In conjunction with:

THE PREDICTION OF JUNCTION EFFICIENCY FOR PARACHUTE HARNESSES: EXPERIMENTATIONS IN BREAKING STRENGTHS AND WEAR CHARACTERISTICS

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1.0 INTRODUCTION

The material herein is an analysis of parachute harness joint efficiency research. There are works of harness research, but with limited accessibility and lack of depth. That would partially be because that modern harness containers are overbuilt with such a large factor of safety, the details are inconsequential. This is an attempt to organize and draw conclusions from all identifiable variables within the simple overlap joint.

This project was set forth with the intentions of predicting joint efficiencies for the simple overlap junction of TY-7 webbing sewn with 5 chord thread. The results of this research are a formula that approximates the breaking strength of the overlap joint and the design for the optimal variable settings of a maximum strength joint.

The variables present within normal construction that were analyzed are treatment of webbing, sewing technique / pattern, stitches per inch, length of stitch pattern, inclusion of confluence wrap, preloaded tension in thread, location of knot, and resew effects.

2.0 METHODS OF TESTING

The order of variable observation was organized to determine optimal variable settings without an excessive amount of tests. These steps outlined here were found to be the logical course of progression for construction of samples.

STEP
1. Preference of treatment (soft or hard)
2. Stitching pattern / concept selection
3. Stitches per inch
4. Length of stitch pattern
5. Pre-loaded tension in threads, Location of knot
6. Inclusion of confluence wrap
7. Twisting effects
8. Resew effects

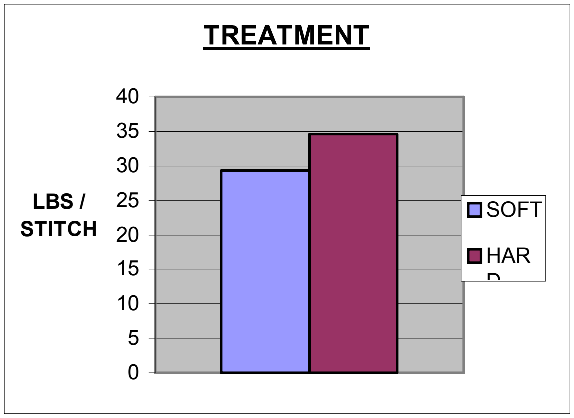
3.0 EXPERIMENT RESULTS

3.1 Treatment Analysis

It is known that lightly treated webbing is stronger than heavily treated webbing without a junction (Poynter). The purpose of this test was to observe the stitch pull-through effect under loading. Because of the physical properties of the soft webbing, it was predicted that the stitches would pull through the webbing further than the hard webbing. It would be expected that the webbing would fail earlier due to non-uniform loading of the strands within the webbing weave.

The results from the testing, keeping the variables constant, the same stitch pattern, length, tension, knot location, and number of stitches, indicate that the heavier treated webbing is better for stitching properties.

The tests conducted used a 2.5 inch 3-PT with equal number of stitches.



Graph 1: Effect of treatment on stitch loading

The heavier treated webbing has an average stitch load of 34.6 lbs per stitch and the lightly treated webbing has only 29.3. The remaining steps will have the samples constructed with heavily treated webbing.

APPLICATION IN BREAKING STRENGTH EQUATION:

Establishing the degree of treatment—measuring the force it takes to fold the webbing in half such that the edges meet (lengthwise). Let treatment, T, vary from 1 to 6 pounds, 1 being soft, and 6 being hard. Using percentage drop in stitch force and interpolating:

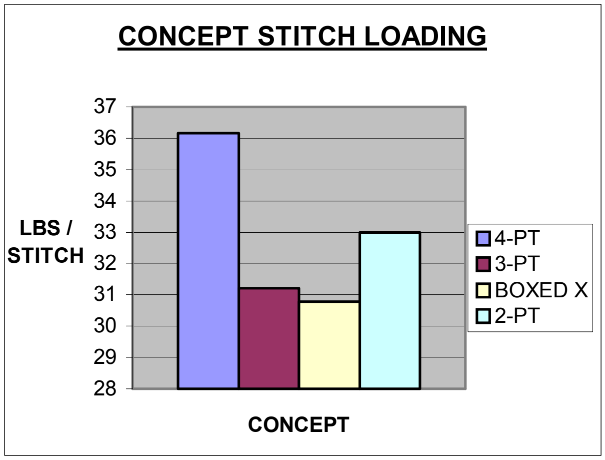
SL(8)' = (1- ((6 – T) * .15)) * SL (This will be referenced after step 8)

