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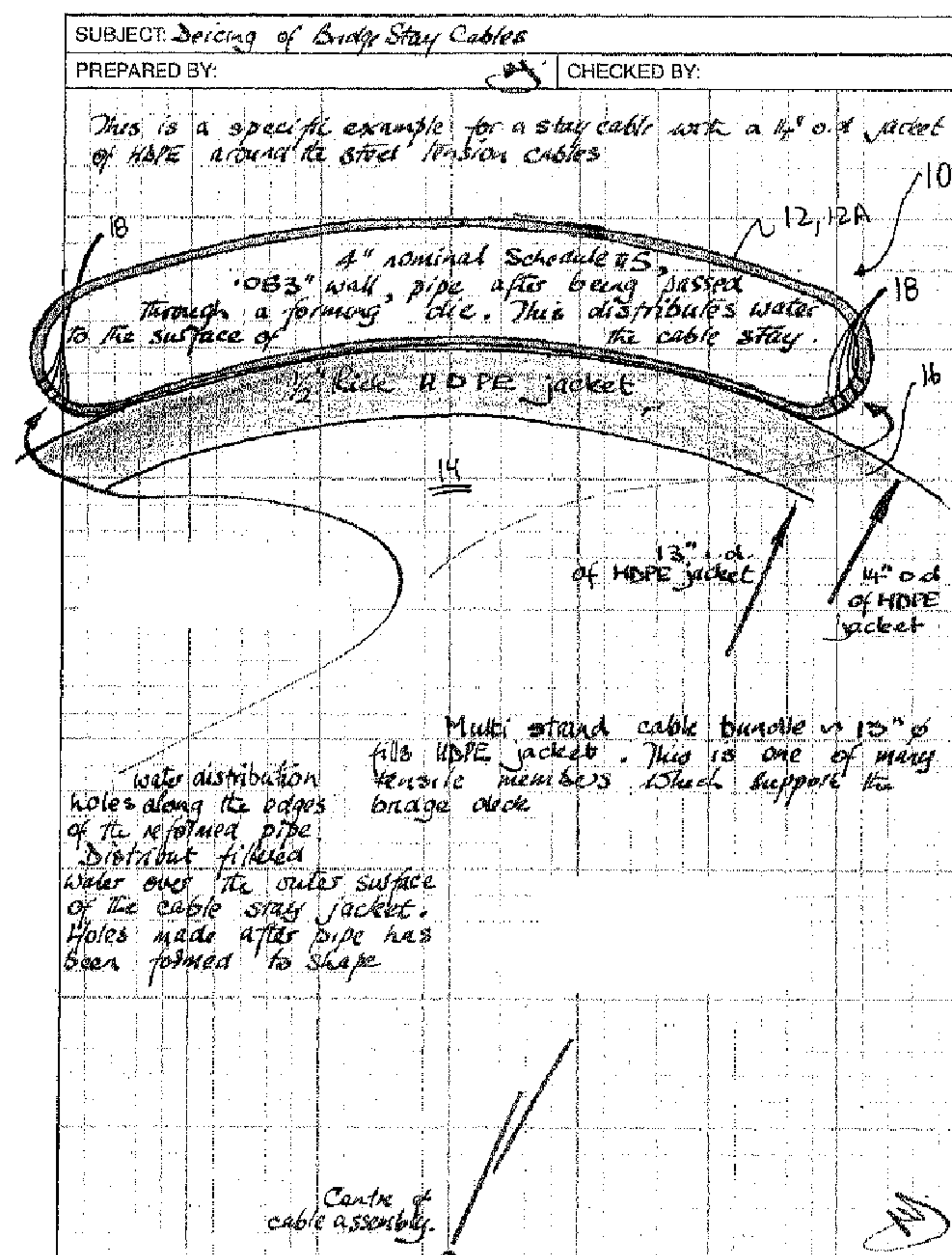
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(54) Titre : REDUCTION DE LA GLACE ET DE LA BOUILLIE DE GLACE POUR SUPPORTS DE PONT ET AUTRES
STRUCTURES DE PONT SUPERIEURES

(54) Title: ICE AND SLUSH MITIGATION FOR BRIDGE SUPPORTS AND OTHER OVERHEAD BRIDGE STRUCTURES



(57) Abrégé/Abstract:

A system is provided for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge. The system comprises: means for moving water from a river spanned by the bridge to a location above the one or more cables; and, for each cable, means for creating a flow of the water in a region proximate to the outer surface of the cable.

Abstract

A system is provided for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge. The system comprises: means for moving water from a river spanned by the bridge to a location above the one or more cables; and, for each cable, means for creating a flow of the water in a region proximate to the outer surface of the cable.

ICE AND SLUSH MITIGATION FOR BRIDGE SUPPORTS AND OTHER OVERHEAD BRIDGE STRUCTURES

Executive Summary

Some bridges have overhead cable stays where ice, snow and slush can accumulate. Other bridges have other types of overhead support structures or other structures where ice, snow and slush can similarly accumulate. In some cases (such as the Port Mann Bridge near Vancouver, British Columbia), these structures (in the case of the Port Mann Bridge, cables) are located over traffic lanes or other places where falling ice, snow and/or slush can cause damage to persons and/or property (e.g. cars traveling over the bridge). We propose to retrofit a fresh water de-icing system on the existing stay cable jackets. This as a solution which will be cost effective, relatively quick to implement, and has minimal environmental impact. It is an efficient technique which will significantly reduce or eliminate the build-up of ice, snow and/or slush on the support cables by acting in both an anticipatory and reactive manner.

