LIFT SAFETY IN SPAIN

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ABSTRACT

The En 81 European regulations have been in force in Spain for new installations since March 26 1992, when some 400,000 lifts were in operation. The author reviews the main safety problems, analyzing each and commenting on some of the main causes of accidents. Although the analysis is centred on Spanish experience, many of the problems expounded probably take place in other countries. Furthemore, some gaps in the present regulations are exposed in the design aspects and in the periodic inspection system.

1. INTRODUCTION.

1.1. The regulations context.

Applying the European Community Directives relative to the approximation of member States legislations concerning elevators, the Spanish State enacted, the 8th November 1985, a new Regulation of Lift and Handling Equipment which replaced the Regulation of Elevators in force from 1966. The safety norms that lifts must fulfill are defined in an attachment to the Mentioned Regulation titled " MIE-AEM-1 Complementary Technical Instruction (ITC) ", which corresponds to the EN 81 European safety codes, became mandatory in Spain for new installation lifts from 26th September 1982.

The Spanish versions of EN 81 codes incorporate some own options. The most significant option is the one relative to the landing door fire performance, which, in the Spanish versions, must correspond to a qualification of flame resistant during 30 minutes, in the conditions of heating foreseen in the ISO 834 norm (UNE 23-093-81).

Those lifts subjected to the Regulation of 1966 will have to keep on fulfilling it. The periodic inspections of those lifts must be carried out following the Industry and Energy Ministry Order of 31st March 1981. Regarding the tests of safety elements to be carried out , this provision isn´t substantially different from the foreseen to this effect by EN 81 codes.

The periodic inspections, delegated in general by the Appropriate Body of the Administration to Inspection and Control Organizations (ENICRE), are obligatory in Spain from the publication of the ITC MIE-AEM-1 the 23rd September 1987. The frequency of the periodic inspections is two years for buildings of public gathering and four years for the remaining ones.

The main difference between the present Spanish regulation, based on EN 81 codes, 1966 regulation and previous ones, consists of the safety elements homologation in these one was made without any previous test, being sufficient the presentation of a project in order to obtain the corresponding certificate. This implies most of the safety elements installed in Spain before the 26th March 1992 have never been object of test in official laboratories.

1.2. Lifts Spanish park.

In the date of EN 81 European codes coming into force, the lifts Spanish park was made up of 400,000 units. Approximately 80 % of this park is installed in residential buildings, being the remaining 20 % distributed among other kind of buildings, such as offices, hospitals, hotels and industries. As regards the antiquity of the park, there aren't official statistics on the matter although it can be said that half park has an age of more than 20 years and it's common to find installations with an antiquity of 30 or 40 years. On the other hand, the modernizations achieved have been frequentlly oriented to replace those apparent elements of the installation, such as decorations, car and landing control stations, landing displays or other components, as controls, which have an apparent translation into the lift working, keeping, on the other hand, the original mechanical components, most of which aren't visible. As a result of this modernization policy, it´s frequent to find installations which have been apparently updated, judging by its visible parts, but whose essential components and, especially, the safety elements, are the original ones, which don´t comply with present standards and which often are in a poor maintenance condition.

1.3 The Safety context.

As far as we know, there aren´t published statistics in Spain about accidents in lifts and escalators. Therefore, the real safety condition of this kind of installations isn´t known by the public opinion. The available informations on the matter come, thus, from the Press, when the importance of an isolated accident or the coincidence of different ones in a short period of time becomes vertical transport installations safety in a newsworthy topic.

The most famous accident in last times was Bellvitge Hospital one, on 21st May 1989, where the seven passengers of one of the main lifts died when the car suspension system broke down and the lift fell down from the 13th floor. The progressive safety gear didn't stop the car.

Recently, the safety topic has occupied again a choice position in the Spanish press informations since, only in the first six months of 1993, four people have died in a lift in Madrid. The first one died in a lift without car door, being squashed by the rubbish container he carried, when this one went round due to the relative motion between the car and the wall of the enclosure. The second one died beheaded when the lift started a travel with open doors just at the moment when the victim came in the lift. Other two people died when the suspension of the service lift where they travelled broke down. This one didn´t comply with the safety norms established for people transportation. In this last accident, other three people were seriously wounded.

