BRIDGES
– CROSSING CORROSION WITH DEHUMIDIFIERS

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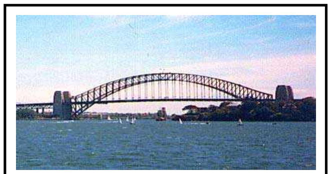
A famous quote by Ian Ritchie about bridges is that "A bridge can be a sculptor, a dynamic art form in its own right; a witty expression of absurdity; decorative furniture; a caricature of technology held together by steel, tension cables and glass; a crossing point over a waterway, roadway, a railway or just a space "

Logs or wines that extended cross-streams probably served as first bridges. Bridges are not only the superstars of the engineering world; they influence the development of cultures, environments and lives around the world in more ways than we can count. Bridges shape skylines, our lives, accelerate commerce, uplift social life and urban development.

TYPES OF BRIGDES

There are various types of bridges depending on the methods of construction and design criteria. The more popular design include:

BEAM BRIDGE: This is the simplest form of bridge. It consists of a horizontal beam supported at each end by piers. The weight of the beam pushes straight down on the piers. The farther apart its piers, the weaker the beam becomes. This is why beam bridges rarely span more than 250 feet.



ARCH BRIDGE: Probably the oldest of its kind has a great natural strength. Romans built arches of stone. Today most arches are made of steel or concrete, and they can span up to 800 feet.

LIFTING BRIDGE: They are the movable bridges that enable boats to pass. They vary from simple wooden design to large steel structure, which carry heavy loads.

SUSPENSION BRIDGE: A suspension bridge works by hanging (suspending) the Deck of the bridge from flexible chains or ropes. The simplest form is made from wood and rope The bridge can span from 2,000 to 7,000 feet – farther than any other type of bridge! Most suspension bridges have a truss system beneath the roadway to resist bending and twisting.

TRUSS BRIDGE... consists of assembly of triangles. They are made from series of straight steel bars. The complex version of truss bridge is cantilever bridge. The Firth of Fourth Bridge in Scotland is made up of pair cantilever arms/beams sticking out from two main

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towers. The beams are supported by diagonal steel tubes projecting from the top and bottom of the towers. These well-secured spans actually support the central span.

CABLE STAY BRIDGE: Newer than the other types of bridge. Large upright steel supports are used to transmit the load into the ground. Strong steel cables are stretched between the supports and the deck. This gives a distinct appearance to the bridges.

The developments in materials and constructions techniques have empowered the engineers to design and construct spectacular bridges internationally. Cable stayed bridges; suspension bridges have been widely adopted all over the world because of economy as well as aesthetics'. Golden Gate Bridge of San Francisco, Brooklyn Bridge of Manhattan, Akashi- Kaikyo of Awaji Island or even Humber Bridge of England are few such examples.

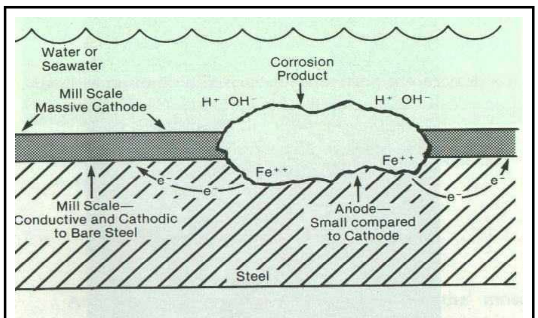
CORROSION IN BRIDGES:

If one looks at the investment scenario, in construction of bridges which is estimated to be more than RS. 300 billion (approximately), and the expenditure on constructions flyovers in next 5 years are expected to touch RS. 2000 billion, one can possibly imagine the impetus provided to the bridge industry.

