EXPECTED SERVICE LIFE ANALYSIS OF STEEL CULVERTS IN FINLAND

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Abstract

In the middle of 1990's The Finnish Road Administration created new method for corrucated steel culverts and pipe arches for public roads. One of the targets of these new regulations was to improve the corrosion protection of corrugated steel structures and to create a method on how to estimate expected service life of a structure.

The result was a simple formula with a few variable factors to calculate the expected service life of a steel culvert. The idea and basis for the formula was found by studying international research material and reports. The formula is not " the absolute truth" but it gives an estimate of the expected service life of a steel culvert and it also enables to compare alternative coating combinations.

The starting point of the calculation is to determine what are the circumstances under which the bridge is situated. For these circumstances there are four catergories. The categories are dependent on the maintenance levels of the crossing roads and on which part and surface is investigated at a time. Within these four categories (for circumstances) pipe bridges are then divided in two categories from the functional point of view; underpasses and viaducts.

The components that are considered in the calculation for the expected service life of a structure are: 20% of the culverts material thickness, galvanizing and some type of painting. The expexted service life is calculated by using estimated corrsosion speed for each of these components.

When paint and galvanized steel are used together, the corrosion control is superior to either individual method. This combination of both protection methods in what is commonly referred to as a duplex system. The galvanized coating protects the base steel and the paint gives additional barrier protection to the galvanized coating by isolating it from the corrosive attack of chlorides and sulfides in the atmosphere. With this synergistic effect, it is typical for a duplex system to provide corrosion protection 1.5 to 2.5 times longer than the sum of the lifetimes of zinc and paint used individually. This equates to steel that is maintenance-free for 75 to 100 years, in most instances. This paper describes the calculation method of expexted service life analysis for corrugated steel culverts and pipe arches used in Finland.

Key words: steel culvert, service life analysis, duplex system

1. BACKGROUND

The Finnish Road Adminstration (Finnra) has around 3000 pipe bridges in their possession. That is approximately one quarter of the total number of bridges owned by Finnra. Two thirds of these pipe bridges are water bridges and the rest are mainly underpasses for light traffic. Half of the all the pipe bridges, approximately 1500 bridges, are 15 years old or older. In addition to the pipe bridges owned by Finnra there are unnumerous pipe briges owned by cities and private road owners.

The first pipe bridges were installed in the late 1940's but the hige tide of the construction started in the late 1960's. During 1960's and 1970's Finnra built approximately 90 pipe bridges per year. The following next two decades were a little bit lower from the volume point of view but in the beginning of the new millennium the pace has been growing again. The reasons for the growing trend are partly the renewal of the old water bridges and partly general growth of civil engineering. Pipe arch is nevertheless a cost efficient way to raise traffic safety.

Finnra established their first regulations of steel culverts and pipe arches in the mid 1970's. First steel pipes with additional coating by painting were delivered in the mid 1980's and guidelines for additional corrosion protection were presented in the Finnra's regulations in 1987. In 1997 Finnra established the latest regulations for corrucated steel culverts and pipe arches for public roads, where the calculation method for the expexted service life was presented.

2. DUPLEX SYSTEM

The calculation method of the expexted service life of a steel culvert is based both on an international research material and to the conclusion that the protective value of the combination of zinc coating alloyed to the steel with an organic coating is higher than the sum of protective values of the zink and paint coatings separately. Depending on the aggressiveness of the surrounding, the synergic effect gives from 1,5 to 2,5 longer durability in years. This combined method is known as the Duplex System.

The effectiveness of Duplex System is based the on idea of covering and protecting the zinc surface exposed to the aggressive surroundings. The speed of corrosion of the zinc surface is drastically reduced because oxidation, attack by moisture, contamination and wearing of flowing water with sand and other small particles are prevented by the organinc coating.

3. SERVICE LIFE ANALYSIS

In the Finnish regulations the factor of synergic effect of Duplex System is chosen to be 1,5. The reason for choosing the factor from "lower limit" was to keep the calculation as simple as possible. It also gives extra safety against the variation of coating thickness.