As a result of these accidents and other ones, the main newspapers of Madrid performed inquiries which revealed the fact 40 % of lifts installed in the Spanish capital city hadn´t been object of periodic inspections and 86 % of the inspected lifts were defectives. According to "El País " daily newspaper, half of the lifts installed in Madrid still lack car doors and for this reason 23 people have died in last five years. The climate of uneasiness awaked by these accidents and by the discovering of the existing deficiencies, in the safety of installations as well as in the control of this subject by the concerned public administrations, has justified that a columnist of the prestigious newspaper " El Mundo " headed one of his columns with the title "Evil Lifts ".

In that alarming context, we present this communication which aim is to expound briefly some of the main deficiencies we have noticed along our practice in Spain and, we believe, contribute in a main way at the low safety level showed by the circumstances mentioned above. We don't think necessary to write about the lack of car door in so many lifts in Spain, in spite of its serious consequences, since its only solution is to install lacking doors.

2. TRACTION DRIVE.

The traction drive is one of the lift essential components, were a largest number of design, manufacturing and maintenance deficiencies, which are the origin of many accidents that can have serious consequences, are observed. The Figure 1 represents a cross-sectional view of t the worm shaft of a little power traction drive, very widespread in Spain. The Figure 2 is a cross-sectional view of the main shaft of a traction drive with external bearing. Some of the main problems this kind of traction drives presents are the following:

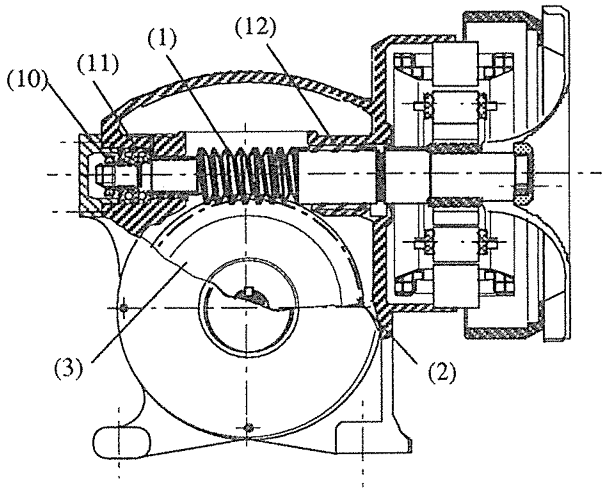

Figure 1
Worm gear
Cross-sectional view of the worm shaft

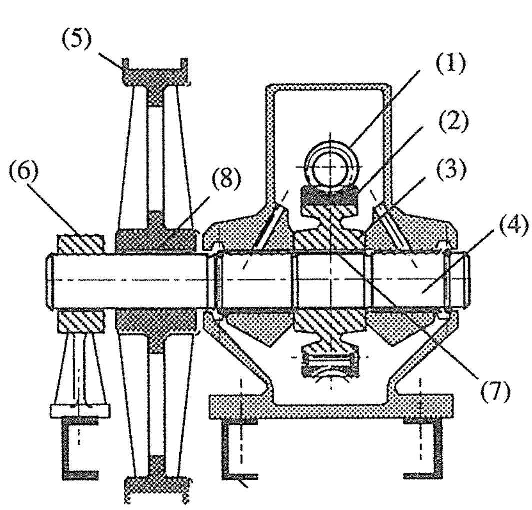

Figure 2
Three bearings worm gear
Cross-sectional view of the main shaft

(1) Worm shaft	(2) Worm wheel rim	(3) Worm wheel hub	(4) Low speed shaft
(5) Sheave	(6) External bearing	(7) Worm wheel keyway	(8) Sheave keyway
(9) Framework	(10) Axial bearing nut	(11) Axial bearing	(12) Radial bearing

2.1 Worm shaft.

a) Inadequate section of the nucleus.
b) Inadequate modulus of the teeth.
c) Inadequate transition radius between the shaft teeth and its nucleus.
d) Inadequate radius of teeth foot.
e) Inadequate teeth hardening, which introduces strong residual stresses.

These problems mean the shaft insufficient fatigue endurance, with breaking of teeth and even of worm shaft , having as result an uncontrolled motion of the lift car.

f) The fixing nut of axial bearing is grown slack and finally goes off, causing shaft ejection.
g) Excessive clearances, in the axial bearing as well as in the radial one.
h) Insufficient service life of both bearings.
i) Inappropriate keyways of the shaft in the fly-wheel and in the motor.

