Evaluation of Slip in Climbing Anchors Rigged with a Girth Hitch at the Masterpoint

Derek DeBruin & John Sohl
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Abstract

This study explored characteristics of the girth hitch as a tool for rigging the masterpoint of recreational climbing anchors. This technique has spread throughout the United States in recent years, but lacks large amounts of relevant publicly accessible data. Drop testing with dynamic rope was used to determine potential slip of the girth hitch in the event of failure of an anchor leg, with findings generally consistent with the limited data available elsewhere. Tests revealed no statistically significant difference in amount of slip between new and used HMPE slings. Wet slings exhibited statistically significant greater slip than dry slings. Tests suggest slip can be minimized across rigging materials and conditions provided that the girth hitch is strongly tightened prior to use.

Introduction

The last few years have seen the proliferation of the girth hitch (GH) as an anchor rigging tool for recreational climbing. The technique is straightforward: clip (or thread) each component of an anchor, tensioning the material to a common nadir, and then join the material at the nadir to a carabiner or ring using a GH. Figure 1 illustrates completed construction of this rigging. The technique appears to have originated in Italy, where climbing in the Dolomites often features anchor stances with multiple fixed components of uncertain history and reliability. Therefore, the simplest solution is to utilize them all, which is facilitated by a GH.

Since then, the technique has spread rapidly due at least in part to social media (Bradford 2021), a video series from Ortovox Sportartikel GmbH (Semmel, Würtl, Hornsteiner 2019), an explainer from John Godino of Alpine Savvy (2019) and endorsement from national alpine clubs, such as the Deutscher Alpenverein (DAV) (Semmel 2019b, Semmel 2020). While the technique does not supplant existing fixed-point belay and fixed-leg load distributing masterpoint riggings (such as the cordelette anchor common in the United States), the GH masterpoint is a useful tool in at least a few applications. The GH is materially efficient. This is particularly useful when rigging material is limited or anchor components are plentiful. In the former case, this could be the result of only a few slings remaining on the rack for anchor construction, such that there simply may not be enough material to both link components and tie a masterpoint knot. In the latter case, the GH eliminates the need to tie a bulky knot when joining multiple anchor components. The lack of a knot is also advantageous in ice/mixed climbing environments. Knot construction requires more dexterity than employing the GH, which is hindered by the need for gloves in cold weather climbing environments. Consequently, the GH speeds anchor rigging and deconstruction in this context. Finally, unlike a knotted masterpoint, the masterpoint is readily adjusted after construction with a GH.

Figure 1: The GH is affixed to a central locking carabiner to create a masterpoint. Each leg is attached to a protection point.

Rigging with a GH masterpoint does have some disadvantages. The first is relatively trivial: the technique requires a dedicated masterpoint carabiner or ring. Individual climbing parties can readily (quite literally) weigh their perceived value of the technique relative to this requirement. More importantly, the GH does not necessarily conform to many climbers' classic notion of redundancy. That is, if a leg of the rigging were to be cut by rock or ice fall, or to come unclipped from a carabiner, the remaining rigging might slip under load. Slip is defined here as rigging material sliding through the GH when under load. Such slip could cause the masterpoint carabiner/ring to slide out from the rigging and cause catastrophic failure.

There is limited publicly available testing data regarding the potential for slip. The GH rigging technique is often referenced as the "South Tyrolean" method in Europe (Semmel, Würtl, Hornsteiner 2019), highlighting its Italian provenance. However, the Club Alpino Italiano (CAI) Centro Studi Materiali e Techniche, home to an array of publicly available data produced from well-conducted testing, has nothing readily available for this technique at present (2021). The authors have found one video of a single drop test released by an Italian mountain guide, presumably from the CAI Torre Padova testing facility (Andriano 2021). The DAV does have a publicly available article that references drop testing, but offers limited detail about these results (Steiner 2015). Similarly, a DAV accident analysis (Semmel 2019a) features a GH masterpoint as an ancillary feature of a failed anchor rigging in the event of a factor-2 fall. The relevant detail of this accident for the present study is simply that the GH masterpoint was not the failure mechanism in a real-world high force anchor failure. Ryan Jenks produced a video (2020) with slow pull testing of the GH demonstrating catastrophic slip; however, such loading is not realistic for a recreational climbing scenario. Conversely, Walter Siebert also conducted slow pull testing of the GH, but with high strength results and little slip (2019). Florian Hellberg of Edelrid GmbH found similar results of high absolute strengths but with slip occurring above 6kN loads in 8mm high-modulus polyethylene (HMPE; trade names Dyneema, Dynex, Spectra) (2020). Yann Camus commissioned drop tests of the GH, but these results were likewise problematic (2021). While Camus' tests included drop tests, which demonstrated catastrophic slip, the tests were direct drops that did not incorporate dynamic rope. Consequently, the applicability of the tests is dubious.

