Trafikkontoret

Göteborgs Stad

Cable Car Gothenburg: Cable Car Safety Memo

Maj 2016

INTRODUCTORY REMARK

In the continuous work with investigating urban cable cars, the issues of safety and security have been lifted. Since Swedish experience is scarce within the field of urban cable car systems this report makes a global outlook on risk and safety for cable cars, as well as a compilation of European regulations. Also the effects environmental conditions may have on cable car systems are presented, and how these risks can be minimized. The last part of the report covers passenger evacuation, which we have noticed is a subject of great interest to both the public and professionals in Gothenburg.

The report was produced during the spring of 2016 by Koucky & Partners AB, Gothenburg, in cooperation with zatran GmbH, Dornbirn, Austria. All facts and conclusions are their own. The Urban Transport Administration and Västtrafik AB (the regional public transport company in West Sweden) will use the report in ongoing planning and investigations.

The City of Gothenburg has through the Urban Transport Committee since 2013 investigated cable cars as a part of public transportation in Gothenburg. If cable cars were to be included as part of the public transportation system, this would be the first addition of a new transport mode for public transport in Sweden since the opening of the subway in Stockholm in the 1930's.

The publicly owned company Göteborg & Co was in 2009 commissioned by the municipal executive board to investigate how the city's 400 anniversary in 2021 could be celebrated. The task was performed in an open dialogue with municipal committees, public companies, the public, and a vast number of experts within various fields. The result was summarised in *Opportunities on the way to Gothenburg's 400th anniversary. Proposed work plan*. Cable car in Gothenburg was there presented as a citizens' initiative.

CABLE CAR GOTHENBURG: CABLE CAR SAFETY MEMO

Dnr 2367/15

Trafikkontoret, Göteborgs stad
Organisationsnummer: 212000-1355
www.forlivochrorelse.se/linbana
www.goteborg.se/trafikkontoret
trafikkontoret@trafikkontoret.goteborg.se
031-365 00 00

FÖRORD

I utredningsarbetet med urbana linbanor har frågor om säkerhet och trygghet lyfts i ett antal olika sammanhang. Då det är ont om svenska erfarenheter och exempel syftar denna rapport till att göra en global utblick avseende risk och säkerhet för linbanor, samt en sammanställning av europeiskt regelverk. Även vilka effekter som klimat och väder kan ha på linbanesystem presenteras, samt hur dessa riskfaktorer kan minimeras. Rapportens sita del handlar om evakuering av passagerare, vilket vi har märkt är en fråga av stort intresse både för allmänheten och professionella i Göteborg.

Rapporten är framtagen under våren 2016 av Kouck & Partners AB, Göteborg, i samarbete med zatran GmbH, Dornbirn, Österrike. På grund av detta är rapporten skriven på engelska. Alla uppgifter och slutsatser är uppdragstagarnas egna. Trafikkontoret och Västtrafik kommer att använda rapporten i det fortsatta planeringsarbetet.

Göteborgs Stad har genom Trafiknämnden sedan 2013 utrett frågan om linbanor som en del av det kollektiva resandet i Göteborg. Skulle linbana börja ses som en del av kollektivtrafiken är detta det första nya kollektivtrafikslaget i Sverige sedan införandet av tunnelbanan i Stockholm på 1930-talet.

Göteborg & Co fick i oktober 2009 i uppdrag av kommunstyrelsen utreda hur stadens 400-årsjubileum skulle kunna firas. Göteborg & Co genomförde utredningsuppdraget i en öppen dialog med nämnder, bolag, allmänhet och ett stort antal experter inom en rad olika områden. Resultatet summerades i *Möjligheter på väg till Göteborgs 400-årsjubileum. Förslag till arbetsplan.* Linbana i Göteborg fanns då med som ett medborgarförslag.

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Author: Christof Albrecht

Contents

1 Accident statistics

The following list is not complete; however most of catastrophic accidents involving fatalities are listed. Worker accidents are excluded, except some major accidents at startups are listed. The focus is on monocable gondola and aerial tramway systems. Chairlift systems used in skiing regions are not considered as they are not used in urban environments. So far no accidents with fatalities happened with tricable gondola systems.

Each incident is a result of inadequately taking care of a prevailing risk, or inadequate design and/or operating measures to counter such risk.

Cable Car Type	Year	Accident Description	No. of fatalities	Location	Country
Aerial Tramway	1956	Failure in rope connection to cabin. Track brakes did not function. Cabin plunged to ground.	1	Buisson	Italy
Aerial Tramway	1959	Cabin plunged to ground due to structural failure of cabin.	31	Santos	Brazil
Monocable Gondola	1960	Cabins plunged to ground. Reason unknown.	4	Kampanien	Italy
Monocable Gondola	1961	Airplane hits gondola line.	5	Aiguille du Midi	France
Aerial Tramway	1961	Car plunged to ground at trial run. Reason unknown.	5	Saddle Mountain	Mexico
Aerial Tramway	1965	Abrupt breaking at power failure. Cabin wall breaks out. Passengers fells out.	7	Fuy de Sancy	France
Monocable Gondola	1967	Haul rope failure. Cabins plunged to ground.	4	Aiguille du Midi	France
Monocable Gondola	1970	Cabins plunged to ground. Reason unknown.	5	Meran	Italy
Aerial Tramway	1972	Haul rope failure. Delayed track brake actuation. Contaminated track rope brakes did not hold the cabin. Cabin crashed into lower terminal.	13	Betten	Switzerland
Aerial Tramway	1974	Haul rope failure. Track brakes were not functioning. Cabin plunged to ground at tower.	4	Bergen	Norway
Bicable Gondola	1976	Failure of outerwires on track ropes which extended and derailed cabins. Two cabins plunged to ground. Reason: Inadequate ratio of track rope tension towheel load.	4	Vail	USA
Aerial Tramway	1976	Track rope cut by moving thrown over haul rope. Allegedly bypassing safety circuit after haul rope throw over. Cabin plunged to ground.	42	Cavalese	Italy
Monocable Gondola	1978	Roller battery seized, haul rope derailed, one cabin plunged to ground. System with grips unable to pass rope catchers	3	St. Louis	USA
Aerial Tramway	1978	Track rope derailment from tower. Track rope hit cabin roof and split cabin.	4	Squaw Valley	USA
Monocable Gondola	1979	Roller battery detached from tower and slammed with rope and cabins to ground	1	Melchsee - Frutt	Switzerland
Monocable Gondola	1979	Haul rope derailment on tower. Two cabins plunged to ground. System with grips unable to pass rope catchers.	1	Dallas	USA
Bicable Gondola	1983	Ship collision with ropeway track. Two cabins plunged to ground.	8	Singapore	Singapore
Aerial Tramway	1984	Part of the upper terminal buffer fell on cabin roof, crashed to the plastic roof and hit passengers.	1	Palm Springs	USA
Monocable Gondola	1988	Misgripping at station exit. Cabin plunged to ground.	1	Grindelwald	Switzerland
Aerial Tramway	1989	Cabin detached from carriage and plunged to ground during trial run.	8	Vaujany	France
Monocable Gondola	1990	Derailment of a cabin from the terminal rails. Hanger hit bystander.	1	Leysin	Switzerland
Aerial Tramway	1990	Haul rope failure. Track brakes did not function. Cabin plunged to ground.	15	Tiflis	Georgia
Monocable Gondola	1991	Reason unknown.	1	Schaffau	Austria
Aerial Tramway	1991	Track rope failure. Cabin plunged to ground.	2	Merida	Venezuela
Bicable Gondola	1992	Misgripping of one cabin at the upper terminal and crash into the next cabin downhill.	3	Skainate Pieso	Slovakia
Monocable Gondola	1993	Cabin slipped on haul rope and collided with cabin downhill.	1	Pitztal	Austria
Monocable Gondola	1996	Axle failure on return bullwheel. Cabins plunged to ground	1	Riederalp	Switzerland
Aerial Tramway	1998	Army jet plane cuts track rope. Cabin plunged to ground.	20	Cavalese	Italy
Monocable Gondola	1999	Rope derailment, three cabins crashed to ground.	3	Crans Montana	Switzerland
Aerial Tramway	1999	"Chapeau-de-Gendarme" of carriage slipped on haul rope. Cabin plunged to ground on next tower downhill.	20	Pic de Bure	France
Monocable Gondola	2003	Rope failure. Three cabins plunged to ground.	7	Panchamahals Gujarat	India
Bicable Gondola	2003	Haul rope derailment & failure. Three cabins plunged to ground.	4	Darjeeling	India
Monocable Gondola	2005	Gondola was hit by concrete bucket dropped by a helicopter.	9	Ötztal	Austria
Monocable Gondola	2007	Cabinr plunged to ground due to structural failure	4	Palani Temple	India

