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Use of gamma rays in the inspection of steel wire ropes in suspension bridges

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ABSTRACT

Regularity visual inspections are performed on steel wire ropes of suspension bridges. However, because the steel wire ropes were coated with plastic materials, inspectors could not visually detect the deterioration conditions of the ropes. In this paper, radiation tests and electromagnetic testing were compared. The gamma rays used in the radiation tests were employed to develop two assessment techniques, namely the exposure time formula and sensitivity assessment of steel wire ropes. Actual tests showed that such techniques can be adopted to evaluate the defects of steel wire ropes and help engineers improve the safety of suspension bridges.

1. Introduction

In November 2013, steel wire ropes of a suspension bridge in New Taipei City, Taiwan snapped (as shown in Fig. 1), resulting in the injuries of four people. Preliminary in situ investigations revealed that the primary reason for the steel wire ropes snapping was their deterioration over time caused by corrosion, abrasion, and broken (or splitting) wires. Therefore, visual inspections are performed periodically on the steel wire ropes of suspension bridges to ensure favorable structural safety. Because the steel wire ropes of the suspension bridge in this incident were coated with plastic materials, inspectors were unable to visually detect the deterioration conditions of the ropes (as shown in Fig. 2). Steel wire rope coating has slowly become a common trend in suspension bridge constructions; thus, effective methods for inspecting steel wire ropes have become a crucial concern in the engineering industry. In addition, steel wire ropes are commonly used in the fields of mining, shipping, construction, and transportation because they are flexible, light, and feature superior strength as well as a static and dynamic load capacity. Objects built using steel wire ropes include suspension bridges, cranes, hoists, lifts, and cable-stayed bridges. However, similar to other mechanical materials, steel wire ropes are subject to abrasion and corrosion or even breakage over long-term usage [1]. Therefore, to ensure the effective and safe use of steel wire ropes, providing an appropriate inspection mechanism is critical.

The testing of steel wire rope-related products in Taiwan primarily complies with the regulations stipulated in the Chinese National Standard 941, which includes various methods for measuring and testing the breaking load, torsion number, wrapping and unwrapping, zinc coating mass, appearance, and diameter of ropes [2]. Nonetheless, for onsite steel wire ropes that have been used for some time, only breaking load testing, visual appearance inspections, diameter measurements (vernier caliper), and service life data can be applied to determine when steel wire ropes must be replaced to ensure the normal operation of the machines and equipment. However, visual inspections and diameter measurements are laborious and time-consuming. Furthermore, using service life data to replace steel wire ropes has created instances in which steel wire ropes exhibiting minimal abrasion and sufficient tensile strength were needlessly replaced, resulting in resource waste. According to Article 99 of the Occupational Safety and Health Act stipulated by the Ministry of Labor, Executive Yuan, employers may not use steel wire ropes as the suspender in any of the following situations: (1) when 10% (or more) of the steel wire ropes are cut off; (2) when the diameter of the steel wire ropes has reduced to 70% (or more) of the nominal diameter; (3) significant deformation and corrosion are present in the steel wire ropes; and (4) the steel wire ropes have become twisted. Article 55 of the Enforcement Rules for the Mining Safety Act states that hoists should not be used when the safety ratio of the steel wire ropes has decreased to 80% (or less) or when the abrasion in diameter has decreased to 90% (or less) of the nominal diameter because of corrosion, abrasion, fatigue, or breakage. These laws and regulations indicate the requirements and limitations imposed on steel wire ropes used in live operations; thus, employing nondestructive testing technology has become increasingly critical

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Fig. 1. Snapping of steel suspender wire ropes.

Fig. 2. Snapped steel wire covered with plastic materials.

for inspecting working steel wire ropes, leading to the improvement and development of related technologies.