The above explorations of the GH represent a very small sample size. Given the relative paucity of available literature, these tests were intended to explore multiple variables in using the GH as an anchor rigging tool. The principal investigation regarded the amount of slip in the GH when rigging an anchor with an HMPE sling. Given recommendations of the GH as an anchor rigging technique from various European climbing associations, the hypothesis was that slip would be minimal; lacking significant experimental data, "minimal" was defined to be "a few centimeters" as noted by the DAV (Steiner 2015). Secondary investigations included explorations of rigging material age, type of material, and wet vs. dry material.

Methods

The authors were grateful for the opportunity to have conducted tests at the Petzl Technical Institute in Salt Lake City, Utah, using the drop tower in the indoor portion of the facility. For this series of tests, a single anchor point connected to a high-speed load cell was used for drop tests with an 80kg rigid mass. (Readers interested in extrapolating results to soft/human masses should see Holden, May, Farnham 2009.) Fresh sections of used 9.5mm Sterling Helix and 9.8mm Sterling Velocity dynamic ropes from 2016 and 2017 respectively were used for each test, except those which did not include rope in the test. Used ropes were selected to better replicate realistic climbing conditions. The majority of tests were rigged with a carabiner clipped to the load cell, which was in turn clipped to a sling. The sling was then girth hitched to another carabiner, to serve as the masterpoint. The other end of the sling was left hanging free, to simulate a failed anchor leg. Affixed to the GH carabiner was a rope tied with a Munter (Italian) hitch secured with an overhand slip hitch. At the other end of the rope was a figure 8 knot affixed to the test mass; there was approximately 1m of rope between the Munter hitch and figure 8. All knots and hitches were tied by the same individual in the same manner, well dressed, and "hand tight" unless noted otherwise. The test mass was raised 1m above the GH masterpoint, a conservative estimate of when a lead climber might seek a first piece of protection on the subsequent pitch. The mass was dropped via quick-release shackle to create a factor-2 fall (FF2). See Figure 2 for a photo diagram of the set up.

Test Case 1: Direct Drop

The first two drop tests were conducted with the mass affixed directly to the masterpoint carabiner attached to a 120cm x 10mm HMPE sling via the GH; that is, there was no rope in the system. These tests were intended to replicate the results of testing done by Camus (2021).

Test Case 2: New Slings
The second test series featured new 10mm HMPE slings in both 120cm and 60cm lengths, with the test mass affixed to the GH masterpoint via the rope for FF2 drop tests as described above. This was intended to better replicate peak forces seen in realistic recreational climbing systems compared to direct drop.

Test Case 3: Used Slings
The third test series featured used 10mm HMPE slings in both 120cm and 60cm lengths, with the test mass affixed to the GH masterpoint via the rope. Slings were of varying age and wear, within 5 years of the date of manufacture, and generally in acceptable condition such that many climbers would continue to use them. These tests were done to contrast new slings, which might exhibit greater slip given the material properties of HMPE.

