Stability of stepladders and maximum push-pull force

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Abstract. Stepladders are used during professional and domestic activities. They have a rectangular base; the rungs are parallel to the short base side. When the stepladder is placed with the long base parallel to a wall and near this wall, the user is close to the wall: it is easier for working. Then the user could exert a force perpendicular to the wall thus parallel to the short base and the stepladder is very unstable. The force producing that instability is small compared to the maximum push force exerted by a human, as low as 60% of the maximum for a strong man. Even if the user is cautious, he could easily overturn a stepladder. The potential for accidents is the result of a conflict between the ease of work and a low overturning force. Therefore fall accidents with a stepladder are still numerous.

Keywords. stepladder, stability, fall, human maximum push force

1. Introduction

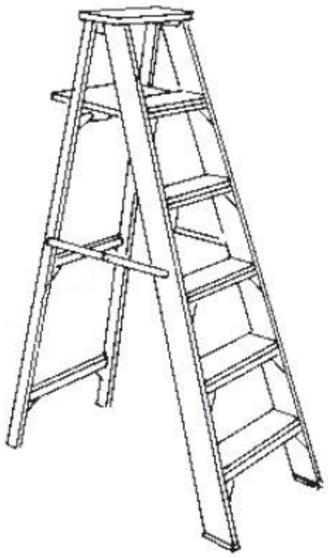


Figure 1. *Typical 6 foot stepladder*

Stepladders (Figure 1) are frequently used during professional and domestic activities. They have a rectangular base; the rungs are parallel to the short base side. The rungs are at 300mm in height from each other. In Canada, fall protection is mandatory for workers exposed to a fall higher than 3m; when working standing on a step ladder, fall protection is not required because the user's feet are at a height lower than 3m. But fatalities occur also for fall lower than 3 m (Culver and Connolly 1994).). Even if progress in fall protection was made since 1990, falls from ladders and stepladders are still the 3rd most numerous group of fall accidents in France as example; they represent around 20% of all fall accidents (Table 1).

The simplistic explanation is firstly, ladders and stepladders are used in all professional sectors so it is normal that accidents are numerous and secondly, users do not have a safe behaviour. There is another explanation based on basic ergonomic and mechanical principles. The stepladder could be placed either perpendicular to the wall with the rungs parallel to the wall (Figure 2a) or with the long base parallel to a wall and adjacent to this wall (Figure 2b). The Health and Safety Executive HSE declares 2a as correct and 2b as incorrect. The so called "correct" is shown in real situation (Figure 2c). As the stepladder is higher, the worker is farther from the wall making the working posture incorrect (Figure 2c). For a worker, the ease of work is the first criterion to meet (Arteau 2012 and Desjardins-David & Arteau 2011); so the stepladder parallel to the wall as per Figure 2b is the choice. When the stepladder is placed with the long base parallel to a wall and adjacent to this wall, the user is close to the wall: it is easier for working. With this arrangement, the user could exert a force perpendicular to the wall thus parallel to the short base making the stepladder and the user on the step ladder very unstable (Figure 2b).

The stability of a stepladder will be analyzed and the results compared to anthropometric data to demonstrate that the instability is very easy to reach. Stepladders are an accident-prone tool.

Table 1. *Falls form ladders and stepladders in falls from height – France 1990 and 2010*

Falls from height – material element	**Work accident – sick leave**		**Work accident – permanent disability**		**Death**	
Year	1990	2010	1990	2010	1990	2010
Ladders, stepladders	23 490	13 125	3 857	1 556	39	7
Total	101 426	74 936	12 960	6 725	234	58
Ladder as % of total	23,2%	17,5%	29,8%	23,1%	16,7%	12,1%
Ref. : INRS Institut national de recherche en sécurité. ED6110, 2012						

Figure 2. *Stepladder with a) rungs parallel to the work, b) rungs perpendicular to the wall and c) a so named correct installation but not workable. Ref. (a) and (b) HSE; (c) US Navy Safety Center*

2. Methodology

The American, Canadian and European standards were reviewed. Using basic static equilibrium equations, the stability is calculated with an horizontal force parallel to the short base or an horizontal force parallel to the long base, both applied at shoulder height when the user is on the second and the third last rung. The force creating the instability is calculated for several conditions: heights, directions, users' mass and users' height. Anthropometric data (Diffrient, Tilley, Harman) are used for users' mass, users' height, and the maximum push-pull force at shoulder level (Table 2). Then this maximum force is compared to the force creating the instability.