Icing Conditions at the Bridge

The Port Mann Bridge is located in a geographical area that is prone to icing. Environment Canada has historical data for Surrey, B.C. See "Canadian Climate Normals or Averages 1971-2000" for Surrey, B.C. The region has two winter months, December and January, that have significant precipitation in the form of rain, ice, and snow - approximately 180 to 200 mm total precipitation per month. During these months, the temperature hovers near 0°C, i.e.: Surrey's average December daily high is 3.3° C and 2.7° C in January, while the average lows are 0.6° and minus 0.2° C, respectively. These were measured at 76 m elevation above sea level.

Fluctuations in temperature in Surrey near 0° C are "average conditions," not extreme or unusual events. Such a temperature range, combined with high precipitation or humidity, is known to produce icing. Also, according Environment Canada, there are other temperatures variation in Greater Vancouver of approximately 4° C due to elevation, i.e.: it is 4° C colder at higher elevation than at sea level. Based on the Environment Canada data for Surrey, one can reasonably conclude that the bridge and its upper supporting cable structures will be subject to icing. One can further predict that the situation will be worse for high snow falls or during an ice storm.

It would be expected that the risk of icing would be reduced in warmer months, especially before November and after March. However, sub-zero temperatures have been observed in the vicinity of the bridge site as late as April, and as early as September, according to Environment Canada.

Based on publically available data, the Port Mann Bridge is a suspension bridge which uses vertical columns that support a cable system. The main span between the two 75 m tall (above the deck level) towers is 470 meters long. The main bridge has a length of 850 meters with 288 cables.

The cable bundle appears to include multiple parallel 15.75 mm diameter high strength steel cables. A single bridge support cable would be made up of a bundle of 23 to 73 of these 15.75 mm cables. These bundles are enclosed in a high-density polyethylene jacket. The HDPE jacket may have a 6 to

10 mm wall, and that it was installed as an environmental wrap, not as a continuous load bearing pipe.

Ice and Slush Formation

Snow can accumulate on the towers and cables, melt, form wet clumps, or re-freeze and form ice. Also, clear ice can be formed directly by super cooled water droplets or by freezing rain. Rough ice can be created by super cooled drops, and the latter leaves a irregular rough ice surface. The snow or snow-ice mixture can harden at night or during low temperature excursions. Then, as temperatures climb, the snow and ice loses adhesion and falls below to the bridge deck. Under the worst case conditions, and depending upon the shape of the ice fragment, detached material from the upper portions of the cable stays near the towers could reach a velocity of about 40 m/sec, ~130 ft/sec, at the bridge deck elevation.

Known Ice and Snow Removal Techniques

There are known methods for ice removal .

De-icing can be accomplished by heating the substrate on which the ice rests - either electrically or by circulating a heated fluid in the base. For the massive 250 mm diameter steel cable assemblies at the Port Mann Bridge, electric current could be forced through the cables. This would be energy inefficient due to the thick plastic (low heat conductivity) covers on the cables of the Port Mann Bridge and the mass of the cable bundles.

Another technique for electrical energy ice removal has been developed at the Thayer School of Engineering, Dartmouth College, N.H., referred to as "Pulse Electro-Thermal De-icing" or PETD. The volume of ice melted with this method is reduced, but a special substrate has to be installed and it might not be appropriate for encased cables. In addition a supplemental mechanical system has to be installed to detach the loosened ice and snow from the cable stays.

Hence, to proceed with either of these electrical heating solutions, one would have to strip the covers from the bundled cables - to improve heat transfer efficiency. Also, appropriate electrical power supplies such as transformers would have to be installed, impedance matched, and load matched for every cable segment. This would be a daunting and expensive retrofit.

It is also know to de-ice structures by applying heat externally. The energy to melt the ice can come by radiation, by microwaves, or from gas convection, or contact with liquids. The problem is that Ice, unlike water, is a dielectric, not an absorber. Thus, radiation heating and microwaves are not considered to be practical operating choices for ice. The heating mechanism is very weak, and not enough energy is transferred from the microwave radiation. Ultrasonic vibrations, structural flexing or the use of small air jets are sometimes used to break the ice/substrate adhesion. In summary, none of these methods are appropriate here because of the mass, extent, and location of the cable stays.

De-icing can also be accomplished by mechanical methods such as scraping or sweeping. This can be effective if the temperature is above 0° C. Also, it can be effective if it is used to remove snow as it is accumulating and before the snow melts and then freezes into ice. It is not effective for removing frozen thick rough ice.

Direct fluid contact with ice, snow and slush is an effective mechanism for heat transfer. Some known fluid contact techniques rely on kinetic removal of ice – i.e.: pushing and breaking the adhesion) as well as possibly melting or reducing the freezing temperature. As an example, Transport Canada has guidelines for recommended de-icing fluids for airplanes. These are ethylene glycol, diethylene glycol, or propylene glycol based fluids containing water, corrosion inhibitors, wetting agents and a dye. Anti-icing fluids are similar except that they contain polymeric thickeners. The glycols can contaminate drinking water supplies and harm aquatic life. For this reason, this ice-removal solution is not desirable for use on bridge supports where the bridge spans water.

Also, there are a range of road salts and other chemicals which depress the freezing point of mixed ice and salt. However, road salts, specifically calcium or sodium chloride are corrosive; and non-toxic, non-corrosive chemicals such as potassium formate, known as Dynalene, are costly. Accordingly, such chemicals are also inappropriate solutions for bridge supports, particularly for bridges spanning water.

Proposed Port Mann Bridge Solution – Detailed Description

A practical end environmentally friendly de-icing fluid is pressurized and filtered fresh river water. During the winter there are 200 mm of precipitation per month in the vicinity of the Port Mann Bridge. For this reason the use of water from the Fraser River (which is spanned by the Port Mann Bridge) has minimal operational or environmental consequences, as well as low pumping and distribution costs.

One embodiment for mitigating the issues associated with ice, snow and slush at the Port Mann Bridge would involve water being pumped up from the Fraser River, optionally filtered, and sprayed over the cables for a short period of time – mimicking the usual rain de-icing, but more intense.