Inspecting and maintenance of structure is as important as construction in order to ensure long service life. Modern bridge infrastructure comprises of primarily concrete (reinforced or pre-stressed) and steel structures. Bridges as we all know are constructed on rivers. The local weather conditions around water bodies are determined by strong wind flowing from water bodies towards land. These winds carry the moisture and salts from the water bodies hence constantly expose the bridges to moisture and vapor and salts in air. Besides this, service life of bridge, its constituent material is persistently subjected to wear and tear due to dynamic vehicular loads. Over loading due to increase in wheel loads and regular exposure to aggressive external environment aggravate the situation further. Poor quality of construction and lack of regular maintenance leads to major retrofit in bridge structure. Defects in constituent material may be manifested in form of cracking spalling of concrete, excessive deflection of structure, rusting of steel components etc….

Besides the spectacular visible mass, these construction marvels hide equally huge volumes of machinery and metal mass for their operation say for folding bridges like the ones over Thames in London and over Neva in St. Petersburg.

As we already know that bridges are persistently subjected to higher RH The water in air at high relative humidity is sufficient for a corrosion process to take place.



Electrolytic Process of Corrosion
Source: Corrosion Protection by Protective Coatings – By Charles Munger

Figure - 1

Corrosion is the deterioration of a material, usually a metal that results from a reaction with its environment. Over a period of time the components of a bridge may deteriorate to the extent that the bridge is no longer safe.

The individual electrode process could be shown as:

At anode : $4\,Fe \rightarrow 4\,Fe^{++} + 8\,e$

At cathode: $4\,H_2O + 2\,O_2 + 8e \rightarrow 8\,OH$

The initial product of oxidation is thus ferrous hydroxide

$4\,Fe^{++} + 8\,OH^{-} \rightarrow 4\,Fe(OH)_2$

In the presence of excess oxygen the ferrous hydroxide is oxidized to hydrated ferric oxide which is rust.

A number of factors contribute to bridge corrosion. One of the most common is the use of deicing salts on roads and bridges, a practice which has contributed significantly to the deterioration of such structures. The salts cause corrosion of the steel reinforcing bars and other steel components supporting the bridge. This form of corrosion is the main cause of concrete bridge deterioration. Another factor is humidity. The limit lies at 45-50 % RH: if humidity lies under that value steel will not face the risk of corrosion. With atmospheric humidity above 60% corrosion process sets in. From 60% to 100% RH the corrosion process will be accelerated at a phenomenal rate and in case of free water on the surface corrosion process will start immediately.

Other problems that lead to corrosion include bridge designs that do not adequately consider drainage requirements, stresses, shrinkage, or expansion, and environmental factors such as frequent freezing and thawing cycles.

Compounding the effects of a corrosive environment is the lack of proper monitoring and maintenance of bridges. Technology exists that can keep bridges free from the harmful effects of corrosion, but it is only effective if it is used properly and regularly monitored.

However, using current corrosion control technology in conjunction with maintenance and monitoring guidelines, we are preventing their decay and extending the lifespan of bridges to a certain extent, but with multiple corrosion protection system strategies, the lifespan can be extended by decades.

CAUSE OF CORROSION

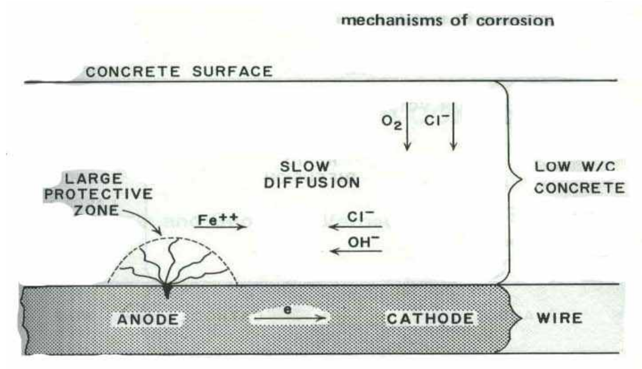


Fig. 8--Schematic representation of corrosion in concrete of low water-cement ratio and well cured

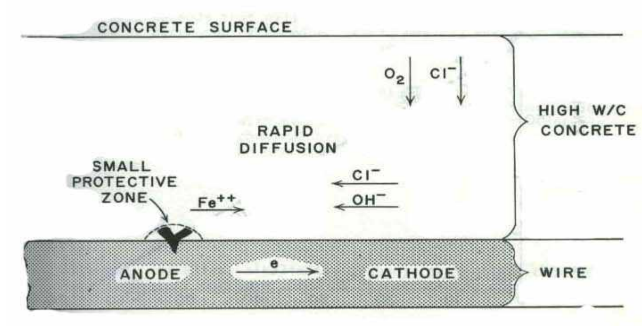


Fig. 9--Schematic representation of corrosion in concrete of high water-cement ratio and poorly cured

