Personal protection rails for strong impacts

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Abstract

According to EN 13374, type C temporary edge protection systems are the set of components designed to protect people from falling to a lower level, and to restrain material. This system may incorporate a safety net attached to a bracket structure so that it may be used vertically. This document analyses such fundamental aspects as their design and the solution to the problem posed by the brackets or hard points which can cause injury to the victim of an accident.

We have therefore studied the phenomenon through a variety of numerical models using ANSYS finite element software, and we have reached useful conclusions such as the required geometrical shape, the cross section of the profiles, and the impact factors suffered by accident victims. We are therefore able to make some general points with regard to the regulatory text.
Keywords: rail, safety, net, fall, impact, stiffness, EN13374.

1 Introduction

If we consider the everyday activities of human beings at work, the construction industry has produced and continues to produce the most serious accidents. According to Spanish Labour Ministry statistics, if we average out the last 5 years, only taking falls to a different level into account, there are 2,042 serious accidents and 114 mortal accidents every year, which equates to 26.74% of the total number of serious accidents and 13.47% of the total number of mortal accidents, respectively.

Safety handrails or temporary edge protection systems are used in construction work, primarily to prevent persons and objects falling to a lower level from rooftops, edges, staircases and other areas where protection is required.

According to EN 13374:2004 [1], three types of handrails exist, A, B and C, depending on the angle of the working surface and the height of the drop. Type

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A handrails have to resist a static load of 0.3 KN, type B handrails have to resist 1.100 joules of kinetic energy and those that we shall analyse below, type C handrails, must be capable of absorbing 2.200 joules of kinetic energy. The system may incorporate a safety net, system U, conformant with EN 1263 [2] and [3].

Their design has not been defined in EN 13374 or in Spain's current safety standard [4] and [5], or in any previous work by national standardisation groups [6]. Nor has any solution been forthcoming for the hardpoints which are part and parcel of handrail brackets. All that has been done [1] has been to establish 200 mm as the minimum deflection value for class C, at any part of the system 200 mm above its lower edge, in the event of an impact with normalised cylindrical ballast of 75 Kg. This value will be questioned and analysed in detail in this investigation, until we are able to confirm or discuss its validity, with regard to whether or not the protection system provides sufficient cushioning, which would therefore mean that the impact suffered by an accident victim would be acceptably low.

Another important aspect of this work will be to come up with an appropriate design for this safety system, and also to provide a solution to the serious injuries or death which may be caused when an accident victim collides into the system's brackets or hardpoints.

2 Studies carried out

2.1 Exposition using a straight bracket and spherical ballast

To simulate when an accident victim bangs his or her head or feet against the protection.

We analysed two possible positions for the protection net, following the specifications laid down in EN 13374 (Figs. 1 and 2), but using a spherical ballast as described below.

In both positions, we assume a C type edge protection system which features a tubular metal bracket, the uprights and sides of which form a constant cross section and which sustains a 4x2 m^2 net. The bracket is supported only at the two lower edges as can be observed in figure 3.

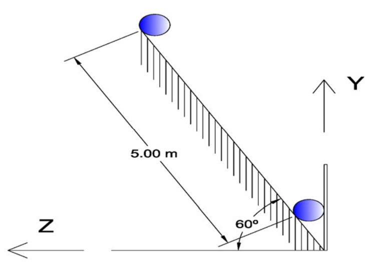

Figure 1: Position A: vertical net.

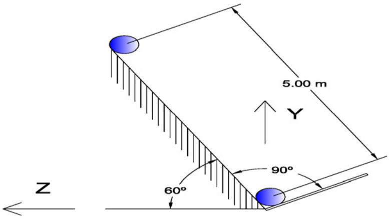

Figure 2: Position B: perpendicular net.