The use of fresh water in appropriate volumes can deliver enough energy, in the form of the latent heat of cooling, at the interface between the cable stay jacket and the freezing/frozen precipitation to melt the snow and ice and/or mitigate its accumulation on the cables. Pumping fresh water from the Fraser River below the Port Mann Bridge is an energy efficient, extremely cost effective, and environmentally benign solution to the problem of ice, snow and slush accumulation on the cable stays of the Port Mann Bridge.

In some embodiments, the traffic may be stopped or redirected during the spraying operation, and only a small proportion of the water would perform a de-icing function. This spraying solution might be most effective in certain conditions, such as:

- In circumstances where that the structure (e.g. the overhead cable stays) could potentially shed ice and snow in such a manner that there is no danger for people or property (e.g. motorists) traveling on the bridge – this could be detected by suitable monitoring systems.

- The bridge cable temperatures are near (0° C) or above, so that more ice is not produced – this could be detected by suitable temperature measurement devices.
- The available water has a temperature a few degrees above freezing– this could be detected by suitable temperature measurement devices.
- The cable temperature is trending upward – this could be detected by suitable temperature measurement devices.

As an example, if snow and/or ice accumulation on the cables stays is detected as a potential threat to motorists below, and if the daytime temperature is expected to reach 3° or 4° C, then fresh water at 4° C could be pumped up from the Fraser River and showered over the cables. The bridge may be closed to traffic, or certain lanes closed, and the de-icing shower would continue until all or most snow and ice was removed.

Another embodiment for mitigating the issues associated with ice, snow and slush at the Port Mann Bridge would involve water being pumped up from the Fraser River, optionally filtered, and caused to flow through conduits shaped and located to deliver the de-icing water to the contact layer between the snow/ice and the cable (or between the snow/ice and the HDPE cable stay jacket). This embodiment may require less fluid than de-icing by spraying and may be implemented without interrupting vehicular traffic on the bridge during the removal of ice and snow from the cables.

Figures 1-3 depict a particular non-limiting example embodiment of this fluid-based ice, snow and/or slush mitigation system 10 and particular non-limiting examples of suitable conduits 12 which may be used in ice-mitigation system 10. Dimensions referred to in Figures 1-3 are intended to be exemplary and non-limiting in nature. Further, Figures 1-3 may not be drawn strictly to scale. It is assumed (in the illustrated embodiments of Figures 1-3 and the description presented below) that cables 14 are coated by jackets 16 which may be fabricated from high-density polyethylene (HDPE) or the like. This assumption is made for brevity only. It will be appreciated that system 10 could be used in a similar manner on cables without jackets 16.

In the illustrated embodiment, the build-up of ice, snow and slush on jackets 16 of cable stays 14 is mitigated by moving fresh water from the river spanned by the bridge (e.g. the Fraser River in the case of the Port Mann Bridge) through thin-walled conduits 12 which are located and shaped to lie flush and parallel to the outer surfaces of cable stay jackets 16. In preliminary calculations, unheated river water at approximately 4°C is likely to be suitable for ice, snow and/or slush mitigation at the Port Mann Bridge. In some embodiments, other suitable fluids could be used in the place of river water. In some embodiments, such fluids may be heated prior to being used for de-icing. By way of non-limiting example, such fluids could include heated air, heated water, steam and/or any other suitable fluid(s). For brevity, it is assumed in the remainder of this description that the fluid used in de-icing system 10 is water from the river spanned by the bridge, without loss of generality that other suitable fluids could be used and that any such fluids could be heated. Conduits 12 could be fabricated from metal, stainless steel, other forms of steel or metal alloys and/or other suitable material(s). In some embodiments, conduits 12 are sized such that in combination they cover 10%-50% of an outer surface area of cable stay jackets 16. In some embodiments, this surface area coverage of conduits 12 may be in a range of 20%-30%. In some embodiments, conduits 12 are sized such that each conduit 12 covers 5%-40% of a cross-sectional circumference of cable stay jacket 16. In some embodiments, this circumferential coverage is in a range of 10%-30%. In some

embodiments, conduits 12 are sized such that each conduit 12 covers 10°-80° of the 360° cross-sectional circumference of cable jacket 16. In some embodiments, this circumferential coverage is in a range of 20°-60°. It will be appreciated, however, that the particular de-icing needs of a particular environment could involve use of conduits having sizes outside these ranges.

In the illustrated embodiment, three conduits 12 are arranged around a cross-sectional perimeter each of cable jacket 16 (see Figure 2) and extend in parallel longitudinal directions along the axis of cable stay 14 (see Figure 3). In some embodiments, different numbers of conduits 12 could be provided and/or conduits 12 may be sized to have different transverse extensions around the cross-sectional perimeter of cable jackets 16. Conduits 12 may be angularly evenly spaced about the circumference of cables 14 – e.g. at 120° spaced apart centers in the case of the illustrated embodiment, where there are three conduits 12. This is not necessary. In some embodiments, conduits 12 may have other angular spacings about the cross-sectional circumference of cables 14. Preferably, one conduit 12 is located at a center (apex) of the top of cable jacket 16 (where it is expected that the most ice might accumulate). Again, this is not necessary and conduits 12 may have other arrangements around the circumference of cables 14. Conduits 12 may be installed in the field (e.g. retrofitted to existing cable stays 14) without modification of existing cable stays 14. By way of non-limiting example, conduits 16 could be clamped to cable stays 14, strapped to cable stays 14 and/or the like. Such clamps, straps or other mounting mechanisms could be made metal, stainless steel, other forms of steel or metal alloys and/or other suitable material(s).