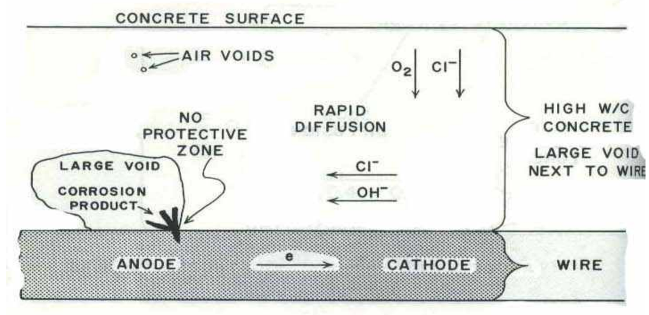


Fig. 10--Schematic representation of corrosion in concrete of high water-cement ratio and with air pocket on steel

Source : Steel Rebar Reinforcement Corrosion in Concrete Bridge design by
Prof. Colin Sandwith

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Concrete is a highly alkaline material when first produced (pH range 12-13). The embedded steel is protected by a passive oxide layer, which is maintained by high alkalinity at the surface of the steel.

Under certain exposures and conditions the natural passivating protection of the steel breaks down. In the presence of moisture and oxygen, corrosion then occurs

The first thing to state is that carbonation and chloride ions equal a lot of corrosion. The carbonation and chloride ions diffuse through the concrete until the reach the embedded steel. Then the pH is lower by the presence of the chloride ions.

This corrosion process also requires oxygen diffused through the concrete, set-up an electrochemical reaction. The process is increased by existence of voids in the concrete adjacent to steel.

The different types of corrosion seen in bridges are as follows:

MICROBIAL CORROSION

Microbial assisted corrosion (MAC) is a well-recognized problem. Micro - organisms such as bacteria, algae and fungi under certain conditions can thrive and accelerate the corrosion of many metals (e.g. iron, steel, copper, aluminum, lead and stainless steel) even in otherwise benign environments. Biological organisms can enhance the corrosion process by their physical presence, metabolic activities and direct involvement in the corrosion reaction. The occurrence of MAC is often characterized by unexpected severe metal attack; the presence of excessive deposits.

CORROSION ON CONCRETE:

Although concrete has evolved to become the most widely used structural material in the world, the fact that its capacity for plastic deformation (so its ability to absorb mechanically imparted energy is essentially nil). This results in practical service limitations. This shortcoming most commonly is overcome by incorporating steel reinforcement into specific locations in the concrete where tensile stresses are anticipated. Consequently, concerns regarding performance must not only focus upon properties of the concrete but also of the embedded steel and, in addition, the manner in which these two components interact. In this regard, steel and concrete are, in most aspects, mutually compatible, as exemplified by the fact that the coefficient of thermal expansion for each is approximately the same. The concrete / cement acts to protect the steel by passivating it. It forms a protective oxide coating on the steel giving a pH of 13-14 adjacent to the steel. The corrosion of steel reinforcement occurs below pH11. The pH of seawater is about 8; hence corrosion process will be accelerated. The carbonation and chloride ions diffuse through concrete until they reach the embedded steel. Then the pH is lower by the presence of chloride ions. This corrosion process also requires oxygen diffused through the concrete, resulting in electrochemical reaction. The process is increased by existence of voids (air gaps) in the concrete adjacent to steel. The seawater can also diffuse through the permeable concrete and evaporate, resulting in salt cells forming in the pores. This can setup a battery action and leading to electrolytic corrosion

CORROSION CONTROL METHODS

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The common corrosion control technique include:

- Material Selection: Selecting corrosion resistant during designing the structure
- Barrier Protection/ MCI: Use of protection coatings, membranes and protective sealers.
- Cathodic Protection: The use of direct electrical current and sacrificial material to mitigate corrosion as reinforced concrete and bridge deck.
- Electrochemical Chloride Extraction: Removal of chloride ion from concrete structures by applying anode and electrolyte to the surface of concrete.
- Dehumidification: Maintaining the right humidity levels to reduce the corrosion to negligible levels.