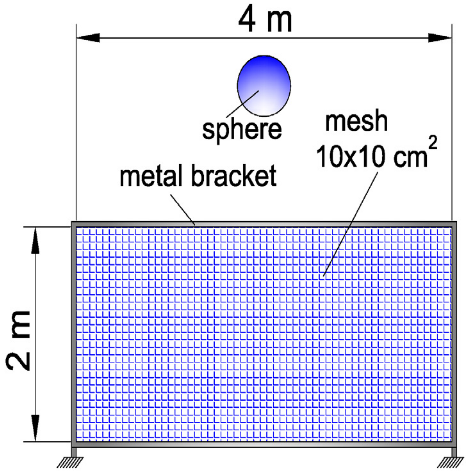

Figure 3: Frontal elevation, vertical or perpendicular net position.

The geometrical requirements of EN-13374:2.004 have been applied, the angle of the slope to horizontal is 60º and the ballast falls 5 m before impacting on the net.

In each position, we model the protection system in a variety of ways using the Ansys finite elements programme. We use tubular metal brackets to sustain the net, with different sections and thicknesses, beginning with a diameter of 60x1mm and increasing to 100x4 mm.

Three principal types of material are involved, with the following characteristics:

A 10x10 cm^2 mesh with braids of 610 N stiffness and weighing 0.008 Kg/m.
Ballast with a radius of 0.25 m and weighing 100 Kg.
Steel brackets with a yield limit of 240 N/mm^2.

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Important movements are generated in the model, and there are important rotations in both of the brackets and the net; what is more, the net suffers considerable strains. Practically zero initial transversal rigidity of the net, which increases as it is tensioned, at least in a part of it. Lack of knowledge of the points where the body makes contact with the net, points which change throughout the phenomenon, the precise identification of which has a decisive impact on the forces generated. The elasto-plastic behaviour of the metal brackets can be easily modelled in steel as bilinear. Elasto-plastic behaviour of the net, much more complex, which also has a decisive importance vis-à-vis its capacity to absorb energy, a key variable of this problem, and one which impacts directly on the brackets and on the forces which affect the accident victim [7].

The Ansys elements used for each material are:

-Net (LINK10). The model proposed for the braids of the net is a law of linear elastic behaviour with no resistance to compression and with structural damping (Fig. 4).

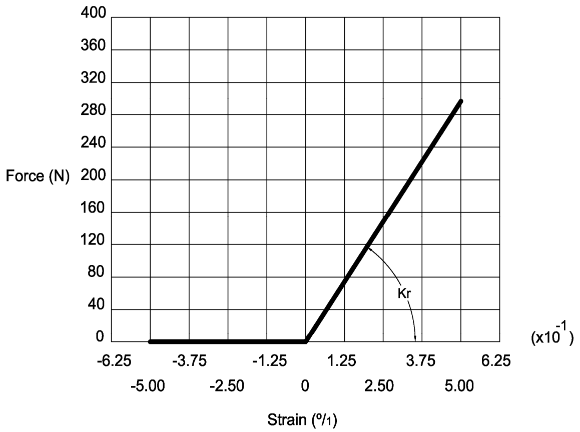

Figure 4: Net behaviour.

To ensure that the net performs in an equivalent manner to the behaviour actually observed, we based our parameters on [7], obtained from theoretical and experimental work carried out in the 1990s [8–13], and which are:

Kr: Slope of the straight line which represents behaviour proportional to that of the net under tension (610 N).

β: Multiplier of the stiffness matrix with which the structural damping matrix is obtained, the value of which is 0.34.

There are two main reasons why the equivalent law of bilinear performance behaviour for the net differs from the real [14]:

-The tightening of the knots.

-When the net is working under tension the relationship between stress and strain is not a straight line.

Prudence is advised as far as giving credibility to some of the results obtained in this modelling is concerned. Such results should be checked against experimental tests for this type of net, given that their starting point is stiffness and damping data which have been checked against type V nets [7].

-Ballast (MASS21). That is how we define the element that we will launch onto the net, a sphere 50 cm in diameter and 100 kg.

