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MECHANICAL BEHAVIOUR OF METAL TIES FOR SECURITY NETS AND IPE's

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Abstract
Compliance with the current Spanish and European legislation on fall protection from heights in the different phases of civil engineering or construction projects ensures that workers will perform their jobs in a safe environment. However, although the rules clearly regulate the features of individual protective equipment (IPE) -such as fall arrest devices, fastening systems or harnesses-, they do not account for the elements that must yield the appropriate static and dynamic mechanical behaviour of different systems, i.e. the anchors of both nets and IPE. This study attempts to define the necessary conditions that must govern the implementation of tests for the different types of anchoring, examining the material used in safety devices.

1 Introduction

The Council Directive of the European Communities dated 21 December 1989 on the unification of laws of the Member States pertaining the issue of personal protective equipment make the essential provisions for the implementation of test methods to accurately predict the correct behaviour of the various security elements. However, neither the present European legislation nor the Spanish legislation [1] have as yet outlined the technical specifications or the tests to be executed on the anchor points in order to fulfill the security objectives marked in the Spanish Standard (UNE-EN 795 and 795/A1) [2,3]. Thus, as can be read in Addendum A, paragraph A.2: "...a qualified engineer is expected to verify by calculation that the design and installation (of anchorage devices) purport adequate resistance to applied force" [3]. The University of Alicante, within the AENOR's Working Group GT 7-CTN81, SC2 (Net Security: Net vertical closure, Safety Requirements) has been fostering for the last few years research on the mechanical properties of both the anchoring systems and the elements (bricks, concrete, walls) to which the anchoring systems are attached. So far, the minimum mechanical properties (cross section of metal ties, tensile stress) needed to guarantee workers security have been determined. It has been already conducted different tests on bricks and concrete samples; five tests were performed on a brick wall with dimensions 110x130cm, using different types of anchors, closely examining the load required to verify the occurrence of safety net failure.

2 Preliminary Tests

Were led preliminary tests on different types and sections of metal anchors which were placed on samples of bricks and concrete blocks, examining the behaviour of not only the anchoring systems but also the base elements and obtaining the results shown in Tables 1 and 2. Two anchors (mainly the most used) were selected for the final tests.

Table 1: Tests on bricks

Element	Sample	Type of Failure	Average (KN)
L8CA	L8CA1, 21, 3, 4, 5	1,1, 14, 14, 14	2,00
L8CC	L8CC1, 2, 3, 4, 5	1, 1, 1, 12, 1	1,92
L10A	L10A1, 2, 3, 4, 5, 6, 7, 8	1,1, 1234, 14, 14, 124, 124, 14R	3,46
L10CC	L10CC1, 2, 3, 4, 5, 6, 7, 8	124, 1234, 1234, 124, 45, 14, 1, 34R	3,80
L516A	L516A1, 2, 3, 4	1, 1, 13, 1	3,38
L516C	L516C1, 2, 3, 4	34, 234, 34, 12	3,43
LCER	LCER1, 2, 3, 4, 5, 6, 7, 8	23, 2, 2, 2, -, 1, -, -	2,20

Table 2: Tests on concrete cubes

Element	Sample	Type of Failure	Average (KN)
CH8CA	CH8CA1, 2, 3	1, 1, 12	2,15
CH8CC	CH8CC1, 2, 3	1, 1, 1	1,77
CH10A	CH10A1, 2, 3	1, 1, 1	3,90
CH10CC	CH10CC1, 2, 3	1, 1, 1	3,90

Figure 1: Metal anchor used.

Figure 2: Failure by splitting of anchor head.

Should be noted that the identification of the distinct samples were given by the base material on which the trial took place (brick: L, concrete cube: C), followed by the metric of the anchor and finished by the type of ring used (open: A, closed: C). The values shown in the third column of both tables -Type of Failure-, are identifiable on the following basis:

1- Anchor head splitting.
2- Anchor casing sliding.
3- Brick pull-off and breaking.
4- Anchor fitting.
5- Mortar-brick adherence.
R- Element breaking during sample preparation.

The results showed good performance of bricks and concrete cubes; the vast majority of cases, as shown in Tables 1 and 2, reflecting that the failure occurred by splitting of the anchor head. Moreover, these trials showed similar results regardless of whether the tests were done on bricks or concrete cubes, allowing to expand the study to brick walls with minimum dimensions 1000x600mm as indicated at the Spanish Standard UNE-EN 795.