In some designs, even in recent ones, the distance between the bearings of the worm shaft is too short. For this reason, the shaft is too rigid, lacking the necessary capability to absorb impacts . In these cases, the breaking of the shaft can be the result of strikes, surpassings of the car travel, its shocks or the collision of the counter-weight against the machine room floor slab or buffers.

2.2. Worm wheel.

a) Gear insufficient modulus.
b) Insufficient thickness of the bronze worm wheel, which causes its cracking.
c) Inadequate quality of the bronze or even using of other inappropriate alloys.
d) Unsuitable interference fitting between the bronze worm wheel and the wheel hub, due to faults in the machining of both parts. After the shrinkage, an insufficient interference produces the sliding of the bronze worm wheel over the hub. An excessive interference has, on the contrary, the effect of excessive stresses, resulting the cracking of the worm wheel
e) To solve this last problem it's possible to inject the bronze rim directly on the hub. This solution isn´t always right since the quality of bronze is more difficult to be controlled and gives rise to interface alloys between the rim and the hub, impossible also to be controlled.
f) Unsuitable keyways of the wheel over the main shaft.

2.3 Main shaft.

The main shaft is an especially critical part in the traction drives with external bearing, due to the phenomenon of fatigue under reversed bending. The section more critical, where the greatest part of the fissures and shaft breakings take place, is logically that corresponding to the sheave seat. Some of the factors more influential in an unfavourable behaviour of the main shafts towards fatigue are the following :

a) Insufficient sections.
b) Inadequate transition radius between adjacent sections of different diameter.
c) Lubrication grooves with insufficient radius.
d) Using of unsuitable steels, especially of high breaking strength.
e) Faults in the alignment of the external bearing, which introduce additional stresses.
f) Insufficient stiffness of the gear frame, in terms of the foreseen supports for the same.
g) Inappropriate keyways and keys for the sheave or worm wheel seating, with excessive sizes or with insufficient transition radius.
h) Unsuitable sheave seating, with excessive or insufficient fitting.
i) Drill holes and notches for the fixing of accessories.
j) Excessive clearances in the bearings.
k) Excessive roughness of the surface, specially in the sheave and worm wheel seatings.

In addition to these problems of design and construction,there are other ones caused by unsuitable erection and maintenance methods, such as :

l) To proceed with the disassembling of the traction drive when this one reaches the site, to make easier its raising until the machine room and the subsequent new assembly.
m) Utilization of unsuitable oils, inadequate oil level, also without being changed regularly.
n) Knurling of the shaft in the sheave seating zone, on the occasion of the change of sheaves, to recover the fitting lost in previous changes.
o) By the same reason, increase of the shaft by welding and subsequent turning of the shaft.
p) Increase of sheave keyway by welding and its subsequent machining.

With this respect, it must be pointed out that all welding on a shaft is indefectibly origin of a fissure in the same. In spite of this, we have even observed gearings where the worm wheel was fixed to the shaft by welding.

This problem of fissures and breakings of shafts has reached a so large scale that an important lift company has launched expensive control programmes of these shafts by ultrasounds to detect the presence of fissures and to avoid possible breakings. Nevertheless, as the appearance of a crack can take place at any time and its growth can be very fast, the only effective way to prevent this kind of accidents is to carry out an evaluation of the design and the real condition of each drive, correcting its faultinesses when its repair is possible and, otherwise, replacing it for other gear designed, manufactured and maintained with suitable approaches.

3. OVERSPEED GOVERNORS AND SAFETY GEARS

The system constituted by the whole of the overspeed governor and the safety gear is directed to stop the car if this one exceeds a predetermined speed in downward direction and, especially, in case of car suspension or counter-weight breaking. This last case of car free fall presents special troubles due to the fast increase of the speed imposed by the gravity acceleration. As a result of this one, the kinetic energy that the safety gear must absorb growths with the square of the speed and it´s necessary that all the elements, sometimes very numerous, which form the cinematic chain of the system, operates satisfactorily at the accurate moment and in a total time that doesn´t exceed the magnitude order of a second. On the other hand, it´s known that the coefficient of friction between the safety gear brake plates and the guide rails decreases with the speed,that´s why from a certain value of this one the safety gear can be unable to brake the car, even when it would have stopped it at a lower speed.