-Bracket or metal frame (BEAM188). In this way we can define the geometry thereof. In this case we chose a hollow tubular profile of different diameters and thicknesses. With this model we can obtain movements and stresses in the bracket.

-Contact elements (CONTA), (TARGET) [7]: The contact between the ballast and the net has been defined as a variable contact between two surfaces, one of which is rigid (ballast) and the other deformable (net).

As the IT tool used does not allow us to define the contact elements directly on the linear elements of the net, rather they must be defined as surface elements, we have used certain auxiliary surface elements of insignificant mass and stiffness, which only transmit tension membrane forces and which use the knots of the net.

The stiffness of the contact is updated each time we perform an analysis, as is each point of contact starting from the average stress of the element involved in this point, so that the stiffness is not so little that it should cause over-penetration nor so great that it should cause any divergence in the analysis.

In each case we obtain:

-The displacement of the ballast, net and bracket.

-The acceleration that the ballast undergoes in its displacement, which varies in relation to the maximum forces that the accident victim suffers.

-The stresses according to the bracket guidelines, the axial forces in the braids of the net, as well as their individual strain.

2.2 Exposition using an ergonomic bracket and cylindrical ballast

This is used to simulate a lateral impact by the accident victim onto the safety net and is the test laid down by EN 13374.

This is done using a cylindrical ballast, 30cm in diameter, 100cm long and weighing 75 Kg, in line with [1], and which is dropped onto the net.

We replaced the straight bracket with an ergonomic one as shown in Fig. 5 (now with a yield point of 275 N/mm^2), thereby resolving the problem of the hardpoints in protection systems with straight brackets, as posed in sub-section 2.1, thereby providing a solution to said problem which was raised in sub-section 6.4.3 of the current version of EN 13374. Its design is based on the prior deformation and the space the net needs to restrain the ballast without it reaching the profile of the bracket.

Using the Ansys finite elements model, we launched the cylinder onto the middle of the mesh, onto a net measuring 8 m long and 2 m high, held up by three brackets each 4m from the other, with an upper handrail and a lower toeboard (Fig. 6).

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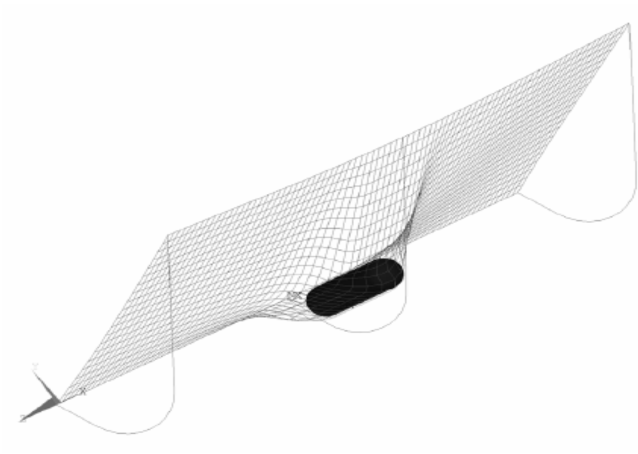

Figure 5: Ballast retention. Moment of maximum deflection.

