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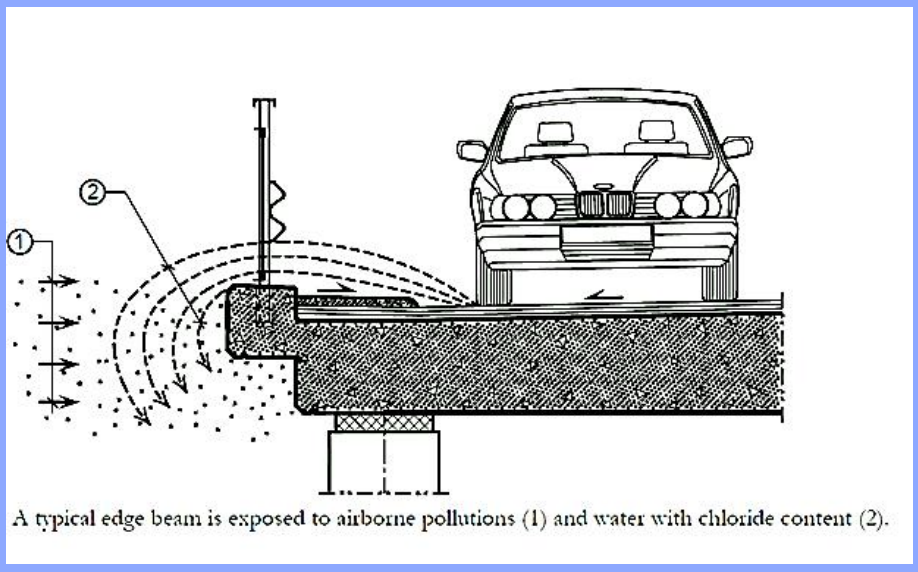

A typical edge beam is exposed to airborne pollutions (1) and water with chloride content (2).

Optimal Edge Beam System

International study

Adebowale Fasheyi

Stockholm 2013

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Optimal Edge Beam System

International Study

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Preface

This international study project is carried out by the *Structural Engineering and Bridges Division* at KTH Royal Institute of Technology for the Swedish Transport Authority (Trafikverket) under the supervision of Professor Håkan Sundquist and Professor Lars Pettersson.
Authorities and engineers concerned with bridges around the world have participated in the international survey which is the basis of the study. Detailed drawings that assisted the project team were received from bridge authorities in Canada, Austria and Denmark.

Stockholm, June 2013

Adebowale Fasheyi

Abstract

The bridge edge beam system is a vital component of the bridge that guards the bridge users and traffic, especially from falling off the bridge. The edge system is not usually protected, like the bridge deck which is usually protected with membrane and asphalt layers, therefore the edge beams are vulnerable to harsh weather conditions, maintenance operations, vehicle crashes, de-icing salts and other detrimental conditions which lead to damage, corrosion and degradation of the system.

In developing an optimal edge beam system, an international electronic survey have been used in gathering experience, problems and solutions concerning bridge edge beam system, having in mind that the weather conditions in different regions of the world affect the edge beam system. From the results of the survey an ideal edge beam system should be an integrated edge beam system with steel railings and an upstanding edge that will not allow water to run off naturally from the bridge. The railing post should be coupled with bolts and nuts to the edge beam and the concrete should be of high grade, such that it will withstand harsh weather conditions and environmental influences. The reinforcement should be rust free, preferably stainless, painted or hot dip galvanized.

Keywords/phrases: Edge beams, de-icing salts, degradation, and international survey

Sammanfattning

Brokantbalkssystem är en viktig del av bron som skyddar brons användare och trafiken på bron, i synnerhet från att falla av bron. Kantsystemet skyddas vanligtvis inte, som brobaneplattan, som vanligtvis skyddas med membran- och asfaltslager, p.g.a. detta utsätts kantbalkar för svåra väderförhållanden, underhållsarbeten, fordonskrascher, avisningssalter och andra skadliga förhålanden som leder till skador , korrosion och nedbrytning av systemet.

Vid utveckling av ett optimalt kantbalkssystem har en internationell elektronisk enkät använts för att samla in erfarenhet, problem och lösningar kring broars kantbalkssystem med hänsyn till att vädret i olika delar av världen påverkar kantbalkssystemet. Enligt resultaten av undersökningen bör ett idealiskt kantbalkssystem vara ett integrerat kantbalkssystem med stålräcken och en uppstående kant som inte låter vattnet rinna av naturligt från bron. Räcket bör fästas med bultar och muttrar till kantbalken och betongen bör vara av hög kvalitet så att den tål tuffa väderförhållanden och miljöpåverkan. Förstärkningen ska vara rostfri, helst målat eller varmförzinkat.

Nyckelord: Kantbalkar, avisningssalter, nedbrytning och internationell undersökning

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1 Introduction

The bridge edge beam system (BEBS) is a vital component of a bridge. The bridge edge beam system protects both the traffic on the bridge and the traffic/environment under the bridge. Safety is the major priority in the use of bridges and the bridge system is the key element guarding bridge users to safety. BEBS consist of the edge beam, the railing that guards bridge users and stands as crash barriers, it also consist of other secondary components such as the lamp post. Structurally the edge beam is the longitudinal end of the bridge. It gives the bridge deck rigidity. Damage to the BEBS will subsequently mean damage to the bridge deck and the whole bridge.
BEBS is exposed to airborne pollutions and water with chloride contents. It is also not protected by waterproof membrane like the bridge deck; this makes it vulnerable to degradation that is expensive to repair or replace. Approximately 60% of the life cycle cost of a bridge structure is created by the BEBS. It is therefore imperative to develop new ideas that will reduce this percentage of LCC.

This study is part of a research on bridge edge beam systems conducted at KTH Royal Institute of Technology's Structural Engineering and Bridges Department in collaboration with Trafikverket (The Swedish transport administration) and it is driven by the need to create innovative solutions to the various problems associated with BEBS and demand for new solutions. The expected outcomes of the study will be internationally obtained measures to increase the life span of BEBS and at the same time reducing the LCC, innovative solutions to various problems associated with edge beam systems.

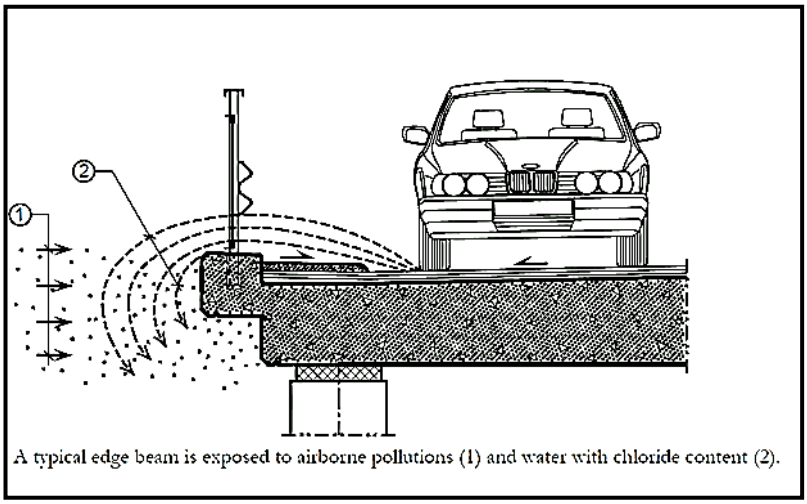


Figure 1.1: Typical bridge edge beam

Components of the bridge edge beam system

- Main components
    - Edge beam
    - Railings, could be concrete, steel or combined railings
- Secondary components
    - Lamp posts
    - Walkway and preceding railings and curb system
    - Cable, hanger and post tension anchorages
    - Drainage system
    - Fencing system

Figure 1.2: BEBS components. Source: http://happypontist.blogspot.se

1.1 Aim

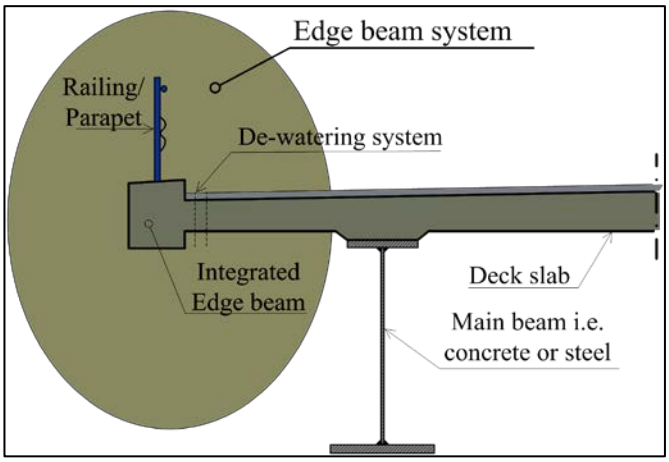
This international study is aimed at obtaining the experience of problems with BEBS in different parts of the world. Having in mind that different weather conditions in different regions of the world determines the requirements and conditions of bridge maintenance. In cold regions for example, winter maintenance may require the use of de-icing salts whereas bridges in warm regions do not require such maintenance. Are BEBS affected by the regions in which they are located? Are BEBS affected by various maintenance practices in different regions of the world? How is the life span of BEBS affected? These questions are expected to be answered by this study.

This study is also aimed at obtaining from different regions of the world design proposals and probable solutions to the various problems associated with the BEBS.

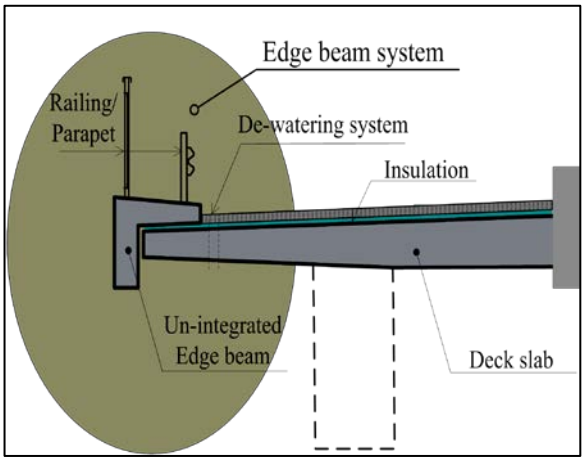
1.2 Edge beam types

Edge beam systems can be classified in different ways according to design, material, drainage system etc. For the purpose of this study edge beam types are categorized as follows;

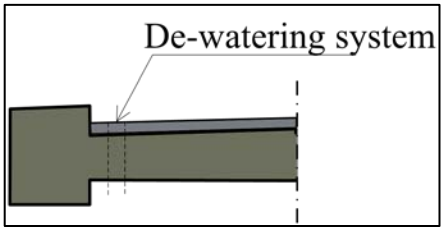
1. According to design
    a. Integrated edge beam
    b. Not-integrated edge beam
2. According to de-watering or drainage criteria
    a. Upstanding edge beam
    b. Low edge beam
3. According to railing/barrier system
    a. Steel barrier edge beam
        i. Post coupled to the edge beams using bolts and nuts
        ii. Post grouted into a recess
    b. Concrete barrier edge beam
        i. Integrated concrete edge beam
        ii. Prefabricated concrete edge beam
    c. Steel concrete combined edge beam



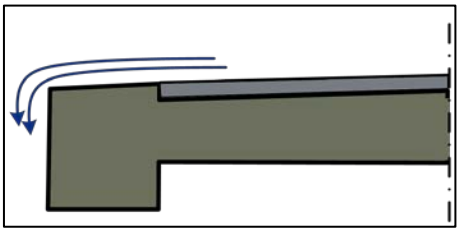
Integrated edge beam system



Not-integrated edge beam system

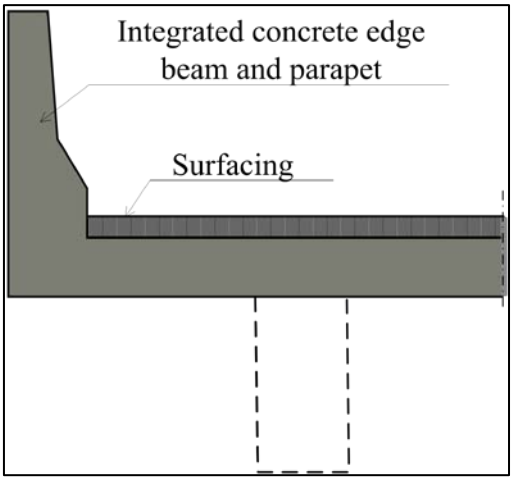


Upstanding edge beam

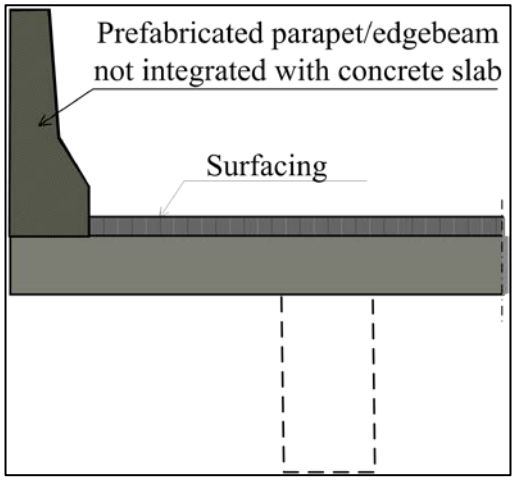


Low edge beam

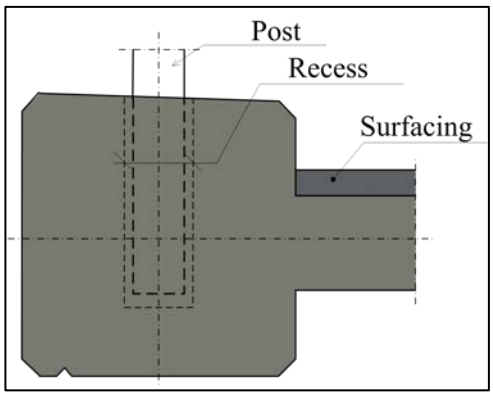
Figure 1.3: Edge beam types. Source: Håkan Sundquist



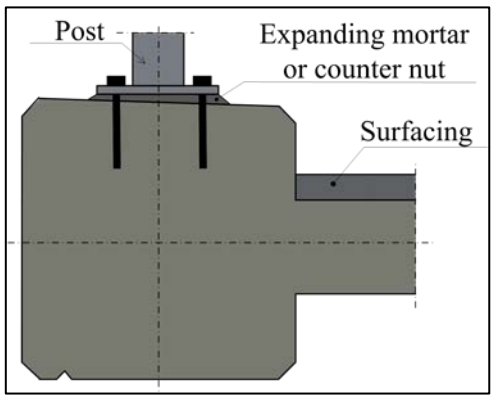
Integrated edge beam with concrete parapet



Not-integrated with prefabricated concrete parapet



Edge beam with post grouted into recess



Edge beam with post coupled with bolt and nuts

Figure 1.4: Edge beam types. Source: Håkan Sundquist

1.3 Problems with BEBS

The BEBS is associated with two major problems, cracking and subsequently spalling of the BEBS concrete and corrosion of the BEBS reinforcement. Both problems lead to degradation of the BEBS. The major cause of these problems is water with deleterious contents percolating into the BEBS, these waters freeze in subzero temperatures causing the concrete to expand and subsequently cracking and spalling. The simplest solution is by preventing this kind of water to come in contact with the BEBS. Problems and perceived causes are listed below.

- Degradation of the edge beam
- Corrosion of reinforcement and cables in edge beams and deck
- Corrosion of steel railings
- Durability and resistance of the constituting concrete to physical, chemical and biological attacks
- Freeze thaw attacks

- Abrasion, erosion and cavitation
- Heat and fire damage
- High level of salinity in the sea and atmosphere (for bridges in the coastal area and waters)
- Water, de-icing salts and other deleterious materials infiltration into the edge beam
- Water tightness, porosity, permeability of the edge beams
- Sway of lamp posts from wind loads causing cracks and other strength compromise in the edge beams
- Collisions, accidents and impact loads on the railings questioning the strength, toughness and impact resistance of the edge beams and railing systems as its primary function is to protect vehicles and bridge users from running off the bridge
- Secondary problems arising from pavement repairs. Water jetting and use of jack hammer during asphalt ripping to effect asphalt wear layer replacement.
- Temperature difference, creep, curling causing cracks on the edge beams
- Problems arising from damaged expansion joints
- Problems arising from ambiguous architectural designs

1.3.1 Sources of water

Contaminated water e.g. water from chloride/de-icing salt, alkali-silica reaction etc. percolate into the edge beams and deck

- Through the anchorage, in the case of post tensioned decks, hangers, cable stayed and suspension bridges
- Through the railing fittings
- Through the grooves between the raised edge beam level
- Through the deck/edge beam surface

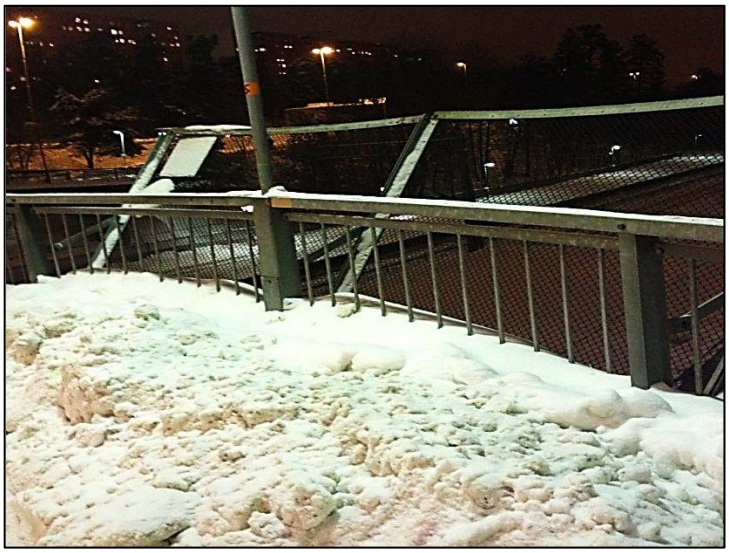


Figure 1.5: Snow pile contaminated with de-icing salt on the BEBS causing chemical attack on concrete and reinforcements

The water ingress into the BEBS subsequently causes several damages as listed in 1:3 above. It creates a network of cracks that leads to spalling. It aids the sedimentation of dirt and vegetation growth.

Figure 1.6: Vegetation growth that subsequently aids biological attacks on the BEBS
Source: Johan Silfwerbrand

1.3.2 Degradation of edge beam systems

Degradation is the combination of several other damaging processes. The process begins with the erosion of the concrete's protective layers by chlorides. Concretes are generally porous and allow water to percolate into it. In cold regions percolated water in the concrete pore freezes in subzero temperatures causing freeze thaws which in turn causes the concrete to crack. The crack opens up the concrete creating more pores and allowing more water ingress. The crack subsequently becomes a network of cracks leading to spalling/peeling of concrete.

When contaminated water percolates into concrete, it erodes the concrete protecting the reinforcement and thereby leading to corrosion of the reinforcements, this corrosion is being speed up with heat arising from high temperature and high humidity. The rust created by corrosion often decreases the strength of steel and increases the volume; this further strains the concrete creating more cracks and damage to the concrete.

Reinforcement corrosion in the edge beam compromises the strength of the bridge. If degradation of the BEBS is not fixed in good time it deteriorates the bridge condition, thereby reducing the bridge life span and increases the life cycle cost. The figures below illustrate some forms of degradation in BEBS.

Figure 1.7: Cracks, corrosion and degradation in BEBS

Figure 1.8: Degradation

Figure 1.9: Faulty expansion joints causing excessive movements at the edge beam can also create cracks and damage to the edge beam

1.4 Probable solutions to problems with bridge edge beams

Some solutions are given to problems with edge beams, they include

- Avoid anchorage on the deck surface
- Provide good runoff and drainage system
- Cathodic protection of reinforcements
- Special fiber concrete
    - Reduced mass leading to easier, faster and more economical installations
    - Good durability in particular to atmospheric degradation and de-icing salts

    - Ability to form prefabricated complex shapes
    - Good thermal properties
- Use of corrosion inhibitors (Cortecvci.com is a popular producer)
    - Corrosion inhibitor is a bio-based material made from by-products of naturally-occurring material, such as concentrated sugar beet. It is added to concrete mix, as well as an inhibitor it is also used as a coating for repairs where cracks appear. It is an environmentally safe sustainable technology.
- Extra high concrete quality
- Extra-large covers
- Rust free (stainless) reinforcements/corrosion resistant steel
    - MMFX makes a good corrosion-resistant steel that has a chloride threshold that is four times higher than the standard black steel
- Use of seals, membranes and other coatings to protect steel
    - Impregnating
    - Water proofing
        - Gel-based Turbostar is a product used for waterproofing membranes where corrosion has led to leaks. It is a non-curing gel that is solvent-free and contains no volatile organic compounds. Some 25% of the product is also made from recycled tires.
- Appropriate design to allow edge beam systems to be self-resistant and safe in the performance
    - Cladding the edge beam with aluminum, glass and other available products. The figure below shows a typical example

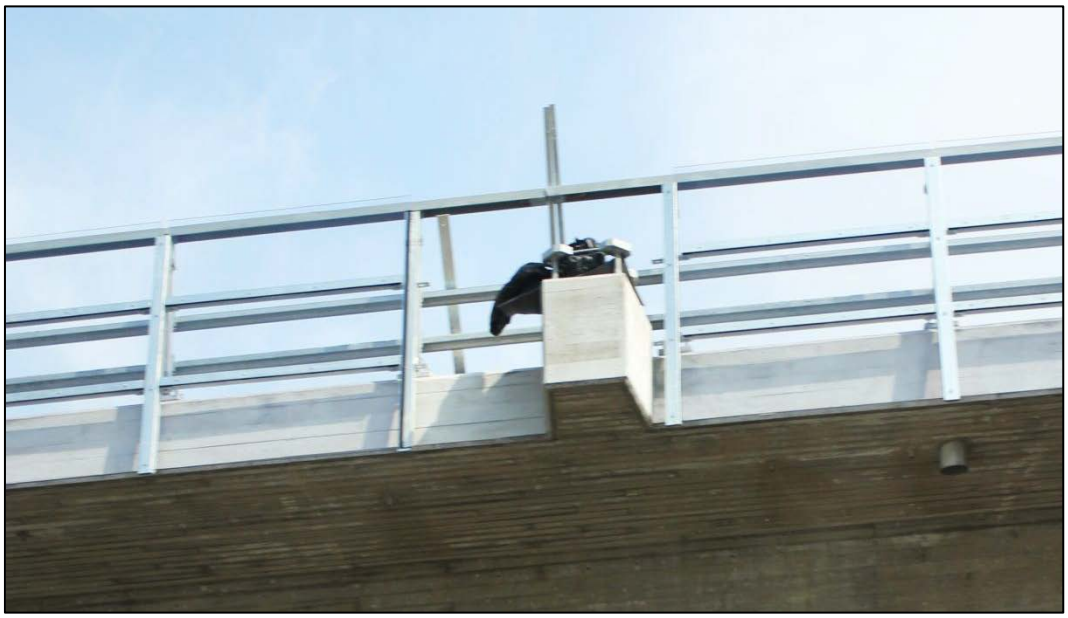


Figure 1.10: Cladding the edge beam with glass. A probable solution

2 Methodology

This survey had been conducted at KTH Royal Institute of Technology's Structural Engineering and Bridges Department in collaboration with Trafikverket (The Swedish transport administration) and it is meant to find innovative solutions to the various problems associated with bridge edge beam system. The survey is an international survey as the problem on bridge edge beam is also encountered in different forms internationally.

Methodology

Survey monkey, an international electronic survey management firm, was employed in hosting the survey since it is expected to be completed around the globe. The surveys were dispatched by electronic mails and this method made it easier and faster in delivering the surveys to recipients around the globe. Engineering drawings were made to clearly describe salient features in the survey and the survey language was English. The survey responses were automatically recorded as each recipient completed the survey and the results were collected after the survey had been closed.

The survey and survey questions

The full survey adopted for this research is presented in the appendix of this report. The survey questions bear key issues affecting bridge edge beam system ranging from structural, maintenance to cost and new ideas on solutions to problems on bridge edge beam systems.

Recipients

The recipients invited to complete this survey are selected parties concerned with bridge management around the globe. The surveys were sent out in batches as described below;

- Batch 1; Authorities concerned with bridge management around the globe
- Batch 2; Authorities concerned with bridge management in Europe
- Batch 3; Bridge engineering firms around the globe
- Batch 4; The Swedish reference group on Optimal edge beam system

Result (response/responses)

In total, thirty responses were received. Responses were received from Switzerland, Denmark, Netherlands, Mexico, UK, US, Austria, Estonia, Slovenia, Germany, Canada, Sweden and other countries. The summary of the responses are presented in chapter three of this report.
It is worthy to know that over 200 people (authorities concerned with bridges, bridge consulting and constructing companies) were invited to complete the survey. Detailed drawings that assisted the project team were also received from Canada, Austria and Denmark.

2.1 Perceived problems encountered

Despite creating an electronic survey which is easier and faster to complete, dispatch and record responses, the responses recorded were still considerably low. This might be as a result of some issues as listed below.

- **Interest**; the key issue lies on the recipient's interest on the bridge edge beam research. Some recipients will like to complete the surveys based on what is obtainable to them.
- **Commitment and time on the side of respondents**; some recipients will readily ignore the survey thinking it will take a lot of their time to complete it.
- **Language**; English had been used in creating the survey but it still seems some recipients might have difficulties in understanding and expressing their response since English is not the official language of communication in some countries.
- **Attack**; some recipients are not allowed to open links on their company's computer, especially if it is received from a foreign country because of fears of cyber/virus attack.
- **Direct contact**; it is difficult to get the direct contact of authorities that are directly responsible for bridges in some countries and in some bridge engineering companies, the people responsible for bridges could not be directly contacted. This might mean that the survey invitation did not get to the desired people.

3 Survey responses

3.1 Study Statistics

Thirty responses were received from different regions of the world. The survey was fully completed by twenty respondents and partially completed by ten respondents. The majority of these respondents (51.7%) specialize on bridge design and consultancy. A large percentage of the respondents (37.9%) specialize in bridge maintenance and repair while a good percentage (31%) in the bridge construction field. Some respondents in the concrete producing also completed the survey. The figure below shows the distribution of respondent's areas of specialization.

