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AN EXPERIMENTAL METHODOLOGY FOR THE ASSESSMENT OF CLIMBING DEVICES ACTUAL STRENGTH

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ABSTRACT

Rock climbing protection devices are crucial for climbing practice safety and for mountaineering in general. The use of these devices, together with appropriate techniques, reduces injuries in the critical event of a climber's fall. Although European standards and rules support the manufacturer in the design, production and laboratory testing, a system able to analyse their behaviour in real environment and during actual placement is not yet assessed.

The aim of this work is to present a methodology and related equipments useful to assess the strength of such devices through the application of a monitored quasi-static increasing force in field environment. Several types of devices have been tested and the results are presented and critically evaluated together with pro and cons of the adopted experimental methodology.

INTRODUCTION

Several type of rock climbing protection devices are currently used such as bolts (adhesive and friction rock anchor), pitons, passive devices (tapers and camming chocks/nuts) and active devices (spring loaded camming devices also known as frictional anchor and called "friends" in climber's jargon). European standards and rules give design and strength requirements to the manufacturers but the compliance verification tests are carried out in laboratories and do not consider several important issues: type of rock (strength and friction coefficient), different shapes of crack (where the devices should be placed), users' ability in placement, etc... Thus a methodology able to investigate these issues in the real environment as well as to measure the strength both in terms of maximum load and failure analyses is needed. Rock climbing protections (as well as the dynamic ropes) are in fact fundamental for the climber's safety when withstanding the load generated during a climber's fall. Unfortunately a generalized and efficient methodology able to verify the behaviour of a rock climbing protection is at present missed in the literature panorama due to the difficulty in simulating satisfactorily and completely the load application during the leader's fall. However, although the actual load application is dynamic, the European standards refer to static tests to verify the compliance to the requested strengths. While static versus dynamic tests is a questionable point, it seems reasonable to neglect the strain rate effect and dynamic influence on the behaviour of the devices (although for spring loaded camming devices this subject needs more accurate evaluations).

EXPERIMENTAL TESTS

Static tests were carried out on pitons, chocks and cam devices, placed on real environment and loaded by means of an oleo-dynamic piston. It is a simple portable system specifically designed in order to assess and compare in a practical way rock climbing protection devices performance. This system can be easily constrained on whatever rock (or ice) surface point and is able to apply a parallel-to-wall load by means of a common actuator. A gauged uniaxial load cell (50 KN rated) is used and peak value recorded. The load cell was interposed between the cylinder and the anchor specimen (however very close to the anchor in order to have a measure as much as possible free of friction effects) recording the collapse load. Care was used in order to avoid flexural load to the load cell. The hydraulic piston was fixed with a chain and pulleys system in order to allow free movements. The load application rate was set on a few mm/s and takes roughly 10-20 seconds for the complete collapse. The cylinder is controlled by an oleo-dynamic system fed by a pump driven both electrically or manually. In **Fig. 1** the cylinder is shown (yellow): in the upper right part the load cell is visible directly connected to an anchor specimen at one side and to the cylinder by means of a chain at the other side. Tests were conducted on a porphyry rock wall. Porphyry is considered an "hard" rock (comparing with limestone and sandstone), therefore expected failure mode is more focused on the failure of the device. On the contrary, on soft stone, the failure of the anchor system may involve both the anchor and the rock itself. It is worth mentioning that the loading mechanism imposed by the piston is intrinsically "displacement dependent" (in the actual falls is "load dependent"), therefore a temporary load decrease is possible in some extent.

The described system allows to obtain the collapse of the system in all the tests: it is one of the pros of this arrangement. On the contrary, when a dynamic test is applied, (involving drop tests) the force is driven by the fall event and the collapse could not be achieved. Again, although the drop test reproduces more realistically an actual fall, this approach involves a lot of organization problems mainly when the tests are performed in the field. Vogwell and Minguez (2007) carried out drop tests in laboratory environment placing the anchor nuts to be tested in a standard simulated crevice device. Even so they had to use standard tensile testing machine in order to determine the ultimate failure load (thus failure) of the anchor specimen because the drop tests failed in collapsing the system.

Each of our test consists in a first phase of placement and a second phase of load application. It is important to state that a good devices placement, such as pitons, chocks and cams, highly depends on a good fitting with the considered rock crack. Therefore the final result depends on the way these devices are placed. During our campaign the devices were placed by mountaineering instructors and/or mountaineering military corps: it seems therefore reasonable to suppose that those were the best possible placements of the anchor devices in those situations.