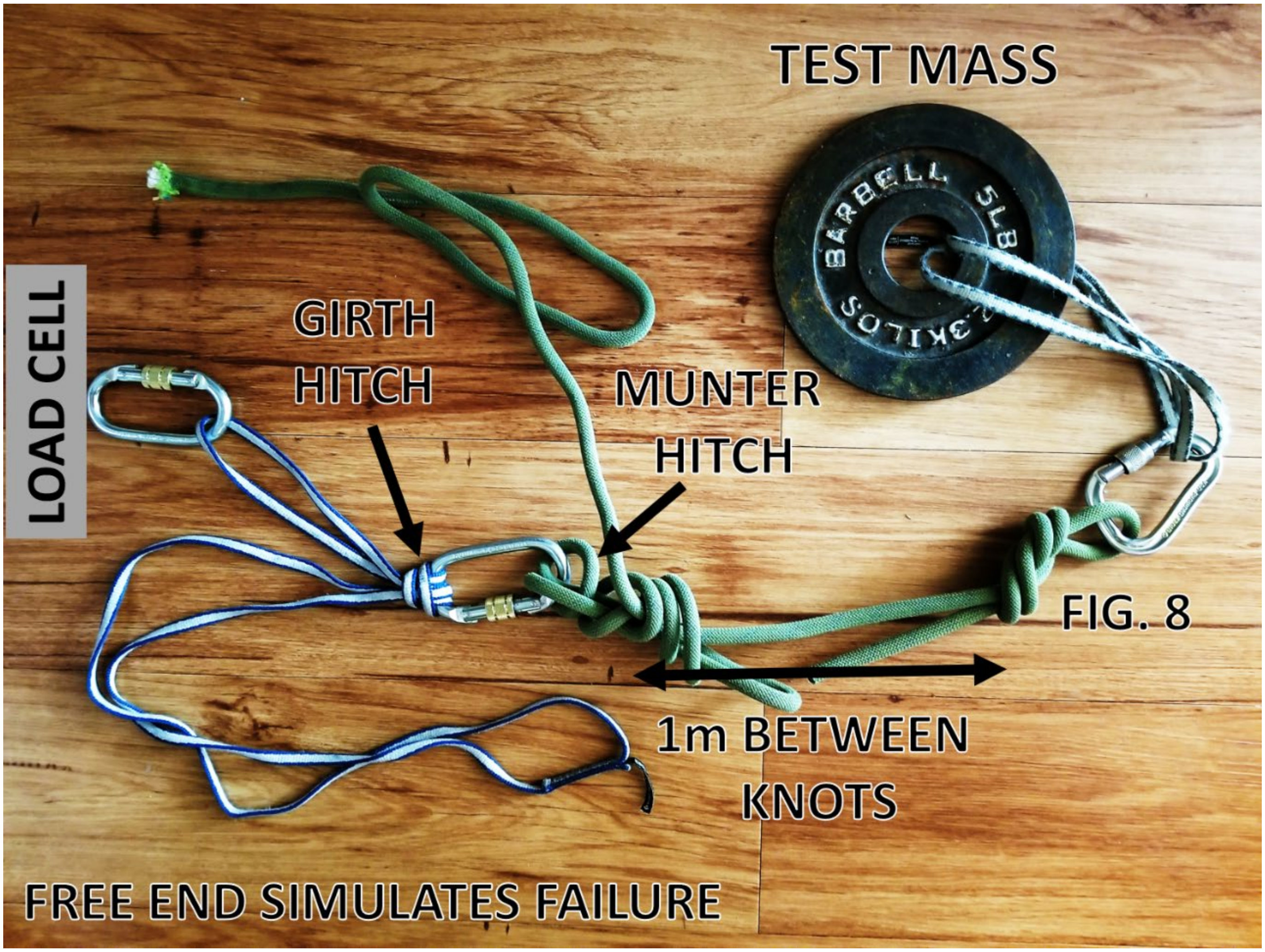

Figure 2: Diagram of the test set up (not to scale).

Test Case 4: Wet Slings
The fourth test series featured used 60cm x 10mm HMPE slings that had been immersed in room temperature tap water immediately prior to testing, with the test mass affixed to the GH masterpoint via the rope. Slings were of varying age and wear as described above. These tests were intended to address wet slings, which might occur during ice climbing or simply being caught out in the rain.

Additional Tests
Additional tests were done with a variety of 1 or 2 sample drops, including slings that were frozen, slings adjusted to be loose or extra tight, 14mm HMPE slings, 18mm nylon slings, 6mm nylon cord, and a slow pull test of a new 60cm x 10mm HMPE sling. These were intended to be illustrative but not statistically significant.