MATERIAL SELECTION:

The use of corrosion – resistant materials is most often indicated in the original design of a structure or a piece of equipment. These materials are selected usually for very specific purpose to withstand a particular corrosion condition. Most often, the selection of specific materials is necessitated by a severe corrosion condition. In such cases, the additional material cost is justified by the additional life obtained through their use

BARRIER PROTECTION:

A few barrier protection strategies are discussed below:

Bare Steel Coatings: Various types of coating systems are used to protect the bare steel from corrosion in highly corrosive atmosphere being very humid, salty with dynamic load. A popular method is using a three coat system namely zinc rich primers, epoxy or urethane intermediates and aliphatic urethane topcoats.

Reinforcement Coatings: This process involves removal of rust and scales from the steel rebars by hard wire brush cleaning or blasting and application of coatings. Anticorrosive coating has excellent resistance to chemicals, corrosion and impact. The coating improves the bond strength between steel and concrete by more than 20% in the case of HYSD bars and by more than 120% in the case of MS bars when compared with uncoated steel. These coatings can be carried out at construction sites after cutting and bending of steel reinforcement rods. No special facilities are required to carry out the coating.

However failures of Steel Reinforced Concrete Constructions occurs due to extensive corrosion of steel reinforcement rods. In such conditions the concrete and mortar surrounding the reinforcement are usually found to contain appreciable amounts of Chlorides and Sulfates.

Migrating Corrosion Inhibitors (MCI): The corrosive effects of carbonation and chlorides cause a breakdown of the natural passivating protection of steel.

MCI is also used with a get deal of success when using low density concrete due to an easier path for the inward diffusion of the MCI, resulting in faster corrosion retardation. MCI offers protection for the steel rebar by using the inhibitors to suppress (raise pH) the chloride ions.

Migrating corrosion inhibitors are based on amino carboxylate chemistry. They are effective "mixed" inhibitors that work on both anodes and cathodes. Under normal conditions these substances increase the vapor pressure and this causes the inhibitor

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molecules to migrate through the pores in concrete. Once MCI's reach a metal surface they form a monomolecular film, which is physically adsorbed on the metal's surface.

CATHODIC PROTECTION:

Cathodic protection (CP) is the technique to prevent corrosion in chloride-contaminated concrete structures. CP reduces corrosion by changing the thermodynamics of the steel, i.e., the chemical potential of the steel in contact with the concrete is changed to make it more inert. Forcing an electrical current at the steel/concrete interface does this. Most CP systems are impressed current, i.e., a rectifier and an anode impress the current. The anode should cover as much of the surface of the protected concrete structure as possible in order to improve both the distribution of the current to the reinforcement and the service life of the system.

The best anode systems developed so far is Metallized zinc

ELECTROCHEMICAL CHLORIDE EXTRACTION

This process involves plastic wrap covering the columns and piers. The plastic wrap is the protective outer layer for removing chloride ions from reinforced concrete structures. The Electrochemical chloride extraction removes chlorides from concrete structures by applying an anode and electrolyte to the surface of concrete and then passing direct current between the anode and the reinforcing steel which acts as cathode since anions (negatively charged ions) migrate towards the anode, the process makes it possible to move the chloride ions towards the anode and out of the structure.

DEHUMIDIFICATION:

This is a relatively newer application used to control corrosion in two types of bridges namely Suspension and Cable Stay bridges and are playing an important role in keeping them safe. It has been found that with constant low atmospheric humidity iron and steel can be protected against corrosion. This can be attained by means of dehumidification.

WHAT IS DEHUMIDIFICATION?

Dehumidification is per say not a complete solution in itself but a complimentary one. When dehumidification solution is applied in conjugation with other method of corrosion control we have more complete system. For example external large metal plane surface, which have to be coated despite dehumidification. For the purpose of this article we will focus on the application of dehumidification in corrosion control for bridges.

