## CLEARANCE REQUIREMENT GUIDELINES

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Registry Number:
SPC-02
Revision History:
Version 22A Board and SOC Approved August 2022
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## Notes for Use:

Terminology from SPRAT's Defined Terms used in this document is shown in bold, italic type unless written in a primary section heading.

Use of the word 'shall' denotes a mandatory requirement.
Use of the word 'should' denotes a recommendation. The word 'should' does not connote indifference or ambivalence regarding a statement.

Approximate conversions of units are presented in parentheses. These approximations are provided as a reference and are not the standard. When a value is presented as a limit, approximations are greater than an expressed minimum or less than an expressed maximum.

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## 1. Purpose, Scope, and Exceptions

### 1.1. Purpose

1.1.1. The purpose of this document is to provide rope access technicians and other individuals that work at height with the resources to estimate and calculate clearance requirements of rope access systems and other personal fall protection systems.
1.1.2. This document is intended to be used in conjunction with manufacturer supplied information during the job planning phase within rope access and fall protection programs that ensures fall protection systems are used in a manner to minimize free fall potential.

### 1.2. Scope

1.2.1. This document provides:
1.2.1.1. The phases of a fall event.
1.2.1.2. Contributing factors to clearance requirements within each fall event phase.
1.2.1.3. Considerations for calculating clearance requirements.
1.2.1.4. Examples of calculating clearance requirements for personal fall protection systems.
1.3. Exceptions
1.3.1. This document does not address:
1.3.1.1. Additional clearance considerations from the sag of horizontally tensioned fall protection systems used within fall protection systems, such as tensioned rope systems or horizontal lifelines.
1.3.1.2. The effect on clearance requirements by obstructions that may contact fall protection systems during a fall event.
1.3.1.3. Calculating anchorage system strength or energy capacity requirements of fall protection systems.
1.3.1.4. Determining fall protection systems for a specific work environment and ensuring their appropriate use is a requirement within managed rope access and fall protection programs.

## 2. Total Fall Distance

2.1. A fall of an individual using a personal fall protection system may consist of three phases:
2.1.1. Free fall, during which a falling individual accelerates due to the forces of gravity, unimpeded by arresting forces of the personal fall protection system.
2.1.2. Swing fall, during which a falling individual experiences a pendulum or swinging effect.
2.1.2.1. A swing fall may occur simultaneously with the other phases of a fall.
2.1.2.2. All clearance requirement examples provided in this document assume zero swing fall.
2.1.2.3. Appendix 1 provides example calculations related to swing falls.
2.1.3. Deceleration, during which a falling individual is brought to rest by the personal fall protection system.
2.2. The sum of the vertical distances traveled during these phases is total fall distance, as depicted by the equations in Figure 1.
Figure 1 Components of Total Fall Distance

| Free fall distance (FF) |
| ---: |
| Swing fall distance (SFD) |
| + Deceleration distance (DD) |
| Total fall distance (TFD) |
| TFD $=\mathrm{FF}+\mathrm{SFD}+\mathrm{DD}$ |

## 3. Free Fall Distance Factors

### 3.1. Free fall potential $\left(F F_{L}\right)$

3.1.1. Free fall potential can be visualized as slack within a fall protection system prior to a fall.
3.1.2. Free fall potential is a result of the harness attachment in relation to its connection to an anchorage or a rope system, the connection length, and additional system slack.
3.1.3. Free fall potential is a sum of these factors, as depicted in Figure 2.

Figure 2 Components of Free Fall Potential
Relative harness attachment height $\left(H_{D A}\right)$
Connection length $\left(L_{y}\right)$

+ Additional system slack $\left(S_{A}\right)$
Free fall potential $\left(F F_{L}\right)$
$F F_{L}=H_{D A}+L_{y}+S_{A}$
3.1.4. Relative harness attachment height ( $H_{D A}$ )
3.1.4.1. The relative harness attachment height $\left(H_{D A}\right)$ is the vertical distance between the harness attachment and its connection via components (e.g., lanyard) to an anchorage system or rope system.
3.1.4.1.1. This value $\left(H_{D A}\right)$ is positive if the harness attachment is above that connection.
3.1.4.1.2. This value $\left(H_{D A}\right)$ is negative if the harness attachment is below that connection.
3.1.5. Connection length $\left(L_{y}\right)$
3.1.5.1. The connection length is the total length of all components (e.g., carabiners, energy absorbers, lanyards) connecting a harness attachment to an anchorage system or rope system.
3.1.6. Additional system slack $\left(S_{A}\right)$
3.1.6.1. Additional system slack may arise from several factors, such as:
3.1.6.1.1. Attachments to anchorages that allow for vertical movement of connectors prior to loading.
3.1.6.1.2. The introduction of slack in a rope system above a backup device.
3.1.6.2. As additional system slack arises only from inappropriate use of the systems analyzed in this document, clearance requirement examples assume zero additional system slack.


