Technical Note No 96

Assessing cradle and suspended access equipment loads

This Technical Note considers the impact loads that may be imposed on a façade by an access cradle or other suspended access equipment. A method of calculation is given.

Impact energies in the range 300 - 1000 Nm are shown to be possible but these will be distributed over two or more points of contact. A plane curtain wall of glass and aluminium stick may be able to withstand these impacts. However, walls with fins and similar projections will be prone to damage unless appropriate measures are taken.

This Technical Note should be read in conjunction with:

TN 97 Selection of access equipment for façade maintenance

Introduction

The use of cradles and other suspended equipment to access the building envelope gives rise to potential impacts on the building envelope. This has implications for both the safety and serviceability of the building envelope.

It should be noted that other forms of access also have safety and serviceability implications. An overview of all methods of access is given in TN 97.

Impact of cradles on the building envelope is sometimes avoided by using guide rails to restrain the cradle movement.

Impact forces caused by cradles can be reduced by using energy absorbing rollers or mounting the rollers on an energy absorbing component. The impact forces also depend on the size and number of buffers.

Causes of impact

Cradle impact against the building envelope may be caused by:

- Wind
- Pushing away
- Collision while manoeuvring

Wind effects

The cradle may be pulled away from or blown against the envelope. The greatest impact forces are associated with the cradle being pulled away from the wall by a gust of wind and then swinging back against the wall as the gust subsides. This is mostly likely to occur near a corner on the leeward wall.

The impact forces are related to:

- The wind speed
- The mass of the cradle
- The area of the cradle
- The suspension length
- The ratio of mass to area of the cradle
- Energy absorption in the rollers and roller mountings
- Number of rollers and contact area.

Pushing away

The cradle may be pushed away from the building envelope by the operatives working in it and then swing back to impact the envelope. The forces moving the cradle are limited by the capacity of the operatives and the movement is limited by the reach of the operatives. Impacts caused in this way are almost always of lower magnitude than those caused by cradle impacts resulting from the wind.

The impact forces are related to:

- The mass of the cradle
- The suspension height of the cradle
- Energy absorption in the rollers and roller mounting.

Collision
Collision of a cradle with the building envelope may take several forms;

Snagging when raising or lowering the cradle can place significant contact loads on components such as signage, lighting, brise soleil and other shading devices.

The contact loads are related to:

- Rate of movement
- Sensitivity of cut-out switches
- Care of cradle operators

Direct impact of the cradle on projecting components when traversing or luffing the cradle will cause large impact forces on those components.

The impact loads are related to:

- Velocity of the cradle
- Energy absorption on the cradle and within the component impacted

Over-run of the cradle when the hoist stops suddenly after traversing or luffing may cause an impact. As the cradle swings it also rises and will generally cause lower impact loads than a direct impact on projecting components. However, at an internal corner it may result in a direct impact on the face of the building envelope.

The impact loads are related to:

- Velocity of the cradle
- Control systems
- Energy absorption on the cradle and within the component impacted
- Building geometry

Calculation of impact energy and forces

Mass of cradle contents
BS EN 1808 gives the mass of the cradle contents as follows:

For single occupancy cradles;

$$R_L = M_p + M_e + M_m$$

For multiple occupancy cradles;

$$R_L = n \times M_p + 2 \times M_e + M_m$$

Where:

n	Number of occupants
M_p	80 kg per person
M_e	40 kg of personal equipment
M_m	Mass of material
R_L	Rated load capacity

Area of cradle
To calculate the wind force on the cradle it is necessary to know the area presented to the wind. BS EN 1808 gives the following areas;

For an individual in an open cradle the area is assumed to be 0.7 m^2 with a centre 1 m above the cradle floor.

For an individual in an enclosed cradle sheltered to a height of 1 m above the cradle floor the area is assumed to be 0.35 m^2 with a centre 1.45 m above the cradle floor.

For an enclosed cradle the area of the cradle is easily ascertained. For an open cradle a more complex assessment is required.

The area of any material exposed to the wind must also be taken into account.