2 General safety assessment of cable cars

2.1 Parameters to assess the relative safety of a cable cars

a) Comparison to other means of passenger transportation

It is difficult to conduct such a survey, since there are different results in the various statistics. Furthermore, the basis of the accident statistics is not clearly defined. For instance, fatalities on railways: It is not known whether only passengers are included, or such figures involve worker accidents, crashes at uncontrolled road crossings etc. For the forthcoming rough appraisal, numbers making the most sense were taken from the internet.

Automobiles

Only the risk we take when boarding a passenger car is considered. Pedestrian, bicycle, motorcycle, truck driving and public transport fatalities are not included in the assessment. For automobiles, there are plenty of data available, and automobile traffic is so extensive, that a single catastrophic accident does not distort any results.

Airplanes

Only the risk we take when boarding a commercial airplane is considered. Freight transport planes, gliders, small airplanes for adventure trips, helicopters etc. are not included in the assessment.

Railways

Only the risk we take, when boarding a passenger railway is considered. Freight train crashes, workers accidents, etc. are not included in the assessment. Also not of interest are crashes on road crossings or on the line, as long the occupants of the railway are not affected.

Cable Cars

Only the risk we take when boarding a cable car cabin or chair is considered. Worker accidents, surface ski lift accidents, etc. are not included in the assessment. Statistics are available; however the number of cases is very limited to truly reflect the actual situation. The cable car means of transportation is by far not as wide spread and total passenger-km is a fraction compared to automobiles, airplanes and railways. The investigations are limited to the Swiss statistics as there is sufficient data available.

b) Safety assessment criteria

The following common used safety assessment criteria are used in the investigations:

1) Fatalities per 10^8 passenger km
2) Time spent in a transport system per fatality
3) Fatalities per 10^8 one-way trips
4) Fatalities per 100.000 population per year
5) Time in life exposed to risk and effect on live expectancy

c) Acceptable risk rates

Pertaining to railways the following criteria could be found:

An international acceptable risk for transport systems is:
- $5*10^{-10}$ deaths per passenger-km => 0,05 deaths per 10^8 passenger-km

In the European Standard EN 50125 (CEN 99):
- $1*10^{-6}$ probability of a fatality per person & per year (such number is not quite clear, since it appears, that it should vary with the exposure time to a given transport system)

Another criterion listed is the "Minimum Endogenous Mortality" (MEM):
- One takes the average mortality of a 15 year old person in Europe as the basis, which is $2*10^{-4}$ probability per person & per year
- A new technical system shall not exceed such rate by more than 5 %:
- Hence, the limiting death rate would be $1*10^{-5}$ per year, which is 10 times higher than the criteria per EN 50125.

2.2 Result of the safety assessment

Various statistics in the internet revealed the following results with regard to above mentioned safety assessment criteria 1) thru 5):

	Fatalities per 10^8 passenger km	Time spent in a transport system per fatality in 10^6 hours	Fatalities per 10^8 one-way trips	Fatalities per 100.000 population	Time of exposure to risk per year in hours	Reduction of life expectancy in weeks
Atomobile, Switzerland	0,18	11,11	3,83	2,10	236,00	3,00
Airlines, USA	0,02	8,89	19,20	0,04	3,10	0,05
Railways, Switzerland	0,03	47,62	0,50	0,08	35,00	0,12
Cable Cars, Switzerland	0,20	29,41	0,30	0,01	4,45	0,03

	Person-km / fatality in 10^6 km	Number of rides per fatality in 10^6 rides	Assumed average one-way trip in km
Atomobile, Switzerland	550,00	26,10	21,30
Airlines, USA	6667,00	5,21	1280,00
Railways, Switzerland	3333,00	200,00	16,70
Cable Cars, Switzerland	500,00	333,00	1,50

2.3 Conclusion

The interpretation of available statistics may not be accurate. With regard to the person-km travelled, the safety of a cable car is comparable to riding a car. Since the exposure is only a fraction of a car rider the outlook for ending up in an accident is minimal. Further, it is pointed out, that above statistics are based on fatalities. The fatality/injury ratio on cable cars and airplanes is probably higher, than on railways or automobiles. Airplane accidents many times end up in crashes with fatalities only, whereas automobile accidents mostly end up with injuries. In the year 2010 there was one fatality per 67 automobile injuries in the USA. Hence, the probability to sustain a serious injury on a cable car appears to be much lower compared to e.g. an automobile. With the progress in technology (calculation methods, inspection procedures, material qualities, improvement of operator education etc.) the safety level increases with time. This is true only to a certain extent, since technological progress also results in higher speeds, capacities, tighter design limits, etc. Hence, some of the gain in safety is offset again. As can be taken from the available statistics, there are different categories, and therefore it is difficult to determine from the numbers what the safest means of transportation really is. Overall, it appears that cable cars are "competitively safe" in comparison to other transportation systems.

