Chapter 4

Preventing Ladder related Incidents in C nstructi n Industry thr ugh Engineering C ntr ls

1 Chapter verview

Falls from height are major contributor for highest number of serious and fatal injuries at construction sites While any fall, including fall on the same level could be dangerous, fall from two meters or more, could lead to serious consequences which may lead to death

Many construction activities involve working at height Though ladder is basically an access equipment, it is sometimes used to perform short-time work such changing of lamps, nailing etc

Ladders also used to provide access to scaffolds (temporary work platforms) and connect various working levels till permanent stairs are built

2 Intr ducti n t Research pr blem (Research bjective)

Fixing of ladder - due to the temporary nature of construction activities ladders often get shifted from one place to the other In absence of a standard and quick-to-fix arrangement with the structures on which it leans, ladders may fall sidewise, causing injury to the person who is using it or even standing nearby

Stability: While several types of ladders are used for various applications, for most commonly used single stock ladder it is suggested to maintain a slope in the ration 1:4 (ratio of base with the height), to find an easier way of assessment of the same by the users

4.3 Experimental meth d l gies

4.3.1 bservati nal studies

Workmen climbing the ladder in various construction situations were observed and the associated risk were identified This included sliding of the ladder, tilting of the ladder, fall of person from ladder

4.3.2 Inspecti ns

Site safety inspections were conducted Incident data as well as findings of deficiencies during safety inspections were captured from five construction projects involving overall 20,000 workers After a detailed study it was observed that effective engineering controls are required to be identified and strengthened and implemented to facilitate safe working conditions

During the study nature of deviations was of varying nature This includes utilizing the ladder such as tying or fixing of ladders, extension of ladders, slope angle, damaged / defective rungs, slippery surfaces, Ladder Not Provided / Improper Access etc

3 The details f these deviati ns are as given bel w:

1 Tying r fixing f ladder:

- Ladders not being supported at base as well as at the top for preventing displacement
- Ladder tied on a unstable structure / flimsy support
- Ladder fixed using a substandard tying material
- Ladder fixed in a way hindering the access of personnel
- Ladder not fixed rigidly ie, ladder is shaking while ascending / descending

2 Extensi n f ladder:

- Extension ladder used on a scaffold
- Overall extension of ladder exceeds 18m
- Sliding section exceeds two in number
- Recommended overlapping of two ladders is not in coherent as per the length of the ladders
- Mere makeshift customized to suit the job requirements

3 Sl pe angle:

- Height to base ratio of 4:1 is not being followed
- Slope is inappropriate and creates condition of over-reaching to workplace
- Slope provided is not conforming to ergonomics

4 Damaged / defective rungs:

- Ladder with missing rung
- Ladder with broken rungs / unfixed rungs
- Substandard makeshift arrangements using rebar / other material as ladder
- Substandard tailor made ladder which has defective rung spacing and dimensions
- Slip resistant not effective / not available on rungs

5 Slippery surface:

- Ladder erected on slippery surface due to external factors such as , water , oil spillage, excavated soil etc
- Ladder erected on smooth surface like tiles etc
- Ladder without slip resistant base

6 Impr per access:

- Scaffold pipes used as access/ Ladder not provided,
- Short ladder used without one meter extension from the workplace
- Ladder fixed in a way hindering the access of personnel

Hazard Identification & Risk assessment (HIRA) were studied and reviewed for various activities involving usage of ladder and findings for the same are as given in the matrix below

1 Study of HIRA on ladder usage

Matrix : Study f HIRA n ladder usage												
Activities	**Descripti n f sub-activity**	**Pr bability**					**Impacts**					**Risk Level**
		M st Un Likely	**Unlikely**	**Likely**	**M st Likely**	**Inevitable**	**First Aid treatment nly**	**requiring Medical treatment but**	**L st Time Accident**	**Seri us injury requiring h spitalizati n**	**Single r multiple fatality**	
1) c ncreting	Access and egress f r p ur inspecti n			✓				✓				**Medi um**
2) welding	Welding structural steel and pipelines					✓			✓			**Medi um**

Matrix : Study of HIRA on ladder usage												
Activities	Description of sub-activity	Probability					Impacts					Risk Level
		Most Un Likely	Unlikely	Likely	Most Likely	Inevitable	First Aid treatment only	requiring Medical treatment but	Lost Time Accident	Serious injury requiring hospitalization	Single or multiple fatality	
3) Gas cutting	Alignment and fit up work				✓				✓			**High**
4) Grinding	Surface finishing of structural steel			✓				✓				**Low**
5) Insulation	Fixing insulation material on pipeline		✓					✓				**Low**
6) Pressure testing	Inspecting pipelines for welding defects		✓					✓				**Low**
7) Painting	For painting structural steel, walls in control room etc				✓				✓			**High**
8) Rigging	For fixing tools & tackles			✓				✓				**Low**
9) Excavation	For reaching the pit					✓			✓			**Medium**
10) Roof work	For fixing the translucent sheet		✓							✓		**High**
11) Fixing Cable tray	fitting and alignment of cable tray				✓		✓					**Low**
12) Structural Erection	For fixing the lifting appliance and preparation for rigging			✓					✓			**High**
13) Pipe erection	For removing the slings after erection			✓						✓		**High**

For each type of cases ladder related deviations were studied and their distribution for unsafe act / conditions and near miss cases are as given below