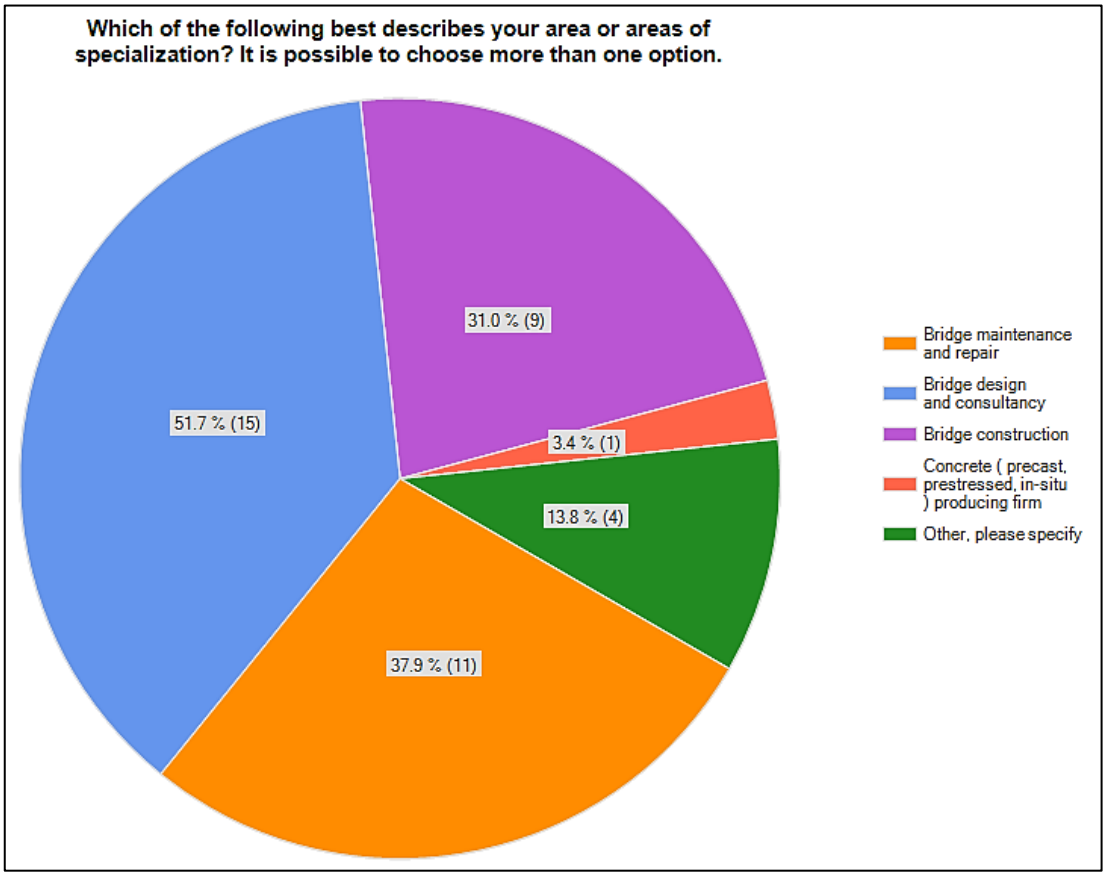


Figure 3.1: Respondent's areas of specialization

Other areas of specialization mentioned are listed as follows

- Bridge asset management
- Bridge inspection
- Concrete durability research
- Bridge management and planning

The greater percentage (44.8%) of the response is from bridge engineering professionals with over twenty years of experience. 17.2% of the respondents have between fifteen and twenty years of experience while 13.8% have between ten and fifteen years of experience. Approximately 75% of the respondents have more than ten years of experience. This gives an assurance of professional and reliable response on the study. The figure bellows shows the years of experience distribution.

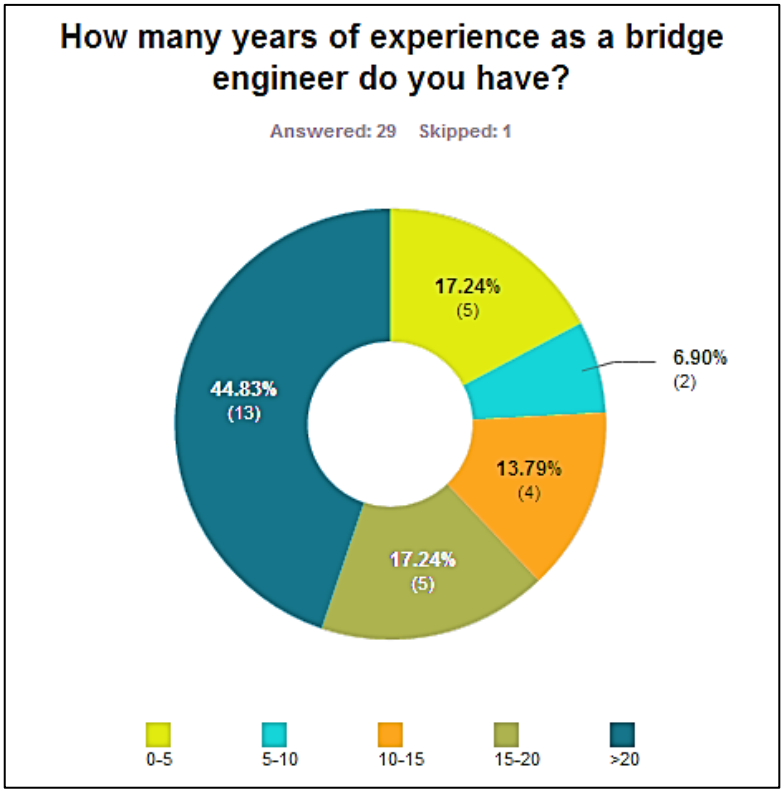


Figure 3.2: Respondent's years of experience

Also a total of thirty three countries have been mentioned as countries where respondents either have practised or are practising. This justifies the expertise garnered in this study. The knowledge of engineers that have practised in different countries and regions with different weather conditions, maintenance and design practises avails the study a diverse experience, judgement and design proposals.
The figure below shows the respondent's countries of practice.

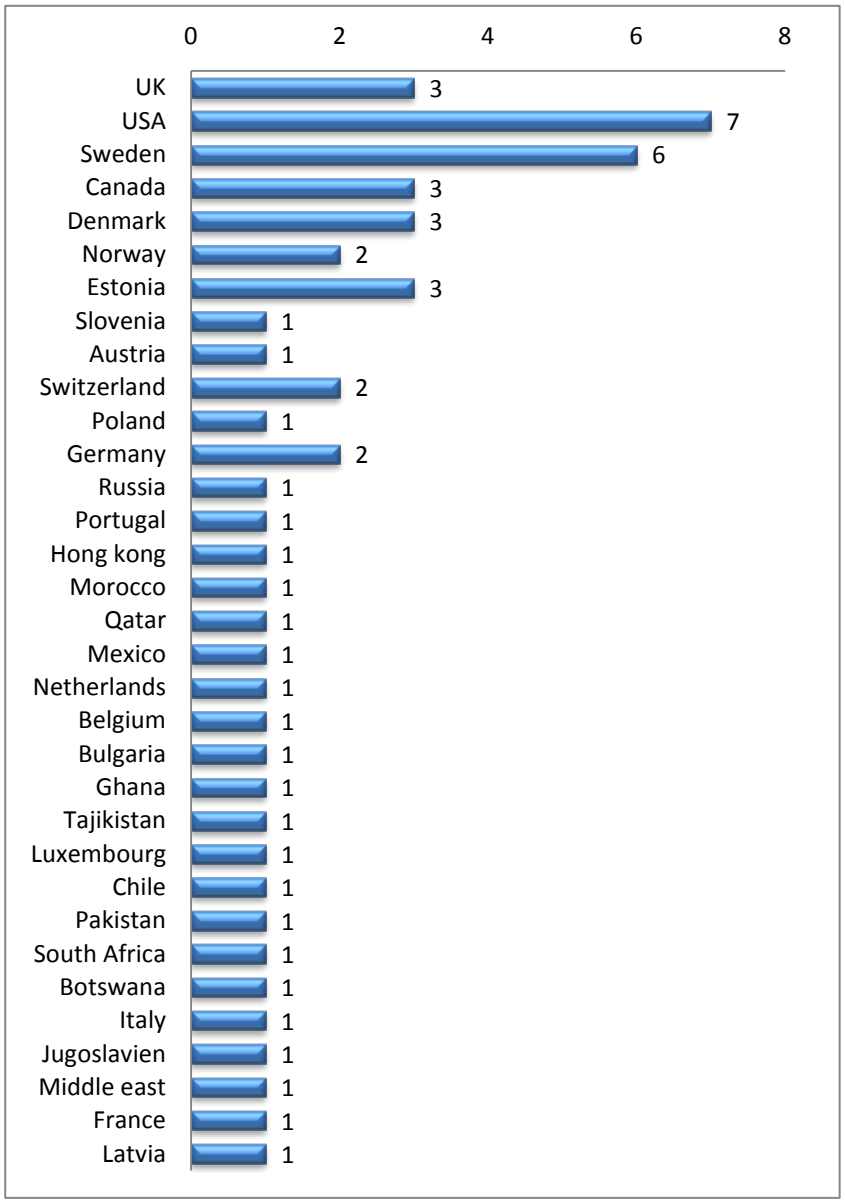


Figure 3.3: Respondent's years of experience

3.2 BEBS Design

To answer the question on BEBS design, figure 3.5 below has been adapted for respondents to indicate their preference of the various forms of BEBS.

3.2.1 Geometric design

On the question to understand the geometric design of respondent's edge beam experience, the majority (68%) have answered NO to the question "is the geometric design of their edge

beams such that will allow snow and water to runoff naturally from the edge beams" while 32% of the respondents have answered YES. The figure below illustrates the response.

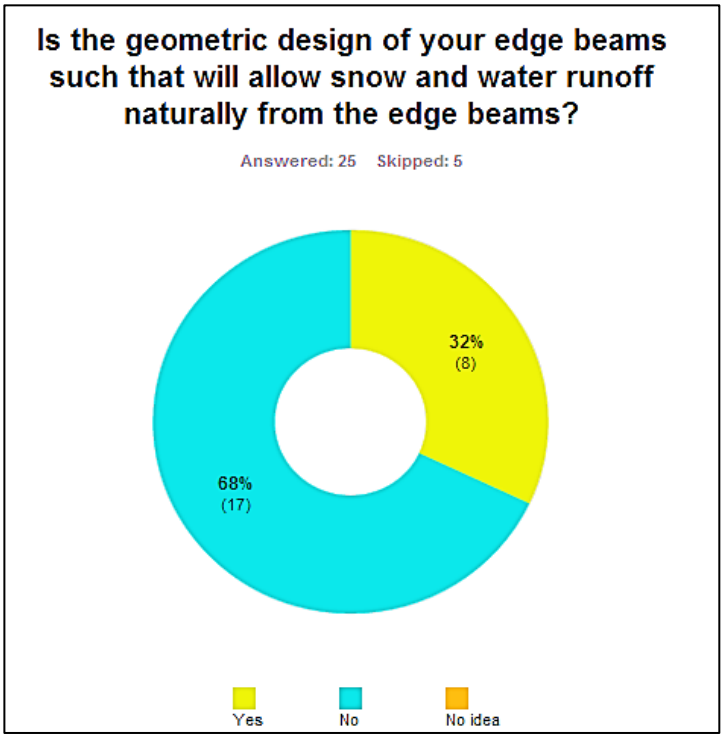


Figure 3.4: Geometric design

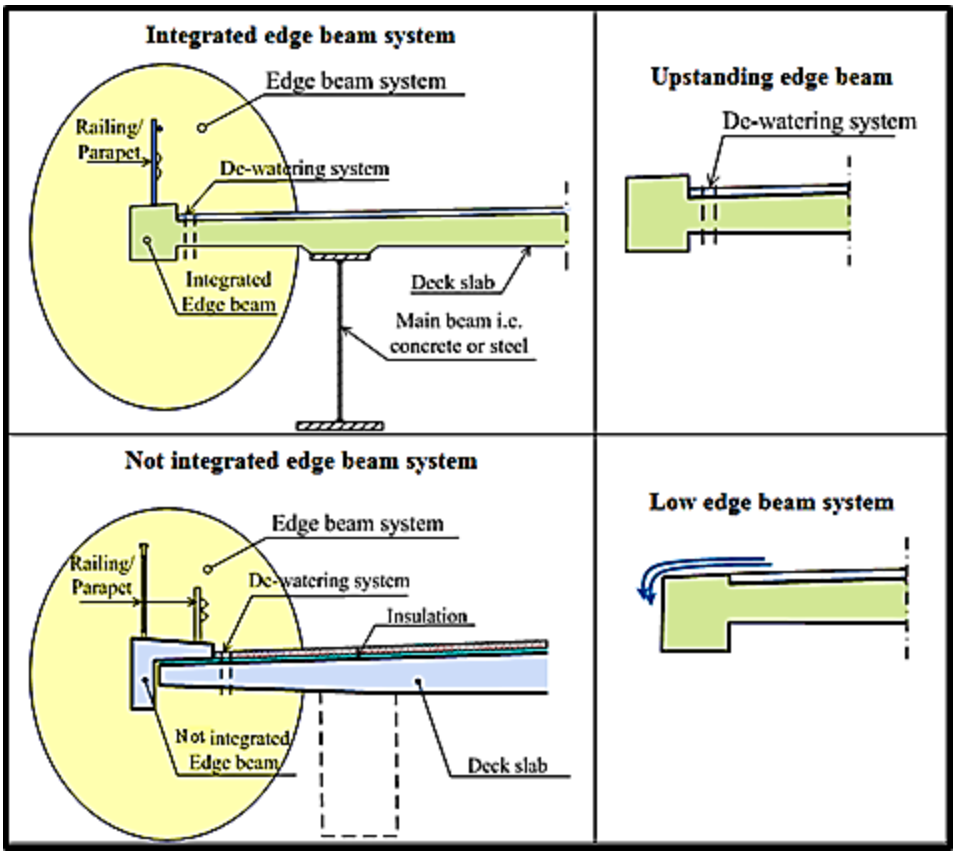


Figure 3.5: Types of edge beam system

With reference to figure 3:5 above, the majority of the respondents prefer the integrated edge beam system to the not-integrated edge beam system as illustrated in the figure below.

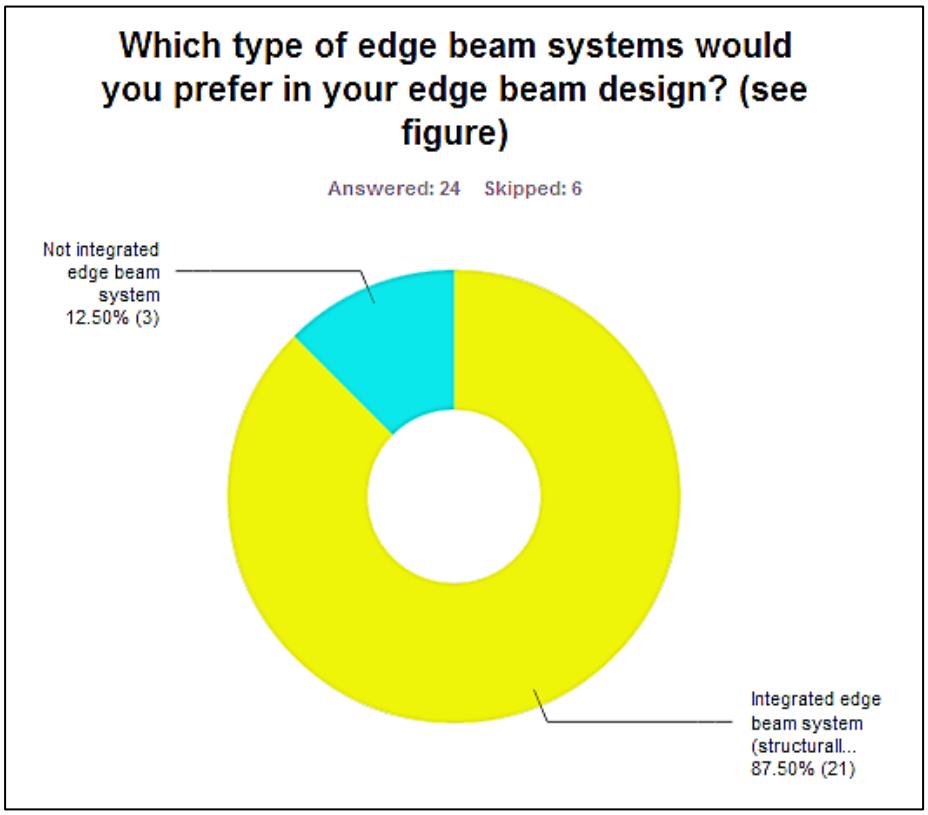


Figure 3.6: Preferred edge beam system

Approximately 88% of the responses prefer the integrated edge beam system. Some explanations were given for these responses and they are as follows in the respondent's own words;

- Site fit up for not-integrated solution can be a major issue if not carefully controlled both from a functionality point of view and visually.
- Stiffens the deck slab
- The edge beam systems incorporated by Alberta Transportation are integrated with the concrete deck slab for anchorage purposes. The deck is designed for the edge beam anchorage forces. Our edge beam designs are based on crash tested systems that meet the NCHRP 350 crash testing guidelines. Please find a link to our standard edge beam design drawings as follows: http://www.transportation.alberta.ca/4855.htm
- We cannot let water runoff of our bridges due to pollution concerns for fish. We typically use a cast-in place concrete barrier cast onto the concrete deck. While we don't consider it, the barrier acts somewhat as an edge beam.
- Because there is less options to damage the membrane

- Have no experience of not integrated edge beam but it seems that there could be a problem with the part of the slab that is hidden under the edge beam system. How do you make sure it´s not exposed to saltwater?
- Too many problems with not integrated edge beams , not used in Denmark anymore
- Solid structures have better durability index, comparing with pre-cast structures.
- Less weight, better structural integrity
- No hidden surfaces, more easy to repair. Water will run under the not integrated edge beam element and destroy the tip of the bridge slab in which place you often got the anchorage of the transverse post tension cables.
- To be able to control the water/snow it is best have a system integrated
- Integrated can give more issue in maintenance, but lack of development in non-integral is holding this back.
- If it is in one cast process, there will be fewer errors than installing another piece of edge that may cause interferences with the drainage.
- The integrated edge beam system has a problem with the sealing in the edge. The not-integrated edge beam can simply be replaced
- Prevents possible water traps and hidden details which cannot be effectively inspected and maintained

In a related question comparing low edge beam system and upstanding edge beam system as illustrated in figure 3:5, the majority of the respondents (88%) prefer the upstanding edge beam system to the low edge beam system. The figure below shows the result.

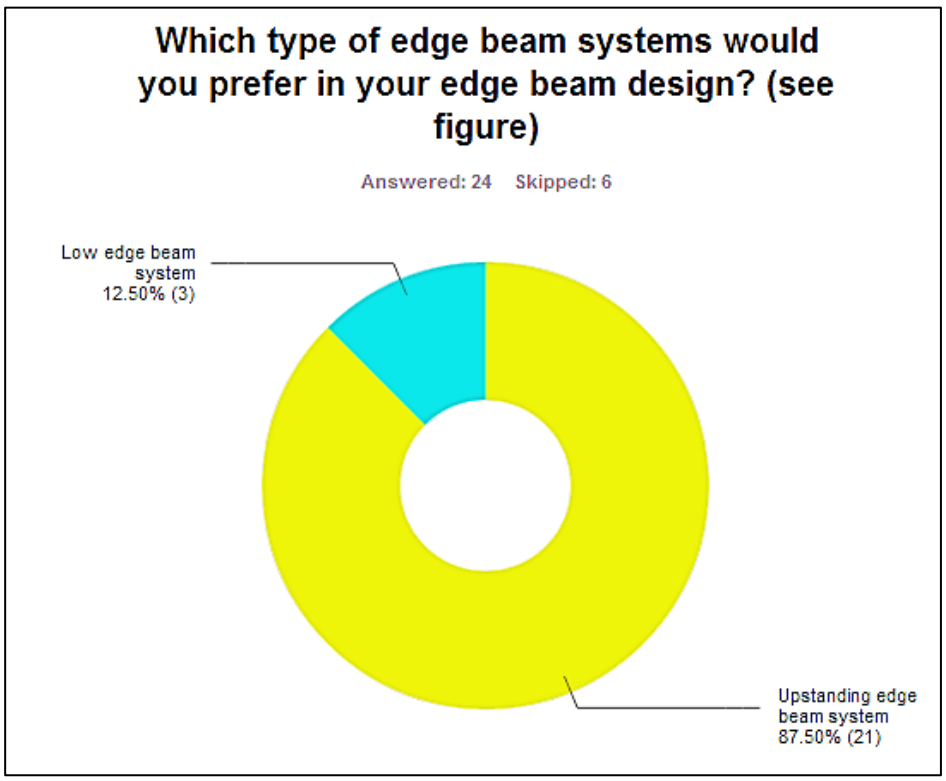


Figure 3.7: Preferred edge beam system

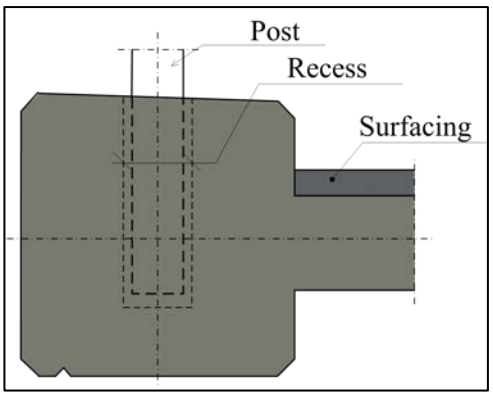
Below are explanations given in the respondent's own words;

- We are not normally permitted to run the rainwater off over the edge without control.
- We can control drainage runoff
- Upstanding edge beams are used to divert water that collects in the gutter area to the ends of the bridge where it drains off the side into a collector trough and down the side slope in a lined swale. An upstanding edge beam is preferred so that the girder fascia (exterior faces) are not exposed to chloride contaminated water
- From an environmental point of view it's not realistic to let the water run of naturally
- Installed de-watering system lets edge beam to extend structure lifetime and reduce maintenance costs
- We do not want anything at all (water, salt, pebbles ...) falling off the bridge
- Water running over the edge beam will in the long run destroy the surface of the edge beam
- Mainly for aesthetical reasons
- To avoid stains to the edge beam due to rainfall
- Is required by our design standards. Also prevents some water run-off and helps to retain some debris
- The safety barrier can simply be replaced
- Because then can give the slope a different value
- Protect streams from pollutant run-off

3.2.2 Coupling method

In a question to compare the type of coupling between the railing/parapet and the edge beam having in mind that the type of coupling system may affect water ingress into the edge beam and the slab. All the respondents (100%) that answered this question preferred that the post should be coupled to the edge beam using bolts and nuts as to the post grouted into a recess. The figure below shows the two types compared.

Edge beam with post grouted into recess



Edge beam with post coupled with bolt and nuts

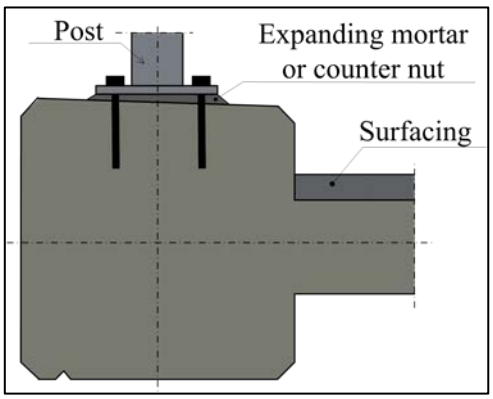


Figure 3.8: Coupling types compared

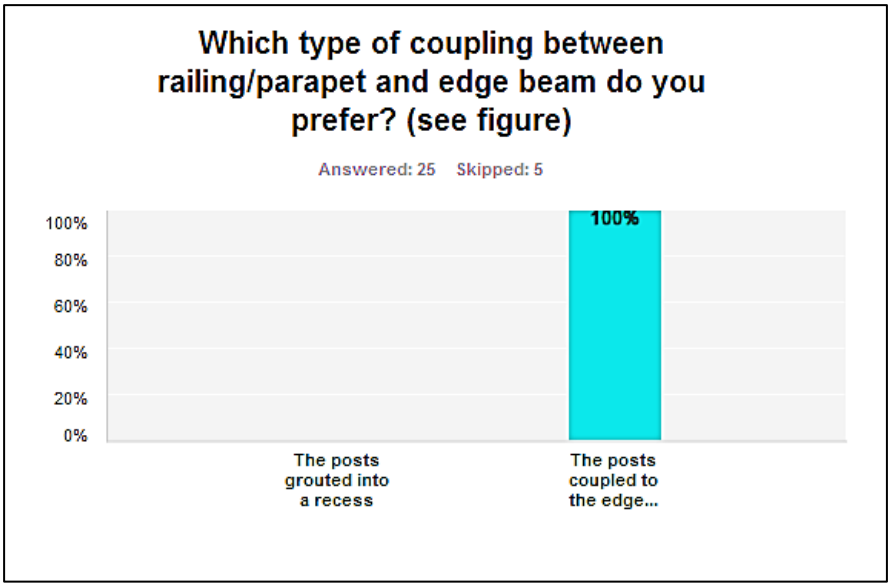


Figure 3.9: Preferred coupling type

Some reasons have been given for the preferred choice of coupling system as listed below in respondent's own words,

- For ease of replacement of posts it is simpler to use a bolted connection
- More adjustability. More easily accommodate eventual replacement of (damaged) railing, reduced interference with reinforcement bars
- Easier maintenance. (Easier to replace due to damage from impact)
- Easier to inspect and replace - the grouted ones have shown too many problems where some were not detected in time
- More easy to change the post
- When damaged easy to repair. But my experience is in steel bridges
- Easier replacement when designed correctly to shear above the bolts
- Need less maintenance than resin type of coupling between edge beam and railing/parapet
- Posts grouted into a recess a reliable to corrosion which is difficult to detect and therefore sudden failure. This type of detail also tends to result in more severe damage to the edge beam in the event of an accident.
- The railing/parapet can simply be replaced
- There is a less damages to the edge beams when the accident happens
- Alberta Transportation has a standard rail and post edge beam system that facilitates post anchorage using anchor rods. Please find a link to our standard rail and post edge beam details: http://www.transportation.alberta.ca/Content/doctype30/production/s1642-00-rev5.pdf

The summary of this choice is centered on ease of maintenance.

3.2.3 Railing type

In comparing the types of railings the steel railing type is most preferred by respondents with 58.33% of the response, 25% of the respondents prefers the concrete railing while 16.67% of the response is for the steel concrete combined railings. The figure below shows the result.

