HISTORY OF THE SAFETY GEAR

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ABSTRACT

The safety gear is regarded as the last line of defence in the relatively safe world of lifts. Industry contemporaries recall Elisha Otis declaring “All safe” after cutting the ropes on a platform upon which he was standing and the safety gear preventing his uncontrolled descent. The design of safety gears has moved on significantly from an original proposal to place a bag of feathers in the lift pit to designs that now arrest uncontrolled movement in ascent. This paper is a developing research project which will look at UK patents and standards and tracks the development of the safety gear from the embryonic days of lift installations to the present day. It will contribute to knowledge by bringing together a number of sources of information not previously brought together into a single paper and thus provide a consolidated history of the safety gear.

INTRODUCTION

A literature search has revealed limited historical information about safety gears fitted to passenger lifts. Most literature is of a technical or sales nature rather than being in a historical context. Manufacturers of lifts have been taken over by companies over the years and in many cases historical information about a company’s history has been lost. There are a few exceptions, but most information is about the company rather than their products. It is common knowledge that Elisha Graves Otis designed the first safety gear and his paper presented to the Newcomen Society American Branch in New York 1945 gave good insight into the man himself as well as the product. Another author, John Inglis, based in Australia presented a paper at Elevcon in 1998 entitled “Evolution of Safety Gear” which has provided some interesting drawings for this paper however the paper did not look at changes in standards in a chronological way. Other historical books were located including “Electric Lift Equipment for Modern Buildings” (1923) by Grierson and “Electric Lifts” by R S Phillips (*dnk*) “Giving rise to the modern city” by Jason Goodwin and “A history of the passenger elevator in the 19th century” by Lee Gray (2002). Various books of a technical nature were located however historical and developmental information about safety gears was not covered. The British Standards published since 1970 were reviewed including BS 2655-1 (1970), BS5655-1 (1979) and BS5655-1 (1986) after which the European Norm standards saw the dropping of the BS prefix for EN. These included EN81-1 (1990) inc Amendment A3, EN81-20 (2014) and EN81-50 (2014). Manufacturers were also contacted for documentation and information will be reviewed as and when it is received. The literature review has revealed that there is very little information about the development of the safety gear and finding information is difficult but not impossible. The elimination of the safety gear has been proposed on many occasions which makes this research a piece of legacy work that may become important in the future as a future student can take it forward from the cessation point of the final research such that a chronology from its invention in 1853 can be established. This work can therefore be concluded as being novel and in the educational and public interest.

THE INVENTION OF THE SAFETY GEAR

“The significant influence of elevators dates from the invention by Elisha Graves Otis of a device capable of keeping an elevator from falling even though the hoisting ropes should break”[1]

In 1851 Elisha Graves Otis went to Bergen, New Jersey and then a year later to Yonkers, New York in his employ as master mechanic of the bedstead plants in which his employer, Josiah Maise, was an owner. It was here that he came face to face with his destiny and he designed and installed the first elevator equipped with an automatic device to prevent it from falling. [1]

He was destined to move to California however an unsolicited order for two safety elevators had been received from a Mr Newhouse, a furniture manufacturer in whose plant at 275 Hudson Street, New York, a serious elevator accident had just been experienced. The order for these two elevators marked the beginning, in 1853, of the now worldwide association of elevators and the name Otis.[1]

In 1853 an exhibition was held at the Crystal Palace in New York City at which Elisha Graves Otis demonstrated his confidence in his own product by standing on the platform of the elevator erected at the exhibition, raising the platform well above the heads of the assembled crowd, and then at the most dramatic point in his oratorical exposition, cutting the rope by which the platform was suspended. Those who had morbidly anticipated a leg breaking crash, however disappointed, were nevertheless impressed with the effectiveness of the Otis Safety when, as a matter of fact, nothing happened. [1] It is said that after the descending platform was arrested that Elisha Otis uttered the words “All Safe Gentlemen”