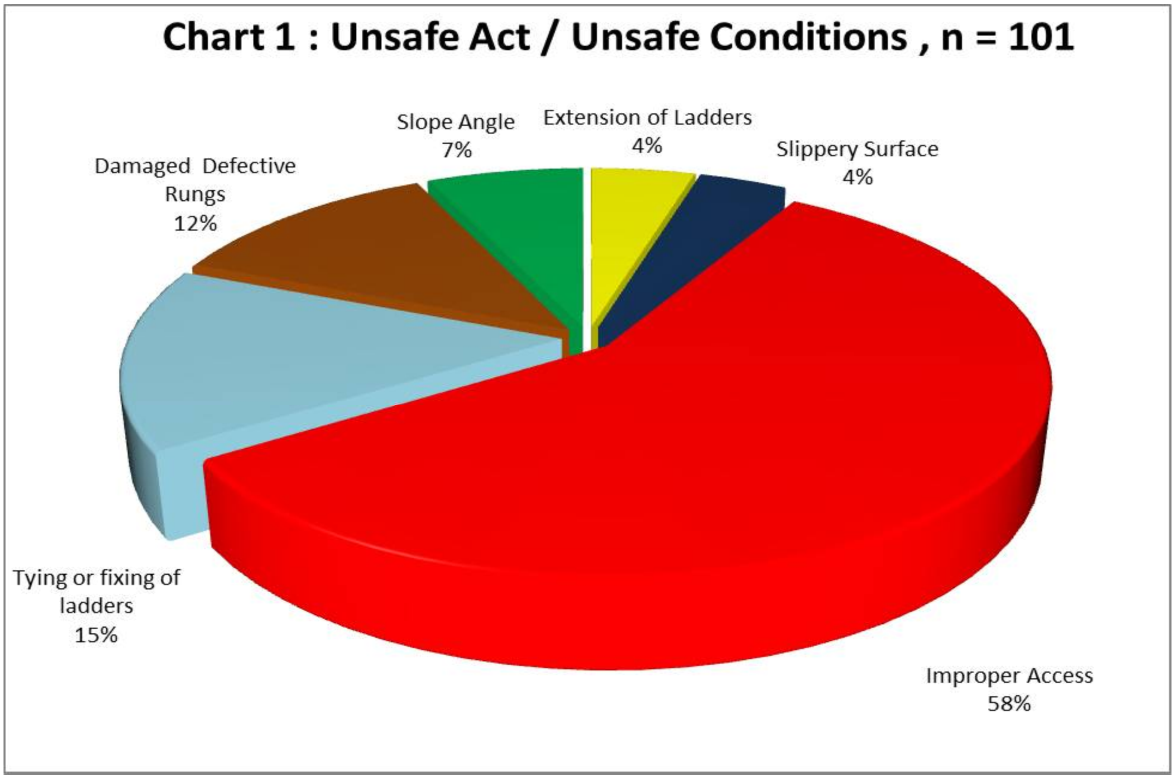


Chart showing Unsafe Acts or conditions

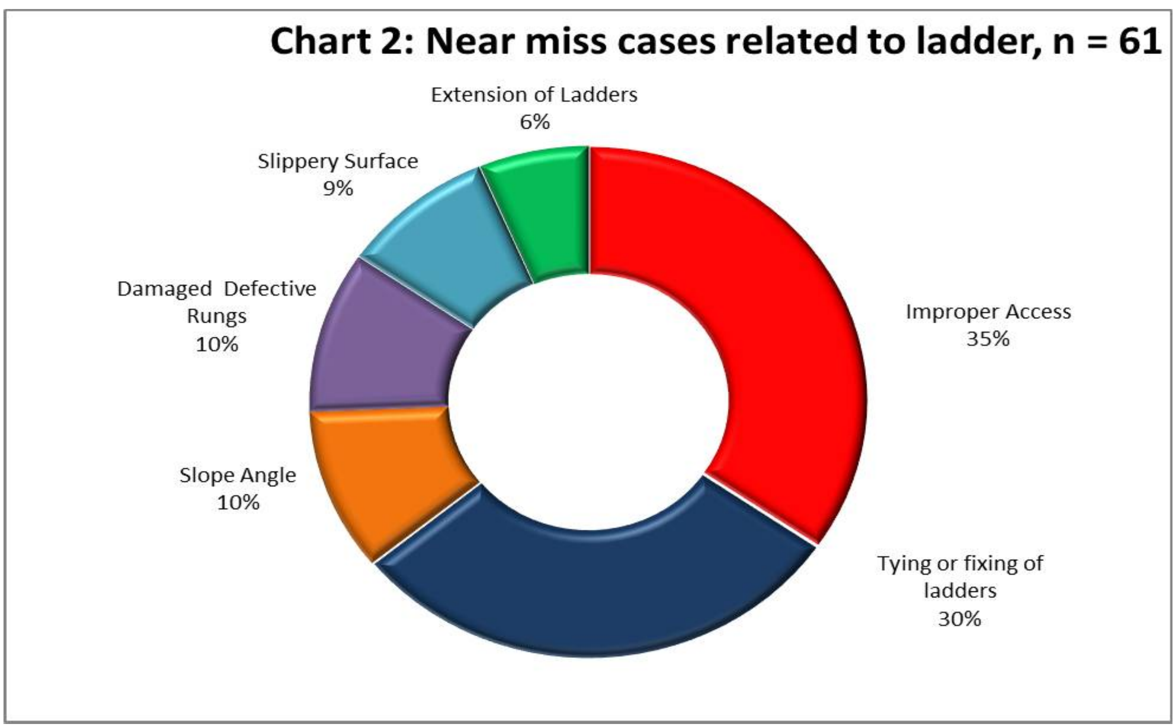


Chart showing near miss cases related to ladder

4 Sh rt descripti n f few typical high p tential cases:

1 Case type 1: Ladder slipped:

A painter was trying to climb 3m wall inside a building using a ladder While ascending he just stepped the 3rd rung (from the bottom, approx 1mtr from ground) of the ladder The Ladder slipped due to slippery surface of tiles He sustained fracture injury on his left wrist & abrasion injury on his right wrist

In another similar typical case, the ladder did slide sidewise while its stiles were resting on a horizontal steel beam at 4 m level There was no anchoring at the top As the ladder got misbalanced at the early attempt of climbing, the welder who was tried to climb the ladder escaped with minor bruises as his fall was from less than 2m height

2 Case type 2: W rker l st balance & fell:

Three people were engaged for light fixing works in a building and all the works were completed While checking the connection, one of light was not glowing at 59m Height The victim was engaged for replacing the defective fixture at 59m height by using Aluminum ladder He lost the balance & Fell from 59m height and caused head injury

3 Case type 3: W rker l st balance & fell:

A fitter was working for an alignment work of a steel plate He fell from a height of 18m while attempting to move towards the ladder attached to the scaffold He hit the left side of his head (behind his left ear) on the corner of a steel working table below the workplace

Shortly before the fall, the fitter was positioned with his left foot on the scaffold and the right foot on the workplace In the process of moving towards the ladder, he tripped on an object or slipped and then fell The fitter sustained a fractured skull (base) and laceration, which caused some bleeding, and immediate swelling to the back of the head He was immediately admitted to the hospital and was placed on life support but latter succumbed to the injury

4 Case type 4: W rker jumped fr m the ladder:

While climbing on a ladder (fixed to a scaffold) the worker jumped from 2m height as he got frightened experiencing that scaffold was getting tiled sidewise He sustained fracture injury on his right leg In fact, earth under the scaffold got loose due to flow of water as a result of dewatering from a nearby pit, by another agency