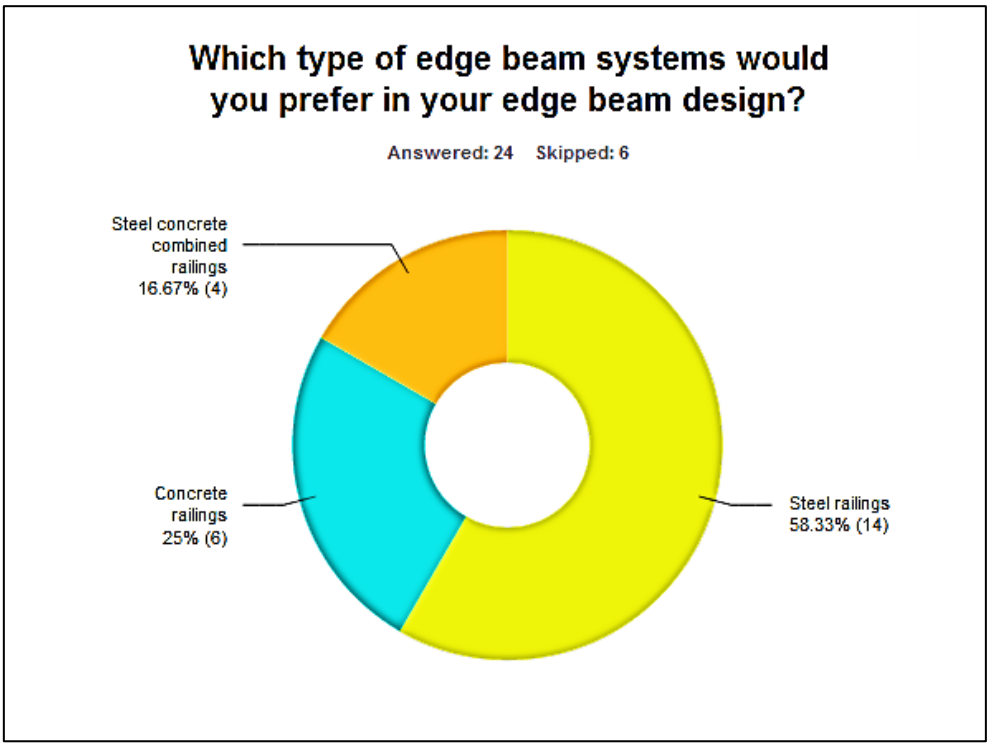


Figure 3.10: Preferred railing type

The followings reasons have also been given to support the respondent's choices,

Steel

- Missing design codes for integrated concrete edge, beam parapets.
- Even if it is preferred, it is not always possible due to the performance level of the barrier (quantity of traffic, importance of highway ...). Sometimes it has to be concrete combined to steel, others only concrete.
- Alberta Transportation utilizes all 3 of these edge beam systems. However, a post and rail system is typically the first choice as the concrete railings can be prone to snow drifting. A combination steel and concrete system is used for areas where extra height is required adjacent to widened lanes that support bicycle traffic.
- If proper coating is used, steel railing durability will be significant.
- Gives the bridge a lighter look.
- Aluminum rails whenever possible. Only concrete if proven to deflect in a suitable manner to safely catch an impact. Some concrete parapets with longitudinal cables can prove such.
- The steel railing has a low dead load.

Concrete

- Single material simplifies construction. No fit up issues between concrete and steel components.
- Little or no maintenance.
- Less maintenance problems.
- Need less maintenance.

Steel concrete combined

- All three options have their place. The decision on which to use depends on many factors including what the structure crosses and the level of containment required.
- We don't have experience with concrete railings and concrete railings are with high repair costs

Didn't select any of the given options but gave an explanation

- It depends on the type of road and what is acceptable from a risk point of view, both to the structure and the vehicles.

3.2.4 Quality assurance

On the study to understand the most employed quality assurance measure in ensuring a long-life span with minimum maintenance requirement, the following measures were compared,

- Increased concrete grade that will withstand harsh weather and environmental influences
- Increased thickness and less reinforcement for the edge beam
- Rust free reinforcement (stainless, painted, hot dip galvanized etc.)
- Impregnation or water proofing

The result for this question is shown in the figure below. The respondents have also been given the option to give other quality assurance measures and the following is specified,

- Alberta Transportation utilized extra concrete cover to the reinforcing steel on the tops and traffic faces of our edge beam systems in addition to corrosion resistant reinforcing steel. We utilize either Stainless Steel or ASTM A1035 low carbon steel.
- Increased cover
- Increased strength

From the result, increased concrete grade is most employed. Rust free reinforcement, impregnation and water proofing are also largely employed as shown in the figure below.

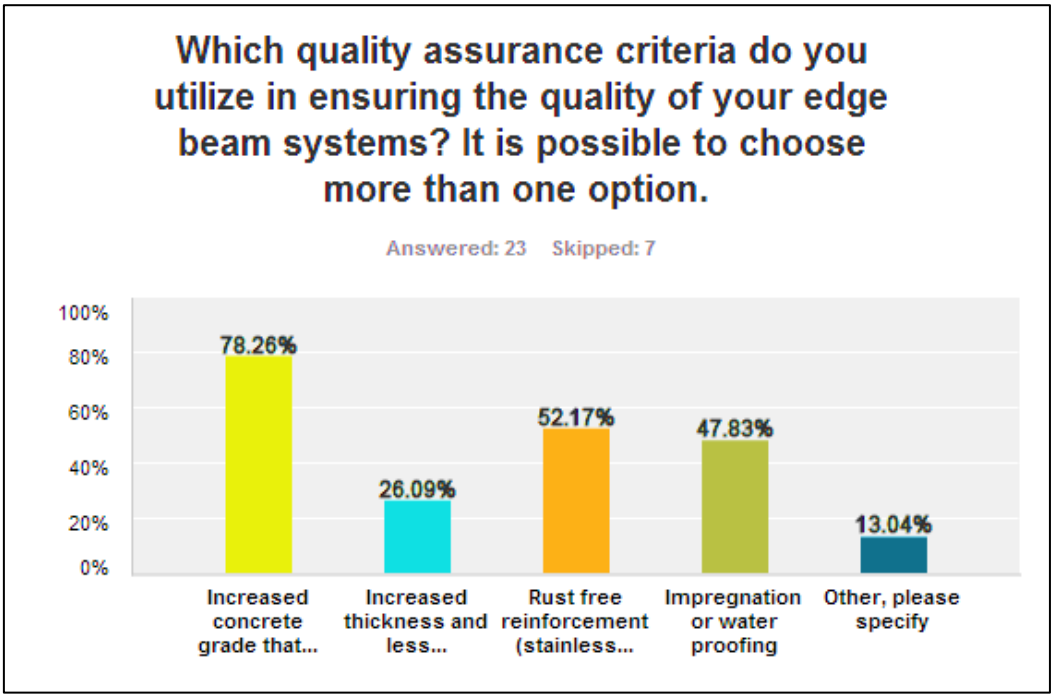


Figure 3.11: Quality assurance measures

3.3 BEBS maintenance, durability and cost

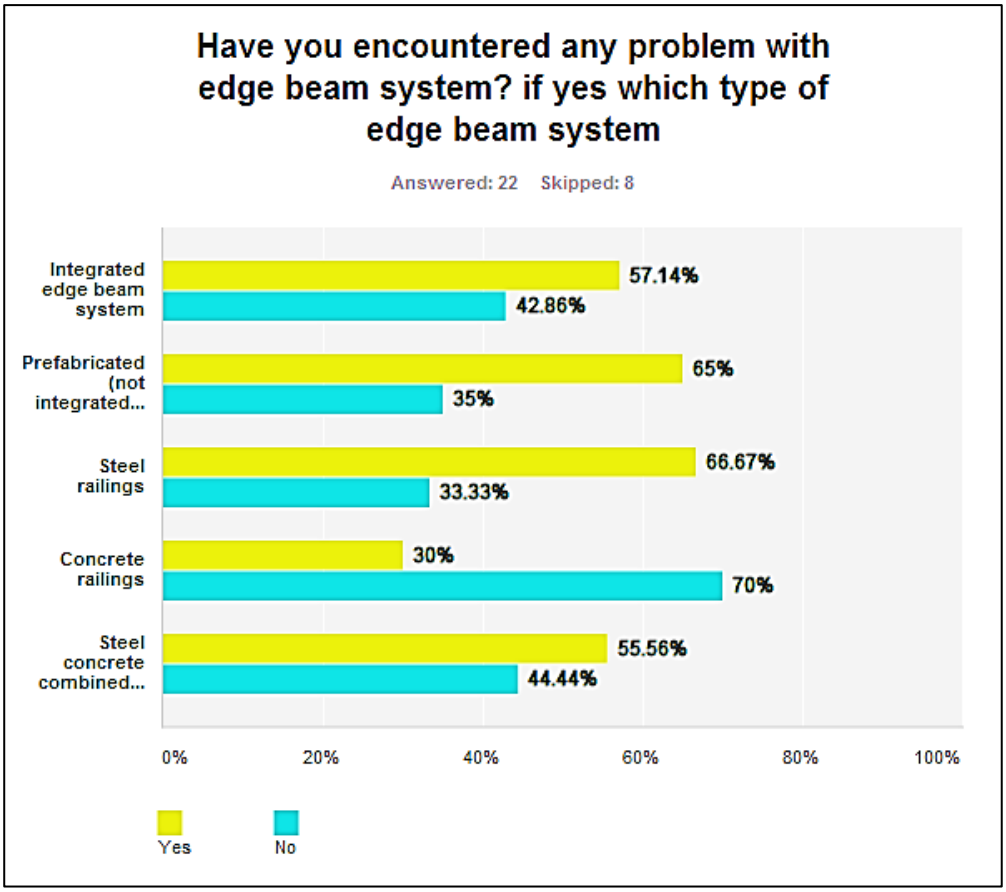


Figure 3.12: Problem with BEBS

The figure above is the response to the question to know if respondents have encountered problems with the different types of bridge edge beam, and as expected the respondents have encountered problems with virtually all types presented, but interestingly the number of respondents that have not encountered problem with the concrete railing type are more than the number that have encountered problem at 70% to 30% respectively. This also corroborates the preference of concrete railings because it requires little or no maintenance as earlier discussed in the question about railing type preference.
Also, it was specified that problems have also been encountered on the aluminum railing type.

In a similar question to know which component of the edge beam system that respondents have encountered problems with that was most defective, the concrete beam has been specified as most defective; slightly more than the railings. Also a respondent specified that they have experienced in the design phase a problem with detailing and providing the appropriate reinforcing steel anchorage into the integrated edge beam/deck to meet the Canadian Highway Bridge Design Code anchorage requirements. The figure below shows the result.

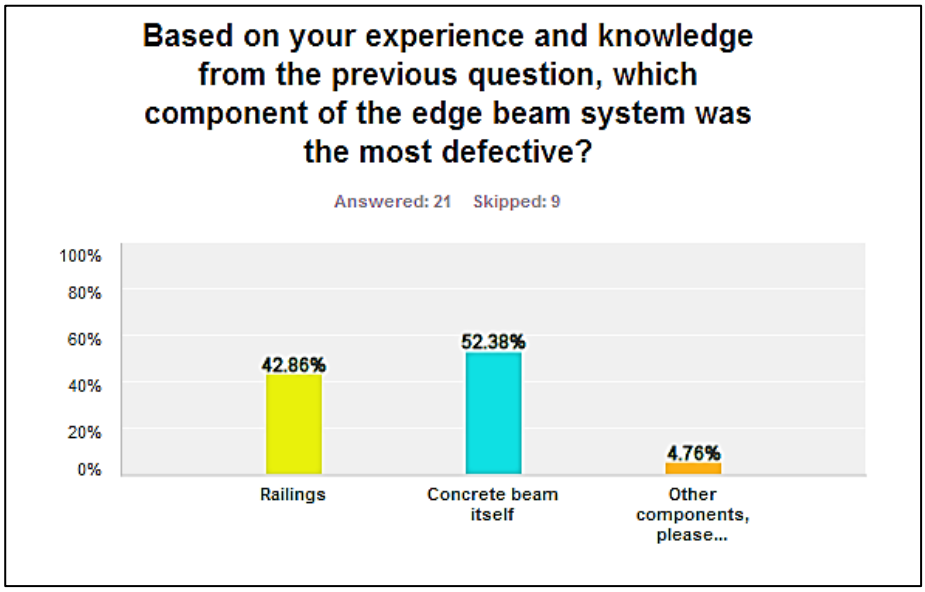


Figure 3.13: Most defective component of edge beam

3.3.1 Frequency of maintenance operation

Majorities (40%) of the respondents often perform or propose to clients to perform general inspection and maintenance on the edge beam system every two years. This is a good practice as the earlier cracks and faults are detected in edge beam the better and easier it is to fix. A large percentage (30%) chose to carry out maintenance operations at every three to five years. A good percentage (25%) prefers to carry out maintenance operations after every five years. Figure 3:14 below shows the result.

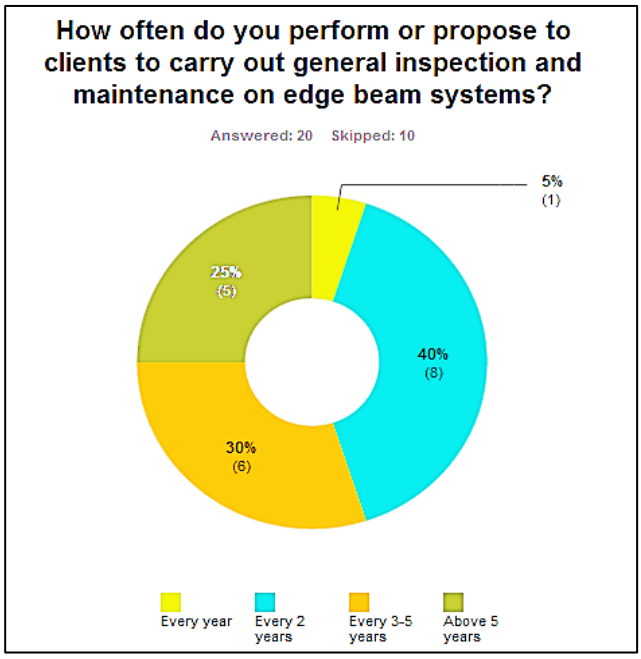


Figure 3.14: Frequency of maintenance operations

3.3.2 Repair work on edge beam

In the question to garner the type of repair work respondents have carried out on edge beam, major replacement (to demolish and construct new including waterproofing, surfacing and railing replacement) is more performed than minor repair (patching with concrete, repair of parapet, repainting of railings etc.) as shown in the figure below. However, it is obvious that repair works, either major replacement or minor repair, is inevitable on edge beams. Other types of repair were also performed as described by respondents. They include upgrades to higher containment classes in accordance to updated safety standards and thrie beam retrofits.

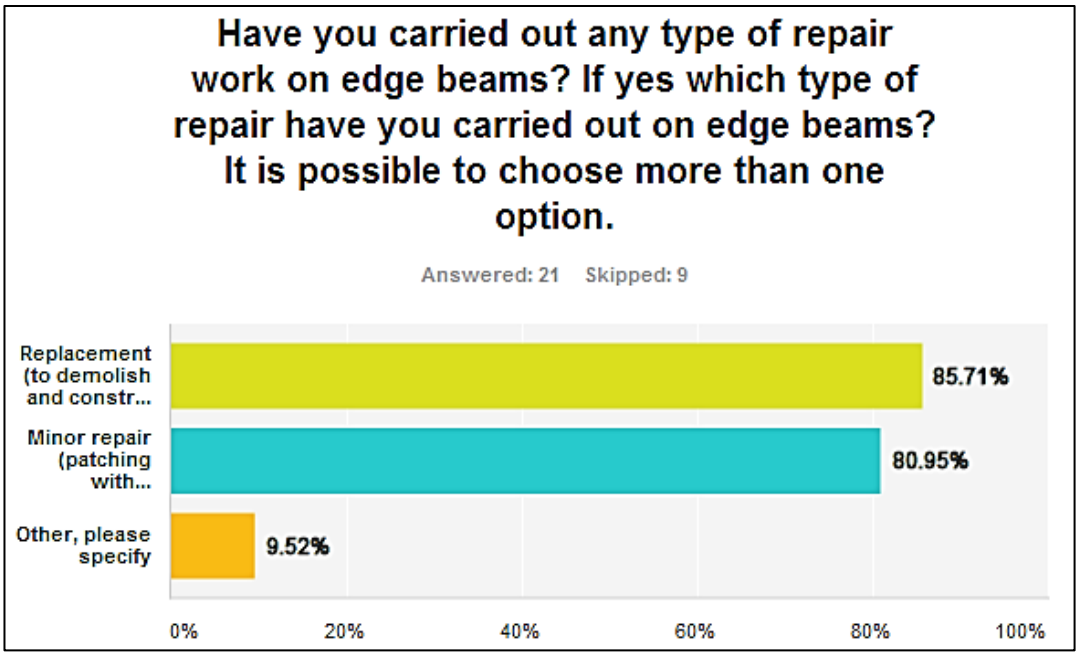


Figure 3.15: Repair work on edge beams

3.3.3 Reason for repair / causes of problem

The most prominent cause of problem to the edge beam as experienced by the respondents (85.75) is corrosion of the edge beam reinforcement. Spalling of edge beam concrete and damage on edge beams from vehicular collisions are also common at, 57.14% each. Corrosion of railings is also experienced and other causes of problems as specified by respondents are as follows;

- Old railings with substandard containment capacity which need to be strengthened or replaced.
- AKR- reactions, chloride attacks etc.
- Edge beam failed because of snow accumulation after long-term (65 years) of chloride deterioration

The figure below shows the result.

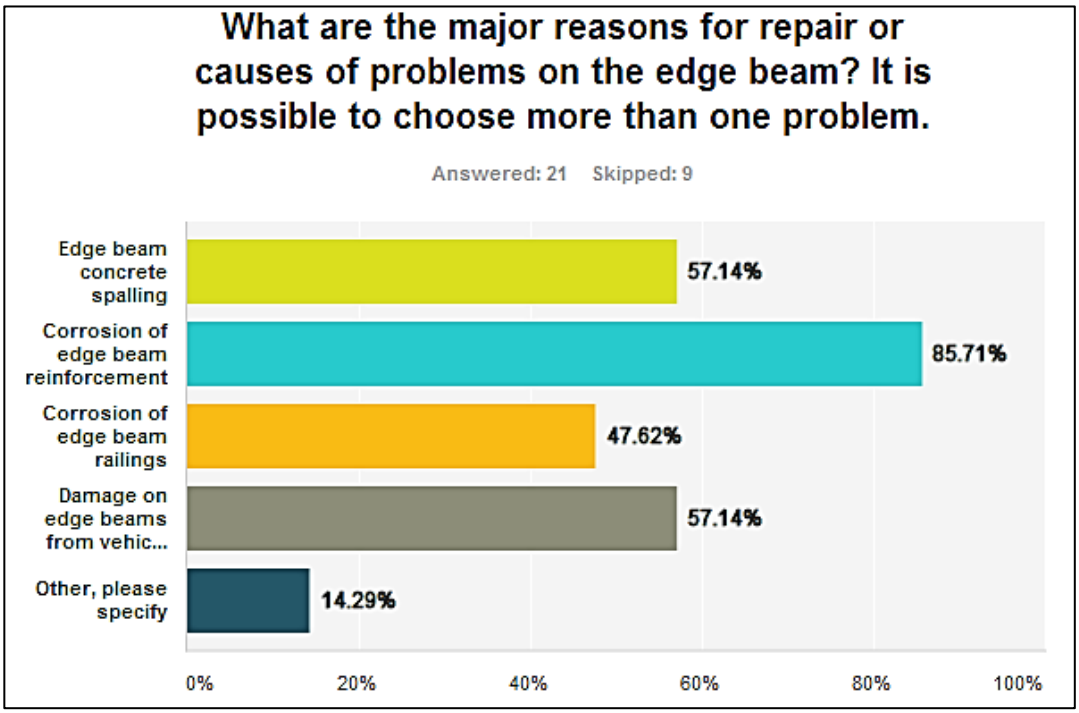


Figure 3.16: Reasons for repair

3.3.4 Bridge type on which problems are encountered

According to respondents problems with edge beams are mostly encountered on reinforced/prestressed concrete bridges. A large percentage (52.38%) is encountered on steel concrete composite bridges and a low percentage (23.81%) is encountered on steel bridges. Edge problems are also encountered on masonry bridges as specified by respondents. The figure below shows the result.

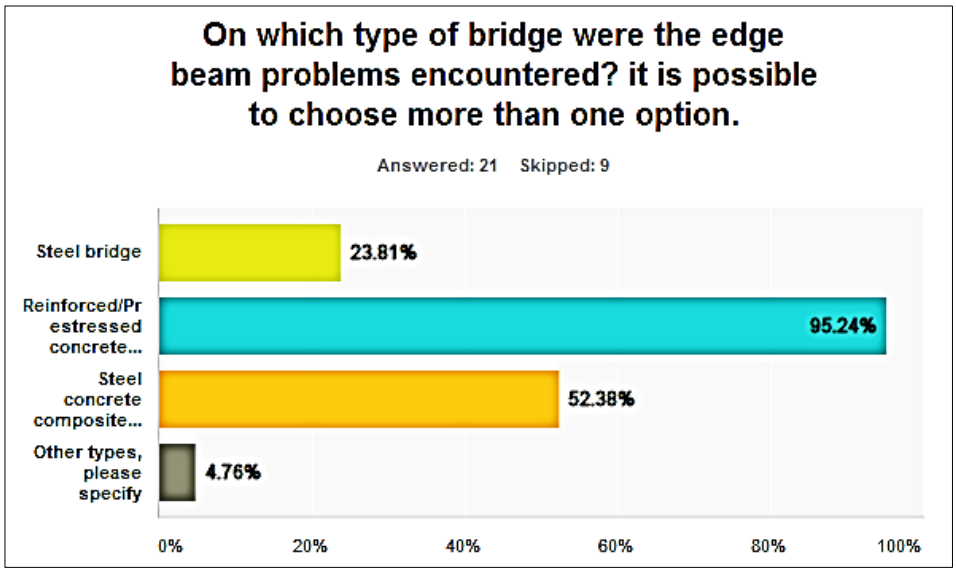


Figure 3.17: Bridge types on which problems are encountered

3.3.5 Average age of repaired edge beams

According to the responses, the average age of repaired edge beams is mostly between ten and twenty years while the average age of replaced edge beam is mostly between twenty and thirty years. A low percentage (9%) of the edge beams replaced have served more than fifty years, a rather low percentage while some percentage (5%) have also been replaced in less than twenty years. These statistics substantially mean increased life cycle cost for the bridges bearing the edge beams. The figure below shows the result.

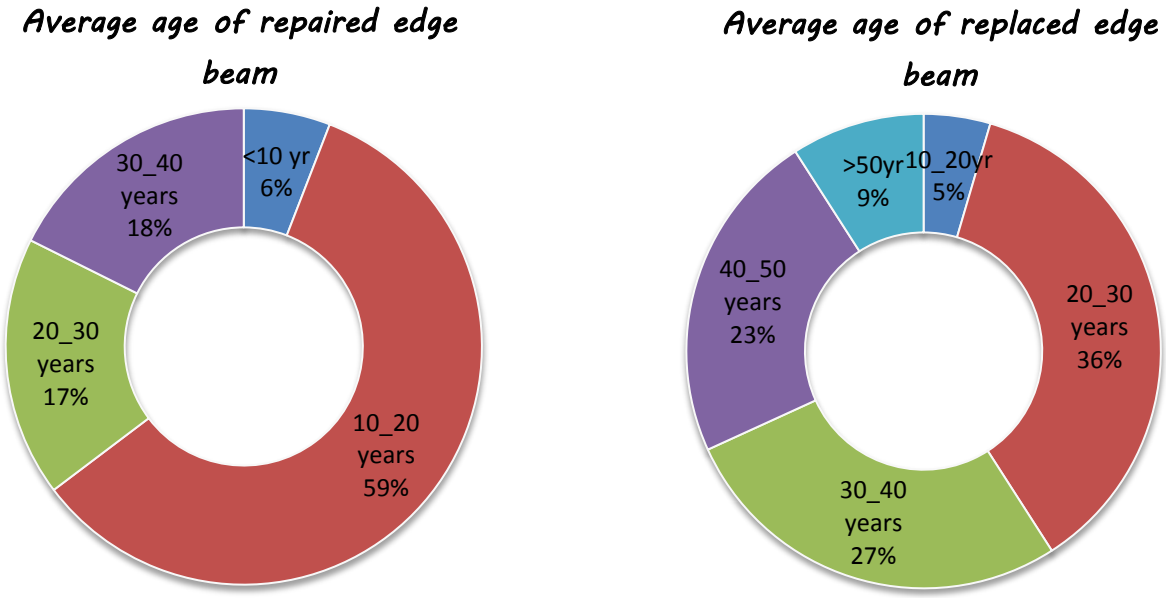


Figure 3.18: Average age of repaired edge beams

3.3.6 Traffic closure to effect edge beam replacement

A wide range of response was received on the question to know how traffic flow was affected during repair/replacement work. Response ranges from no closure, traffic re-routing, and partial lane closure to full closure for at least three months to execute repair works. According to the responses, lanes have to be closed for weeks. Lane closure for days, weeks or months will amount to great increase in the life cycle cost of bridges.

3.3.7 Main causes of edge beam degradation

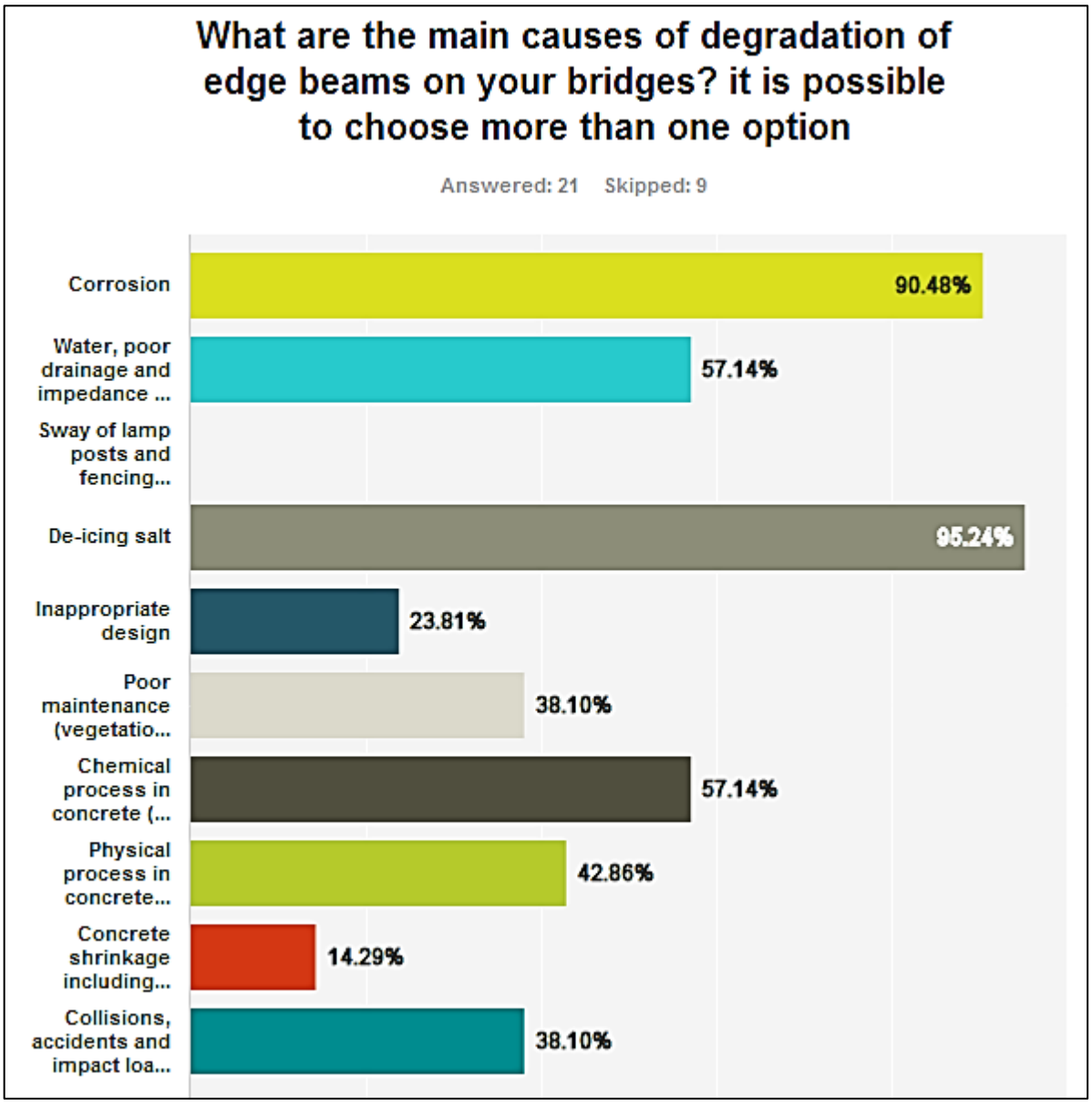


Figure 3.19: Main causes of edge beam degradation

The figure above shows the result of the question on the main causes of degradation of edge beams as experienced by respondents. As expected de-icing salt is the most outstanding cause of degradation with 95.24% of the response. Corrosion, a major consequence of de-icing salt is also outstanding as the cause of degradation 90.48%. Other prominent cause includes chemical processes in concrete (chloride, alkali, acid and sulphate attacks) and water (including poor drainage and impedance to water runoff on the deck) with 57.14% each. Other main causes with varying response as shown in the figure above are;

- Physical process in concrete (freeze thaw, abrasion, erosion, cracking, heat and fire damage) with 42.86% response.
- Poor maintenance (vegetation growth and sedimentation) with 38.1% response.
- Collisions, accidents and impact loads on the railings with 38.1% response.
- Inappropriate design with 23.81% response.
- Concrete shrinkage including cracking, warping (or curling) and joint spalling with 14.13% response.