Another noteworthy issue is the climber's capability in evaluating the ultimate load of each protection point placed. In our campaign each qualified person attending the tests was requested to guess/evaluate the collapse load of each device before testing. Thus we got for each device a population of 26 data to be statistically processed.

It's the authors' will to remind that the aim of the work is to set up a methodological approach to the problem, as stated in the introduction, for future campaigns; therefore the a comprehensive definition of the ultimate strength of climbing devices and, moreover, the evaluation of the prediction ability of mountaineers is out of the scope of this work. Much more data for different kind of rocks, devices and evaluators are needed to solve the problem satisfactorily; so, at present, extrapolations and wide ranging conclusions have to be avoided.

In the following, the tests results on the three categories of rock anchor considered will be presented and preliminary discussed. During each test, pictures and medium velocity films (240- 480 FPS) were taken and used for the failure mode evaluation.

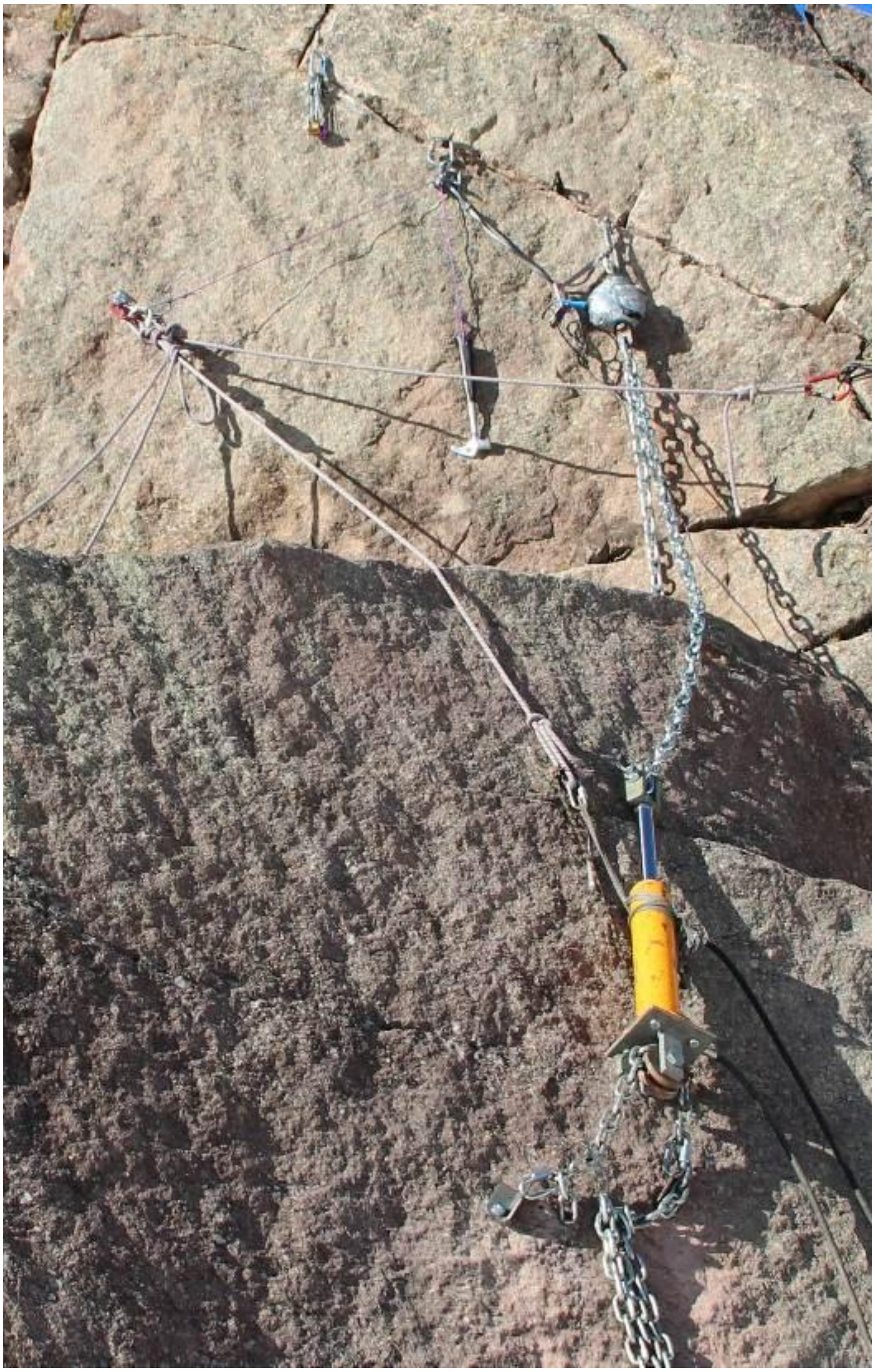

Fig.1 Experimental system for load application on real environment; no load is applied at the picture time.

PITONS

Pitons are anchor devices that can be placed inside the cracks using an hammer. Generally they are built with a blade (to be insert in the cracks) with a lug in a side to be clipped by a

karabiner. EN 569 requires tensile strength tests with different loading direction but with the pitons constrained in an “artificial” holding system. As far as radial direction concerns, the minimum values for ultimate load are 25 KN (for safety pitons) and 12.5 KN (for progression pitons). Different configurations and type of pitons were tested, in particular hard steel (dedicated for this type of rock) as well as soft metal alloy types (more suitable, according to experience, for soft rocks). The most recurrent actual failure mode which involves the pitons is a sort of slippage out of the rock crack. Tanks to medium speed camera records, the collapse steps were observed: firstly a slight piton’s deformation followed by a medium to sever bearing destruction of crack edges; finally an abrupt piton pop out conclude the collapse, **Fig. 2**. The measured ultimate load scattered from about 6 up to 18 KN.