Table 2. *Anthropometric data – Maximum arm strength standing - push.*

Anthropometric group (percentile)	Maximum force one arm (N)	Shoulders' height (cm)	Height (cm)
Small woman (2,5%)	97	119	149,5
Avg woman (50%) **Small man (2,5%)**	151	131	161,5
Large woman (97,5%) **Avg man (50%)**	177	141	174
Large man (97,5%)	177	151	188
Ref.: Diffrient, N., Tilley, A.R., Harman, D. 1983 Chart 4a Human strength and Tilley 2002			

3. Results

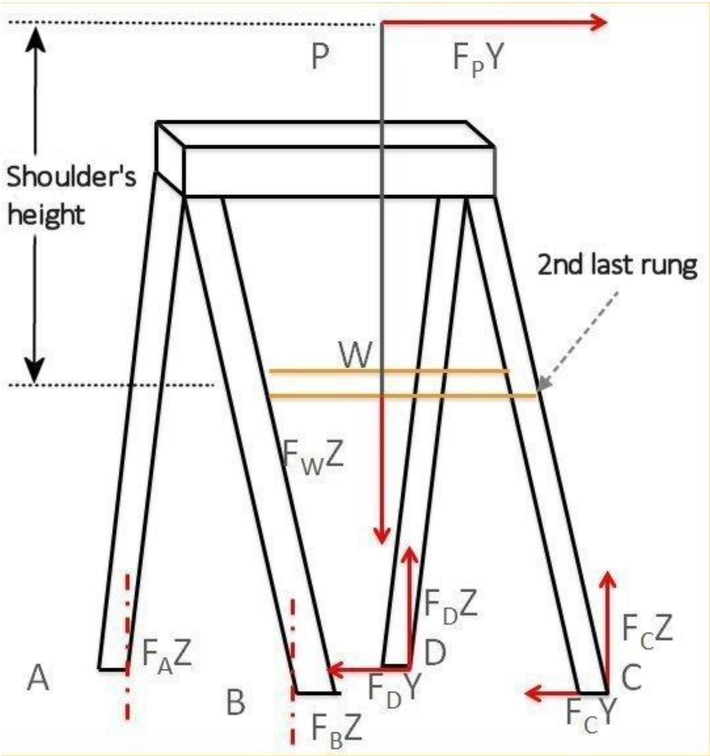
3.1 Stepladder standards

The requirements of the American, Canadian and European standards are limited to the strength of the structural members that are making the stepladder. The applied forces are related to the user's mass according to the different classes. Nothing is relevant to the overall stability of the assemble user-stepladder. In American and Canadian standard, stabilizers are not mandatory neither evaluated.

3.2 Equilibrium of forces

A 3 dimensional model was created; the case of a side loading is presented in Figure 3. The force F_{PY} is the horizontal push-pull force applied by the worker on the wall. As example, the force is applied at the shoulder level (height = 151 cm; Table 2) of a tall man (height = 188 cm; Table 2) standing on the second top rung (height of the rung: 4 X 30 cm = 120 cm from the ground; Table 3) so the force F_{PY} is applied at 120 cm + 151 cm = 271 cm above the ground. The critical condition is the force F_{PY} for which the reaction forces F_{AZ} and F_{BZ} become zero. At that instant, a small increase of F_{PY} will make the system (the stepladder and the user) overturning. A simple Excel spreadsheet (Simeon) was used for the calculation. The most critical loading case is a side loading when the stepladder is parallel to a wall.

Table 3 presents the most significant results. The horizontal force F_{PY} causing the overturning is 105 N, 60% of the maximum push force 177 N. Overturning could easily append. As a technical solution to overturning, stabilizers are analyzed.



