectors are not necessarily knowledgeable enough to know what they should know. Separate from Level 2 Unbonded?
    c. Also maybe consider BC installer certification requirements separate from Level 1 Unbonded.
    d. PTI certification of BC materials? CRT-20 should perhaps look at this to determine what might be needed to beef up certification for BC suppliers/manufacturers.
    e. Maybe more information is needed to provide guidance on design and detailing of BC anchorage, connections. Maybe incorporate into the FAQ.

Meeting Adjourned: X:XX pm ET

Next Meeting: 2021 PTI Convention, Westin Indianapolis, IN – April 18-21, 2021

Meeting Exhibits: PTI Anti-Trust Policy
161116-TN 14 Revision Proposal - FAB-AB Comments.pdf

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PTI POLICY STATEMENT ON COMPLIANCE WITH ANTITRUST LAWS

At a meeting on October 8, 1980, the Board of Directors first discussed the Institute's status and policies regarding compliance with antitrust laws. After review of both the internal and external compliance procedures, the following resolution was approved:

"*The staff, officers, directors and members of the Post-Tensioning Institute are reminded that they are required to comply with the spirit and specific requirements of the antitrust laws on all activities within the scope of, and related to, the official functions of PTI. Further, this restated position, along with appropriate explanatory material, should be placed in all meeting folders/books periodically, beginning with the 8th of October meeting of PTI.*"

On July 24, 2012 and again on October 7, 2015, the Executive Committee authorized Legal Counsel to review and update this Policy Statement in the perspective of the Department of Justice Business Review Letter of July 30, 1997 and current case law. As a continuing guide for your participation in PTI's meetings, please review and continue to adhere to the following "Legal Limitation on Discussions at PTI Meetings."

LEGAL LIMITATION ON DISCUSSIONS AT PTI MEETINGS AND EVENTS

A free exchange of ideas on matters of mutual interest to the members is necessary for the success of all meetings. Indeed, such an exchange of views is essential to the successful operation of every trade association and the law specifically allows legitimate exchange of views pertaining to, e.g., quality control, safety, building design and construction integrity, etc.

It is not the purpose of this memorandum to discourage the exploration in depth of any matters of legitimate concern to meeting participants. Nevertheless, to ignore certain antitrust ground rules, either through ignorance or otherwise, is to create a civil and criminal hazard businessmen simply cannot afford.

It is for these reasons that PTI provides you with a reminder that certain areas of formal and informal communication between competitors or between manufacturers and their suppliers and customers must be avoided, as posing potential antitrust problems.

The Sherman Antitrust Act, the Clayton Act, the Federal Trade Commission Act, and the Robinson-Patman Act comprise the basic federal antitrust laws, which set forth the broad areas of conduct considered illegal as restraints of trade. In general, agreements or understandings between competitors that operate as an impediment to free and open competition are forbidden. Federal antitrust prohibitions forbid any "agreement or understanding...to substantially lessen competition or tend to create a monopoly in any line of commerce." An important point to keep in mind is that communications and discussions between competitors or between sellers and customers, about matters which may be considered anti-competitive, often comprise the evidence from which courts infer antitrust violations. ***It is the policy of the Post-Tensioning Institute that such agreements, understandings or communications shall not be tolerated at any formal or informal meetings or social events of the Institute.***

The general prohibitions contained in the federal antitrust laws, have been particularized in the form of a series of consent decrees, originally entered against a number of member companies of various trade associations and the associations themselves. It is important to note that these laws not only apply to PTI members, but also to PTI itself. Often trade associations have been and are presently co-defendants in cases brought by the Justice Department and the Federal Trade Commission ("FTC"). Recently, the FTC has stated: "*Because trade associations are by their nature collaborations among competitors, the Commission and courts have long been concerned with anti-competitive restraints imposed by such organizations under the guise of codes of conduct. Competing for customers, cutting prices, and recruiting employees are hallmarks of vigorous competition. Agreements among competitors not to engage in these activities injure consumers by increasing prices and reducing quality and choice.*" Similar "codes" or policies and requirements that encourage directly or indirectly members' unlawful activity are strictly forbidden by PTI in the course of its business with its members.

SPECIFIC EXAMPLES OF ACTIVITIES AND PRACTICES PROHIBITED AT ALL PTI MEETINGS AND EVENTS:

Included in activities and practices which are forbidden, and are contrary to the policy of the Institute, both under the general antitrust laws and the consent decrees, subject to the said Business Review Letter, are the following:

- Agreeing to allocate markets, customers or suppliers among competitors, classify certain customers or suppliers being entitled to preferential treatment by manufacturers, and establish geographic trading areas.
- Participating in any plan designed to induce any manufacturer or distributor to sell or refrain from selling, or discriminate in favor of, or against any particular customer or class of customers.
- Agreeing in any manner to fix or otherwise establish bids, prices (including price increases, decreases, standardization or stabilization), profits, costs, contract terms affecting price (such as discounts and credit terms), etc. because, e.g. prices were too low, with the exception of certain resale pricing agreements between manufacturers and retailers or distributors.
- Agreeing in any manner to limit or restrict the quality of products to be produced (e.g., restrictions on selling coated strand to certain customers).
- Participating in any plan which has the effect of discriminating against, or excluding competitors, suppliers or customers.

These examples are provided to guide you in your discussions during formal and informal PTI meetings and social events. If the occasion arises, more specific advice will be provided by legal counsel, who is required by Article IV, Section 7 of the PTI By-Laws to be present at all meetings of the Board of Directors and the Executive Committee.

CONTENTS

1.0 INTRODUCTION

The selection and design of a vehicle barrier system is an ~~important~~ essential element in the structural design of every parking garage. Some type of barrier system must be erected at the perimeter of the structure and at the open edges of the ramps to prevent automobiles and pedestrians from falling from the open sides.

The *International Building Code* ~~2003[2]~~ 2015 [fb1][AB2]~~gives~~ (IBC) provides requirements for vehicle barriers and guards. The barrier system, including its components and the attachment of the barrier system to the structure, must be capable of resisting the loads prescribed in the IBC and ~~impact resistance and states that the barrier system must have anchorage or attachments capable of~~ transmitting the resulting loads to the structure through the attachments. The[AB3] licensed design professional in charge of the building must consider the effects of the ~~Since the~~ vehicle impact loads that are transmitted through the barrier system attachments ~~to~~ for the ~~structure, it is important that the structural designer consider the vehicle barrier system in the~~ overall design of the structure.