Only in few cases it was possible to note a mechanical collapse of the piton lug metal part. This was observed by a failure analysis showing also a large permanent deformation of the main blade, **Fig. 3**.

Fig.2 A picture of a test just a step before the abrupt pop out. For pitons it is evident a permanent deformation of the devices

Fig.3 A picture of a failure in the piton lug after the test

Post mortem analyses, **Fig. 4** confirmed a low exploit in plastic domain and very little scratches into the blades; this means null to moderate frictional interaction with the rock surfaces. In particular, soft metal alloy pitons (Fig.4.a.b) exhibit higher plastic deformation, as expected, respect to hard steel (Fig.5.c). However soft pitons do not exhibit lower collapse load, with respect to hard steel ones. It's a common practice in the mountaineering community to use hard pitons (as far as it concern materials used in manufacturing) on hard rock. However tests show very little difference in ultimate load; moreover soft metal pitons show an increased capability to deform and to fit the internal shape of the crack also during load application. This is a topic that is very interesting and need further focused tests and more population data. Specifically, equally shaped pitons (built with different materials) have to be tested in the same cracks in order to analyse carefully the material behaviour. It's authors' opinion that this type of pitons could withstand, thanks to the plastic deformation, higher failure load with respect to the hard steel pitons. On the contrary hard steel pitons exhibits very reduced plastic deformation making them very fitted for a re-use.
In **Fig. 5** a boxplot of ultimate load (a value for each specimen) withstood by pitons (reported as "collapse load") and boxplot of the evaluations (26 evaluations for each specimen) is represented (reported as "evaluated load").

