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Fatigue durability study of high density polyethylene stay cable sheathing

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HIGHLIGHTS

- Investigation on the strain level of the HDPE cable sheathing under variable loads.
- Fundamental fatigue load characteristics of HDPE cable sheathing.
- Studies on the major factors affecting the cable fatigue lifetime.
- Discussions on the causes of early fatigue failure in cable sheathing.
- Theoretical proof for engineering measures to increase the lifetime of HDPE sheathing.

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ABSTRACT

Stay cable is the primary load-bearing structure of cable-stayed bridges, and the durability of high-density polyethylene (HDPE) stay cable sheathing is essential to the serviceability, safety, and durability of the entire bridge. Considering the damage owing to fatigue cracks in the HDPE sheathing during actual operation, this paper investigates the strain level on the HDPE cable sheathing under variable loads through on-site experiments on a cable-stayed bridge in service. The fundamental fatigue load characteristics were analyzed. The cable fatigue lifetime was further studied to reveal the major factors affecting the distribution pattern of the lifetime of the HDPE sheathing. The study results partially explained the cause of early fatigue failure in certain cable sheathing and provided theoretical proof for engineering measures for increasing the lifetime of HDPE sheathing.

1. Introduction

As the major load-bearing components of the cable-stayed bridges, the durability of stay cable play vital roles on the serviceability, safety, and durability of the entire bridge. Currently, the commonly used anti-corrosion material for bridge stay cables worldwide is high-density polyethylene (HDPE) [1]. It is applied as sheathing in two ways: “hot-extruding and preformed HDPE sheathing”. The difference of this two ways is how does HDPE sheathing wrap the inner steel wires of the cable, i.e., the tube of the former is formed after the steel wires are bundled up, while tube of the latter is formed in advance. The HDPE has excellent properties such as anti-corrosion, hardness and rigidity, anti-scratch, and low cost. However, because of factors such as raw materials, manufacturing and construction techniques, environmental erosion, and dynamic stress in the work environment, many cases of crack damage of HDPE sheathing have been reported globally [2–4]. In recent years, the HDPE sheathing of the bridge stay cables across China showed frequent cracks, some of which appeared just after the cable-stayed bridges were put into service [5–8]. The most commonly observed damages include hoop cracks, longitudinal cracks, scratches, indents, and peelings as shown in Fig. 1 [7].

It is observed from survey data on cable damages that HDPE cracks are quite common, and about 60% of the crack damages can be ascribed to the strain during service [8]. Once the cracks in HDPE sheathing appear, they start penetrating into the interior metal cable, and then the anti-corrosion system begins to lose its effectiveness. Therefore, as the beginning of the failure process of the cable, the crack on HDPE sheathing will affect the safety and durability of whole cable system eventually. As a type of construction material with excellent performance, the HDPE is widely used in various fields with different strain behaviors. Apart from the

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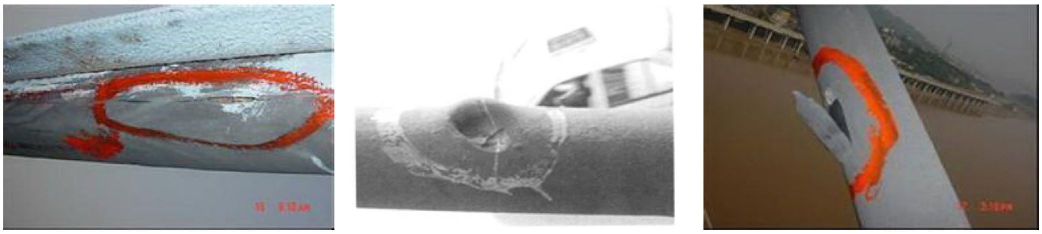
(a) Hoop cracks (b) Close hoop cracks (c) Longitudinal cracks



(d) Scratches (e) Indents (f) Peelings

Fig. 1. Common damages of stay cable HDPE sheathing.

static stretching in certain fields [9], dynamic environment often affects the HDPE material used in marine and bridge cable applications, and the major cause of mechanical cracks and failure is fatigue [10,11]. As a result, many researchers have attempted to study the mechanism of fatigue crack from the viewpoint of macromolecular chemistry and materials science [12–14]. Others investigated the fatigue properties and fatigue failure behaviors of HDPE using macro mechanical experiments [15–17].