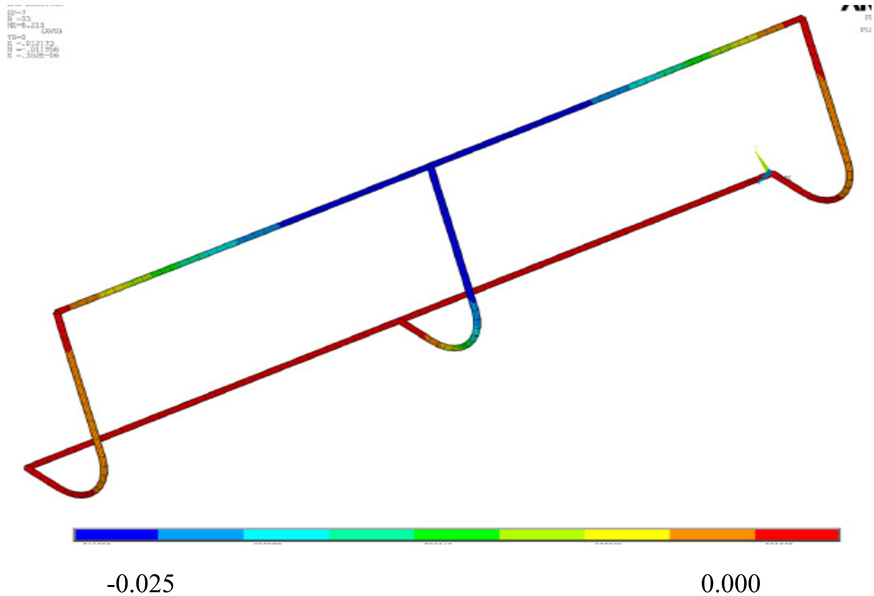

Figure 6: Detail of the proposed ergonomic bracket, maximum deflection (m).

The net was placed perpendicular to the plane of the fall of the ballast, as in sub-section 2.1 we reached the conclusion that this was the most ideal position as far as the impact factor suffered by the accident victim was concerned.

The Ansys elements used are identical to those used in point 2.1, with the exception of the cylindrical ballast (Fig. 7). This was modelled using two types of elements, the inside was SHELL181, steel, and the outer covering was SOLID45, a very deformable rubber, in line with [1].

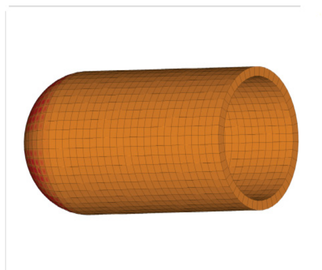

Figure 7: Detail of a half of the cylindrical ballast.

2.3 Discussion of the minimum required deflection

Finally, to evaluate the minimum required deflection, as laid down in EN 13374, we analysed a set of ergonomic brackets, using a frame with a 60x3 tubular profile and nets of increasing stiffness until the established 200 mm deflection was reached, measuring the accelerations suffered by the ballast.

3 Results

3.1 Straight bracket and spherical ballast

The accelerations suffered by the ballast with vertical net are greater than with perpendicular net. This result is important given that such acceleration means directly the maximum force that the accident victim suffers. As can be observed in table 1, using the same bracket section (60x2) we obtain accelerations of 125 m/s^2 ($12.5 \cdot g$) and 67.1 m/s^2 ($6.71 \cdot g$) in a vertical and a perpendicular position to the net, respectively.

The deflection generated in the net is greater in the perpendicular position, around 80% more than in the vertical position. As far as the accident victim is concerned, the perpendicular position will therefore behave in a much more flexible manner.

The maximum axial forces for the braids of the net are around 800 N for the vertical position and 600 N for the perpendicular position.

The strains of the net are also greater in the vertical position than in the perpendicular one.

According to the results obtained, bracket stresses indicate that when they have minor cross section, yield stresses are achieved. These stresses diminish as the section of the profile increases, as can be observed in table 1, until they remain within the range of elasticity.

Table 1: Results for straight bracket and spherical ballast.

size bracket		sphere	mesh			bracket
Ø x t (mm)		maximum acceleration (m/sg^2)	maximum deflection (m)	maximum axial force (N)	maximum strain (°/1)	maximum stress (N/mm^2)
Vertical	60X1	-91,7	1,067	892	1,462	240
	60X2	-125,0	0.887	804	1,319	240
	80X1	-112,9	0.898	808	1,324	240
	60X3	-132,0	0.854	791	1,297	240
Perpendicular	60X1	-60.0	1,237	551	0.903	240
	60X2	-67,1	1,080	615	1,009	240
	60X3	-68,0	1,032	627	1,028	240
	60X4	-68,5	1,008	634	1,040	203
	80X2	-68,7	0.996	634	1,039	215
	80X3	-69,5	0.983	634	1,039	146
	80X4	-69,6	0.978	633	1,038	120
	100X2	-69,7	0.977	633	1,037	140
	100X3	-69,8	0.972	632	1,037	95,2
	100X4	-69,9	0.970	632	1,036	73,5