3 Risk & safety analysis for cable cars

Particularly for new designs, design changes and changes of technical cable car parameters, it is required to produce a detailed risk & safety assessment according to CEN standards. New designs are subject to Murphy's law. It is important to catch all scenarios which may represent a hazard to passengers.

The following is a generally accepted method of a risk & safety analysis for cable cars:

Extent of accident/incident

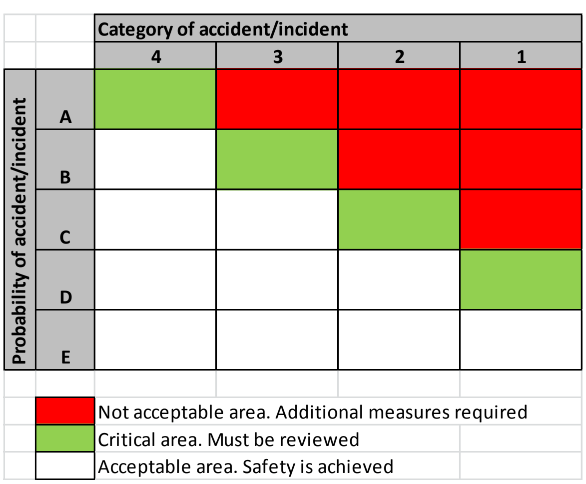
Getegory	Accident/Incident	Extent of accident/incident
1	Catastrophic	Several fatalities must be expected. Major system damage
2	Severe	Single fatality, critical injuries, massive system damage
3	Marginal	Minor injuries and minor system damage
4	Negligible	Potential minor injuries and system damage

Probability of accident/incident of above extent

Classification	Probability	Criterion
A	Periodic	May happen repeatedly
B	Probable	May happen a few times during the life cycle period of the cable car
C	Ocassionally	May happen during the life cyce time of the cable car
D	Seldom	Unlikely to happen during the life cycle time of the cable car but cannpot be excluded
E	Improbable	It can be assumed that such occurance will not take place during the life cycle time of the cable car

Risk & safety matrix - summary of analysis

For each scenario the extent of the accident is structured in categories 1 through 4. The probabilities of the accident/incident are listed in A through E. Hence, each number of the scenario is related to the accident category and its probability. Pertinent are the last two columns after execution of the required safety measures. Such numbers are now inserted in the following matrix. Ideally all numbers should be in the white windows.



4 Remaining risks on cable cars

4.1 General notes

- **Environmental conditions:** Wind and ice are enemies to cable cars. Many incidents happen, because the environmental conditions were not assessed properly, or the economic pressure leads to operating the system even though e.g. wind conditions are critical.
- **Code & standard requirements:** Do not take it for granted, that even if you meet all technical code & standard requirements, you will end up with a safe cable car. Many code & standard clauses are incomplete and erroneous. The cable car designer must look at rules critically. Unfortunately, nowadays many designers think if they meet the code & standards, their job is well done. Such thinking may lead to a catastrophe eventually.

4.2 Monocable cable cars

The haul rope derailment is probably the most wide spread cause of accidents. The reasons are the mechanical restraints on groove depth and flange extensions on tower sheaves. An effective rope position supervision, which shuts down the drive before a rope contacts a side flange should reduce the risk. Such devices have been developed. Even though they may not be fail-safe, if they function in 99% of the cases, they would reduce the probability of a derailment substantially.

4.3 Cable cars with track ropes (e.g. tricable gondola systems)

There are no specific single risks that are responsible for a majority of accidents. Each accident is unique. In comparison to monocable cable cars, systems with track ropes are not as standardized, and still require individual designs. Consequently, the potential for any design fault and faults within the material, production and installation is higher. Hence, causes for accidents are diversified.

Looking at the statistics, most accidents were caused by rope failures or derailments. However the development in technology with regard to track brakes (for aerial tramways), or, alternatively designing a safe haul rope loop, reduced respective risks drastically. As modern systems are concerned, there have been no serious incidents within the last 10 years. Hence, at this point it is difficult to pin point a distinct prevailing cause of an accident that is related to cable cars with track ropes.

When designing a system with track ropes there is an extensive list of potential risks. Nevertheless, except for vandalism, fire and collisions with airplanes the designer is able to provide the required precaution and safety.

5 CEN code requirements

5.1 General

Governing is the directive 2000/9/EC of the European Parliament relating to cable car installations designed to carry persons.

Pertaining to the CEN standards the following article of above directive is important:

"In order to make it easier that the essential requirements have complied with, it is useful to have harmonized European standards, compliance with which enables it to be presumed that the product is in conformity with the said essential requirements. Harmonized European standards are drawn up by private bodies and must retain their non-mandatory status. For this purpose, the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardisation (Cenelec) are recognized as the bodies competent to adopt harmonized standards that follow the general guidelines for cooperation between the Commission and those two bodies signed on 13 November 1984."

Complying with the CEN cable car standards is one way to presumably meet the above directive. Obviously, the door is open to achieve conformance with the directive by different approaches.

In practice, the procedure which has been assumed, was complying with the CEN standards and assuming in doing so the directive is met. Hence, it is preferable that such standards are technically correct and conforming to them will lead to a safe cable car. Unlike the ANSI code or the CSA code, the CEN code ended up being viewed as a "design hand book" with many shortcomings. The contributors of the CEN standard were heavy loaded with people from cable car authorities of various countries. Contributors of many countries were involved and a consensus of thousands of details had to be achieved which ended up in many compromises. In overall there is much valuable information and many suitable requirements in the standards, and considering all the people involved and mutual agreements which had to be achieved, the standards are generally good.

5.2 Details of the CEN cable car standards

In this chapter the applicable CEN safety requirements for cable car installations designed to carry persons are listed and their aim is discussed briefly.

5.2.1 EN 1709 - Pre-commissioning inspection, maintenance, operational inspection and checks

This standard specifies the safety requirements applicable to the pre-commissioning inspection, maintenance and operational inspections and checks of cable car installations designed to carry persons. This standard is applicable to the various types of installations and takes into account their environment. It also includes requirements relating to accident prevention and to worker protection.

The following events may lead to hazardous situations which can be avoided or limited by the requirements of these codes & standards:

a) physical construction of the installation not in conformity with the documents presented
b) defective operation of individual components with each other and in their local environment
c) defects arising from long-term operation, prolonged stoppages or repeated and long-term operating conditions
d) use of insufficiently qualified and trained personnel
e) operation with the installation and its components in a defective condition
f) absence of measures for maintaining or re-establishing the specified condition of the installation and its components
g) dangers stemming from the environment
h) absence or non-compliance with a procedure

The following safety measures shall be taken prior to acceptance and during operation in order to eliminate the hazard scenarios listed above:

a) a pre-commissioning inspection of the installation prior to its acceptance, intended to verify the correct operation of each component with the others, and of the installation as a whole within its local environment
b) maintenance work intended to maintain and re-establish the specified condition of the installation and its components
c) daily operational inspection and checks intended to verify the correct operating condition of the installation before and during operation
d) all work shall be carried out and all activities conducted taking the necessary measures for preventing danger to the safety and health of the workers

5.2.2 EN 1908 – Tensioning Devices

This standard specifies the safety requirements applicable for the tensioning devices for cable car installations designed to carry persons. This standard is applicable to the various types of installations and takes into account their environment. Moreover it applies to the design, manufacture, installation, maintenance and operation of rope tensioning devices and anchorages for cable car installations. It includes requirements relative to the prevention of accidents and the protection of workers.