5 Case type 5: Fall due t Impr per ladder Inclinati n:

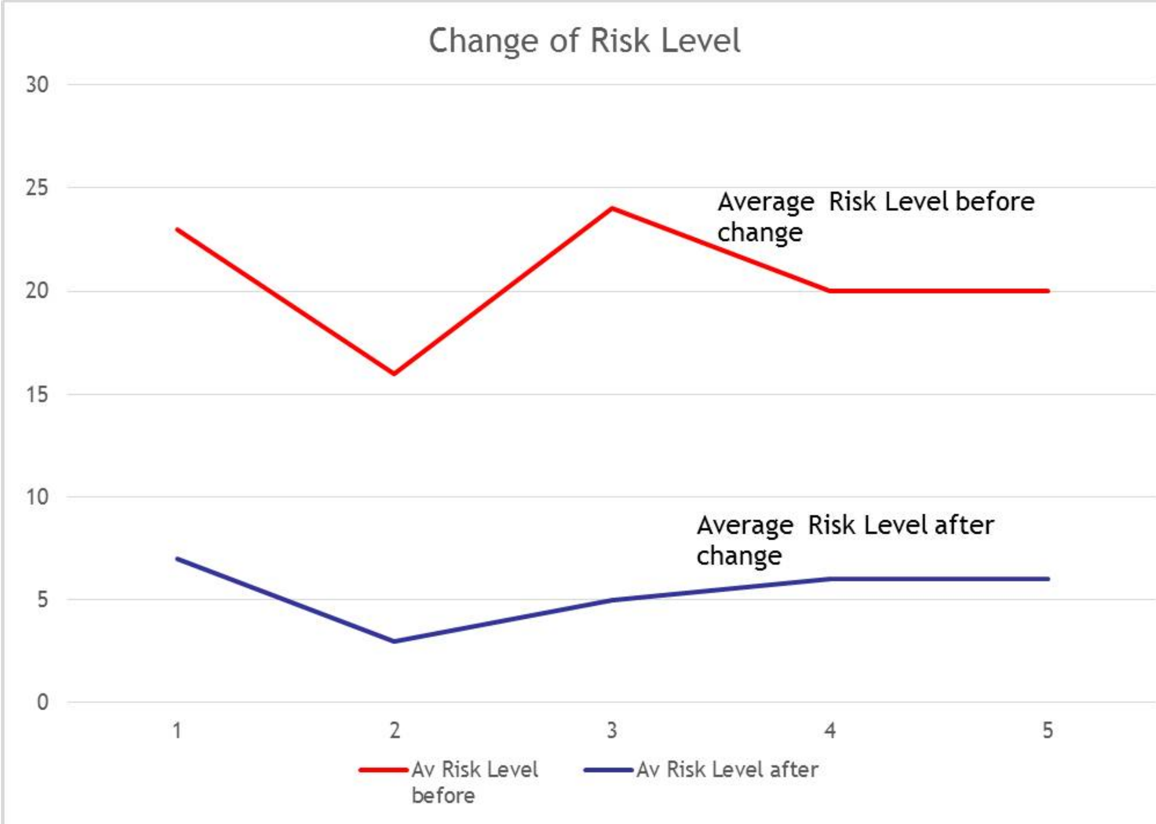
One staff was climbing the ladders for inspection and it slipped backwards – possibly due to wrong inclination (angle with the base) The ladder was not anchored at the top

6 Case type 6: Incident due t damaged rungs:

Rung of one ladder came out while one worker was climbing This was due to manufacturing defect of the ladder The concerned person fortunately did not receive any serious injury

7 Case type 7: Impr per usage f ladder:

One grinder was working on ladder - he fell down while the ladder was being used as a scaffold – grinder hurt himself



Graph showing the change of risk level

X axis: Site l cati n **Y Axis : Risk level**

5 Understanding engineering aspects influencing stability f ladder:

This discussion is specific to portable ladder which is commonly used in construction site Load calculation on ladders is provided for further understanding the needs of engineering aspects involved in the same

A man of weight w_m(blue dotted arrow) climbs a ladder of length $L$and weight $w_L$placed against a wall at an angle θ Vary the height of the ladder to see the forces acting on this system The weight of the ladder is taken to be at its geometrical center $L/2$(red arrow), the ground exerts a reaction force (Green arrow) on the ladder, and a frictional horizontal force H(Violet arrow) stops the ladder from slipping along the ground Additionally, there is a force Fat the top of the ladder normal to the wall (orange arrow, between the arms of the man)

Since the ladder is in static equilibrium, the condition for equilibrium on the forces is $H = F$, and for torques is

$w_L(L/2)\cos(\theta) + w_m(L-d)\cos(\theta) = F\,L\sin(\theta)$

The basic equilibrium equations governing the stability of this ladder are:

i) Σ Forces acting in x direction = 0

$$H - F = 0$$

Where, H=Friction between ground and the ladder and F = Normal reaction of the wall on the ladder

$$F = \mu \times R_1 = 018371 \times (800+300) \times 987 = 202 \text{ N}$$

ii) Σ Forces acting in y direction = 0

$$Fr + R_1 - Wm - W_L = 0,$$

Where, Fr = Friction between ladder and the wall, R1 = Normal reaction of ground on the ladder, Wm = Weight of Man and W_L = weight of ladder

iii) Σ Moments about a point = 0

$$w_L(L/2)\cos(\theta) + w_m(L-d)\cos(\theta) = F\,L\sin(\theta)$$

The minimum coefficient of friction required is

$$\mu_S = \frac{H}{F_N} = \frac{H}{w_L + w_m}$$

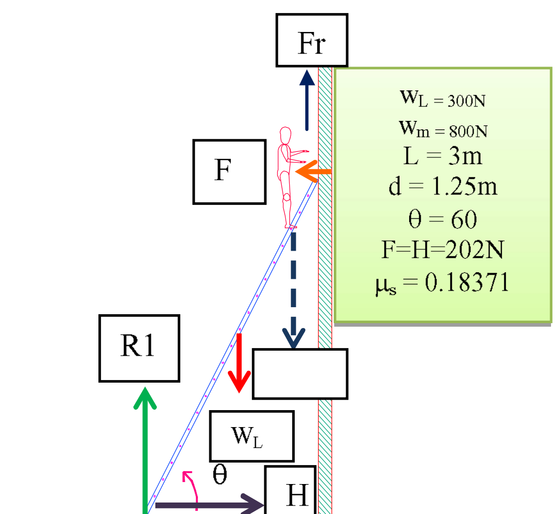


Figure : 14

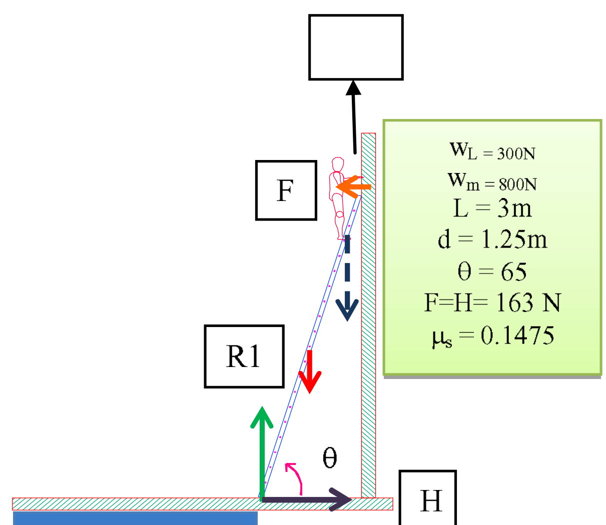
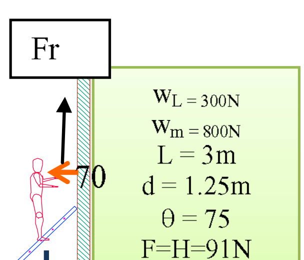
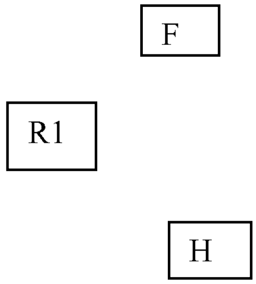