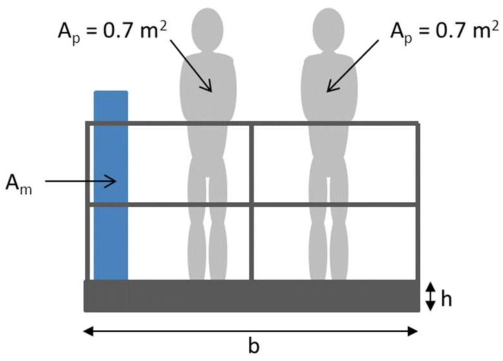

Figure 1a **Open cradle**

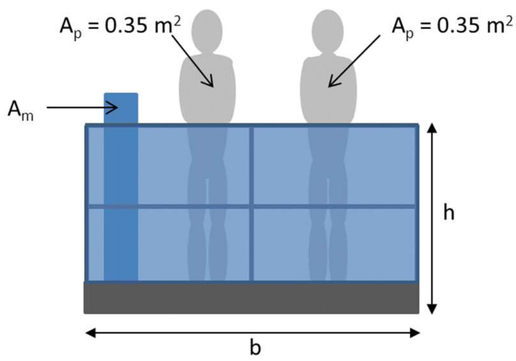

Figure 1b **Enclosed cradle**

A_m Area of material
A_p Exposed area of an operative
b x h Area of cradle (Note that an allowance has to be made for exposed frame)

Calculation of wind induced impacts
It is first necessary to determine an appropriate wind speed, wind profile and wind duration. These have the greatest influence on the calculated impact energy.

BS EN 1808 gives design wind speeds for cradles of:

- Free cradles 14 ms^{-1}
- Restrained cradles 20 ms^{-1}

Safe operating wind speed will depend on the type of work to be carried out but is likely to be less than the design wind speed. The operating wind speed may also be limited to reduce the effects of impact.

EN1808 limits the operating wind speed to that speed which causes either:

- The cradle to move 4m from the face of the wall,
- The cradle to move more than 40% the length of the cradle parallel to the wall.

Typically cradle manufacturers have limited the operating wind speed to 20 or 25 m.p.h. (8.9 or 11.1 ms^{-1}). The safe operating wind speed is a fundamental design parameter that should be agreed between the cradle designer and the specifier. The safe operating wind speed should be recorded in the O&M manual and be evident to the cradle operative.

Wind pressure is related to wind speed by:

$$p = 0.613\ v^2$$

So that:

v	p
14 ms^{-1}	120 N/m^2
20 ms^{-1}	245 N/m^2

The wind that lifts the cradle away from the building will not change direction immediately and propel the cradle back against the envelope and it is appropriate to take a monotonic pressure.

Skew impacts in which one corner of the cradle initially impacts the wall are no more severe than parallel impacts. If the cradle impacts skew to the wall it initially rotates imparting low dynamic forces to the wall. Once the cradle is parallel to the wall larger forces are required to decelerate the cradle.

It may therefore be assumed that a cradle movement with the cradle parallel to the wall gives the greatest impacts.

Two approaches are possible:

- If the peak pressure and period are known a sinusoidal pulse as shown in Figure 2 may be applied.
- Alternatively a constant pressure pulse of average pressure may be applied.

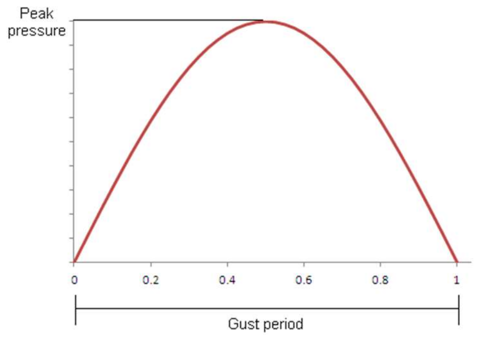

Figure 2 **Wind pulse**

Constant average pressure pulse

In defining design wind speeds of 14 ms^{-1} and 20 ms^{-1}, BS EN 1808 does not give a corresponding gust period. It is practical to assume that these are the three second average gust velocities if they are to be measured by anemometer on the cradle or building.

BS 6399-2 gives gust factors related to short duration gusts.

The gust factor applied to the wind velocity is given by:

$$g(t) = 0.42 \times ln\left(\frac{3600}{t}\right)$$

Where:

t = Gust period

The average gust design velocities for other gust periods are shown below

Gust period	V_3 = 14 ms^{-1}	V_3 = 20 ms^{-1}
1s	16.2	23.1
2s	14.8	21.1
3 s	14.0	20.0
4 s	13.4	19.2
5 s	13.0	18.5
6 s	12.6	18.1
7 s	12.3	17.6
8 s	12.1	17.2

The most significant gust acting on a cradle is not the one with highest average gust velocity but a more sustained gust of slightly lower average gust velocity.