3.3.8 Remedies utilized in solving degradation

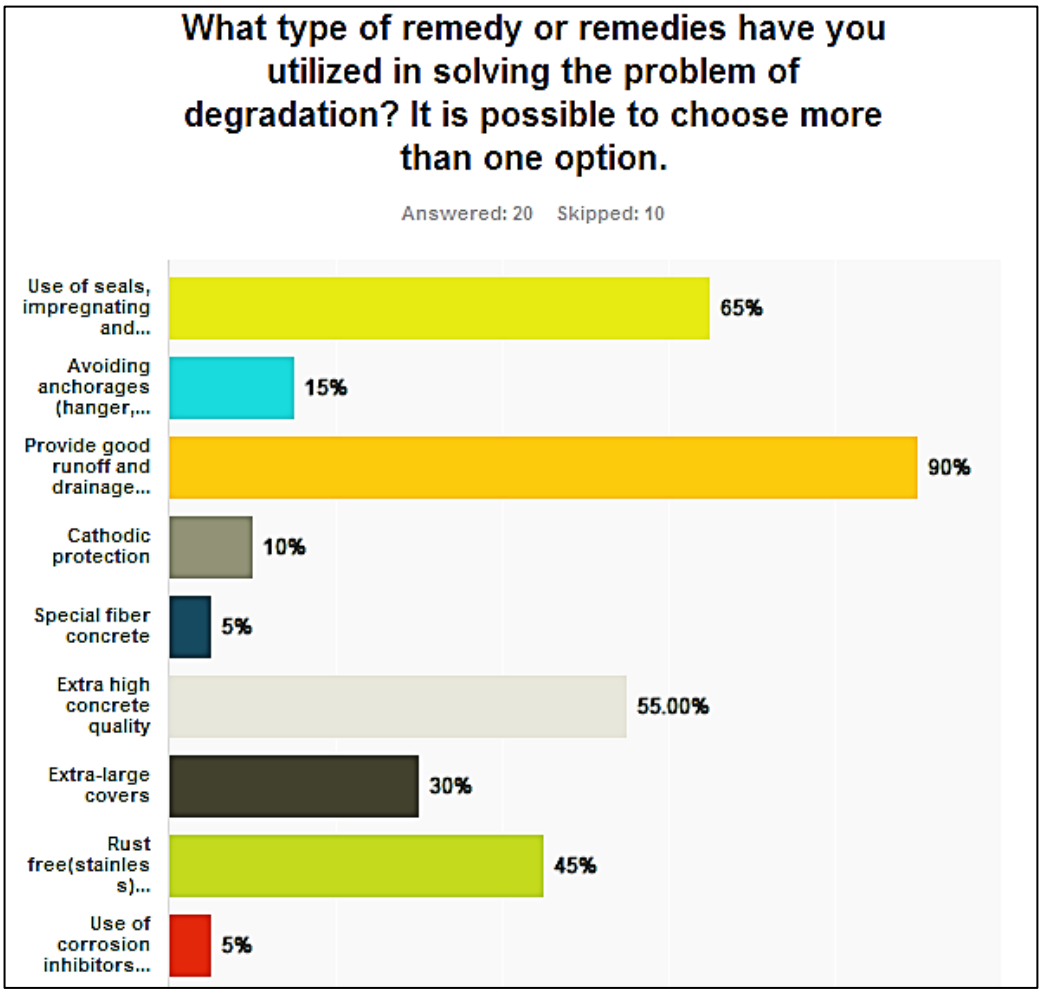


Figure 3.20: Remedies utilized in solving degradation

According to respondents, the most practical remedy is to provide good runoff and drainage system with 90% response for this option. Use of seals, impregnating and waterproofing systems came behind with 65% response. Rust free (stainless) reinforcements, membranes and other coatings to protect steel are also common with 45% response and extra-large covers with 30% response. To avoid anchorages (hanger, railings, sign & lamp posts etc.) on the deck, edge beam surface and cathodic protection are fairly common with 15% and 10% responses respectively. Other remedies include the use of corrosion inhibitors in concrete mix and Special fibre concrete at 5% each.

3.3.9 Cracks emanating from wear course replacement/other bridge repairs

In a question to know if respondents have experienced any form of crack or other concrete damages on edge beams after executing a wear course replacement on bridges, the answers received were mostly NO. However a few response were recorded to have experienced such problems and they are specified as follows,

- Local delamination, transverse cracks, local spalling
- Shrinkage cracks between old and new concrete (normal physical effect)
- In the past the crack control joints used in the edge beams varied and various systems and spacing were used in order to determine the best method of controlling shrinkage cracking in the concrete curb portion of post and rail systems and full concrete edge beams. It was determined that control joints with plastic crack inducers with a reveal subsequently waterproofed with sealant and discontinuous longitudinal rebar at the control joints provided a superior crack control mechanism. See link for detail of the crack control joint:
  http://www.transportation.alberta.ca/Content/doctype30/production/s1680-07-rev2.pdf

3.3.10 Most prominent source of water ingress into the edge beams

According to respondents the most prominent source of water ingress into edge beam is through the deck and edge beam surfaces, with 75% of the response. Water ingress through the railing fittings is also common with 40% of the response while 30% of the response is for water through the grooves between the raised edge beam level and the deck (gutter). Water ingress is also possible through the anchorages of cables, hangers, lamp post, fence system etc. with 5% of the response.
Other source specified by a respondent is given below

- Alberta Transportation uses a hot pour water proofing system with butyl rubber strips placed over the construction joints between the concrete deck and edge beam. Two lifts of 40mm thick ACP is placed on top of the membrane on the traffic wearing surface. The most common method of ingress/exposure to the barriers ***is through salt laden splash and sprays on to the barriers***. See link to the standard waterproofing detail at deck to edge beam joint:

http://www.transportation.alberta.ca/Content/doctype30/production/S1443-11-rev1.pdf
Refer to Detail "A"

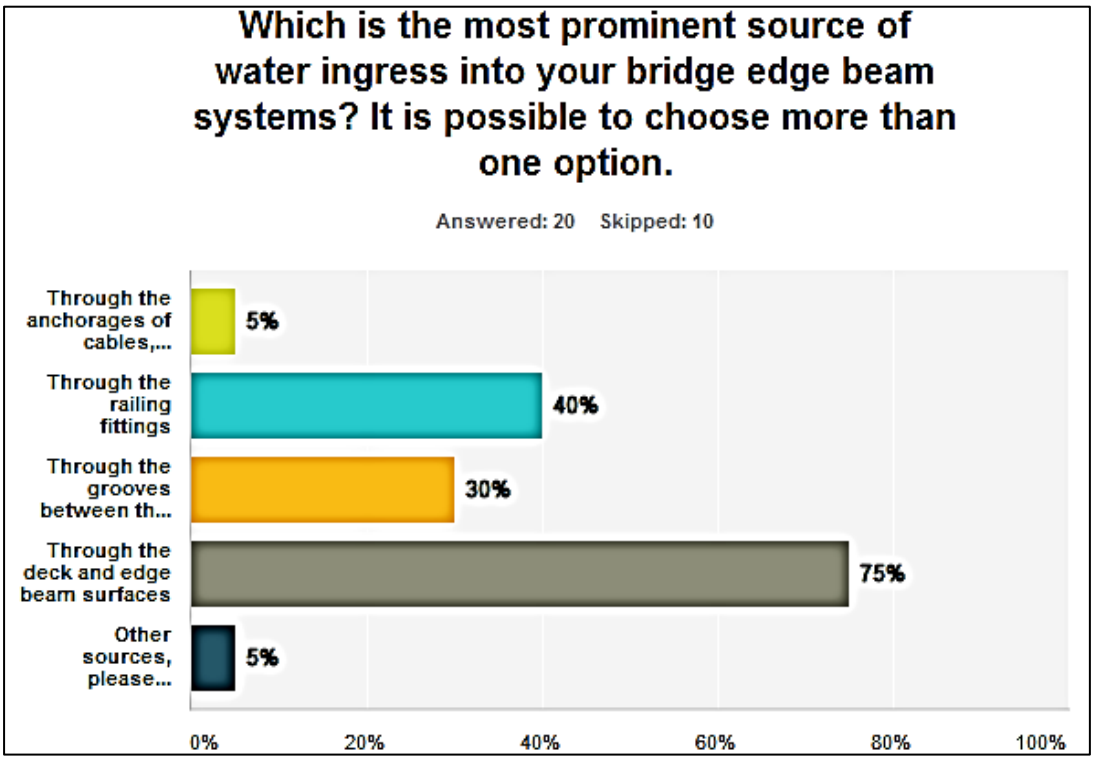


Figure 3.21: Most prominent source of water ingress

3.3.11 Most expensive considering construction cost

According to the results obtained the most expensive type of railings considering the cost of construction is the steel concrete combined railing. The steel railing is next and the concrete railing is least expensive. The figure below shows the result.

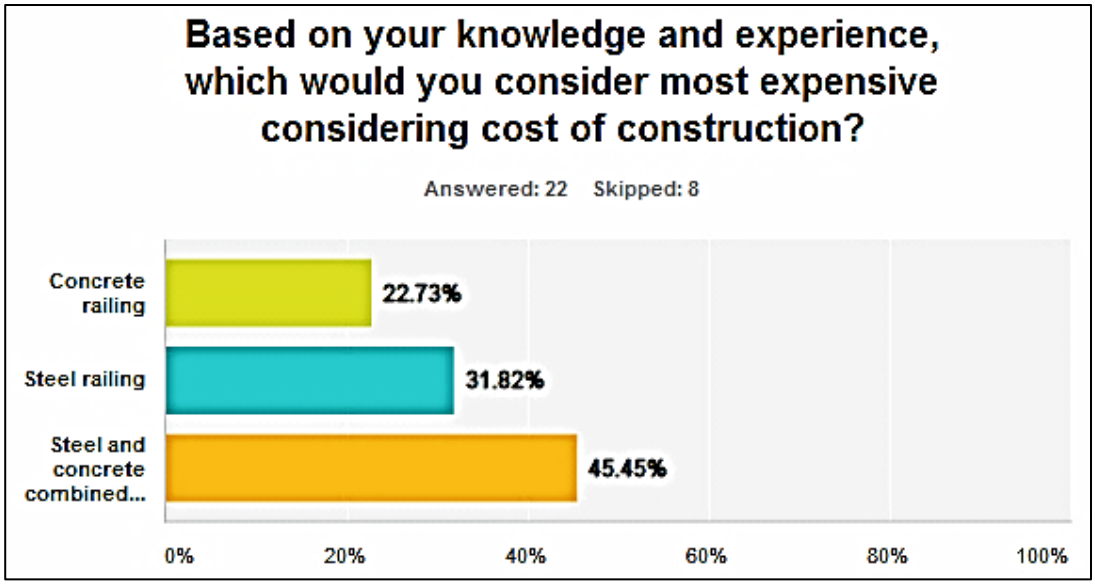


Figure 3.22: Most expensive considering construction cost

3.3.12 Most expensive considering maintenance cost

Considering the general cost of maintenance steel railings and the steel concrete combined railings have been jointly selected as the most expensive according to the results. Again the concrete railing is least expensive. The figure below shows the result.

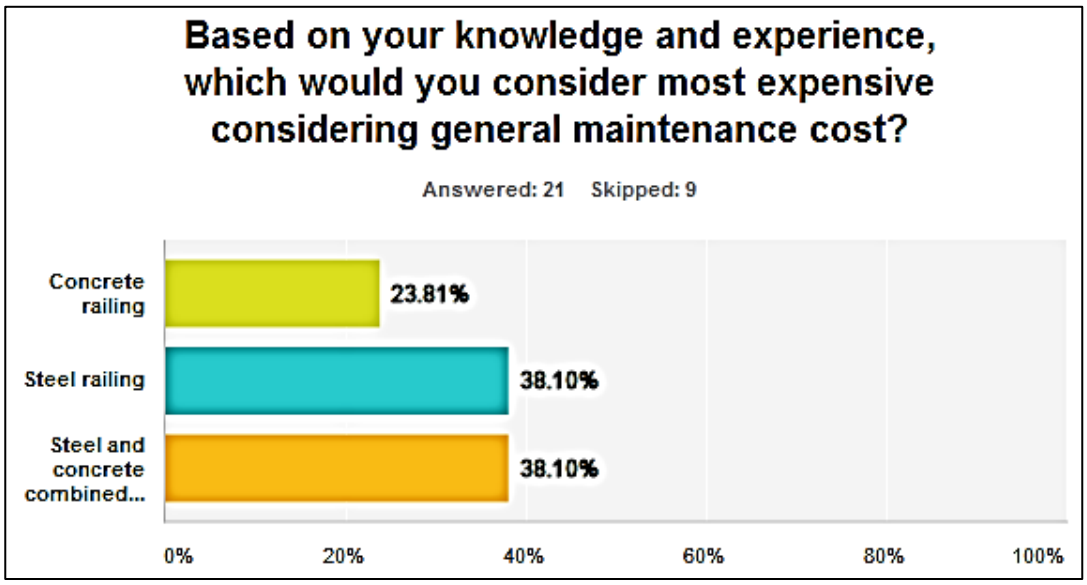


Figure 3.23: Most expensive considering maintenance cost

3.3.13 Most expensive considering repair and replacement cost

The steel concrete combined railing type is again selected as the most expensive considering the cost of repair and maintenance. The concrete railing type follows and the steel railing type is least expensive. The figure below shows the result.

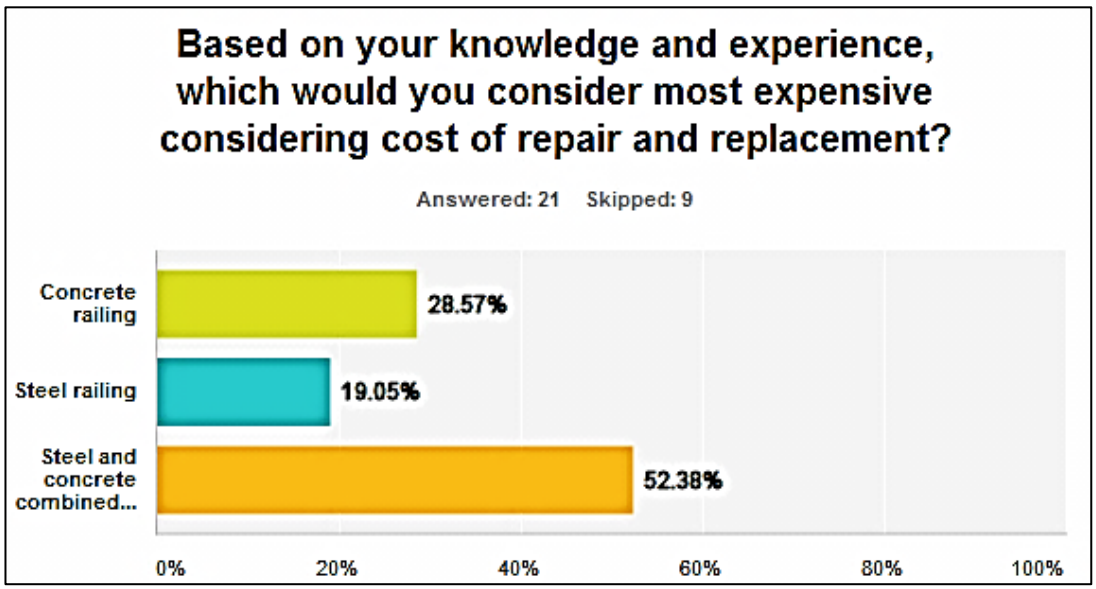


Figure 3.24: Most expensive considering repair and replacement cost

Similarly, the options are compared and rated as low, moderate and high. Below is the result.

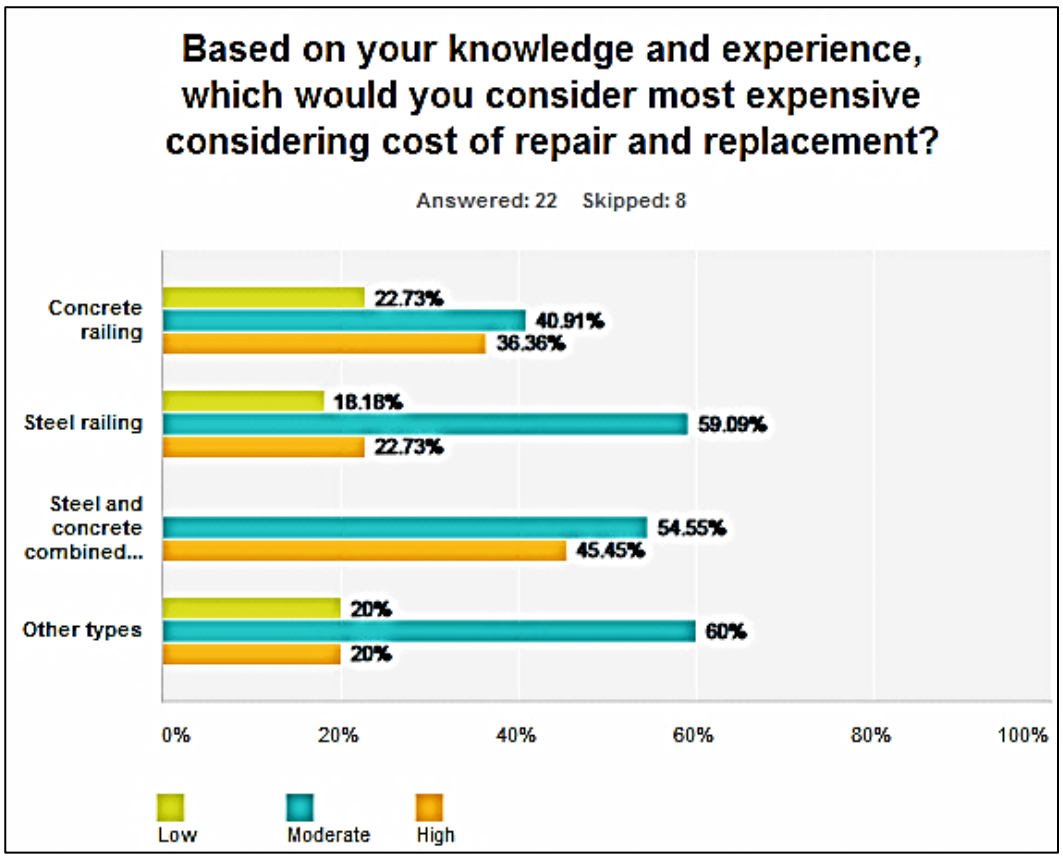


Figure 3.25: Cost rating considering repair and replacement.

Observe that the steel concrete combined railing has no low rating which further justifies earlier results that the steel concrete combined railing is the most expensive considering, construction, maintenance and replacement however more respondents thinks the cost is moderate rather than high. The steel railing is considered to be moderate and lowest when compared with other options in terms of repair and replacement cost.

Also more respondents reflects the cost of repair and replacement concrete railing is moderate than it is considered high. Other options specified by respondents are aluminium and timber railings and both options are considered most moderate of all the options compared in terms of the repair and replacement cost.

3.4 Respondents proposal of BEBS for a simple concrete bridge

On a summarising note of this study, respondents have been asked to describe briefly their proposal for optimal edge beam system for a simple concrete bridge the following response were received.

- Using stainless steel reinforcement and high quality concrete

- The one made of concrete with w/c ratio not higher than 0.45, a reinforcement concrete cover no less than 5 cm, and cementitiuos content (Portland cement + puzzolans) no less than 360 kg/m3. All drainage should be fabricated with a durable material (not PVC). For example high carbon content steel, and should be located at close distances between them (not further than 3 m).

- Alberta Transportation considers the steel post and railing system incorporating a short concrete curb to be the most optimal edge beam system for the Province. This is a PL2 (TL4) rated system and represents the majority of the barrier requirements on our bridges. This is a crash tested system that incorporates a crash tested approach rail transition as well. The crash testing was done in accordance with the guidelines of NCHRP report 350. A link to the edge beam and approach rail transition can be found respectively at the following links:
  http://www.transportation.alberta.ca/Content/doctype30/production/s1642-00-rev5.pdf
  http://www.transportation.alberta.ca/Content/doctype30/production/s1643-00-rev5.pdf
    - Alberta Transportation uses increased concrete cover on the top and traffic faces of the edge beams in addition to corrosion resistant reinforcing (ASTM A1035 and Stainless Steel). The construction joint between the barrier and the concrete deck is waterproofed with hot applied membrane and supplemented by a butyl rubber strip that turns up the vertical face of the concrete curb portion of the barrier. See the following link especially Detail "A" for details:
  http://www.transportation.alberta.ca/Content/doctype30/production/S1443-11-rev1.pdf

    - If light poles are required on the bridge they have to be located behind the edge beam barrier with sufficient set back coincident with the barrier performance level required. See Bridge Structures Design Criteria Version 7 Section 21.3:
      http://www.transportation.alberta.ca/Content/docType30/Production/2012BridgeDesignCriteria70.pdf

    - Drainage of surface water is collected at the gutter lines and conveyed off the bridge with the raised edge beam were it is collected at the bridge end and directed down a lined side slope. Any water that percolates below the ACP to the top of the waterproofing membrane is collected at the gutter line using a plastic wick drain that runs the full length of the bridge where the water is discharged

3.5 Drawings

Drawings of respondent's proposal of edge beam system were received from Austria, Denmark and Canada. These drawings are to be studied by the research team in developing an optimal edge beam system.

3.5.1 Denmark

Excerpts from drawing of prefabricated edge beam received are presented below. Observe the mode of connection between edge beam and the bridge deck which is by drilled anchors. Observe also the mode of connection between the steel railing and the edge beam which is by bolts and nuts. The asphalt layer and waterproof membrane layers on the edge beam will aid rigid connection to the bridge deck and will protect water ingress, especially to the hidden part between the deck and the edge beam. The edge beam is upstanding thereby preventing water runoff from the bridge.

This system has been used in replacing damaged edge beam systems in Denmark and the major advantage is that it is faster and more efficient with least possible disturbance to traffic. This design is possible in different forms, it carries the drainage system in some forms and it is used to widen existing bridge by increasing edge beam concrete section.

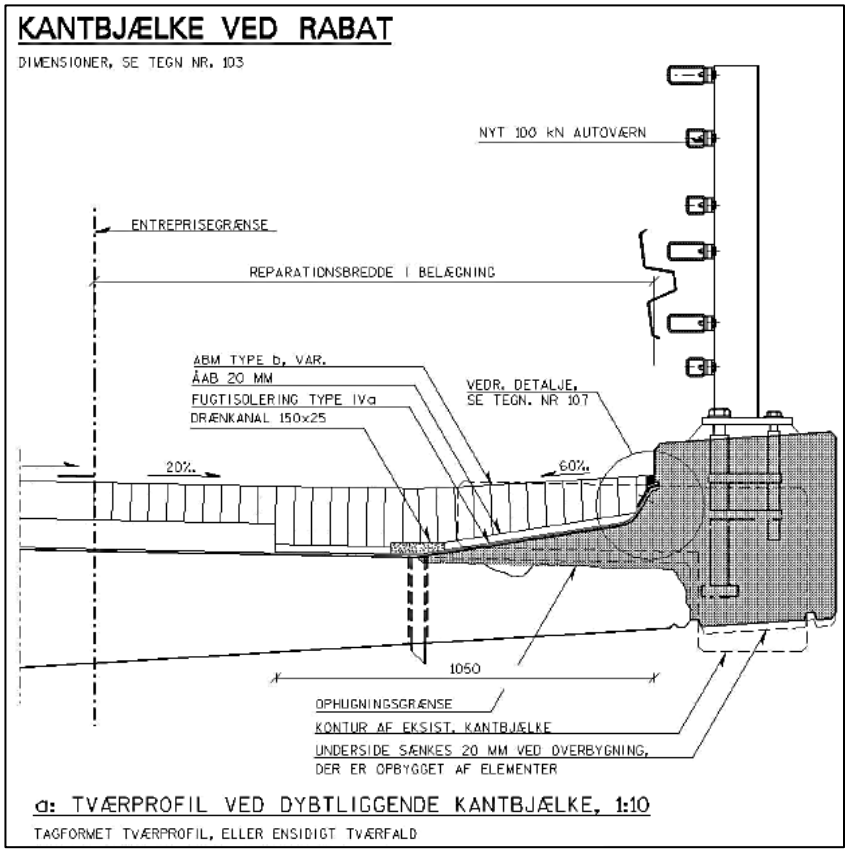


Figure 3.26: Edge beam proposal from Denmark

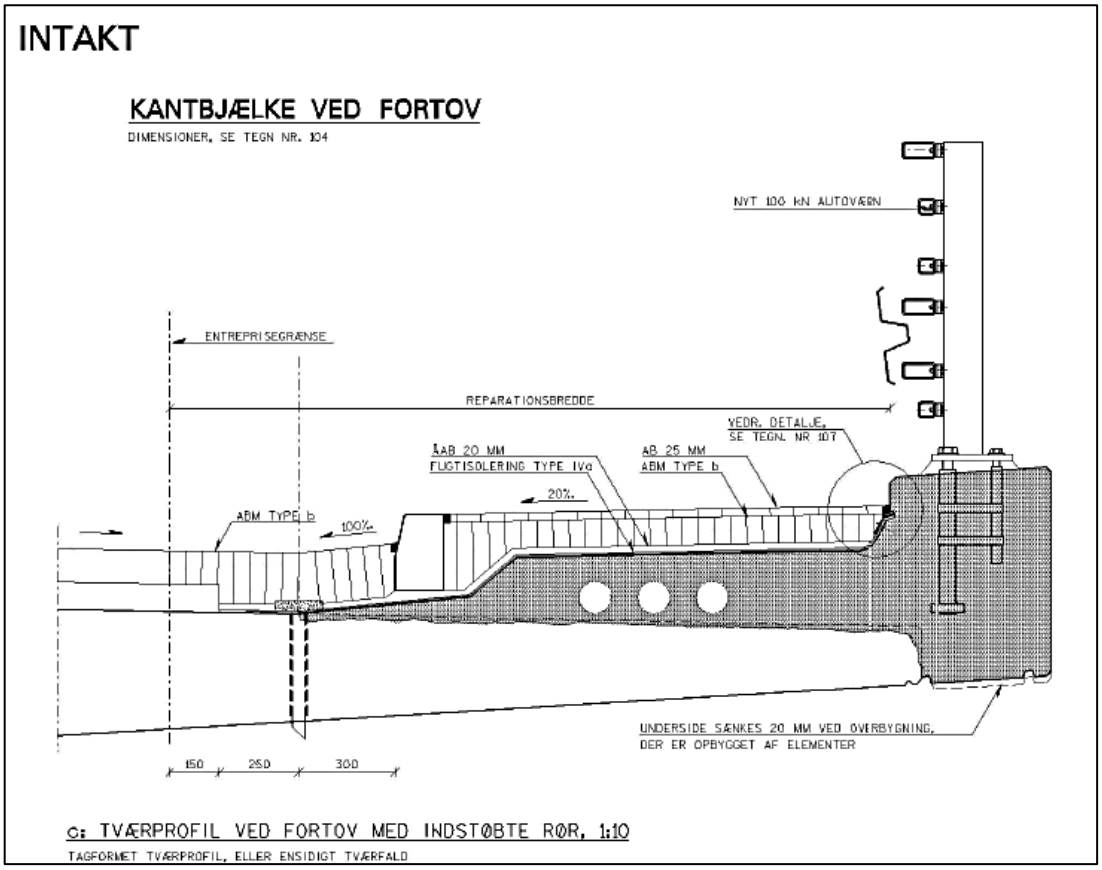


Figure 3.27: Edge beam proposal from Denmark.