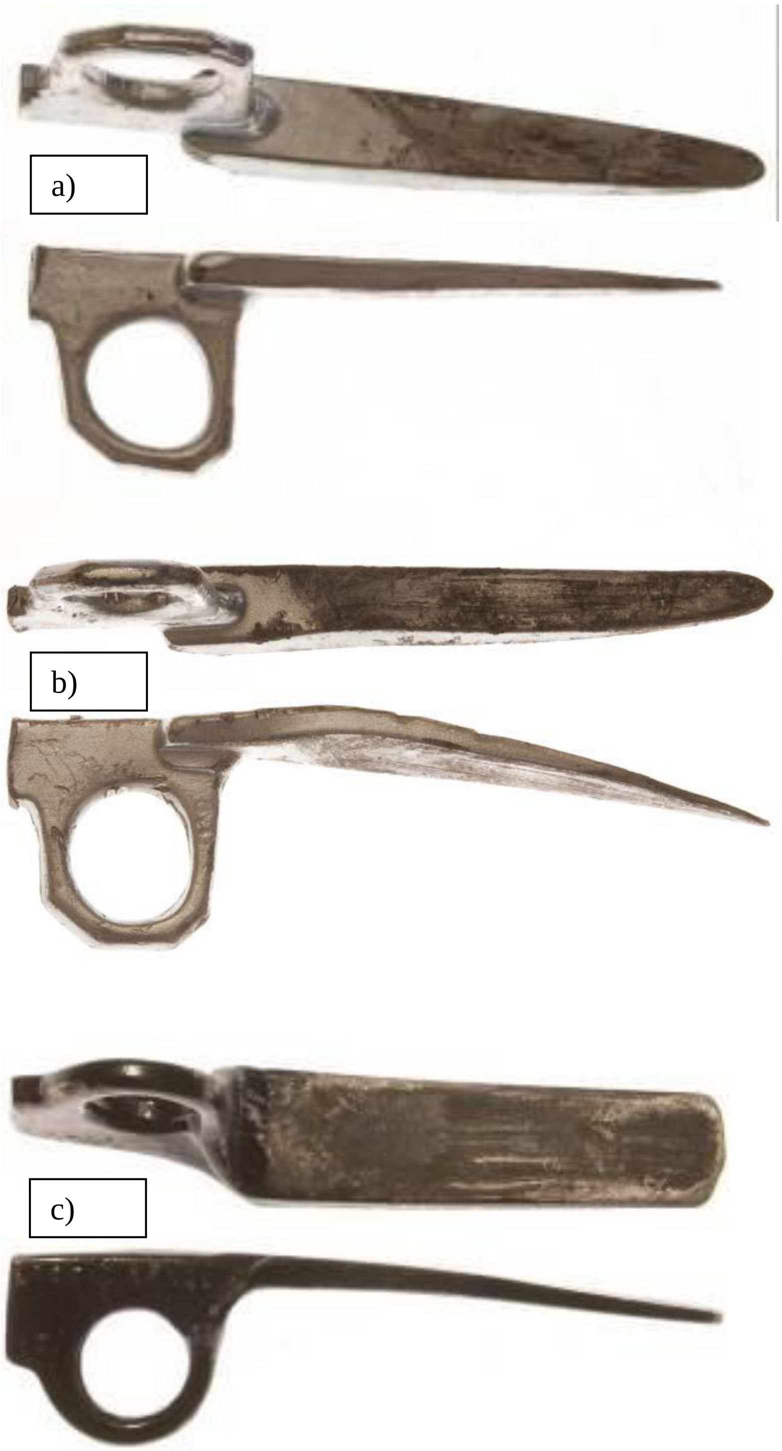

Fig.4 “Post mortem” analysis, a) soft metal piton - low residual deformation, b) soft-metal piton – medium residual deformation c) hard steel – low residual deformation