One option for vehicle barrier systems is the use of prestress~~ed~~ing seven wire steel strand conforming to the Post-Tensioning Institute's *Specification for Seven Wire Steel Strand Vehicle Barrier Cable Applications*[3]. Steel strands conforming to this specification are capable of restraining the impact load of a moving vehicle and are economical and flexible in meeting various ~~the~~ geometric layouts~~ of a specific project~~. Figure[AB4] 1.1 shows a cost comparison between various types of vehicle barrier systems and illustrates why ~~seven~~ seven-wire steel strand barrier cable systems are a popular choice for garages of all types of construction. The chart uses the following configurations:

- Barrier cable system typically[fb5] consisting~~s~~ of 11 cables
- Masonry/~~ and ~~cast-in-place ~~spandrels ~~bumper walls or spandrels ~~are ~~42 inches~~.~~ high and built on the slab
- Precast bumper walls or spandrels ~~are ~~60 inches~~.~~ high and extending~~and extend~~ over the edge of the slab

2.0 BUILDING CODE REQUIREMENTS

IBC 2018 outlines requirements for parking garage barrier systems in Section 406.~~2~~4. This section lists requirements for both pedestrian protection[AB6] (~~Section 406.2.3~~Section 1012.9) and ~~for ~~automobile restraint (~~Section 406.2.4~~Section 406.4.2). While the ~~structural designer~~LDP will typically only be concerned with the barriers that ~~will ~~handle automobile restraint, these vehicle barriers will most likely need to meet the provisions for pedestrian protection as well. Provisions for meeting both requirements are discussed below.

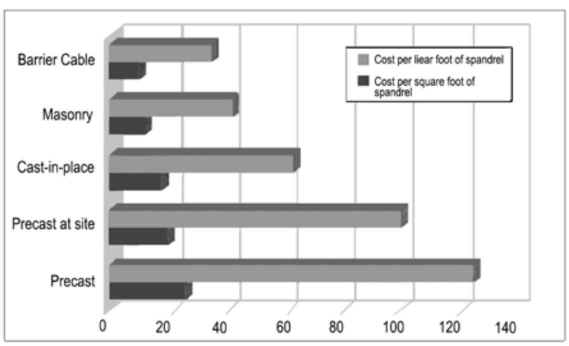


Figure 1.1 - Cost of Exterior Barrier Systems

Note that local building code requirements may be more stringent than the IBC requirements, particularly with regard~~s~~ to vehicle impact loads. ~~, t~~Therefore larger values may need to be used in the design~~ equations that follow~~.

2.1 Pedestrian protection

Barrier systems for pedestrian protection are required at exterior ~~-~~and interior vertical openings where vehicles are parked or moved. They are also needed a~~, and a~~long ~~open~~ open-sided walking areas, or ramps~~,~~ that are located more than 30 inches (762 mm) measured vertically to the floor or grade below and at any point measured within 36 inches (914 mm) horizontally to the edge of the open side.~~ when the vertical distance to the ground or surface below exceeds 30 in.~~ ~~(check current IBC for additional criteria)~~ ~~[762 mm].~~ Because of this requirement, most vehicle barrier systems will double as also ~~the~~ a means for providing pedestrian protection ~~for pedestrians~~ by meeting the physical requirements of IBC Section ~~1003.2.12~~1015 Guards.

~~This~~ IBC section 1015 states that ~~the~~ guards must form a protective barrier not less than 42 inches~~.~~ [1067 mm] high, "measured vertically from the leading edge of the tread or adjacent walking surface." Openings in the guard, if any, must be ~~limited~~ such that a 4 inch~~.~~ [102 mm] diameter sphere cannot pass through any opening up to~~ a height of 34 in. [864 mm]~~ the required guide height. ~~Above~~ From the~~a~~ height of ~~34~~36 to 42 inches~~.~~ [~~864~~ 914-1067 mm], a sphere of ~~8~~ 4 3/8 inch~~.~~ [~~203~~ 111 mm] diameter cannot pass through the opening(s).

IBC section 1015 ~~This section~~ also outlines the minimum loading requirements for guards for pedestrian protection. ~~, h~~However, ~~-~~these loads are not discussed herein since they represent only a small fraction of the load capacity required for vehicle barriers.

2.2 Automobile restraint

IBC Section ~~406.2.4~~406.4.~~3~~2 requires vehicle barriers not less than ~~24~~ 2 feet 9 in. [~~607~~ 835 mm] in height, to be placed at the ends of drive lanes and at the end of parking spaces where the ~~difference~~ vertical distance to the ground or surface directly below ~~in adjacent floor elevation~~ is greater than 12 in. [305 mm].

Vehicle barriers of all types must meet the physical requirements of IBC Section ~~1607.7~~1607.8.3, which state~~s~~ that barriers for garages designed for passenger cars ~~are to~~must be designed to resist a single concentrated load of 6,000 lbs [26.70 kN] applied horizontally in any direction to the system (also see Section 4.5.3 of ASCE 7 (xx Ref)). For design purposes, the code ~~assumes~~ requires that the LDP design for the maximum load effects due to the concentrated load applied between ~~load to act at~~ a ~~minimum~~ height of 18 inches [457 mm] and a height of 27 inches [686 mm] above the floor or ramp surface. ~~between 18 in. and 27" [457 mm] above the floor surface.~~ ~~The worst- case scenario from the two load heights is used for design.~~ The concentrated ~~is~~ load should be applied to an area that does not ~~is not to exce~~exceedd ~~on~~ an area ~~not to exceed~~of ~~1 sq ft~~12 in. by 12 in. [305 mm by 305 mm~~0.9 m²~~] and should be located ~~as~~ to produce the maximum load effects. Additionally, this load is not required to act concurrently with any handrail or guardrail loading. ~~The worst case scenario from the two load heights is used for design.~~

~~This s~~Section 1607 of IBC classifies vehicular impact load as a live load. While the code does not[AB7] have an explicit load combination for strength or service load design, it is common practice amongst engineers to consider a load factor of 1.6 for the strength design of the barrier system components, anchorages or attachments, and connecting elements of the structure. ~~;~~ ~~therefore, a load factor of 1.6 should be applied to the impact load~~If allowable stress design is used, the load factor = 1.0~~.~~

Barriers for garages that accommodate trucks and buses must ~~are to~~ be designed ~~in accordance~~ with an approved method that contains provisions for ~~larger vehicles~~traffic railings. ~~Depending on the interpretation of the building official,~~ Consideration ~~this~~should be given to ~~may include~~ levels or areas of the garage subject to truck traffic, such as delivery areas and loading zones. The traffic patterns in these areas should be carefully considered, as it ~~can be~~is common for these larger delivery trucks to impact barriers when backing up in close quarters.