3.2 Stitching Pattern Analysis

Four techniques in common use were selected for analysis. For each of the techniques 3 samples were created. The four stitching patterns are: the 4-Point, the 3-Point, the Boxed-X, and the 2-Point. Since the total length traveled by the sewing machine ((stitches per inch) * (# of stitches)) is different for each technique, the total number of stitches was kept constant. Then the comparison of lbs per stitch yielded the superior concept.

The expected superior concept is the 4-PT. This is because this concept has a more even distribution of stitches across the total 'stitched area'. The idea behind this is to distribute areas of concentrated / localized stress apart from one another.

The tests for this section were conducted using a 3-inch pattern with equal number of stitches, medium tension and the knot located in the middle.



Graph 2: Effect of concept technique on stitch loading

The above graph shows that the best concept is the 4-PT. Surpassing the other concepts by at least 10% efficiency in stitch strength.

APPLICATION IN BREAKING STRENGTH EQUATION:

For equation purposes, the Concept Selection, C, will designate the origination of strength per stitch:

C = 36.2 lbs, 4-PT 31.2 lbs, 3-PT 30.8 lbs, Boxed-X 33.0 lbs, 2-PT

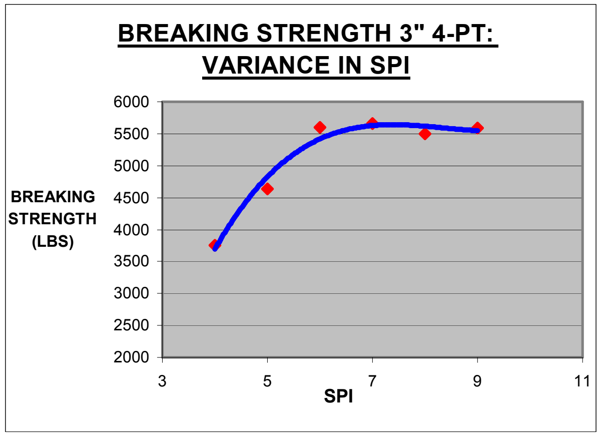
Stitch Loading------ SL(1) = C (SL will be incremented through the steps)

3.3 Variance in SPI

The number of stitches per inch, SPI, that were analyzed ranged from 4 to 9. The foreseen potential effect is the concentration of needle perforations of the webbing. As the stitches per inch increases, the needle perforations get closer together. In the case were there are enough stitches in the joint where there will be failure by webbing rather than by stitching, any further increase in SPI might cause the webbing to break earlier.

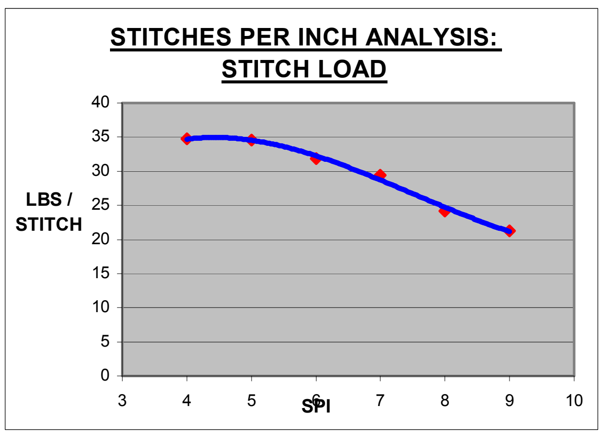
It is expected that upon reaching the thread breaking-webbing breaking threshold, that an increase in SPI will decrease the Breaking Strength. This would mean that the threshold SPI would be the maximum strength of the joint and thus the optimal selection.

The tests for this section were conducted using a 3 inch 4-PT with medium tension and knots in the middle.



Graph 3: Effect of SPI on Breaking Strength

Graph 3 demonstrates a small drop in breaking strength after it's maximum of 5660 lbs. If not for the fact that 10 SPI and beyond are unpractical within the ability of harness sewing machines, we could test and observe a potentially continuing decrease in joint strength.

