# Flex Fatigue Testing - Final Report[1]

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## Overview

The purpose of this project was  to conduct an evaluation of the escape ropes currently being carried by operational personnel focusing on whether there is a potential for premature failure due to flex fatigue.

## Background

The escape systems that all operational members of the department carry utilize a 50' length of Sterling EscapeTech rope as the basis for the system. This rope has a diameter of 7.5 mm and is constructed with a 100% braided, Technora sheath and a Nylon core.

All certified escape rope constructions are one the following:

- Technora sheath/Technora core (T/T)
- Technora sheath/Nylon core (T/N)
- Nylon sheath/Nylon core (N/N)

We chose to utilize the T/N construction for the benefits you obtain by using a Technora sheath (heat, cut, and abrasion resistance, low stretch) over a Nylon core (stretch and energy absorption). Many departments use the T/T ropes as well; personal preference, cost and application are the factors that many utilize to determine their choice. Very few departments utilize the N/N ropes as they provide little resistance to high heat conditions.

Most manufacturers use 10 years as the lifespan of the rope assuming it passes requires inspections.

The subject of using your issued escape system during initial and ongoing training is one that each department takes a different stance on. NFPA states that systems should be retired after use in an “emergency” situation which is commonly understood as actual firefighting conditions and not training. SFD’s approach has been to utilize the member’s issued system during the initial training and ongoing training for the following reasons:

1. A system that has been used 3-4 times becomes “broken-in” and operates more smoothly.
2. There was no evidence that any component would wear out through normal training use during the lifespan of our systems (10 years for the rope).

During the 2017 International Technical Rescue Symposium in Golden, Colorado, CMC Rescue presented a paper titled “Is My Escape Line Still Safe After...? An investigation into the fatigue strength of aramid fibers in escape applications.”

The goal of their testing was to evaluate the longevity of Technora products used in escape systems that are subjected to bailout scenarios (as in training) and to help develop an appropriate service life recommendation.

They subjected their products (T/T [rope and webbing] and N/N rope) to a series of tests.

While their testing did not include ropes of T/N construction it did bring up some concerns that may or may not apply to ropes similar to ours. Issues I observed that pertain to us were:

1. Since the Technora fiber had the most strength degradation and our ropes have a Technora sheath there is a potential for a strength reduction.
2. We use our ropes in training and subject them to repeated cyclic bending. The testing showed significant strength reductions of 30% with T/T ropes subjected to 100 cycles. I would estimate individuals who have used their ropes the most have seen 50+ cycles.
3. The N/N ropes did not see the strength reduction apparent with T/T ropes. This is encouraging and suggests that a Nylon core could contribute to a better lifespan of a rope. Since our ropes are T/N this may be beneficial.
4. Our descender, the HALO, is different than the one used in the CMC testing. We don’t know the effects this descender has on the rope without testing.

Our current ropes in service and the ones that were removed from service during the initial training have been subjected to various degrees of use. Some of the ropes have seen severe use similar to those in CMC testing while most have seen significantly less use (<50 jumps over their entire life).

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[1] This report has been modified from its original form. This is a condensed report presented at the International Technical Rescue Symposium in Portland, OR in 2018. The full report can be found at www.itrsonline.org.

## Guiding Questions

The following guiding questions were used in the development of this project:

1. Have our in-service escape ropes that have been used for initial and on-going training suffered a strength loss that is significant enough to warrant early retirement?
2. Do we need to change our initial and/or on-going training to using dedicated training systems that we can monitor and retire as necessary?
3. Can our research provide information regarding T/N ropes to the fire service community and manufacturers that can help in the development of new technologies or methods for implementing successful escape programs?

## Observations

1. While many of the ropes tested in this project did not perform well and would be considered unacceptable for use, the in-service ropes on average tested at the NFPA standard of 13.5 kN (3027.2 lbf). This is a reduction of 9% over new rope. These results are obtained using a method that yields on average a 21.3% reduction in strength when using new rope. We cannot simply add 21.3% to the above results for statistical reasons, however we can reasonably say that the in-service ropes will test higher if tested using the industry standard method (CI 1802).
2. When comparing the number of descents to the overall strength of the rope we see a pattern that develops at approximately 40 descents. At this point the rope loses enough strength to not pass the 13.5 kN requirement of NFPA 1983. This is a very conservative number and would likely be higher based on the logic described in Observation #1.
3. If we evaluate the appearance of the rope as it compares to strength we can see that the ropes with the most descents and least strength appear the most worn. We can also look at the descent control device and see the most wear as well. While this is not surprising and difficult to quantify, it is of use for field inspections in determining retirement criteria.

