TECHNICAL REPORT

Resistance test to impact from hard and soft body, in thermoplastic protections on exposed reinforcing steel(rebar) in construction works.

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TEST SPECIMEN	**Identification as per applicant:** *Protection on exposed reinforcing steel (rebar) in construction works* **Reference N°:** 50969 **Date of reception:** 03/03/2009
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1.- PURPOSE AND SCOPE

This report sums up the dynamic test of resistance carried out on pieces made up of thermoplastic material which pretend to be used in construction works such as **"Protection of exposed reinforcing steel (rebar) in construction works",** whose double function is to protect the workers from possible cuts, pricks, bumps, etc. as well as being able of resisting the impact on a worker which falls on these steel elements from a height of 2m or higher.

The applicant company of these tests has been the Instituto Tecnológico del Juguete (*AIJU),* which has requested AIDICO, through the *Safety Elements Laboratory,* to carry out a series of dynamic impact tests, with the purpose of assessing the mechanical performance of these "protections of exposed reinforcing steel (rebar) in construction works", reproducing as far as possible, the real conditions of use in constructions works, which includes the possibility that these elements are subject to a series of actions, which can be of a static nature (workers who lean on these elements or material placed on them) or of a dynamic nature (worker who walking along these elements bumps into them and falls on the exposed reinforcing steel (rebar) in construction works).

Therefore, taking into account the function of these safety devices, the *Safety Elements Laboratory* of AIDICO, has suggested to carry out the following tests with the purpose of assessing the resistance capacity of these elements:

- **Resistance test to impact from hard body:** Non-standardized test, carrying out impacts through a hard body (metal sphere mass of 100kg and Ø500mm) with different impact kinetic energies.
- **Resistance test to impact from soft body:** Non-standardized test, carrying out impacts through crash with soft body (sphericonical bag of 50kg) applying different impact kinetic energies.

The tests have been carried out at the facilities of the *Safety Elements Laboratory of AIDICO,* since it is a laboratory specialized in the experimental verification of the Collective Protection Elements, Auxiliary Means and different safety devices used in the Construction Works, since it has the necessary Infrastructure and Equipment to carry out these kind of tests.

With the Dynamic tests of fall through crash with hard and soft body we have assessed the performance of this kind of protections of exposed reinforcing steel (rebar) against the dynamic actions, taking into account that the elements are exposed to the situation of a worker falling on them.

The tests carried out and described in this report only give information on the dynamic capacity of resistance of these thermoplastic pieces, and no tests have been carried out and other properties are not in the scope of this report, such as:

- Performance against ageing (durability conditions)
- Static resistance of the protections against a possible removal of the different diameters of the armours, in case of a rising isolated dynamic action.

This document refers to the conditions and results of the test indicated, with the considerations and limitations expressly pointed out herein.

2.-REFERENCE STANDARD

Regarding the technical regulation of product of application on the *"Protections of exposed reinforcing steel (rebar) in construction works"* currently there are not regulation documents neither at a national level nor harmonized at a European level, which establish the specifications of the product and the technical requirements which these protection devices must meet. This situation, together with the standardized use of these elements in the construction works have caused the recent creation, inside the technical commission of standardization AEN/CTN 81 *"Prevention and personal and collective protection means at work",* of a work group (AEN81/SC2/GT08), who is writing the draft of the Spanish regulation project, in which the different specifications, technical requirements and method of conformity assessment for these protections are been collected.

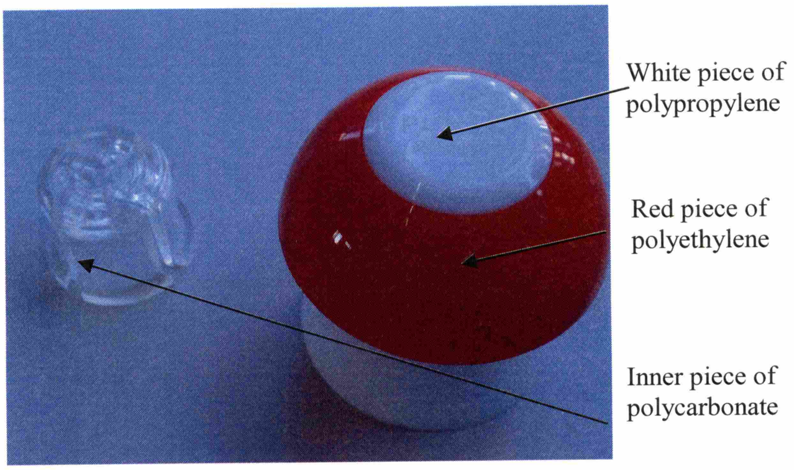
Therefore, taking into account this absence in the Regulatory Framework on this type of protections manufactured with thermoplastic materials, the *Safety Elements Laboratory* of AIDICO suggested to carry experimental trials (tests) with the purpose of checking the mechanical-resistance performance of these pieces when a dynamic action is applied on them, such as the impact of a person against these elements.