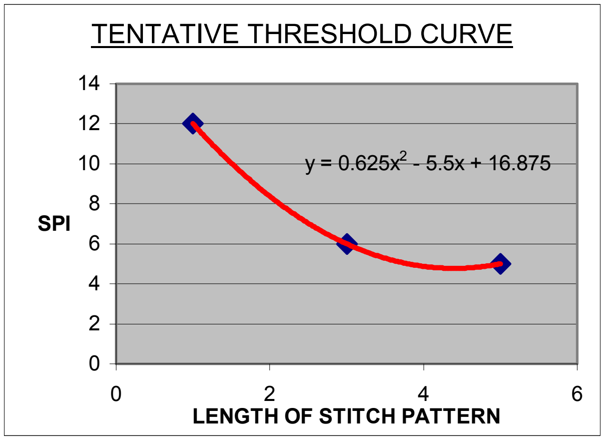


Graph 4: Effect of stitches per inch on stitch loading

In this next particular analysis, it is important to note that the stitching-webbing threshold is just underneath 6 SPI. The SPI settings below 6 have similar stitching strengths for the scenario tested. At 6 SPI the webbing fails before all the stitching fails. Therefore not all of the stitches are being optimized. One can conclude that in order to efficiently use all of the stitching, one should use a SPI setting of less than 6 in this case.

APPLICATION IN BREAKING STRENGTH EQUATION:

The adverse effect of stitches per inch takes place only after having reached the stitching-webbing threshold. This threshold is not the same for different variable settings of SPI and Length of Stitch Pattern, as they are interdependent. So this component of the breaking strength equation will be conditional upon the stitching-webbing threshold and the length-SPI interdependence:



Graph 5: Threshold curve

For Z = 0.625 Length^2 - 5.5 Length + 16.875 (Based on threshold curve)
Where Length is L, the length of the stitch pattern.

If SPI > Z, then:

SL2 = SL1 * (0.98 ^ (SPI – Z))
-not to exceed Breaking Strength of 6250 lbs (webbing)

If SPI < or = Z, then:

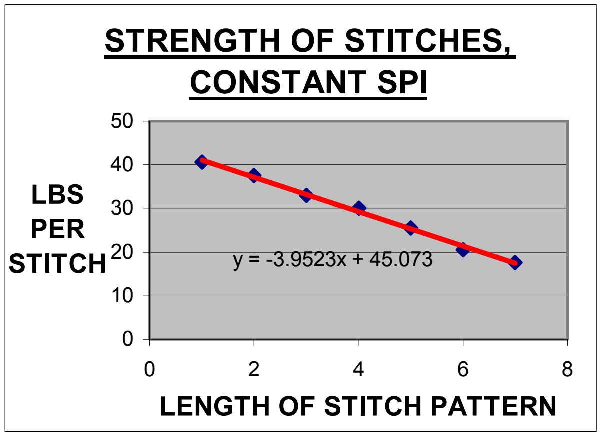
SL2 = SL1

Note that this is just an approximation and that for a true representation, especially for SPI and Length. Also, due to the presence of many loading discrepancies, such as different rates of loading and different webbings and thread (between steps), connections between SPI and Length would require extensive additional research.

3.4 Length of Stitch Pattern

There is an optimal length for every increment of SPI. In order to reach the stitching-webbing threshold, for a small length, a rather large SPI would be required for the necessary # of stitches. Similarly, for a larger length, a smaller SPI would be required for the necessary # of stitches. The confusion enters because these #'s of stitches are not the same.

Lengths tested ranged from 1 inch to 7 inches, incrementing by 1" for a total of 7 sample sizes. The patterns were created using 4-PT, 5 SPI, medium tension, and knot in middle.



Graph 6: Effect of longer junctions with constant SPI

By observing Graph 5, it is apparent that the force per stitch decreases 4 lbs for every inch lengthened. Also, the largest stitch strength comes from the 1" pattern.

The results of this graph are just enough to get an idea of the behavior of stitch loading at different lengths for the 5 SPI setting.

APPLICATION IN BREAKING STRENGTH EQUATION:

An increase in length, L, of the stitch pattern will increase the # of stitches in a linear fashion. The strength per stitch will decrease, but not linearly. This linearity will be used to determine number of stitches for equation purposes.