3 Full Scale Tests

Five tensile tests on a safety net mounted on a brick wall were conducted. It was built a stiff metal frame, consisting of 1UPN-160 and 1UPN-100 respectively and welded by the web alongside the frame, and joined through a connecting element in L, allowing to join up the various parts of the frame to the desired length, so this framework would simulate the bracing of a complete front wall. Inside this element was fitted a brick wall. A wooden truncated ovoid was used as element for the transmission of the force to the different anchors located in the brick wall (bricks and bed joints), spreading a uniform load around the frame, instead of burdening just one point load. It was established a free area of 1,30x1,10m^2, with approximate distance between anchors of 0,50m (imposed by the size of the net), serving both guidelines of the Working Group as stated in the UNE-EN 795, including minimum dimensions of 1000x600mm for test object. The metal anchors elements were used with metal and plastic casing, with cross sections diameter as can be seen in Table 3.

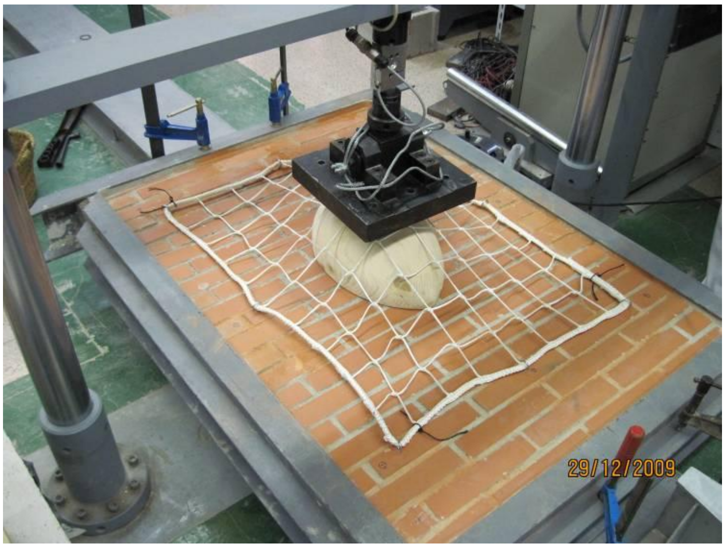

Figure 3: Stiff metal frame and wooden truncated ovoid.

Table 3: Anchors characteristics

Casing	Plastic	Metal
Cross Section Diameter	3,6mm – 3,9mm	5,1mm – 6,9mm

The testing frame used a 2T loading gear and a normal speed of 1mm/s, generating data files including displacements every second. In Table 4, there is an example of data acquired during the tests, including time-displacements values and the resulting load (according with anchor cross section diameter and anchor placing, see Table 3). The tests were carried out until the splitting of several anchors head or/and the broken of the security net took place, because the net become out of order at this same time.

Figure 4: Metal anchors used in full scale tests.

Table 4: Example of data obtained

Time (s)	**Displacement (mm)**	**Load (Kg)**				
		3,6 Brick	**5,1 Brick**	**6,9 Brick**	**3,9 Bed Joint**	**5,1 Bed Joint**
101	101,02	32,80	34,00	26,00	49,70	99,90
102	102,02	34,10	35,00	24,40	50,80	102,20
103	103,00	35,00	35,80	25,10	51,80	103,50
104	104,01	36,00	36,80	23,90	52,90	104,90
105	105,01	36,90	37,60	25,60	54,00	107,80
106	106,02	37,70	38,70	25,60	55,10	110,50
107	107,03	38,50	39,80	25,40	56,20	113,20
108	108,00	39,40	39,40	26,40	57,30	115,70
109	109,01	40,30	40,30	24,30	58,40	118,40
110	110,02	41,10	41,80	24,90	59,50	121,00
111	111,03	42,00	43,00	27,50	60,70	123,70
112	112,03	42,50	44,20	29,40	61,80	126,50

113	113,01	43,10	45,30	30,70	63,00	129,10
114	114,02	44,00	46,50	31,90	64,30	131,80
115	115,02	44,90	47,50	33,00	65,60	134,50

Finally, in order to determine the tensile strength and homogeneity respect to the mechanical characteristics of the anchors previously used, were carried out tensile tests as are shown in Table 5.

Table 5: Tensile Strength of the Anchors

Element	Sample	Cross Section Diameter (mm)	Average (N/mm^2)
ACMP36	ACMP36-1, 2, 3	3,6	552,0
ACMP39	ACMP39-1, 2, 3	3,9	527,2
ACMM51	ACMM51-1, 2, 3	5,1	504,4
ACMM69	ACMM69-1, 2, 3	6,9	473,6

4 Results and Conclusions

All the tests stopped when the anchor head of several elements split and, in many cases, the net also broke –but always after the first anchor split-. Fig. 5 to 8 shows the development of the tests: starting with the metal anchor in the initial stages, during the tests swung on their axis, at the end of the test when the anchor head split and, finally, when the net gets smashed. As Fig. 9 shows, all the results are presented in a saw-tooth form; all the maximum agrees with every splitting anchor head, usually four times per test until finished. While all the tests were carried out in a quasi-static form, due to the normal speed (1mm/s) used, the Spanish Standard UNE-EN 795 demands a dynamic test to be performed using a mass of 100Kg falling from a height of 2m. Assuming this standard, the values obtained should be increased by a factor approximately of 2,5; so, the minimum accepted value would be 250Kg.