In the illustrated embodiment, sections 12A of conduits 12 are provided with an elongated “C” shaped cross section (see Figures 1 and 2) with the elongated sides contoured to fit against cable stay jackets 16. This is not necessary. In some embodiments, one side of a conduit section 12A (i.e. the side proximate cable stay jacket 16) could be provided with a concave curved shape complementary to the convex shape of the outer surface of cable stay jackets 16 while the other side(s) of conduit sections 12A could be provided with other (preferably convex) shapes. By way of example, it may be desirable for a side opposite cable stay jacket 16 to have a sharply convex (e.g. angular) cross-section to minimize the propensity for snow and ice accumulation thereon.

Sections 12A of conduits 12 may be provided in manageable lengths. In some embodiments, sections 12A of conduits 12 are provided with longitudinal dimensions in a range of 2m-25m. In currently preferred embodiments, sections 12A of conduits 12 are provided with longitudinal dimensions in a range of 6m-18m. Sections 12A of conduits 12 may be connected to one another at connections 20 (see Figure 3). Preferably, connections 20 are configured to permit fluid coupling between conduit sections 12A without rotation of adjacent sections 12A relative to one another. Conduits 12 may be connected in fluid communication to one or more sources of fresh water pumped, or otherwise moved, to one or more locations above the uppermost extents of cables 14 (e.g. to the tops of (or suitably high locations on) bridge support tower(s)).

Conduits 12 may be provided with arrays of apertures 18 at suitable locations along their transverse edges for directing water from conduits 12 in transverse directions along cable jackets 16 at high velocity. In this manner, the flow of water through conduits 12 could be directed along the longitudinal axes of cables 14 and the flow of water through optional apertures 18 would be directed in directions generally transverse to the longitudinal axes of cables 14. Water traveling through conduits 12 would mitigate the accumulation of snow, ice and slush on the surfaces of

conduits 12. Water emitted in high velocity streams from apertures 18 could remove snow and ice from regions between conduits 12. Apertures 18 may be designed with different orientations, different diameters, different spatial densities, different array patterns and/or the like. In some embodiments, apertures 18 could be fitted with suitable jets, nozzles injectors and/or the like for increasing the pressure and/or rate at which water is ejected from apertures 18 and the corresponding efficacy of ice and snow removal.

The Applicant's experiments suggest that at current British Columbia Hydro and Power Authority (BCHPA) industrial rates the estimated system operating cost to provide de-icing might be on the order of about CA\$200/hr.

In addition to the fluid-based ice and snow removal techniques described above, some embodiments may additionally comprise mechanical sweeping apparatus to remove snow as it is accumulating. This is a safe method if snow is removed in multiple small sweeps.

In some embodiments, it can be desirable to detect one or more of: weather that might be indicative of snow, freezing rain, and/or other conditions that might lead to accumulation of snow, ice and/or slush on cables 14; and actual accumulation of snow, ice and/or slush on cables 14.

At some weather stations, Environment Canada uses instruments to measure rainfall and ice, or to differentiate between wet snow and rain. Two meteorological systems with these capabilities have already been incorporated into the Port Mann Structural Integrity Monitoring System. These units are capable of providing information (e.g. data from temperature sensors, humidity sensors and/or the like) related to the probability of ice deposition on the cable stays. In particular embodiments, de-icing system 10 comprises a control system (not expressly shown) which is provided with such information and which is capable of making autonomous decisions to proactively activate fluid flow in conduits 12 in circumstances indicative of the existence of ice, snow and/or slush accumulation conditions. Hence de-icing system 10 may be proactive and reactive, in the sense that it can anticipate the development of icing conditions, and then react to them by initiating remedial action to mitigate the problem. In this manner appropriate actions may be initiated to inhibit the build-up of ice on cable stays 14, and to remove rapidly any ice which may have already formed.

Additionally or alternatively, an imaging system may be used in particular embodiments to verify ice build-up on cables 14. The images from such an imaging system could be used to establish if snow or ice accumulation was actually occurring on cables 14.

When the temperature is near 0°C, it may be desirable to know if the precipitation in a particular location is in the form of rain, freezing rain, or wet snow. It is conceivable that the existing meteorological systems of the Port Mann Structural Integrity Monitoring System may not be able to provide suitable data to make such distinctions, particularly on a localized basis. In some embodiments, these meteorological systems can be retrofitted to provide desired data. Some embodiments comprise multiple additional or alternative ice/rain detection systems (at different locations – e.g. one or more on each bridge tower) which can be spatially distributed and which provide information to a centralized de-icing control system and/or to distributed de-icing control systems in real time. Such ice/rain detection systems may comprise temperature sensors, humidity sensors, imaging sensors and/or the like.

Data from any available sensing systems may be analysed, a determination may be made and suitable emergency signal(s) generated to communicate “a dangerous bridge condition” – e.g. a potential serious icing of cables 14 and/or other upper support structure(s) which might lead to damage to persons or property on the bridge deck below. Such a system may be designed to stop traffic from traveling on the bridge in the event of the dangerous bridge condition.

WHAT IS CLAIMED IS:

1. A system for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge, the system comprising:

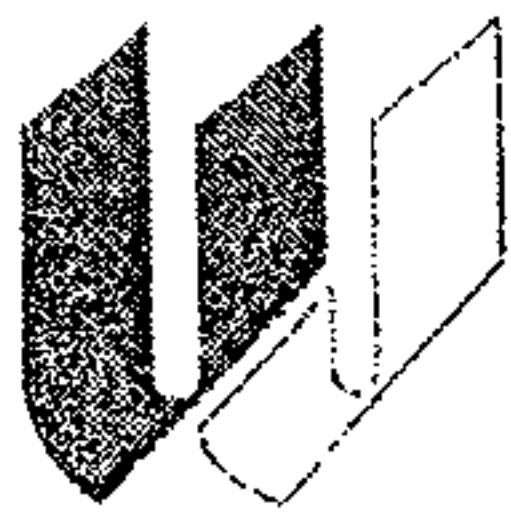
 means for moving water from a river spanned by the bridge to a location above the one or more cables; and