The tests to which these pieces have been subject to, *" soft and hard body impact test",* have been carried out, as far as possible, reproducing the real conditions of use in the construction work, with the limitations which can be expressly understood since they were carried out in a laboratory environment.

3.- DESCRIPTION AND CHARACTERISTICS OF THE TESTED PROTECTION

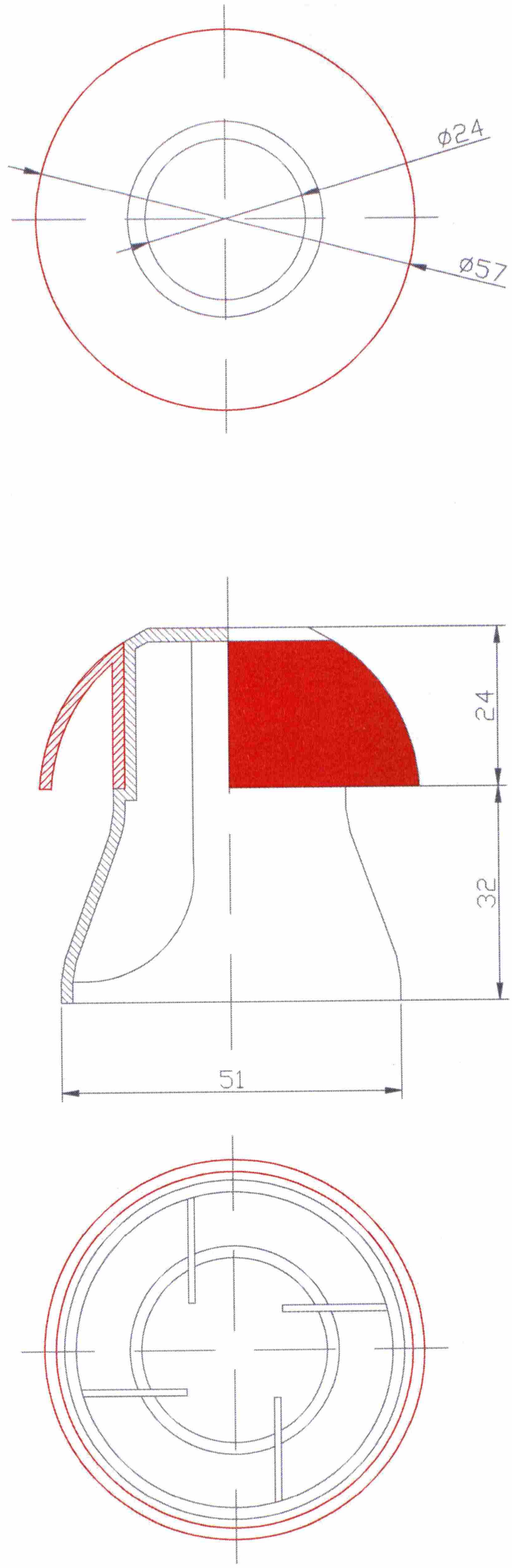
The specimens were supplied to the Safety Elements Laboratory before the date of test and they were duly received and stored in the laboratory facilities.

These protections are made up of three different pieces, manufactured from materials of different thermoplastic nature, whose final composition is a combined piece which must confer it the searched properties. The outer casing of the protection is made up of two pieces, the white piece is made up of polypropylene and the red one of polyethylene, and finally a reinforcement inner piece made of polycarbonate is integrated and this inner piece is the one which confers it the resistance capacity against impacts.