SL3 = SL2 (lbs) + (2.5 (in) – L (in)) * 4 (lbs / in)

Where C = designated force from concept
and L = length of pattern in inches

For 4-PT only:

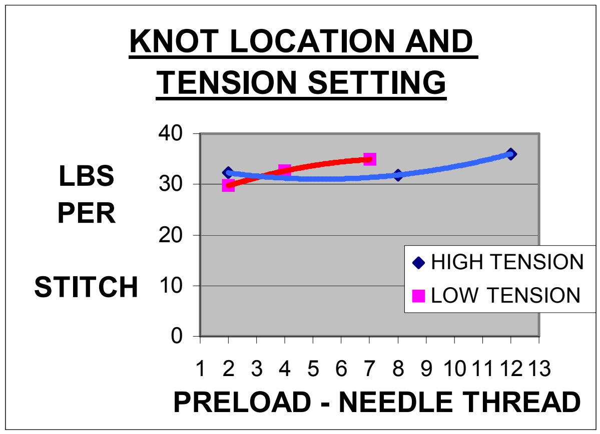
# of stitches = 9.45 * L * SPI (Breaking Strength = # * SL)

3.5 Preloaded Tension, Knot Location

The tension and knot location were lumped together because of their interrelation. The tension will dictate where the knot shall lie. For this particular sewing machine, the needle thread ranged in tension from 2 – 12 lbs, and the bobbin from 0.5 – 1 lb. Sewing machines can get away with this difference because the knot is formed below the two plies and has to be pulled up.

The tension mentioned above is preloaded tension. These are residual forces within the joint. Thus, one might draw from this that the higher the preloaded tension, the sooner the stitches may fail. The values calculated throughout this report are actually the applied load and not the total load.

The bobbin thread will distinguish between low and high tension, 0.5 and 1 lb, respectively. The needle thread will distinguish the knot location, below, middle, and above, 2, 6, and 12 lbs, respectively. The tests for this section use 5 SPI, 3" 4-PT, medium treatment webbing, and an average of 143 stitches. It was anticipated that the largest stitch loading would come from a sample with the knot location above. This was expected because the entire shear forces within the joint will be taken on the bobbin thread, which only has a preload of 0.5 to 1 lb.



Graph 7: Effect of knot location and tension setting

As seen in Graph 6, the knot location in the above position yields higher stitch loadings for both high and low tension. Though not aesthetically pleasant, the knot above location is 12 % stronger than the middle or below location for high tension and 6 % greater than the middle or below location for low tension. During testing, it was observed that the majority of threads breaking were on the needle side. This is most likely due to the difference in preloaded tension.

APPLICATION IN BREAKING STRENGTH EQUATION:

The effect of tension and knot location on the breaking strength equation will be divided into 2 categories: Low and High Tension.

For Low Tension:

SL4 = SL3 *	1.07	for above
	1.00	for middle
	.911	for below

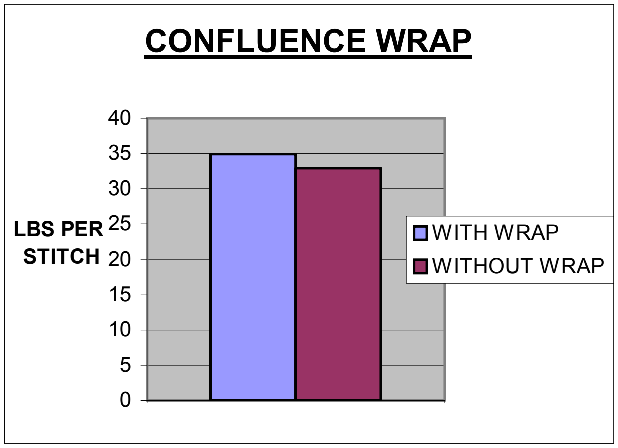
For High Tension:

SL4 = SL3 *	1.13	for above
	1.00	for middle
	1.01	for below

3.6 Inclusion of Confluence Wrap

During the failure of an overlap junction, much deformation occurs in the webbing. The inclusion of a confluence wrap restricts the mobility of the webbing. The confluence wrap also prevents the pull through effect of the stitches. With this increased integrity, it is expected that the breaking strength shall be larger than without the confluence wrap.