 for each cable, means for creating a flow of the water in a region proximate to the outer surface of the cable.
2. A system according to claim 1 wherein the outer surface of the cable comprises at least one of: an outer surface of a jacket surrounding a circumference of a cable bundle; and an outer surface of an unwrapped cable bundle.
3. A system according to any one of claims 1 and 2 wherein, for each cable, the means for creating the flow of the water in a region proximate to the outer surface of the cable comprises a plurality of elongated tubular conduits, each elongated tubular conduit located to convey the water to the region proximate to the outer surface of the cable.
4. A system according to claim 3 wherein, for each cable, each elongated tubular conduit comprises an inner surface, the inner surface elongated in a longitudinal direction and having a concave cross-section in a direction transverse to the longitudinal direction for abutting against the outer surface of the cable in a complementary manner.
5. A system according to claim 4 wherein, for each cable, the inner surface of each elongated tubular has a transverse dimension that spans an angular region of a transverse circumference of the outer surface of the cable, the angular region in a range of 20°-60° of the transverse circumference of the outer surface of the cable.
6. A system according to any one of claims 3 to 5 wherein, for each cable, the plurality of elongated tubular conduits comprises one elongated conduit located on top of the cable.
7. A system according to any one of claims 3 to 6 wherein, for each cable, the plurality of elongated tubular conduits comprises three or more elongated conduits.

8. A system according to any one of claims 3 to 7 wherein, for each cable, each elongated tubular conduit comprises a plurality of elongated tubular conduit sections, adjacent sections connected to one another at a corresponding coupling which permits fluid flow between the adjacent sections.
9. A system according to claim 8 wherein each elongated tubular conduit section has a length in the longitudinal direction on the order of 5m-25m.
10. A system according to any one of claims 3 to 9 wherein, for each cable, each elongated tubular conduit comprises a plurality of apertures in a wall thereof for directing the water conveyed in a bore of the conduit toward an outside of the conduit and toward the outer surface of the cable.
11. A system according to claim 10 wherein the plurality of apertures are oriented for directing the water toward a region of the outer surface of the cable transversely spaced apart from the elongated tubular conduit.
12. A system according to any one of claims 1 to 11 comprising a heater for heating the water at the location above the one or more cables.
13. A system according to any one of claims 1 to 12 wherein the means for moving the water from the river to the location above the one or more cables comprises one or more pumps and one or more suitable pipes for conveying the water from the river to the location above the one or more cables.
14. A system according to any one of claims 3 to 13 wherein, for each cable, the means for creating the flow of the water in the region proximate to the outer surface of the cable comprises one or more suitable pipes for conveying the water from the location above the one or more cables to the plurality of elongated tubular conduits.
15. A system according to any one of claims 1 to 2 wherein, for each cable, the means for creating the flow of the water in a region proximate to the outer surface of the cable comprises a plurality of spray nozzles, the spray nozzles oriented to spray the water toward the outer surface of the cable.

16. A system for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge, the system comprising, for each cable, a plurality of elongated tubular conduits, each elongated tubular conduit located to convey a fluid to a region proximate to the outer surface of the cable and along a longitudinal direction generally parallel to an axial extension of the cable.
17. A system according to claim 16 wherein, for each cable, each elongated tubular conduit comprises an inner surface, the inner surface elongated in the longitudinal direction and having a concave cross-section in a direction transverse to the longitudinal direction for abutting against the outer surface of the cable in a complementary manner.
18. A system according to any one of claims 16 to 17 wherein, for each cable, each elongated tubular conduit comprises a plurality of apertures in a wall thereof for directing the fluid conveyed in a bore of the conduit toward an outside of the conduit and toward the outer surface of the cable.
19. A method for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge, the method comprising:
 - moving water from a river spanned by the bridge to a location above the one or more cables;
 - and
 - for each cable, creating a flow of the water in a region proximate to the outer surface of the cable.
20. A method according to claim 19 comprising method steps for implementing any of the features of claims 1-18.
21. A method for mitigating a build-up of ice on one or more bridge-support cables located above a deck of the bridge, the method comprising, for each cable:
 - providing a plurality of elongated tubular conduits,
 - locating each elongated tubular conduit to convey a fluid to a region proximate to the outer surface of the cable and along a longitudinal direction generally parallel to an axial extension of the cable;
 - creating a flow of the fluid in each elongated tubular conduit.

