Nondestructive Testing of Bridge Stay Cables

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INTRODUCTION

Today the most advanced and economical systems of bridge constructions are cable-stayed bridges. Cable-stayed bridge consists of one or more pylons which are connected to the roadway with the stay cables. The spread of cable-stayed bridges was in 1950s and since then hundreds of cable-stayed bridges of different design had been built around the world. At present there are more than 100 cable-stayed bridges worldwide with the span longer than 300 m.

One of the most important elements of the cable-stayed bridge construction is stay cable. Regardless of bridge design only two types of stay cable are used: cables of locked coil construction and cables with parallel wires and parallel strands. Lately constructions with parallel strands and parallel wires are mostly used as stay cables due to convenient installation and further maintenance and repair. According to relevant standards stay cables serve at least 100 years.

Stay cables are subject of big static and dynamic loading that leads to their degradation. Although stay cables have anticorrosive coating, they are exposed to the influence of the environment, which can be especially aggressive on the bridges over sea surface. The age of many cable-stayed bridges is over 50 years. During their operation the intensity of road traffic and dynamic load on the stay cables did grow considerably, and these factors increased the probability of different defects in the cables.

Basically these defects are corrosion damages, wear of the wires as a result of internal friction at alternating loads and broken wires, produced by metal fatigue or hidden defects. Cables can be also damaged by fire, resulting loss of their strength, or traffic accident which leads to destruction of the outer layer of the cable.

During the inspection the most important factor is knowledge of cable condition in the anchorage, where the probability of damage increases because of dynamic loads and the possibility of moisture penetration. Defects reduce cable strength and operational safety. To secure safe operation the whole bridge should be periodically inspected in order to prevent accident. Some standards [1, 2] provide for the basic and detailed bridge inspection. During detailed inspection all bridge constructions, including cables, are to be inspected more thoroughly. Exhaustive information about the technical condition of a bridge can be obtained with use of nondestructive testing (NDT).

NDT METHODS FOR CABLE INSPECTION

Different parts of the stay cable are subject to different loading and environmental effects, thus they deteriorate in different ways. Accessibility of different cable parts varies; certain preparations may be required prior to inspection. For these reasons it may be necessary to apply different NDT methods and instruments to inspect the whole cable.

Visual Testing

Visual testing (VT) reveals only outer defects such as corrosion, broken and missing wires if there is no protective coating on the cable. VT may be accompanied with haptic testing and is often carried with special trolleys, travelling along the cable at a very low speed, so the method is time-consuming and cumbersome. Reliability of VT depends on expert judgment and the experience of the inspector, i.e. information obtained from the rope is quite subjective. Prior to conducting VT the cable should be properly prepared, so there are no obstacles on the way of the trolley, and the cable surface is available for examination. For this reason, free cable with corrosion protection may not be inspected. Anchorage area may not be inspected either, only entrance of the cable into the anchor can be examined. However VT is considered a very important part of cable inspection – whatever NDT method has been used for inspection, it is always supplemented with VT.

Magnetic Particle Testing

Magnetic particle testing (MT) has been widely used for common rope NDT for decades and from 1990-th – for inspection of stay cables at bridges. Nowadays usually magnetic flux leakage (MFL) principle is used for nondestructive testing of steel ropes and stay cables. MFL instruments can quickly and precisely measure the loss of metallic cross-section area (LMA) to assess the level of corrosion, and detect outer and inner wire fractures (broken wires), known as local flaws (LF) even under the protective coating on the cable. The MFL instrument INTROS [3, 4] is successfully used for cable inspection. The principle of its operation is shown in Figure 1.

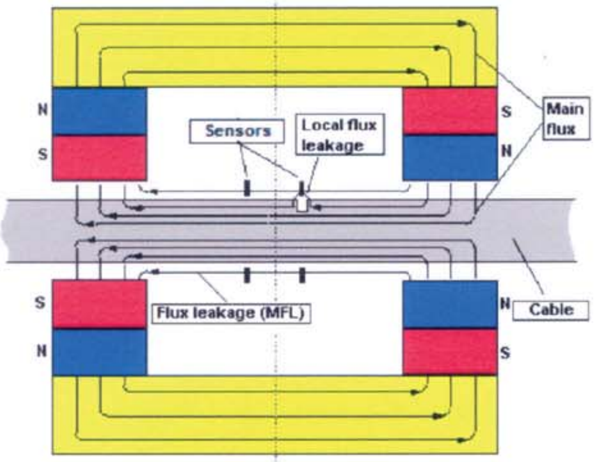

Figure 1: Cable tester INTROS. Principle of operation.