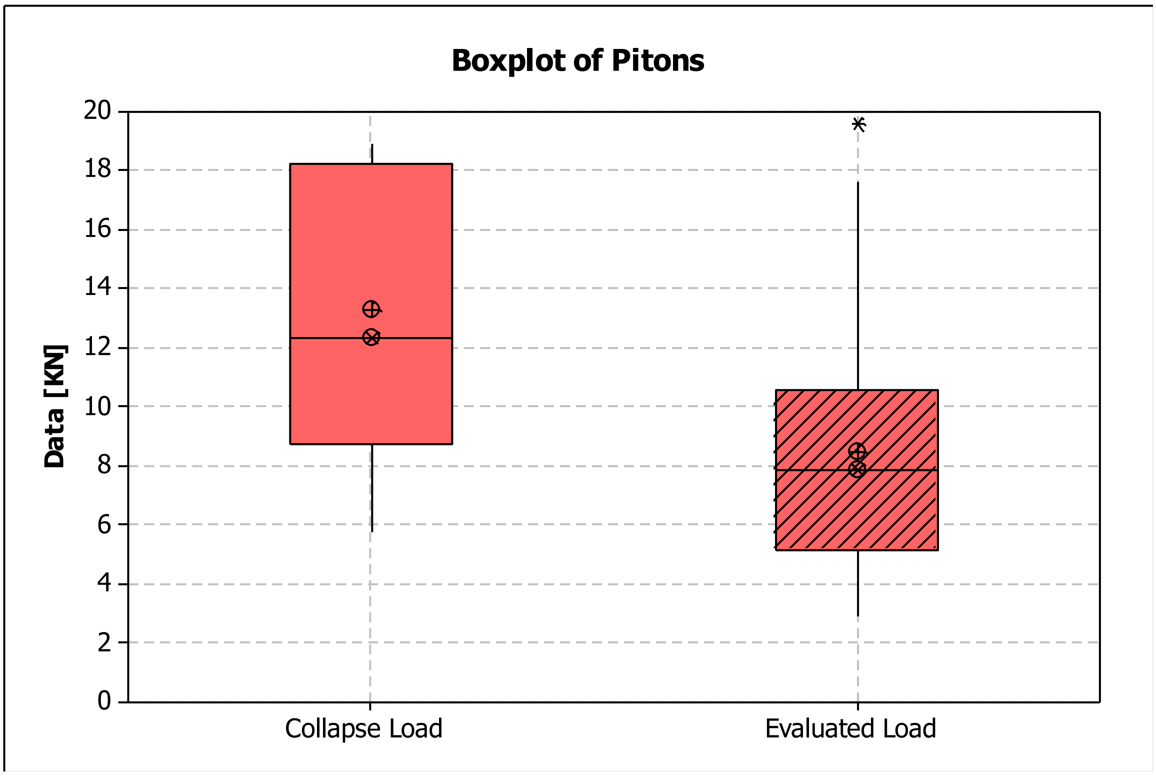

Fig. 5 Boxplot of two population data: "collapse load" refers to the ultimate load value obtained during tests (a value for each tests), "evaluated load "refers to the blind evaluation from estimators (26 evaluations for each test)

CHOCKS

Chocks are special shaped nuts with a metal wire for the placement and the load application by clipping a karabiner. EN 12270 require that chooks, tested in an "artificial holding" have to prove a failure load over 2 KN. Chocks are simply placed in the crack by hands, so are defined as "fast placement" anchors. All the placed chocks failed without leaving their hoisting crack. Generally failure involving chocks is located in the metal wire, sometime in the loop interfacing the karabiner body, other along the wire.

The failure mechanism observed, **Fig. 6,** consists of: practically null relative movement between the chock and the hoisting fissure, rope loop elongation, breaking of initiating single wire followed by chain-collapse of companion strand wire up to full separation associated to a certain amount of single wire unwound. The "post mortem" analysis proved that chock-to-rock contact points were limited and localized among relatively small surfaces, as witnessed by chock overall coloured chemical conversion in pristine condition. The measured ultimate load scattered between about 6 up to 12 KN.

Also for chocks, a boxplot both of failure and evaluated loads is presented in **Fig. 7**.

Fig.6 "Post mortem" analysis, a) failure in the wire at the loop interfacing body b) failure along the wire