Photograph 1: Description of the protection

The following sketch reflects the geometric characteristics of the protections supplied:



4.- DESCRIPTION OF THE TEST PROCESS

Taking into account the functionality in the construction works of these protection devices, which are pieces whose purpose is to avoid or reduce the damage on workers, caused by accidental falls on the different elements of reinforced concrete in which the reinforcing steel (rebar) are exposed, the *Safety Elements Laboratory* of AIDICO suggested to carry out following tests and in the order stated:

- Hard body impact test.
- Soft body impact test.

In order to run these tests the following tasks, which are common for both types of tests, were carried out:

- Selection of passive armours of corrugated steel, for the nominal diameters more extensively used in construction works: Ø12mm and Ø16mm.
- Placing of armours in grid arrangement, inserting them both on the precast concrete truss, and on the concrete bottom bean of the outer structure of the Safety Elements Laboratory, for different rebar lengths: 100-150-300mm.
- Selection of different kinetic fall energies on the protections of armours, with the purpose of assessing the dynamic resistance capacity of these safety elements, up to a maximum fall height of 2m (energy 2000 Joules).
- Photographic report and assessment of the mechanic performance of the protection for the different fall energies, both in the case of crash with hard body and with soft body.

For the purposes of the tests carried out and taking into account the distribution of the mass in a human body, and that it has a certain deformability capacity when impacting against this kind of pieces, the real performance of these plastic pieces are more similar to the tests carried out by impact from soft body (sphericonical bag).

4.1 Hard body impact test

This test has consisted on the impact by free fall of a hard body on the protections placed on the exposed steel rebar and from a preestablished height, with the purpose of checking the resistance of these devices in case of penetration against the steel elements.

The hard body which has been used for this test consists of a steel ball with a diameter of 500mm and with a weight of 100kg. To handle and control the test ball, as well as to apply the kinetic energy of impact, the tower crane and its parameterization system have been applied since they allow to carry out and control all the test parameters.

Obviously, this test is more restrictive than the one carried out with soft body since in this case, the rigid mass does not have any deformability capacity, and the impact energy is transmitted with a greater aggresivity than in the case with soft body.
In all the impacts the rigid body has been placed in the centre on the four armours with their relevant protections already installed, with the purpose of guaranteeing a vertical fall and centred on the protections, a situation which has not always been possible due to the variations introduced by the

own instantaneous system of freedom of the rigid test mass, having detected in some cases that, from the four protections, nearly all the impact has been transmitted to only one protection of the four predicted. Tests with the protection on only one armour were also carried out and, however directing the impact on it, and due to the complexity of guaranteeing the perfect verticality on the impact, such as stated before for the arrangement of the four protections, these test have not had significant results for the final evaluation of the resistance performance of these plastic pieces.

Below there is a table which sums up the six arrangements tested and the variations of some test parameters, such as *"fall height", "rebar diameter", "rebar lenght" and "number of steel rebars".*

	FALL HEIGHT	REBAR DIAMETRE	REBAR HEIGHT	Nº OF REBARS	IMPACT ENERGY
Test 1	1m	12mm	150mm	4	1000J
Test 2	2m	12mm	300mm	4	2000J
Test 3	2m	16mm	300mm	4	2000J
Test 4	3m	12mm	100mm	4	3000J
Test 5	3m	16mm	100mm	4	3000J
Test 6	2.5m	16mm	100mm	4	2500J

Hard body:
Steel sphere with a mass of 100kg and a diameter of 50cm

Photograph 2: Arrangement Hard Body Test

4.2 Soft body impact test

This test has consisted on the impact by free fall of a soft body on the protections placed on the steel armours and from a preestablished height, with the purpose of checking the resistance of these devices in case of penetration against the steel elements.

The soft body used for this test is a sphericonical bag with a weight of 50kg. To handle and control the test bag, as well as to apply the kinetic energy of impact, the tower crane and its parameterization system have been applied since they allow to carry out and control all the test parameters.

This test is less restrictive than the one carried out with hard body, since in this case, the test mass has a great deformation capacity, taking part, to a greater extent, in the energy absorption during the impact.

In all the impacts the soft body has been placed in the centre on the four armours with their relevant protections already installed, with the purpose of guaranteeing a vertical fall and centred on the protections, a situation which has not always been possible due to the variations introduced by the own instantaneous system of freedom of the hard test mass, having detected in some cases that, from the four protections, nearly all the impact has been transmitted to only one protection of the four predicted.