In the last case, all the anchors would not be suitable, since the first splitting head anchor should be upper to 250 Kg, becoming the net out of order. This is the case of the tests carried out on 3,6-Brick and 3,9-Bed Joint, where the maximum load before first splitting were 157,4Kg and 240,2Kg respectively. Thus, the cross section minimum diameter would be set at 5,1mm with metal casing.

Figure 5: Initial stages.

Figure 6: Anchor head swinging.

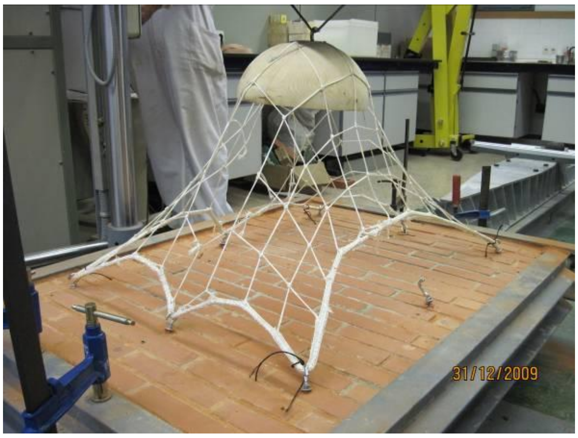

Figure 7: Anchor head split.

Figure 8: Broken net.

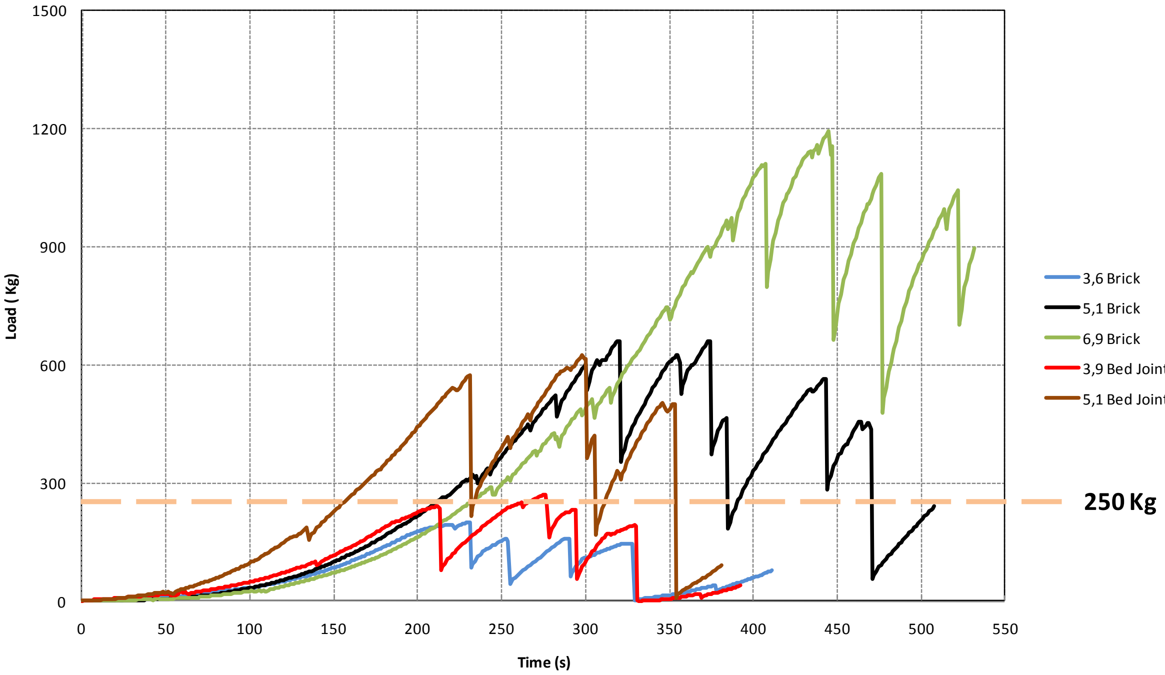

Figure 9: Load-time results and minimum value for cross section diameter.

Finally, it must be indicated the good performance of bricks and joints, since there was not in any case the breaking of bricks or joints, while the net smashed at maximum load, ensuring in this way, a sufficient bearing capacity when used as a basis for the anchors.

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References

[1] *Instituto Nacional de Seguridad e Higiene en el Trabajo. Normas para el cumplimiento de requisitos esenciales de seguridad de la directiva 89/686/CEE sobre equipos de protección individual de ámbito laboral no eléctrico*.

[2] *Norma UNE-EN 795, p. 18 (Punto 7) y 19 (Anexo A, apartado A.2)*.

[3] *Norma UNE-EN 795/A1, p. 7 (Anexo A, apartado A.2)*.