For a fully functional barrier system, it is critical that the vehicle barrier system ~~Another very important (and often overlooked) element of the code is the requirement that the barrier system~~ have anchorages or attachments capable of transmitting the loads (resulting from a vehicle impact) to the structure and for the structural elements that receive this load to be adequately designed to support the loads at impact. The LDP must carefully consider the load path from the point of impact to the location(s) where the load gets transmitted to the structure and must adequately design and detail the various elements, including the structure along that load path.

Prestressed barrier cable systems are typically anchored to supporting columns or walls in ~~the~~ a garage. On a typical concrete garage level, the barrier cables transmit the impact load to the full height of the column or wall between the levels. In most cases, the column/wall size and reinforcement design without impact is usually adequate, and no additional reinforcement is required. However, on the top level of a parking garage where the connecting columns behave as short “stub” columns, the column size and reinforcement may not be adequate, and additional reinforcement may be necessary. At such conditions, the stub columns should be detailed to ensure that the reinforcement provided can be adequately developed. The same concept applies to barrier cable systems attached to a steel structure.~~It is important that the designer calculate the stresses that will result from a vehicle impact to ensure that these connecting elements have the capacity to resist this force. This is particularly important when the connecting column is a short “stub” column (sometimes used on the top level of a parking garage) that most likely will not have the capacity to handle these loads unless additional reinforcing is added.~~

The following sections ~~will~~ present ~~a~~ design methods and examples that illustrate how to ~~a procedure for~~ calculate~~ing~~ the forces and deflections in a prestressed barrier system due to vehicular impact. ~~that result from a vehicle impact. It will also provide information in the form of c~~Calculations and examples ~~to~~for ~~Licensed Design Professionals (LDP) for~~ short single-span conditions are provided. The calculations illustrate that ~~situations where a vehicular barrier cable system is being proposed for a short single span condition. This note shows that~~ there is a minimum dimension under which a single-~~-~~span becomes too short to be able to accommodate a prestressed barrier cable system.

3.0 DESIGN CONSIDERATIONS

The primary design consideration is to provide protection by resisting the impact of a vehicle without a failure of the barrier cable system, its attachment to the structure, and the elements of the structure supporting the barrier system. It is important to recognize that the failure of the barrier cable system can occur in several different modes:

1. Failure of the cable or group of cables resisting~~to resist~~ the impact without breaking[AB8].

2. Failure of the barrier cable system anchorage ~~system~~ components (either due to the anchorage (or anchorage assembly) itself pulling out of the column, or due to the cable pulling out of the anchorage) for internally and externally mounted systems~~.~~

~~1.~~3. Failure of the attachment assembly (either due to the member of the assembly, connecting components of the assembly, or the anchoring of the assembly to the structure) for externally mounted systems

4. Failure of the system to limit deflection of the cable on impact to a value that still provides protection (resulting in impact to an external or internal nonstructural or structural component)~~.~~

5. Failure of the connecting column(s), wall(s), slab/beam of the structure for internally and externally mounted systems

~~2.~~1.

~~3. Failure of the cable or group of cables to resist the impact without breaking.~~

~~4. Failure of the connecting column(s) or wall(s)~~

3.1 Failure of the barrier cable system anchorage ~~system~~components

The connection of the barrier cable system anchorage components ~~anchoring system~~ to the column(s) or wall(s) for internally mounted systems or an attachment assembly for externally mounted systems is explained in Section 3 of PTI's Specification for Seven Wire Steel Strand Barrier Cable Applications[3]. Appropriate material reports and test data should be used to calculate the ultimate pull out and shear strength of all component parts being used. Once the magnitude of tension ~~created~~ in a cable immediately after ~~at~~ vehicle impact is ~~calculated~~determined, the capacity of each anchorage component of the vehicle barrier cable

~~anchorage~~ system should be validated as being able to ~~sustain~~resist this load, with a proper safety factor.

Failure caused by the cable pulling out of the anchoring device can be avoided by following the material requirements listed in Section 3[3], and by strict enforcement of the installation requirements detailed in Section 5[3]. ~~; s~~Specifically, all wedge type anchorage devices, which are ~~(~~the most commonly used in this type of system~~)~~ must be back-stressed to a force equal to 80% of the Minimum Ultimate Tensile Strength (MUTS) of the ~~cable~~strand. Barrier cable systems are typically tensioned to a relatively low force, unlike tendons in other post-tensioning applications where the tendon is stressed to its full jacking force. The low tension force in the cable ~~that~~ is not ~~adequate~~ enough to properly seat the wedges to~~and~~ form the mechanical connection that the system relies ~~on~~upon for adequate anchorage. Hence, each barrier cable is ~~B~~back-stressed~~ing~~ to ensure~~s~~ that the wedges are adequately seated~~-~~ in the anchorage device~~and the proper (permanent) connection is made~~.

Procedures for backstressing are outlined in Section 5 of the Specification[3], and calculations for adjusting the initial strand tension to accommodat~~eing~~ for the seating losses from backstressing ~~the loss of force due to seating loss~~ are discussed ~~later~~ in Section 5.0 of this document.~~herein.~~

3.2 Limiting deflection

Prestressing steel strand elongates under a load as follows:

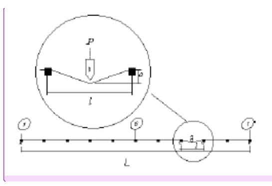
$$\Delta = \frac{PL}{AE} \quad (1)$$

Where: P = the applied load in lbs

L = the length of the strand in inches, from anchorage to anchorage. For short span calculations, it is critical to properly identify the anchorage system used as this will determine the exact value of this dimension. This dimension is what will determine if a vehicle barrier cable system can be used in a specific short span application.

A = area of prestressing steel in sq in.

E = modulus of elasticity of the steel



[fb9]

Figure 3.2.1 – Deflection Under a Point Load

Using the model shown in Figure 3.2.1 and ignoring any applied prestressing force, other than what is necessary to remove the slack in the cable, total deflection in a barrier cable strand a can be calculated as

$$a = \left[\frac{Pl^2L}{8EA}\right]^{\frac{1}{3}}$$

Using galvanized PC strand with the following properties:

270 KSI galvanized strand (290 KSI strand which becomes 270 KSI after the galvanizing process). Some suppliers may use a 270 KSI strand that becomes 250 KSI after the galvanizing process. It is important to verify the grade of the galvanized strand that will be used prior to doing the calculations.

Cross Sectional Area of Steel (A) = 0.153 in^2

Modulus of Elasticity (E) = 28,500,000 lbs/in^2

and a barrier cable system with a total length (L) of 200 ft and a column to column span (l) of 20 ft, the deflection of one cable under a 2000 lb load (P) would be:

$$a = \left(\frac{2000 \times 20^2 \times 200}{8 \times 0.153 \times 28,500,000} \right)^{1/3} = 1.66\,ft.$$

Note: ***l*** = free length of the cable between supports – This distance will vary slightly depending on the type of support or anchor selected, but for simplification purposes, and since *Fe* has a relatively small impact on the overall value of the total tension *T*, we will use the value of the span (distance between center lines of columns) for ***l*** in all conditions.