Analysis
As these tests were generally exploratory, sample sizes were largely determined by available resources (i.e. no power analyses were conducted with regard to sample size). Both histogram analysis (with bins determined by the Freedman-Diaconis rule) and χ^2 testing revealed non-normality in the sample distributions for new, used, and wet slings. Given the non-Gaussian distribution and small dataset, the Mann-Whitney *U* was used for nonparametric testing between these three classes of slings. Statistical significance was set at $p = 0.10$. This more permissive value was selected given the limited sample sizes.

Results

Test Case 1: Direct Drop
Two drop tests were conducted with 120cm x 10mm HMPE slings, one in new condition and one used. The test mass was affixed directly to the masterpoint carabiner with no rope in the system. Both drops produced peak forces in excess of 9kN and caused large amounts of slip and/or damage to the sling, consistent with the results of the 2021 Camus tests. The new sling was quite abraded, glazed, and ruptured, with 38cm of slip at the GH (see Figure 3). The used sling broke at the GH. Subsequent tests included climbing rope to better replicate realistic climbing forces.

Test Case 2: New Slings
Among new 10mm HMPE slings subject to FF2 testing rigged with dynamic rope, the mean slip was 8.0cm with a standard deviation of 6.0cm and range of 2.5 to 18.5cm across 8 tests. Tests with the dynamic rope typically featured little damage; see Figure 4 for examples of the most significant damage. Peak force on the anchor was quite consistently near 7kN (see Figure 5).

Figure 3: Sling damage via direct drop (test case 1).

Figure 4: Sling damage from FF2 drops with dynamic rope (test case 2): abrasion (yellow), fusing and stretching (blue).

Test Case 3: Used Slings
Used 10mm HMPE slings subjected to the same FF2 tests described above ($n = 7$) resulted in $\bar{x} = 4.5$cm ($s = 1.6$cm) and range of 2.5 to 6.5cm. Nonparametric testing indicated the difference in slip between new and used slings was not statistically significant ($U = 20.5$ $n_{new} = 8$, $n_{used} = 7$).

Test Case 4: Wet Slings
Wet 10mm HMPE slings (n = 5) subjected to FF2 falls with rope in the rigging resulted in a mean of 15.0cm of slip (s = 7.7cm, range = 2.5 - 21.5cm). Comparison of slip among all dry HHMPE slings ($\bar{x}$ = 6.4cm, s = 4.8cm, range = 2.5 – 18.5cm) to slip of wet slings yielded significantly greater slip in wet slings (mean difference 8.8cm) compared to dry slings (U = 16.5 n_{dry} = 15, n_{wet} = 5). See Table 1 for a summary of test cases 2, 3, and 4.

Table 1: Summary of test cases 2, 3, and 4, new, used, and wet conditions, respectively.

Test Condition (*n*)	**Slip (cm)**				**Force$_{max}$ (kN)**			
	Mean	Median	Std. Dev.	Range	Mean	Median	Std. Dev.	Range
New HMPE (*n*=8)	8.0	5.0	6.1	2.5 – 18.5	7.0	7.1	0.3	6.5-7.5
Used HMPE (*n*=7)	4.5	5.0	1.6	2.5 – 6.5	7.1	7.1	0.3	6.8-7.5
Wet HMPE (*n*=5)	15.0	17.0	7.7	2.5 – 21.5	7.2	7.2	0.3	6.8-7.7

Test Case 5: 14mm HMPE Slings
Two tests were conducted with 14mm HMPE slings. Resulting slip values were 2.5 and 5.0cm. (No statistical analysis was conducted due to the limited sample size).

Test Case 6: Frozen Slings
Two slings were drenched in water and placed in a below 0^{o}C environment for 5 hours to cause the slings to become frozen and coated with ice in places. Icy portions of the sling were excluded from the GH but otherwise rigged the same as other tests. Drop tests recorded slip values of 5.0 and 11.5cm. Most tests (excluding test case 1 with no rope) had remarkably uniform peak impact forces in the vicinity of 7kN. The one exception to this was a peak force of 9.3kN with the second frozen sling. The high-impact GH was as tight as we could get it by hand. Either this is an outlier, or it is possible that frozen slings might be prone to producing higher impacts. At this point we do not have enough data to determine the cause of the high impact force we measured.