### 3.2. Activation distance $\left(\mathrm{FF}_{\mathrm{A}}\right)$

3.2.1. Activation distance is any vertical increase in the length of a fall protection system that does not correspond to absorption of appreciable energy of a fall.
3.2.2. Activation distance may vary with the free fall potential of a fall protection system.
3.2.3. As measuring activation distance is not practical in some fall protection systems, manufacturers will often provide an arrest distance value, which combines activation distance with deceleration distance.

### 3.3. Obstructions

3.3.1. When the harness attachment of the individual is not on the same approximate fall line as the anchorage, the free fall distance may be reduced.
3.3.2. If the fall protection system may encounter an obstruction during free fall, the geometry of the anchorage location, individual, and any possible obstructions, should be analyzed to determine the free fall distance.
3.3.2.1. A common example of this scenario is when an anchorage is selected away from an exposed edge.
3.3.3. Clearance requirement examples in this document assume zero horizontal distance between the anchorage and the individual.

## 4. Deceleration Distance Factors

### 4.1. Personal energy absorber deployment ( $x_{P E A}$ )

4.1.1. If the average deployment force of the personal energy absorber and an individual's weight are known, deployment of an energy absorber for a given height can be calculated by the equation shown in Figure 3.

Figure 3 Calculating Energy Absorber Deployment

$$
\begin{aligned}
\text { Personal energy absorber deployment }\left(x_{P E A}\right) & =\frac{\text { Weight }(W) \times \text { Free fall distance }(F F)}{\text { Average deployment force }\left(F_{C L R}\right)-\text { Weight }(\mathrm{W})} \\
x_{P E A} & =\frac{W \times F F}{F_{C L R}-W}
\end{aligned}
$$

4.1.1.1. As average deployment force values published on equipment may be a maximum allowable value, any published value should be confirmed by the manufacturer prior to using this method for calculation energy absorber deployment.
4.1.1.2. Overestimating the average energy absorber deployment force leads to underestimating deceleration distance and thus underestimating clearance requirements.
4.1.2. Manufacturers can provide data that provides energy absorber deployment distance as a function of an individual's weight, which may then be used to calculate clearance.
4.1.3. An example of an energy absorber with maximum deployment of 100 cm ( 39 in ) that deploys at an average force of $3.2 \mathrm{kN}(710 \mathrm{lbf})$ is provided in Figure 4.
4.1.4. If no other data is available, the maximum deployment of the energy absorber should be used.

Figure 4 Chart and Graph of Energy Absorber Deployment Distance as a Function of Mass and Free Fall Distance

Mass

| Free Fall Distance | $60 \mathrm{~kg}(132 \mathrm{lb})$ | $100 \mathrm{~kg}(220 \mathrm{lb})$ | 141 kg (310 lb) |
| :---: | :---: | :---: | :---: |
| $0.3 \mathrm{~m}(1 \mathrm{ft})$ | 7 cm (2 in) | 14 cm (5 in) | 24 cm (9 in) |
| 0.6 m (2 ft) | 14 cm (6 in) | 28 cm (11 in) | 48 cm (19 in) |
| 0.9 m (3 ft) | 21 cm (8in) | 41 cm (16 in) | 71 cm (28 in) |
| 1.2 m (4 ft) | 28 cm (11 in) | 55 cm (22 in) | 95 cm (37 in) |
| 1.5 m ( 5 ft ) | 35 cm (14 in) | 68 cm (27 in) | 100 cm (39 in)* |
| 1.8 m (6 ft) | 42 cm (17 in) | 82 cm (32 in) | 100 cm (39 in)* |
| 2.1 m (7ft) | 49 cm (19 in) | 96 cm (38 in) | 100 cm (39 in)* |
| 2.4 m (8ft) | 56 cm (22 in) | 100 cm (39 in)* | 100 cm (39 in)* |
| 2.7 m (9 ft) | 63 cm (25 in) | 100 cm (39 in)* | 100 cm (39 in)* |

*Bold, red font indicates maximum energy absorber deployment

Example: $1.5 \mathbf{m}$ ( $\mathbf{5 ~ f t ) ~ f r e e ~ f a l l ~ o f ~ a ~} 100 \mathbf{~ k g ~ ( 2 2 0 ~ l b ) ~ i n d i v i d u a l ~}$

4.2. Rope stretch $\left(x_{R}\right)$ and Lanyard stretch $\left(x_{L}\right)$
4.2.1. The force used for calculations should be the average deployment of an energy absorber incorporated into the backup system, or the slippage force of the backup device.
4.2.2. If lanyard or rope stretch values are available from a manufacturer, rope stretch may be calculated through modeling.
4.2.3. Alternatively, rope stretch may be estimated by measuring the stretch of a rope under the user's weight, multiplying that value by the average deployment of the energy absorber, and dividing by the user's weight.
4.2.4. If manufacturer or testing data is unavailable, the following percentages should be used when calculating clearance for rope systems:
4.2.4.1. Low elongation rope: $10 \%$
4.2.4.2. High elongation rope: $35 \%$
4.3. Combining deceleration distance factors
4.3.1. All deceleration distance factors dissipate a portion of the kinetic energy created during the fall.
4.3.2. Energy balance analysis allows for accounting the multiple factors to provide a more accurate deceleration distance.
4.3.2.1. If energy balance analysis is not possible, each deceleration distance factor should be considered and added together separately.