The following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) exceeding permissible limits for tension and variation in length of a rope
b) exceeding permissible pressure limits in a hydraulic tensioning device
c) jamming or catching which impedes the free movement of a rope
d) jamming, wedging or incorrect position of the moving parts of a tensioning device
e) deterioration or failure of the components of a tensioning device due to wear, corrosion or fatigue
f) failure of components in a tensioning device as a result of incorrect dimensioning
g) hazards which a tensioning device can present for persons in access and work areas
h) improper behavior of persons (passengers, operating personnel, third parties)

The safety measures to be taken to eliminate the hazard scenarios listed above are the following:

a) ensure that rope tensions are maintained within permissible limits
b) prevent or avert the failure of safety-related mechanical and hydraulic components and systems for measuring forces and pressures
c) prevent and detect the malfunction of a tensioning device
d) protect persons against the risk of falling or of contact with moving parts of a tensioning device
e) prevent non-permissible load conditions in the case of tensioning device failures

5.2.3 EN 1909 – Recovery and evacuation

This standard specifies the safety requirements applicable to carrier recovery and passenger evacuation from cable car installations designed to carry persons. This standard is applicable to various types of installations and takes into account their environment. Moreover it establishes the requirements relating to the methods and equipment to be used to ensure the safety of passengers on cable cars in the event of extended stoppage of the installation. It covers only the situation resulting from immobilization of the carriers, even if the passengers are not in immediate danger. It does not cover specific operations resulting from an accident. It also includes requirements relating to the prevention of work accidents and to worker protection.

The following events may lead to hazardous situations which may be avoided or limited by the safety requirements of these codes & standards:

a) prolonged exposure of persons to bad weather conditions as for example, wind, cold, etc.
b) prolonged immobilization
c) incompetence, unfitness, carelessness or failure on the part of the evacuation personal
d) non-existence or inadequacy of organization
e) unsuitable, inadequate or improperly used equipment
f) unreasonable behavior of the passengers
g) lack of self-sufficiency of the passengers

In order to meet the hazard scenarios mentioned above, the following safety measures shall be taken:

All cable cars shall be designed, constructed and operated in such a way that, in the event of extended stoppage, it is possible to inform the passengers quickly and to ensure their return to safety within a reasonable time, without compromising their safety or the safety of the evacuation personnel. In such circumstances, it is preferable to recover the carriers. Failing this, the passengers shall be evacuated in accordance with the provisions of a previously established evacuation plan.

5.2.4 EN 12397 - Operation

This standard specifies the safety requirements applicable to the operation of installations for passenger transportation by rope. This standard is applicable to the various types of installations and takes into account their environment. Moreover it applies to the operation of an installation and to the passenger transport conditions and also contains requirements for passengers. It is applicable to individual installations or a set of installations. It does not cover legal provisions for the transport service nor transport obligations. It includes requirements relating to the prevention of accidents and protection for workers.

The following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) inappropriate behavior of passengers, operating personnel and third parties
b) unsuitability of the passengers
c) incompetence of the operating personnel, absence or inadequacy of the operating regulations
d) insufficient or inadequate signs, instructions, information or means of communication
e) failure to observe signs, instructions or operating regulations
f) influence of ice, fog, wind, storms

The safety measures to be taken to eliminate the hazard scenarios listed above are the following:

a) use of qualified and trained operating personnel
b) preparation of suitable operating requirements:
   - during normal service
   - under exceptional circumstances
c) defining and displaying passenger access and transportation measures

5.2.5 EN 12927-1 – Ropes Part 1: Selection criteria for ropes and their end fixings

This part of EN 12927 specifies the safety requirements applicable to the selection criteria for ropes and their end fixings for installations for passenger transportation by rope. Its requirements are to be met taking into account the various types of installations and their environment.

The following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) The breakage of a rope or the failure of an end fixing may lead to the following hazardous situations:
   1) Falling down of rope with the risk of carrier crash and the risk of impact to persons
   2) Release of the elastic potential energy of a tensioned / extended rope
b) Deterioration/damages of the structure of the rope can lead to the following hazardous situations:
   1) Derailment of rope (deropement)
   2) Derailment of carrier truck

The safety measures to be taken to eliminate the danger factors listed above are to select ropes and end fixings in accordance with this part of this standard in order to apply and to put into effect also the other parts of this standard.

5.2.6 EN 12927-2 – Ropes Part 2: Safety factors

This part of EN 12927 specifies the safety requirements applicable for safety factors for steel wire ropes (tensile safety factor, bending ratio and transverse force factors) for installations for passenger transportation by rope. This standard is applicable to the various types of installations and takes into account their environment. The requirements relating to the protection of workers are not included in this standard.

Especially the following event may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

Excessive working stress in the steel wires may lead to premature fatigue breaks and rope-failure within the inspection intervals given in EN 12927-7.

The risk of a rope failure within the inspection intervals given in EN 12927-7 shall be limited by:

a) incorporating a tensile safety factor in accordance with this standard into the rope design calculation according to EN 12930
b) incorporating a bending ratio in accordance with this standard into the design of sheaves, drums, saddles or any support of ropes where the curvature of the rope is determined only by the curvature of the support; and by
c) avoiding a bending stress in the steel wires exerted by transverse forces exceeding the allowable bending stress limited by the bending ratio given in this standard.

5.2.7 EN 12927-3 – Ropes Part 3: Long splicing of 6 strand hauling, carrying hauling and towing ropes

This part of EN 12927 specifies the safety requirements applicable to long splicing of steel wires 6 strand hauling, carrying-hauling and towing ropes for installations for passenger transportation by rope. This standard is applicable to the various types of installation systems and their environment.

If ropes of different productions are required to be spliced together, they shall have the same basic design characteristics in terms of nominal rope diameter, strand construction, minimum breaking force, direction and type of lay, wire grades, measured rope diameter and measured lay length.

Especially the following events may lead to hazardous situations, which may be avoided or limited by the requirements of these codes & standards:

a) slipping apart of the two rope ends connected by a long splice may lead to a failure of the long splice
b) slipping or malfunction of the grip in the splice area can lead to insufficient attachment of the grip.

The risk of slipping apart of the spliced rope ends may be reduced by a correct correlation of geometrical characteristics of the two ropes connected by the splice, by selecting the splice geometry in accordance with this standard and by selecting the correct auxiliary (wrapping) material.