Magnetic head, which comprises strong permanent magnets and sensors, surrounds the section of cable and magnetically saturates the steel wires. The main flux value is directly proportional to the cross-section area of cable, thus with measuring the main flux it is possible to assess changes in the cable cross-section area of the cable. The magnetic flux leakage value is directly proportional to the loss of cross-section area (LMA) of cable, and so assessing LMA is possible with measuring the flux leakage value with sensors as shown in Figure 1. These sensors may also catch distortion of the flux leakage caused by cable fractures – broken wires, strands, pitting corrosion, etc. Measuring is carried with certain frequency during the movement of the magnetic head along the cable. Signals from sensors are processed with basic units and after downloading to a computer are presented to the inspector as LMA and LF traces (Figure 2). Upper trace, in Figure 2, shows the distribution of LMA value in percentage along the cable 9.5 m in length, and LF trace shows the location of fractures detected by INTROS. The operator uses special software, Wintros, to download traces from the basic unit to the computer for further analysis. It is also possible to look after the traces on-line.

Modern MFL instruments [3, 4, 5] can store testing data into built-in data loggers and simultaneously send data to computers through a wireless interface to watch data on-line. MFL instruments can provide cable inspection at relatively high speeds that make this method much less time-consuming than VT, also unlike visual inspection objective records from MFL instruments are available. Due to operational principles, MFL instruments must contain strong permanent magnets, which make MFL instruments quite bulky – the bigger the cable, the bigger and heavier is the instrument. Nevertheless MFL is the major method for inspection of the free parts of stay cables. However this method is not applicable for inspection of anchorage.

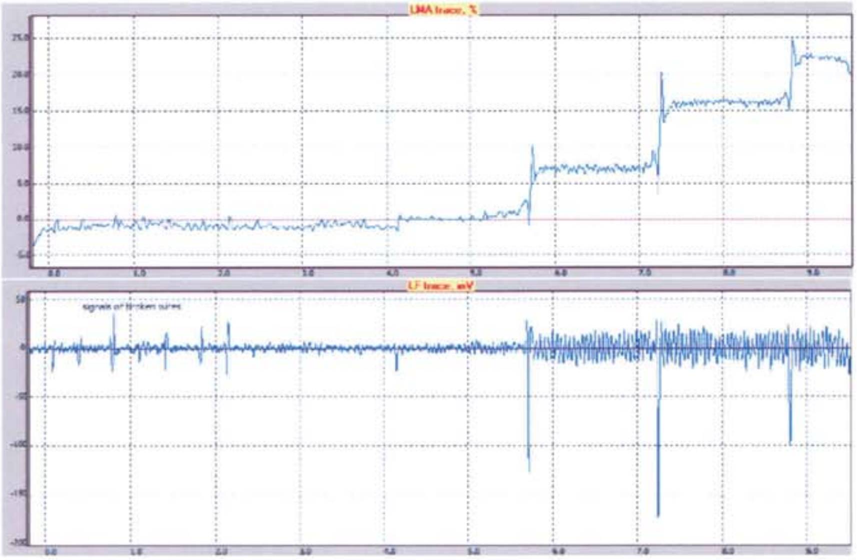

Figure 2: LMA (upper) and LF traces obtained from cable with artificial defects.

Electromagnetic Testing

Electromagnetic testing (ET) of steel wire ropes with AC or DC magnetization is detailed and described in Weischedel[6]. Instruments, magnetizing cable with DC coils, may have as good performance as instruments with permanent magnets. Instruments with DC magnetization for inspection of cables 160 mm to 250 mm in diameter was developed by EMPA [7]. Usually the weight of instrument with DC magnetization is more or less same to the weight of instruments with permanent magnets due to heavy copper coils, while necessity of battery power supply makes such instrumentation less convenient in operation. It is noted [8] that instruments with AC magnetization can only measure LMA, and are not intended for detection of LF. Our experiments with cables, comprising parallel strands, show that AC can be used to reveal individual strand fractures in stay cables of different constructions. For inspection of big cables (bigger than 150 mm in diameter) equipment with AC magnetization may be a good alternative solution to MFL instrumentation, because the weight of AC equipment is much less. The new instrument with electromagnetic head EH-300 for inspection of cables with parallel strands is now in operational testing (Figure 3). It is designed for inspection of cables with parallel strands from 125 to 300 mm in diameter at speeds up to 0.5 m/s. The instrument is dual-functional – it measures LMA and detects broken strands. It is sensitive enough to detect each individual broken strand, and LMA measuring accuracy is 1%. The instrument weighs 50 kg and has dimensions 678 × 640 × 625 mm.

Figure 3: Electromagnetic head EH-300 (a) and testing of EH-300 at the bridge cable (b).

Ultrasonic Testing

MT and ET allow inspection of free length of the cable, but they may not be used for inspection of anchorage. Ultrasonic testing (UT) can be used for inspection of anchorage area for cables with parallel wires [9] to detect wire fractures and corroded areas. It is known [10, 11], that during recent years there were attempts taken to inspect cables with long-range guided waves, including cable in anchorage. However lack of information about results of these inspections as well as possible limitations of this method in regard to cable inspection makes judgment about effectiveness of such approach quite difficult.

X-ray Testing

X-ray is mentioned in Jiang XU [12] as experimental for free lengths of cable, not for anchorage. However in comparison with MFL this method may not show sufficient advantages, and hardly may be used in practice.