## 5. Additional Clearance Factors

### 5.1. Stretch-out ( $x_{W}$ )

5.1.1. Harness stretch-out
5.1.1.1. Factors affecting harness stretch-out under normal use may include:
5.1.1.1.1. Harness stretching.
5.1.1.1.2. Flipping of the D-ring.
5.1.1.1.3. Sliding of the D-ring.
5.1.1.1.4. Deployment of any visual indicator.
5.1.1.2. Additional stretch-out will occur from a harness not being fitted to the individual.
5.1.1.2.1. Clearance requirement examples in this document assume an appropriately fitted harness.
5.1.1.3. The manufacturer should be consulted for a harness stretch-out value.
5.1.1.3.1. If manufacturer or testing data is unavailable, a value of $0.45 \mathrm{~m}(1.5 \mathrm{ft})$ should be used to account for harness stretch-out variables.
5.1.2. Body stretch-out
5.1.2.1. During a fall, an individual's body will straighten and rotate until supported by the selected harness attachment to the fall protection system, which may increase the overall clearance requirement.
5.1.2.2. The following values should be added during clearance calculations as additional stretch-out:
5.1.2.2.1. For a seated individual, $0.45 \mathrm{~m}(1.5 \mathrm{ft})$ for dorsal attachments, $0 \mathrm{~m}(0 \mathrm{ft})$ for sternal attachments.
5.1.2.2.2. For a kneeling individual $0.75 \mathrm{~m}(2.5 \mathrm{ft})$ for dorsal attachments, $0.3 \mathrm{~m}(1 \mathrm{ft})$ for sternal attachments.
5.1.2.2.3. For a prone individual $1.2 \mathrm{~m}(4 \mathrm{ft})$ for dorsal attachments, $0.75 \mathrm{~m}(2.5 \mathrm{ft})$ for sternal attachments.
5.1.2.3. If the harness attachment cannot be ensured for a given fall, the dorsal attachment should be used as a reference in calculations.

### 5.2. Clearance margin (CM)

5.2.1. A Clearance margin should be added to allot for considerations that have not been accounted for in the other clearance factors, such as:
5.2.1.1. Taller individuals.
5.2.1.2. Elongation of anchorage systems or lanyard stretch.
5.2.1.3. Underestimation of deceleration distance due to modeling assumptions.
5.2.2. Clearance margins should not be used to account for inappropriate use of equipment.
5.2.3. Clearance margin may be reduced as:
5.2.3.1. A fall event is better modeled during clearance calculations to account for variables, such as the reduction of impact force during deceleration.
5.2.3.2. Other controls in rope access and fall protection programs are implemented.
5.2.4. For the purposes of this document, $0.6 \mathrm{~m}(2 \mathrm{ft})$ is used as a clearance margin.

## 6. Calculating Required Clearance

6.1. For the purposes of this document, clearance is calculated with reference to the work platform.
6.1.1. Calculating clearance using the height of the anchorage may be appropriate in some circumstances, the reference used for clearance requirements should be verified for comparing clearance calculations with other references, such as manufacturer specifications.
6.2. Required clearance below a platform $\left(C_{P}\right)$ is expressed as a sum of the clearance factors, as depicted in Figure 5.

| Figure 5 Calculating Clearance Below a Work Platform |
| ---: |
| Free fall distance $(F F)$ |
| Swing Fall distance $(S F D)$ |
| Deceleration distance $(D D)$ |
| Stretch-out $\left(x_{W}\right)$ |
| + Clearance margin $(C M)$ |
| Required clearance below platform $\left(C_{P}\right)$ |
| $C_{p}=F F+S F D+D D+x_{W}+C M$ |

6.3. Assuming no swing fall distance and expressing free fall distance as a sum of its factors allows for the expressions in Figure 6 to be derived.

Figure 6 Calculating Clearance with Separated Free Fall Distance Components
Free fall distance $(F F) \quad\left\{\begin{array}{r}\text { Free fall potential }\left(F F_{L}\right) \\ \text { Activation distance }\left(F F_{A}\right) \\ \text { Deceleration distance }(D D) \\ \text { Stretch-out }\left(x_{W}\right)\end{array}\right\}$ Arrest distance $(A D)$
6.4. If the available clearance for a given work location is lower than the calculated required clearance, consideration should be given for one or more of the following:
6.4.1. A more appropriate fall protection system.
6.4.2. A more accurate calculation of required clearance.