Removal of water vapour from air is known as dehumidification. Air may be dehumidified by

(1) Cooling it or increasing its pressure

(2) Removing moisture by attracting water vapour with a solid or liquid desiccant

Since the presence of moisture is essential for the chemistry of corrosion to occur, dry air provides an absolute deterrent. Corrosion does not occur in dry environment. To understand dehumidification in the eliminating condensation, an understanding of the psychrometric variable will be necessary. These include the surface temperature of the steel, air dewpoint and air temperature inside; and the air temperature, air dewpoint and projected rate of change in ambient conditions outside. The primary purpose of understanding the effect of these variables is to determine the proper level of relative humidity that must be achieved and maintained inside the steel to prevent rust bloom from condensation.

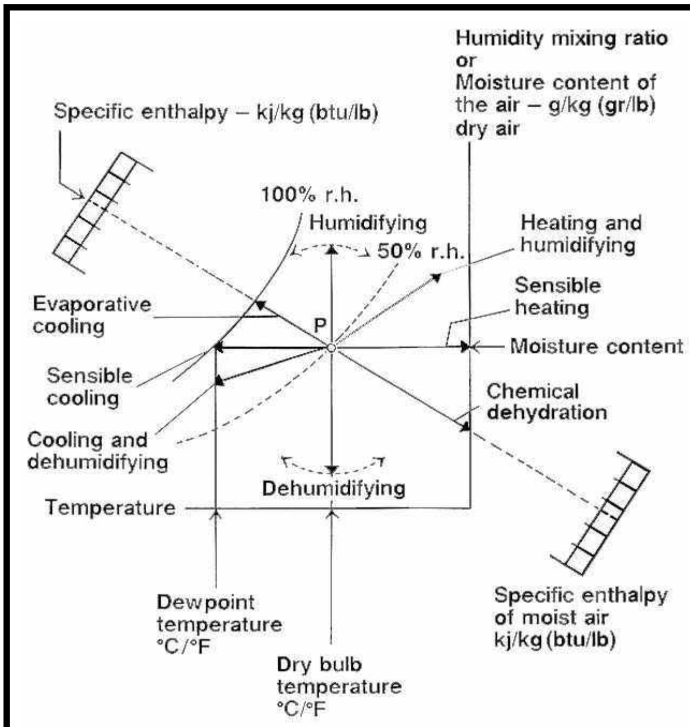

Figure - 3

- **Inside Surface temperature of Steel.** The temperature of the steel itself is affected by the inside temperature of the air during working conditions, outside air temperature, evaporative cooling that may take place during rain, and the radiational heating and cooling created by day/night cycle.
- **Inside Air Dewpoint.** The dewpoint is the temperature at which the air achieves 100% humidity. Additional cooling below the dewpoint will create condensation. The inside air dewpoint is likely to be uniform throughout an enclosed tank but variations can occur in areas where air infiltrates in from the outside, standing water evaporates and in tall tanks where the moisture has a tendency to rise.
- **Inside Air Relative Humidity.** The inside air relative humidity is only useful to know at the surface of the material to be coated. At a constant moisture level in the air, the relative humidity varies widely with the temperature of the air.
- **Outside Air Temperature.** The outside air temperature will change with the day night transition. Additional changes can be caused by evaporative cooling effect of rainstorms. Various geographic areas may have wider swings in temperature depending on the time of the year.
- **Outside Air Dewpoint.** The outside air dewpoint will change if the temperature falls and the moisture has been condensed. It potentially increases during the day as rising temperatures create a re-evaporation.
- **Outside Air Relative Humidity.** The relative Humidity is a function of the amount of moisture and temperature As a given volume of air increases in temperature, the volume has a greater potential for holding more moisture… thus a lower relative humidity. As the

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temperature decreases, the relative humidity increases to a point where the moisture will condense out of the air as the temperature continues to fall. The chart that follows displays the properties of air water mixture.