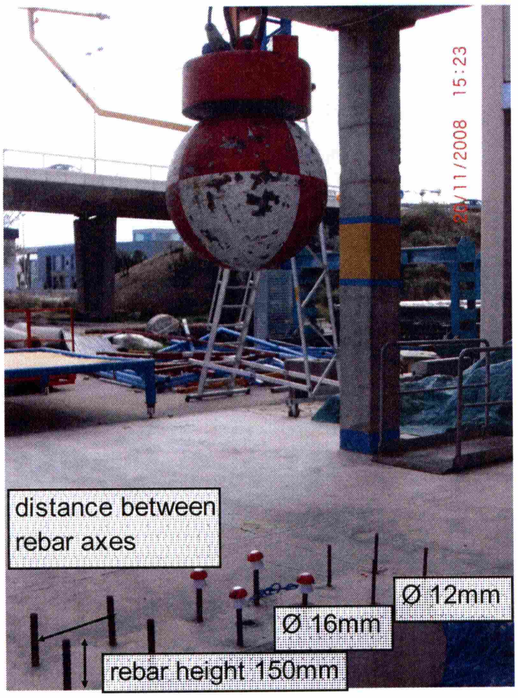
Below there is a table which sums up the four arrangements tested and the variations of some test parameters, such as *"fall height" and "rebar diameter"*.

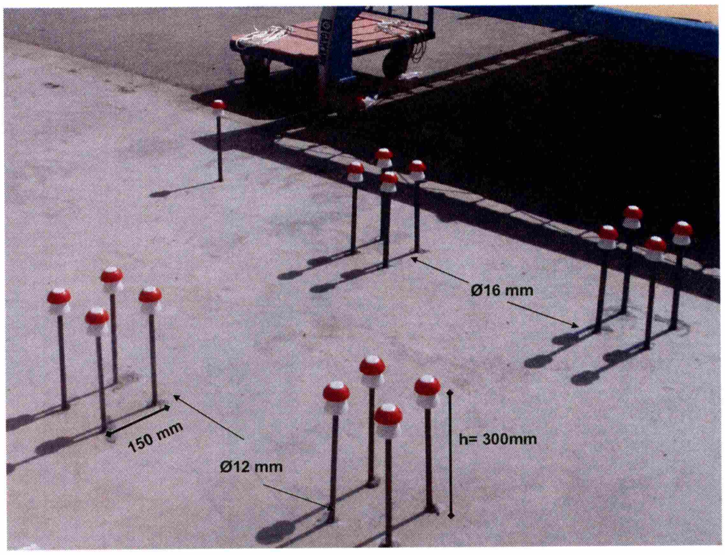
	FALL HEIGHT	REBAR DIAMETRE	REBAR HEIGHT	Nº OF REBAR	IMPACT ENERGY
Test 1	4m	12mm	150mm	4	2000J
Test 2	4m	16mm	150mm	4	2000J
Test 3	2m	16mm	150mm	4	1000J
Test 4	5m	16mm	150mm	4	2500J