Typically, maximum allowable deflection should be limited to 18 in. in order to prevent the front wheels of an impacting vehicle from traveling over the edge of the slab. However, there are instances where it is important to limit deflection to a lower value. This includes instances when the barrier cable system is placed in front of architectural masonry walls or precast panels that are not specifically designed to handle impact loads. In this case it would be important to limit deflection so that an impacting vehicle would be stopped before it impacted the wall (and sent debris to the ground below). It may also be necessary to limit deflection to the point where a vehicle will not impact cars in opposing stalls or the edge of the slab at adjacent ramps.

When calculated deflection exceeds allowable deflection, the designer has two options:

Increase the pretensioning force in the barrier cable strands (explained in the next section)

or

Add intermediate anchorage devices which shorten the effective length L

Using the previous example and adding intermediate anchorage devices on either side of column line 6 will shorten the effective total length (L) to 100 ft, which reduces deflection (a) to 1.32 ft.

The need for intermediate anchorage devices should be determined by the structural designer and their locations should be clearly shown in the contract documents.

3.3 Calculating the capacity of the barrier cable system

The load on a cable during a vehicle impact is not constant in value, but actually changes with deflection. Therefore, the method originally presented in Concrete International[5] termed the "energy method" is the more rational approach to barrier cable design. This method is based on energy principles where the kinetic energy of a moving vehicle is converted to cable force and deflection. Using this method, the designer can accurately calculate both the tension in a cable and the deflection in a cable resulting from the impact of a vehicle of a given mass traveling at a given velocity.

The method consists of two steps; first, determining the tension (T) in a cable upon impact, and then determine the resulting deflection (a). Figure 3.3.1 illustrates a cable of total length L strung between two points A and B. The cable is assumed to be supported by frictionless[fb10] bearing points at C and D.

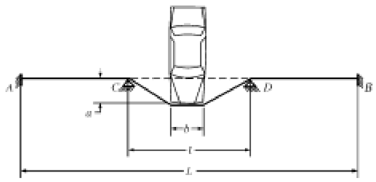


Figure 3.3.1 – Deflection Under Vehicle Impact

This figure represents a typical straight run of barrier cable, anchored only at its end points (A and B). The run may have several spans in its ~~length~~length, but the designer should use the longest span l to calculate tension in the cable as follows:

$$T = \sqrt{\left(\frac{EA}{L}\right)\left(\frac{MV^2}{N}\right) + F_e^2}$$ [fb11] $$T = \sqrt{\frac{EA}{L} * \frac{MV^2}{N} + F_e^2} \quad (3)$$

Where N is the number of cables resisting the impact, V is the velocity of the vehicle in ft/sec, and M is the mass of the vehicle calculated as:

$$M = \frac{VehicleWeight}{g} \quad (4)$$

The designer starts by choosing an initial value of prestressing force Fe in order to calculate T. The resulting value is then used in the following equation to calculate the deflection of the cable (a) upon impact.

$$a = \sqrt{\left[\left(\frac{T - F_e}{2AE}\right)L + l - b\right]\left[\left(\frac{T - F_e}{2AE}\right)L\right]} \quad (5)$$

If calculated deflection exceeds allowable deflection, the designer can choose a higher value for Fe and recalculate the resulting force T and deflection a, or intermediate anchors can be added (as described in Section 3.2) and then recalculate T and a using the smaller value of L.

As a check against the IBC requirements, the following equation can be used to ensure the system meets the 6000 lb ~~point~~ concentrated load requirement.

$$T = \frac{(6000/N)\times l}{4a} \qquad (6)$$

Note that a static load of 6,000 lbs is roughly equivalent to a 5,000 lb vehicle impacting the cables at a velocity of 5 mph (~~14.67~~ 7.35 ft[fb12]/sec).

g = 32 Ft / sec^2

therefore M = 156 Lbs $\frac{sec^2}{Ft}$

V = velocity of the vehicle = 5 mph = 7.35 $\frac{Ft}{sec^2}$

In either equation, the resulting value of T is the total tension present in each resisting cable upon vehicle impact. This value should be compared with the yield strength of the cables (not the breaking strength) to determine the factor of safety against yielding. If prestressing steel strand conforming to ASTM A416 is used, yield is calculated as 90% of Minimum Ultimate Tensile Strength.

3.4 Column Design

The connecting column or wall must be designed to resist the total lateral load that is transmitted to them. This load includes both the initial prestressing force that is present in each cable, plus the added force generated by a vehicle impact, with the 1.6 load factor included[AB13]. This is calculated by using the highest value obtained for T (from Equation 3 or Equation 6) and multiplying it by the number of cables used to resist the impact N, then adding the product of the remaining cables multiplied by the prestressing force (Fe) that has been applied.

Each of the connecting columns should be evaluated to ensure they are able to withstand this total lateral force. This is usually not a controlling factor on a typical column that spans from floor to floor. However, examples in the next section will show that total prestressing force plus the force generated upon impact can be well over 40,000 lbs which can be a factor when using short “stub” columns on the top level of a garage.

Since these short columns do not connect above, they do not have the same capacity as the other “typical” columns. This condition should be carefully evaluated to determine the need for additional reinforcing at the anchoring column(s).

Another factor to consider when using these stub columns is the ability of the intermediate stub columns to resist the same lateral impact load as the rest of the barrier system. In other words, the columns themselves must be able to resist the lateral forces of a vehicle impact without failure. Failure of intermediate stub column(s) upon impact would greatly increase the effective length of l, thereby increasing the deflection (a) to the point of not providing adequate protection. It is particularly important to evaluate this condition when using small steel columns that are simply anchored to the floor.

4.0 PRESTRESSING TO ELIMINATE CABLE SAG

A minimum amount of prestressing force must be applied to the cables to eliminate sagging of the cables under their own weight. PTI's Specification for Seven Wire Steel Strand Barrier Cable Applications[3] in Section 5.4 requires all cables to be stressed to a minimum force (Fe) of 2 kips [8.9 kN] for 18 ft [5.5 m] spans in order to limit sagging to an acceptable value.

Excessive sag in the cables is not visually appealing and it may allow the passage of a 4 in. diameter sphere even though cable spacing is less than 4 in. For example, if cable spacing is 3.5 in. but there is 1 in. of sag in the cables, a 4 in. diameter sphere will pass through the opening if enough force is applied to overcome the weight of the cable. Conversely, if cable spacing is 3.5 in. and sag is reduced to 1/8 in., a 4 in. diameter sphere will not pass through unless enough force is applied to start elongating the steel itself.