The risk of an insufficient grip attachment may be reduced by applying the diameters overall to the splice in accordance with this standard.

5.2.8 EN 12927-4 – Ropes Part 4: End fixings

This part of EN 12927 specifies the safety requirements applicable to end fixings of steel wire ropes for installations for passenger transportation by rope. This standard is applicable to the various types of installations and takes into account their environment.

This part of EN 12927 applies to the following types of end fixing when used in installations for passenger transportation by ropes in conformity with EN 12927-1:

- filled socket
- clamp socket
- drum
- bolted clamp
- wedge socket
- spliced eye
- gripped eye
- ferrule secured eye
- lever winch

Taking its scope into account, it does not include requirements relating to the prevention of accidents and the protection for workers.

The following events may lead to hazardous situations, which may be avoided or limited by the requirements of these codes & standards:

a) failure of the end fixing may lead to the release of the rope end from the end fixing or from the installation anchor point
b) slipping of the rope end in the end fixing may lead to hazardous disturbances in the function with other components

The safety measures to be taken to eliminate the danger factors listed above are the following:

a) the risk of release of the rope end may be reduced by design and executing the end fixing in accordance with this standard and by discarding the end fixing according to EN 12927-6
b) the risk of hazardous disturbances in the function with other components may be reduced by performing the end fixing in accordance with this standard and by inspecting the end fixing in accordance with EN 12927-7

5.2.9 EN 12927-5 – Ropes Part 5: Storage, transportation, installation and tensioning

This part of EN 12927 specifies the safety requirements for the storage, transportation, installation and tensioning of ropes for installations for the transportation of passenger by rope. It also includes the requirements for adjusting, measuring and recording the condition of the rope during and on completion of the installation. It provides the safety requirements and measures to reduce the effect of hazards to the rope and possible hazards from the rope to persons and equipment during these operations.

The following events may lead to hazardous situations, which may be avoided or limited by the requirements of these codes & standards:

a) inefficient rope protection during storage may lead to corrosion which may lead to rope failure within an inspection period
b) the package on reels may lead to hazardous situations if by a failure of the support the reel can start rolling
c) the failure of the rope connection with an auxiliary rope or with the brake controlled reel as well as the turn out from the installation support may lead to the release of the elastic potential energy of the pulled rope during the installation process

5.2.10 EN 12927-6 – Ropes Part 6: Discard criteria

This part of EN 12927 specifies the safety requirements applicable to discard criteria for steel ropes for passenger transportation by rope. This standard is applicable to the various types of installations and takes into account their environment. This part of EN 12927 applies to all types of ropes and end fixing used in cable cars for passenger transport. Requirements relating to the protection of workers are not included in this part of EN 12927.

Irrespective of whether the rope is inspected by MRT or visual means, the same wire broken in several places over the stated reference length shall be regarded as a single broken wire. Loose wires and wires repaired by welding, brazing or gluing shall be regarded as broken wires. Ropes shall be discarded if their condition cannot, or can no longer, be assessed with the current methods of inspection. After an external event (lightening, derailment, etc.) the discard criteria shall be checked by a competent person before further operation.

Especially the following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) excessive decrease of the metallic cross sectional area may lead to the breakage of the rope
b) fatigue breaks, corrosion and wear may lead to a failure of end fixing and of tension ropes
c) deterioration/damaging of the structure of the rope can lead to deropement or to insufficient attachment of the grip
d) slipping apart of two rope ends connected by a long splice may lead to a failure of the long splice

The safety measures to be taken to eliminate the danger factors listed above are the following:

a) the decrease of the metallic cross sectional area shall be limited by repair according to EN 12927-7 or by discarding the rope according to this standard
b) the risk of a failure of end fixing and of tension ropes may be reduced by discarding by timeout (hours or years) according to this standard
c) deterioration/damaging of the structure of the rope shall be limited by repair according to EN 12927-7 or by discarding the rope according to this standard
d) the risk of slipping apart spliced rope ends may be reduced by repair according to EN 12927-3 and EN 12927-7 or by discarding the long splice according to this standard.

5.2.11 EN 12927-7 – Ropes Part 7: Inspection, repair and maintenance

This part of EN 12927 specifies the safety requirements applicable to maintaining, inspecting and repairing steel wire ropes and their related installations for passenger transportation by rope. It is essential to meet its requirements taking into account the various types of installation systems and their environment. Requirements relating to the protection of workers are not included in this part of EN 12927.

The following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) deposits on the rope surface may lead to a malfunction of components (track rope brakes, detachable grips etc.) interacting to the rope
b) corrosion and wear by excessive internal friction may lead to a failure of rope and end fixing
c) stress concentration effecting an essential reduction of the rope fatigue properties may lead to premature fatigue breaks and rope-failure within the inspection intervals given in this standard
d) excessive fatigue breaks by the working stress in the steel wires of rope and end fixing may lead to a failure of rope and end fixing

The safety measures to be taken to eliminate the danger factors listed above are the following:

a) the risk of malfunction of components may be reduced by cleaning the rope surface
b) the risk of corrosion and excessive internal friction may be reduced by dressing the rope in accordance with this standard
c) the risk of stress concentration shall be limited by discarding the rope in accordance with EN 12927-6 or by relocation in accordance with this standard
d) the effect of the working stress on the steel wires shall be controlled by assessing the current condition of rope and end fixing by inspections at intervals in accordance with this standard

5.2.12 EN 12927-8 – Ropes Part 8: Magnetic rope testing (MRT)

This part of EN 12927 specifies the minimum requirements of MRT equipment and procedures for use in the examination of steel wire ropes used on cable cars for passenger transport. Performance requirements and testing of MRT equipment and qualification of personnel engaged in carrying out MRT are also included. This part of EN 12927 does not include requirements relating to the protection of workers.

The following events may lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) defect of the MRT instrument design preventing it from performing the functions required for the inspection
b) defect of the MRT instrument sensitivity
c) malfunction of the MRT instrument during the inspection
d) inability of personnel to carry out properly the inspection
e) absence of, or inaccuracy in, the inspection report

The safety measures to be taken to eliminate the danger factors listed above are the following:

a) the conditions during use of the MRT instrument shall allow the inspection to be carried out in optimal security and quality conditions
b) performance of the apparatus shall be checked before its first use
c) signals of the sensors shall be measured or registered
d) MRT instrument sensitivity shall be tested at regular time intervals
e) MRT instrument operating state shall be tested before each inspection
f) the inspection report shall include all necessary details

5.2.13 EN 12929-1 – General Requirements Part 1: Requirements for all installations

This part of EN 12929 specifies the safety requirements for general requirements for cable car installations designed to carry persons. These requirements are applied to the various types of installations and their environment. This standard defines general technical characteristics and prescribes design principles and general safety requirements. It does not deal with details of operation and maintenance, nor with calculations and detailed requirements for the manufacturing of components. This Part 1 does not deal with special requirements applicable to bicable reversible aerial cable cars without carrier truck brakes, which are the subject of Part 2 (not included in this memo, because it does not apply). It includes requirements relating to the prevention of accidents and the protection of workers.