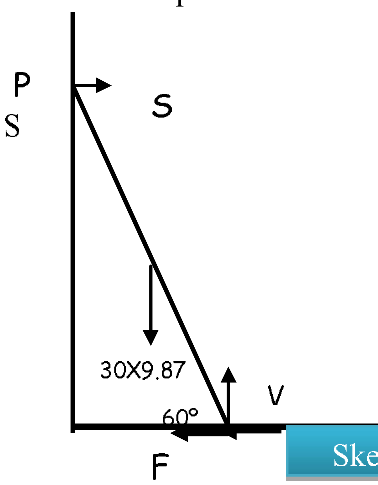
Figure : 15





4 Schematic showing ladder placed at different angles

A uniform ladder of mass 30kg rests against a smooth vertical wall with its lower end on rough ground (coefficient of friction 025), and its top against a smooth vertical wall The ladder rests at an angle of 60° to the horizontal Find the magnitude of the minimum horizontal force required at the base to prevent slipping



Sketch: 1

We need to find S, V, R and F Let's determine find first is S

Taking moments about Q gives:

S X L Sin60° = 30Kg X 05 Cos 60°

S = 30 X 987 X 15 Cos 60° / L Sin 60°

S = 8557 N

Resolving vertically gives:

R = 30X987 = 2961 N

Resolving horizontally gives:

S = F + V

Given that F = μR , where coefficient of friction μ = 025

$$8557 = 025 \times 30 \times 987 + V$$

8557 = 7402 + V

V = 1155 N

What is the maximum horizontal force that could be applied at the base of the ladder without slipping occurring?

In this situation friction is acting in the opposite direction

Therefore, S + F = V

8557 + 7402 = V, V = 159595 N

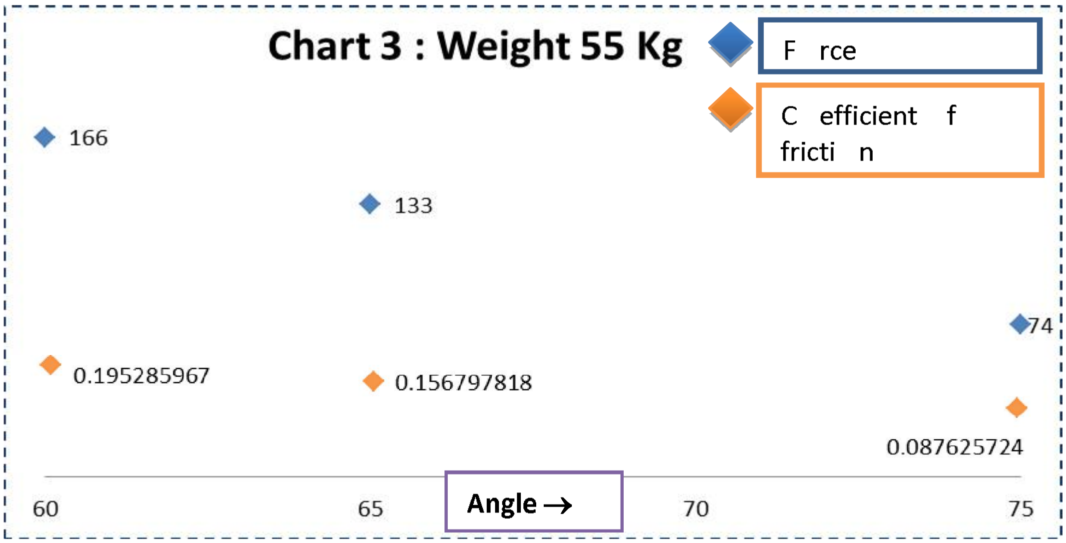
However usage of ladders and mounting it with varying slope angles as per different applications on various structures poses a big challenge, prompting the need of exploring easily adoptable solutions Slope of the ladder (angle with the base) creates significant impact on the acting force of the ladder as well as on the coefficient of friction Details of the same are as provided below

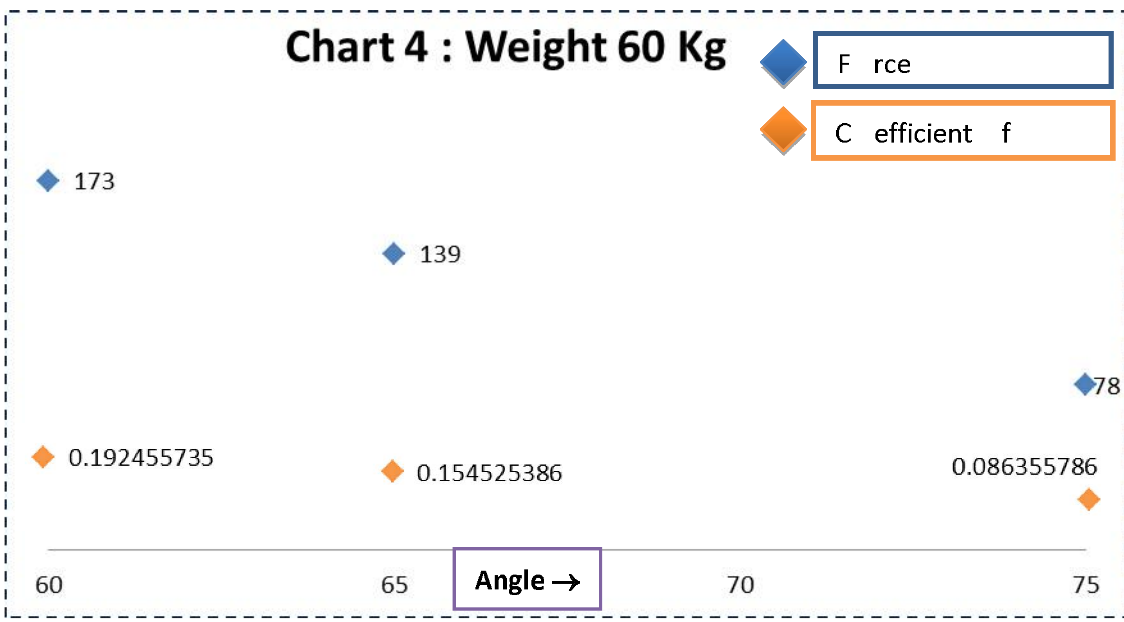
2 Variation of co-efficient of friction and force with various angles