Fig 1: Elisha Otis demonstrating his safety gear in 1853

The New York Tribune reported the exhibition and made mention of the Otis invention however it should be noted that they referred to the elevator at the exhibition as one for hoisting goods and it was not until three years later that the first passenger elevator was manufactured by Otis and installed in a five-story building on the north-east corner of

Broome Street and Broadway which belonged to E V Haughwout & Co, dealers in china and glassware. [1]

This differs to an account in Goodwin [10] in which it is said that in the audience at the demonstration were a number of significant people. These included Mr Wilde of the Cohoes Cotton Mills, represnetatives of Johnson, Cox & Fuller, A visiting businessman from Charleston, South Carolina, a Boston based manufacturer of linseed oil and a contractor for the US assay office. Goodwin claims that all had placed orders with the Otis Union Works by the end of the year.

Sadly, Elisha Graves Otis died in 1861 owning a factory worth not more than $5,000 and employing only 8 or 10 men. [1]

POST DEMONSTRATION

According to Goodwin [10] the apparatus for the Elisha Otis demonstration was sold to Barnum, the famous circus performer, for $100.

THE EARLY ARGUMENT FOR NO SAFETY GEAR

In the same year that Elisha Graves Otis died Tufts secured a patent on the use of multiple lifting ropes [10] and argued for this as a passive safety measure. According to Goodwin Otis maintained a barrage of facetious propaganda against the whole concept of a passive safety system, boldly welcoming the scrutiny that Otis Tufts had attracted to the dangers of the lifting rope itself. “Any lifting rope or other labouring member that can be made,” warned the Otis catalogue for 1869, “must fail at some time, and MAY fail at any time. The fallacy under consideration may be set in a striking light by asking the question: why, if xix ropes are safer than one, are not twelve ropes twice as safe as six, and sixty ropes ten times as safe?....We would better untwist all our cables, and simply string the wires straight and distinct, in groups like a harp.” The catalogue revelled in providing details of grisly accidents, all suffered in rival’s machines.

DEVELOPMENT OF SAFETY GEAR DESIGN

According to Inglis[2] the earliest story known about safety of persons whilst travelling in a lift dates back to a Sultan who required a means of lifting people to the upper floor of his castle. It is said that a large bag of feathers was placed in the pit and one of his servants rode in the lift car whilst the rope was cut. The servant apparently survived the fall with only a broken leg and the Sultan therefore concluded that no one would be killed whilst using his lift.

In the early days car guide rails were often timber and a knife action safety gear would embed itself into the timber guides which would have to be replaced after each application. This was obviously an unsatisfactory situation and often rendered a lift out of service for a long period of time whilst replacement guide sections were obtained. This type of safety gear, as with many others, was also plagued by nuisance tripping in the event that the knife blade ran too close to the timber guides or a build-up of detritus would cause it to operate.

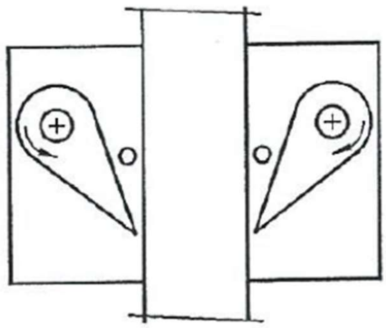

Fig 2: Early design of a safety gear using knives that dug into

wooden guides (source: Inglis)

Inglis goes on in his paper to a further development where an Italian invented a method of preventing injury in the event of free fall or an overspeed condition in the down direction. This is the first located mention of an overspeed condition. The invention consisted of some rods across the car above the passengers' head with the rods terminating in two rubber diaphragms at their ends. In the event of overspeed in the down direction a passenger would hold onto the bar with the diaphragms taking the force out of the impact when the car hit the buffers. There was the obvious question of how many passengers could be protected by such a device.