All cable car installations designed to carry persons shall be designed, constructed and operated by applying the following principles in the order indicated:

a) avoid or at least limit the risks by appropriate design or construction measures
b) take the necessary protective measures with respect to remaining risks which cannot be avoided by design and construction measures
c) define and make known the precautions to be taken to reduce those risks which it has not been possible to avoid completely by the previous preventative and protective measures

The hazards to be taken into account are those which can in particular result in the following injuries to persons:

a) injuries caused by falls (including those caused by carriers falling)
b) bruising, crushing or injury by trapping of persons (other than falls)
c) impairments to health resulting from extended exposure of persons to adverse weather conditions
d) other dangers to health, for example electrocution, burns, inhalation of poisonous gases, etc.

The following events can give rise to hazardous situations which are avoided or reduced by the safety requirements of these codes & standards:

a) failure (rupture, malfunction or non-functioning) of a component of an installation
b) breakdown of functional equilibrium between the components in an installation or between the components and their environment
c) incorrect behavior of persons (passengers, personnel or third parties)

d) foreseeable external events (for example caused by avalanches, landslides, rock falls, lightning, aircraft, etc.)

The following events in particular shall be considered:

- failure of or defects in the civil engineering structures
- defective condition of loading and unloading areas
- failure of tensioning systems and rope end fixings
- failure of rope support and guide elements
- failure of carrier components
- failure of or defects in drive systems and brakes
- failure of or defects in control systems and monitoring, safety and signaling devices
- incorrect behavior of persons

Chain reactions which can happen as a result of an event shall be taken into account. On the other hand, the simultaneous occurrence of two independent hazardous situations may be ignored.

This standard sets out general measures to reduce the hazards listed above and to prevent the hazardous situations:

A safety study shall be presented for each installation project. It shall take into account all the components and their technology, as well as the innovative character, if any, of the installation. Where a planned installation is similar to an already constructed and well proven installation which has formed the subject of a safety study and for which a list of safety components exists, that study and list of components may be used to justify the planned installation, provided that its environment is taken into account and its compliance with European Standards is demonstrated.

The safety study comprises:

- a safety analysis aimed at identifying all the hazardous situations and assessing the nature and seriousness of the risks
- a description of the measures provided for in the project to meet the hazardous situations identified in the safety analysis, including the necessary justifications

For each installation, a list of all the safety components shall be drawn up in accordance with EN 12408.

5.2.14 EN 12930 – Calculations

This standard specifies the general safety requirements applicable to the calculations for cable car installations designed to carry persons. This standard is applicable to the various types of installations and takes into account their environment.

This standard contains:

- general requirements for calculations and their presentation
- general requirements relating to the actions to be taken into account in the calculation of components as a basis for the requirements of the standards EN 13223, EN 13107, EN 12927 (Parts 1 to 6) and EN 1908

- requirements relating to verification of ropes by calculation
- requirements relating to the determination of the drive power
- requirements for the actions of the ropes and carriers on the support structures and for the deformations of these support structures

The following events may lead to hazardous situations, which may be avoided or limited by the requirements of codes & standards:

a) lack of or poor assessment of the actions on the individual components of the installation
b) use of inappropriate calculation methods or formulas
c) lack of or inadequate consideration of dynamic effects and fatigue effects on individual components
d) lack of or incorrect assessment of the most unfavorable combinations of actions when dimensioning and carrying out calculations
e) incorrect assumptions in the calculations

This standard contains the necessary measures to avoid the hazard scenarios listed above when carrying out verification by calculation and when designing the complete installation as well as individual components, in particular when calculating the longitudinal profile and the rope.

5.2.15 EN 13107 – Civil engineering works

This standard specifies the safety requirements applicable to civil engineering works for installations for passenger transportation by rope. It is essential that its requirements are met by taking into account the various types of installations and their environment. It includes requirements relating to the prevention of accidents and the protection of workers.

This standard is applicable to:

- new cable cars
- alterations of existing cable cars as far as the safety of civil engineering works or part of it is involved

5.2.16 EN 13223 – Drive systems and other mechanical equipment

This standard specifies safety requirements for the mechanical and electrical devices of the drive system and other mechanical devices for cable car installations designed to carry persons. This standard is applicable to the various types of installations and takes into account their environment. This standard applies to the design, production, installation, maintenance and operation of the mechanical and electrical devices of the drive system and other mechanical devices for cable car installations. It includes requirements relating to the prevention of accidents and protection for workers.

The following events may lead to hazardous situations which may be avoided or limited by the safety requirements of these codes & standards:

a) derailment of ropes
b) obstruction of the operating movement of ropes due to obstruction by mechanical devices or hooking over parts of the installation

c) damage to or failure of drive and braking devices and support and guiding elements of ropes due to wear heat, corrosion or fatigue
d) failure of drive and braking devices and support and guiding elements of ropes and other mechanical devices in stations and on the line due to inadequate dimensioning
e) reduction of the force transmission from the drive sheave to the haulage rope or carrying hauling rope
f) reduction of the frictional force of the braking device
g) hooking or falling of carriers at line support structures and in stations
h) collision of carriers or between a carrier and an obstacle when entering into, exiting from and passing through stations
i) faulty attachment or detachment of carriers with detachable grips
j) excessive deceleration or acceleration of the haulage ropes and carrying hauling ropes and of the carriers
k) exceeding the maximum permissible speed
l) unintentional movement of the cable car
m) hazards to persons in passageways and working areas, due to mechanical devices
n) inadmissible pitch between carriers
o) operation in unfavorable weather conditions (e.g. wind, frost, icing, rain)
p) inappropriate behavior on the part of persons (passengers, personnel, third parties)

Safety measures are required to avoid the hazard scenarios listed above. The measures specified in this standard are essentially construction-related and have the following aims:

a) prevention of rope derailment
b) in the event of rope derailment: catching the rope, prevention of hooking or jamming the rope and bringing the installation to a standstill
c) prevention of derailment, falling, hooking and dangerous collision of carriers
d) prevention of failure of mechanical and hydraulic safety devices
e) detection of hazardous malfunctioning of detachable grips and bringing the carriers safely to a standstill
f) detection of inadmissible pitch between carriers and taking the required measures
g) prevention of insufficient or excessive deceleration and excessive acceleration of haulage and carrying hauling ropes and carriers
h) detection of exceeding of maximum permissible speed and bringing the cable car to a standstill
i) detection of unintentional movement of the cable car and taking the required measures
j) protection of persons against falling and against contact with moving parts
k) prevention of hazards to persons due to collision with carriers

5.2.17 EN 13243 – Electrical equipment other than for drive systems

This standard specifies safety requirements for electrical devices, apart for those in drive systems, for cable car installations designed to carry persons. This standard is applicable to the various types of installations and takes into account their environment. Electromagnetic compatibility (EMC) is not covered in this document; cable cars and their components should comply with general requirements for EMC. For electrical devices which are parts of drive systems, the requirements of those sections of EN 13223 listed in its scope as relating to drive systems should be observed. This standard contains requirements for prevention of accidents and protection of workers.