## Recommendations

1. The ropes we are using can remain in service until the anticipated replacement period in 2023-2026 assuming they have not been subjected to more than 40 jumps from either the medium or high prop. In addition to this, an inspection of the rope should be performed by the user that compares the current condition of the rope to a small sample of worn rope from this testing that would indicate retirement. For those ropes that do not pass the inspection a supply of new ropes should be available for replacement.
2. When performing training that involves many evolutions, individuals should ensure they rotate the system they are using so as to minimize the use of any one system.
3. If training is going to be performed where extremely high use (>20 descents) is expected then one of the systems assigned to the Field House Escape Cabinet should be used and logged on the use form. It is recommended that an escape instructor be present for this training so documentation and an assessment of the rope can be completed post training.
4. As part of this testing, 5 of the ropes that were destroyed will be replaced with a different rope that has shown to perform better in terms of flex fatigue. These 5 replacement ropes will be field tested by escape instructors for any issues and will be considered as a a replacement when all of the in-service ropes retire in 2023-2026.
5. While the addition of the knot at the end of the rope ensures that you cannot descend off the end, it reduces the strength significantly (average 39% for in-service ropes). Since end-of-rope techniques such as lowering victims is being incorporated into an advanced escape system class, addressing this issue is important. Some of the advanced techniques require a carabiner to be installed in the rope at the end and it is recommended that this be done with a double overhand noose (scaffold) knot. As individuals are trained in these techniques the removal of the sewn eye and replacement with a carabiner is advised.

## Test Method - Overview

Developing a project to adequately answer the above questions is difficult and can be time consuming.  Initially my thoughts were to test 5 in-service escape systems that had seen heavy use by some of the escape instructors. While this is "snap shot" of its current state and indicative of what is being used in the field, it may not show the extent of wear that a system could receive through continued heavy use. Ropes from this group will be referred to as "in-service" ropes.

During our initial training in 2013, the instructors utilized several systems for the training as we had not taken delivery of the main order of escape systems yet. Each of those systems saw approximately 200 descents before being retired and would be indicative of a heavily used system that no member would easily be able to replicate during the service life of their issued system. I retained several of these out-of-service ropes for future use and included 3 of them in this project. Ropes from this group will be referred to as "initial training" ropes.

In addition to these 2 distinctive groups of like ropes, I included an additional rope from the initial training group that had been additionally subjected to a high cycle lifting application[2]. The intent of including this rope was to show how a rope that had beyond normal use could perform.

Since the ropes are each 50' long and the majority of the jumps a user in our training program are from approximately 20' high there is a portion of the rope that will see very little use and would be expected to retain more strength. In addition to this, there have been several users that are employing more advanced techniques with the system that involve lowering a person with the end of the rope. This can cause wear in the rope as well and was taken into consideration during this project. The position of the sample relative to the anchor end[3] was tracked so a correlation could be made between sample ropes.

My testing included a series of static pull-tests using a hydraulic tensile tester. These tests were correlated to the estimated history of the ropes and a strength reduction calculated from this.

# Test Method - Details

## Hydraulic Tensile Tester

A dual beam hydraulic tensile tester capable of pulling 55 kN (12364 lbf) was used. The pull rate for all samples was 1400 mm (55.1 inches) per minute. It should be noted that this is faster than the Cordage Institute's standard (CI 1801) of 38 – 150 mm (1.5 - 6 inches) per minute. Testing at the standard rate for rope manufacturers is prohibitively slow and other testing has shown that results will be higher at the standard rate. This was acceptable as a reasonable conclusion can be made that any test results would be lower and therefore err on the side of caution when drawing any conclusions.

Force was measured using an Optima S-Beam Load Cell, 10k lbf rated capacity. Data was acquired at 500 Hz using a wireless bluetooth connection to a tablet. This data was then input into a database created by RopeCraft for conducting this type of testing.

## Grips

Grips are the device used to hold a sample in a tensile tester. When testing rope they are typically a round drum where several wraps of the sample are placed around the drum and secured. This allows the full strength of the rope to be evaluated instead of a knot or other termination. Many times when testing rope the method of holding the sample becomes the weak point and can defeat the intent of the test. The standard for testing rope is to use 4 wraps of rope around a 4" drum that is terminated at "cleat". One issue with this type of testing is that it requires approximately 56" of rope for each end just to hold the sample. This would result in approximately 132"[4] of rope for each test equating to just 4 tests per test rope.

In order to get the maximum number of tests out of each rope, a custom-made 1" self-centering drum was created. This custom drum reduced the sample length to 62", enabling 10 samples per test rope. The drawback to this grip is the reduction in desired 8:1 ratio of rope diameter to drum diameter. This grip yields a 3.4:1 ratio (7.5 mm rope to 25.4 mm drum). This reduction will cause the force values to likely be lower as the tension in the rope will be increased at the initial round turn of the grip.

For the tests that involved the sewn eye termination a carabiner (CMC Steel Locking D, 72 kN) was used as the attachment point.

## Groups

The individual ropes were grouped into 10 different groups.

The approximate number of descents is difficult to determine and a potential for error in the calculations of this report. I obtained as accurate of a history from the user as was known and made estimates based on log information. We do not track individual descents and it should be noted that each descent can be different depending on the location (medium prop, 2nd story, 3rd story, etc…).