## 7. Clearance of Energy Absorbing Lanyards

### 7.1. Free fall distance factors

7.1.1. With no activation distance, free fall distance is equal to free fall potential and can be expressed as:

$$
F F=F F_{L}=H_{D A}+L_{y}
$$

7.2. Deceleration distance factors
7.2.1. Deceleration distance includes deployment of the energy absorber and any lanyard stretch:

$$
D D=x_{P E A}+x_{L}
$$

7.2.1. When an energy absorber is incorporated within a lanyard with a maximum length of $1.8 \mathrm{~m}(6 \mathrm{ft})$, the effect of lanyard stretch on deceleration distance is typically nominal.
7.2.1.1. Lanyard stretch is considered negligible in the clearance requirement examples for energy absorbing lanyards in this document.

### 7.3. Schematic

7.3.1. A schematic depicting the factors for calculating clearance is presented in Figure 7.
7.4. Final equations

$$
\begin{aligned}
& C_{p}=\overbrace{H_{p}}^{F F}+\overbrace{H_{D A}+L_{y}}^{F}+\overbrace{x_{P E A}+x_{L}}^{D D}+x_{W}+C M
\end{aligned}
$$

Figure 7 Clearance Components of Energy Absorbing Lanyards

7.5. Clearance Requirement Examples for Energy Absorbing Lanyards
7.5.1. Example 1 - Clearance assuming full deployment of energy absorber
7.5.1.1. An individual is standing on a platform and is attached to an anchorage $0.6 \mathrm{~m}(2 \mathrm{ft})$ above the harness attachment with an energy absorbing lanyard that has a length of $1.8 \mathrm{~m}(6 \mathrm{ft})$ and a maximum deployment distance of 1 m ( 3.5 ft ). Harness stretch-out is known to be $0.3 \mathrm{~m}(1 \mathrm{ft})$.
7.5.1.2. What is the clearance requirement below the platform assuming negligible lanyard stretch and full deployment of the energy absorber?

| Relative harness attachment height $\left(H_{D A}\right)$ | -0.6 m | -2 ft |
| ---: | ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 1.8 m | 6 ft |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 1 m | 3.5 ft |
| Lanyard stretch $\left(x_{L}\right)$ | 0 m | 0 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| + Clearance margin $(C M)$ | 0.6 m | 2 ft |
|  | 3.1 m | 10.5 ft |

7.5.2. Example 2 - Clearance using energy balance analysis
7.5.2.1. If the energy absorber in the lanyard is the same as the one in Figure 4, what is the clearance requirement below the platform for a $100 \mathrm{~kg}(220 \mathrm{lb})$ individual?

| Relative harness attachment height $\left(H_{D A}\right)$ | -0.6 m | -2 ft |  |
| ---: | ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 1.8 m | 6 ft |  |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 0.55 m | 1.8 ft |  |
| Lanyard stretch $\left(x_{L}\right)$ | 0 m | 0 ft |  |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |  |
| + Clearance margin $(C M)$ | $\frac{0.6 \mathrm{~m}}{2 \mathrm{ft}}$ | $\frac{2.65 \mathrm{~m}}{}$ |  |
| Required clearance below platform $\left(C_{P}\right)$ | 8.7 ft |  |  |

7.5.3. Example 3 - Clearance from attaching energy absorbing lanyard at height of platform
7.5.3.1. Instead of attaching to a higher anchorage, the individual attaches the energy absorbing lanyard to the height of the platform, which is located $1.5 \mathrm{~m}(5 \mathrm{ft})$ below their harness attachment. Using the energy absorber from Figure 4, what is the clearance requirement below the platform for a $100 \mathrm{~kg}(220 \mathrm{lb})$ individual? Is there any additional concern from this configuration?

| Relative harness attachment height ( $H_{D A}$ ) | 1.5 m | 5 ft |
| :---: | :---: | :---: |
| Connection length ( $L_{y}$ ) | 1.8 m | 6 ft |
| Energy absorber deployment ( $x_{P E A}$ ) | 1 m | 3.5 ft |
| Lanyard stretch ( $x_{L}$ ) | 0 m | 0 ft |
| Stretch-out ( $x_{W}$ ) | 0.3 m | 1 ft |
| + Clearance margin (CM) | 0.6 m | 2 ft |
| Required clearance below platform ( $C_{P}$ ) | 5 m | 21 ft |

The energy absorber is expected to reach maximum deployment at a free fall distance of $2.4 \mathrm{~m}(8 \mathrm{ft})$. A free fall distance of $3.3 \mathrm{~m}(11 \mathrm{ft})$ exceeds this threshold and is a clear misuse of this equipment. Arrest forces can be expected to be much higher, with increased possibility of injury sustained by the individual.

## 8. Clearance of Self-retracting Devices

### 8.1. Free fall distance factors

8.1.1. Free fall distance for self-retracting devices is the same as that of the energy absorbing lanyard example, with the addition of activation distance:

$$
F F=H_{D A}+L_{y}+F F_{A}
$$

8.1.2. For overhead self-retracting devices, free fall potential is zero, with only activation distance contributing to free fall distance.
8.1.3. Activation distance is variable based on the type of locking mechanism of a self-retracting device and the characteristics of the arrested fall.
8.1.4. If a fall initiates when the individual's harness attachment starts above the connection, unless otherwise specified by the manufacturer, no reeling in of the self-retracting device should be assumed.