Cable sag is a function of the weight of the cable itself and the spacing of its supports (l). The following equation[6] is used to calculate sag in barrier cable due to self-weight (w).

$$s_{inches} = \frac{l^2 w}{8F_e} \qquad (7)$$

Using the weight of galvanized PC strand, and based on the recommendation of using a prestressing force of 2000 lbs for an 18 ft span, allowable sag calculates to approximately 1/8 in. It is recommended that this ratio (1/8 in. per 18 ft or 0.007 in./ft) be used in calculating the maximum[AB14] allowable sag in spans longer than 18 ft.

Using this ratio and solving for Fe, the equation for calculating the minimum prestressing force required to reduce sag to an acceptable level is:

$$F_e = \left(\frac{l^2 w}{s/12}\right)/8 \qquad (8)$$

Replacing (s) with the ratio of 0.007l, the equation becomes:

$$F_e = \left(\frac{l^2 w}{(.007 \times l)/12}\right)/8$$

$$F_e = \left(\frac{l^2 \text{[fb15]} W * 12}{0.007\ l}\right)/8 \qquad (9\text{[AB16]})$$

W = weight per linear foot of 270 KSI, 0.5” diameter galvanized cable. This value may vary with the supplier of strand. We are using 0.550 Lbs / LF in our calculations

~~The chart included as Appendix A of the Specification for Seven Wire Steel Strand Barrier Cable Applications lists approximate values for the weight of various types of strand used as barrier cables. Use these values in the above equation to ensure that the prestressing force being used will eliminate sag to an acceptable value~~. If the force obtained in Equation 9 is higher than the value used in the design equations the designer has two options:

- Use the higher prestressing force obtained in Equation 9 and re-run the design equations, finding a new value for T, a, and for the total load being applied to the anchoring columns.
- Add some type of intermediate spacers or supports to reduce the value of l in Equation 9.

Adding intermediate spacers or supports increases material and labor costs, but may be necessary in garages with very long spans or where it is not desirable to increase the loading on the anchoring columns (or brackets). Note that since these spacers do not provide any lateral ~~resistance~~ resistance, they only reduce the value of l as used in Equation 9.

5.0 CALCULATING JACKING FORCE

As previously stated, the relatively low prestressing force (Fe) that is applied to the cable to reduce deflection and eliminate sag is not enough to properly seat the wedges into the anchorage devices typically used with seven wire steel strand barrier cable systems. These wedge type anchorage devices are designed to form a mechanical (not a friction) connection between the cable, the wedge, and the anchor, when the wedges are fully seated. It takes an applied force equivalent to 80% of the Minimum Ultimate Tensile Strength (MUTS) of the cable to fully seat the wedges. When using ½ in. grade ~~250 PC strand, this force is 30,600 lbs~~ 270 PC strand, this force[fb17] is 33[AB18],050 Lbs , much higher than the prestressing force (Fe) that is being applied to the cables.

In order to apply the required seating force, the installer must backstress the cable at all anchors to the required 80% of MUTS. This involves stressing each cable to a force equivalent to the calculated final effective force (Fe) plus an additional force needed to compensate for the seating loss that will occur, then removing the stressing jack and using it on the other side of the anchoring assembly to apply the required 80% of MUTS and fully seat the wedges.

The actual technique used for backstressing will depend on the particular job site conditions and is explained in more detail in Section 5.4 of the Specification for Seven Wire Steel Strand Barrier Cable Applications.

It is appropriate to assume that the anchorage will experience the full seating loss only upon backstressing. This value is typically ~~3/8~~ ¼ in[fb19][AB20]. but can vary depending on the particular anchorage system being supplied. The following equation can be used to calculate the jacking force (Fpj) that will be required to maintain the required final effective force (Fe) that was determined in the design equations.

$$F_{pj} = F_e + \frac{SeatingLoss \times A \times E}{12 \times L} \quad (10)$$

Since seating loss can vary according to the type of anchorage system and/or stressing equipment being used, it is typically not appropriate for the designer to specify a required jacking force, but instead should specify the required final effective force (Fe) and then require the barrier cable material supplier to calculate the required jacking force according to materials and equipment being supplied to the project. The supplier should submit this jacking force to the designer as part of the submittal package. The supplier should also supply a stressing equipment calibration chart with the stressing equipment that is being supplied to show the gauge force that corresponds to the required jacking force.

6.0 DESIGN EXAMPLES

6.1 Meeting pedestrian requirements

All of the following design examples will use 11 cables, spaced at 4 in. center to center, with the center of the first cable positioned 3.5 in. above the floor. Using ½ in. cable, this results in a 3.5 in. spacing between each cable, and the height of the center of the top cable is 43.5 in.

[fb21]

Assuming the cables have enough prestressing force applied to them to limit sag and deflection, this will meet the requirements relating to opening sizes and total overall height.

6.2 Number of cables resisting impact

The International Building Code requirements state that the system must resist an impact load located a minimum of 18 in. from the floor and centered on a 1 sq ft area. Given ~~this criteria~~these criteria and the cable spacing cited above, all of the following examples assume that a total of three (3) cables will resist the vehicle impact.

6.3 Example 1

The mass of the vehicle is determined by Equation 4:

Total length of cable (L)	= 180 ft	
Span length (l)	= 18 ft	
Cable		
	Grade	= 250 ksi[fb22][AB23]
	Yield strength	= 90% MUTS
	Cross sectional area (A)	= 0.153 in^2
	Modulus of Elasticity (E)	= 28,500,000
	Weight of vehicle	= 5,000 lbs
	Width of vehicle	= 6 ft
	Impact velocity	= 5 mph

The mass of the vehicle is determined by Equation 4:

$$M = \frac{5000}{32} = 156 lb - \sec^2 / \; ft$$

Select an initial pretensioning force (F_e) of 3,000 lbs and calculate the tension upon impact using Equation 3:

$$T = \sqrt{\left(\frac{0.153 \times 28,500,000}{180}\right)\left(\frac{156 \times 7.34^2}{3}\right) + 3,000^2} = 8,768 lbs$$

Using this pretensioning force, deflection is calculated using Equation 5[AB24]:

$$a = \sqrt{\left[\frac{(8768 - 3000)180}{2 \times 0.153 \times 28,500,000} + (18 - 6)\right]\frac{(8768 - 3000)180}{2 \times 0.153 \times 28,500,000}} = 1.2 \; ft$$

The yield strength of the cable is 34,425 lbs, which results in a factor of safety against yielding in this example of 3.93. Total load transmitted to the end (anchoring) columns would be:

$$(8768 \times 3) + (3000 \times 8) = 50,305 lbs$$ [fb25]

Use Equation 6 to check conformance with building code requirements

$$T = \frac{(6000 / 3) \times 18}{4 \times 1.2} = 7,500 lbs$$

Since this result is lower than the value obtained for T using the energy method, no additional steps are required.