The Dehumidifier:

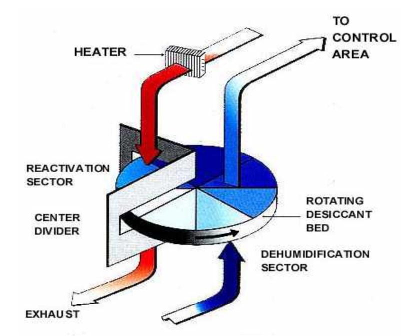


Figure - 4

The Desiccant based Dehumidifier removes moisture from the air by chemical attraction rather than condensation. Humid air is directed across a desiccant material that acts as a drying agent. The moisture is collected on or in the desiccant rather than as a liquid. A second hot air stream that heats the desiccant and releases the moisture dries the moist desiccant. Then the desiccant is reused to dry more air. In a continuous process, the Air is dried by the desiccant at the same time that more desiccant is being dried in preparation for reuse, so that dry air is available at all times. This dynamics is referred to as Process air stream.

Rotating Honeycomb Dehumidifiers: In its latest configuration, solid desiccant is impregnated into a rotating wheel that contains structured air contact media in the form of a honeycomb. Air passes through the open flutes in the media and releases the moisture to desiccant contained in the media walls. The moist media then rotates into the reactivation air stream. It is separated from the process air by a partition. The heated desiccant releases its moisture and is ready to reuse on the process airside of the partition.

APPLICATION OF DEHUMIDIFICATION FOR BRIDGE

Dehumidification finds application in following types of two bridges:

- Suspension Bridge
- Cable Stay Bridge

SUSPENSION BRIDGE

The suspension bridge have a roadway that hangs from the steel cables supported by two high towers. The suspension bridge have benefited from dehumidification in two areas

(i) Cable Anchorages

(ii) Cable Protection

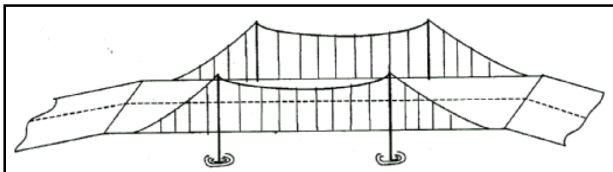
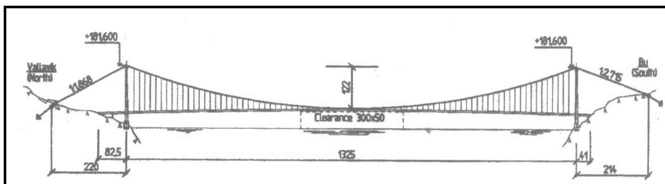
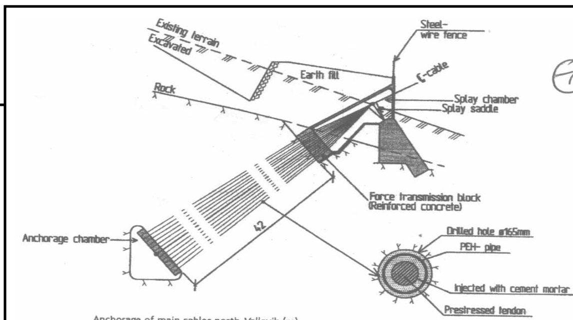


Figure - 5

CABLE ANCHORAGES



Elevation
Source: Article on the Haradanger Bridges
Figure - 5

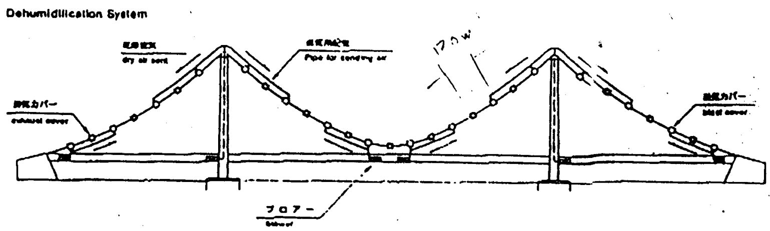


Anchorage of Main Cables
Source: Article on the Haradanger Bridges
Figure - 6

The cable anchorage room of the suspension bridge is one of the most critical elements of design and are suspect to failure as well. Due precautions are taken during the design of the cable anchorage as the fate and longevity of the bridge depend on the quality of anchora Also the anchorage with cables at very high tension is prone to corrosion attack.