3.2 Ergonomic bracket and cylindrical ballast

Table 2, below, lists the values obtained as far as the accelerations suffered by the ballast are concerned, the deflections, axial forces and net strains, the stresses of the original ergonomic brackets of different cross sections, with the net in a perpendicular position and using cylindrical ballast.

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Table 2: Results for an ergonomic bracket and cylindrical ballast.

size bracket		cylinder	mesh			bracket
Ø x t (mm)		maximum acceleration (m/s^2)	maximum deflection (m)	maximum axial force (N)	maximum strain (°/1)	Maximum stress (N/mm^2)
Perpendicular	25x3	-70.3	1,06	174	0.285	273
	30x2	-70.5	1,00	194	0.319	274
	30x3	-80.3	0.84	225	0.368	272
	35x2	-79,2	0.84	227	0.372	273
	35x3	-87,5	0.72	254	0.417	266
	40x2	-85,7	0.73	256	0.419	267
	40x3	-95,8	0.64	274	0.450	243
	45x2	-93,9	0.69	266	0.436	218
	50x2	-99,5	0.62	280	0.458	199
	45x3	-99,9	0.62	279	0.457	174
	55x2	-105,2	0.60	286	0.468	198
	50x3	-104,7	0.59	289	0.474	189
	60x2	-108,8	0.58	290	0.475	192
	55x3	-108,6	0.58	292	0.478	185
	60x3	-111,1	0.56	295	0.484	178

The accelerations suffered by the ballast are between 70 and 111 m/s^2, which imply impact factors of 7 and 11g, respectively.

The axial forces of the net increase as the stiffness of the bracket increases, from 173 N to 295 N for the brackets of greatest diameter.

The strains of the net increase as the stiffness of the bracket increases. This has been established as 0.484 for the larger sections.

The stresses are greater in thin brackets, achieving yielding, and diminishing as we increase the section of the brackets until they remain within the range of elasticity.

3.3 Minimum deflection according to EN 13374

Using the Ansys model for the Class C temporary edge protection system, we compared the same 60x3 mm cross section of an ergonomic bracket in a perpendicular position, for different net stiffnesses, obtaining relevant results as far as the impact factor suffered by the accident victim is concerned.

For stiffnesses 10 times greater than the one calibrated for the actual performance in type V nets [7], the maximum deflection is practically reduced to the 200 mm established as the minimum by EN 13374. But the corresponding accelerations increase to values greater than 20·g which are absolutely unacceptable for an accident victim falling onto such a rigid protection system.

4 Conclusions

In class C temporary edge protection systems, it has been demonstrated that positioning the net perpendicular to the plane of the fall is better than positioning it vertical, as in that way we obtain lower rates of acceleration, the system becomes more flexible and more adequately arrests the fall of a person working on a slope.

By means of the proposed design of ergonomic brackets for such Class C temporary edge protection systems, the problems posed by the hardpoints inherent in straight brackets are resolved, a problem which has still to be resolved in the current version of EN 13374, thereby guaranteeing, as the standard suggests, minimum deformability at any point of the system (including directly in front of the brackets).

With the results obtained and with regard to the minimum 200 mm deflection value laid down in the current EN 13374, it can be stated that this value is insufficient as in order to absorb the energy created, the accident victim suffers very high forces which are capable of causing very serious injury or death. To reduce the impact factor to acceptable values to the order of 6 or 7 units, it would be necessary to modify the text of the standard, increasing the minimum deflection to values 4 or 5 times greater than that which is currently established.

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