In the introduction we have mentioned some tragic accidents due to a wrong performing of the safety gear and whoever has carried out or been present at free fall tests knows that the smaller fault in some of the system elements or the lesser variation in some of the factors that influence in its working, means inevitably the failure of the test and the car fall down. Next, we expound some defectivenesses which can cause a fault in the system

3.1. Centrifugal overspeed governors.

A kind of overspeed governor very common is the one composed by two movable masses that turn together with the sheave and which are separated by the action of the centrifugal force. When a certain speed is exceeded, one of the masses actuates a trigger which releases a swinging jaw that falls and brakes the governor rope against other fixed jaw, placed in the base of the mechanism. This type of overspeed governor is dangerous due to the excessive delay which is produced between the moment when the nominal tripping speed is reached and the moment when the governor rope is really braked. In fact, it can happen that one of the movable masses passes near the trigger at a speed lightly lower than the tripping one. In this case the shot only will take place when the sheave has completed half a turn. Meanwhile, the car will have gone down in free fall a height equal to half the sheave development and its speed will have been increased consistently. On the other hand, the time spent by the swinging jaw in falling and braking the rope imposes a new delay.

As the Figure 3 shows, a governor of this kind can have a real tripping speed between 3. 97 m/ s and 5.03 m/s, for a nominal car speed of 2.50 m/s, against a nominal tripping speed of 3.12 m/s. Consequently, the choosen safety gear would have to be homologated to stop the car at a speed of 5.03 m/s. This kind of governor seems doesn´t comply with the 9.9.7 article of the EN 81-1 code since presents an excessive answer time and an indefinite tripping real speed. However, there is a large number of these governors which have been installed, even in lifts of high nominal speed, having some of them the corresponding EEC Type-Examination Certificate , which allows them to be used with nominal speeds over 4.0 m/s. Other problems that appear in this kind of governors are those related with the rope braking, such as the clearance between the jaws, its wear and the regulation of the braking spring.

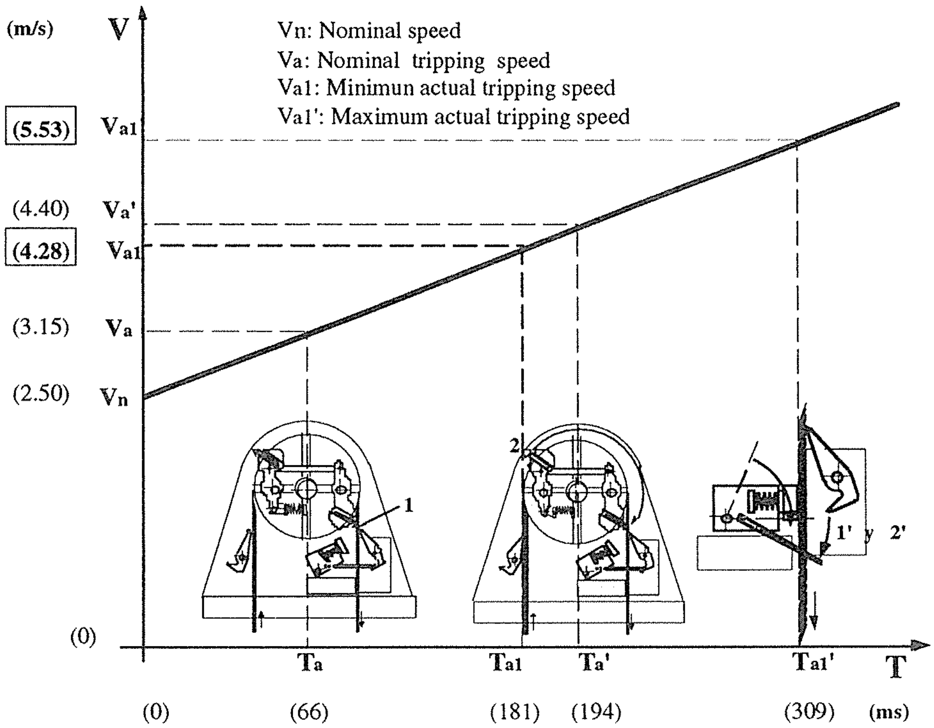

Figure 3
Centrifugal
Overspeed governor

3.2. Sheave friction overspeed governors

In these governors the rope braking is got by the friction between this one and the sheave when this last stops by the action of the ratched device. Although this kind of governors can also present a problem of delay, depending on the number of wheel teeth and the number of ratchets, the most important problem they have is the lost of friction between the rope and the sheave, due to the wear of this last one. In these conditions, the friction force developed can be insufficient to make the safety gear operates. In the Figure 4 is shown the system made up by the overspeed governor, the rope and the tension pulley.