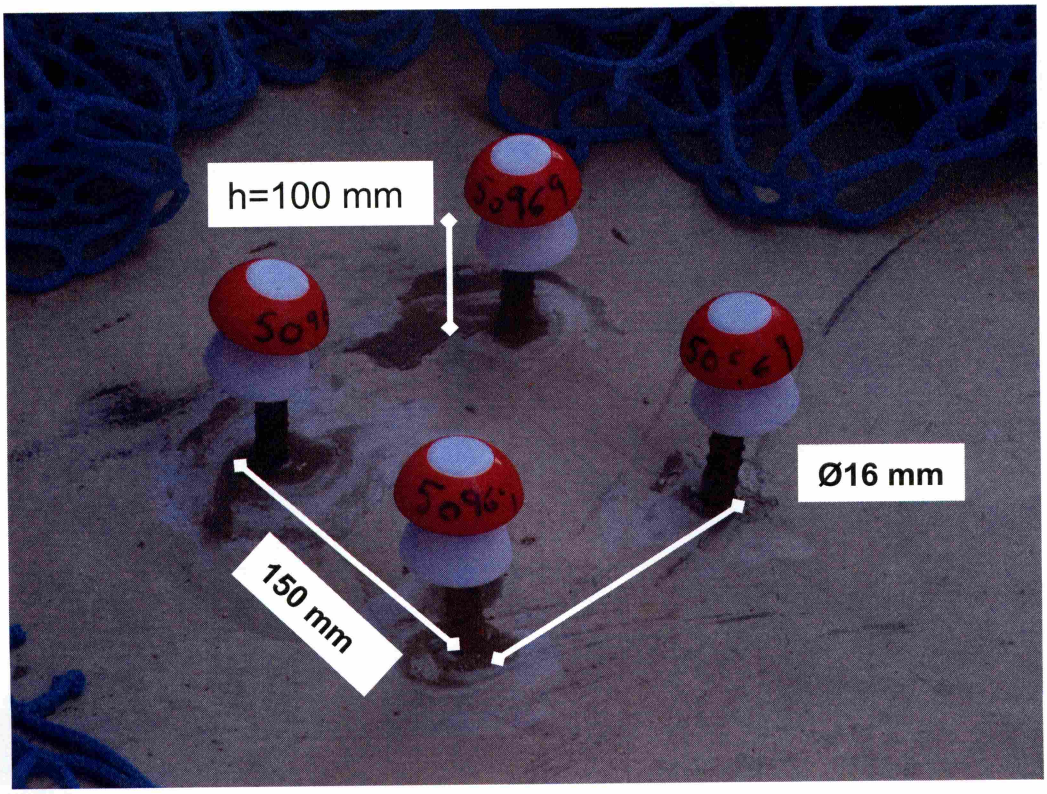
Soft body:
Sphericonical bag with a 50 kg mass

Photograph 3: Arrangement test for soft body impact.

Examples test arrangements







5.- RESULTS AND DESCRIPTION OF RESISTANCE PERFORMANCE OF PLASTIC PIECES IN THE DIFFERENT TESTS

Below there is a description and assessment of the structural performance detected on the protection of steel armours manufactured in thermoplastic injected from the materials; polyethylene, polypropylene and polycarbonate, for each one the dynamic tests of resistance applied, and with the arrangements expressly pointed out, carrying out the fundamental differentiation of test through impact with hard body and soft body.

5.1 Hard body impact test

Test 1 *(H_{fall}=1m; $\varnothing_{armour}$=12mm; h_{armour}=150mm)*

After the impact carried out for a kinetic energy of 1000 joules, the protection of the armour with the polycarbonate reinforcement resists perfectly to this level of applied dynamic load, and there is not perforation of the armour through the plastic pieces

Test 2 *(H_{fall}=2m; $\varnothing_{armour}$=12mm; h_{armour}=300mm)*

In the second test carried out, increasing by two the applied dynamic load, which in terms of accumulated kinetic energy during the fall means an impact of 2000 joules, we verify again that the protections are able to resist the said level of impact, since in none of the four affected protections has been detected neither a perforation of the steel armours on the top part of the pieces nor laterally. Some fissures may be observed on the top part of the pieces, just in the contact area with the impact body, resulting only in a superficial damage on the polypropylene white piece, but not a total penetration of the whole piece passing through the inner reinforcement of polycarbonate.

Test 3 *(H_{fall}=2m; $\varnothing_{armour}$=16mm; h_{armour}=300mm)*

Similar performance as the previous case, although in this test the diameter of the armours used is 16mm and the contact surface to resist the same level of impact is higher

Test 4 *(H_{fall}=3m; $\varnothing_{armour}$=12mm; h_{armour}=100mm)*

Despite the important level of impact applied, fall energy of 3000 joules, with the aim of checking if the plastic pieces object of the test have a safety factor regarding the maximum fall height which should be allowed and which should be of 2m, it is verified again that there is not a total penetration of the armours through the protections. This situation is beneficial, taking into account that part of the impact energy is absorbed by the deformation suffered by the steel armours, which already have a considerable slenderness since an effective length of 30cm with respect to the concrete base have been planned, taking into account this effect.