F_{PY} horizontal push-pull force applied at the shoulder level of a tall man

F_{WZ} weight of the stepladder

W weight of the user at the 2nd top rung.

F_{AZ}, F_{BZ}, F_{CZ}, F_{DZ}: vertical reaction at each foot A, B, C and D.

F_{CY}, F_{DY} friction.

Because we calculate at the instant that overturning starts, there is no friction forces F_{AY} and F_{BY} neither reactions F_{AZ} and F_{BZ} at A and B.

Figure 3. *Stepladder with side push-pull*

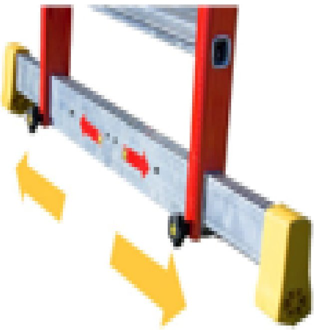
Table 3. *Overturning side push force on a stepladder*

	Overturning side push force				**Maximum push force Strong man (N) (1)**
Stepladder size	6ft (1,8m)	6ft (1,8m)	8ft (2,4m)	8ft (2,4m)	
Position of the user's feet	2nd top rung	3rd top rung	2nd top rung	3rd top rung	
Height of the rung (cm)	120	90	180	150	
Overturning side push force (N)	105	120	100	105	177
(1) Table 2					

3.3 Stabilizers

Four stabilizers were analyzed. The maximum horizontal force causing the overturning of 8 foot (2,4m) stepladder was calculated while standing on the 2nd top rung on 8 foot stepladder. The results are presented in Table 4. Three stabilizers increase the force 143 N to 164 N but the telescopic foot fixed at the top of the stepladder needs a force of 270 N to produce overturning, a force larger than the maximum 177N. The telescopic foot is the safest and also brings stability to stepladder.

Table 4. *Overturning side horizontal force without and with stabilizer.*

Overturning side horizontal force without and with stabilizer	
Maximum push force: large man = 177 N	
8 foot stepladder standing on the 2^{nd} top rung Without stabilizer: = **100 N**	
 Stabilizer bar **143 N**	 Ladder stabilizer **157 N**
 Stabilizer at the foot **164 N**	 Telescopic foot **270 N**

4. Discussion and conclusion

According to the standards, stepladders are resistant to the applied forces but they could be easily overturned still remaining unbroken. Stabilizers are not mandatory neither considered in American and Canadian standards.

The overturning horizontal force with a side push (105 N) is only 60% of the maximum push force (177 N) (Table 3). This demonstrates that stepladders are unstable when the forces are parallel to the short base and at the user's shoulder level. The force that creates the overturn of the stepladder is small compared to the maximum push-pull force applicable by the user. During his activities, the worker could push strongly on a hand tool for any reason and he could do this action as a reflex. In work situation, the user could easily apply a force perceived as low but being large enough to overturn the stepladder. The probability that a user could reach a force level creating the instability is high. The situation has a great potential for accident. This calculation demonstrates that a stepladder is very prone to overturning even if the worker is doing safely. So the simplistic explanation putting the focus on the unsafe behaviour of the worker is not supported by basic mechanical principles. A stepladder could easily be overturned.

A first technical solution is the use of personal elevated work platforms PEWPs for prolonged work. Personal elevated working platforms are more stable. A second technical solution is the use of stabilizers. They are need because stepladders will continue to be used: their cost is low, they are light and portable. Table 4 demonstrates that the telescopic foot increases the overturning force to 270 N, a value larger than the maximum push force of 117 N. Unfortunately stabilizers are not common in Canada. A recommendation for their addition will be sent to the standardization committee.