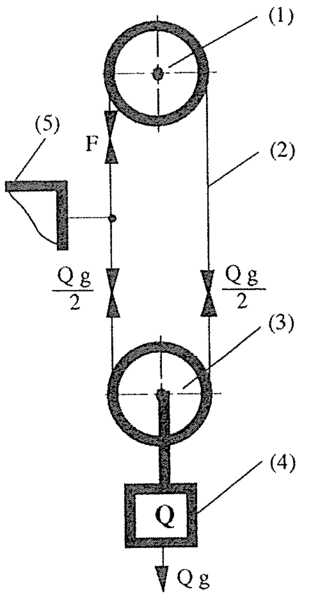

Figure 4
Overspeed governor system

1. Governor pulley
2. Governor rope
3. Tensioning pulley
4. Tensioning weight
5. Safety gear

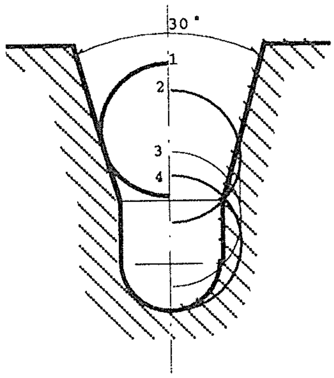

Figure 5
Wear of governor groove

The available friction force for the safety gear operation is :

Q: Tension mass (kg).
g : Gravity acceleration (m/s^2).
f: Apparent coefficient of friction.
F : Available activating force (N)

As Figure 5 shows, at the same time as the groove gets wear and the rope penetrates into it, the groove shape evolves from a groove in V to a groove in U, decreasing the apparent coefficient of friction in accordance with the known formulas. Accepting an actual coefficient of friction μ = 0. 125, the available friction force with a new groove (1) , as the one represented in the figure, would be of the order of 610 N, enough for operating a safety gear that requires an activating force of 305, taking into account the safety coefficient of 2 the EN 81 code prescribes. Nevertheless, with the weared groove the available force would be only 110 N, inadequate to activate the safety gear. The usual cast iron, with a hardness of the order of 200 HB, is unsuitable since gives rise to a fast wearing of the sheave. It´s necessary to harden the sheave in the groove zone, by induction hardening until it reaches a hardness of 50 HRC approximately. However, it´s difficult to reach an uniform hardness in this zone due to the lack of uniformity of the material thicknesses there.

3.4 Progressive safety gear.

Figure 6 shows a detail of the safety gear block of a very common progressive safety gear . In case of free fall, once the overspeed governor has activated the safety gear operation rods, the car keeps on falling with the acceleration of gravity a height h_1, until the movable wedges get into contact with the guide rail. In the example of 3.2 section, the car would have reached at that moment a speed of 5.12 m/s. While the car goes down the height h_2, the spring is compressed and develops a progressively growing braking force until the wedges bump into the wedges box and the spring reaches its smallest length, developing from that moment a constant braking force. In the same mentioned example, depending on whether the overspeed governor works at its lowest tripping speed or at the maximum one, the car stopping distances in free fall will be 859 mm in the first case and 3263 mm in the second one, assuming that the spring is adjusted to produce a deceleration of 0.6 g. It can be noticed, thus, the great variability of the system performance just by this reason. Other factors which can have a negative influence in the working of a safety gear of this kind are the following :

i) As a result of the safety gear acting, several parts of the mechanism as the braking shoes or the movable wedges can get fissures and be broken in the course of a later activation.

4. CAR SUSPENSIONS

The breaking of the car or counter-weight suspension isn´t, luckily, a common fact. However, when happens, usually has catastrophic effects. The simultaneous breaking of the suspension ropes seems it has never happened. Nevertheless, we have noticed serious defects in the equalizing of tensions between the different ropes of the same suspension and the breaking of some of them in double wrap drives. In these conditions, those problems which stem from the design and construction of rope fastenings, suspensions and the crosshead of the car as well as of the counter-weight still represent serious risks. In the following paragraphs we present two examples of suspension designs especially unfortunate. However, the fatigue-design of these elements under the cyclic loads they are subjected to hasn´t been completely developed and many present designs would be questionable under this point of view.