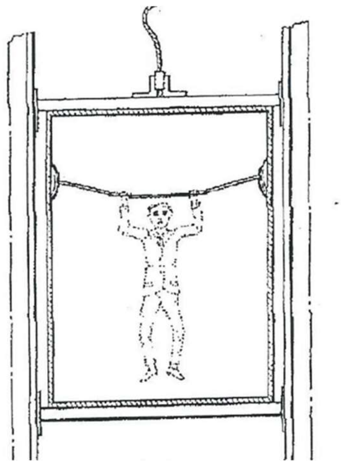

Fig 3: Italian invention with rods above

passenger's heads (source: J Inglis)

The development of high speed elevators necessitated the development of a new type of safety. It is elementary that the purpose of a safety device is not merely to stop the elevator platform, since this could be done with absolute certainty by simply letting the platform hit the bottom of the hatchway, but rather to bring the platform to a sufficiently gradual stop to prevent injury. The early safety, which contributed so greatly to the fame and fortune of Elisha Graves Otis, was of the instantaneous type which operated only in the event of slack or broken ropes and was useful only because it applied when the elevator had barely started to fall and before it had attained a downward speed greatly in excess of the normal speed, which was slow. Obviously, with a high-speed elevator it would be almost as disastrous to stop the elevator at high speed with a safety of instantaneous type as it would be too hit the bottom, or at any rate the stop would be more sudden than the human body could stand without injury. [1]

According to Grierson[3] up to about the year 1880 cast iron racks or ratchets were attached to the guides, and a pair of dogs, fixed at the top of the car attached to the single suspension rope, and operated by springs, formed the safety gear. Note the single rope, a situation no longer permitted for lifts although still seen in mine winding and cable car applications. When the rope failed, the springs that operated the dogs engaged with the racks on the guide posts and immediately brought the car to a dead stop. Grierson also states that "safety gear is not ordinarily fitted to counterbalance weights, only the car."

The next important development, according to Grierson, appeared around 1893 and is still extensively in use in Great Britain (bear in mind Grierson was published in 1923) was cam type guide grips. It consists of four serrated steel cams, mounted on two turned steel rods, that, when the necessity arises, rotate and bring the cams into contact with the guide rails or wood backing.

This safety gear was only suitable for slow speed cars (100 ft./min) due to being of practically instantaneous action. The design would also only protect against a too rapid descent of the lift car and was useless for excessive speed in the upward direction. Grierson noted that various manufacturers used different methods of safety gear activation including slack rope activation and a separate safety line connected between the car and counterweight.

In 1878 an overspeed governor of the fly ball type was invented for the purposes of operating a progressive safety gear. This was invented by Charles R Otis.[1]

SAFETY RECORD

With one exception (until the Petersen paper [1] was published in 1945) there is not a single known instance of an Otis traction elevator falling because of broken ropes or for any other reason. The one exception was furnished by a single elevator in the Empire State Building in New York on July 28th, 1945, while travelling downward at about the 17th floor, had all hoisting and governor cables severed by an aeroplane which crashed through the hatchway at the 89th floor. This rendered inoperative the safety equipment which understandably was not proof, nor intended to be proof, against aeroplane collision any more than a railway block system will protect a train from the remote contingency of a collision with a Flying Fortress. Happily, the operator (who was alone in the car) survived the crash. Since this incident cannot be regarded as a failure of the ropes or of the safety equipment, the record previously mentioned remains unimpaired. [1]

DEVELOPMENT OF BRITISH & EUROPEAN STANDARDS

Further work is required into researching of older standards and codes of Practice as there is clearly a gap between Otis demonstrating his safety gear in 1853 and the 1970 edition of BS2655-1. It is understood that there was a BS2655 published around 1958 but even then, this leaves a gap of over 100 years in documentary evidence of design.