The nondestructive testing methods adopted in studies to assess steel wire ropes include both the visual inspection and electromagnetic testing methods, with the visual inspection method being more commonly used. In this method, inspectors visually observe the external appearance of steel wire ropes before measuring their diameters by using vernier calipers. Some studies have investigated the use of nondestructive methods for assessing steel wire ropes, such as ultrasound, eddy current, radiation, optic, and electromagnetic testing. However, except for electromagnetic testing, most of these inspection methods have disadvantages such as signals susceptible to interference, test results that are difficult to record, numerous testing limitations, and expensive equipment. Therefore, electromagnetic testing is currently more widely used [3]. In the present study, the radiation test method was adopted and compared with the electromagnetic testing method. The results can serve as a reference for engineers conducting related assessments.

In the past 5 years, the author has researched in using γ-rays to detect reinforced concrete bridges. Reinforced Concrete (RC) is a highly non-uniformed complex material; therefore, it is very difficult to achieve expected accuracy in determining the size of steel bars and locating concrete defects in RC members. In the research, penetrating γ-rays were used to project images of steel bars, cracks and holes in RC members on a film. In another case, the author also used γ-rays to detect corrosion in the tendons of prestressed concrete bridges. The results show that γ-rays detection is very effective in preventing the damage to bridges and reducing the risk of bridge failures.

2. Principles of testing

2.1. Use of radiation tests

In general, radiation tests are used for welding-related inspections in the engineering industry, particularly for inspecting steel structure, the internal quality of equipment and pipeline welds, and internal weld defects such as holes, slags, cracks, corrosion, and poor and insufficient fusion. These defects, which vary in shape, size, and orientation, create problems with varying degrees of severity. For example, cracks and poor fusion cause stress to concentrate at the sharp edges, which significantly decreases the maximum stress that can be sustained by the welds. Weld interior that has such a defect is prone to the risk of sudden failure. Therefore, if radiation tests are performed to identify defects in weld interior in advance, repairs can be made according to related provisions to patch the defect areas, which would improve the structural safety and usage performance of the welds.

2.2. Principles behind the radiation test

Radiation test is a common nondestructive method widely used in the engineering industry. Radiation can penetrate the materials to be inspected and reach mediums such as photographic films (hereafter referred to as "films") and screens to generate images for subsequent recording. Typically, radiation tests can be divided into two categories according to how the source of radiation is generated. These sources of radiation comprise X-rays and gamma (γ) rays, both of which travel in a straight line to irradiate materials. When the radioactive rays reach the materials to be inspected, a portion of the radioactive rays is absorbed by the materials, and the remaining radioactive rays penetrate the materials. The penetration ability of the radioactive rays can be expressed using Eq. (1) [4]

$$I = I_0 e^{(-\mu \ T)} \left[B(x, h\upsilon, A, L) \right] \quad (1)$$

where

I_0: energy prior to penetration (MeV),
I: remaining energy after penetration (MeV),
T: penetration thickness (cm),
μ: radiation–absorption coefficient of the material (cm^{-1}),
x: thickness of the material (cm),
$h\upsilon$: energy (MeV),
A: area (cm^2), and
L: distance between the source of radiation and the film (cm)

Eq. (1) shows that the amount of radiation absorbed by materials differs according to factors such as density, thickness, and atomic number change. High-density materials (e.g., rebars and other metallic materials) or those large in thickness can absorb relatively high amounts of radiation, which results in little radiation on the films. After the film is developed, because the blackness level and amount of radiation penetrating the film are correlated, the variation in thickness and material used create a black and white contrast on the film. Thus, inspectors can identify the quality of the objects by examining the images. Because test results obtained from the film images can be displayed directly, disputes pertaining to the results (e.g., different signal analyses) are avoided. In addition, the radiation test method can be used for both metallic and nonmetallic materials, making it popular in various engineering applications, such as weld and pipeline wall thickness inspections.

Typically, gamma rays have higher energy compared with portable X-rays and can therefore be employed to test thick objects. In addition, gamma rays are suitable for in situ inspections because no electricity or cooling water is required. By contrast, X-