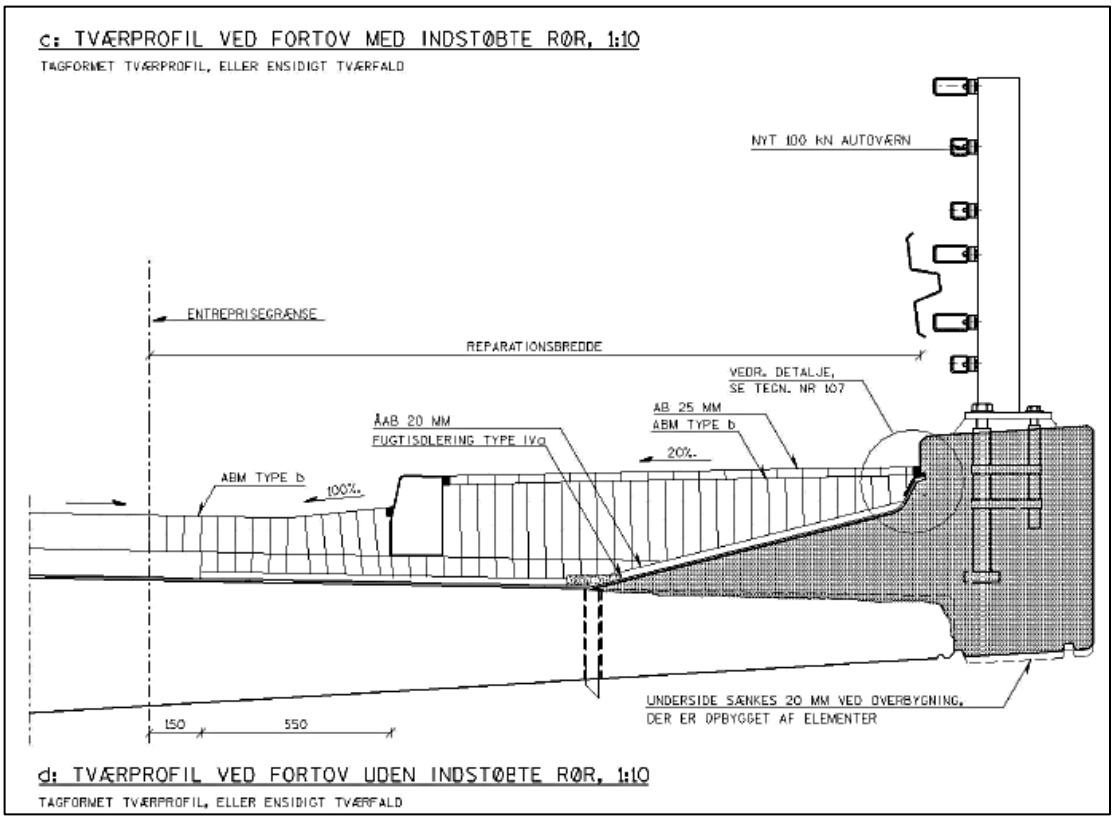


Figure 3.28: Edge beam proposal from Denmark.

3.5.2 Alberta region, Canada

The edge beam proposal from the Alberta region of Canada is typically an integrated edge beam with upstanding edges. The railing is the steel type and concrete railing is also used to demarcate the pedestrian walkway from the car traffic. The steel railing is connected to the edge beam using bolts and nuts on expanding mortar. Excerpts of drawings that are obtainable from the Alberta transport administration website are presented below.

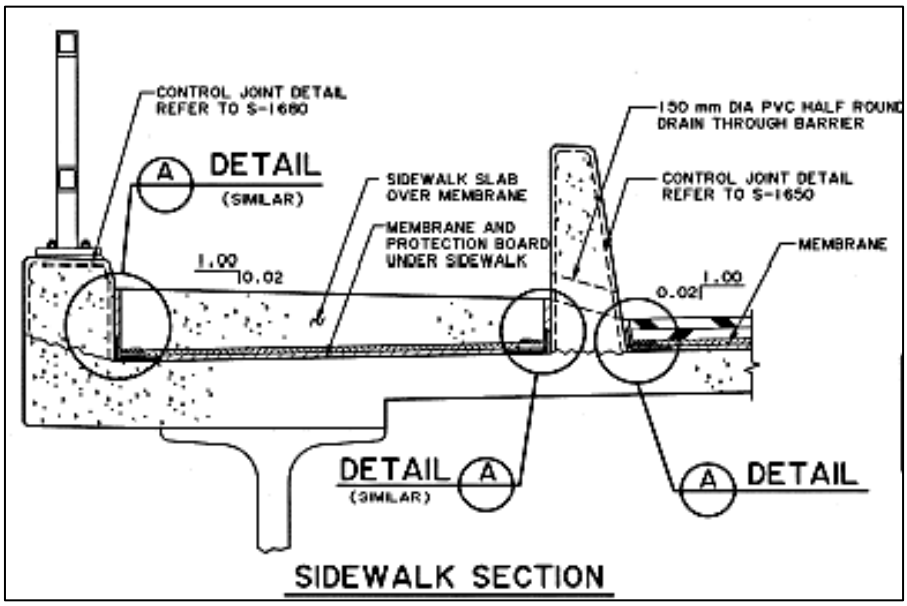


Figure 3.29: Edge beam proposal from Canada.

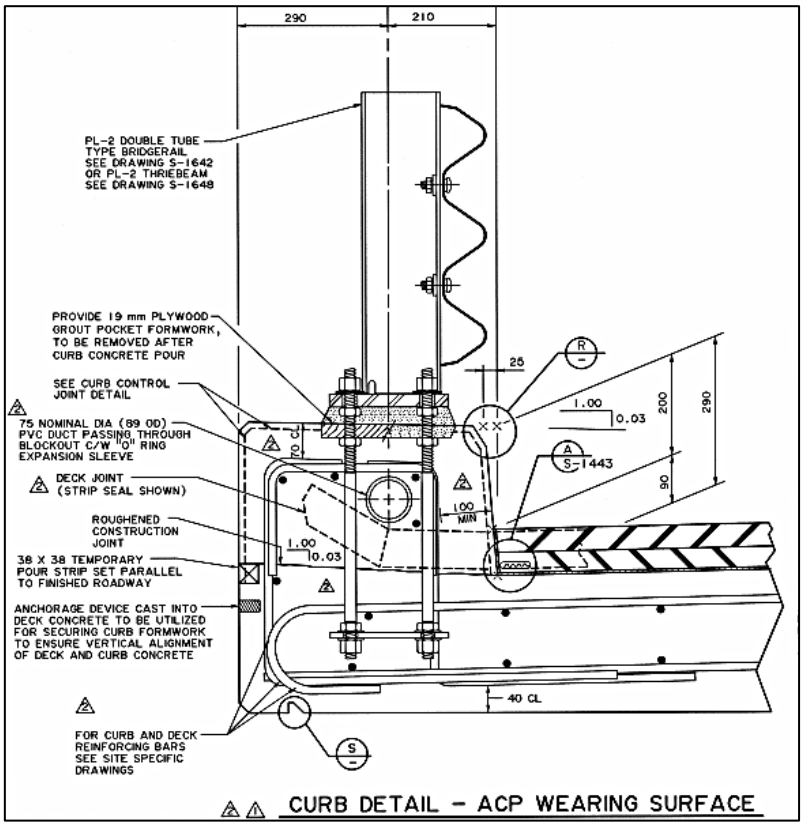


Figure 3.30: Edge beam proposal from Canada.

3.5.3 Austria

The Austrian proposal of optimal edge beam system was received from ASFINAG, the state owned company in charge of the entire primary road network in Austria. The proposal is different forms of replaceable edge beam system that have been used for new edge beams and in renewing old edge beams.
The system is an upstanding prefabricated system with steel railings and possibility of adapting different form of steel railings and concrete railing in different positions. The system is connected to the bridge deck with anchor bolts and the railings are connected to the system with bolts and nuts on expanding mortar. Below are few drawings

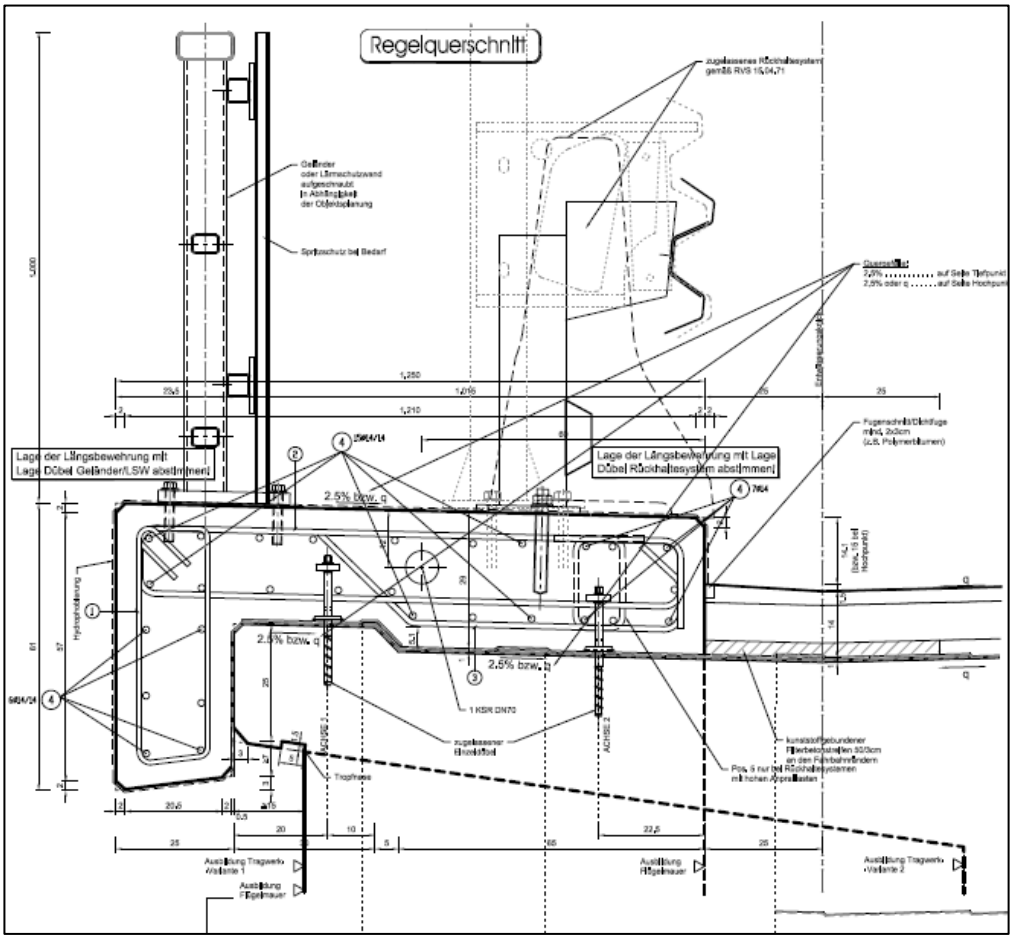


Figure 3.31: Edge beam proposal from Austria.

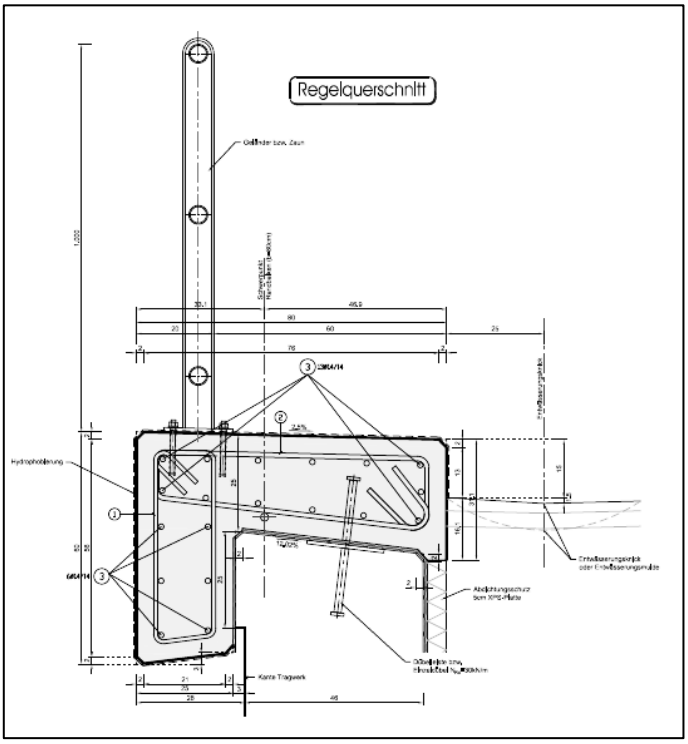


Figure 3.32: Edge beam proposal from Austria.

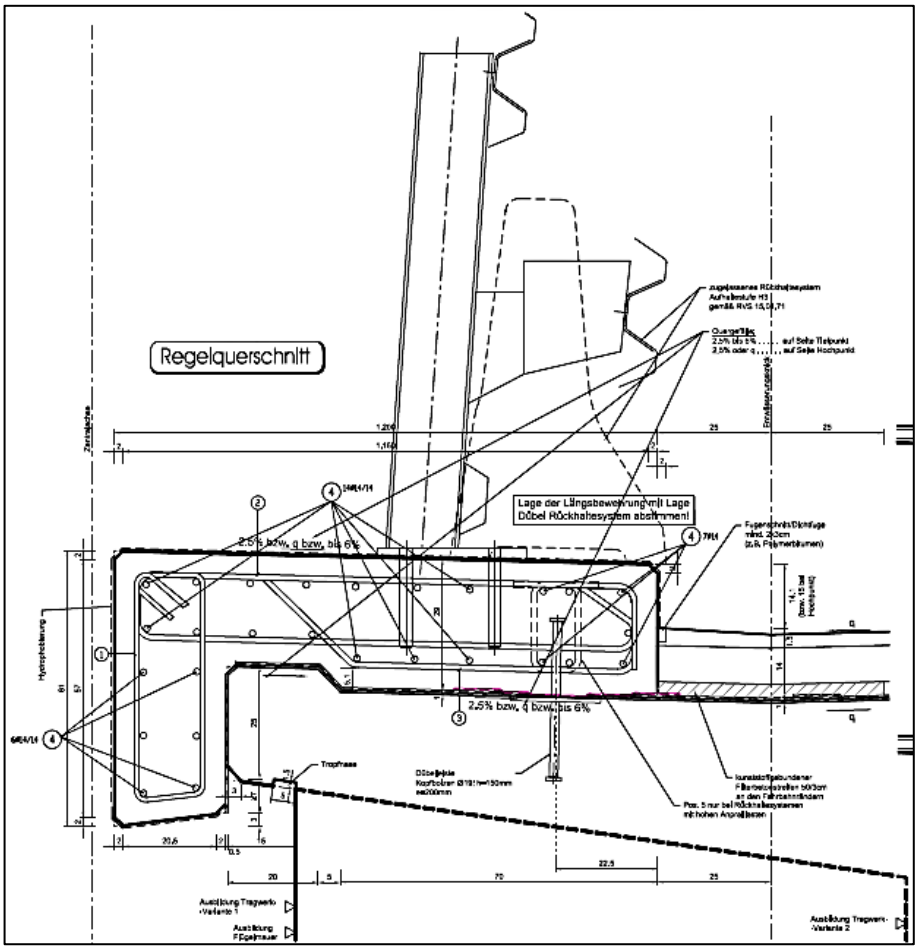


Figure 3.33: Edge beam proposal from Austria.

4 Conclusion

Many interesting facts have been gathered from this study as seen from the result presented in chapter three. However, an idea of a typical edge beam system based on the results will be an integrated edge beam system with steel railings and an upstanding edge that will not allow water to run off naturally from the bridge. The railing post will be coupled with bolts and nuts to the edge beam and the concrete will be of high grade such that will withstand harsh weather conditions and environmental influences. The reinforcement will be rust free preferably stainless, painted or hot dip galvanized.

Vital points gathered from this study are listed in points as follows

1. Most fundamental problem on bridge edge beam system: Corrosion of edge beam reinforcement
2. Most underlying cause of degradation: De-icing salts
3. Most affected bridge type: Reinforced/prestressed concrete bridge
4. Most executed repair work: Replacement (to demolish and construct new ones)
5. Most defective part in damaged BEBS: Concrete beam
6. Most problematic BEBS: Prefabricated BEBS
7. Most problematic railing type: Steel railings
8. Preferred frequency of maintenance operation: Every 2 years
9. Average age of repaired edge beam: 10-20 years
10. Average age of replaced edge beam: 20-30 years
11. Most proffered remedy: Provide good runoff and drainage system
12. Most prominent source of water ingress: Through the deck and edge beam surfaces
13. Most expensive considering construction cost: Edge beam with steel and concrete combined railing system
    a. Least expensive: Concrete railing
14. Most expensive considering maintenance cost: Edge beam with steel and concrete combined railing system
    a. Least expensive: Concrete railing
15. Most expensive considering cost of repair and replacement: Edge beam with steel and concrete combined railing system
    a. Least expensive: Steel railing

Observe that these are only excerpts from the survey results based on respondents' experience, several other points can be deduced from the detailed result as presented in chapter three and the result summary in appendix.

4.1 Recommendations

In future research and developments emphasis should be placed on concrete that can be less porous or permeable in order to prevent ingress of water with deleterious contents into the edge beam. Emphasis should also be placed on understanding the behaviour of the different kind of rust free reinforcement (painted, stainless, hot dip galvanised etc.) in determining the most suitable against attacks from de-icing salts.

The study have also shown that large concerns are expressed for the prefabricated edge beam system concerning it's installation, ease of construction, durability, cost and maintenance, especially in the hidden areas between the deck and the prefabricated edge beam. However, drawings received from recipients also showed that the prefabricated edge beam system, when properly designed and constructed, can be more advantageous as it can be easily replaced, thereby saving cost and time. Lack of development of the prefabricated systems which is evident from the results as some recipients do not have any knowledge or experience about it has stalled the advantages of the system. Hence emphasis should also be placed on developing appropriate design and construction methods for the prefabricated edge beam system.

In terms of maintenance requirements the concrete railing has been preferred by respondents to steel railing, however, concerns were raised on higher self-weight compared to the steel railings. It will be profitable if light weight, less permeable and harsh weather resistant concrete railings can be developed as substitutes.

Aluminium railings have also been suggested by respondents, considering the light weight properties of aluminium, availability and ease of construction however there is need to study the behaviour and reactions of aluminium to de-icing salts.

Cladding is a probable solution that should be studied. Though not evaluated in this study, a water tight cladding with aluminium, glass or other cheap materials can be successful in preventing contaminated water ingress into the edge beam concrete. Figure 1:10 illustrates a typical example of glass cladding but the reliability of this cladding system needs to be studied, the cost should also be evaluated.

Bibliography

1/ Hans-Åke, M., 2008. Integrated bridge maintenance. *KTH Royal Institute of Technology.*

2/ Håkan, S., 2011. Robustare brobaneplatta, state of the art och förslag till FUD program. *KTH Royal Institute of Technology.*

3/ Håkan, S., 2012. Optimala kantbalkssystem, state of the art å program för forskning, utveckling å demonstration. *KTH Royal Institute of Technology.*

4/ Johan, S., 2002. Aktivt brounderhåll-en forstudie. *KTH Royal Institute of Technology.*

5/ Johan, S., 2007. Improving preventive bridge maintenance. *CBI Betonginstitutet.*

6/ Johan, S., 2011. Repair and maintenance lecture notes. *KTH Royal Institute of Technology.*

Home pages/websites

1/ http://www.mmfx.com/products/
2/ http://www.cortecvci.com/Products/products.php
3/ http://www.vikorsta.no/en/Products/Traffic-safety/Safeline-series/Bridge-parapet/
4/ http://www.doka.com/web/products/system-groups/doka-load-bearing-ystems/bridge-formwork/bridge-edge-beam-formwork-T/index.en.php
5/ http://en.re-new.co.kr/products/turbo-seal
6/ http://www.efcoforms.com/
7/ http://orthotropic-bridge.org/
8/ http://www.paschal.de/english/service/hire.php
9/ http://www.istructe.org/journal/volumes/volume-48-%28published-in-1970%29/issues/issue-8/articles/eccentric-edge-beams-on-bridge-slabs
10/ http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09004/asr09.cfm
11/ http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09004/asr06.cfm
12/ http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09004/asr01.cfm
13/ http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_425.pdf
14/ http://www.constructionweekonline.com/article-18539-corrosive-force/
15/ http://www.fhwa.dot.gov/publications/publicroads/98septoct/channel.cfm
16/ http://www.concreteconstruction.net/reinforced-concrete/worlds-most-extensive-concrete-bridge-repairs.aspx
17/ http://www.design-technology.org/beambridges.htm
18/ http://dbmbridges.com/Project-8.php
19/ http://www.mdt.mt.gov/other/bridge/external/structures-manual/part_II/chp-15-final.pdf
20/ http://www.fhwa.dot.gov/publications/publicroads/98septoct/channel.cfm
21/ http://www.concreteconstruction.net/reinforced-concrete/worlds-most-extensive-concrete-bridge-repairs.aspx
22/ http://dbmbridges.com/Project-1.php
23/ http://www.emerysapp.com/publicworks/viewproject.php?project_id=272
24/ http://www.daytonsuperior.com

Appendix

Survey and results

Welcome to this survey on Bridge Edge Beams

Thank you for participating in our survey. Your feedback is important. It takes an average of fifteen minutes to complete the survey and your response is highly confidential.

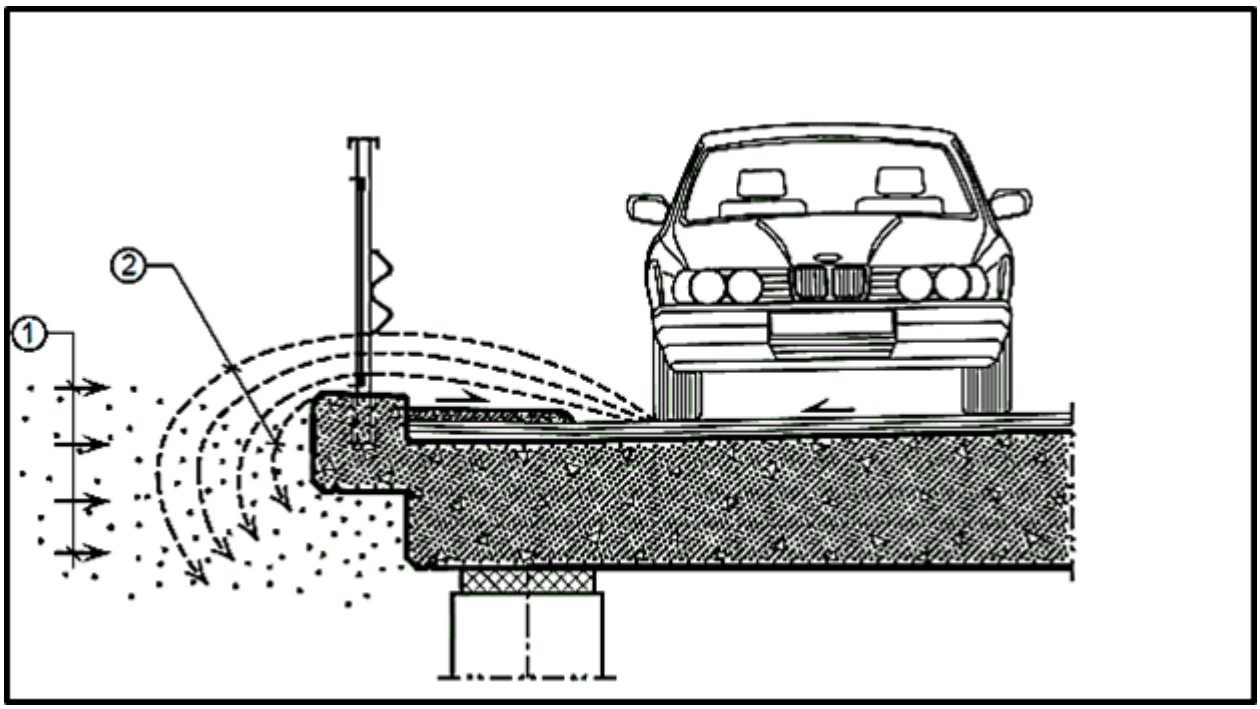
This survey is part of a research on bridge edge beam systems being conducted at KTH Royal Institute of Technology's Structural Engineering and Bridges Department in collaboration with Trafikverket (The Swedish transport administration). It is driven by the need to create innovative solutions to the various problems associated with bridge edge beam system and a demand for new solutions. Edge beam systems and surfacing create approximately 60% to the life cycle cost of a bridge structure and it is therefore important to develop new ideas that will reduce this percentage of life cycle cost.