The calculation of the expected service life contains three components: steel as a base material, zinc coating and organic coating, usually painting. The expected service life according to Finnish method is calculated by the following formula

$$SL = T1 + 1,5*(T2+T3) \tag{3.1}$$

where

SL = expected service life (years)
T1 = service life of steel (20% of steel thinkness is considered)
T2 = service life of zinc coating
T3 = service life of coating

The result is not considered as "the absolute truth" but it gives an good estimate of the expected service life and possibility to compare various protection combinations. At the moment the requirement for service life is 60 years for motor ways and highways and 40 years for other roads.

3.1 Categories of Cicumstances

To be able to calculate the expected service life, the category of circumstances where the pipe arch is situated needs to be determined. The corrosion speed of each component is determined according to the category.

Categories 1 and 2 are applied to underpasses which are considered as so called "dry bridges". The whole pipe belongs to catergory 1 if there is no salt used in the maintenance of the roads during winter period. If salt is used on the road, the outer surfaces under the side slopes belong to the category 2. If the salt is used on the crossing road going through the bridge the inner surface of the bridge till 0,5 m above the road line belongs to the category 2.
Categories 3 and 4 apply to water bridges. The category is 3 if the water inside the pipe is slightly aggressive and 4 if the water is medium aggressive. The coating in these categories extend to 0,5 m above of the medium water level and is required both on outer and inner surface. Rest of the pipe belongs to either category 1 or 2. The aggressivity of the water is determined by the pH of the water, stream velocity, hardeness and the quantity of clorides and sulphates of the water.
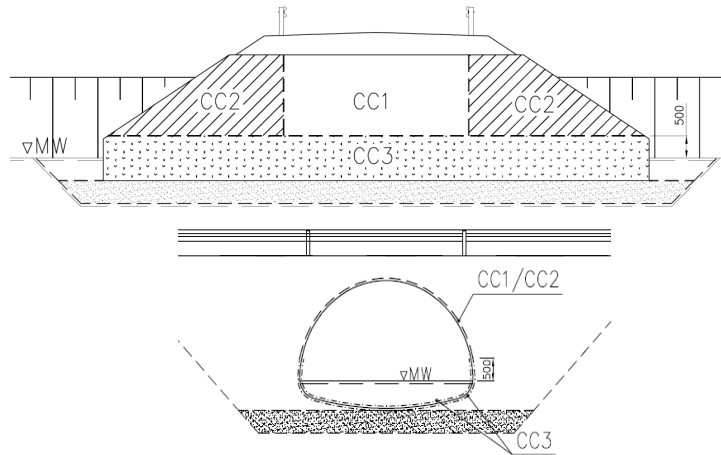
Figure 1. Areas of different categories of circumstances (CC)

3.2 Corrosion Speed

Currently the most common way for organic coating in Finland is epoxy painting. The other method for coating mentioned in the regulations is coating by epoxy tar. In the following table presents the corrosion speeds of steel (S), zinc coating (ZN), epoxy painting (EH) and epoxy tar (EP) according to the Finnish standards.

Table 1. Corrosion speeds in different categories of circumstances (µm/a)

Class of CC	S	ZN	EH	EP
1	30 µm/a	2 µm/a	3 µm/a	4 µm/a
2	45µm/a	3 µm/a	5 µm/a	6 µm/a
3	75 µm/a	5 µm/a	8 µm/a	10 µm/a
4	120 µm/a	8 µm/a	12 µm/a	15 µm/a

3.3 Calculation of the expected service life

The basic assumptions for the calculation of the expected service life calculation for a typical pipe bridge are following; water bridge is under a highway. Water is slightly aggressive and the road above is salted during wintertime. The thickness of the steel is 3,0 mm. The target of service life is 60 years according the road class.

Lower part of the pipe, inner and outer surface
The calculation is done in the category of circumtances 3. The thickness of the zinc coating is 70 µm (according EN-ISO 1461). The additional coating is epoxy painting and the thickness is chosen to be 160 µm.

SL = 0,2*3000/75 + 1,5*(70/5+160/8) = 59 years ~ 60 years

Upper part of the pipe under the side slopes
The calculation is done in the category of circumtances 2. The additional coating is epoxy painting and the thickness is chosen to be 80 µm.