Thus, stay cables may not be completely inspected with only one method. Results obtained by different methods supplement each other and make the information complete and reasonable. Design of stay cable systems can make accessibility to the cable difficult, and create problems for inspectors. To make the bridge suitable for inspection, including inspection of cables, the bridge should be designed in the proper way. Some codes [1, 13] note that bridges have to be designed with consideration of easy and economical regular inspections during bridge operation.

EXPERIENCE WITH NDT OF STAY CABLES

Intron Plus is experienced with wire rope testing in different industries since 1995. Inspection is made by in-house equipment INTROS. At the present time the company has the MFL instruments for inspection of ropes with a diameter up to 150 mm. The first commercial inspection of cable-stayed bridge was completed in 2009 in the city of Surgut, Russia. The bridge is equipped with 130 full locked cables 72 mm in diameter each. Cables have good access to install the instrument, and the inspection was possible with the magnetic head MH 60-85. The MH 60-85 with attached basic unit was moving up and down along each cable with the use of slings, winches and pulleys installed on the top of the pylon. A basic unit, attached to the magnetic head, was switched on to collect data from the cable and store into the built-in data logger. On-site photos are presented in Figure 4. After completion of the inspection, a detailed report, including assessment of residual cable strength was issued for the customer.

Figure 4: Inspection of a stay cable 72 mm in diameter with MH 60-85.

Thereafter Intron Plus has completed cable inspections of the YongJong suspended bridge in Seoul, Korea, and cable-stayed bridges Oktyabrsky in the city of Cherepovets and Fakel in the city of Salekhard, Russia (Figure 5).

(a) (b)

Figure 5: Inspection at Fakel (a) and YongJong (b) bridges.

In 2011 Intron Plus received the order to inspect 72 mm stay cables at the Oktiabrsky bridge in the city of Cherepovets, Russia, erected in 1979. Cable tester INTROS with magnetic head MH 60–85 could not be used for inspection because of too narrow of a space between cables. For this reason it was decided to redesign the magnetic head to make it flat and fit each individual stay cable. The customized magnetic head MH 50–80 is shown in Figure 6. This instrument was successfully used for the inspection of all 128 stay cables

(a) (b)

Figure 6: Cable structure of the Oktiabrsky bridge (a), and customized instrument INTROS (b).

ASSESSMENT OF CABLE RESIDUAL BREAKING STRENGTH

Providing examination of cable, the pursued target is assessment of the residual strength of the cable in order to know the residual life of the cable with consideration of its operational condition. Intron Plus has created a mathematical model of rope deterioration that allows calculating the rope safety factor, which, in turn, is used for assessment of rope residual strength [14]. Experiments with ropes made in mechanical laboratories in France, Finland and Ukraine, and following comparison of experimental results with calculated residual strength showed their agreement. This makes it possible to assess stay cable residual strength based on the LMA and LF traces. As a result, the distribution of safety factor (SF) along the cable length can be obtained. Figure 7 depicts distribution of SF for the bridge stay cable construction 1+7+7/7+14+24+33z+34z+41z, diameter 72 mm containing defects at distances of 225 m, 235 m, 270 m (local out-of-lock wires) and 315 m (two outer broken wires). The minimum SF value is at the distance of 315 m, and it is equal to 2.4. Considering that SF for such stay cable is stated as much as 2 [15], it can be concluded, that the cable may still remain in service. Assessment of cable residual lifetime requires accessible data from several consecutive inspections obtained from the same cable. Comparison with data obtained from the just erected cables is very informative.

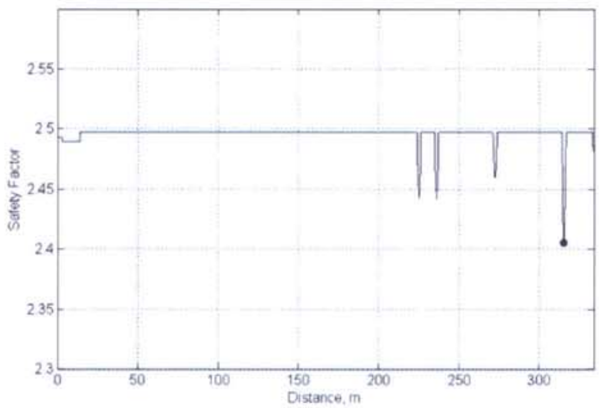

Figure 7: Distribution of cable safety factor.

CONCLUSION

Nondestructive testing of bridge stay cables allows obtaining important information about the technical condition of stay cables, and is, at the moment, one of the most effective ways to provide the safe operation of stay cables and of the whole bridge. Each of the inspecting methods has certain limitations, and gathering sufficient information about the cable requires the use of different NDT methods – VT, MFL and UT. Comparison of results obtained from different methods makes it possible to gain more knowledge about the cable, for example, MFL instruments can inspect the free cable length, but anchorage can be inspected only with UT, while visual inspection always supplements each inspection method. New construction of stay cables may require special approaches to their inspection, new equipment, and NDT procedures. It is very important that bridge designers consider the possibility of future inspections during development and erection of bridges to make stay cables more available for inspection.

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