### 8.2. Deceleration distance factors

8.2.1. Arresting elements of self-retracting devices may be approximated in a similar manner to the deployment of energy absorbers, and the equation is the same:

$$
D D=x_{P E A}+x_{L}
$$

8.2.2. Manufacturers typically use wire rope for longer lanyards resulting in negligible lanyard stretch.
8.3. Final equations
8.3.1. Including all terms of total fall distance factors, the final equation may be written as:

$$
C_{p}=\overbrace{C_{p}}=\overbrace{D A}^{+L_{y}+F F_{A}}+\overbrace{x_{P E A}+x_{L}}^{F F}+x_{W}+C M
$$

8.3.2 If arrest distance is available from the manufacturer, the equation may be written as:

$$
C_{p}=H_{D A}+L_{y}+A D+x_{W}+C M
$$

8.4. Clearance Requirement Examples for Self-Retracting Devices
8.4.1. Example 1 - Overhead self-retracting device
8.4.1.1. An individual is using an overhead self-retracting device with a verified arrest distance of $0.6 \mathrm{~m}(2 \mathrm{ft})$ and negligible lanyard stretch attached to their dorsal attachment on their harness. Assuming a harness stretchout of $0.3 \mathrm{~m}(1 \mathrm{ft})$, what is the clearance requirement?

| Free fall potential $\left(F F_{L}\right)$ | 0 m | 0 ft |
| ---: | ---: | ---: | ---: |
| Arrest distance $(A D)$ | 0.6 m | 2 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| + Clearance margin $(C M)$ | +0.6 m | +2 ft |
|  | 1.5 m | 5 ft |

8.4.2. Example 2 - Overhead self-retracting device: kneeling or crouching individual
8.4.2.1. The individual from Example 1 kneels on the platform to complete a task. Assuming all other variables from Example 1 are the same, what is the clearance requirement now?

| Free fall potential $\left(F F_{L}\right)$ | 0 m | 0 ft |
| ---: | ---: | ---: | ---: |
| Arrest distance $(A D)$ | 0.6 m | 2 ft |
| Stretch-out $\left(x_{W}\right)$ | 1.05 m | 3.5 ft |
| + Clearance margin $(C M)$ | +0.6 m | +2 ft |
| Required clearance below platform $\left(C_{P}\right)$ | 2.25 m | 7.5 ft |

8.4.3. Example 3 - Self-retracting device attached below harness attachment
8.4.3.1. A $141 \mathrm{~kg}(310 \mathrm{lb})$ individual has attached their self-retracting device, which arrests a fall with the same average deployment force as in Figure 4, to an anchorage 0.45 m ( 1.5 ft ) below their harness attachment. Assuming no reeling of the self-retracting device during a fall, negligible lanyard stretch, an activation distance of $0.15 \mathrm{~m}(0.5 \mathrm{ft})$, and a harness stretch-out of $0.3 \mathrm{~m}(1 \mathrm{ft})$, what is the clearance requirement?

| Relative harness attachment height ( $H_{D A}$ ) | 0.45 m | 1.5 ft |
| :---: | :---: | :---: |
| Connection length ( $L_{y}$ ) | 0.45 m | 1.5 ft |
| Activation distance ( $F F_{A}$ ) | 0.15 m | 0.5 ft |
| Energy absorber deployment ( $x_{P E A}$ ) | 0.95 m | 3 ft |
| Stretch-out ( $x_{W}$ ) | 0.3 m | 1 ft |
| + Clearance margin (CM) | + 0.6 m | $+2 \mathrm{ft}$ |
| Required clearance below platform ( $C_{P}$ ) | 2.9 m | 9.5 ft |

## 9. Clearance of Backup Systems

### 9.1. Free fall distance factors

9.1.1. Free fall distance for backup systems is the same as that of self-retracting devices:

$$
F F=H_{D A}+L_{y}+F F_{A}
$$

9.1.2. Activation distance for backup systems is highly variable, and may be directly or inversely related to free fall potential.
9.1.2.1. If no activation distance value is available from a manufacturer or from testing, $30 \mathrm{~cm}(1 \mathrm{ft})$ is commonly used as an approximation in clearance calculations.
9.2. Deceleration distance factors
9.2.1. Deceleration distance may be written as the sum of rope stretch $\left(x_{R}\right)$, energy absorber deployment ( $x_{P E A}$ ), and lanyard stretch $\left(x_{L}\right)$ :

$$
D D=x_{R}+x_{P E A}+x_{L}
$$

9.2.2. While backup systems using manual backup devices and rope lanyards may be modeled similarly to energy absorbing lanyards, clearance requirements should be calculated by treating backup device movement as activation distance.
9.3. Schematic
9.3.1. A schematic depicting the factors for calculating clearance is presented in Figure 8.