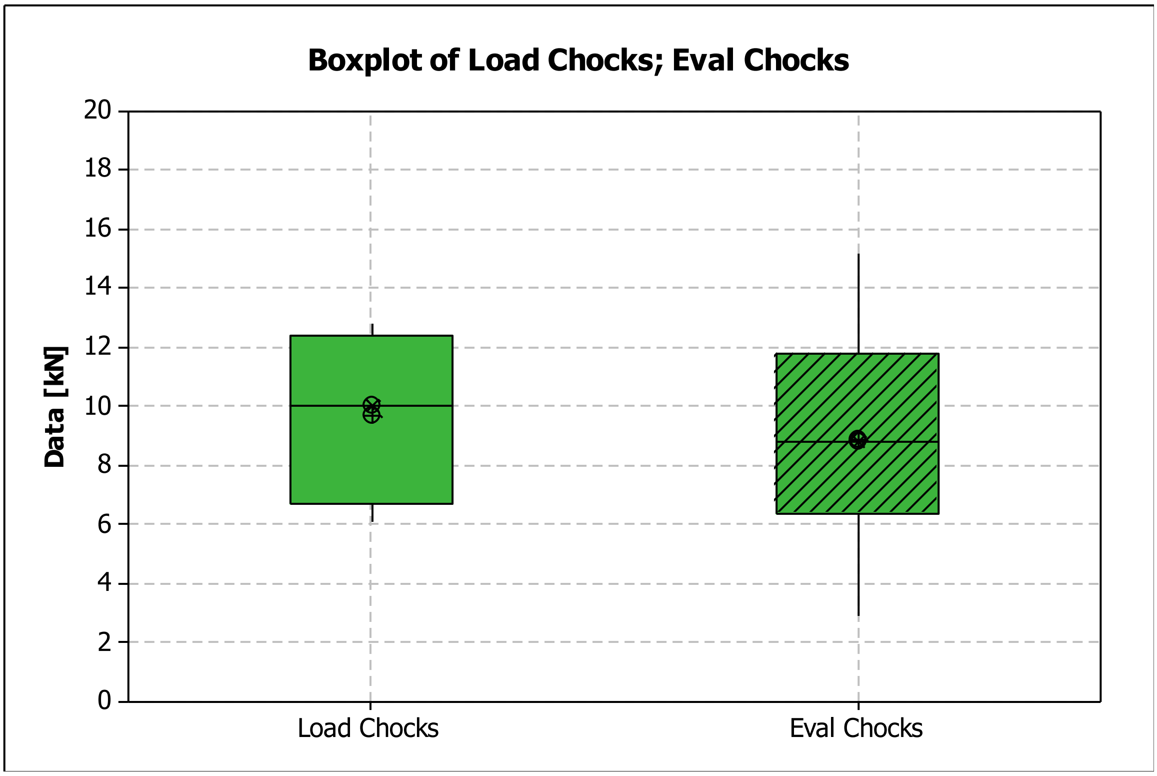

Fig. 7 Boxplot of two population data: "collapse load" refers to the ultimate load value obtained during tests (a value for each tests), "evaluated load "refers to the blind evaluation from estimators (26 evaluations for each test)

Fig.8 “Post mortem analysis of cam devices

CAM DEVICES

Cam devices belong, like chocks, to “fast placement” devices. They are a sort of chocks but due to the spring system, each device can fit different measures of cracks. EN 12276 require that cam devices (frictional anchor), tested in an “artificial holding”, have to prove a failure load over 5 KN (in two different positions). Due to the fact that their gripping action is obtained by means of friction different shapes have been designed and built. The range of

tested devices spanned from: a) old-fashioned solid bar models to b) modern wired body with built-in slings devices, passing through c) early wired body models.
Each of them shows a peculiar failure mode, **Fig. 8.**
Model a) was characterized by snaking out the hoisting fissure together with ultra large permanent bending of the rigid bar or by the main shaft double shear at the two sides of the bar bore. This is an interesting result: it is believed that such solid bar model tends to break the bar (with reduced load) in case of contact with rock. On the contrary the ductility of the material is fundamental to prevent the failure and allow the device to work and withstand further load. Obviously this “damage tolerant” behaviour cause huge deformation thus it is no more possible to reuse the device.
Model b) popped out from fissure after snaking settlement as the load increased.
Model c) failed in the crimp as the wire loop slide out from it. From the “post mortem” analysis performed on the failed devices it is worth noting that on model b) the only remarkable outcomes are the limited scratches on cams teeth. At the contrary, on the other models the obvious clues of described failure mode were apparent. The measured ultimate load scattered between 7 up to 14 KN. Also in this case a boxplot both of failure and evaluated loads is shown in **Fig. 9**