The expected outcomes of this study will be internationally obtained measures to increase the life span of edge beam systems at the same time reducing the lifecycle cost, innovative solutions to various problems associated with edge beam systems.

Questions regarding this survey can be sent to hakan.sundquist@byv.kth.se or fasheyi@kth.se at KTH, Department of Bridge and Structural Engineering.

Thank you in advance

A typical edge beam is exposed to (1) airborne and other pollution (2) water with chloride and other deleterious content



1. Which of the following best describes your area or areas of specialization? It is possible to choose more than one option.

- [ ] Bridge maintenance and repair
- [ ] Bridge design and consultancy
- [ ] Bridge construction
- [ ] Concrete (precast, prestressed, in-situ) producing firm
- [ ] Other, please specify

2. How many years of experience as a bridge engineer do you have?

0-5	5-10	10-15	15-20	>20
◯	◯	◯	◯	◯

3. In which country or countries have you practiced or practising? Please state

4. If you would like to receive a copy of the results of this survey, please fill in your details

Name:

Company:

Address 1:

Address 2:

City/Town:

State/Province:

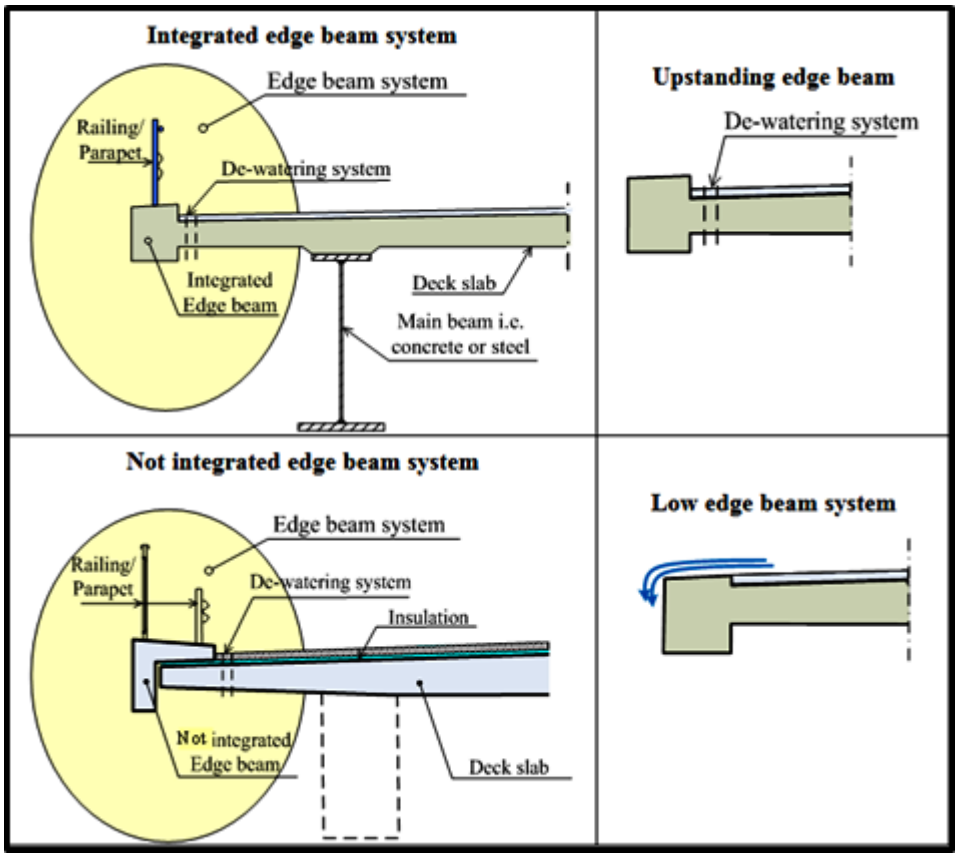
ZIP/Postal Code:

Country:

Email Address:

Phone Number:

Observe the different forms of edge beam as illustrated below in answering the following questions



5. Is the geometric design of your edge beams such that will allow snow and water runoff naturally from the edge beams?

Yes	No	No idea
◯	◯	◯

6. Which type of edge beam systems would you prefer in your edge beam design? (see figure)

◯ Integrated edge beam system (structurally integrated with the slab)

◯ Not integrated edge beam system

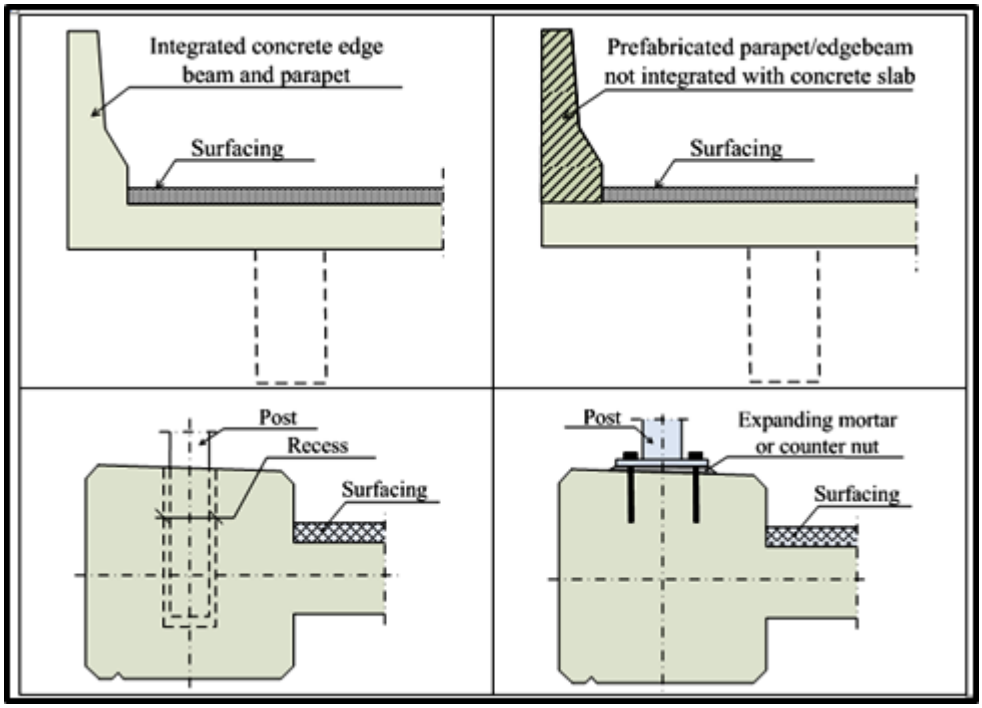
Please give brief reasons (optional)

7. Which type of edge beam systems would you prefer in your edge beam design? (see figure)

- ◯ Low edge beam system
- ◯ Upstanding edge beam system

Please give brief reasons (optional)

Observe the different forms of edge beam as illustrated below in answering the following questions



8. Which type of coupling between railing/parapet and edge beam do you prefer? (see figure)

- ◯ The posts grouted into a recess
- ◯ The posts coupled to the edge beams using bolts and nuts

Please give brief reasons (optional)

9. Which type of edge beam systems would you prefer in your edge beam design?

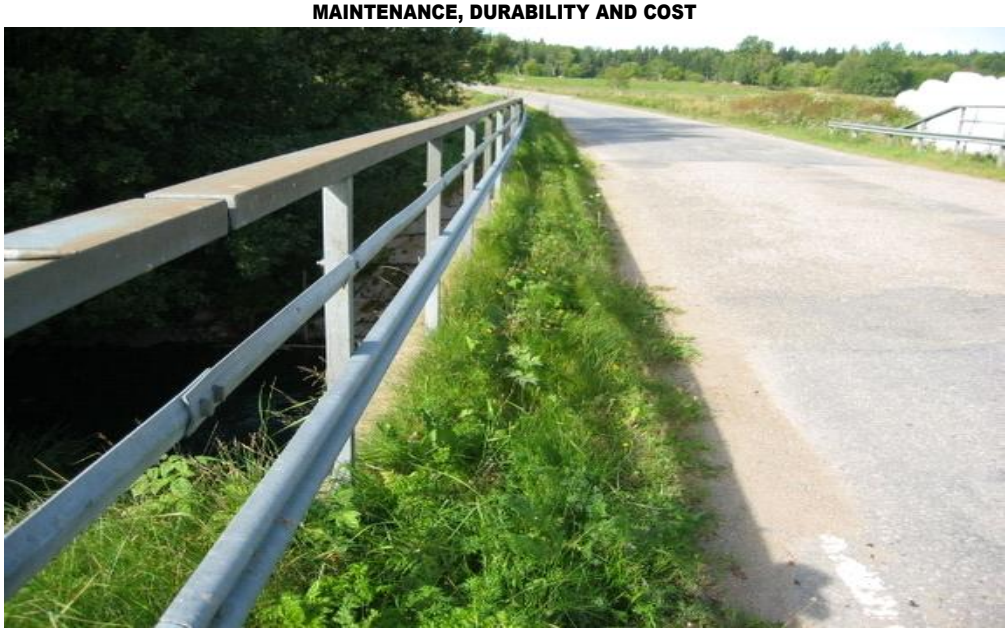
- ◯ Concrete railings
- ◯ Steel railings
- ◯ Steel concrete combined railings

Please give brief reasons (optional)

10. Which quality assurance criteria do you utilize in ensuring the quality of your edge beam systems? It is possible to choose more than one option.

- ☐ Increased concrete grade that will withstand harsh weather and environmental influences
- ☐ Increased thickness and less reinforcement for your edge beam?
- ☐ Rust free reinforcement (stainless, painted, hot dip galvanized etc.)
- ☐ Impregnation or water proofing
- ☐ Other, please specify

MAINTENANCE, DURABILITY AND COST



11. Have you encountered any problem with edge beam system? if yes which type of edge beam system

	Yes	No
Integrated edge beam system	◯	◯
Prefabricated (not integrated) edge beam system	◯	◯
Steel railings	◯	◯
Concrete railings	◯	◯
Steel concrete combined railings	◯	◯

Other types, please specify

12. Based on your experience and knowledge from the previous question, which component of the edge beam system was the most defective?

◯ Railings

◯ Concrete beam itself

◯ Other components, please specify

13. How often do you perform or propose to clients to carry out general inspection and maintenance on edge beam systems?

Every year	Every 2 years	Every 3-5 years	Above 5 years
◯	◯	◯	◯

14. Have you carried out any type of repair work on edge beams? If yes which type of repair have you carried out on edge beams? It is possible to choose more than one option.

- [ ] Replacement (to demolish and construct new including waterproofing, surfacing and railing replacement.)
- [ ] Minor repair (patching with concrete, repair of parapet, repainting of railings etc.)
- [ ] Other, please specify

15. What are the major reasons for repair or causes of problems on the edge beam? It is possible to choose more than one problem.

- [ ] Edge beam concrete spalling
- [ ] Corrosion of edge beam reinforcement
- [ ] Corrosion of edge beam railings
- [ ] Damage on edge beams from vehicle collisions
- [ ] Other, please specify

16. On which type of bridge were the edge beam problems encountered? it is possible to choose more than one option.

- [ ] Steel bridge
- [ ] Reinforced/Prestressed concrete bridge
- [ ] Steel concrete composite bridge
- [ ] Other types, please specify

17. What is the average age of edge beams subjected to minor repairs?

18. What is the average age of replaced edge beams?

19. Did you have to close or stop the bridge traffic during the period of edge beam replacement or repairs? If yes, please state approximate duration.

20. What are the main causes of degradation of edge beams on your bridges? it is possible to choose more than one option

- [ ] Corrosion
- [ ] Water, poor drainage and impedance to water runoff on the deck
- [ ] Sway of lamp posts and fencing systems from wind loads causing damage
- [ ] De-icing salt
- [ ] Inappropriate design
- [ ] Poor maintenance (vegetation growths, sedimentation etc.)
- [ ] Chemical process in concrete (chloride, alkali , sulphate and acid attacks)
- [ ] Physical process in concrete (Freeze thaw, abrasion, erosion, cracking, heat and fire damages)
- [ ] Concrete shrinkage including cracking, warping (or curling) and joint spalling
- [ ] Collisions, accidents and impact loads on the railings
- [ ] Other, please specify

21. What type of remedy or remedies have you utilized in solving the problem of degradation? It is possible to choose more than one option.

- [ ] Use of seals, impregnating and waterproofing systems
- [ ] Avoiding anchorages (hanger, railings, sign & lamp posts etc.) on the deck, edge beam surface
- [ ] Provide good runoff and drainage system
- [ ] Cathodic protection
- [ ] Special fiber concrete
- [ ] Extra high concrete quality
- [ ] Extra-large covers
- [ ] Rust free(stainless) reinforcements, membranes and other coatings to protect steel
- [ ] Use of corrosion inhibitors in concrete mix
- [ ]

- [ ] Other, please specify

22. Are there any forms of crack or other concrete damages observed or recorded on the edge beams after a wear course replacement or repair on your bridges? if yes please describe

23. Which is the most prominent source of water ingress into your bridge edge beam systems? It is possible to choose more than one option.

- [ ] Through the anchorages of cables, hangers, lamp post, fence system etc.
- [ ] Through the railing fittings
- [ ] Through the grooves between the raised edge beam level and the deck (gutter)
- [ ] Through the deck and edge beam surfaces
- [ ] Other sources, please specify

24. Based on your knowledge and experience, which would you consider most expensive considering cost of construction?

- ◯ Concrete railing
- ◯ Steel railing
- ◯ Steel and concrete combined railing

25. Based on your knowledge and experience, which would you consider most expensive considering general maintenance cost?

- ◯ Concrete railing
- ◯ Steel railing
- ◯ Steel and concrete combined railing

26. Based on your knowledge and experience, which would you consider most expensive considering cost of repair and replacement?

- ◯

- ◯ Concrete railing
- ◯ Steel railing
- ◯ Steel and concrete combined railing

27. Based on your knowledge and experience, which would you consider most expensive considering cost of repair and replacement?

	Low	Moderate	High
Concrete railing	◯	◯	◯
Steel railing	◯	◯	◯
Steel and concrete combined railing	◯	◯	◯
Other types	◯	◯	◯

Other (please specify)

28. Based on your experience, what is your proposal for optimal edge beam system. Please describe your proposal for a simple concrete bridge including details for railings, fastenings, waterproofing, lamp post, fencing system, drainage system etc. if possible please provide, pictures, sketches and drawings for easier understanding of the concept.
Drawings and details can be sent by:

Email:
Håkan Sundquist at hakan.sundquist@byv.kth.se
Adebowale Fasheyi at fasheyi@kth.se

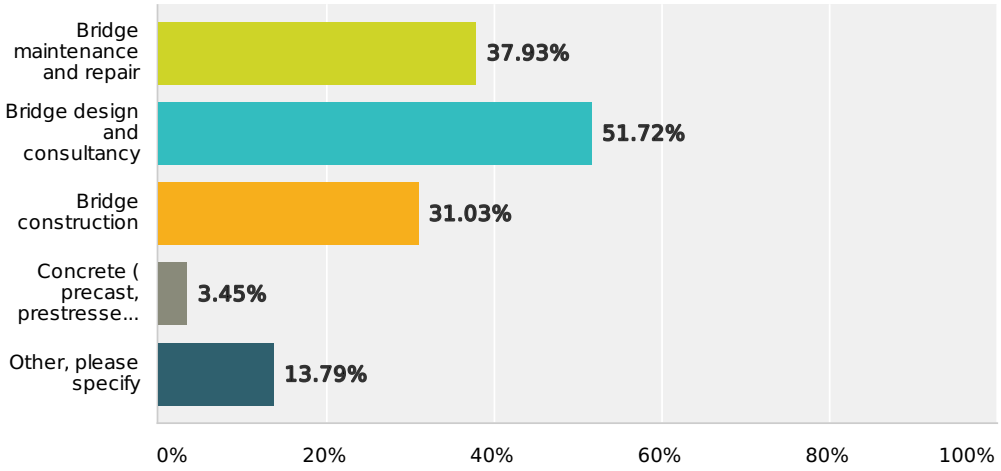
Post:
Department of Bridges and Structural Engineering,
KTH Royal Institute of Technology,
100 44 Stockholm, Sweden.

Thank you. The survey is now completed. Questions and drawings can be sent by email to:
Håkan Sundquist at hakan.sundquist@byv.kth.se
Adebowale Fasheyi at fasheyi@kth.se

or by post to
Department of Bridges and Structural Engineering,
KTH Royal Institute of Technology,
100 44 Stockholm, Sweden.

Q1 Which of the following best describes your area or areas of specialization? It is possible to choose more than one option.

Answered: 29 Skipped: 1

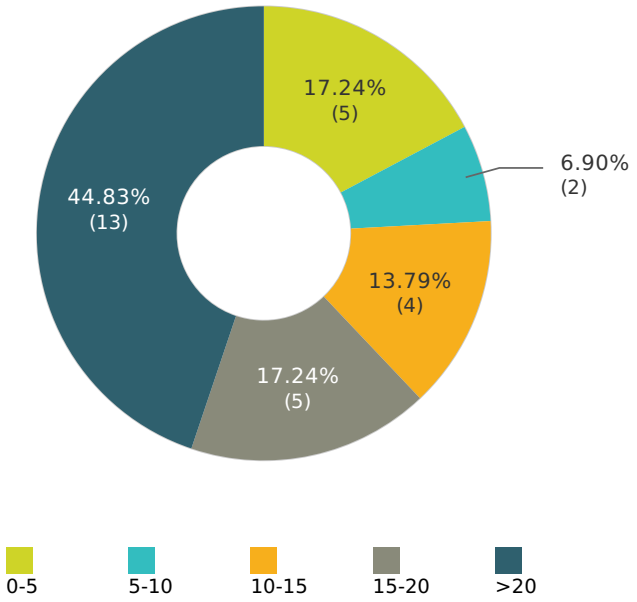


Answer Choices	Responses	
Bridge maintenance and repair	**37.93%**	11
Bridge design and consultancy	**51.72%**	15
Bridge construction	**31.03%**	9
Concrete (precast, prestressed, in-situ) producing firm	**3.45%**	1
Other, please specify	**13.79%**	4
Total Respondents: 29		

#	Other, please specify	Date
1	concrete durability (research)	5/2/2013 10:09 AM
2	Bridge management and planning	4/22/2013 1:11 PM
3	Asset management	12/5/2012 9:26 AM
4	Inspection	11/28/2012 5:02 PM

Q2 How many years of experience as a bridge engineer do you have?

Answered: 29 Skipped: 1



	0undefined5	5undefined10	10undefined15	15undefined20	>20	Total	Average Rating
(no label)	**17.24%** 5	**6.90%** 2	**13.79%** 4	**17.24%** 5	**44.83%** 13	29	3.66

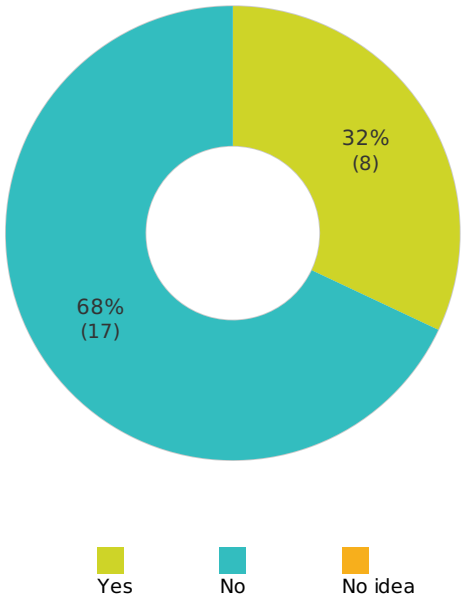
Q3 In which country or countries have you practiced or practising? Please state

Answered: 29 Skipped: 1

#	Responses	Date
1	USA	5/16/2013 9:21 PM
2	united states	5/8/2013 8:09 PM
3	Sweden, Poland	5/6/2013 1:59 PM
4	Jugoslavien, Sverige	5/6/2013 12:05 PM
5	Sweden, Norway	5/4/2013 2:19 PM
6	Québec - Canada	5/3/2013 4:33 PM
7	Sweden	5/3/2013 4:29 PM
8	Canada	5/3/2013 3:45 PM
9	UK, US, Germany, Italy, Middle East	5/3/2013 2:48 PM
10	Canada	5/2/2013 10:31 PM
11	State of Washington, United States	5/2/2013 8:07 PM
12	United States	5/2/2013 6:27 PM
13	United States	5/2/2013 5:44 PM
14	Sweden	5/2/2013 3:22 PM
15	France	5/2/2013 10:09 AM
16	Latvia	4/22/2013 1:11 PM
17	Denmark	4/21/2013 8:46 AM
18	Estonia	4/17/2013 7:54 AM
19	USA	4/16/2013 6:23 PM
20	Estonia	4/16/2013 7:45 AM
21	Switzerland	1/15/2013 12:35 PM
22	Denmark, Botswana, South Africa, Ghana, Pakistan, Bulgaria, Russia, Hong Kong.	1/14/2013 9:24 AM
23	Netherlands, Belgium, Germany, Norway, Chili, Luxembourg	12/18/2012 4:47 PM
24	Denmark, Sweden, England, Tajikistan, Portugal, Morocco, Qatar	12/11/2012 12:02 PM
25	United States and Mexico	12/5/2012 3:54 PM
26	UK	12/5/2012 9:26 AM
27	Switzerland, Austria	12/4/2012 8:50 AM
28	Estonia	11/29/2012 11:03 AM
29	SLOVENIA	11/28/2012 5:02 PM

Q4 Is the geometric design of your edge beams such that will allow snow and water runoff naturally from the edge beams?

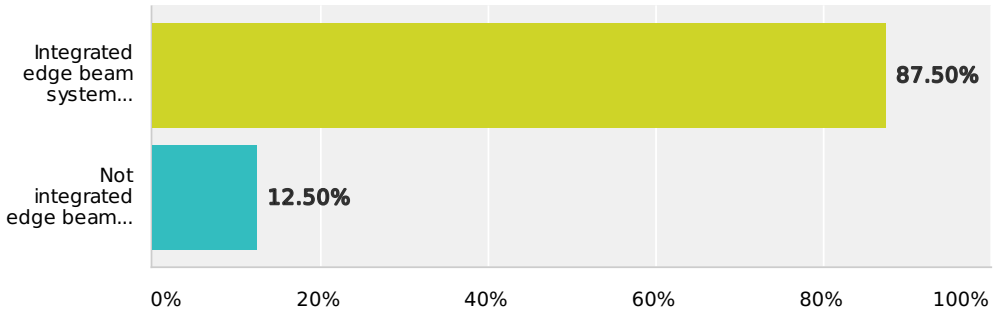
Answered: 25 Skipped: 5



	(no label)	Total	Average Rating
Yes	**100%** 8	8	1.00
No	**100%** 17	17	2.00
No idea	**0%** 0	0	0.00

Q5 Which type of edge beam systems would you prefer in your edge beam design? (see figure)

Answered: 24 Skipped: 6



Answer Choices	Responses	
Integrated edge beam system (structurally integrated with the slab)	**87.50%**	21
Not integrated edge beam system	**12.50%**	3
Total		24

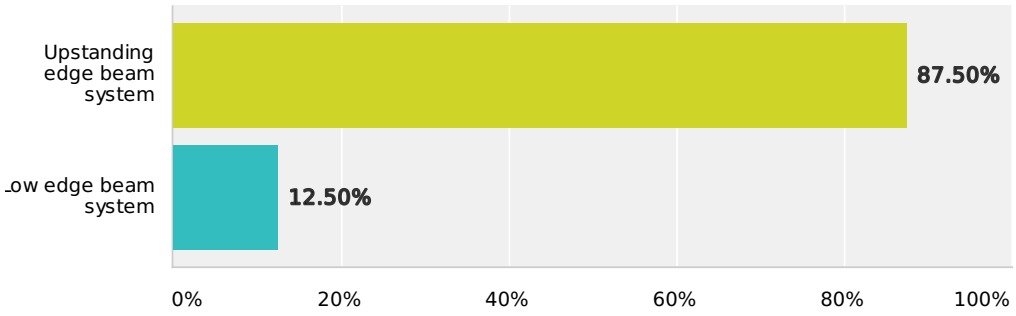
Please give brief reasons (optional) (15)

#	Please give brief reasons (optional)	Date
1	Site fit up for non integarted solution can be a major issue if not carefully controled both from a functionality point of view and visually.	5/3/2013 3:47 PM
2	Stiffens the deck slab.	5/3/2013 12:54 AM
3	The edge beam systems incorporated by Alberta Transportation are integrated with the concrete deck slab for anchorage purposes. The deck is designed for the edge beam anchorage forces. Our edge beam designs are based on crash tested sytems that meet the NCHRP 350 crash testing guidelines. Please find a link to our standard edge beam design drawings as follows: http://www.transportation.alberta.ca/4855.htm	5/2/2013 10:50 PM
4	We cannot let water runoff of our bridges due to pollution concerns for fish. We typicall use a a cast-in place concrete barrier cast onto the concrete deck. While we don't considered it, the barrier acts somewhat as an edge beam.	5/2/2013 8:13 PM
5	Less weight, better structural integrity	5/2/2013 6:32 PM
6	Have no experience of not integrated edge beam but it seams that there could be a problem with the part of the slab that is hidden under the edge beam system. How do you make sure it´s not exposed to saltwater.	5/2/2013 3:37 PM
7	Solid structures have better durability index, comparing with pre-cast structures.	4/22/2013 1:36 PM
8	Too many problems with not integrated edge beams - not used in Denmark anymore.	4/21/2013 8:51 AM
9	No hidden surfaces, more easy to repair. Water will run under the not integrated edge beam element and destroy the tip of the bridge slap in which place you offen got the anchorage of the transverse post tension cables.	1/14/2013 9:42 AM
10	To be able to control the water/snow it is best have a system integrated	12/18/2012 5:09 PM
11	Integrated can give more issue in maintenance, but lack of development in nonintegral is holding this back.	12/11/2012 12:08 PM
12	If it is in one cast process, there will be fewer errors than installing another piece of edge that may cause interferences with the drainage.	12/5/2012 4:01 PM

#	Please give brief reasons (optional)	Date
13	Prevents possible water traps and hidden details which cannot be effectively inspected and maintained	12/5/2012 9:33 AM
14	The integrated edge beam system has a problem with the sealing in the edge. The non integrated edge beam can simply be replaced.	12/4/2012 8:59 AM
15	because there is less options to damage the membrane	11/29/2012 12:30 PM

Q6 Which type of edge beam systems would you prefer in your edge beam design? (see figure)