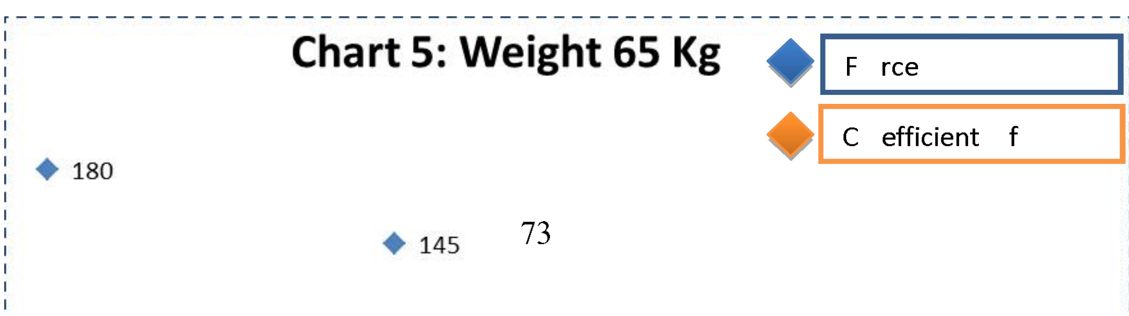
Weight	Angle	µs	F rce
Weight 55 Kg	60	0195286	166
Weight 55 Kg	65	0156798	133
Weight 55 Kg	75	0087626	74
Weight 60 Kg	60	0192456	173
Weight 60 Kg	65	154525	139
Weight 60 Kg	75	0086356	78
Weight 65 Kg	60	189923	180
Weight 65 Kg	65	152492	145
Weight 65 Kg	75	008522	81
Weight 70 Kg	60	187644	188
Weight 70 Kg	65	0150662	151
Weight 70 Kg	75	0084197	84
Weight 75 Kg	60	0185582	195
Weight 75 Kg	65	0149007	156
Weight 75 Kg	75	0083272	87
Weight 80 Kg	60	0183708	202
Weight 80 Kg	65	147502	162
Weight 80 Kg	75	0082431	91

However when the slope is maintained at 75 degree which is considered safe, no significant change is observed in the horizontal component while requirement of coefficient of friction also remains almost unchanged irrespective of weight of the subject

Study on the force and required coefficient of friction of ladder at various angles with varying weight of the subject are represented in the graphs given below:







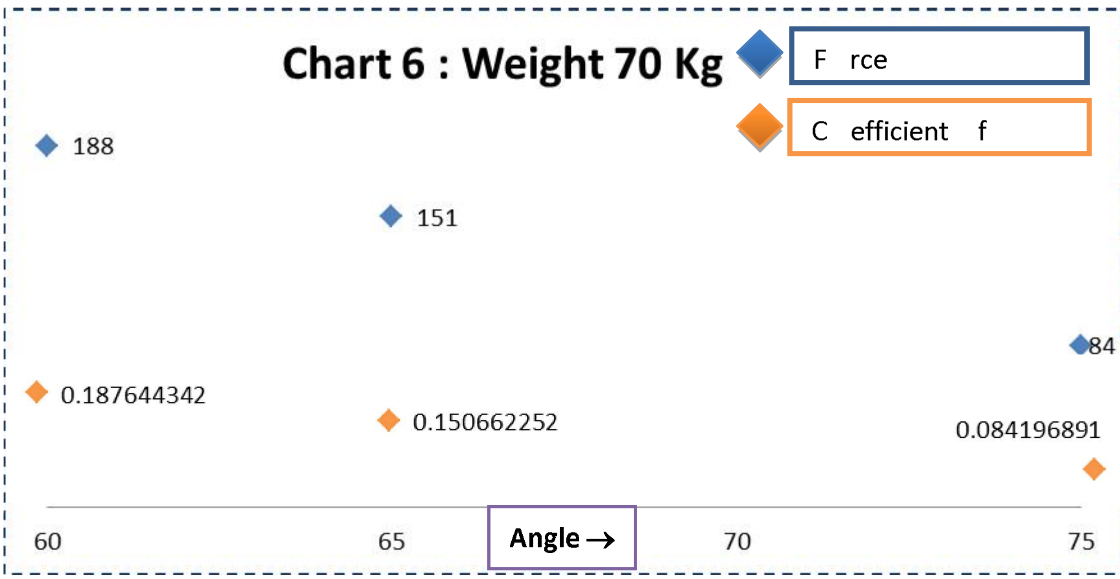


Chart 6 : Weight 70 Kg
F rce
C efficient f
188
151
84
0.187644342
0.150662252
0.084196891
60
65
Angle →
70
75

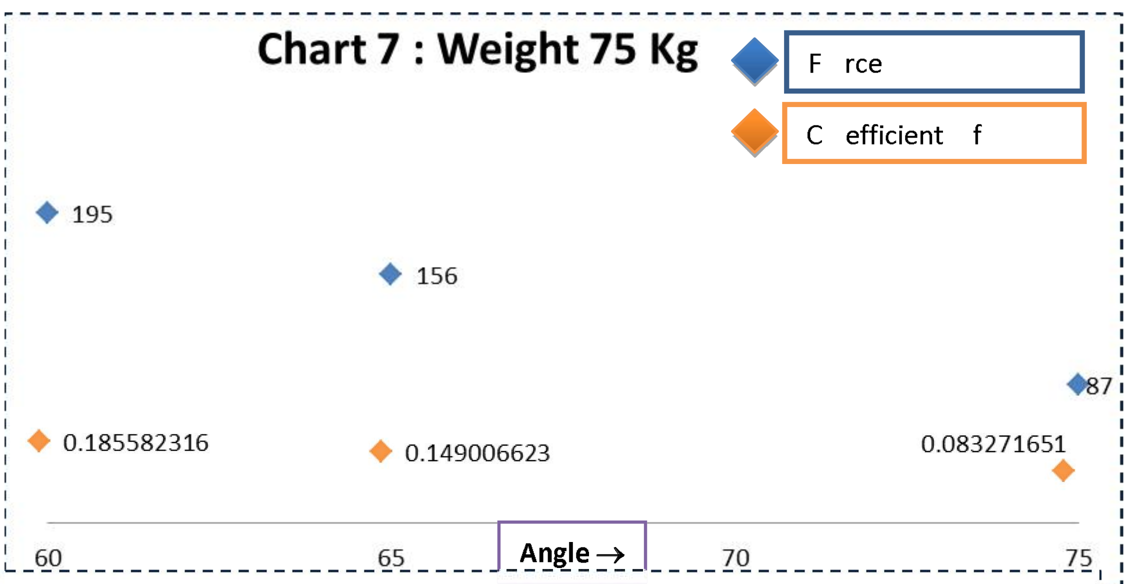


Chart 7 : Weight 75 Kg
F rce
C efficient f
195
156
87
0.185582316
0.149006623
0.083271651
60
65
Angle →
70
75