Test Case 7: 18mm Nylon Sling
A single test was completed for an 18mm Nylon sling with a resulting slip of 5.0cm and peak force of 7.1kN.

Test Case 8: 6mm Nylon Cord
6mm nylon cord was used for a single test that resulted in slip of 6.0cm and peak force of 6.9kN.

Test Case 9: Loose vs. Tight
Given the relatively large variance in slip across new, used, dry, and wet tests conditions ($\bar{x}$ = 8.6cm, s = 6.7cm, range = 2.5 – 21.5cm), a single test was conducted for each of a loose and tight GH. In the loose test condition, a used 10mm x 60cm HMPE sling was utilized to construct a GH masterpoint with the hitch as loose as possible while still retaining its shape and function. This test resulted in 9.5cm of slip. A second test was conducted with a wet, used 10mm x 60cm HMPE sling to construct a GH masterpoint. The GH was tightened by hand as much as possible. The resulting drop test saw a slip of 2.5cm.

Test Case 10: Slow Pull
A single slow pull test was conducted using a new 10mm x 60cm HMPE sling with a GH tightened by hand as much as possible. Pulling force increased steadily to a peak of 8kN before slip was induced, then dropped off to a steady force of 5.5kN as the sling was ultimately pulled completely through the GH and off the pin.

Overall Impact Force Analysis
Three general configurations were tested: 120cm sling only, 120cm sling with 1m of dynamic rope, and 60cm sling with 1m of dynamic rope. The first two trial runs were intended to replicate measurements made by others as discussed above. As it is unlikely that someone would take a FF2 fall exclusively on the anchor slings, those two trials are not included in any of the analysis below. The remaining 26 trials used heavily used, retired, ropes as described in the Experimental Set-Up section above. There was one outlier that is included in the graphs below and in all analyses unless noted. A second outlier was in behavior, not numbers. In that trial the retired rope failed at the Munter hitch. Since the peak impact force prior to failure, the amount of slippage in the sling, and the amount of sling damage were all

consistent with the other trials, that value is also included unless noted. Finally, as individual test cases are reported in detail above, this section looks at the values in aggregate.

There was no observed correlation between the peak impact force and any of the following: which of the two ropes was used, sling length between the GH and the anchor point, or amount of sling that slipped through the GH. Including the outliers, the peak impact force for all 26 trials with the rope was 7.2±0.1kN. Removing the one high impact outlier (9.3kN) results in 7.11±0.05kN average force on the anchor. This can be seen in figures 5 and 6. Clearly the impact energy was being dissipated by the ropes and not the slings.

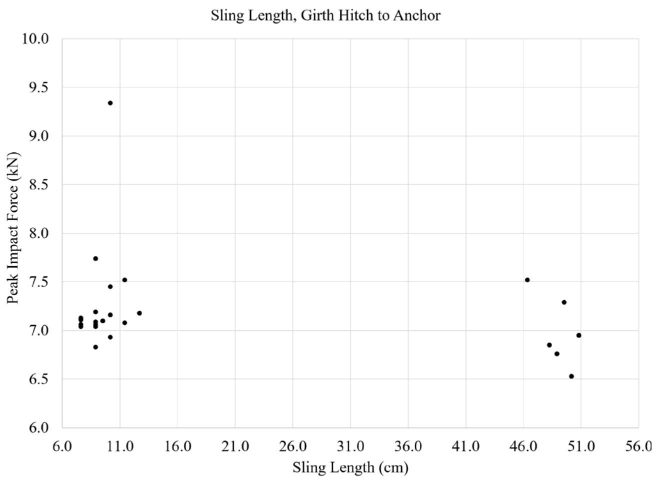

Figure 5: Peak impact force is independent of sling length between the GH and the anchor.