Standards since 1970 have developed as follows:

1970 BS 2655-1:1970: Specification for lifts, escalators, passenger conveyors and paternosters. General requirements for electric, hydraulic and hand-powered lifts

1970 BS 2655-7:1970: Specification for lifts, escalators, passenger conveyors and paternosters. Testing and inspection

1979 BS 5655-1:1979, EN 81-1:1977: Lifts and service lifts. Safety rules for the construction and installation of electric lifts

1986 BS 5655-1:1986, EN 81-1:1985: Lifts and service lifts. Safety rules for the construction and installation of electric lifts

1986 BS 5655-10:1986: Lifts and service lifts. Specification for the testing and inspection of electric and hydraulic lifts

1995 BS 5655-10.1.1:1995: Lifts and service lifts. Specification for the testing and examination of lifts and service lifts. Electric lifts. Commissioning tests for new lifts

1995 BS 5655-10.2.1:1995: Lifts and service lifts. Specification for the testing and examination of lifts and service lifts. Hydraulic lifts. Commissioning tests for new lifts

1998 BS EN 81-1:1998+A3:2009: Safety rules for the construction and installation of lifts. Electric lifts

1999: PAS 32-1:1999: Specification for examination and test of new lifts before putting into service. Electric traction lifts

1999 PAS 32-2:1999: Specification for examination and test of new lifts before putting into service. Hydraulic lifts

2007 BS 8486-1:2007+A1:2011: Examination and test of new lifts before putting into service. Specification for means of determining compliance with BS EN 81. Electric lifts

2007 BS 8486-2:2007+A1:2011: Examination and test of new lifts before putting into service. Specification for means of determining compliance with BS EN 81. Hydraulic lifts

2014 BS EN 81-20:2014: Safety rules for the construction and installation of lifts. Lifts for the transport of persons and goods. Passenger and goods passenger lifts

2014 BS EN 81-50:2014: Safety rules for the construction and installation of lifts. Examinations and tests. Design rules, calculations, examinations and tests of lift components

FACTORS AFFECTING SAFETY GEAR DESIGN

A number of factors seem to have driven safety gear design over the years.

- The desire to prevent an uncontrolled descent.
- The relationship between speed and safety gear design (principally to protect passengers against injury)
- The desire to protect against uncontrolled ascent as well as descent.

As the research progresses more categories may be identified although it currently appears that from 1853 onward for over a century it was simply a desire to prevent uncontrolled descent to allay passenger fears about this risk.

1970 BS 2655-1:1970: SPECIFICATION FOR LIFTS, ESCALATORS, PASSENGER CONVEYORS AND PATERNOSTERS. GENERAL REQUIREMENTS FOR ELECTRIC, HYDRAULIC AND HAND-POWERED LIFTS

This standard was published in 1970 and ended up with 6 amendments to its original form.

There were four separate sections on safety gear requirements which could be found in sections 2, 3, 5 and 6.

Safety gears shall comply with the following general requirements:

- Every passenger and goods lift shall be provided with a safety gear attached to the car frame and placed beneath the car platform.
- Safety gear shall also be provided on the counterweight where there is an accessible space **beneath** the travel of the counterweight.
- It shall be possible to release car safety gears by raising the car, and counterweight safety gears by raising the counterweight.
- Each car safety gear shall be operated by means of either a governor or a safety rope. All sheaves or pulleys in contact with any part of this rope, which is normally in motion at the same time as the car, shall have diameters at least 30 times the diameter of the rope.
- A car safety gear shall **not** operate to stop an ascending lift car. If an ascending lift car is to be stopped on account of overspeed then a safety gear shall be fitted to the counterweight for this purpose. Where an overspeed governor is used, it shall cause the motor control and brake control circuits to be opened in the event of overspeed in the upward direction.
- The application of the safety gear shall not cause the car platform to slope at more than 1 in 25 to the horizontal
- The motor control and brake control circuits shall be opened by a switch on the car safety gear before or at the time the safety gear is applied.
- When the car safety gear is applied, no decrease in the tension of any rope used for applying the safety gear, or motion of the lift car in the downward direction shall release the car safety gear.
- It shall not be possible for vibration of the car frame to cause a safety gear to be applied.
- No safety gear shall depend for its operation upon completing or maintaining an electric circuit.
- The gripping surfaces of a safety gear shall be held clear of the guides during normal operation of the lift.
- Any levers or cams operated by shafts shall be fixed to such shafts by means of welding, sunk keys or by equivalent positive connection.
- Safety gears shall be designed to grip each guide and to operate on the guides simultaneously
- Any shaft, jaw, wedge or support which forms part of a safety gear and which is stressed during its operation shall be made of steel or other ductile material
- The drive to a car governor rope shall be effected from the car frame.