Test 5 *(H_{fall}=3m; $\varnothing_{armour}$=16mm; h_{armour}=100mm)*

In this new test, there is a total penetration of the steel armours on the plastic protections. The significant magnitude of the impact applied, can be seen on the final state of the own steel armours, such as the images included on the photographic series of this report show.

Test 6 *(H_{fall}=2.5m; $\varnothing_{armour}$=16mm; h_{armour}=100mm)*

For a fall height of 2.5m and for an armour with a Ø16mm diameter, the protections have not been able to absorb the level of impact applied, and a total penetration of the armours through the protections and total longitudinal breakages of the protections are detected

5.2 Soft body impact test

Test 1 (H_{fall}=4m; $\varnothing_{armour}$=12mm; h_{armour}=150mm)

For a kinetic energy of impact of 2000 joules, which would correspond to the fall of a person on the protections from an approximate height of 2m (limit value a priori for these protections) the following performance is detected:

- Of the four protections affected in the impact and, taking into account the difficulty of applying the load perfectly centred on the four of them, it is on three of them, on which mainly the dynamic efforts are transmitted, checking in all cases that there is no penetration of the armours on the thermoplastic protection, but there is a perforation of the superficial material of the impacting bag, and one of the plastic protections introduces totally in the inside of the sphericonical bag.

- Relative displacement of the white polypropylene piece on the red polyethylene piece and this situation causes a bigger punching effect on the soft body.

Test 2 (H_{fall}=4m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)

Such as in the previous case, but this time with steel armours of nominal diameter of Ø16mm, a similar performance is observed, without a perforation of the steel elements on the plastic protections, but again a penetration in the impacting bag of two of the four plastic protections, motivated by the level of impact applied and by the relative displacement suffered by the red polyethylene pieces in comparison the white polypropylene pieces increasing the punching effect.

Test 3 (H_{fall}=2m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)

In this case, for a fall height of 2m of the round conic bag of 50kg, which would correspond to a fall of 1m for a mass of 100kg, which could be the common fall situation to the same level in a building site, taking into account that the gravity centre of person is placed approximately at 1m with respect to the inferior level. It has been checked, that all the protections which have suffered this level of impact have resisted without a perforation of the steel armours or partial fissures, but the penetration of the whole of a protection in the inside of the impacting bag has happened again.

Test 4 (H_{fall}=5m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)

Finally, carrying out a test for a kinetic energy magnitude of fall of 2500 joules, situation which exceeds the maximum limit (≤2m of fall) foreseen for these protections, the following structural performance is observed:

- Whole penetration on the impacting bag of two of the four pieces in the area of impact influence, and such as in the previous cases, the plastic protections are embedded in the inside of the mass.
- No perforation of the plastic protections by the steel armours, taking into account the capacity of absorbing dynamic efforts conferred by the inner polycarbonate reinforcement and that, part of the impact is absorbed by the deformability of the soft body.

6.- PHOTOGRAPHIC REPORT

6.1.- Dynamic impact test through crash with rigid body

Test 1 (H_{fall}=1m; $\varnothing_{armour}$=12mm; h_{armour}=150mm)

Photograph 1: Initial test disposition.

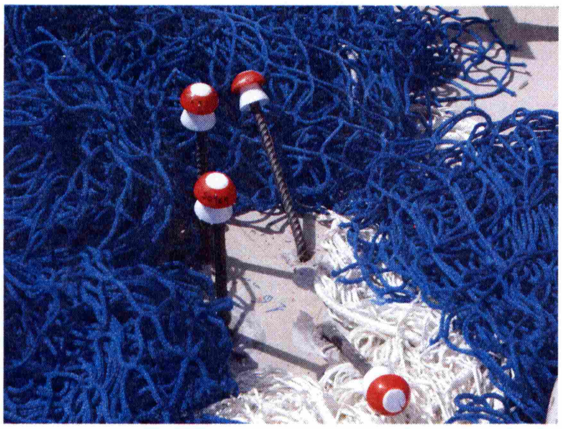
Photograph 2: final state of the protections after the impact.