Figure 8 Clearance Components of Backup Systems

9.4. Final equations

$$
C_{p}=\overbrace{p}=\overbrace{H_{D A}+L_{y}+F F_{A}}^{C_{2}+x_{R}+x_{P E A}+x_{L}+x_{W}+C M}
$$

### 9.5. Clearance Requirement Examples for backup systems

9.5.1. Example 1 - Manual backup device using drop test data
9.5.1.1. A rope access technician with a mass of $100 \mathrm{~kg}(220 \mathrm{lb})$ is working with $15 \mathrm{~m}(49 \mathrm{ft})$ of rope above their backup device.
9.5.1.2. The backup device is $0.3 \mathrm{~m}(1 \mathrm{ft})$ above the rope access technician's sternal attachment.
9.5.1.3. The lanyard, which incorporates a dynamic rope, connecting the backup device to the rope access technician's sternal attachment is $0.6 \mathrm{~m}(2 \mathrm{ft})$ long.
9.5.1.4. Drop testing using a $100 \mathrm{~kg}(220 \mathrm{lb})$ weight has shown that the backup device slides up to $0.15 \mathrm{~m}(0.5 \mathrm{ft})$ prior to engaging the rope during a fall event.
9.5.1.5. Using the arrest forces from the drop testing, the backup rope is calculated to elongate $0.9 \mathrm{~m}(3 \mathrm{ft})$, and the dynamic rope lanyard is calculated to elongate $0.3 \mathrm{~m}(1 \mathrm{ft})$.
9.5.1.5.1. Harness stretch-out is known to be $0.3 \mathrm{~m}(1 \mathrm{ft})$.
9.5.1.6. How much clearance below the rope access technician is required?

| Relative harness attachment height $\left(H_{D A}\right)$ | -0.3 m | -1 ft |
| ---: | ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 0.6 m | 2 ft |
| Activation distance $\left(F F_{A}\right)$ | 0.15 m | 0.5 ft |
| Rope Stretch $\left(x_{R}\right)$ | 0.9 m | 3 ft |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 0 m | 0 ft |
| Lanyard stretch $\left(x_{L}\right)$ | 0.3 m | 1 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| + Clearance Margin $(C M)$ | 0.6 m | 2 ft |
| $\left(C_{P}\right)$ | 2.55 m | 8.5 ft |

9.5.2. Example 2 - Automatic backup device using energy balance analysis
9.5.2.1. A rope access technician with a mass of $100 \mathrm{~kg}(220 \mathrm{lb})$ is working with $15 \mathrm{~m}(50 \mathrm{ft})$ of rope above their backup device.
9.5.2.2. The backup device is $0.3 \mathrm{~m}(1 \mathrm{ft})$ above the rope access technician's sternal attachment.
9.5.2.3. The lanyard, which incorporates an energy absorber, connecting the backup device to the rope access technician's sternal attachment is $0.6 \mathrm{~m}(2 \mathrm{ft})$ long.
9.5.2.4. The ropes in use have a stretch of $5.8 \%$ at the average deployment force of the energy absorber.
9.5.2.5. Testing has shown that the backup device has a $0.3 \mathrm{~m}(1 \mathrm{ft})$ activation distance.
9.5.2.6. Energy balance analysis predicts that the energy absorber will deploy 0.15 m ( 0.5 ft ).
9.5.2.7. Harness stretch-out is $0.3 \mathrm{~m}(1 \mathrm{ft})$.
9.5.2.8. How much clearance below the rope access technician is required?

| Relative harness attachment height $\left(H_{D A}\right)$ | -0.3 m | -1 ft |
| ---: | ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 0.6 m | 2 ft |
| Activation distance $\left(F F_{A}\right)$ | 0.3 m | 1 ft |
| Rope Stretch $\left(x_{R}\right)$ | 0.9 m | 3 ft |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 0.15 m | 0.5 ft |
| Lanyard stretch $\left(x_{L}\right)$ | 0 m | 0 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| + Clearance Margin $(C M)$ | 0.6 m | 2 ft |

9.5.3. Example 3 - Low backup device
9.5.3.1. The rope access technician from Example 2 has their backup device $0.3 \mathrm{~m}(1 \mathrm{ft})$ below their sternal attachment when the main system fails.
9.5.3.2. Energy balance analysis predicts that the energy absorber will deploy 0.45 m ( 1.5 ft ).
9.5.3.3. All other variables from Example 2 are the same.
9.5.3.4. How much clearance below the rope access technician is required?

| Relative harness attachment height $\left(H_{D A}\right)$ | 0.3 m | 1 ft |
| ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 0.6 m | 2 ft |
| Activation distance $\left(F F_{A}\right)$ | 0.3 m | 1 ft |
| Rope Stretch $\left(x_{R}\right)$ | 0.9 m | 3 ft |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 0.45 m | 1.5 ft |
| Lanyard stretch $\left(x_{L}\right)$ | 0 m | 0 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| + Clearance Margin $(C M)$ | 0.6 m | 2 ft |
| Required clearance below platform $\left(C_{P}\right)$ | 3.45 m | 11.5 ft |