The construction of these samples use a 3” 4-PT, with 5 SPI, medium tension and middle knot location. The confluence wrap is 3” wide TY-12 with one overlap.



Graph 8: Effect of confluence wrap

The inclusion of a confluence wrap gives an added benefit of 6 % stitch strength. The failure mechanism was by stitching, but was extremely slow and could be easily observed.

APPLICATION IN BREAKING STRENGTH EQUATION:

The stitch loading increases 6 % with the inclusion of a confluence wrap so:

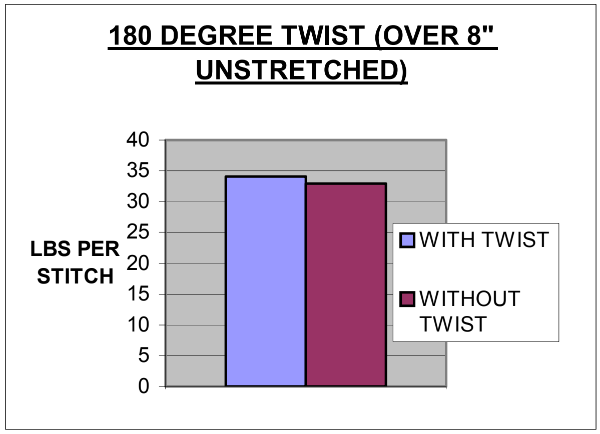
SL5 = 1.06 SL4

Or SL5 = SL4 without confluence wrap

3.7 Twists

The twist that is going to be analyzed is the 180 degree twist. By adding this new element, the webbing will be uniquely loaded and will create different torsional forces within the junction. It would be expected that these forces would combine with the tension and shear forces already seen.

This test was set up with a 180 degree twist over 8 inches as a 3” 4-PT, with 5 SPI and heavily treated webbing.



Graph 9: Effect of induced twist

This graph shows that the twisted samples actually have a larger stitch load than without the twist. There is a gain of 3 % stitch strength when adding a 180 degree twist. Without a sufficient number of sample tests performed for this step, a proper error analysis would not prove meaningful. However, proceeding with this information, we can further modify the Stitch Load function.

APPLICATION IN BREAKING STRENGTH EQUATION:

The deformation aspects of the 180 degree twists would be impeded by the confluence wrap. Since the confluence wrap posts a gain of 6 % stitch load capability and the 180 degree twist gains only 3 %, given an option, one should choose confluence wrap.

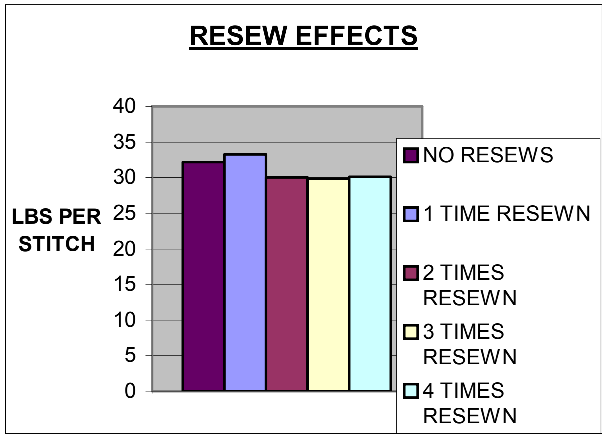
SL6 = 1.03 SL4 (can not be combined with confluence wrap for added benefit)

Or SL6 = SL5 for samples without the 180 degree twist

3.8 Resew Effects

Each time a junction is resewn, two types of damages occur. One damage is that from the needle having penetrated the weave of the webbing, which distorts the uniformity and makes small cuts within the strands. The other damage occurs when the job performer removes the previous stitches. Many scrapes and cuts come from the scissors or knifes that are required to cut the threads. This is an important issue because parachute riggers in the field may rework a used harness and may not get it right the first time.

This step will include the observation of samples resewn 1 through 4 times. The samples were constructed as 3” 4-PT, 5 SPI, medium treatment, medium tension and knot located in the middle.



Graph 10: Resew effects

The bar chart shows little deviation between a 0 times resewn and that which has been once resewn. There is almost no discernable difference between 2 – 4 resews. Strength integrity of the joint had been maintained. Significant visual damage was present from both removal of previous threads and repeated penetration from the needle. According the graph there is an 8 % drop in stitch loading performance after the second time resewing.