22. A method according to claim 21 comprising method steps for implementing any of the features of claims 1-18.



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SHEET 1 OF 3

DATE 26.12.12

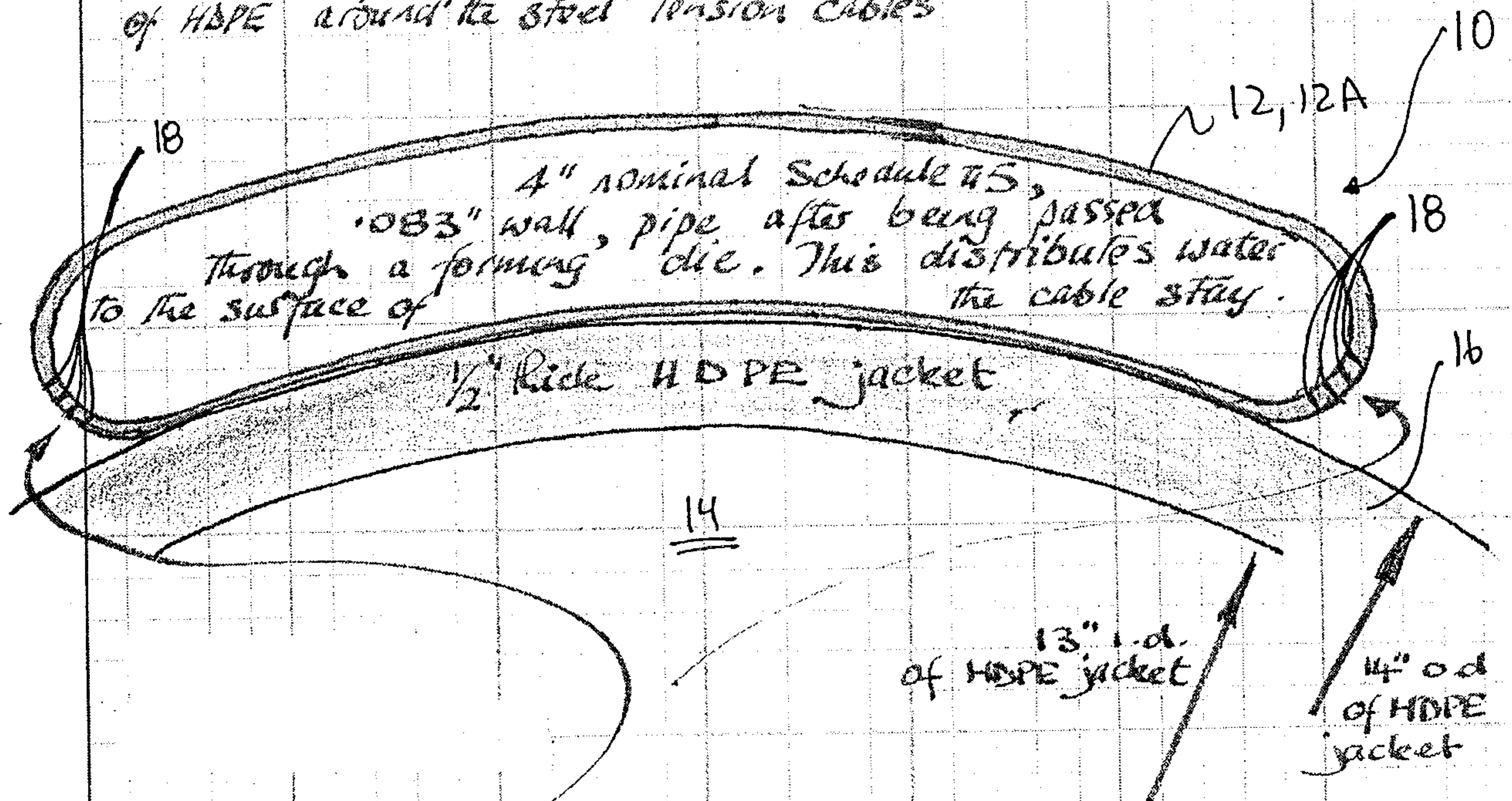
FILE Kiewit Solution

SUBJECT: *Design of Bridge Stay Cables*

PREPARED BY:

CHECKED BY:

This is a specific example for a stay cable with a 14" o.d. jacket of HDPE around the steel tension cables.



Water distribution holes along the edges of the reformed pipe.

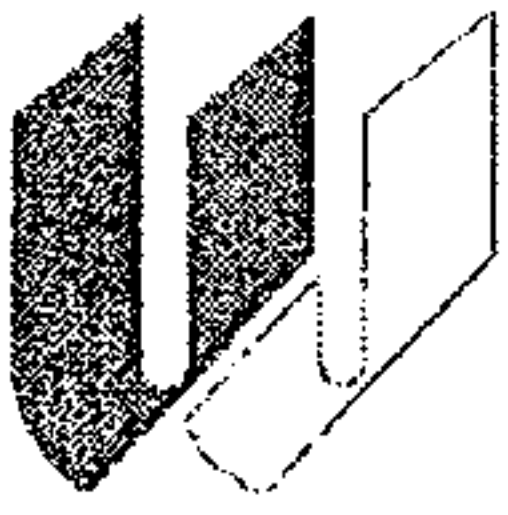
Distribute filtered water over the outer surface of the cable stay jacket. Holes made after pipe has been formed to shape.

Multi-strand cable bundle ~ 13" ϕ fills HDPE jacket. This is one of many tensile members which support the bridge deck.

FIGURE 1

Centre of cable assembly.