9.5.4. More rope in use
9.5.4.1. The rope access technician from Example 2 descends until there is $76 \mathrm{~m}(249 \mathrm{ft})$ above their backup device.
9.5.4.2. Energy balance analysis predicts that the energy absorber will not deploy, and the rope will stretch 4.4 m ( 14.5 ft ).
9.5.4.3. All other variables from Example 2 are the same.
9.5.4.4. How much clearance below the rope access technician is required?

| Relative harness attachment height $\left(H_{D A}\right)$ | -0.3 m | -1 ft |
| ---: | ---: | ---: | ---: |
| Connection length $\left(L_{y}\right)$ | 0.6 m | 2 ft |
| Activation distance $\left(F F_{A}\right)$ | 0.3 m | 1 ft |
| Rope Stretch $\left(x_{R}\right)$ | 4.4 m | 14.5 ft |
| Energy absorber deployment $\left(x_{P E A}\right)$ | 0 m | 0 ft |
| Lanyard stretch $\left(x_{L}\right)$ | 0 m | 0 ft |
| Stretch-out $\left(x_{W}\right)$ | 0.3 m | 1 ft |
| Required clearance below platform $\left(C_{P}\right)$ | 0.6 m | 2 ft |

9.5.1. Example 5 - High elongation rope
9.5.1.1. The rope from Example 2 is substituted with a rope with higher elongation of $35 \%$ at the average deployment force of the energy absorber.
9.5.1.2. Energy balance analysis predicts that the energy absorber will not deploy, and the rope will now stretch 5.3 m (17.4 ft).
9.5.1.3. All other variables from Example 3 are the same.
9.5.1.4. How much clearance below the rope access technician is required?

| Relative harness attachment height ( $H_{D A}$ ) | -0.3 m | -1 ft |
| :---: | :---: | :---: |
| Connection length ( $L_{y}$ ) | 0.6 m | 2 ft |
| Activation distance ( $F F_{A}$ ) | 0.3 m | 1 ft |
| Rope Stretch ( $x_{R}$ ) | 5.3 m | 17.4 ft |
| Energy absorber deployment ( $x_{P E A}$ ) | 0 m | 0 ft |
| Lanyard stretch ( $x_{L}$ ) | 0 m | 0 ft |
| Stretch-out ( $x_{W}$ ) | 0.3 m | 1 ft |
| + Clearance Margin (CM) | 0.6 m | 2 ft |
| Required clearance below platform ( $C_{P}$ ) | 6.8 m | 22.4 ft |

## Appendix 1. Swing Fall Information

A.1.1. Swing Falls
A.1.1.1. If a falling individual is not located along the fall line of the anchorage, and will not encounter any obstructions restricting horizontal movement during the fall, a swing fall will occur.
A.1.1.2. Swing fall distance may be added as a factor of free fall distance when calculating clearance requirements.
A.1.1.3. Swing fall distance may increase activation distance of some fall arrest systems.
A.1.1.4. All clearance requirement examples provided in this document assume zero swing fall.

## A.1.2. Calculating Swing Fall Distance

A.1.2.1. Assuming no free fall and no increase in length of the fall protection system during the swing fall, swing fall distance (SFD) may be calculated if two of any of these variables are known:
A.1.2.1.1. Horizontal distance (d) between the individual or load to the connection to an anchorage or rope.
A.1.2.1.2. Vertical distance $\left(\mathrm{H}_{\mathrm{B}}\right)$ of the harness attachment below the connection to an anchorage or rope.
A.1.2.1.3. Connection length $\left(L_{y}\right)$ of connection of the individual to the anchorage or rope.
A.1.2.1.4. Pendulum angle $(\theta)$ of the connection (degrees from vertical).
A.1.2.2. A schematic depicting these variables in a swing fall is shown in Figure 9.

A.1.2.3. The relation of swing fall distance to these variables is shown in Figure 10.

Figure 10 Equations for Calculating Swing Fall Distance

$$
\begin{array}{cc}
\mathrm{SFD}=\mathrm{L}_{\mathrm{y}}-\mathrm{H}_{\mathrm{B}} & \mathrm{SFD}=\frac{\mathrm{H}_{\mathrm{B}}}{\cos \theta-1} \\
\mathrm{SFD}=\mathrm{L}_{\mathrm{y}} \times(1-\cos \theta) & \mathrm{SFD}=\mathrm{L}_{\mathrm{y}}-\sqrt{\mathrm{L}_{\mathrm{y}}^{2}-\mathrm{d}^{2}} \\
\mathrm{SFD}=\sqrt{\mathrm{H}_{\mathrm{DA}}^{2}+\mathrm{d}^{2}} \pm \mathrm{H}_{\mathrm{DA}} & \mathrm{SFD}=\frac{\mathrm{d}}{\sin \theta}-\frac{\mathrm{d}}{\tan \theta}
\end{array}
$$