The most significant gust period will depend on the mass of the cradle and the suspension length. Calculating the impact energy for each gust period and its associated average gust velocity will show the maximum impact energy associated with all gusts.

Example 1

For a cradle with total mass 220 kg, area 2.35 m^2 and suspension height 10 m. The impact energy and greatest displacement from the wall for wind speed of V_3 = 14 ms^{-1} and pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	789 Nm	2650 mm
4 s	574 Nm	2467 mm
5 s	224 Nm	2289 mm

The greatest impact energy is 789 Nm and this occurs for a gust period of 3 s.

Example 2

For the cradle arrangement of example 1 but with the operating wind speed limited to V_3 = 11.1 ms^{-1} (25 m.p.h) the impact loads for wind pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	316 Nm	1680 mm
4 s	228 Nm	1556 mm
5 s	89 Nm	1444 mm

The greatest impact energy is now 316 Nm and this occurs for a gust period of 3 s.

Limiting the operating wind speed has reduced the greatest impact energy by 60%.

Example 3

For the arrangement in example 2 but increasing the suspension length to 20m

Gust period	Impact energy	Peak displacement
3 s	461 Nm	2884 mm
4 s	515 Nm	3049 mm
5 s	443 Nm	2871 mm

The greatest impact energy is now 515 Nm and this occurs for the longer period gust of 4 s.

Increasing the suspension length has increased the impact energy and significantly increased the peak displacement.

Example 4
For a cradle with total mass 300 kg, area 4.25 m^2 and suspension height 15 m. The impact energy and greatest displacement from the wall for wind speed of V_3 = 14 ms^{-1} and pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	2444 Nm	4914 mm
4 s	2415 Nm	4888 mm
5 s	1688 Nm	4536 mm

The greatest impact energy is much greater than that of example 1. However the peak displacements are so large that it is unlikely operatives would use the cradle under these conditions. EN1808:2015 gives 4m as the maximum allowable displacement and suggests operating wind speed is limited to ensure this displacement is not exceeded.

Example 5
If the operating wind speed for the cradle in example 4 is limited to V_3 = 11.1 ms^{-1} (25 m.p.h) the impact loads for wind pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	980 Nm	3112 mm
4 s	961 Nm	3083 mm
5 s	672 Nm	2863 mm

Limiting the operating wind speed has again reduced the greatest impact energy by 60%.

Example 6
If the operating wind speed for the cradle in example 4 is further limited to V_3 = 8.9 ms^{-1} (20 m.p.h) the impact loads for wind pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	407 Nm	2006 mm
4 s	397 Nm	1982 mm
5 s	281 Nm	1850 mm

Sinusoidal pressure pulse

Figure 3 shows a typical sinusoidal wind pulse and the resulting typical displacement of the cradle away from the wall.

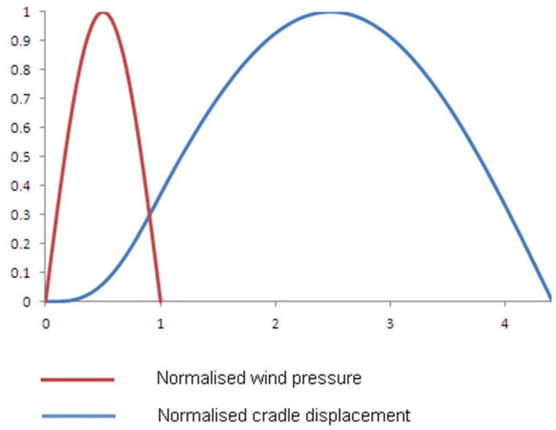

Figure 3 Cradle displacement

This approach may be adopted when the peak velocity and period are known; for instance if wind tunnel tests have been undertaken.

Example 7
For a cradle with total mass 220 kg, area 2.35 m^2 and suspension height 10 m. The impact energy and greatest displacement from the wall for wind speed of peak velocity V_{peak} = 18 ms^{-1} and pulses of different period are as follows:

Gust period	Impact energy	Peak displacement
3 s	1277 Nm	3374 mm
4 s	1347 Nm	3485 mm
5 s	1130 Nm	3356 mm
6 s	760 Nm	3141 mm

The greatest impact energy is 1347 Nm and this occurs for a gust period between 4 s.