To determine the required jacking force[AB26], assume the supplier has given a value of 3/8 in. for expected seating loss and use Equation 10 as follows:

$$F_{pj} = 3000 + \frac{0.375 \times 0.153 \times 28,500,000}{12 \times 180} = 3,757 lbs$$

6.4 Example 2

All of the above data is the same, except span length (l) is increased to 27 ft and the total length (L) is increased to 270 ft.

Using the same initial prestressing force (Fe) of 3,000 lbs and solving for T:

$$T = \sqrt{\left(\frac{0.153 \times 28,500,000}{270}\right)\left(\frac{156 \times 7.34^2}{3}\right) + 3,000^2} = 7,366 lbs$$

Using this force, deflection is calculated as

$$a = \sqrt{\left[\frac{(7366 - 3000)270}{2 \times 0.153 \times 28,500,000} + (27 - 6)\right]\frac{(7366 - 3000)270}{2 \times 0.153 \times 28,500,000}} = 1.69\, ft$$

In order to limit deflection to 1.5 ft, use a higher initial prestressing force of 5,000 lbs and recalculate the resulting tension (T) and deflection (a):

$$T = \sqrt{\left(\frac{0.153 \times 28,500,000}{270}\right)\left(\frac{156 \times 7.34^2}{3}\right) + 5,000^2} = 8,382 lbs$$

and deflection is

$$a = \sqrt{\left[\frac{(8232 - 5000)270}{2 \times 0.153 \times 28,500,000} + (27 - 6)\right]\frac{(8232 - 5000)270}{2 \times 0.153 \times 28,500,000}} = 1.49\, ft$$

This limits deflection to 18 in. but total lateral force transmitted to the anchoring columns increases due to the increase in prestressing force applied to the cables.

$$(8232 \times 3) + (5000 \times 8) = 64,146 lbs$$

Since the span length exceeds 18 ft use Equation 9 to calculate the minimum amount of prestressing force required to reduce sag to an acceptable value in the 27 ft span.

$$F_e = \left(\frac{27^2 \times 0.544}{(0.007 \times 27)/12} \right) / 8 = 3{,}147 lbs$$

Since the force being used (Fe=5,000 lbs) exceeds the force required to reduce sag, no further steps are required.

6.5 Example 3

This example will use the same spans given in Example 1, but will increase the vehicle weight to 17,000 lbs (delivery vehicle on a plaza level[AB27]):

The mass of the vehicle is

$$M = \frac{17{,}000}{32} = 531 lb - \sec^2 / \ ft$$

Use an initial prestressing force of 3,000 lbs and solve for T:

$$T = \sqrt{\left(\frac{0.153 \times 28{,}500{,}000}{180} \right) \left(\frac{531 \times 7.34^2}{3} \right) + 3{,}000^2} = 15{,}486 lbs$$

Using this value, the resulting deflection is

$$a = \sqrt{\left[\frac{(15486 - 3000)180}{2 \times 0.153 \times 28{,}500{,}000} + (18 - 6) \right] \frac{(15486 - 3000)180}{2 \times 0.153 \times 28{,}500{,}000}} = 1.78 ft$$

In this example, the prestressing force would have to be increased to 9,000 lbs in order to limit deflection to 1.5 ft, which would increase the total load transmitted to the anchoring columns to 125,000 lbs. Deflection could also be limited to 1.5 ft by adding intermediate anchorages to reduce the total effective length (L) to 90 ft and increasing prestressing force to 4,000 lbs. This would reduce the total load transmitted to the columns to 98,000 lbs, but the use of the shorter cable length decreases the factor safety against yielding to 1.6.

Another option would be to decrease cable spacing in the area of impact and use five cables pretensioned to 4,000 lbs to resist the impact. This would limit deflection to 1.46 ft and would increase the factor of safety to 2.8.

7.0 SHORT SPAN CALCULATIONS EXAMPLES

I- Design elements to be validated:

a. Deflection limit
   i. The shorter the span, the smaller the deflection of the cable at impact. The deflection of the cable must be validated (and is provided for the examples below), but is not a concern for short spans

b. Capacity of the Barrier Cable System:
   i. Calculate the tension created in a cable at vehicle impact, using the Energy[AB28] Method described above
   ii. Once the tension is calculated, the capacity of each component of the vehicle barrier cable system should be validated as being able to sustain this load, with a proper safety factor
   iii. F_e = final effective tension force in the cable after seating losses. This value should be selected to minimize cable sag between support points, and to ensure cable deflection at impact is less than 18 inches. For short cables, deflection does not come into play. For the short span calculations in this technical note, Fe is set equal to 4[AB29],000 Lbs

II- Capacity of the various components of a vehicle barrier cable system

a. The cable

i. The tension applied to a cable is compared to its yielding capacity. Per code, the yield is defined as 90% of maximum ultimate tensile strength.

ii. For a 0.5” 270 KSI cable, yield= 37,179 Lbs

b. The anchorage system

i. PT anchorage (either barrel anchor or anchor with barring surface), either live end or dead end anchor

1. Per ACI 423.7, the PT anchor shall develop at least 95% of F_{pu} of the cable. Therefore, the PT anchorage systems will always have a capacity greater than the yield of the cable and is not a concern for design verification purposes.