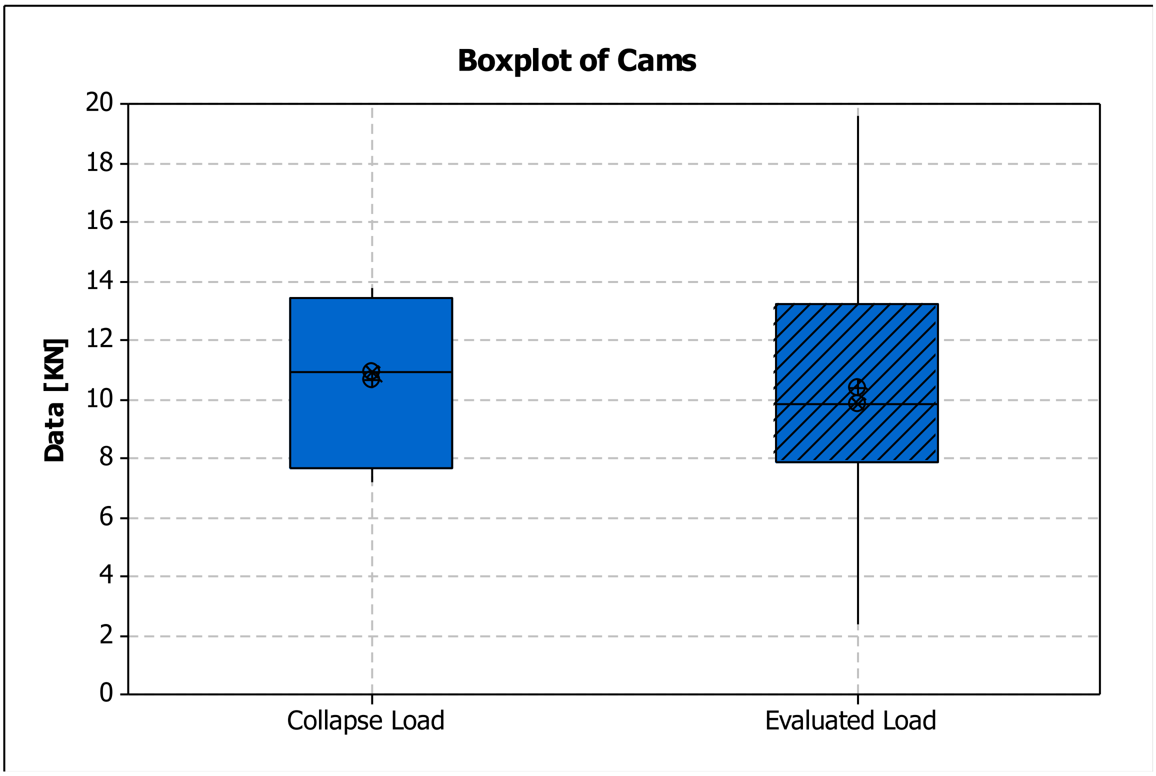

Fig. 9 Boxplot of two population data: “collapse load” refers to the ultimate load value obtained during tests (a value for each tests), “evaluated load“refers to the blind evaluation from estimators (26 evaluations for each test)

DISCUSSION AND CONCLUSIONS

As far pitons actual strength concerns, the knowledge gained through the field experiments confirms that the characteristics requested by EN specifications and rules are functional to product qualification purposes but very little to the definition of the load holding capabilities once the devices are in place. Users seem to be aware to this behaviour giving credit to a

lower value to the ultimate strength as certified by standards; the large amount of scattering in the evaluator guesses makes difficult the assessment of human factor at the present.
Although its limited possibility to be re-used is clearly a drawback, ductile metal in hard rocks exhibit better strength. Hard metal in hard rocks, on the contrary, sometimes can produce poor performances because of its low capability to adapt: this can generate only few contact points with the hosting crack and consequently an abrupt popping out can be expected once loaded.
Placement configurations, when lug contact with the crack edges is present, tend to bear higher ultimate loads, although not confirmed for particular mutual positioning between blade and load direction.
Concerning chocks, it's worth to underline the importance of a correct placement: when the case, the actual strength achieved by the device in the field complies and overcame the classification of the EN standard since the weak item most likely is the device itself. This is fairly true in all the arrangements where the "obstacle" function is fulfilled; conversely lower performances may be expected when the "friction" function (between the wedge-shaped block and the hosting crack) play a predominant role. It is worth noting that the cracks used were very suitable for chocks placement confirmed by the high guessed collapse load: this means a good shared judge by the evaluators.
Similar behaviour for cams for which we suggest that outdated models should be retired from daily use by owners.
The lesson learned from the experiments is that modern equipment show a step better behaviour and, similarly to pitons, the device-rock coupling dictates the pair actual strength, assuming of course a sound placement.
As previously stated, more samplings are needed to recognize even a behaviour tendency for each device and for a human prediction; further development tests are foreseen on this subject and this is the authors' intention for future work.
Finally it's worth mentioning another aspect that this work highlights. The value obtained as limit load in the field should be compared with the actual force acting on the devices during the leader fall. This is not an easy task because both the two values have uncertainties that should be investigated. However, an upper limit of 9 KN (as peak force on the anchor point) can be considered as worst case with a modern rope when a correct dynamic belaying technique is applied, as reported by Bedogni and Manes (2011).
Thus: - failure load of the anchor – load generated during the leader fall – capability of the climber to evaluate the anchor failure load is a very remarkable safety triangle that should be investigated. This work represents a first and original step in this direction, suggesting an experimental methodology for devices actual strength assessment and a stimulus for further experimental activities on this subject crucial for climber's safety.

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