Appendix B gives a time stepping approach to the solution of this problem. It may be written into a spreadsheet and the example above used to validate the spreadsheet calculation.

Effect of restraints
Taking example 1 above and calculating the impact energy for different suspension heights gives the impact energies shown below for pulses of period 3, 4, 5, 6 and 7s.

	10m	15m	20m
3s	**789**	**1019**	1150
4s	574	1007	**1296**
5s	224	704	1111
6s	138	338	773

Reducing the suspension height by restraining the suspension cable in a clip on the façade can considerably reduce the impact energy. Note that the maximum impact energy corresponds to a different gust period for each suspension length.

Load on restraints
Once the maximum displacement of the cradle from the wall is known it is possible to calculate the force in the suspension cable and the resultant force on the restraints. This force may act normal to the wall or parallel to the wall.

Calculation of collision impacts and forces

Snagging
When a rising cradle snags on a projection from the wall it will exert a force on the projection. EN1808 requires suspended access equipment to have a cut out that stops the cradle if the load in the cables exceeds 125% of the design live load. The force exerted on the projection cannot therefore exceed 125% of the design live load less the minimum weight of the cradle and operator. N.B. may also be a dynamic enhancement.

When a descending cradle snags on a projection from the wall it will exert a force on the projection. Provided that the cradle is fitted with an 'obstacle device' that makes first contact with the projection the cradle will come to a stop. The forces exerted on the projection will depend on the 'obstacle device' but will be relatively small.

A transiting cradle may snag on vertical fins and similar projections. Forces will be lower than the snagging forces described above but are not generally limited by automatic motion controls.

Direct impact
The energy of the transiting cradle will be its kinetic energy;

$$E = 0.5\ m\ v^2$$

If a collision occurs that brings the cradle to a stop when transiting or luffing this is the impact energy. Limiting the transiting velocity will reduce impact loads, the table below gives collision impact energies for the cradle of mass 220 kg in example 1 above.

Transit velocity	Impact energy
1 ms^{-1}	110 Nm
2 ms^{-1}	440 Nm
3 ms^{-1}	990 Nm

This impact may occur on a façade at an internal corner or on a projection from the façade such as a fin.

In the case where a cradle swings beyond the nominal limit of its transiting movement the cradle will rise; this gives an increase in potential energy and the impact energy is reduced.

In this case the impact load may be reduced by reducing the suspension height. As cradle restraints prohibit transiting this would require that the cradle was raised, transited and then lowered.

Interpretation of impact energy

The impact energies calculated above are upper limits to the impact energy transferred to the wall. They are the total energy of the cradle and will be distributed over one or more points of contact or over a linear contact.

Any deformable energy absorbing component on the cradle will reduce the energy transfer to the wall.

Impact energies for some of the scenarios considered above lie within the range of impact energies covered by EN 13830. A wall CE marked to an impact class of E5 will be able to resist cradle impacts if appropriate restraints are provided and suitable limits are placed on operating wind speeds. However this performance would depend on the design of the buffers on the cradle. Note that the glazing is not subject to impact testing when CE marking to EN 13830.

Class	Drop height	Impact energy
E0	Not tested	Not tested
E1	200 mm	98 Nm
E2	300 mm	147 Nm
E3	450 mm	221 Nm
E4	700 mm	343 Nm
E5	950 mm	466 Nm

Impact classes from EN 13830

Impact tests on curtain walling to EN 14019 are conducted using two inflated tyres as an impactor. The classification of impact given on a CE mark is only applicable to cradle impacts if:

- The cradle has a buffer with similar deformation characteristics to the test impactor,
- The cradle impacts on the framing or other opaque area of the wall.

Impact forces

Cradle impact force on the wall can be calculated if the rate of deceleration of the cradle can be calculated. However this is difficult as the deceleration will depend on:

- The deformation characteristics of any buffers on the cradle
- The deflection of the wall
- The inertia of the wall

A dynamic finite element analysis of the wall would be necessary to establish the dynamic forces and interpretation of the transient forces and stresses is not straightforward.

It is for this reason that most impact effects are assessed on the basis of impact energy.

Forces associated with cradles snagging cladding can be calculated from knowledge of the hoist motor characteristics and mass of the cradle. These forces are applied less rapidly than impact forces and are easier to interpret.

Forces associated with collisions from MEWPs and hydraulic arms can be similarly calculated from knowledge of the forces that can be generated by the access equipment. These forces are also applied less rapidly than impact forces and are easier to interpret.