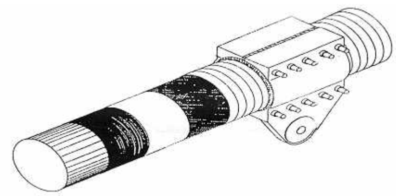
The dehumidifier is selected for maintaining the relative humidity under 40% all the time. At this humidity level the corrosion rate drops to negligible value.

CABLE PROTECTION:



Dehumidification System

Figure - 7



Corrosion Protection of Cable

Figure - 8

The cables, which are the lifeline of suspension bridges, are protected by dehumidification by wrapping them with loose rubber covers and releasing dry air in the chloroprene rubber jackets. These jackets run over the length of cable maintaining an RH of 40% around them. They are generally applied to the main cables of the suspension bridge:

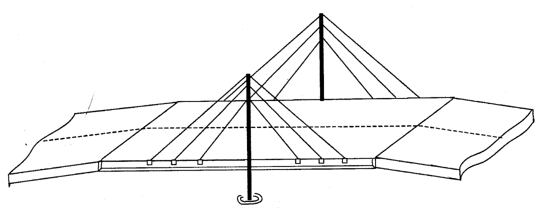
ADVANTAGES:

(i) By using dehumidification for Cable Anchorage and cable protection the life of bridge can be increased.

(ii) Maintenance cost can be reduced.

(iii) Inspection cost can be controlled and frequency reduced.

CABLE STAYED BRIDGE:



Cable Stay Bridge with metal deck exposed cable end ties

Figure - 9

Cable stay bridges have roadways hung from cables. These cables are directly connected to towers. The cable stay can have single metal deck or a metal deck surrounded by concreted decks as described in the diagrams.

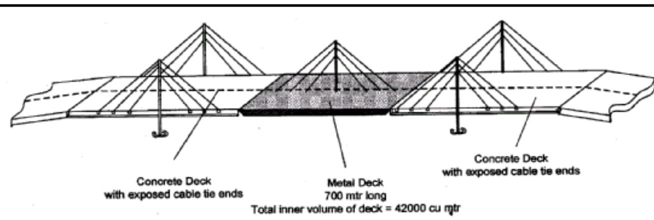


Figure - 10

The dehumidifiers are applied to the middle span of the bridge, which is the metal deck. The metal decks have large internal volume of about 50,000cu.mts in a medium sized bridge.

SIZING OF DEHUMIDIFIERS:

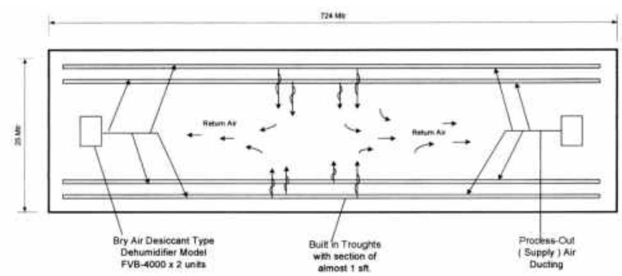
The selection procedure is as follows:

(i) The dehumidifiers are sized based on air-change rate of around 0.1- 0.12 air change rate per hour.

(ii) The dehumidifiers are selected on 100% re-circulatory basis however some times little fresh air is released inside through relief dampers when there is high velocity /presume wind outside.

(iii) The relative humidity targeted inside the metal deck is around 40% on re-circulatory basis. However the RH is allowed to increase the little during ingress of Fresh air as mentioned in point above.