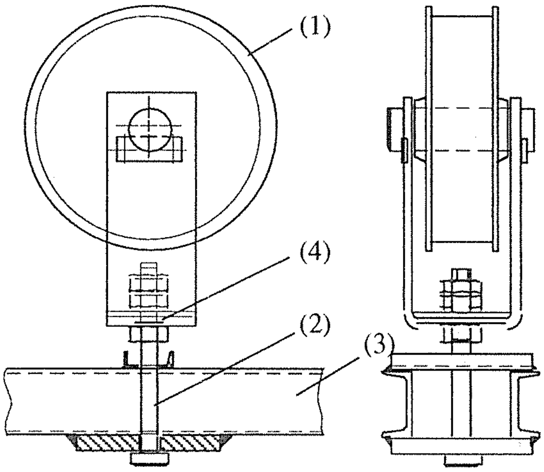

Figure 7
One bolt car suspension

1. Diverting sheave
2. Suspension bolt
3. Car crosshead
4. Breaking section

4.1. One-bolt suspensions.

Figure 7 shows a typical one bolt-suspension, as the one was cause of the mentioned Bellvitge Hospital accident. The bolt, probably calculated simply under static tensile load and which, under this kind of load, presented indeed an enough coefficient of safety , got broken under alternating bending loads, due probably to fastening system and eccentricities in the load and in the ropes tension. Faults in the thread machining gave rise to a high stress concentration in the bottom of it, causing the bolt breaking in one of those sections near to the suspension fixing.

While it could be thought that, after a so serious accident as Bellvitge one, all suspensions of this kind would have been replaced, we still have had the opportunity to observe recently this kind of suspensions in the lifts main group of a tower in a Spanish town, although reinforced on site.

4.2 Welded suspensions.

Figure 8 shows a roping factor 1 suspension with rope fixing plate welded on the frame crosshead. Figure 9 shows a roping factor 2 suspension based on the same principle. The danger of this kind of suspensions is due to the residual stresses introduced by welding as well as, in many cases, to its poor quality. There are still thousands of these suspensions installed in Spain.

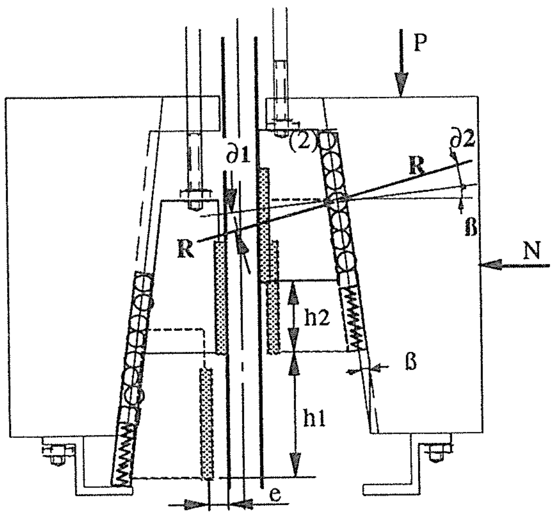

Figure 6
Progressive safety gear

Condition of equilibrium :
$\beta \leq \partial_1 - \partial_2 \qquad P \leq N \text{ tg. } \partial_1$

ß : Angle of the wedge
∂_1 : Angle of friction between wedge and guide
∂_2 : Angle of friction between rollers and wedges

a) The change in the coefficient of friction between the braking shoes and the guide rails depending on a very large number of factors, such as the speed, the superficial condition of the guide rails, the material, the superficial condition of the braking shoes, the fact that the guide rails are dry or lubricated, the kind of lubricant used in this second case, the dirtiness of contact surfaces, etc. The dependence between the coefficient of friction and the speed has been not much studied. Although some authors have proposed formulas for the same, we observe that the static coefficient of friction is confered a value of 0.4 in these formulas. However, in our tests, we have never got values higher than 0.21, which is an important difference.

b) The great variability in the characteristics of the braking springs, especially when these ones aren´t constituted by " Belleville " washers packets. On the other hand, the rust and dirtiness accumulated in these springs by time increases their internal friction, modifiying their behaviour.

c) The lack of synchronism in the working of the two wedges sets due to dimensional or levers operating mechanism defects which transfers the over speed governor action.

d) The use of drawn guides instead of machined ones.

e) Using of lubricated guides, especially high pressure oils or with improving lubrication additives.

f) The dirtiness oftenly accumulated in the rollers cage, with the consequent increasing of the coefficient of friction, which can hold up the action of the wedges, break the static equilibrium condition of the whole and even prevent the wedging action.