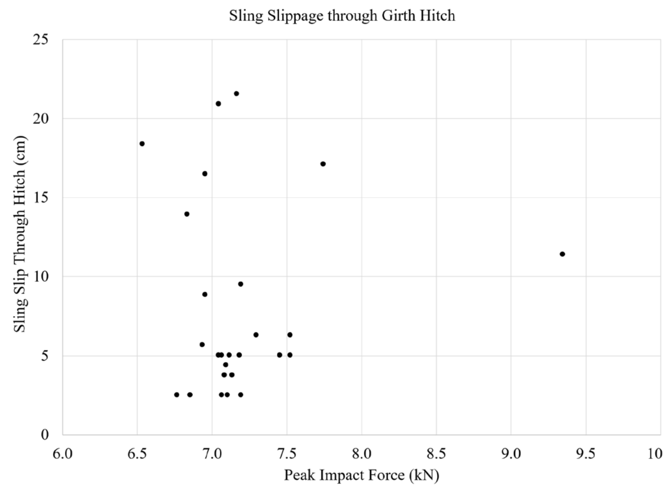

Figure 6: The amount of sling that passes through the GH does not depend on the peak impact force.

Likewise, there was no observed correlation between how much sling was between the GH and the anchor with how much slipped through the hitch (see Figure 7).

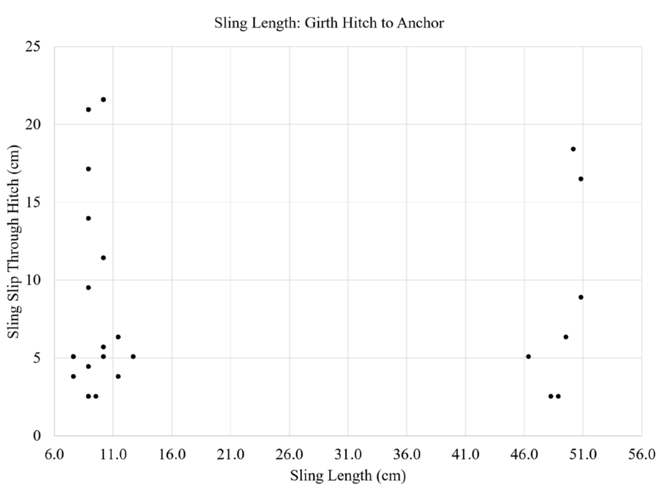

Figure 7: The amount of sling between the GH and the anchor does not determine how much will slip through the hitch.

The load cell recorded data at 5,000Hz which gave excellent temporal resolution for the impacts. The dynamic impact forces all showed similar patterns. For the larger slips it is clear that the GH grabbed the load then slipped, tightened, and grabbed again. Slow motion videos were taken of each drop at a frame rate of 240fps (4 milliseconds between frames). On the larger slips one can visually see the sling grab, slip through the hitch, then grab again. The timing matches the results from the load cell perfectly. While the small slips are not visible in the video capture, they are clearly present in the force data. In all cases it follows the same pattern: grab, slip, tighten, grab and hold. Small slips grabbed quickly but large slips usually happened in the middle of the peak force. The slipping is quite dramatic as the force typically drops to 2kN-3kN then holds at 7kN.

The figures 8 – 11 are selected as being representative of the 26 trials observed. In all cases the choice of time-zero is arbitrary. In some cases, small forces are registered before the fall is initially captured; these are caused by the drop mass bumping the carabiner with the GH as the load passed by. All these force plots have been shifted up slightly to keep the data at or above zero for plotting. In fact, sometimes the load cell went negative as the support chains bounced during low load conditions. The offsets are only for the plotting, all reported data are the actual forces.

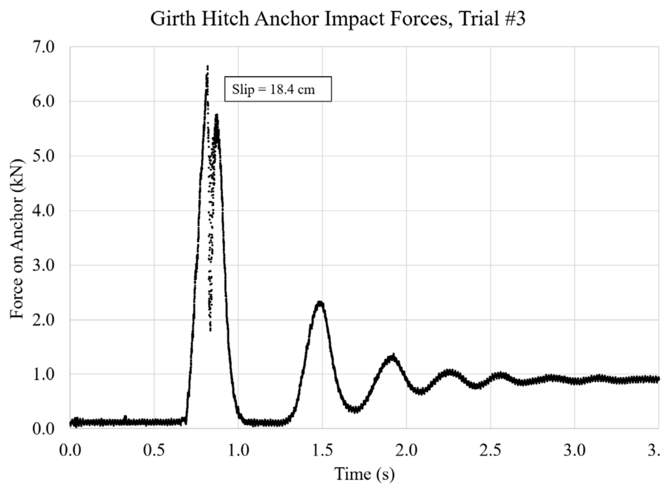

Figure 8: Large slips occur in the middle of the peak impact. This trial was part of "test case 2: new slings."