## Positions

The rope was cut into 10 sections prior to testing. The position of the section relative to the anchor end was identified and tracked throughout the tests. This was done to acknowledge the different uses each portion of the rope receives. For example, the first ≈ 20' of the rope sees the most wear from a 2 story descent and the tail end of the rope sees more use if conducting advanced techniques.

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[2] This rope was used to conduct 500+ lifts of a 100-200 kg steel test mass for a project that involved cutting of ropes on RopeCraft, LLC's sharp edge test device. This rope was noticeably more worn than all other ropes and would be considered not acceptable for any life-safety application.

[3] The anchor end and the first 20' are subjected to the most wear when exiting from the 2nd floor window of our training facility.

[4] 56" for each end plus 20" between grips.

# Test Results

## Calibration Tests

An initial set of 6 tests on unused rope of the same age was conducted to get a baseline value to compare the sample ropes to.

The manufacturer's published minimum breaking strength (MBS)[5] of this rope is 17.4 kN. This testing resulted in 13.7 kN, a 21.3% reduction in strength. Rate of pull and drum diameter are most likely the cause of this difference.

Since the method will be consistent between all tests we can compare results within the dataset, however we will not be able to correlate our results to the manufacturer's values. It is important to note that the tests results will almost assuredly be higher if we were to use the same method (CI 1801 standard) as the manufacturer does. While it is tempting to say that our samples would be 21.3% higher using the standard method, this would be statistically flawed and an incorrect use of information.

Results stated in this report will be relative to the dataset acquired and based on average values between samples.

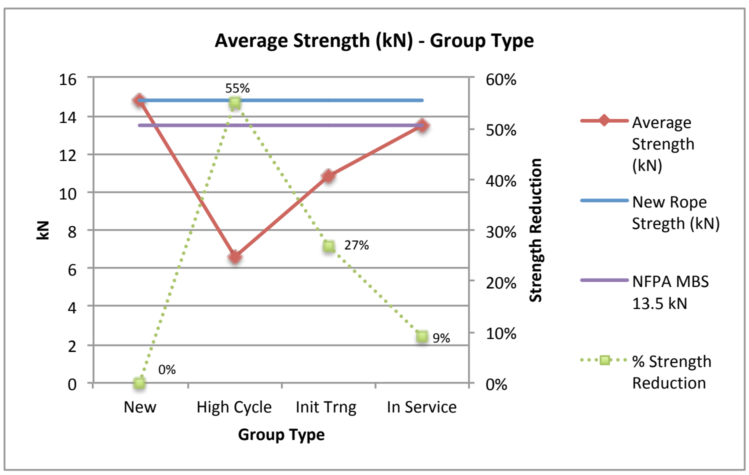
## Rope Samples

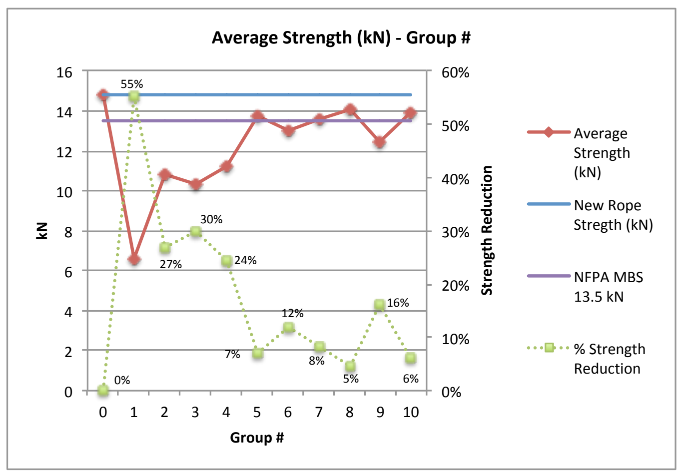
**Average breaking strengths of all samples by group:**

It should be noted that data from Position #10 was removed from calculations since the overhand knot that is tied near the sewn termination was the failure point at a value significantly lower than other portions of the rope. Since we are seeking the average strength of the rope and not the effect the knot has on the rope, Position #10 data was not included for any group.

If we compare the number of descents to the average strength we see the following:

Since we are most interested in the in-service ropes and their performance, the following chart depicts those results. 40 descents appears to be the line where the rope transitions from meeting the NFPA strength requirement to not. This is a conservative number and is more likely closer to 50 when we take into account that the test method results in lower results than the NFPA standard.




**Average breaking strength of samples by position:**

Group 1 was not included in these figures as this rope did not see typical escape system use. Groups 2-4 are separate from the others since these ropes saw significantly more use than Groups 5-10.

<u>Groups 2-4 - Initial Training Ropes</u>

Position 1 was not included as these ropes did not have a sewn eye on them since the hook had been removed when they were retired from service.

[5] This figure is a 3-Sigma rating which equals Average - 3*(Standard Deviation). The probability is 99.73% that all subsequent tests will be at or above this value.

Groups 5-10 - In Service Ropes