

Tests on Roped Climbing Techniques

WILLIAM E. SIRI

THE INSTANT a rope is uncoiled, mountaineering becomes, in part, an engineering project. Yet so far as the engineering element is concerned, it is often more an art than a science—a choice of techniques by intuition rather than by objective investigation. Perhaps the single most important innovation in climbing technique developed from a sound rational basis is the now generally practiced “dynamic belay,” so ably studied by Leonard and Wexler¹ and by Wexler.² While sound in principle, the dynamic belay can still be misused in practice. There still remains not only selection of the best belay methods, but also a need for better understanding of the mechanics generally involved in climbing: the maximum forces a belayer can sustain, frictional forces on the rope through carabiners and over rock, forces on rappels, and the strength of pitons.

In an effort to answer some of these questions, the author undertook, with the cooperation of the Sierra Club, a program of tests on the mechanics of various aspects of roped climbing. The tests were also aided by the use of a high-capacity dynamometer lent by W. C. Dillon and Company, Los Angeles, and by the assistance of Mr. Clarence Rose of the Rose Manufacturing Company, Denver, Colorado. Space does not permit a detailed account of the tests nor a justification of the conclusions, but a few of the observations are presented here for consideration by

¹ Leonard, R. M., and Wexler, A., “Belaying the Leader,” *Sierra Club Bull.*, 31 (1946), 68.

² Wexler, A., “The Theory of Belaying,” *A. A. J.*, VII (1950), 379.

TESTS ON ROPED CLIMBING TECHNIQUES

safety and climbing committees. A full description of the tests is now in press and will appear in the *Sierra Club Bulletin*.

Belay stances fall naturally into four main categories: the sitting-hip; standing-hip; standing-seat; and the shoulder belay. Each position and its many minor variations was tested at climbing sites with scores of belayers and always to the point where the belay yielded. The maximum tension that could be held was limited by failure (complete loss of rope control), collapse (partial loss of control), rope slippage, or pain.

Sitting belays, with the climbing rope passing around the waist, were by far the most secure positions and rarely yielded in failure. The average yield tension was 340 pounds, but the yield point ranged from 200 to 550 pounds, with the highest tension held only if the legs were straight and firmly braced. A sitting belay from a ledge without foot support is highly effective provided the rope runs between the thighs and immediately over the rock edge. The importance of an anchor when belaying the leader is evident, in view of the average yield tension of 340 pounds—only twice a man's weight.

The standing-hip belay yielded usually in complete failure at an average tension of about 225 pounds. In our opinion it is a belay stance that should be used only when the sitting belay is impossible.

The standing-seat (slingshot) belay, in which the rope passes around the buttocks and upward through a carabiner, is often essential in climbs where pitons are used, but it is the weakest belay position tested. Belayers were partially dislodged by tensions ranging from only 50 to about 150 pounds and consequently could arrest falls only if anchored with a taut rope. This position is helped considerably, however, by an anchor and by carabiner and rock friction which absorb much of the energy in arresting a fall.

The standing-shoulder belay held tension varying from less than 200 pounds to slightly more than 300 pounds, but every belay tested yielded in failure with complete loss of rope control and the anchor was of no direct aid beyond safeguarding the belayer. It is by all odds the least secure of belays and its use cannot be recommended under any circumstances.

Carabiner and rock friction are important aids to the belayer

TESTS ON ROPED CLIMBING TECHNIQUES

in arresting a fall, for they absorb a large fraction of the energy and greatly reduce the restraining tension that is needed. For a rope making an angle of 45° through a carabiner, the tension is reduced by $\frac{1}{4}$; at 90° it is reduced by $\frac{1}{2}$; and at 180° the reduction is about $\frac{2}{3}$. Rock friction is more variable, but, in general, rope tension is reduced by $\frac{1}{4}$ to $\frac{1}{3}$ where the rope turns an angle of 45° over a ledge, while at 90° it is reduced $\frac{1}{2}$ to $\frac{2}{3}$.

On leads where substantial carabiner and rock friction are encountered, the belayer must exercise considerable discretion in arresting a fall since the tension felt by the falling leader—and the force on the highest piton—may easily exceed 10 times the restraining tension applied by the belayer. There is, consequently, a very real danger in extreme cases of seriously injuring a falling leader by decelerating him at too high a rate and of pulling pitons if the belayer applies too great a restraining tension.

At the other extreme, which exists when no pitons are placed, it would seem desirable for the belayer to apply the greatest restraining tension his stance will permit. It is unlikely that the belayer, aided only by moderate rock friction, can seriously injure the falling climber with excessive rope tension, and it is then better to arrest the fall as quickly as conditions permit to minimize the danger of striking rock enroute.

The leader also bears a responsibility in safeguarding himself, the rope, and his belayer. If the maximum safe deceleration in arresting a fall is set at 6 gravities, which is possible only when pitons are used, then the leader should never advance more than a distance $\frac{3}{4}$ (L-H) beyond his last piton, where L is the total rope length and H is the rope length from belayer to the highest piton. This leaves only enough rope for the belayer to arrest the fall at maximum deceleration. On the other hand, for 4th class leads (no pitons) the advance should be limited to about 70 feet beyond the belayer since the belay, on the average, cannot hold more than about 600 pounds' tension even with the help of rock friction.

Belay conditions on ice and snow are far less favorable than on rock. The belayer usually has little or no aid from frictional forces and his position is often insecure. The difficulties are

TESTS ON ROPED CLIMBING TECHNIQUES

further compounded by the more frequent need of all climbers on a rope moving simultaneously in hazardous areas, which means setting an improvised belay while the fall is in progress. Thus far, a wholly satisfactory belay procedure for snow climbing does not appear to have been developed. Perhaps none approaching the security of a belay on rock is possible, but further study is urgently needed.

Measurements on rappel systems revealed that rope tension rarely exceeds the body weight by more than 75 pounds. Under normal conditions on a vertical face, the tension more often varied from something less than the body weight to a few pounds greater than the weight.