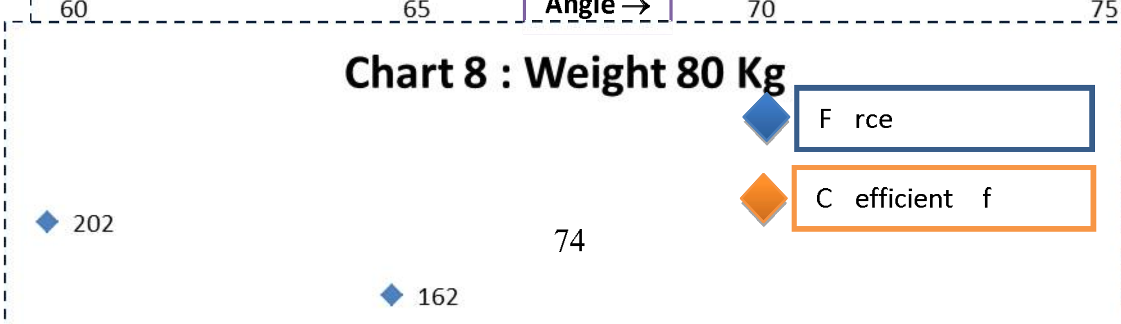


Chart 8 : Weight 80 Kg
F rce
C efficient f
202
162

5 Charts showing force and required co-efficient of friction at various angles

Ladder is not intended to be used as work platform or scaffold Only low-risk, light works of small duration such as changing of lamp or fixing a poster, may be done using a ladder Vibrational study, as well as deflection of ladder could be relevant but will involve complex calculations and may lead to significant errors Hence we are limiting our study to static loading of ladders

1 Deflecti n f Aluminum ladder:

When tested in accordance with annex B of British Standard 2037: 1994, the deflection of the loaded stiles shall not exceed the limit determined by the following equations:

Maximum allowable deflection (mm) for ladders with test span less than 12m

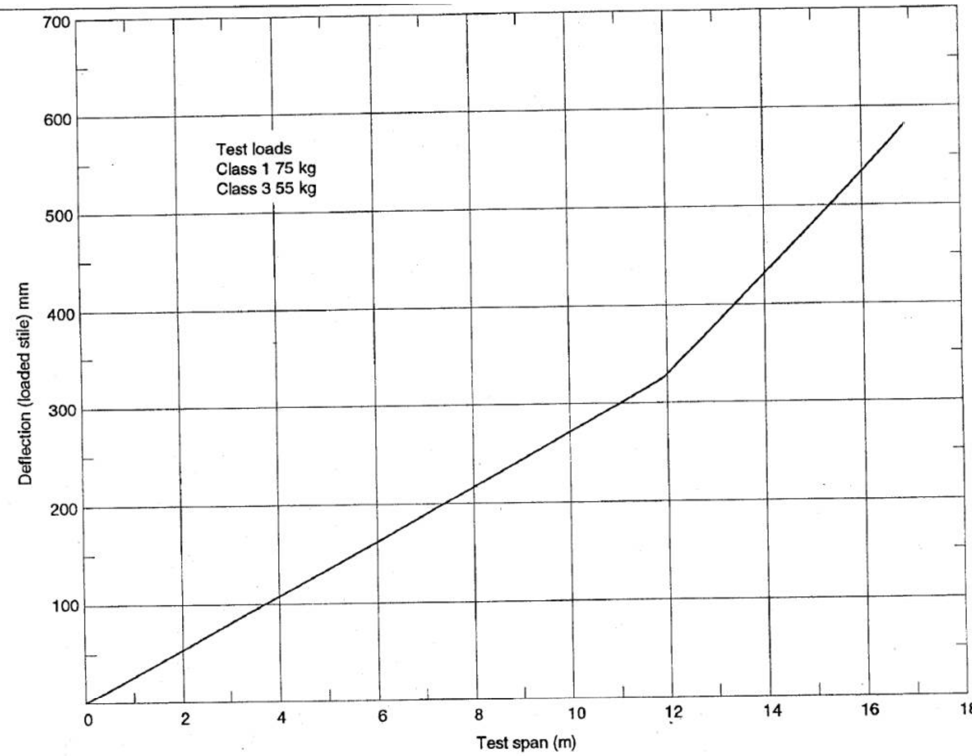
= L/372

Maximum allowable deflection (mm) for ladder with test span over 12m

= 3225 + (L-12000)/1875

Where

L is the test span (mm)



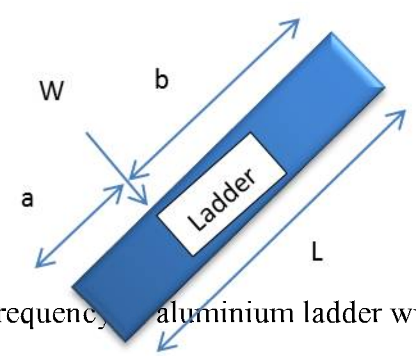
NOTE. The graph is for guidance only. The equations given in 2.1.2.1 are to be used for limit determination.
Figure 2. Maximum stile deflection under load

6 Deflection versus span length graph

In view of this the length of ladder should be limited to 12 m In fact as per the requirements of Indian Standards it is also recommended to ensure that overall length of stock ladders shall not exceed 10 m[1]

2 Deflecti n f a ladder

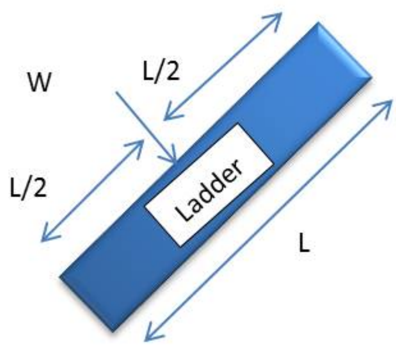
Aspect of deflection and vibration of ladder may play an important role in stability Accordingly, these aspects are studied assuming the ladder as a tubular structure made of single tube of 6m length Range of weight of a person is studied for two criteria namely, with eccentric point load as well as central point load Details for the same are as given below:



Ta Deflection and frequenc aluminium ladder with eccentric load

Sl No	Weight of person in kg	Weight of person in (N)	Deflection (δ), m $\delta = W a^2 b^2 / 3EIL$	Frequency (f_n), Hz 04985/√δ
1	90	883	03	10
2	85	834	02	10
3	75	736	02	11
4	65	638	02	12
5	55	540	02	13

Case 2: With point load at the centre:



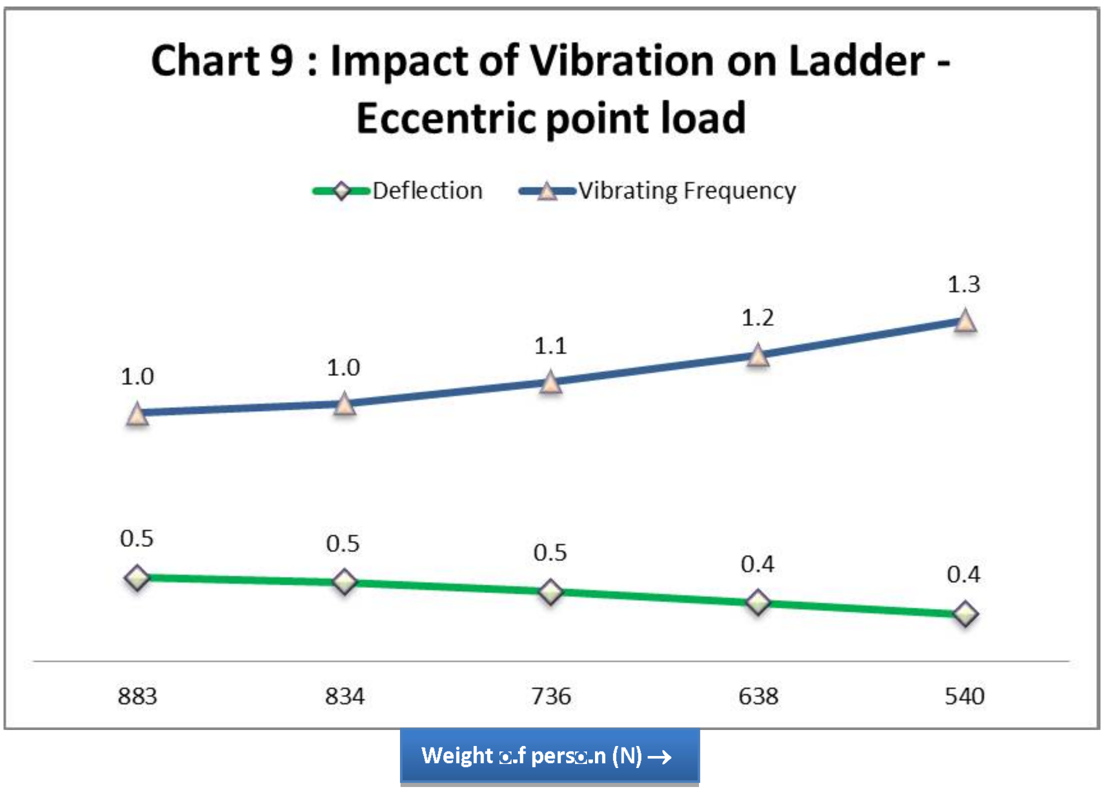
Deflection and frequency of aluminium ladder with point load at the centre

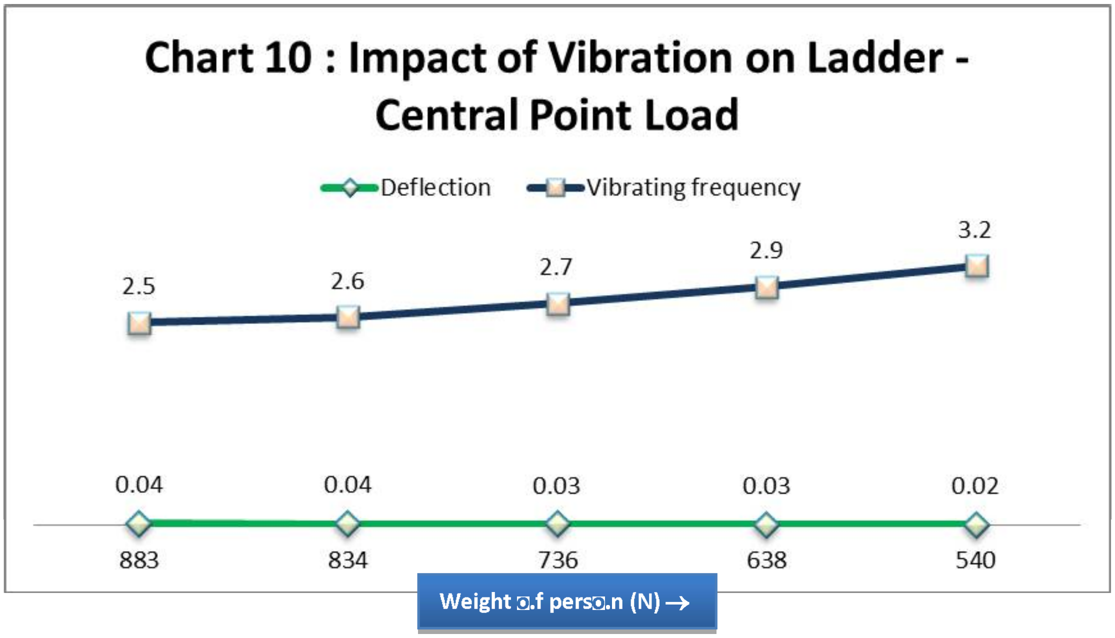
Sl No	Weight of person in kg	Weight of person in (N)	Deflection (δ), m $W L^3 / 48EI$	Frequency (f_n), Hz 04985/√δ
1	90	883	003	25
2	85	834	003	26
3	75	736	003	27
4	65	638	002	29
5	55	540	002	32

From the study we infer that the deflection of ladder is directly proportional to the increase in weight of the person for both the cases of eccentric loading as well as with point load at the centre However, it is found that frequency of vibration of a ladder is inversely proportional to the weight of the person for both the cases, ie, with eccentric loading as well as at the central point loading The inverse variations of vibrational frequencies is mainly attributed to the damping factor resulted due to variation of weight of the person

It is observed that the frequency of vibration at central point loading increases to nearly 25 times in comparison to eccentric point loading

The details of the same are given in chart 9 and 10 as given below:





Impact of vibration on ladder

6 HSE systems t check ladder c mpliance:

During regular HSE inspections at site several deviations are highlighted including ladders usage These deviations were highlighted through a site wide survey of Unsafe Act / Unsafe Condition indicator which highlights with an alarm point

The system of scaffold management were enhanced though involvement of competent scaffold erectors at scaffold construction stage, inspection checks by Supervisors of Sub-contractors as well as from the company, inspection and certification by scaffold inspectors , HSE personnel etc