Test 2 (H_{fall}=2m; $\varnothing_{armour}$=12mm; h_{armour}=300mm)

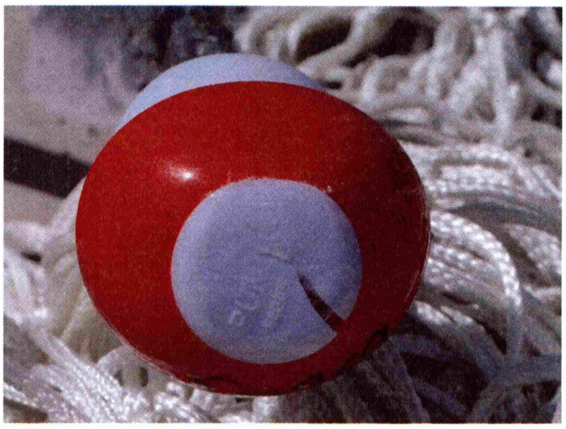
Photograph 3: Detail of the final state of one of the protections after the impact.

Photograph 4: Example protection in good condition after the impact.

Test 3 (H_{fall}=2m; $\varnothing_{armour}$=16mm; h_{armour}=300mm)

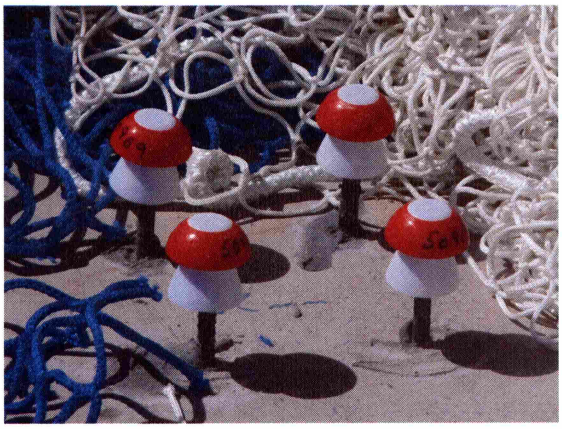


Photograph 5: State of the protections after the test. The protections remain in good condition after the impact.



Photograph 6: Detail of the partial fissures observed in one of the protections

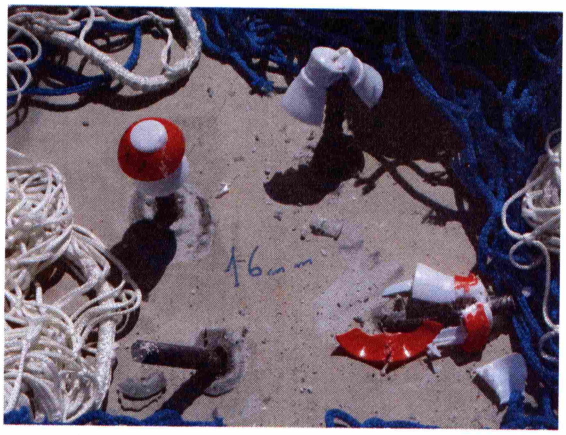
Test 4 (H_{fall}=3m; $\varnothing_{armour}$=12mm; h_{armour}=100mm)



Photograph 7: Initial test disposition.

Photograph 8: Detail of the protection after the impact.

Test 5 (H_{fall}=3m; $\varnothing_{armour}$=16mm; h_{armour}=100mm



Photograph 9: Perforation of the protections after the impact.

Photograph 10: Detail of the state of one of the protections which has suffered the impact.

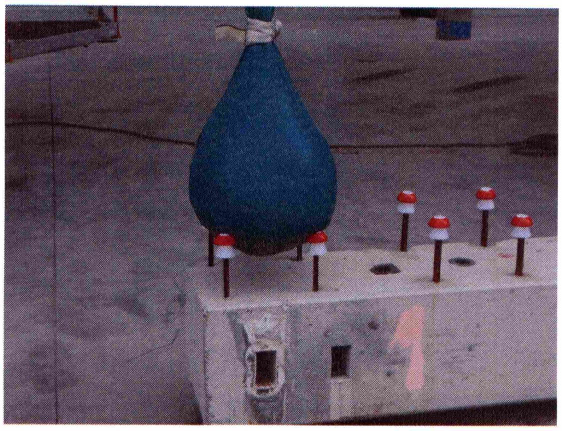
Test 6 (H_{fall}=2.5m; $\varnothing_{armour}$=16mm; h_{armour}=100mm)

Photograph 11: Initial test disposition.