g) In view of the little wedge angle, which a light increase of the clearance " e " (Figure 6) between the wedges and the guide rails, which usually doesn´exceed 2.5 mm, can bring about that the braking spring compression gets very reduced or its not carrying out and even that the wedges reach their extreme position without getting in contact with the guide rail. This play, is also hardly controlable with the mechanism having been assembled, in working conditions.

h) The braking shoes hardness is a very important factor. If the hardness isn´t enough, the shoes can get wear out during the lift normal working as a result of the friction with the guide rails due to the mechanism unsuitable adjustment. This means a growing of the play between the braking shoes and the guide rails, with the consequences mentioned above and, on the other hand, the shoes remaining thickness can be insufficient to assure the car stopping. The GG 20 normal cast iron is inappropriate and must be used cast irons as the GGG 60 one.

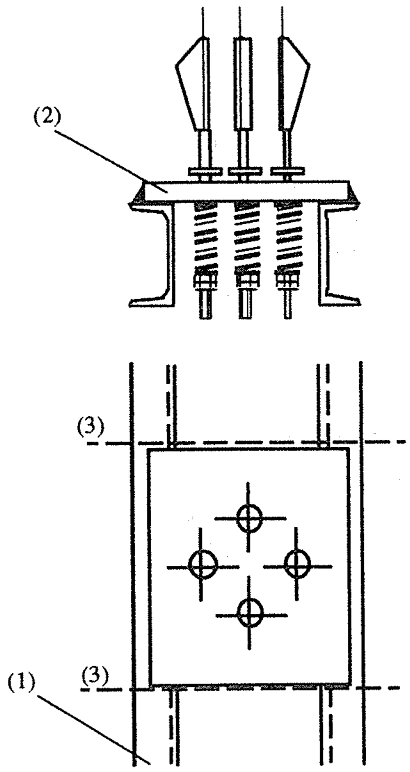

Figure 8
Welded suspension : roping factor 1

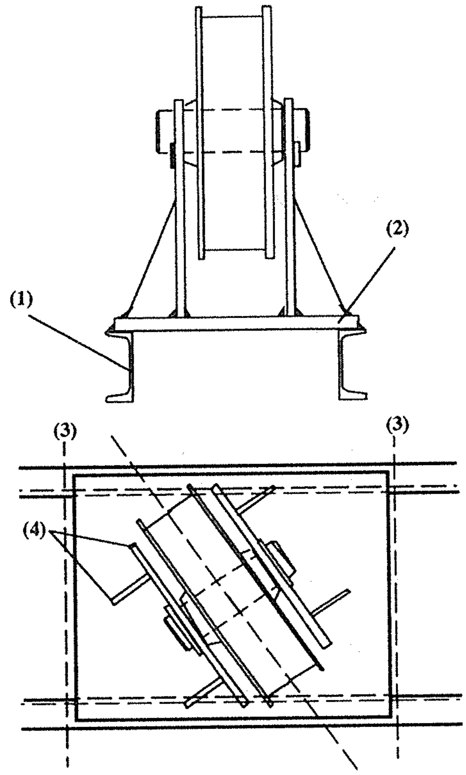

Figure 9
Welded suspension : roping factor 2

1. Crosshead 2. Welded plate 3. Critical section 4. Critical point

5. PERIODIC INSPECTIONS.

The EN 81 codes assum that the capability of the safety elements has been checked during the Type test and its working has been proved before its putting into service. Therefore, the inspections and tests in the periodic inspections have a relatively poor demand level. This principle is questionable by itself since it can be doubt that all installed elements correspond exactly to the homologated prototype and that, even in this case, keep its initial characteristics after having been working fifteen or twenty years. On the other hand, for the remaining components, EN 81 codes foresee only a "visual " inspection of the good construction rules application (Attachment D, D.1 d). Now, if this principle is extrapolated to elements which have never been tested, as it´s done in the present Spanish regulation, for those lifts installed before the EN 81 codes coming into force, the consequences can be very serious, as unfortunately it´s happening.

BIOGRAPHICAL NOTE

The author is Dr. Industrial and Textile Engineer by the Polytechnic University of Barcelona, having performed General Management tasks in several industrial companies. From twelve years ago he works in the lifts field, firstly as Industrial Manager of an international firm branch in Spain and nowadays as Managing Director of Lift Consult S.L. He is also the IAEE regional coordinator for Spain.