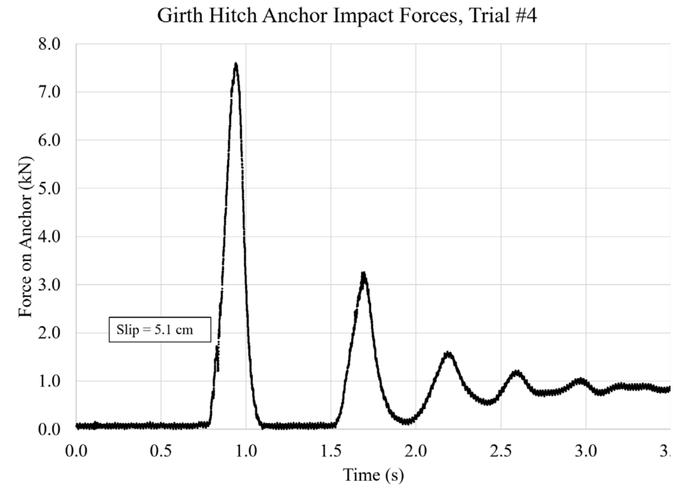

Figure 9: Small slips grab early and quickly. These trials were part of "test case 3: used slings."

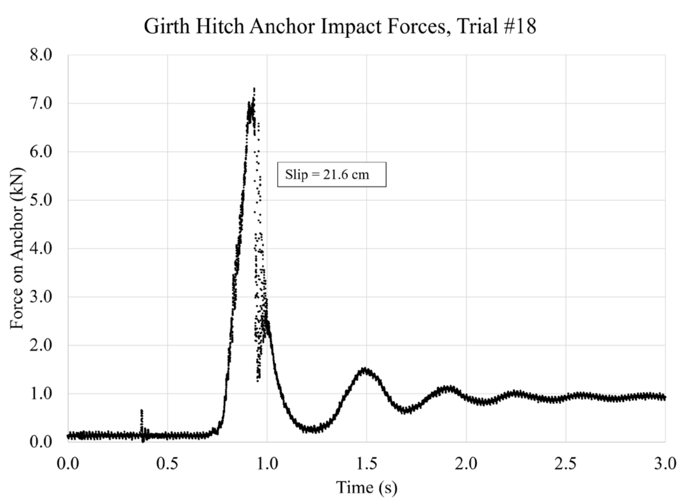

Figure 10: An example of "test case 4: wet slings." Similar to dry slings, larger slips happen later in the impact than small slips.

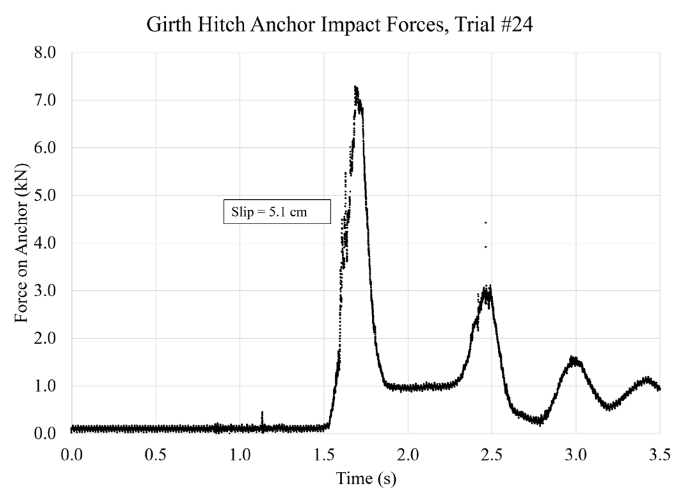

Figure 11: The familiar pattern of small slips generally happening early during the impact. Part of "test case 6: frozen slings."