The following events many lead to hazardous situations which may be avoided or limited by the requirements of these codes & standards:

a) accidental contact of a person with a live metallic component
b) failure of an electrical safety function
c) voltage drop or total loss of voltage
d) occurrence of a short-circuit, earth fault or open circuit
e) failure of electrical or electronic components
f) foreseeable external influences, in particular, environmental conditions and electromagnetic fields

For each individual safety function, the hazard to persons is to be defined by means of a risk analysis. A distinction is made between the following 3 hazard categories:

a) Hazard category 1: failure of an electrical device that cannot lead to an accident (no personal hazard)
b) Hazard category 2: failure of an electrical device that could lead to a slight accident (reversible injuries to persons)
c) Hazard category 3: failure of an electrical device that could lead to a serious accident (irreversible injuries, death of persons)

The safety functions are allocated to 4 graded requirement classes taking into account the respective hazard category and the probability of occurrence of the hazardous situation. The requirement class of a safety function is determined.

5.2.18 EN 13796-1 – Carriers Part 1: Grips, carrier trucks, on-board brakes, cabins, chairs, carriages, maintenance carriers, tow-hangers

This standard specifies the safety requirements applicable to carriers for cable car installations designed to carry persons. It is applicable to the various types of installations and takes into account their environment. It includes requirements relating to the prevention of accidents and the protection of workers.

The following events may lead to hazardous situations that may be avoided or limited by the safety requirements of these codes & standards:

a) overloading of the carrier
b) exceeding the limits of use permitted by the manufacturer
c) damage caused by ageing, corrosion, wear, fatigue or deformation
d) hooking up and impact (carrier with carrier, carrier with people, carriers with ropes, stations, line structures and external objects)
e) derailment and deropement when carrier passes
f) derailment or instability of the carrier
g) failure of the haulage rope or carrying hauling rope where a grip is attached
h) failure of the attachment or detachment of a grip
i) inadequate resistance to slipping and pull-off of a rope grip
j) faulty door operation (unexpected opening, slamming shut)
k) inadequate protection against passengers and any element falling out of the carrier
l) inadequate positioning and difficult access for the maintenance and evacuation personnel
m) fire

The safety measures to be taken to eliminate the hazard scenarios listed above are the following:

a) checking of the load or limiting the area available to each passenger and systematically
b) informing the passengers of the maximum authorized load
c) establishment of an operating manual defining the limits of use
d) requirements relating to design and manufacture, to the selection of materials, production checks, type approval tests, pre-commissioning tests and checks during operation
e) compliance with space envelopes, monitoring of the maximum permissible wind speed in operation, damping devices on the outside of the carriers
f) design to allow unrestricted passage of the grips past the rope-catchers
g) requirements relating to the guiding and stability of the carriers
h) adequate design of the grip to limit the risks of fatigue failure of the haulage rope or carrying hauling rope
i) monitoring the attachment and detachment of the carriers, catching a carrier not properly attached to the rope
j) monitoring during operation of the gripping force, or of a value representative of this force, of detachable grips
k) design of fixed grips to facilitate their systematic displacement without upsetting the adjustment of the spring force
l) periodic checks during operation
m) limiting the effect of an impermissible reduction in the gripping force of the grip
n) monitoring the closing and locking of the doors prior to departure of the carrier; monitoring of the position and speed of the carriers prior to unlocking and opening of the doors, limiting the closing force of the doors, fitting the edges of the doors with soft material
o) use of an efficient safety bar on chairlifts, minimum height of backrests and sides, selection of non-slip materials
p) use of handholds and anchorage points for PPE against falls from a height
q) use of positions and access allowing personnel to carry out maintenance and evacuation operations
r) selection of suitable materials to limit the risks of fire

5.2.19 EN 13796-2 – Carriers Part 2: Slipping resistance test for grips

This standard specifies the safety requirements applicable to carriers for cable car installations designed to carry persons. It is applicable to the various types of installations and takes into account their environment. This standard describes the requirements to be met when testing the slipping resistance of grips clamped:

- on the haulage or carrying hauling rope of carriers of monocable or bicable aerial cable cars with fixed or detachable grips
- on the towing rope of ski-tows with fixed grips

5.2.20 EN 13796-3 – Carriers Part 3: Fatigue tests

This standard specifies the safety requirements applicable to carriers for cable car installations for passenger transportation. This standard is applicable to the various types of installations and takes into account their environment. This standard sets out the requirements to be met for fatigue tests for carriers of unidirectional monocable aerial cable cars of capacity not greater than 16 persons.

6 Environmental conditions

6.1 Wind

The effects of wind on cable cars are as follows:

- Rope derailment
- Lateral swing of cabins (clearance on terrain, passing cabins and towers)
- Track gauge
- Rope vibrations
- Design of structures (stations, towers)

In operation

The design stagnation wind pressure in operation is derived according to the maximum wind speed an operating system may be exposed to. It is obvious that the in-operation wind speed must be lower than the wind speed governing the static and dynamic calculations.

The actual wind speed to operate a cable car is an important parameter and must be agreed upon with the client. The design stagnation wind pressure will be selected higher accordingly. The wind speed is affected by the shape of the terrain. There may be sections very much wind protected with following sections shaped as wind channels.

Special care is recommended for the design of evacuation systems. An evacuation just may be the consequence of extreme wind conditions. It is advisable, that any evacuation should be designed for a wind load exceeding the design stagnation wind pressure in operation by suggested 50 %.

Out of operation

The stagnation wind pressure out-of-operation must be selected based on local statistics and considering the topography. There is no possible corrective action like stopping of operation; the wind must be taken as it is.

Actual wind load

Shape coefficients for wind exposed areas of structures and ropes must be considered to calculate wind loads. Code requirements show plenty of information.

Watch out

The wind shape coefficient collapses if the wind speed exceeds a certain value. For example on a 50 mm diameter locked coil track rope the shape factor collapses from 1,2 to an estimated 0,6 at wind speeds exceeding 40 to 45 m/s. The criteria depend on the "Reynold" number which again depends on rope diameter, wind speed etc. The relative collapse of the wind shape coefficient depends on the shape of the rope. For example on a spiral rope such decrease may only be from 1,2 to an estimated 0,9.

Wind monitoring

Wind gauges must be placed on wind exposed towers and stations. Preferably, the selected wind gauges shall also indicate the wind direction. The readout of the wind speed shall be placed in the control rooms. A warning signal within the station shall be provided. Such warning signal may be activated at about 80 % of the maximum tolerable wind speed for operation.