Finally, information leaflets, guidance brochures and safety posters shall integrate the issue of the low value for the force that is causing the overturning. Most workers are not able to translate into equations the overturning of a stepladder. But every day, they experiment this instability and their real experience is the demonstration of our equations. Every day they are facing a dilemma: a safe behavior (Figure 2a) leading to an unacceptable work posture (Figure 2c) vs an unsafe behavior (Figure 2b) leading to an acceptable work posture (Figure 2b). Workers generally choose workability (Arteau 2012 and Desjardins-David & Arteau 2011). Our calculations give a mathematical sense and demonstrate the intrinsic instability of a step ladder to a horizontal side push. If information documents give the rigorous and real explanation for the overturning instead of transferring the responsibility on the unsafe behaviour of the worker, the safety message will gain credibility. Also because the rigorous issue will be explained and because the efficiency of the stabilizers will be demonstrated, this efficient solution will be accepted, integrated in the practice and used. The worker will solve his dilemma; he will use a safe and workable posture.

5. References

American National Standards Institute (2007) Ladders - Wood Safety requirements. ANSI-ASC-A14.1-2007

American National Standards Institute (2007) Ladders - Portable metal – Safety requirements. ANSI-ASC-A14.2-2007

American National Standards Institute (2007) Ladders - Portable reinforced plastic – Safety requirements. ANSI-ASC-A14.5-2007

ARTEAU, J (2012) Fall arresters tested for mechanical and ergonomics criteria – CSA Z259.2.1-1998 standard. Frühjahrskongress 2012 der Gesellschaft für Arbeitswissenschaft GfA. 22-24. Februar 2012, Kassel, Deutschland, p.157-164.

Canadian Standards Association (1981) Portable ladder. CAN3-Z11-M81

CEN, European Committee for Standardization (2012) Ladders – Part 2: Requirements, testing. EN 131-2-A1-2012

Culver, C and Connolly, C (1994). Prevent Fatal Falls in Construction, Safety and Health, p. 72-75, September

DESJARDINS-DAVID, I and ARTEAU, J (2011) Evaluation of personal protective equipment used for work: considerations and proposed methodology – the criteria to be checked. 57. Kongress der Gesellschaft für Arbeitswissenschaft, March 23rd to 25th, Chemnitz, Germany. p. 361-365.

Diffrient, N., Tilley, A.R., Harman, D. (Henry Dreyfuss Associates). (1981, 1993) «Humanscale. 4/5/6». Cambridge, Mass. MIT Press, 1993, c1981. 48 p.: ill. + 3 selecting wheels

Health and safety executive HSE-UK (2011). A toolbox talk on leaning ladder and stepladder safety. INDG403 09/11. 12p.

Institut national de recherche en sécurité INRS (2012). "Prévention des risques de chutes de hauteur" ED6110, 48 p. France www.inrs.fr

Simeon, L. Statique for Windows, v.4.2. Lycée Pierre-Paul Riquet, St-Orens, France.

Tilley, A R and Henry Dreyfuss Associates. 2002 The measure of man and woman: human factors in design. Wiley. 98 p

US Navy Safety Center. Photo of the week #447. www.public.navy.mil/navsafecen

Worksafe-New-Brunswick (2011). Falls from stepladders can kill. Hazard Alert. February 2011.

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62. Kongress der
Gesellschaft für Arbeitswissenschaft

RWTH Aachen University
Institut für Arbeitswissenschaft (IAW)

2. – 4. März 2016

GfA Press

B.4 Arbeitsschutz, Arbeitssicherheit und Arbeitsmedizin

B4.1
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Bericht zum 62. Arbeitswissenschaftlichen Kongress vom 2. – 4. März 2016, RWTH Aachen University,
Institut für Arbeitswissenschaft (IAW)

Herausgegeben von der Gesellschaft für Arbeitswissenschaft e.V.
Dortmund: GfA-Press, 2016
ISBN 978-3-936804-20-1

NE: Gesellschaft für Arbeitswissenschaft: Jahresdokumentation

Als Manuskript zusammengestellt. Diese Jahresdokumentation ist nur in der Geschäftsstelle (s. u.) erhältlich.

Schriftleitung: Matthias Jäger
im Auftrag der Gesellschaft für Arbeitswissenschaft e.V.

USB-Print: Markus Harlacher, Aachen

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