ii. Adjustable anchorage system

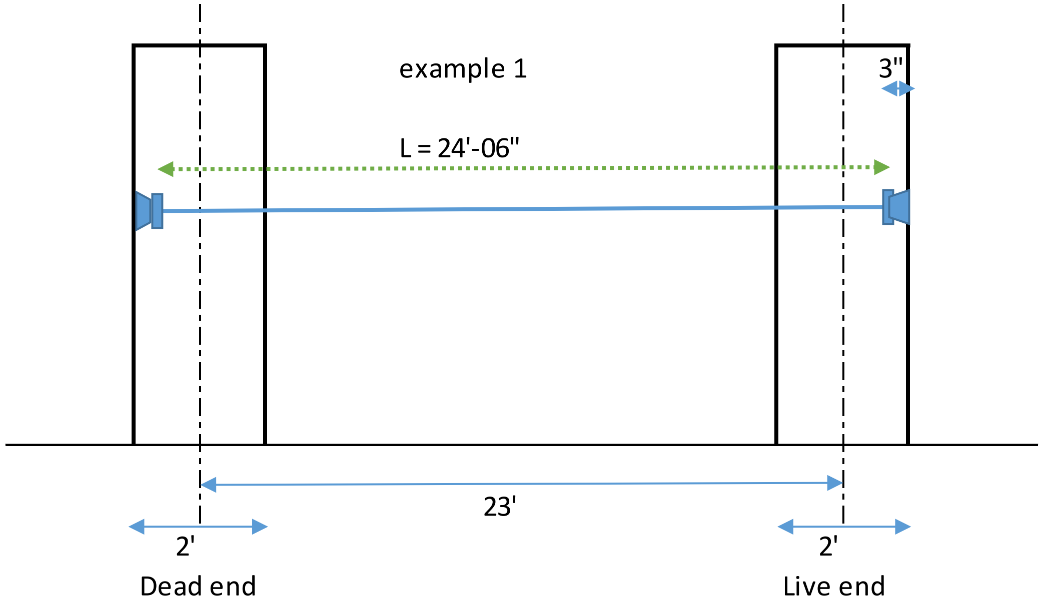
1. An adjustable anchor system is typically made of a barrel anchor attached to a spinning / threaded bolt (adjustable). This assembly is typically threaded into an insert embedded into the concrete support (column or wall).
2. For these systems, it is necessary to verify the capacity of the anchorage assembly and the insert connecting it to the support.
3. The capacity of each system will depend on the type of system selected (different manufacturers) and the capacity of the insert will depend not only on the type of insert used but also on the support’s concrete strength and the installation method (how is the insert secured in the support). Design of systems that anchor to the supporting concrete should be designed in accordance with ACI 318 Chapter 17.

iii. Other anchorage systems: refer to the manufacturer’s design capacity for verification

III- Determination of the shortest allowable span

Based on the design example below, we can conclude that the shortest length of barrier cable that meets the requirements of the energy method and the IBC code is approximately[AB30] 23 ft.

Example 1



Column span from center line of column to center line of column is 23' [fb31](the distance from anchorage to anchorage is about 24'-06" based on 2.5" pocket formers). The anchorage system is using PT anchors with pocket formers, with either end being the stressing (live) end.

Per the formula (1) above, using F_e = 4,000 Lbs:

T = 22,715 Lbs

i. We verify that the safety coefficient applied to the yield of the cable is at least 1.6:

37,179 / 22,715 = 1.637 > 1.6 pass

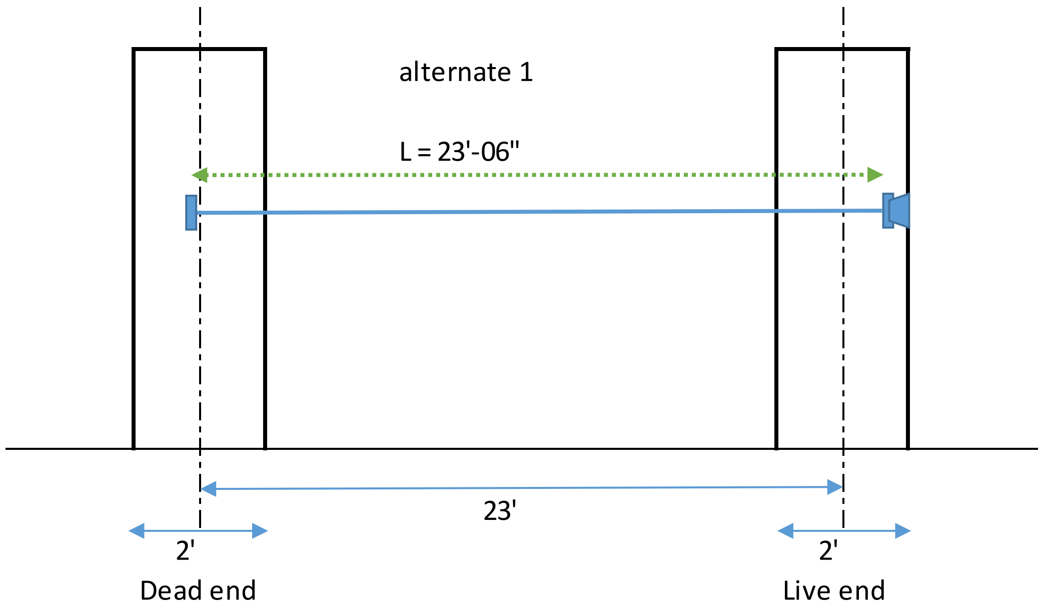
ii. We verify that F_e value selected for the pre-stressing force (4,000 Lbs) is sufficient to remove the sag of the cables using formula (2) :

$F_e = (\frac{23^2 * 0.550 * 12}{0.007 * 20})$ / 8 = 3[AB32],117 Lbs < 4,000 Lbs - OK.

The 23' span from support to support works when using PT anchors embedded at the end of each support, with supports at least 2' wide.

Alternate 1:

We use the same span and support configuration, but this time the dead end is fully embedded inside the support, just past the center line. In this configuration, L is reduced to 23’-06”