WJ



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SHEET 2 OF 3

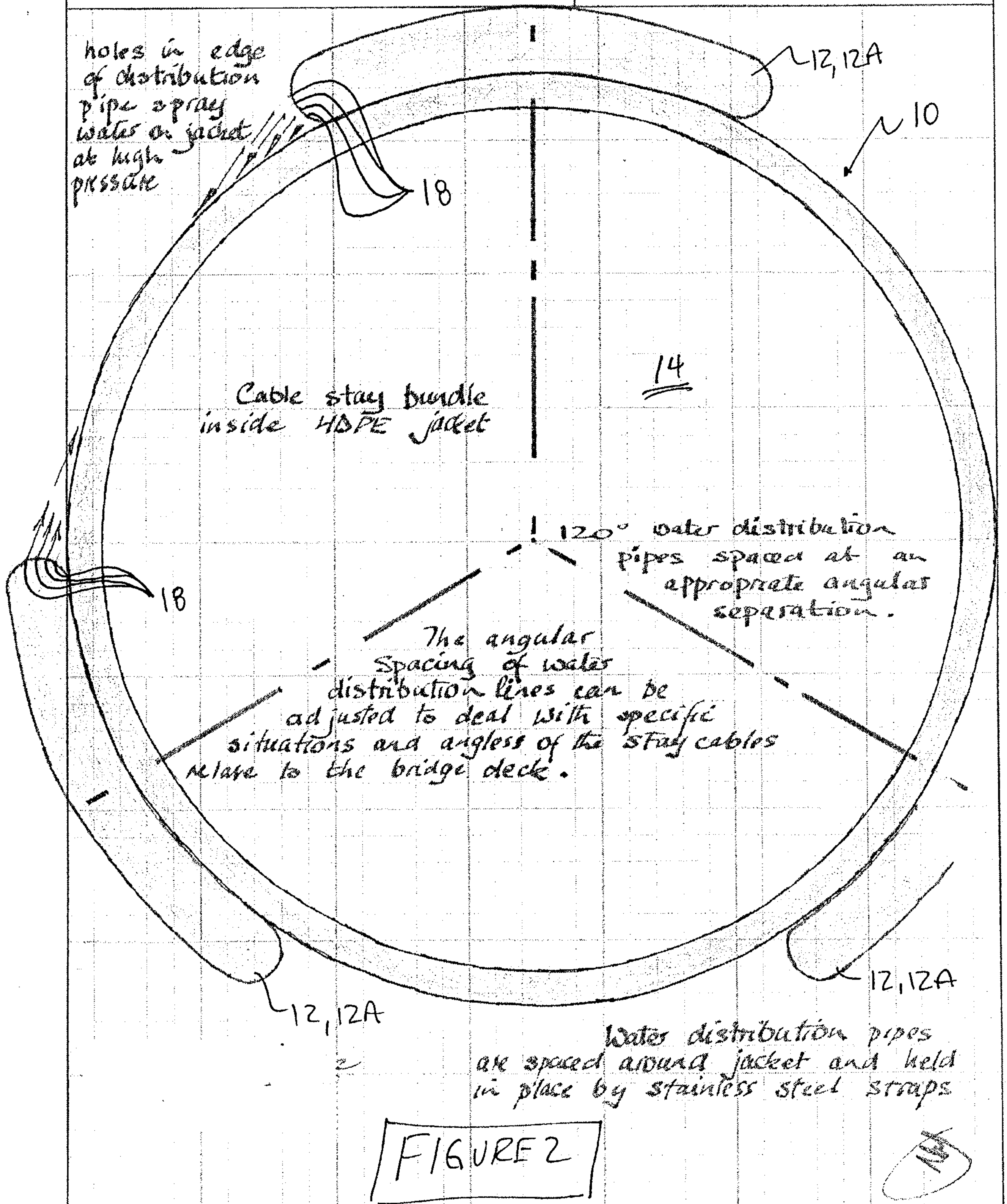
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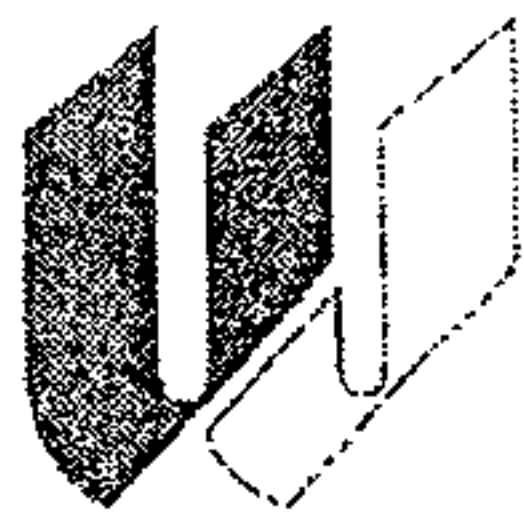
FILE Kiewit Solution

SUBJECT: Seicing of Bridge Stay Cables

PREPARED BY:

CHECKED BY:





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Vancouver, British Columbia, Canada

SHEET 3 OF 3

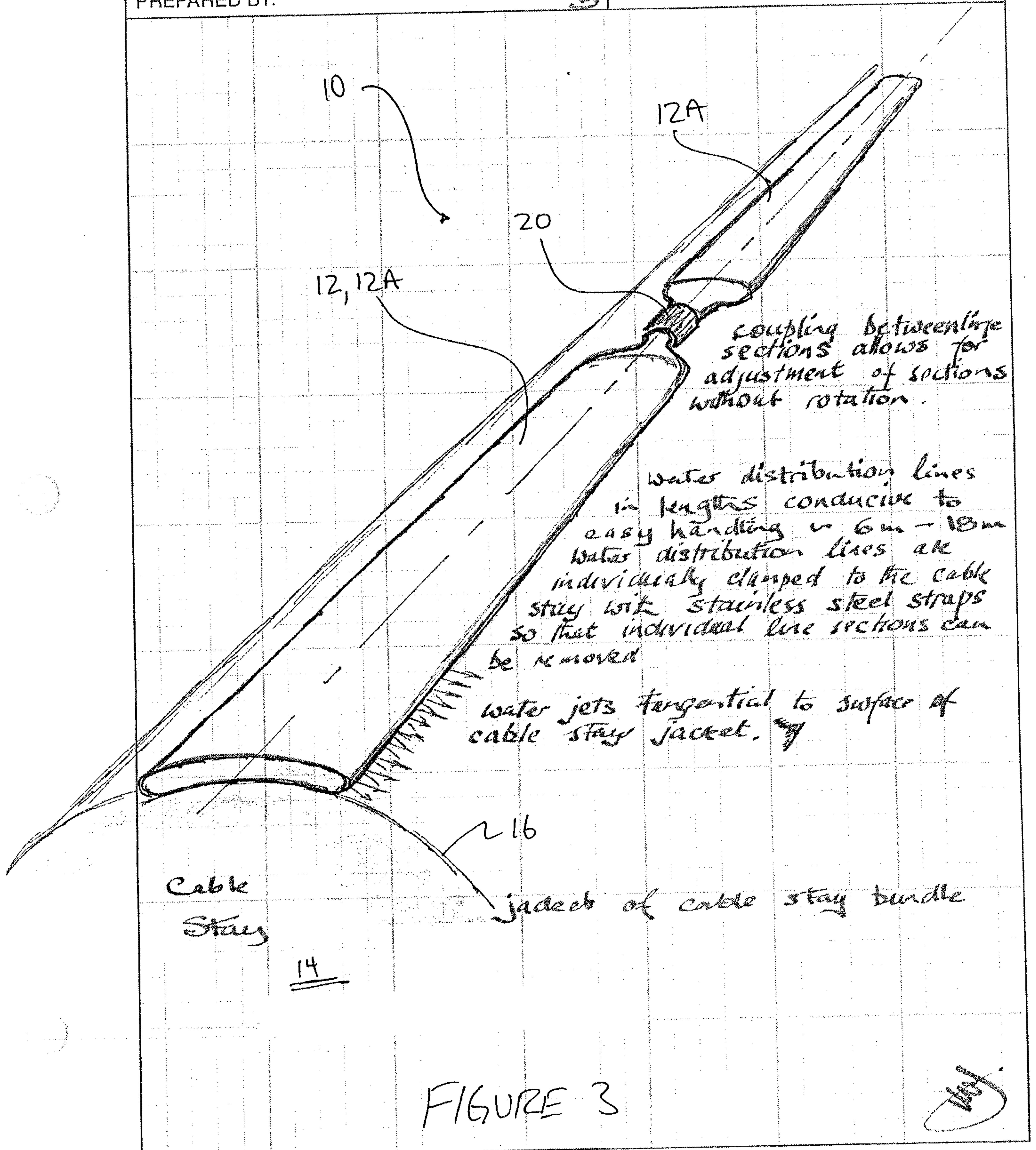
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SUBJECT: Seicing of Bridge Stay Cables