Discussion and Recommendations

These tests indicated that the GH masterpoint can exhibit minimal slip in the event of failure of one leg of the anchor, congruent with the previously reported results mentioned by Steiner (2015) and shown by Andriano (2021). However, tests also revealed significant variability among slip values, ranging from 2.5 to 21.5cm when dynamic rope was present in the system. No statistically significant difference was found between new and used slings with respect to amount of slip in the GH, a reassuring finding as one might reasonably expect new HMPE to slip more than used HMPE. Conversely, a statistically significant difference was revealed in slip amount between dry and wet slings. This raises concerns for the use of the GH masterpoint for ice climbing, or any other application where slings are more likely to be wet. The limited results with icy slings were inconsistent. The single tests of 6mm nylon cord and 18mm nylon sling exhibited slip values below the mean; the authors do not suspect a significant difference compared to HMPE when using these materials, although more testing is warranted.

As testing progressed, the authors explored other explanations for the range of slip amounts. This led to the single test of a very loose GH masterpoint, a condition which led to slip similar to the mean slip amount (9.0cm vs $\bar{x}$ = 8.6cm) and did not lead to a large amount of relative slip as was suspected. This was followed by a test in a wet sling with a tight GH masterpoint, snugged by hand as much as possible. This effectively eliminated slip in the wet sling test condition (2.5cm), suggesting that a tight GH is advisable when using this anchor rigging. The single slow pull test was similarly conducted with a snug hitch that did not result in slip until 8kN, a higher value than reported elsewhere (Jenks 2020, Camus 2021, Hellberg 2020), which also supports use of a tight hitch. Consequently, the authors recommend that the GH is cinched tightly prior to use. Hand tightening followed by weighting the hitch with bodyweight from the climber's personal attachment to the anchor should be sufficient force to replicate the test condition and discourage large amounts of slip. There was no correlation between peak force ($\bar{x}$ = 7.1kN, s = 0.3kN) on the anchor and amount of slip in the GH across tests (R^2 = 0.006); therefore, securing the GH as suggested should come with no concomitant drawback in increased anchor forces.

Damage varied among the slings tested, with little consistency between slip amount and damage to the sling upon inspection. While some damage rendered slings unusable for subsequent climbing, generally damage was minimal, such that a climber might elect to place the sling back into service if they were unaware of the loads it had already experienced.

Ultimately, prior to employing the GH masterpoint, the climbing party must determine an acceptable level of slip for their risk tolerance. Slip of only a few centimeters seems a reasonable proposition with three cases to consider for potential failures of an anchor component:

> 1) The anchor component pulls from the rock. In this case, even complete slip to the end of the sling will be arrested by the carabiner/protection interfering with the GH.
>
> 2) The carabiner joining the sling to the anchor component unclips. In the case with two anchor components, the sling could slip completely through the GH; therefore, slip must be considered. With three or more components, the amount of slip required for complete failure is so large as to be unrealistic, or slip ceases when the free bight contacts the GH (depending on the specifics of the rigging).
>
> 3) The sling is cut by rock/ice fall or another sharp object (perhaps the falling leader's crampons). In this case, minimizing potential slip is crucial. While catastrophic anchor failure due to slip may be possible with very small slip values (ex. 2.5cm with a tight GH), whatever mechanism causes the sling to cut is likely to have cut all legs of the anchor if it strikes within 2.5cm of the masterpoint. Consequently, catastrophic anchor failure would occur regardless of slip.

With these factors in mind, the authors recommend the GH as an effective tool for masterpoint construction for a variety of applications, whether ice climbing to avoid the dexterity concerns arising from tying knots with gloves, limited anchor rigging material that might make it impossible to tie a knot, or large numbers of anchor components that might make a knot impractical. A closed ring is preferable to a carabiner when rigging the masterpoint in order to better distribute forces when clipping carabiners to the masterpoint. However, an HMS carabiner is acceptable with no loss in strength due to the GH (Feryok 2021); off-axis loading concerns still apply as with any chaining of carabiners. Regardless of material choice (HMPE, nylon, cord), or material condition (wet, dry), the GH should be cinched tightly by hand and tensioned with bodyweight prior to use.

Conclusion

The GH is a viable solution for the masterpoint for anchor rigging, provided that 1) approximately 5cm of slip is within the climbing party's risk tolerance and 2) the GH is cinched snugly by hand and body weight prior to use. This applies to a variety of rigging materials, such as HMPE or nylon slings or cord, as well as material conditions, whether new or used, dry or wet.

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