## A.1.3. Swing Fall Distance Examples

A.1.3.1. Example 1 - Swing fall distance of a rope-to-rope transfer
A.1.3.1.1. A rope access technician is in the middle of a rope-to-rope transfer that spans a horizontal distance of $4 \mathrm{~m}(13 \mathrm{ft})$.
A.1.3.1.2. The technician is located a vertical distance of $2 \mathrm{~m}(6.6 \mathrm{ft})$ below the anchorages of the rope-to-rope transfer.
A.1.3.1.3. The rope access technician inexplicably removed their backup device from their descent side.
A.1.3.1.4. If the main system from the descent side were to fail at this time, what would be the swing fall distance?

$$
\begin{gathered}
\mathrm{SFD}=\sqrt{\mathrm{H}_{\mathrm{DA}}^{2}+\mathrm{d}^{2}}+\mathrm{H}_{\mathrm{DA}} \\
\mathrm{SFD}=\sqrt{4 \mathrm{~m}^{2}+4 \mathrm{~m}^{2}}-2 \mathrm{~m}=0.82 \mathrm{~m}
\end{gathered}
$$

A.1.3.2. Example 2 - Swing fall distance of a shallower rope to rope transfer
A.1.3.3. While remaining in the middle of the rope-to-rope transfer, the rope access technician from Example 1 shortens the vertical distance below the anchorages to $1 \mathrm{~m}(3.3 \mathrm{ft})$
A.1.3.4. If the main system from the descent side were to fail at this time, what would be the swing fall distance?

$$
\begin{gathered}
\mathrm{SFD}=\sqrt{\mathrm{H}_{\mathrm{DA}}^{2}+\mathrm{d}^{2}}+\mathrm{H}_{\mathrm{DA}} \\
\mathrm{SFD}=\sqrt{4 \mathrm{~m}^{2}+1 \mathrm{~m}^{2}}-1 \mathrm{~m}=1.23 \mathrm{~m}
\end{gathered}
$$

A.1.3.5. Bonus Example - Velocity of a swing fall
A.1.3.6. What would be the velocity of the rope access technician in both Examples 1 and 2 when they reach the bottom of the swing fall?

$$
\mathrm{v}=\sqrt{2 \mathrm{gh}}
$$

Example 1:
$\mathrm{v}=\sqrt{2 \times 10 \mathrm{~m} / \mathrm{s}^{2} \times 0.82 \mathrm{~m}}=4 \mathrm{~m} / \mathrm{s} \approx 14.4 \mathrm{~km} / \mathrm{h} \approx 9 \mathrm{mph}$
Example 2:
$\mathrm{v}=\sqrt{2 \times 10 \mathrm{~m} / \mathrm{s}^{2} \times 1.23 \mathrm{~m}}=5 \mathrm{~m} / \mathrm{s} \approx 18 \mathrm{~km} / \mathrm{h} \approx 11 \mathrm{mph}$

## Appendix 2. Equations and Worksheets for Calculating Clearance Requirements

A.2.1. Equations for Calculating Clearance Requirements

| $\boldsymbol{C}_{\boldsymbol{p}}=$ | $\boldsymbol{F F}$ | + | $\boldsymbol{D} \boldsymbol{D}$ | $+\boldsymbol{x}_{\boldsymbol{W}}+\boldsymbol{C M}$ |
| :--- | :--- | :--- | :--- | :--- |
| Energy absorbing lanyards | $H_{D A}+L_{y}$ |  | $x_{P E A}+x_{L}$ |  |
| Self-retracting devices | $H_{D A}+L_{y}+F F_{A}$ | + | $x_{P E A}+x_{L}$ | $+x_{W}+C M$ |
| Backup systems | $H_{D A}+L_{y}+F F_{A}$ |  | $x_{R}+x_{P E A}+x_{L}$ |  |

A.2.2. Energy absorbing lanyard worksheet
Relative harness attachment height $\left(H_{D A}\right)$
Connection length $\left(L_{y}\right)$
Lanyard stretch $\left(x_{L}\right)$
Energy absorber deployment $\left(x_{P E A}\right)$
Stretch-out $\left(x_{W}\right)$

+ Clearance margin $(C M)$
Required clearance below platform $\left(C_{P}\right)$
A.2.3. Self-retracting device worksheets

Relative harness attachment height $\left(H_{D A}\right)$
Connection length ( $L_{y}$ )
Activation distance $\left(F F_{A}\right)$
Energy absorber deployment ( $x_{P E A}$ )
Lanyard stretch $\left(x_{L}\right)$
Stretch-out ( $x_{W}$ )

+ Clearance margin (CM)
Required clearance below platform $\left(C_{P}\right)$


Required clearance below platform $\left(C_{P}\right)$

## A.2.4. Backup system worksheet

Relative harness attachment height $\left(H_{D A}\right)$
Connection length $\left(L_{y}\right)$
Activation distance $\left(F F_{A}\right)$
Rope stretch $\left(x_{R}\right)$
Lanyard stretch $\left(x_{L}\right)$
Energy absorber deployment $\left(x_{P E A}\right)$
Stretch-out $\left(x_{W}\right)$

+ Clearance margin $(C M)$$\square$