- Any connecting device between a governor rope and car frame (or counterweight) that is intended to be released when the safety gear is applied shall be retained in its normal position by a spring loaded device
- A pawl and ratchet shall not be used as a safety gear

LIFT SPEED AND SAFETY GEAR SELECTION

BS2655-1 (1970)

BS2655-1 (1970) stated 2.12.3 Safety gears of the instantaneous type may be used for lift cars having a contract speed not exceeding 0.75 m/s or 150 ft./min.

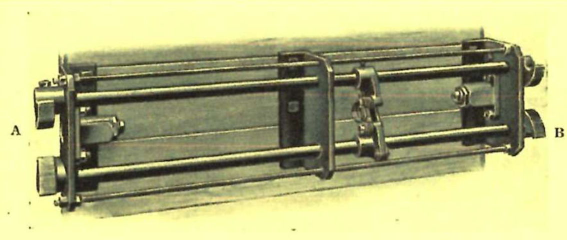

FIG. 17.—Instantaneous (serrated cam type) safety gear, fitted below car.
[By the courtesy of Messrs. Waygood-Otis, Ltd.]

Fig 4: Waygood Otis instantaneous safety gear (source; Grierson)

BS5655-1 (1979)

There was a shift in the 1979 standard which introduced the buffered effect for the first time:
9.8.2.1 Car safety gear shall be of the progressive type if the rated speed of the lift exceeds 1.0 m/s. It can be (a) of the instantaneous type with buffered effect if the rated speed does not exceed 1.0 m/s (b) of the instantaneous type if the rated speed does not exceed 0.63 m/s

The buffered effect was rarely used but when it was it involved the sling having an additional and independent travelling section underneath it which had an instantaneous safety gear attached. This safety gear would operate and the forces were reduced by the lift car sling being separated from the safety gear by devices such as hydraulic pistons (rather like buffers) which would take the forces out of the operation.

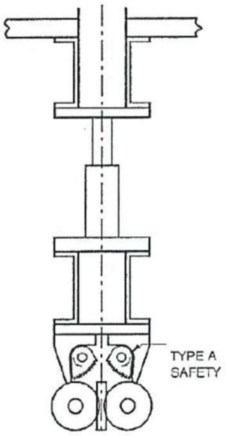

Fig 5: Buffered effect safety gear with a buffer
between the car and safety gear (source: Inglis)

Different manufacturers came up with different designs for both instantaneous and progressive safety gears.

Examples of different arrangements from different companies can be seen below.