Answered: 24 Skipped: 6



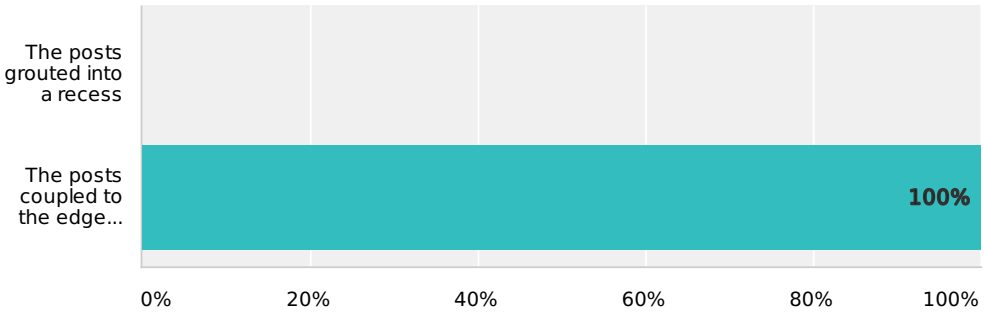
Answer Choices	Responses	
Upstanding edge beam system	**87.50%**	21
Low edge beam system	**12.50%**	3
Total		24

Please give brief reasons (optional) (14)

#	Please give brief reasons (optional)	Date
1	We are not normally permitted to run the rainwter off over the edge withput control.	5/3/2013 3:47 PM
2	We can control drainage runoff.	5/3/2013 12:54 AM
3	Upstanding edge beams are used to divert water that collects in the gutter area to the ends of the bridge where it drains off the side into a collector trough and down the sideslope in a lined swale. An upstanding edge beam is preferred so that the girder fascias (exterior faces)are not exposed to chloride contaminated water.	5/2/2013 10:50 PM
4	see answer to question 5	5/2/2013 8:13 PM
5	Protect streams from pollutant run-off	5/2/2013 6:32 PM
6	From a environmental point of view its not realistic to let the water run of naturally.	5/2/2013 3:37 PM
7	Installed de-watering system lets edge beam to extend structure lifetime and reduce maintenance costs.	4/22/2013 1:36 PM
8	We do not want anything at all (water, salt, pebbles, ...) falling off the bridge.	4/21/2013 8:51 AM
9	Water running over the edge beam will in the long run destroy the surface of the edge beam.	1/14/2013 9:42 AM
10	Mainly for aestetical reasons	12/11/2012 12:08 PM
11	To avoid stains to the edge beam due to rainfall.	12/5/2012 4:01 PM
12	Is required by our design standards. Also prevents some water run-off and halps to retain some debris	12/5/2012 9:33 AM
13	The safety barrier can simply be replaced.	12/4/2012 8:59 AM
14	because then can give to a slope a different value	11/29/2012 12:30 PM

Q7 Which type of coupling between railing/parapet and edge beam do you prefer? (see figure)

Answered: 25 Skipped: 5



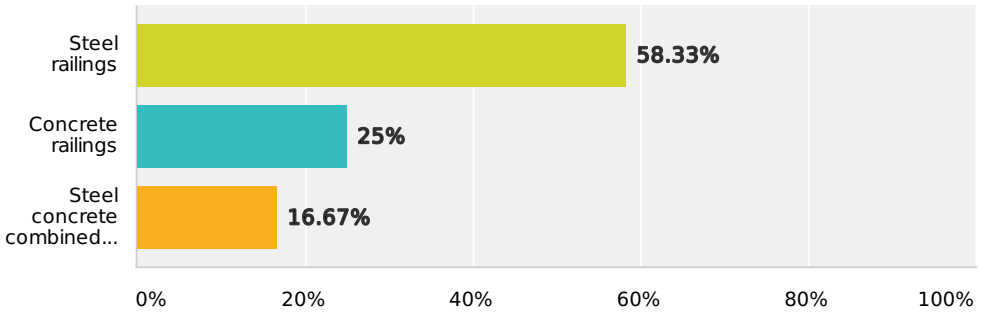
Answer Choices	Responses	
The posts grouted into a recess	**0%**	0
The posts coupled to the edge beams using bolts and nuts	**100%**	25
Total		25

Please give brief reasons (optional) (12)

#	Please give brief reasons (optional)	Date
1	For ease of replacement of posts it is simpler to us a bolted connection.	5/3/2013 3:47 PM
2	More adjustability. More easily accommodate eventual replacement of (damaged) railing, reduced interference with reinforcement bars.	5/3/2013 12:54 AM
3	Alberta Transportation has a standard rail and post edge beam system that facilitates post anchorage using anchor rods. Please find a link to our standard rail and post edge beam details: http://www.transportation.alberta.ca/Content/doctype30/production/s1642-00-rev5.pdf	5/2/2013 10:50 PM
4	Easier maintenance. (easier to replace due to damage from impact.	5/2/2013 8:13 PM
5	Easeir to inspect and replace - the grouted ones have shown too may problems where some were not detected in time!	4/21/2013 8:51 AM
6	More easy to change the post.	1/14/2013 9:42 AM
7	When damaged easy to repair. But my experience is in steel bridges	12/18/2012 5:09 PM
8	Easier replacement when designed correctly to shear above the bolts	12/11/2012 12:08 PM
9	Need less maintenance than resin type of coupling between edge beam and railing/parapet	12/5/2012 4:01 PM
10	Posts grouted into a recess a reliable to corrosion which is difficult to detect and therefore sudden failure. This type of detail also tends to result in more severe damage to the edge beam in the event of an accident.	12/5/2012 9:33 AM
11	The railing/parapet can simply be replaced.	12/4/2012 8:59 AM
12	there is a less damages to the edge beams when the accident happens	11/29/2012 12:30 PM

Q8 Which type of edge beam systems would you prefer in your edge beam design?

Answered: 24 Skipped: 6



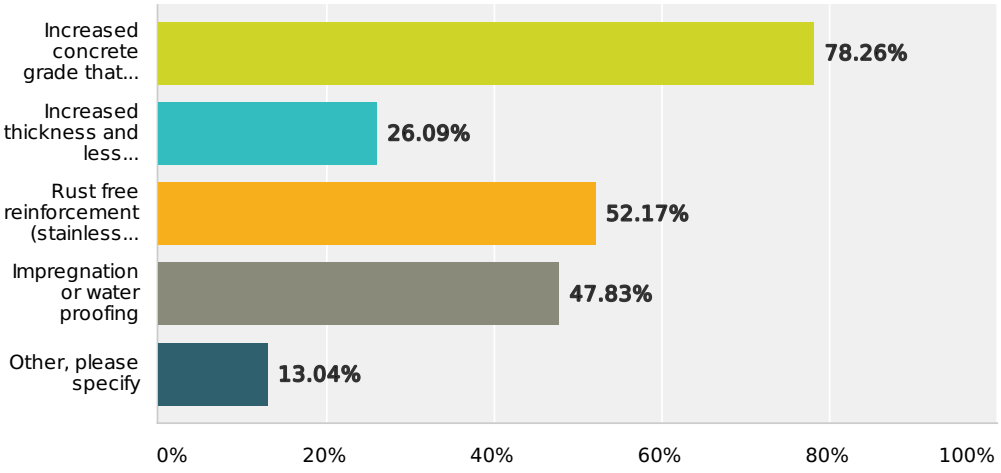
Answer Choices	Responses	
Steel railings	**58.33%**	14
Concrete railings	**25%**	6
Steel concrete combined railings	**16.67%**	4
Total		24

Please give brief reasons (optional) (14)

#	Please give brief reasons (optional)	Date
1	Missing designcodes for integrated concrete edge , beam parapets	5/6/2013 2:02 PM
2	Even if it is prefered, it is not always possible due to the performance level of the barrier (quantity of traffic, importance of highway, ...). Sometimes it has to be concrete combined to steel, others only concrete.	5/3/2013 4:40 PM
3	The answer the question is that it dpends on the ype of road and what is accepatbel from a risk point of view, both to the structure and the vehicles.	5/3/2013 3:47 PM
4	Single material simplifies construction. No fit up issues between concrete and steel components.	5/3/2013 12:54 AM
5	Alberta Transportation utilizes all 3 of these edge beam systems. However, a post and rail system is typically the first choice as the concrete railings can be prone to snow drifting. A combination steel and concrete system is used for areas where extra height is required adjacent to widened lanes that support bicycle traffic	5/2/2013 10:50 PM
6	Little to no maintenance.	5/2/2013 8:13 PM
7	Less maintenance problems	5/2/2013 6:32 PM
8	If proper coating is used, steel railing durability will be significant.	4/22/2013 1:36 PM
9	Gives the bridge at lighter look.	1/14/2013 9:42 AM
10	Aluminium rails whenever possible. Only concrete if proven to deflect in a suitable manner to safely catch a impact. Some concrete parapets with longitudinal cables can provided such.	12/11/2012 12:08 PM
11	Need less maintenance.	12/5/2012 4:01 PM
12	All three options have their place. The decision on which to use depends on manay factors including what the structure crosses and the level of containment required.	12/5/2012 9:33 AM
13	The steel railing has a low dead load.	12/4/2012 8:59 AM
14	we dont have experience with concrete railings and concrete railings are with high repair costs	11/29/2012 12:30 PM

Q9 Which quality assurance criteria do you utilize in ensuring the quality of your edge beam systems? It is possible to choose more than one option.

Answered: 23 Skipped: 7

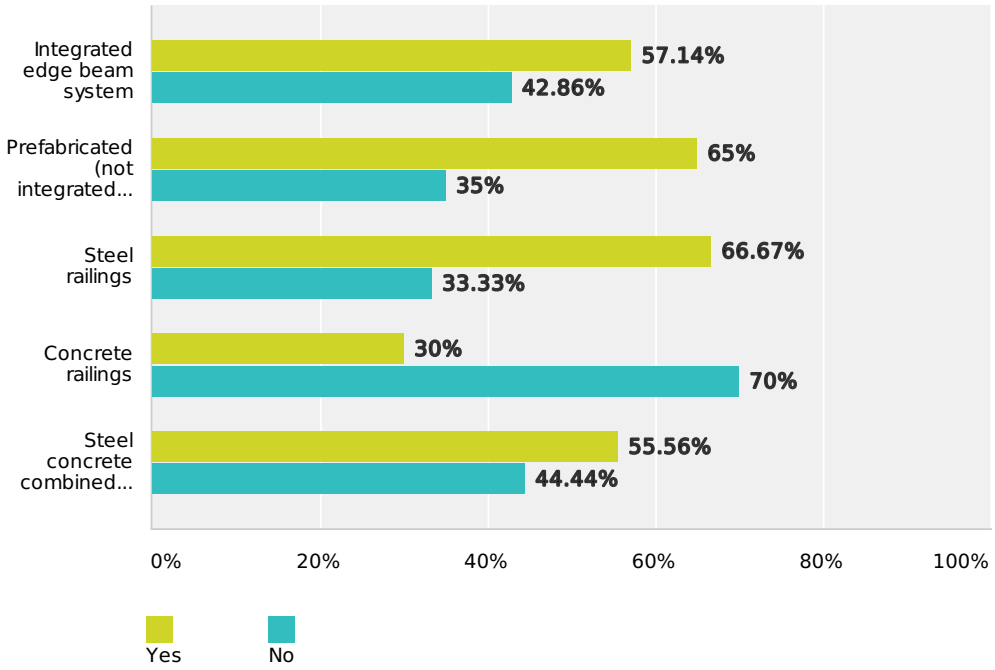


Answer Choices	Responses	
Increased concrete grade that will withstand harsh weather and environmental influences	**78.26%**	18
Increased thickness and less reinforcement for your edge beam?	**26.09%**	6
Rust free reinforcement (stainless, painted, hot dip galvanized etc.)	**52.17%**	12
Impregnation or water proofing	**47.83%**	11
Other, please specify	**13.04%**	3
Total Respondents: 23		

#	Other, please specify	Date
1	Strength	5/3/2013 3:47 PM
2	Alberta Transportation utilized extra concrete cover to the reinforcing steel on the tops and traffic faces of our edge beam systems in addition to corrosion resistan reinforcing steel. We utilize either Stainless Steel or ASTM A1035 low carbon steel	5/2/2013 10:50 PM
3	Increased cover.	12/5/2012 9:33 AM

Q10 Have you encountered any problem with edge beam system? if yes which type of edge beam system

Answered: 22 Skipped: 8



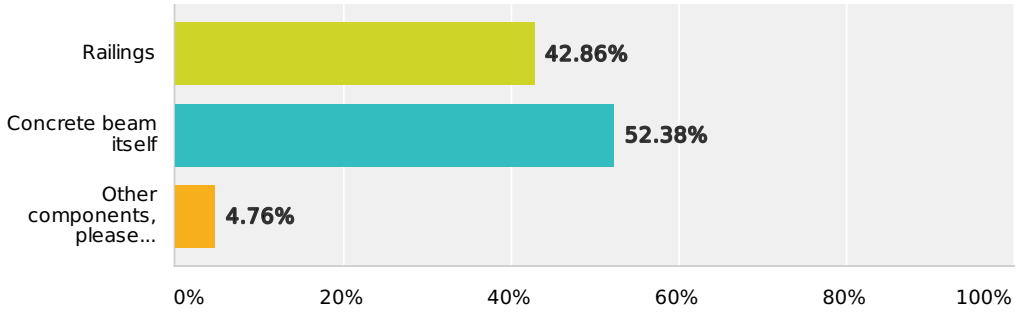
	Yes	No	Total
Integrated edge beam system	**57.14%** 12	**42.86%** 9	21
Prefabricated (not integrated) edge beam system	**65%** 13	**35%** 7	20
Steel railings	**66.67%** 14	**33.33%** 7	21
Concrete railings	**30%** 6	**70%** 14	20
Steel concrete combined railings	**55.56%** 10	**44.44%** 8	18

Other types, please specify **(1)**

#	Other types, please specify	Date
1	Aluminium	12/11/2012 12:16 PM

Q11 Based on your experience and knowledge from the previous question, which component of the edge beam system was the most defective?

Answered: 21 Skipped: 9

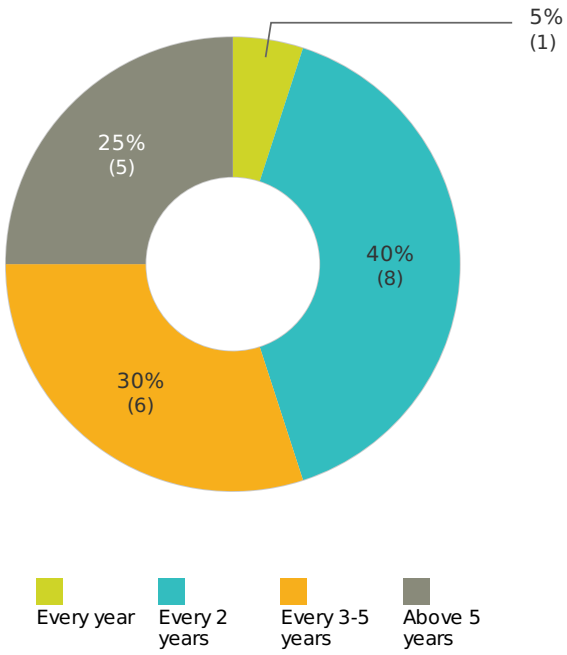


Answer Choices	Responses	
Railings	**42.86%**	9
Concrete beam itself	**52.38%**	11
Other components, please specify	**4.76%**	1
Total		21

#	Other components, please specify	Date
1	Only issue we have experienced is in the design phase with detailing and providing the appropriate reinforcing steel anchorage into the integrated edge beam/deck to meet the Canadian Highway Bridge Design Code anchorage requirements.	5/2/2013 11:07 PM

Q12 How often do you perform or propose to clients to carry out general inspection and maintenance on edge beam systems?

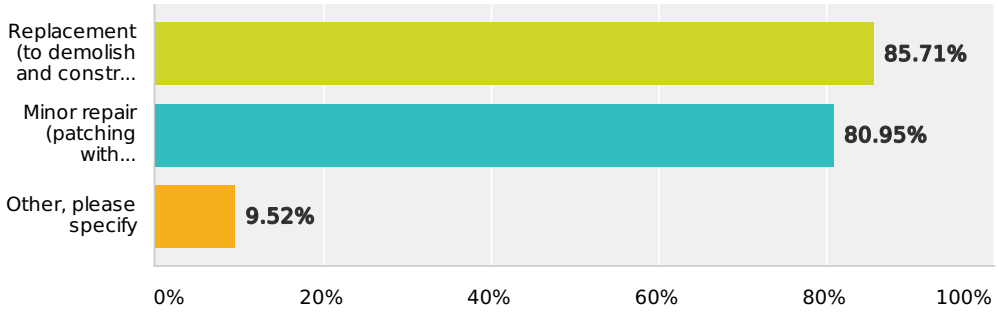
Answered: 20 Skipped: 10



	Every year	Every 2 years	Every 3undefined5 years	Above 5 years	Total	Average Rating
(no label)	5% 1	40% 8	30% 6	25% 5	20	2.75

Q13 Have you carried out any type of repair work on edge beams? If yes which type of repair have you carried out on edge beams? It is possible to choose more than one option.

Answered: 21 Skipped: 9

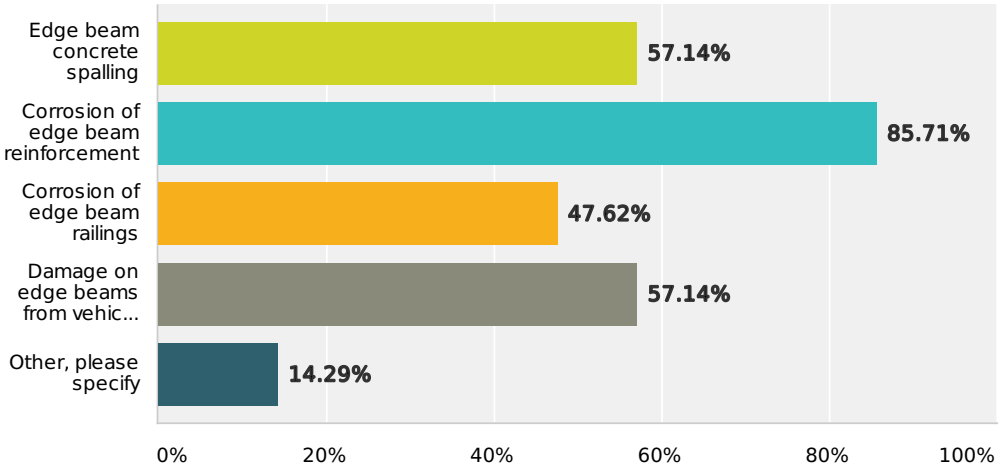


Answer Choices	Responses	
Replacement (to demolish and construct new including waterproofing, surfacing and railing replacement.)	**85.71%**	18
Minor repair (patching with concrete, repair of parapet, repainting of railings etc.)	**80.95%**	17
Other, please specify	**9.52%**	2
Total Respondents: 21		

#	Other, please specify	Date
1	Thrie beam retrofits	5/2/2013 8:18 PM
2	upgrades to higher containment classes in accordance to updated safety standards	12/11/2012 12:16 PM

Q14 What are the major reasons for repair or causes of problems on the edge beam? It is possible to choose more than one problem.

Answered: 21 Skipped: 9

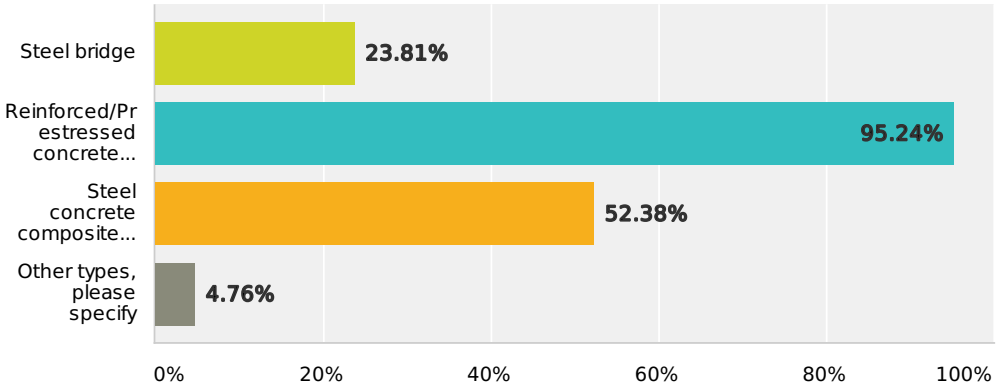


Answer Choices	Responses	
Edge beam concrete spalling	**57.14%**	12
Corrosion of edge beam reinforcement	**85.71%**	18
Corrosion of edge beam railings	**47.62%**	10
Damage on edge beams from vehicle collisions	**57.14%**	12
Other, please specify	**14.29%**	3
Total Respondents: 21		

#	Other, please specify	Date
1	Edge beam failed because of snow accumulation after long-term (65 years) of chloride deterioration.	5/3/2013 1:12 AM
2	AKR- reactions, cloride etc.	1/14/2013 9:51 AM
3	Old railings with substandard containment capacity which need to be strengthened or replaced.	12/5/2012 9:38 AM

Q15 On which type of bridge were the edge beam problems encountered? it is possible to choose more than one option.

Answered: 21 Skipped: 9



Answer Choices	Responses	
Steel bridge	**23.81%**	5
Reinforced/Prestressed concrete bridge	**95.24%**	20
Steel concrete composite bridge	**52.38%**	11
Other types, please specify	**4.76%**	1
Total Respondents: 21		

#	Other types, please specify	Date
1	Masonry	12/5/2012 9:38 AM

Q16 What is the average age of edge beams subjected to minor repairs?

Answered: 19 Skipped: 11

#	Responses	Date
1	ca 10yrs	5/6/2013 2:05 PM
2	I do not know	5/4/2013 2:25 PM
3	Approx 15-20 years	5/3/2013 5:11 PM
4	20-25 years	5/3/2013 4:43 PM
5	10 years	5/3/2013 3:51 PM
6	40 years	5/3/2013 1:12 AM
7	Typically minor repairs are not necisary due to use of corrosion resistant reinforcing steel and 100mm of concrete cover on the traffic side	5/2/2013 11:07 PM
8	10	5/2/2013 6:37 PM
9	Can not answer. All types of ages	5/2/2013 3:53 PM
10	10-15 years	4/22/2013 1:33 PM
11	+30 years	4/21/2013 8:55 AM
12	20	1/15/2013 12:41 PM
13	30 - 40 years	1/14/2013 9:51 AM
14	10-15 years, with no data to back it up	12/11/2012 12:16 PM
15	5 years	12/5/2012 4:08 PM
16	10 years +	12/5/2012 9:38 AM
17	10-15 years	12/4/2012 9:15 AM
18	10-15 years	11/29/2012 12:36 PM
19	15 to 25 years	11/28/2012 5:12 PM

Q17 What is the average age of replaced edge beams?

Answered: 20 Skipped: 10

#	Responses	Date
1	ca 40 yrs	5/6/2013 2:05 PM
2	I do not know	5/4/2013 2:25 PM
3	Approx 30-35 years	5/3/2013 5:11 PM
4	40-45years	5/3/2013 4:43 PM
5	+20 years	5/3/2013 3:51 PM
6	65 years	5/3/2013 1:12 AM
7	Typically these are replaced on an as needed basis based on a cost benefit analysis if they do not meet the current code requirements. Typically this is at the 25-35 year mark	5/2/2013 11:07 PM
8	50 years plus, most repair/replacement was due to functional reasons rather that deterioration.	5/2/2013 8:18 PM
9	35	5/2/2013 6:37 PM
10	45 years	5/2/2013 3:53 PM
11	25-30 years	4/22/2013 1:33 PM
12	Anywhere between 25 and 50	4/21/2013 8:55 AM
13	40	1/15/2013 12:41 PM
14	40 - 50 years	1/14/2013 9:51 AM
15	25years, with no data to back it up	12/11/2012 12:16 PM
16	10 years	12/5/2012 4:08 PM
17	30	12/5/2012 9:38 AM
18	30-40 years	12/4/2012 9:15 AM
19	20-30 years	11/29/2012 12:36 PM
20	20 to 35 years	11/28/2012 5:12 PM

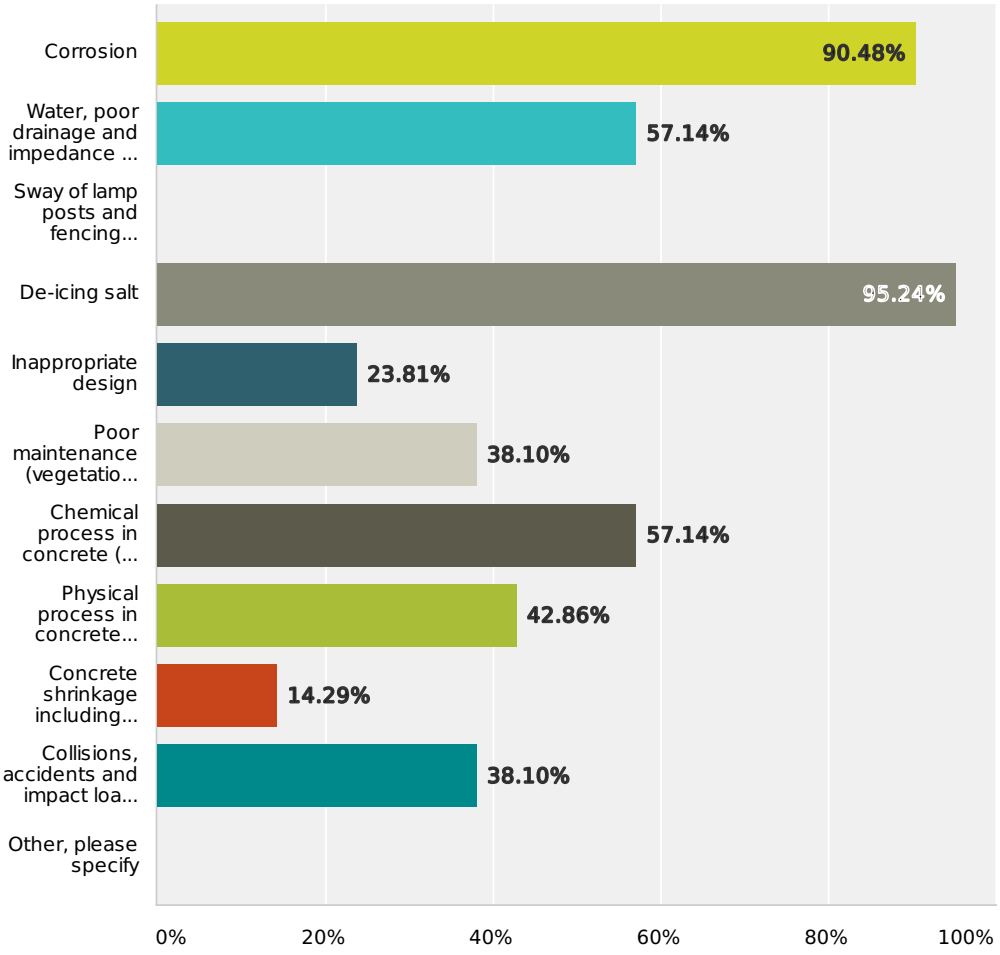
Q18 Did you have to close or stop the bridge traffic during the period of edge beam replacement or repairs? If yes, please state approximate duration.

