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An experimental investigation on the bedding-in behavior of synthetic fiber ropes

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ABSTRACT

The bedding-in process of synthetic fiber ropes such as polyester, nylon, aramid and HMPE is of vital importance to experimental research and engineering application. In the present work, several important topics are systematically investigated by utilizing an experimental setup for cyclic loading tests of synthetic fiber ropes. These topics include the effects of bedding-in level on rope properties, a quantitative method for determining the bedding-in level of ropes and the main factors of influencing the bedding-in level. First, effects of the bedding-in level on properties of synthetic fiber ropes are investigated. A quantitative method for determining the bedding-in level is first proposed by utilizing the tension-strain curve of static tensile tests for synthetic fiber ropes based on the concept of bedding-in. This method is conducive to accurate comparison and evaluation of the elongation data obtained from different guidelines for synthetic fiber mooring ropes. Second, effects of the mean load, loading amplitude and loading cycles on the bedding-in level of HMPE and polyester ropes are systematically investigated. Based on measured data, the recommended method for determining the bedding-in procedure is proposed for synthetic fiber mooring ropes. Furthermore, an empirical expression that takes into account both the mean load, loading amplitude and number of loading cycles is proposed, which is the only one that can quantitatively evaluate the bedding-in level of fiber ropes under previous cyclic loading. The present work is of great necessity and benefit to capturing the loading history behavior and failure mechanism of synthetic fiber ropes, and also to designing convenient bedding-in procedures that are required for the installation of synthetic fiber mooring ropes.

1. Introduction

Synthetic fiber ropes have been proved to be the most suitable substitute for steel wire ropes or chains in deepwater mooring applications over the past two decades, due to apparent advantages in terms of cost, ease of handling and the ability to reduce peak loadings compared to steel wire ropes or chains (Banfield and Casey, 1998). However, synthetic fiber ropes show the loading history effect, which means that different initial bedding-in levels of rope samples have a strong influence on the load-strain characteristic. The bedding-in is the loading process of compaction of internal rope components to reduce the constructional stretch, stabilize the rope length and increase rope and termination efficiencies (American Petroleum Institute (API), 2007; 2015). To obtain the representative and reasonable experimental values of synthetic fiber ropes, the bedding-in procedure is a necessary loading process.

Previous researchers shared their significantly different understandings of the bedding-in process. Del Vecchio (1992) used a bedding-in loading between 10% and 30% of the breaking load for 1000 cycles before performing experiments on synthetic fiber ropes. Banfield and Casey (1998) concluded that any test procedures should be monitored and recorded to correctly interpret the test results of synthetic fiber ropes because the bedding-in effect dramatically changes rope properties. Bosman and Hooker (1999) found that the mean load is the main parameter of determining the dynamic modulus of polyester ropes under the condition that the minimum number of bedding-in cycles has to be 10,000. In 1999, researchers of the joint industry project considered that documenting the bedding-in process of synthetic fiber ropes is necessary to assure accurate comparison of elongation and stiffness data between ropes and to investigate the failure mechanism of ropes (BP, 1999). François and Davies (2000) found that the permanent elongation of fiber

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ropes is a combination of rope construction and material elongation. They also noted that a range of cyclic loading as small as possible is desirable during the bedding-in process. Casey et al. (2000) concluded that once the sample is fully bedded-in, the dynamic stiffness of ropes remains virtually constant. Casey and Banfield (2002) noticed that almost every cyclic run exhibits a period of bedding-in, but they did not propose a measurement method for calculating the bedding-in level of synthetic fiber ropes. In addition, Casey and Banfield (2003) concluded that many thousands of cycles may be required to achieve full bedding-in state of synthetic fiber ropes. However, due to the high cost of large numbers of cycles in full-scale ropes, they suggested that 100 cycles may achieve a full bedding-in state. Flory et al. (2004) concluded that constructional stretch is caused by the bedding-in process. Davies et al. (2006) stated that there is large difference in tension-strain curves of static tensile tests between bedded-in and new ropes. François and Davies (2008) held that the bedding-in process is a particularly important aspect and quite specific to fiber ropes. François et al. (2010) concluded that the bedding-in process for a mooring line will happen during installation or shortly afterwards. For example, a bedding-in operation of polyester mooring ropes was performed by two anchor handling vessels during installation (Deandrade and Duggal, 2010). Weller et al. (2014) discovered that the bedding-in process has a significant effect on the operational performance of synthetic fiber ropes by originally performing harmonic loading tests of nylon ropes with different initial bedding-in levels. In addition, many researchers (Ghoreishi et al., 2007a; b; Vu et al., 2015; Davies et al., 2016) focused on the finite element simulation of complex behaviors of fiber ropes to improve the understanding of rope structures and mechanical elongations. These investigations are helpful to understanding the bedding-in behavior of synthetic fiber ropes.