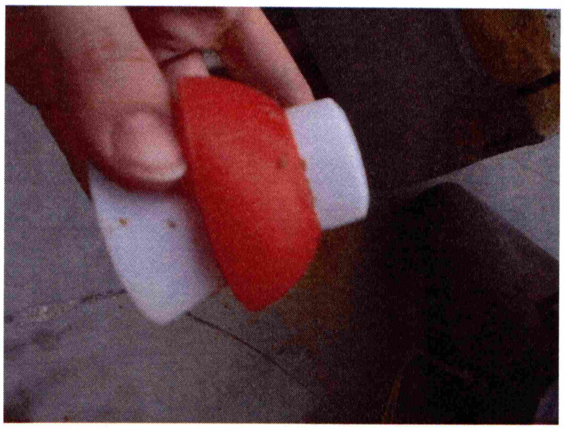
Photograph 12: Total perforation and longitudinal breakages of the protections.

6.2.- Soft body impact test

Test 1 (H_{fall}=4m; $\varnothing_{armour}$=12mm; h_{armour}=150mm)

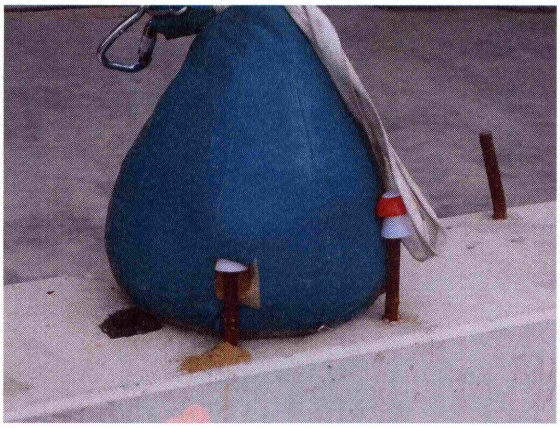


Photograph 13: Initial test disposition.



Photograph 14: State of the protection which introduced itself on the inside of the bag. Relative displacement between white and red piece.

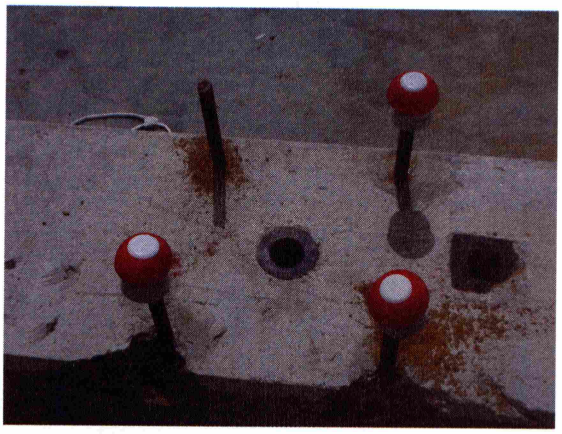
Test 2 (H_{fall}=4m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)



Photograph 15: Final disposition after impact.

Photograph 16: State of the two protections which ended up on the inside of the bag after the impact.

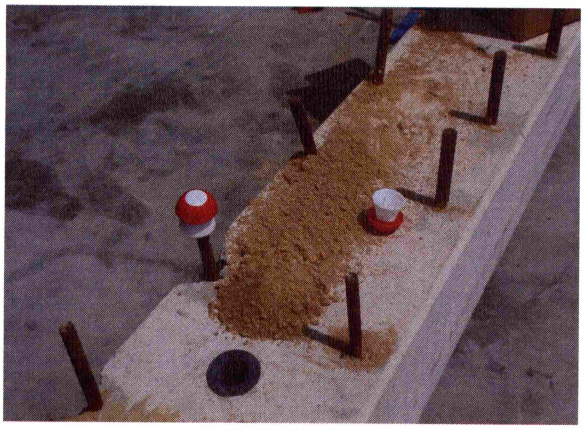
Test 3 (H_{fall}=2m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)



Photograph 17: Final disposition after impact.

Photograph 18: The fourth protection through the bag.

Test 4 (H_{fall}=5m; $\varnothing_{armour}$=16mm; h_{armour}=150mm)



Photograph 19: Final disposition of test, several protections embedded in the bag.

Photograph 20: Detail of the state of one of the protections which ended up inside the bag. There is no perforation of the steel armour through the plastic piece.

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