APPLICATION IN BREAKING STRENGTH EQUATION:

For 0 or 1 resews:

SL7 = SL6

For 2 – 4 resews:

SL7 = 0.91 * SL6

4.0 CONCLUSION

Each step in the analysis of the simple overlap joint has contributed to a model for predicting breaking strength. They are combined her to form the breaking strength equation. Optimal settings within these steps were also identified.

4.1 The Breaking Strength Equation:

SL1	SL2	SL3	SL4	SL5
SL1 = C	IF SPI > Z = .625* L^2 - 5.5 * L + 16.875	SL3 = SL2 + (2.5 - L) * 4	IF LOW TENSION (BELOW, MIDDLE, ABOVE)	WITH CONFLUENCE WRAP
	THEN SL2 = C * (0.98 ^ (SPI - Z))		THEN SL4 = (0.911, 1.00, 1.07) * SL3, RESPECTIVELY	THEN SL5 = 1.06 * SL4
	IF SPI < OR = Z		IF HIGH TENSION (B, M, A)	WITHOUT
	THEN SL2 = SL1		THEN SL4 = (1.01, 1.00, 1.13) * SL3	THEN SL5 = SL4

SL6	SL7	SL8
WITH 180 TWIST THEN SL6 = 1.03 * SL4 WITHOUT THEN SL6 = SL5	FOR 0 OR 1 RESEWS THEN SL7 = SL6 FOR 2 THROUGH 4 THEN SL7 = 0.91 * SL6	FOR T = # LBS TO FOLD IN WEBBING IN HALF SL8 =(1- (6-T) *.15)* SL7

Figure 1: Breaking strength equation

Take the resultant stitch load SL8 should then be multiplied by the # of stitches. The # of stitches for the 4-PT only is **# ST = 9.45 * L * SPI.**

4.2 The Optimal Variable Settings:

1>	**Treatment**	**Heaviest 6 lbs**
2>	**Concept Selection**	**4-PT**
3>	**Stitches Per Inch**	**4 – 5 SPI**
4>	**Length of Stitch Pattern**	**5 inches**
5>	**Tension, Knot Location**	**High, Above**
6>	**Confluence Wrap**	**With**
7>	**Twist**	**Without**
8>	**Resews**	**0 – 1**

Resultant joint strength = 7414 lbs**

**** This is an analysis of stitching strength, the true joint strength would be the webbing limitation strength with junction ~ 6250 lbs.**

There are possible discrepancies due to dissimilar loading rates and loading times. However, for each step, there was only one observation in mind. To establish near true relations, and not approximate, significant testing and monitoring would be required. This pertains to the length of stitch pattern and stitches per inch mostly.

Future applications for this work could be directed to a number of places. There is a need for better observation of the interrelation between length of stitch pattern and stitches per inch. Especially interesting would be the small length patterns where the stitching load reached 41 lbs. There would also be use for a retrace of the twisting effects. If the twist does, in fact, prescribe a greater breaking strength, pursue different angles of twists.

The steps that have been followed have outlined the fundamentals in which to understand the failure mechanisms of the simple overlap junction. As a result of these observations and calculations, there are several characteristics which can not be analyzed through the methods outlined in the steps.

One of these, and one of the more interesting aspects are that many stitches will pop while the force is still climbing. In essence there is a reduction in total material binding the joint. This can be compared to engineering stress and true stress. Engineering stress would be the breaking strength over the total number of stitches and true stress would be the breaking strength over the number of stitches left at the time of rupture. True stress is much higher.

Another important aspect would be the difference in the magnitude of localized strain (The stretch of a specified distance divided by that distance). Since the actual joint resists stretching (much, much less than the 30% (approximate) elongation of the webbing) the localized strain is very small. The resulting event is a near zero localized strain at the edge on the joint positioned right next to a strain of 0.3. This dramatic increase in rate of strain over a small distance creates a higher load on the end stitches than the stitches just an inch or so from the edge. This causes the edge stitches to pop first. This is true for both ends. In effect, the stitches pop from the edges inward.

Using this new knowledge, it may be possible to design a new sewing technique to reduce the rate of strain increase over an incremental distance.

5.0 REFERENCES

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