Important aspects of scaffold management system are as given below:

1 Design and Selecti n:

During this phase scaffold and ladder requirements are stu Ladder specification determined considering the angle and base material specification

2 Ladder fixing:

During this stage competent crew fixes the ladder under the surveillance of competent supervisor and will be put to scrutiny before use by the end-user

3 Inspecti n and certificati n:

After erection and fixing, complete safety aspects, including fixing of ladders, slope angle, conditions of ladder etc are checked and inspected by team before putting it into use Once after clearing inspection criteria suitable scaffold tags are provided such as RED for not for use and GREEN ready for use

7 Pr p sed Impr vement:

It is evident from the study that slippage of ladder is one of the most important contributor of ladder related incidents Hence it was felt necessary to bring out improvement in this specific area through engineering controls focusing on ladder fixing arrangement [2]for improving safe conditions at work place

Accordingly an effective latching system has been developed for quick and easy fixing of the ladders to prevent slipping as well as for providing appropriate safe angle for usage An Indicative drawing and its fixing arrangement are as given below In-built check for the ladder angle and confirmation of the same in the ladder checklist which forms the basis for certification The same shown in figure 16 and 17 given below

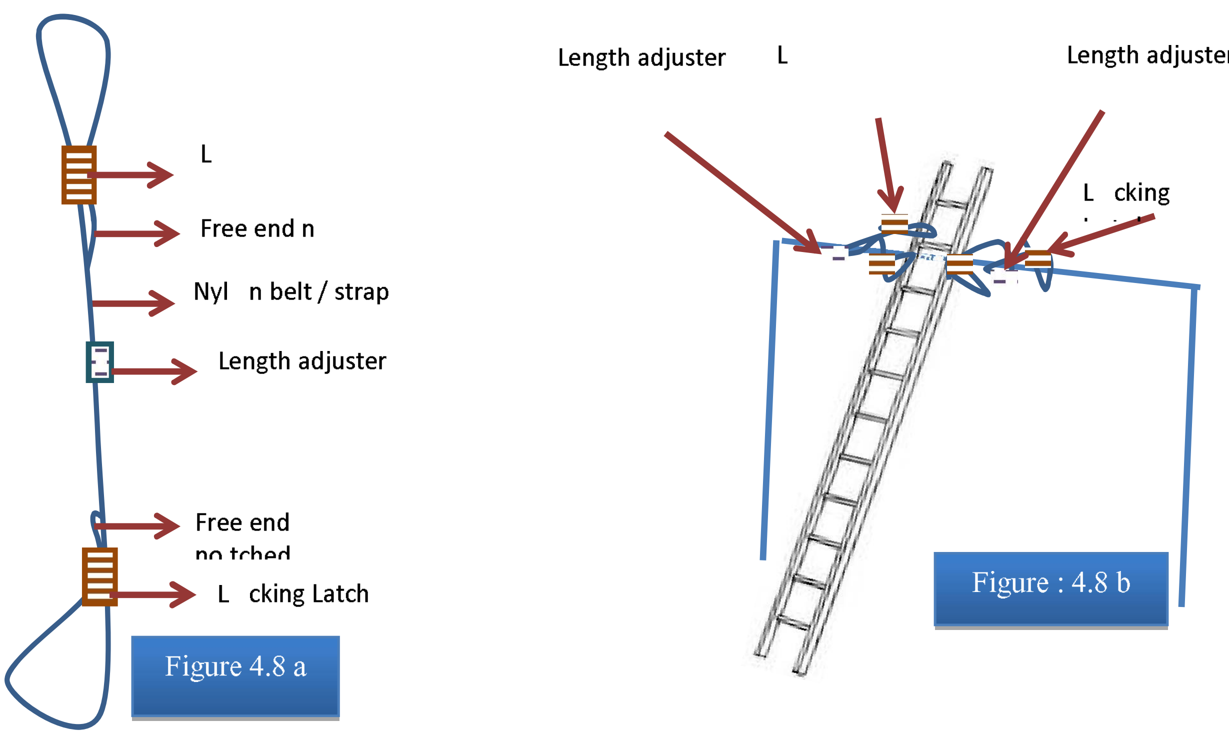


Figure 4.8 a

Figure : 4.8 b

Details of Latching system

Figure 4.9 a

Figure 4.9 b

Sketch of latched ladder

Safety aspects of ladder are covered in various legal and other requirements In India, Rule 172 of Building and other Construction Workers' (Regulation of Employment and Conditions of Service) Central Rules, 1998 address this in detail Similarly, in USA, OSHA Regulation Rule 19261053(b)(1) of Safety and Health Regulations for Construction highlights the same

Similarly, Indian Standards 3696 (Part 2) "Scaffolds and Ladders Code of Safety" covers various aspects of Safe Usage of ladder

8 Discussi n

In view of the extensive usage of portable ladders at construction sites for various reasons, it is necessary to ensure that effective engineering and administrative measures are taken to ensure overall safe usage and prevention of incidents This includes placement of ladder at recommended angle to ensure stability and rigidity of the same Considering frequent mobility requirements, it is important to have some "easy-to-fix" arrangement from practical view point

In order to check the impact of coefficient of friction and forces on ladder a wide range of personnel with various body weights, starting from 55kg to 80 kg were considered Subsequently impact of the load on ladders placed at an angle 60°, 65° & 75° was determined

From this study it revealed that the values of coefficient of friction were almost same for various body weights when ladder was placed at a different angle The values of coefficient of friction increased as the ladder was decreased from the safe angle of 75° Coefficient of friction increased to 44% when the angle of ladder was reduced to 65° and it further increased to 55% when the angle of ladder was further reduced to 60° The values of force showed variance with respect to the change in body weights as well as the change in ladder angle However the impact of force was found to be notably low when the ladder was kept at 75° angle and the same increased with reference to the decrease in angle as well as with increase in body weight When the ladders was decreased from its safe angle of 75°, force increased by 44% when the angle of ladder was reduced to 65° and it further increased to 55% when the angle of ladder was further reduced to 60° Hence in from the perspectives of coefficient of friction as well as the force it was observed that safe angle of ladder with reference to the ground level is 75° irrespective of the body weight It is advisable to maintain the ladder angle of 75°

In terms of deflection and vibrational frequency ladder was tested at point load at center as well as at eccentric point with varying body weight at a range of 55, 65, 75, 85, & 90 Kgs In both the cases no significant impact was observed in terms of deflection However there were considerable variations in vibrational frequency in comparison with eccentric as well as centric point loads From eccentric point loading to point load at center, vibrational frequencies increased over 145% Hence from this research we infer that the safe angle of ladder with respect to the horizontal is 75° and natural frequency of vibration tends to be higher when any person moves past the center portion of the ladder