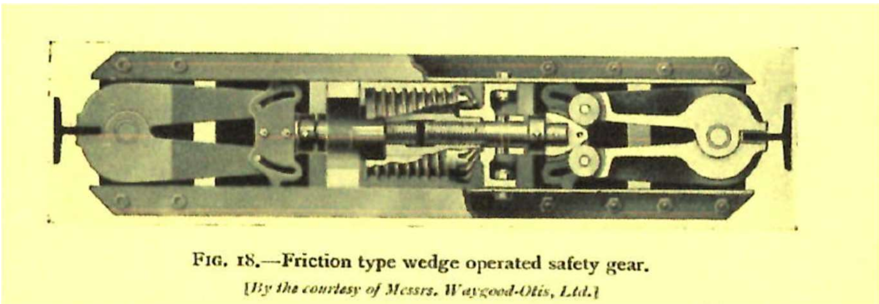

Fig 6: Otis Waygood wedge type progressive safety gear

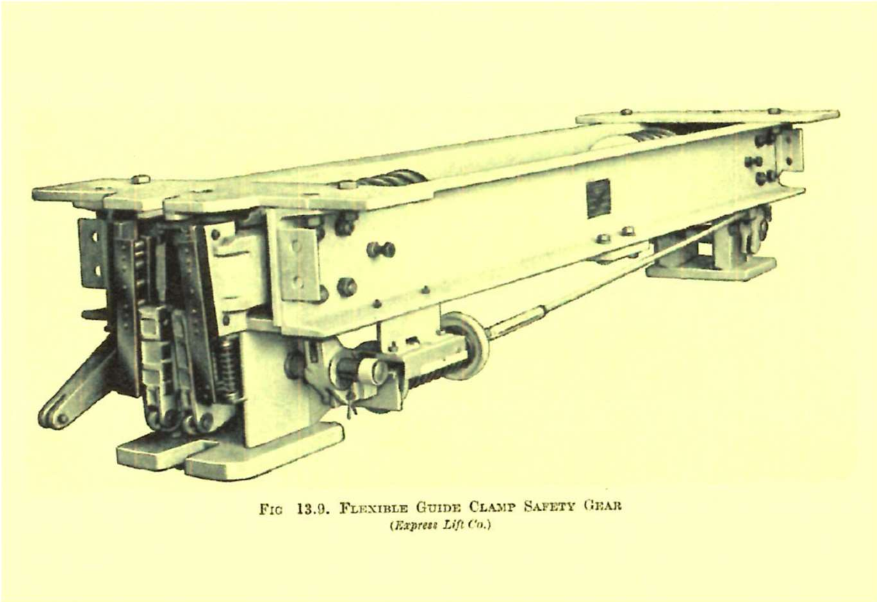

Fig 7: Express Lifts clamp type progressive safety gear (source: Philips [9])

BS5655-1 (1986)

This standard mirrored the BS5655-1 (1979) standard.

EN81-1 (1990) + A3 (2009)

Again, this standard mirrored the BS5655-1 (1979) standard.

EN81-20 (2014)

However, the publication of EN81-20 (2014) saw the end of the buffered effect with the wording being amended as follows:

5.6.2.1.2.1 Car safety gear (a) shall be of the progressive type or (b) may be of the instantaneous type if the rated speed of the lift does not exceed 0.63 m/s

The philosophy behind the change in speed between the 1970 and 1979 standards for instantaneous safety gears is not known however it can be seen that the EN81-20 (2014) standard limits instantaneous to a maximum speed of 0.63 m/s whereas the BS2655-1 (1970) standard allowed the higher speed of 0.75 m/s so despite the buffered effect being removed the reduced speed from the 1979 standard is still adopted.

FORCES

Initial considerations were that considerations with respect to forces imposed on passengers may have caused the change.

Standards do not specifically state forces applied on a passenger during the operation of a safety gear.

The best that can be referred to is the forces permissible in the event of a buffer collision.

BS2655-1 (1970)

BS2655-1 (1970) simply stated in clause 3.4:

"Buffers shall be installed under all cars and counterweights. Springs buffers or buffers of rubber or timber may be used."

By today's standards a completely meaningless statement but clearly there is no consideration as to the forces permitted to be placed upon a passenger and no distinction between instantaneous or progressive safety gears. In particular it should be noted that timber buffers were permitted.

BS5655-1 (1979)

BS5655-1 (1979) saw the introduction of consideration into forces imposed on a passenger.

Clause 10.4.3.3 stated "With the rated load in the car, in the case of free fall, the average retardation during action of the buffers shall not exceed gn. Retardation of more than 2,5 gn shall not be longer that 1/25 of a second. The speed of impact on the buffers to be considered is equal to that for which the stroke of the buffer is calculated (see 10.4.3.1 and 10.4.3.2)

Whilst the introduction of forces into the standards came with the 1979 standard it is unlikely to account for the difference in speed with reference to safety gear speed between the 1970 and 1979 standards.

BS5655-1 (1986)

BS5655-1 (1986) mirrored the 1979 standard with the exception the $1/25^{th}$ of a second was replaced by 0.04 seconds thus eliminating the fraction for a decimal.

DIRECTION OF LIFT AND SAFETY GEAR SELECTION

BS2655-1 (1970)

As previously stated in BS2655-1 (1970) "A car safety gear shall **not** operate to stop an ascending lift car. If an ascending lift car is to be stopped on account of overspeed then a safety gear shall be fitted to the counterweight for this purpose."