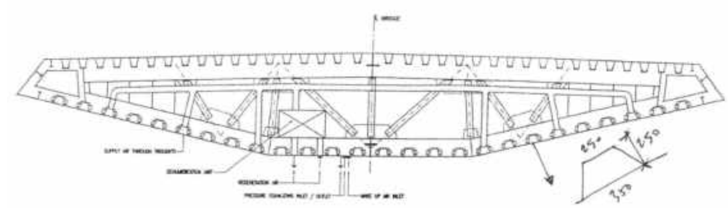
INSTALLATION PROCEDURE:



Air Flow
Figure - 11

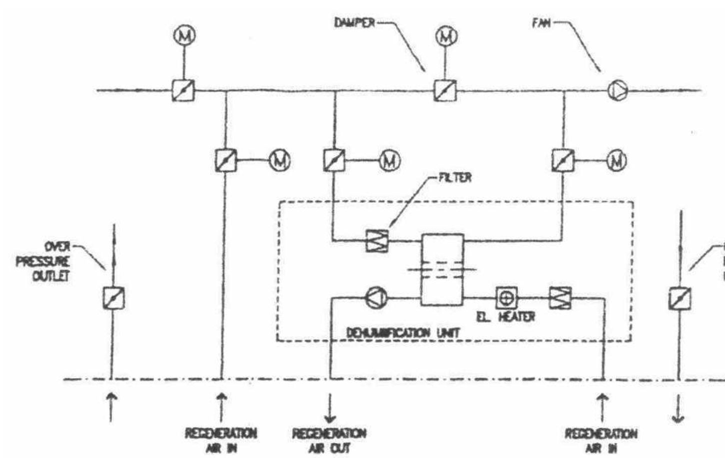
The installation procedure is detailed as follows:

- Dehumidifiers are to be placed within the deck, which has about 2mtr height.
- Relief dampers are use to bring in fresh air into deck space at times when outside pressure is high due to wind velocity. Set point for pressure difference is 400pa.



Scan copy of section of the deck
Figure - 12

- The dehumidifiers have free suction from conditioned space and the dry air is ducted to far end of the deck. For this purpose the troughts are used as duct, which are actually hollow structural members that run along the length of bridge. Short duct lengths are required to connect process fans to troughts. Reactivation air is ducted out of deck.
- When more than one unit are installed inside the deck they are connected through an intelligent Control system.



Principle Diagram
Figure - 13

The ventilation fans and the dehumidification units are controlled by 24hrs timer combined with a humidistat and switch in the access doors.

ADVANTAGES:

(i) With the use of dehumidification corrosion rate will drop to negligible levels.

(ii) Painting will last more than specified life of 10 years

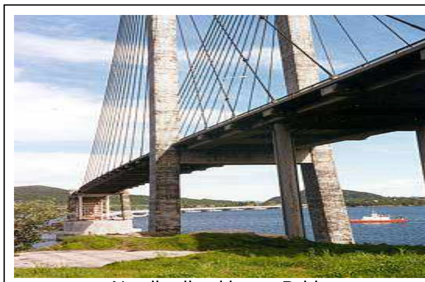
(iii) Although manual inspection is conducted, it is impossible to check every point inside and dehumidification will ensure control at a very low cost.

CONCLUSION

Modern bridge infrastructure comprises of primarily concrete and steel structures. Besides the spectacular visible mass, these construction marvels hide equally huge volumes of machinery and metal mass for their operation say for folding bridges like the ones over Thames in London and over Neva in St. Petersburg. Over the service life of bridge, its constituent material is persistently subjected to wear and tear resulting in spalling of concrete, excessive deflection of structure, rusting of steel components etc….

Hence it is very important to protect these bridges. Lot of corrosion protection techniques have been laid, to name a few Material selection, barrier coatings, Electrochemical chloride extraction, cathodic protection, including Dehumidification.

It has been found that with constant low atmospheric humidity iron and steel can be protected against corrosion. This can be attained by means of dehumidification, in as much corrosion does not depend upon temperature.



Nordhodlandsbroen Bridge
Figure - 14

The paper has detailed the technique, working principles and installation process of how dehumidification plays an important role in corrosion control of superstars of the engineering world.

Example (Figure-14) of this can be found in Nordhorlandsbroen Bridge in Bergen, Norway. This bridge is kept free of corrosion by means of dehumidifiers. The internal surface of bridge is protected by means of dry air a fact that has turned out to be an efficient as well as economical solution.

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