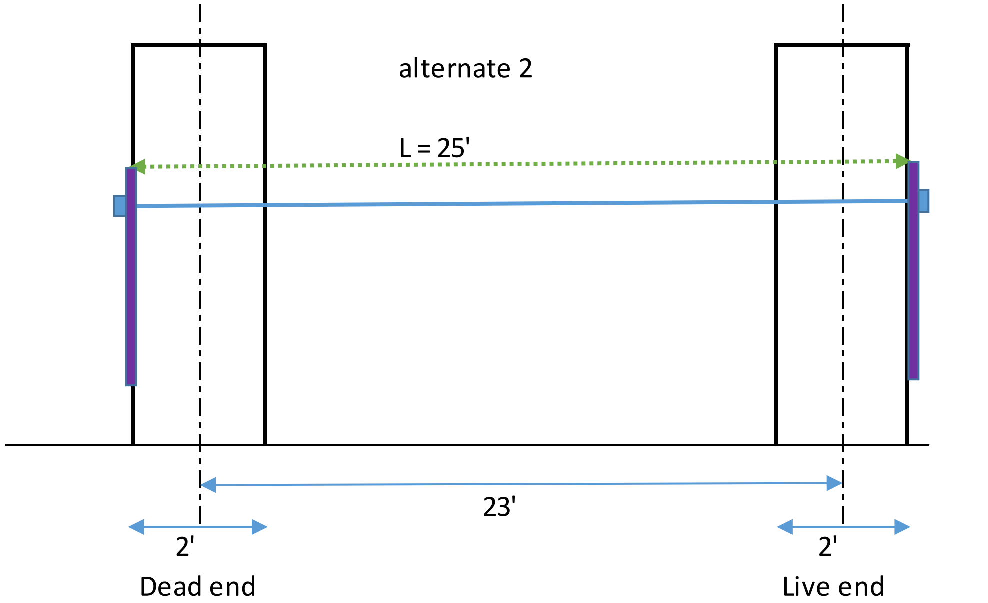


T = 23,179 Lbs and Fe = 4,000 Lbs

37,179 / 23,179= 1.604 > 1.6 pass

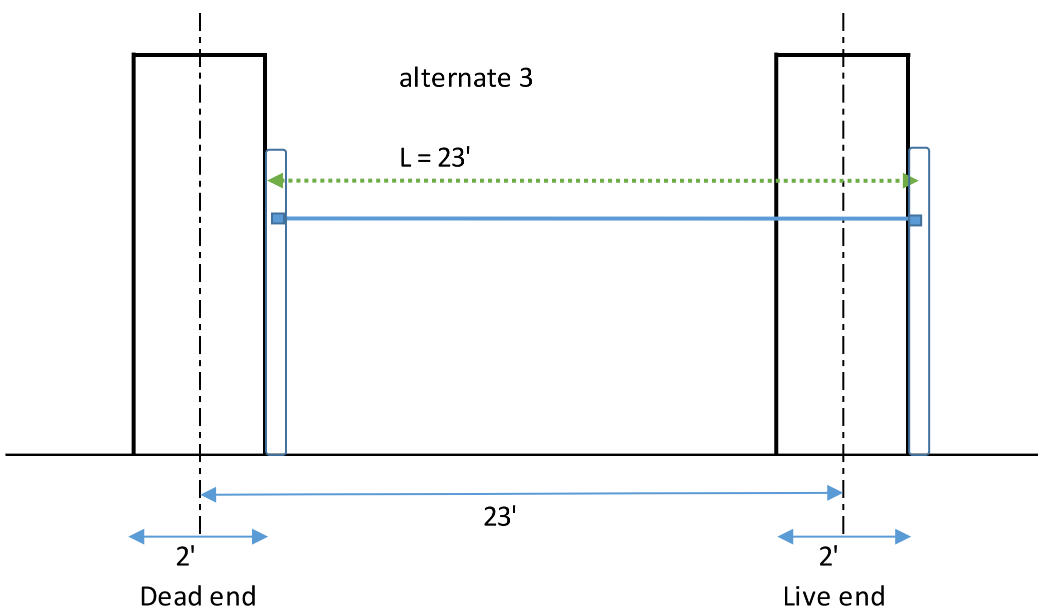
Alternate 2:

We use the same span and support configuration, but this time both ends are anchored with barrel anchors, bearing on a metal plate placed on the outside of each support. In this configuration, L is increased to 25’ and therefore T will be less than in example 1 .The minimum requirement of 1.6 for the safety coefficient is met.



Alternate 3:

We use the same span and support configuration, but this time the dead end is installed at the face of one of the supports. In this configuration, L is reduced to 23'. This may be required due to constructability issues, where there is no access to the back of a supports (such as one support being a wall or having an expansion joint at its back) or due to architectural requirements:

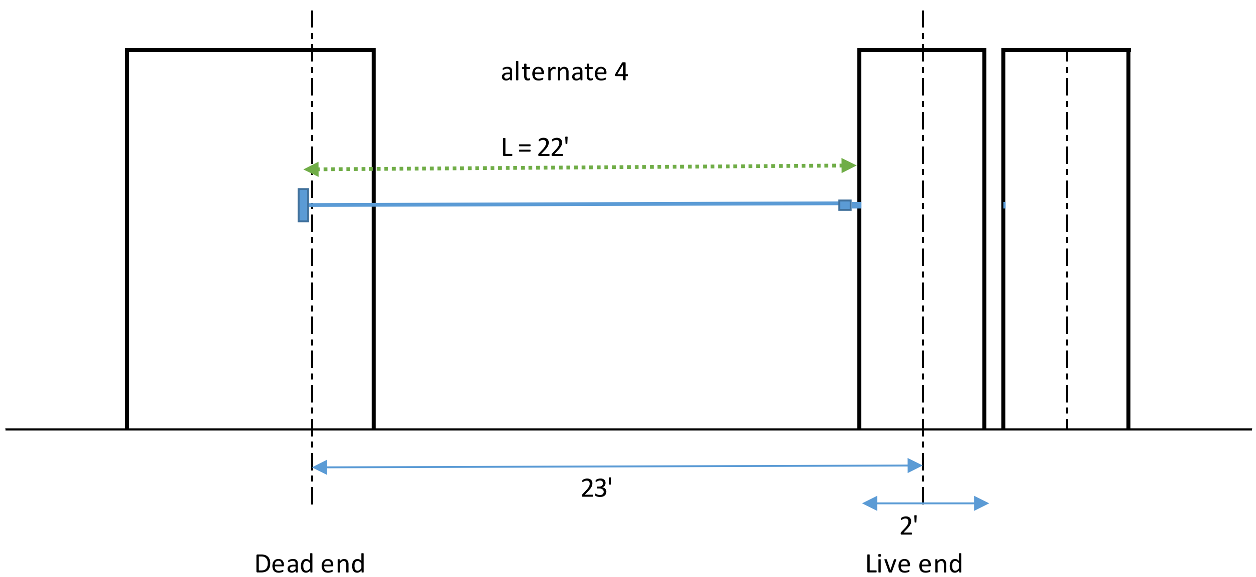


T = 23,422 Lbs and Fe = 4,000 Lbs

37,179 / 23,422 = 1.588 < 1.6 Fail

Alternate 4:

We use the same span configuration, but this time the live end has to be installed at the face of a support, and therefore uses an adjustable anchorage system, while the dead end can only be embedded 1 foot deep into the other support, with no access to its back. In this configuration, L is reduced to 22’. This may be required due to constructability issues, where there is no access to the back of either supports (such as one support being a wall and the other having an expansion joint at its back) or be an architectural choice:



T = 23,933 Lbs and Fe = 4,000 Lbs

37,179 / 23,933 = 1.55 < 1.6 Fail

8~~7~~.0 LIST OF NOTATIONS

A = Cross sectional area of cable, in2

a = Cable deflection, ft

b = Width of vehicle, ft

E = Modulus of elasticity of cable, lb/in2

F_e = Final effective pretensioning force, lbs

F_{pj} = Jacking force, lbs

g = Acceleration due to gravity (32.174 ft/sec2) L = Total length of cable, anchor to anchor, ft l = Span of cable between supports, ft

M = Mass of vehicle, lb-sec2/ft

N = Number of cables resisting impact

P = Applied load, lbs

s = Sag in cable due to self weight, in.

T = Cable tension on impact, lb

V = Velocity of vehicle, ft/sec.

w = Weight of cable per ft, lbs

~~8~~9.0 REFERENCES

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~~6.~~16. ADD ASCE 7 Reference