BS5655-1 (1979)

The wording changed in the 1979 standard to the following:

9.8.1.1 The car shall be provided with a safety gear capable of operating only in the downward direction and capable of stopping a fully laden car, at the tripping speed of the overspeed governor, even if the suspension devices break, by gripping the guides, and holding the car there.

It should be noted that the overspeed governor was introduced into the wording of standards at this point as a mandatory clause for all electric lifts including those with instantaneous safety gears albeit, as previously mention Charles Otis invented the flyball overspeed governor for progressive safety gears in 1878.

Prior to this BS2655-1 (1970) offered an overspeed governor as an option as follows:

2.12.3 The safety gear shall operate to stop and sustain the lift car with contract load in the event of failure of all suspension ropes or chains or their attachments, or in the event of the lift car exceeding a predetermined speed in the downward direction, when the safety gear is operated by an overspeed governor.

BS5655-1 (1986)

BS5655-1 (1986) adopted the same wording as the 1979 standard.

EN81-1 (1990) + A3 (2009)

It was not until EN81-1 (1998) Amendment 3 (2009) that the requirement to stop an ascending lift car came into being with clause 9.8.10 which stated:

9.10 A traction lift shall be provided with ascending car overspeed protection means conforming to the following:

9.10.1 The means, comprising speed monitoring and speed reducing elements, shall detect uncontrolled movement of the ascending car at a minimum 115% of the rated speed, and maximum as defined in 9.9.3, and shall cause the car to stop, or at least reduce its speed to that for which the counterweight buffer is designed.

EN81-20 (2014) varied the wording to as follows

5.6.1.1 Devices, or combinations of devices and their actuation shall be provided to prevent the car from (a) free fall, (b) excessive speed, either downwards, or up and down in the case of traction lifts, (c) unintended movement, with open doors (d) in the case of hydraulic lifts, creeping from a landing level.

CONCLUSION

The history of the safety gear is an interesting subject and it has been identified that there is a long gap of inactivity in design from 1853 to 1970 which requires further investigation. Sources thus far identified show development from a state of concern about the risk of falling to the quality of the fall should it happen with the introduction of acceptable forces relative to speed. Furthermore, the need to address other technical issues such as uncontrolled movement in the ascending mode have also caused developments in safety gear design. Research will continue to establish development of the safety gear from its initial design in 1853 to the present day.

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BIOGRAPHY

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David Cooper is the Managing Director of UK based lift consultants LECS (UK) Ltd. He has been in the lift & escalator industry since 1980 and is a well-known author and speaker. He holds a Master of Philosophy Degree following a 5-year research project into accidents on escalators, a Master of Science Degree in Lift Engineering as well as a Bachelor of Science Honours degree, Higher National Certificate and a Continuing Education Certificate in lift and escalator engineering. He is a co-author of "*The Elevator & Escalator Micropedia*" (1997) and "*Elevator & Escalator Accident Investigation & Litigation*". (2002 & 2005) as well as being a contributor to a number of other books including CIBSE Guide D. He is a regular columnist in trade journals worldwide including Elevation, Elevator World and Elevatori. He has presented at a number of industry seminars worldwide including 2008 Elevcon (Thessaloniki), 2008 NAVTP (San Francisco),1999 LESA (Melbourne), 1999 CIBSE (Hong Kong), 1999 IAEE (London), 1998 (Zurich), 1997 CIBSE (Hong Kong), 1996 (Barcelona) and 1993 (Vienna) as well as numerous presentations within the UK. He is also a Founding Trustee of the UK's Lift Industry Charity which assists industry members and/or their families after an accident at work. In 2012 David was awarded the silver medal by CIBSE for services to the Institution. David Chairs the Charity that runs the Lift Symposium and is an Honorary Visiting Fellow at The University of Northampton.

PRESENTATIONS OF THIS PAPER

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PUBLICATIONS OF THIS PAPER

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OFFERED

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161117 Elevator World (not peer reviewed)

161117 Offered to Elevatori (not peer reviewed)

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