Answered: 16 Skipped: 14

#	Responses	Date
1	-	5/6/2013 2:05 PM
2	no	5/4/2013 2:25 PM
3	Yes, for a 30 m long bridge, it could be a 3-4 weeks period	5/3/2013 5:11 PM
4	No	5/3/2013 4:43 PM
5	At least a week	5/3/2013 3:51 PM
6	Yes, approximate 10 days.	5/3/2013 1:12 AM
7	Typicall traffic accommodation is used to re-route traffic away from the work. Typically the work can be completed in 1-2 weeks	5/2/2013 11:07 PM
8	Depends on width and length of the bridge as well as volume of traffic.	5/2/2013 8:18 PM
9	Lane closures lasting approximately 3 months typically.	5/2/2013 6:37 PM
10	I have always had at least one lane open.	5/2/2013 3:53 PM
11	Some needed closure - som not! The duration can be from 2 weeks til 12 weeks depending on the situation	4/21/2013 8:55 AM
12	no	1/15/2013 12:41 PM
13	Partial lane closure in all cases lasting for 2-4 months.	12/11/2012 12:16 PM
14	Yes, one lane at most. Duration: two weeks	12/5/2012 4:08 PM
15	Yes. three months	12/5/2012 9:38 AM
16	no	11/29/2012 12:36 PM

Q19 What are the main causes of degradation of edge beams on your bridges? it is possible to choose more than one option

Answered: 21 Skipped: 9



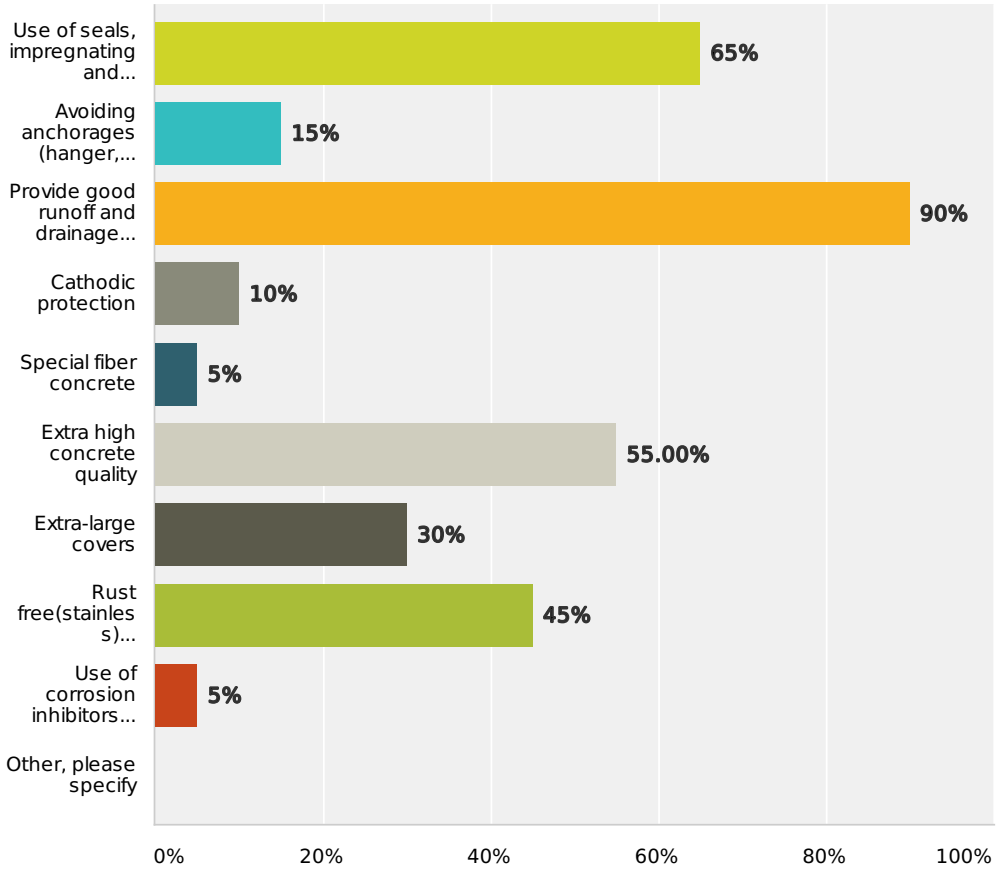
Answer Choices	Responses	
Corrosion	**90.48%**	19
Water, poor drainage and impedance to water runoff on the deck	**57.14%**	12
Sway of lamp posts and fencing systems from wind loads causing damage	**0%**	0
De-icing salt	**95.24%**	20
Inappropriate design	**23.81%**	5
Poor maintenance (vegetation growths, sedimentation etc.)	**38.10%**	8
Chemical process in concrete (chloride, alkali , sulphate and acid attacks)	**57.14%**	12
Physical process in concrete (Freeze thaw, abrasion, erosion, cracking, heat and fire damages)	**42.86%**	9
Concrete shrinkage including cracking, warping (or curling) and joint spalling	**14.29%**	3
Collisions, accidents and impact loads on the railings	**38.10%**	8
Total Respondents: 21		

Other, please specify	**0%**	0
Total Respondents: 21		

#	Other, please specify	Date
	There are no responses.	

Q20 What type of remedy or remedies have you utilized in solving the problem of degradation? It is possible to choose more than one option.

Answered: 20 Skipped: 10



Answer Choices	Responses	
Use of seals, impregnating and waterproofing systems	**65%**	13
Avoiding anchorages (hanger, railings, sign & lamp posts etc.) on the deck, edge beam surface	**15%**	3
Provide good runoff and drainage system	**90%**	18
Cathodic protection	**10%**	2
Special fiber concrete	**5%**	1
Extra high concrete quality	**55.00%**	11
Extra-large covers	**30%**	6
Rust free(stainless) reinforcements, membranes and other coatings to protect steel	**45%**	9
Use of corrosion inhibitors in concrete mix	**5%**	1
Other, please specify	**0%**	0
Total Respondents: 20		

#	Other, please specify	Date

#	Other, please specify	Date
	There are no responses.	

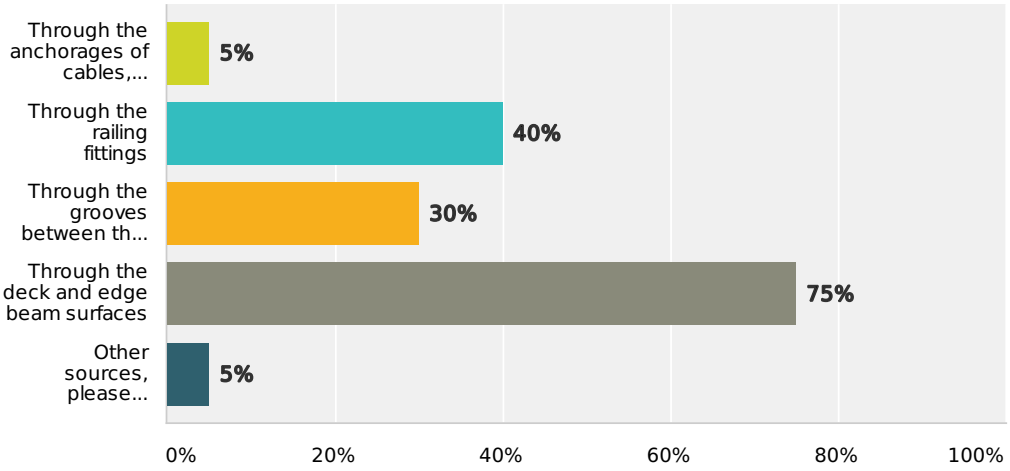
Q21 Are there any forms of crack or other concrete damages observed or recorded on the edge beams after a wear course replacement or repair on your bridges? if yes please describe

Answered: 16 Skipped: 14

#	Responses	Date
1	-	5/6/2013 2:05 PM
2	No	5/4/2013 2:25 PM
3	No	5/3/2013 5:11 PM
4	No	5/3/2013 4:43 PM
5	-	5/3/2013 3:51 PM
6	No.	5/3/2013 1:12 AM
7	In the past the crack control joints used in the edge beams varied and various systems and spacings were used in order to determine the best method of controling shrinkage cracking in the concrete curb portion of post and rail systems and full concrete edge beams. It was determined that control joints with plastic crack inducers with a reveal subsquently waterproofed with sealant and discontinuous longitudinal rebar at the control joints provided a superior crack control mechanism. See link for detail of the crack control joint: http://www.transportation.alberta.ca/Content/doctype30/production/s1680-07-rev2.pdf	5/2/2013 11:07 PM
8	No	5/2/2013 8:18 PM
9	"wear course" ?	4/21/2013 8:55 AM
10	shrinkage cracks between old and new concrete (normal physical effect)	1/15/2013 12:41 PM
11	Not to my knowledge	12/11/2012 12:16 PM
12	No	12/5/2012 4:08 PM
13	No	12/5/2012 9:38 AM
14	No	12/4/2012 9:15 AM
15	no	11/29/2012 12:36 PM
16	Local delaminations, transverse cracks, local spalling.	11/28/2012 5:12 PM

Q22 Which is the most prominent source of water ingress into your bridge edge beam systems? It is possible to choose more than one option.

Answered: 20 Skipped: 10

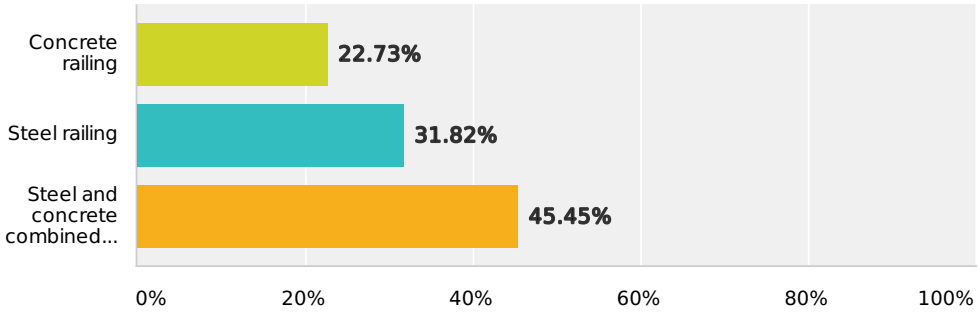


Answer Choices	Responses	
Through the anchorages of cables, hangers, lamp post, fence system etc.	**5%**	1
Through the railing fittings	**40%**	8
Through the grooves between the raised edge beam level and the deck (gutter)	**30%**	6
Through the deck and edge beam surfaces	**75%**	15
Other sources, please specify	**5%**	1
Total Respondents: 20		

#	Other sources, please specify	Date
1	Alberta Transportation uses a hot pour water proofing system with butyl rubber strips placed over the construction joints between the concrete deck and edge beam. Two lifts of 40mm thick ACP is placed on top of the membrane on the traffic wearing surface. The most common method of ingress/exposure to the barriers is thru salt laden splash and spray on to the barriers See link to the standard waterproofing detail at deck to edge beam joint: http://www.transportation.alberta.ca/Content/doctype30/production/S1443-11-rev1.pdf Refer to Detail "A"	5/2/2013 11:07 PM

Q23 Based on your knowledge and experience, which would you consider most expensive considering cost of construction?

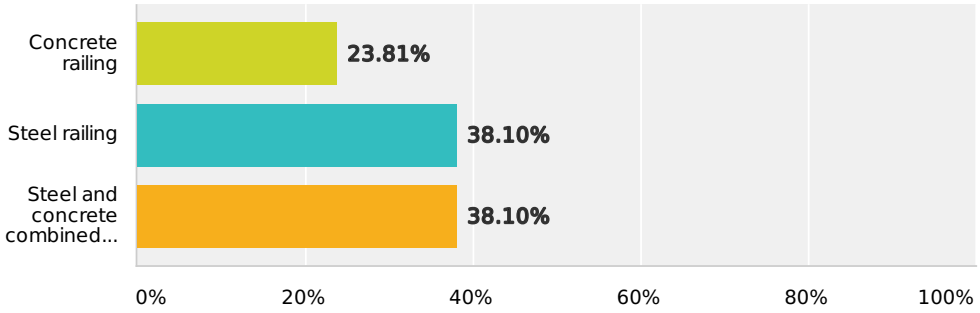
Answered: 22 Skipped: 8



Answer Choices	Responses	
Concrete railing	**22.73%**	5
Steel railing	**31.82%**	7
Steel and concrete combined railing	**45.45%**	10
Total		22

Q24 Based on your knowledge and experience, which would you consider most expensive considering general maintenance cost?

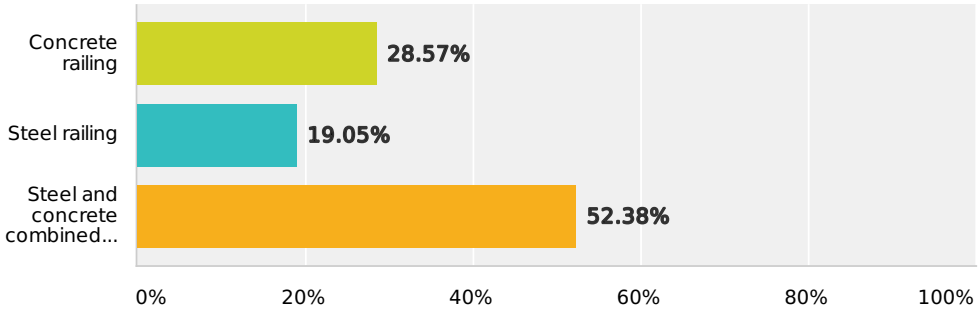
Answered: 21 Skipped: 9



Answer Choices	Responses	
Concrete railing	**23.81%**	5
Steel railing	**38.10%**	8
Steel and concrete combined railing	**38.10%**	8
Total		21

Q25 Based on your knowledge and experience, which would you consider most expensive considering cost of repair and replacement?

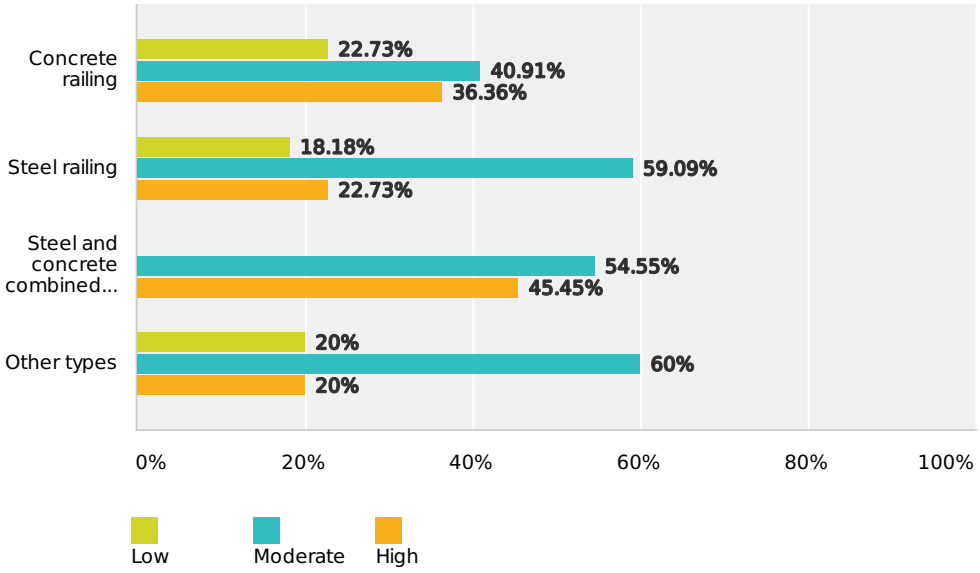
Answered: 21 Skipped: 9



Answer Choices	Responses	
Concrete railing	**28.57%**	6
Steel railing	**19.05%**	4
Steel and concrete combined railing	**52.38%**	11
Total		21

Q26 Based on your knowledge and experience, which would you consider most expensive considering cost of repair and replacement?

Answered: 22 Skipped: 8



	Low	Moderate	High	Total
Concrete railing	**22.73%** 5	**40.91%** 9	**36.36%** 8	22
Steel railing	**18.18%** 4	**59.09%** 13	**22.73%** 5	22
Steel and concrete combined railing	**0%** 0	**54.55%** 12	**45.45%** 10	22
Other types	**20%** 1	**60%** 3	**20%** 1	5

Other (please specify) **(4)**

#	Other (please specify)	Date
1	Aluminium	5/3/2013 3:52 PM
2	based on life cycle cost	5/2/2013 8:22 PM
3	Timber railing	4/22/2013 10:21 AM
4	Aluminium	12/11/2012 12:18 PM

Q27 Based on your experience, what is your proposal for optimal edge beam system. Please describe your proposal for a simple concrete bridge including details for railings, fastenings, waterproofing, lamp post, fencing system, drainage system etc. if possible please provide, pictures, sketches and drawings for easier understanding of the concept. Drawings and details can be sent by: Email: Håkan Sundquist at hakan.sundquist@byv.kth.se Adebowale Fasheyi at fasheyi@kth.se Post: Department of Bridges and Structural Engineering, KTH Royal Institute of Technology, 100 44 Stockholm, Sweden.

Answered: 3 Skipped: 27

#	Responses	Date
1	Using stainless steel reinforcement and high quality concrete	5/4/2013 2:27 PM
2	Alberta Transportation considers the steel post and railing system incorporating a short concrete curb to be the most optimal edge beam system for the Province. This is a PL2 (TL4) rated system and represents the majority of the barrier requirements on our bridges. This is a crash tested system that incorporates a crash tested approach rail transition as well. The crash testing was done in accordance with the guidelines of NCHRP report 350. A link to the edge beam and approach rail transition can be found respectively at the following links: http://www.transportation.alberta.ca/Content/doctype30/production/s1642-00-rev5.pdf http://www.transportation.alberta.ca/Content/doctype30/production/s1643-00-rev5.pdf Alberta Transportation uses increased concrete cover on the top and traffic faces of the edge beams in addition to corrossion resistant reinforcing (ASTM A1035 and Stainless Steel). The construction joint between the barrier and the concrete deck is waterproofed with hot applied membrane and supplemented by a butyl rubber strip that turns up the vertical face of the concrete curb portion of the barrier. See the following link especially Detail "A" for details: http://www.transportation.alberta.ca/Content/doctype30/production/S1443-11-rev1.pdf If light poles are required on the bridge they have to be located behind the edge beam barrier with sufficient set back coincedent with the barrier performance level required. See Bridge Structures Design Criteria Version 7 Section 21.3: http://www.transportation.alberta.ca/Content/docType30/Production/2012BridgeDesignCriteria70.pdf Drainage of surface water is collected at the gutter lines and conveyed off the bridge with the raised edge beam were it is collected at the bridge end and directed down a lined sideslope. Any water that percolates below the ACP to the top of the waterproofing membrane is collected at the gutter line using a plastic wick drain that runs the full length of the bridge where the water is discharged	5/2/2013 11:24 PM
3	The one made of concrete with w/c ratio no higher than 0.45, a reinforcement concrete cover no less than 5 cm, and a cementitiuos content (Portland cement + puzzolans) no less than 360 kg/m3. All drainage should be fabricated with a durable material (not PVC). For example high carbon content steel, and should be located at close distances between them (not further than 3 m).	12/5/2012 4:21 PM

Q28 If you would like to receive a copy of the results of this survey, please fill in your details

Answered: 14 Skipped: 16

Answer Choices	Responses	
Name:	**100%**	14
Company:	**100%**	14
Address 1:	**92.86%**	13
Address 2:	**7.14%**	1
City/Town:	**92.86%**	13
State/Province:	**28.57%**	4
ZIP/Postal Code:	**92.86%**	13
Country:	**92.86%**	13
Email Address:	**100%**	14
Phone Number:	**92.86%**	13
Total Respondents: 14		

#	Name:	Date
1	Louis-Marie Bélanger	5/3/2013 5:17 PM
2	Ralph Dornsife	5/3/2013 1:14 AM
3	Clayton	5/2/2013 11:24 PM
4	Julija Ivanova	4/22/2013 10:21 AM
5	Finn Jensen	4/21/2013 8:56 AM
6	Dr. Philipp Stoffel	1/15/2013 12:35 PM
7	Henrik O. Nielsen	1/14/2013 9:24 AM
8	Niels Kuijpers	12/18/2012 4:47 PM
9	Christian Frandsen	12/11/2012 12:02 PM
10	Andres A. Torres-Acosta	12/5/2012 3:54 PM
11	Stephen Pottle	12/5/2012 9:26 AM
12	Erwin Pilch	12/4/2012 8:50 AM
13	Olari Valter	11/29/2012 11:03 AM
14	Bevc	11/28/2012 5:02 PM
#	**Company:**	**Date**
1	Ministry of Transports of Québec	5/3/2013 5:17 PM
2	WSDOT Bridge & Structures	5/3/2013 1:14 AM
3	Matwychuk	5/2/2013 11:24 PM
4	Latvian State roads	4/22/2013 10:21 AM
5	COWI	4/21/2013 8:56 AM
6	Helbling Beratung + Bauplanung AG	1/15/2013 12:35 PM
7	Roaddirectorate	1/14/2013 9:24 AM

#	Company:	Date
8	Janson Bridging BV	12/18/2012 4:47 PM
9	COWI	12/11/2012 12:02 PM
10	Instituto Mexicano del Transporte	12/5/2012 3:54 PM
11	Transport for London	12/5/2012 9:26 AM
12	ASFINAG	12/4/2012 8:50 AM
13	Estonian Road Administration	11/29/2012 11:03 AM
14	ZAG Ljubljana	11/28/2012 5:02 PM
#	**Address 1:**	**Date**
1	930 Ch Ste-Foy 7th floor	5/3/2013 5:17 PM
2	P.O. Box 47340	5/3/2013 1:14 AM
3	4999 98 Avenue	5/2/2013 11:24 PM
4	Gogoļa Str. 3	4/22/2013 10:21 AM
5	Parallelvej 2	4/21/2013 8:56 AM
6	Hohlstrasse 614	1/15/2013 12:35 PM
7	Niels Juels Gade 13	1/14/2013 9:24 AM
8	Keizersveer 9	12/18/2012 4:47 PM
9	km 12 Carretera Queretaro-Galindo	12/5/2012 3:54 PM
10	Palestra, 8G2	12/5/2012 9:26 AM
11	Fuchsenfeldweg 71	12/4/2012 8:50 AM
12	463a Pärnu str	11/29/2012 11:03 AM
13	Dimičeva 12	11/28/2012 5:02 PM
#	**Address 2:**	**Date**
1	197 Blackfriars Road	12/5/2012 9:26 AM
#	**City/Town:**	**Date**
1	Québec	5/3/2013 5:17 PM
2	Olympia	5/3/2013 1:14 AM
3	Edmonton	5/2/2013 11:24 PM
4	Riga	4/22/2013 10:21 AM
5	Lyngby	4/21/2013 8:56 AM
6	Zürich	1/15/2013 12:35 PM
7	Copenhagen	1/14/2013 9:24 AM
8	Hank	12/18/2012 4:47 PM
9	Sanfandila	12/5/2012 3:54 PM
10	London	12/5/2012 9:26 AM
11	Graz-Raaba	12/4/2012 8:50 AM
12	Tallinn	11/29/2012 11:03 AM
13	Ljubljana	11/28/2012 5:02 PM
#	**State/Province:**	**Date**
1	Québec	5/3/2013 5:17 PM

#	State/Province:	Date
2	WA	5/3/2013 1:14 AM
3	Alberta	5/2/2013 11:24 PM
4	Queretaro	12/5/2012 3:54 PM
#	**ZIP/Postal Code:**	**Date**
1	G1S 4X9	5/3/2013 5:17 PM
2	98504-7340	5/3/2013 1:14 AM
3	T6B 2X3	5/2/2013 11:24 PM
4	LV-1050	4/22/2013 10:21 AM
5	2800	4/21/2013 8:56 AM
6	8048	1/15/2013 12:35 PM
7	1059	1/14/2013 9:24 AM
8	4273 LD	12/18/2012 4:47 PM
9	76703	12/5/2012 3:54 PM
10	SE1 8NJ	12/5/2012 9:26 AM
11	8074	12/4/2012 8:50 AM
12	10916	11/29/2012 11:03 AM
13	SI-1000	11/28/2012 5:02 PM
#	**Country:**	**Date**
1	Canada	5/3/2013 5:17 PM
2	USA	5/3/2013 1:14 AM
3	Canada	5/2/2013 11:24 PM
4	Latvia	4/22/2013 10:21 AM
5	Denmark	4/21/2013 8:56 AM
6	Switzerland	1/15/2013 12:35 PM
7	Denmark	1/14/2013 9:24 AM
8	Netherlands	12/18/2012 4:47 PM
9	México	12/5/2012 3:54 PM
10	UK	12/5/2012 9:26 AM
11	Austria	12/4/2012 8:50 AM
12	Estonia	11/29/2012 11:03 AM
13	Slovenia	11/28/2012 5:02 PM
#	**Email Address:**	**Date**
1	louism.belanger@mtq.gouv.qc.ca	5/3/2013 5:17 PM
2	dornsir@wsdot.wa.gov	5/3/2013 1:14 AM
3	Clayton.Matwychuk@gov.ab.ca	5/2/2013 11:24 PM
4	Julija.Ivanova@lvceli.lv	4/22/2013 10:21 AM
5	fnje@cowi.dk	4/21/2013 8:56 AM
6	philipp.stoffel@helbling.ch	1/15/2013 12:35 PM
7	hn@vd.dk	1/14/2013 9:24 AM

#	Email Address:	Date
8	niels@jansonbridging.com	12/18/2012 4:47 PM
9	CFN@COWI.COM	12/11/2012 12:02 PM
10	atorres@imt.mx	12/5/2012 3:54 PM
11	stephen.pottle@tfl.gov.uk	12/5/2012 9:26 AM
12	erwin.pilch@asfinag.at	12/4/2012 8:50 AM
13	olari.valter@mnt.ee	11/29/2012 11:03 AM
14	lojze.bevc@zag.si	11/28/2012 5:02 PM

#	Phone Number:	Date
1	418-646-0352 ext 4207	5/3/2013 5:17 PM
2	360-705-7199	5/3/2013 1:14 AM
3	780-415-0437	5/2/2013 11:24 PM
4	+37167028310	4/22/2013 10:21 AM
5	+4529370127	4/21/2013 8:56 AM
6	+41 44 438 18 11	1/15/2013 12:35 PM
7	+45 72443448	1/14/2013 9:24 AM
8	+31 162 480383	12/18/2012 4:47 PM
9	524422169777	12/5/2012 3:54 PM
10	02030541274	12/5/2012 9:26 AM
11	+43 (0) 664 60108-14966	12/4/2012 8:50 AM
12	+37253603049	11/29/2012 11:03 AM
13	+386-1-2804-487	11/28/2012 5:02 PM