It should be pointed out that different guidance notes of synthetic fiber ropes advise different bedding-in procedures, such as from American Petroleum Institute (API, 2007, 2015), International Standards Organization (ISO, 2007), Bureau Veritas (BV, 2007), American Bureau of Shipping (ABS, 2011) and Det Norske Veritas and Germanischer Lloyd (DNVGL, 2017), as summarized in Table 1. The similarity of these guidelines is that harmonic intervals are proposed to bed-in the rope structure, stabilize the rope length and increase rope and termination efficiencies. Note that, the loading period of harmonica intervals is not considered as an influential parameter by any guidelines. The differences include the initial loading process, harmonic interval and creep procedure. Only Bureau Veritas (BV) (2007) and American Bureau of Shipping (ABS) (2011) require an initial loading process. In addition, only American Bureau of Shipping (ABS) (2011) requires a creep procedure after harmonic intervals. Obviously, different guidelines for offshore synthetic fiber ropes define different bedding-in processes. This means that the bedding-in process is indeed not a unified suggestion. Even though the bedding-in process suggested by the International Standards Organization (ISO) (2007) is now widely adopted, the effects of the bedding-in process from different guidelines on the behavior of synthetic fiber ropes need to be further explored.

To sum up, the survey of current research reveals that the experimental investigations of the bedding-in level are significant not only for installing synthetic fiber ropes in practical engineering but also for capturing the mechanical behavior of synthetic fiber ropes. However, there are still questions that need to be further clarified: (a) because different guidance notes of synthetic fiber ropes proposed different bedding-in procedures, accurate comparison of elongation and stiffness between ropes becomes difficult; (b) previous research lacks introducing the measurement of bedding-in level and a quantitative equation to describe the bedding-in level of synthetic fiber ropes; (c) the relevance of the lab tests to engineering applications in the aspect of bedding-in processes of synthetic fiber ropes is insufficiently established.

The present study aims to answer the questions above. Based on the essential concept of bedding-in for synthetic fiber ropes, experimental investigations of HMPE and polyester ropes are systematically performed utilizing an experimental setup for cyclic loading tests of synthetic fiber ropes. To begin with, effects of the bedding-in level on properties of HMPE ropes are investigated. Then, a method for quantitatively determining the bedding-in level of synthetic fiber ropes is proposed by utilizing the tension-strain curve of static tensile tests for synthetic fiber ropes. Based on the test results, the bedding-in suggestions of HMPE and polyester ropes are proposed. An empirical expression that accounts for the mean load, loading amplitude and loading cycles is also proposed to describe the factors upon bedding-in level of synthetic fiber ropes. The present work is of great necessity and benefit to capturing the loading history behavior and failure mechanism of synthetic fiber ropes, and also to designing convenient bedding-in procedures that are required for the installation of synthetic fiber mooring ropes.

2. Experimental setup and rope specimens

2.1. Experimental setup for synthetic fiber ropes

The experimental setup is made up of four parts, i.e., the loading elements, the equipment foundation, the rope measurement system and the water cycling system, as shown in Fig. 1. The loading elements include the dynamic loading and static loading components. The maximum capacity of static loading is 60 kN, while the corresponding capacity of dynamic loading is 50 kN. The equipment foundation is designed to make the experimental setup be easily installed in the laboratory. The rope measurement system includes the rope elongation and the loading measurement systems. The rope elongation measurement system consists of a wire transducer and two axletrees, as shown in Fig. 2. These axletrees are installed above the outer water tank. There are two sliding blocks on axletrees, one serves as the base for the wire transducer, and the other is used to fix the wire. Two specially designed clamps installed under the sliding blocks are used to calibrate the test region. These clamps can be reliably fixed on the gauge marks of the rope even if the load is near the

Table 1
Summary of bedding-in procedures from different guidelines.

Guideline	Initial loading process			Harmonic intervals		Creep procedure
	Ramp load range (% MBL)	Ramp duration(s)	Hold duration(s)	Cyclic load range (% MBL)	Number of cycles	
American Petroleum Institute (API, 2007)	–	–	–	A few cycles		–
International Standards Organization (ISO, 2007)	–	–	–	10.0–30.0	100	–
Bureau Veritas (BV, 2007)	0.0–50.0	–	1800	10.0–30.0	100	–
American Bureau of Shipping (ABS, 2011)	pre-tension-65.0	390	6000	35.0–65.0	1000	Reduce to pre-tension and hold the tension for 6000s
American Petroleum Institute (API, 2015)	–	–	–	A few cycles		–
Det Norske Veritas and Germanischer Lloyd (DNVGL, 2017)	–	–	–	1.0–50.0	10	–