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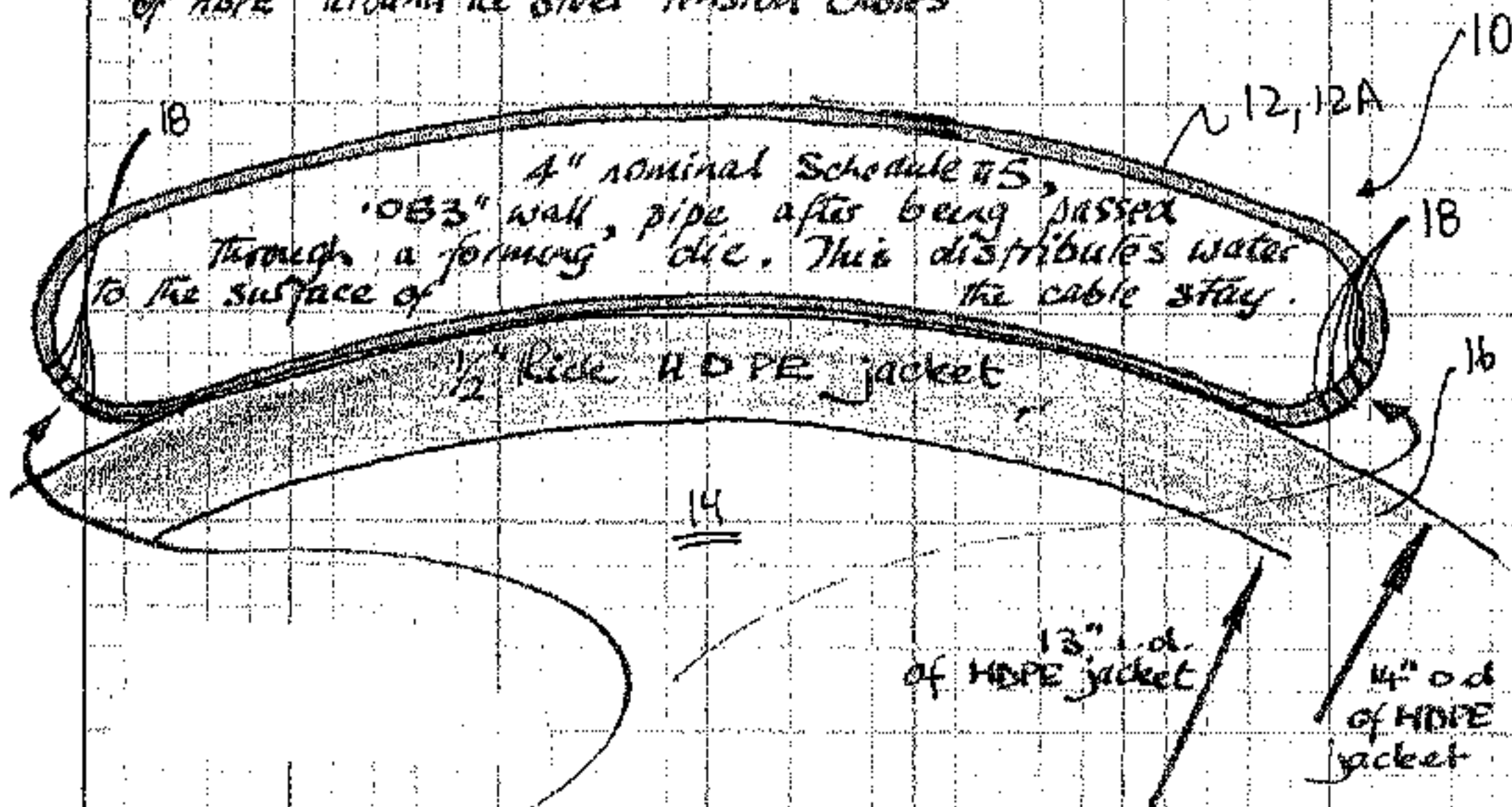


SUBJECT: Seicing of Bridge Stay Cables

PREPARED BY:

CHECKED BY:

This is a specific example for a stay cable with a 1 1/2" o.d. jacket of HDPE around the steel tension cables.



Multi strand cable bundle is 13" o.d. fills HDPE jacket. This is one of many tensile members which support the bridge deck.

Water distribution holes along the edges of the reformed pipe. Distribute filtered water over the outer surface of the cable stay jacket. Holes made after pipe has been formed to shape.

Centre of cable assembly.

AMJ