References

BS 6399-2 Loading for buildings – Part 2 Code of Practice for wind loads

BS EN 1808 Safety requirements for suspended access equipment – Design calculations, stability criteria, construction – Examination and tests

BS EN 13830 Curtain walling - product standard

BS EN 14019 Curtain walling - Impact resistance - Performance requirements.

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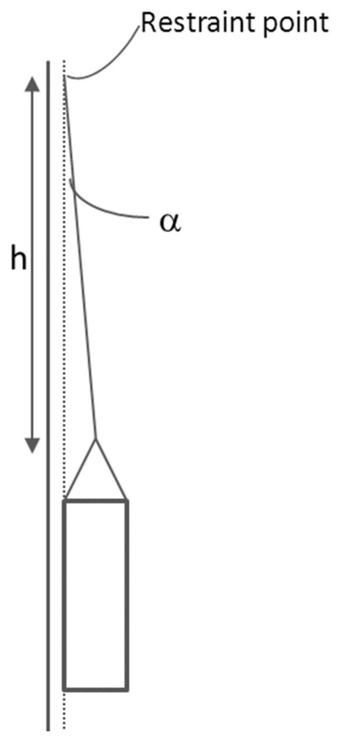
Appendix A

Notation

A = area of cradle, occupants and equipment subjected to wind
a = horizontal acceleration of cradle
α = inclination of suspension cable
Δt = Time interval
E = energy
g = acceleration due to gravity
h = suspension height
m = mass of cradle, occupants and equipment
p = instantaneous wind pressure on cradle
p_{peak} = maximum wind pressure on cradle (adjusted for t_{period})
t_{period} = period of wind pulse
T = horizontal component of tension in suspension cable
v = horizontal velocity of cradle
W = horizontal force due to wind pressure
x = horizontal displacement of cradle from vertical
$_{n}$ = value calculated at timestep n



Appendix B

Wind calculation

The wind induced impact of a cradle may be modelled in a spreadsheet using the formulae below. The calculated displacement and wind pressure should be plotted to give a similar diagram to Figure 3.

Column 1	t	$t = n\Delta t$	
Column 2	v	$v_0 = 0$	$v_n = v_{n-1} + a_{n-1}\Delta t$
Column 3	x	$x_0 = 0$	$x_n = x_{n-1} + v_n\Delta t + 0.5a_{n-1}\Delta t^2$
Column 4	α	$\alpha_n = \sin^{-1}\frac{x_n}{h}$	
Column 5	T	$T_n = mg\sin\alpha_n$	
Column 6	p	$p_n = p_{peak}\sin\frac{2\pi t_n}{2t_{period}}$ (if $t_n < t_{period}$ else 0) or constant	
Column 7	W	$W_n = Ap_n$	
Column 8	a	$a_n = \frac{(W_n - T_n)}{m}$	

Δt is the time interval between successive calculations. Δt has to be sufficiently small if the calculations are to give the correct answer. Too large a value of Δt will give results that oscillate unrealistically. Conversely, too small a value Δt will require many rows of calculation with greater rounding errors in the spreadsheet calculation. Δt is typically around 0.05 seconds or less. This requires some 100 rows of calculation in a spreadsheet. Running the calculations for several different values of Δt will indicate whether the results converge to the correct answer.

At time step n when x_n returns to zero the value v_n is the velocity of impact, this will occur sometime after the wind pulse has ceased.

The impact energy is the kinetic energy given by:

$$E = 0.5mv_n{}^2$$

This procedure calculates the impact energy for a particular gust period. The calculations should be repeated for different gust periods to ascertain the worst impact load.

A spreadsheet may be validated by reproducing the results in the examples given in this Technical Note.

There are three possibilities for examining the effect of this impact on the wall:

1. E may be taken as the impact energy for a physical test.

2. Subsequent movement of the cradle and impact forces may be calculated in a simplified method similar to the time stepping calculations set out above. By assuming the wall is rigid and establishing a value of stiffness for the cradle rollers and supports a dynamic force calculation can be included in the spreadsheet. This will be an overestimate of the dynamic force as it neglects the flexibility of the wall. Using this dynamic force in a static calculation of the wall deflections will overestimate the wall deflections as the static calculation ignores the inertia of the wall.

3. A more complex structural analysis may be undertaken to account for the mass and stiffness of the wall as well as the stiffness of the cradle rollers.