However until now, there is a lack of research on the properties of fatigue load on the cable sheathing and thus the fatigue performance analysis of HDPE based on its actual strain environment. The fatigue crack behavior of a stay cable HDPE sheathing during service was studied by testing the actual stress level inside the cable HDPE sheathing and analyzing the statistical characteristics of the corresponding strain data as well as the fatigue load features. The Palmgren–Miner linear damage accumulation model [18] was further employed to analyze the distribution of fatigue lifetime of the cable HDPE sheathing that underwent potential damages.

2. On-site measurement of strain level in bridge cable HDPE sheathing

As the primary load-bearing structure of cable-stayed bridges, the stay cable bears not only the dead load of the bridge but also the loads from vehicles, people, and wind, which cause changes in the cable stress.

In general, the cable stress produced by the dead load is designed to be within 30–35% of the standard value of the cable's static tensile strength, while the stress due to variable loads should not exceed 10% of the standard value of the tensile strength [7]. For a stay cable with a hot-extruding HDPE sheathing, the HDPE sheathing provides a strong bonding stress to the cable wires, and therefore, the strain on the HDPE sheathing is assumed to be approximately identical as that of the cable. Assuming the cable strength to be approximately 1570 MPa, the strain on the HDPE sheathing can be estimated to be between 50 $\mu\varepsilon$ and 140 $\mu\varepsilon$ with general loads on a highway.

On-site measurement of the sheathing stress level was necessary to obtain valid data. Experiments were conducted on Xupu Bridge, a cable-stayed bridge in Shanghai, China. The full length of the bridge is 6019 m. The main bridge is a double-tower double-plane cable-stayed bridge with a length of 1074 m and a main span of 590 m. The height of the "A" shaped main tower is 217 m. The entire bridge consists of 240 stay cables. The experiment was conducted during regular bridge operating hours, and the strain tests were conducted on the HDPE sheathing of six stay cables, which represent short (116.138 m in length), moderate (201.916 m in length), and long cables (289.440 m in length). The strain data was continuously collected at a sampling frequency of 128 Hz using a DH5920 dynamic data acquisition system. The duration of data collection was 1800 s for cable 1 and 2, and 1200 s for the rest of the cables. Fig. 2 shows a picture of the on-site measurement and the sensor positions of the measurement sites. Fig. 3 illustrates the time-strain curves recorded from six cables, which were measured by strain gauge 1 of each cable located at a height of 2.2 m.

The real-time data in Fig. 3 indicates that although the HDPE sheathing of the stay cable was not considered as a load-bearing component, the cable oscillation caused by wind and traffic flow induced axial strain in the outer layer of HDPE material with randomly distributed amplitude. In Fig. 3, the six tested cables are corresponding to the cable WEU5, WEU14, WEU27, MWD27, MWD14, and MWD5. The 3th and 4th cable are designed with a relative bigger strain range than other four cables under traffic load. It can be proved by the fact that the strain data of 3th and 4th cables are bigger than other four cables. However, the data of cable 4 had the largest strain variation between $-70\ \mu\varepsilon$ and $150\ \mu\varepsilon$, while the range of strain change for other cables was -50–$100\ \mu\varepsilon$. This is consistent with the results from earlier theoretical analysis [7].

3. Fatigue load spectrum characteristics of HDPE cable sheathing

To further investigate the fatigue load spectrum characteristics of HDPE cable sheathing during service, fatigue characteristic analysis was applied to the strain data from the six cables. The analysis procedure is as follows:

(1) remove the trend in the original strain data by the moving average method;
(2) filter out spurious signals with an amplitude less than $2\ \mu\varepsilon$ using a rain-flow counting filter;