SL = 0,2*3000/45 + 1,5*(70/3+80/5) = 72 years > 60 years

4. EXPERIENCES IN PRACTICE

As it was mentinoned earlier part of the construction volume of pipe bridges and especially growth of the volume is generated by renewing old water bridges. The age of renewed pipes are between 30 to 40 years old and almost 100% of the pipes are water bridges.

The reason for renewing is the fact that the only corrosion protection of the pipes has been hot dip galvanizing. If we use the presented calculation method we come approximately to the same result

SL = 0,5*3000/75 + 70/5 = 34 years

The factor 0,5 for plate corrosion speed differs from the calculation of a new pipe because the plates in the old bridges are usually at least half way or totally worn out.

Figure 2. Typical rust in water line after 30 years

5. FUTURE

At the moment the Finnish authorities have started a project for renewing the pipe bridge regulations. The calculation method will be developed further to

allow the use of new additional coating materials. One of the new coating materials is heavy-cauge protection film which is a tough plastic coating.

The criterias of the catergories of circumstances will also be developed further. The main principle is that when the pipe is installed in water it always has to have an additional coating with the zinc coating. From the criteria point of view it means that the aggressivity of the water is not so important because the additional coating is not so sensible to the acidity of the water. More important issue is the stream velocity because it affects the quantity and size of the particles floating with the stream which causes wearing of the surface through abrasion.

The defining of the target of the service life will also be simplified. In all cases the target of service life is 50 years minimum. The calculation method allows also longer service life demands if necessary.

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FIŃSKA ANALIZA ŻYWOTNOŚCI KONSTRUKCJI Z BLACH FALISTYCH

Streszczenie

W połowie lat dziewięćdziesiątych Fińska Administracja Drogowa stworzyła nową metodę dla karbowanych konstrukcji z blach falistych i rur o kształcie łukowym na drogach publicznych. Jednym z celów tych regluacji było ulepszenie ochrony przed korozją konstrukcji stalowych i stworzenie nowej metody szacowania oczekiwanej żywotności konstrukcji.

Wynikiem był prosty wzór z kilkoma zmiennymi czynnikami by oszcować oczekiwany czas żywotności konstrukcji stalowej. Pomysł oraz podstawa dla stworzenia tego wzoru została znaleziona przy analizie międzynarodowych badań i raportów. Wzór nie jest „prawdą absolutną”, ale daje szacowaną żywotność konstrukcji z blach falistych i umożliwia porównanie z alternatywnymi kombinajcami pokryć.

Punktem wyjścia obliczeń jest określenie warunków w jakiś znajduje się most. Sa cztery kategorie warunków. Sa one zależne od poziomu utrzymania drówg przebiegających nad przepustem oraz części powierzchni nad którą prowadzone są badania. W tych czterech kategoriach (warunków) mosty z konstrukcji podatnych są podzielone na dwie grupy zależnie od ich funkcji; wiadukty oraz przejścia pod drogami.

Składniki które rozważane są w obliczeniach oczekiwanej żywotności konstrukcji to: 20% grubości materiału, z którego wykonana jest konstrukcja, galwanizowanie, rodzaj farby. Oczekiwana żywotnośc konstrukcji jest obliczna przy użyciu szacownej prędkości korozji dla każdego ze składników.

Kiedy farba i galwanizowana stal są użyte jednocześnie, kontrola korozji jest lepsza od innych selektywnych metod. Połączenie obu metod ochrony jest powszechnie odnoszone do innych systemów typu duplex. Powłoka galwaniczna chroni stal, a farba daje dodadkową ochronną warstwę dla powłoki galwanicznej poprzez izolację od korozji przez chlorki i siarczany w atmosferze. Wraz z synergicznym efektem, typową ochroną jaką daje system typu duplex jest 1,5 do 2,5 raza dłuższy okres trwałości niż suma okresów dla każdej z metod użytych osobno. Jest to równe okresowi użytkowania stali bez zabiegów utrzymaniowych przez okres 70 do 100 lat, w większości przypadków.