Consequently, the operator will be alerted to monitor the wind more closely. A visible and audible wind alarm signal shall indicate that the maximum allowable wind speed for operation is approached or exceeded. Consequently, the operator will slow down system speed and be prepared to terminate operation. To augment the monitoring, the operator may observe lateral swing of carriers at wind exposed towers along the visible line by means of binoculars.

As soon as the wind alarm is repeatedly activated by wind gusts, the operator must cease operation and move the cabins to the stations at low speed, maybe with intermediate stops at extreme wind, when cabins cross towers and approach the stations.

Consequently the "wind alarm wind speed" should be adjusted lower than the wind speed used to calculate the stagnation wind pressure, which is used for dimensioning of structures and system calculations as mentioned above.

It is recommended that the wind alarm be triggered at about 80 % of the base wind speed that is used for dimensioning a cable car. The base wind speed results from the "design stagnation wind pressure in operation".

Accuracy of wind gauges and wind indication

The wind gauges as well as the proper transmission of data are not fool proof. The operator must simultaneously observe wind conditions. As conventional wind gauges are concerned, if the wind blows in the plane perpendicular to the axis of the wind gauge, the values shown of the wind speed are rather accurate.

Watch out, if the wind does not blow in such plane, e.g. at a given angle upward the error in wind speed indication is substantial. Hence, the actual wind speed may be much greater than the measured data. Consideration must also be given to the predominant wind direction when placing the anemometer.

Furthermore wind gauges may not necessarily be located at the location of the maximum wind speed, since its attachment is restricted to towers and stations. For example in large tower spans a cabin may be much higher above terrain with exposure to higher wind speed.

6.2 Ice

The effects of ice loads on cable cars are as follows:

- Ice load on structures and ropes
- Wind exposed areas of ropes, cabins and structures, wind load
- Rope tensions, rope sags
- Dynamics and hazards as ice is dropping off and ice chunks are sliding down the rope

General information

Depending on climatic conditions, such as maritime climate, the ice buildup on ropes may be a decisive factor to design a cable car. Localized ice buildups may occur when crossing rivers, ponds etc. in areas usually not subjected to icing. Respective surprises have occurred in the past with ice buildups over a very restricted length of maybe 15 to 30 m.

For cable cars it is suggested to fix the required ice loads at the time the environmental parameters are established based on experience. Referring to established tourist resorts, ample experience is usually available.

The question may come up on how environmental parameters may be affected by the change of the climate. Whereas some precautionary measures may make sense, with regard to wind, the effect on icing is unpredictable. Present conditions must be the basis with periodic reviews and possible reinforcements in the future, if icing changes.

Load combinations in operation, out of operation, simultaneous wind load, seismic load, etc. usually can be taken from code requirements and may be augmented by common engineering sense.

Risks associated with icing

- Overloading of structures (towers, ropes, rope anchoring, etc.)
- Sagging overhead lines (telephone rope, communication cable, rescue tram ropes) contacting the track ropes with the moving cabins
- Failing overhead cables tangling up with moving haul rope and cabins
- Dropping of chunks of ice on people or property below a cable car line
- Ice chunks sliding down on the rope, and colliding with towers or cabins and equipment at the lower station
- Rope derailment and dynamics of ropes as the ice load drops to ground
- Cable cars with dual track ropes per track: Rotating of entire track in case track ropes and haul rope are connected by ice and ice is dropping from one track rope only
- Derailment of cabins in case of undetected ice buildup on track ropes
- Rope vibration: For example as icing occurs in combination with crosswind on the track, building up a horizontal fin, which then is induced to oscillate by wind causing torsional track oscillation.

Measures to counter icing problems

- Moving of cabins as soon as icing is about to take place.
- On an installation with a counterweight, a limit switch may be placed at the counterweight, which alarms an operator as soon as the counterweight moves up due to ice load. This triggers action, even if icing occurs during the night.
- Alternatively, a rope angle measurement may be provided, triggering an alarm as such angle exceeds a given value.
- In case of icing forecast, track ropes may be clamped onto the tower saddles by hydraulically actuated paws.
- Supervision of tension on overhead cables, to stop operation in case of excessive icing.
- Provide heating of rope support profiles on towers on systems with track ropes.
- Provide rugged carriages with suitable de-icing means (ice scrapers) to remove ice when moving the system on cable cars with track ropes.

- Invent means to remove ice from overhead lines. Nothing very practical is available at this time except trying to remove ice by hitting with a stick. Such overhead lines however are usually too far away to be accessible, particularly on systems with track ropes. Vibration could be a possible means.
- Smooth tower sheaves without any bolts are less likely to become stuck, if icing occurs.

Initial design parameters of ice load

Applying EN 12930, clause 6.5.5.2 requires calculating with a minimum 25 mm ice coat on the ropes. For many ski resorts extensive data are available about potential icing problems. It appears that the maximum ice load must be determined and agreed upon by competent people who are familiar with the resort e.g. a local civil engineer or geologist.

6.3 Fire

National codes & standards regulate the fire protection of cable cars. The protection of the cable car track route is very important.

E.g. the Austrian fire protection law for cable cars regulates the protection of the cable car track route in the following way:

- The immobile and mobile fire load in the building ban zone has to be kept as low as possible
- If there are buildings with a fire load within the building ban zone suitable fire protection measures have to be established to achieve the defined protection objectives
- The buildings and assets which create a danger to the cable car operation in case of a fire are to be designed and built in way that the ropes of the cable car must not melt in any case.

6.4 Seismic

The pertinent accelerations to be considered can be taken out of national building codes. An earthquake may occur during operation. According to local codes or common engineering sense the proper load superposition must be established (combination of operating load, wind, snow, seismic, etc. must be superimposed).

6.5 Temperature

The extreme temperature range to dimension a cable car must be established initially as an important design parameter.

6.6 Lightning

Assess local conditions and take required measures for the cable car design.

6.7 Geology

The required reports must be produced by a specialist to accumulate all necessary information for the civil engineer.

6.8 Corrosion

For cable cars proper corrosion protection is important.

Considerations are the following:

- Is the installation nearby the sea? Salty environment?
- Humidity?
- Precipitation?
- Temperature?
- Industrial air pollution?
- Sand storms?
- Protection from chemicals?
- Melting snow and ice?

It is important to investigate the environment. You have to check experience on other nearby machinery. Moreover you have to provide water drainage to prevent water accumulation on structures and cable car components.

7 Impact of system speed

Be aware that most of the safety parameters are affected by the square of the speed such as:

- Energy, braking distances, brake liner wear, impact loads in case of crashes, centrifugal forces, heat, wear and tear, etc.
- To some extent also vibrations, noise, and thus passenger comfort is affected

One can take from the above that maintaining equal safety level at higher speed, substantial investment in supervision and safety precautions is necessary. Hence, practical line speeds are limited at certain levels for individual types of cable cars.

8 Passenger evacuation

8.1 Requirements

Evacuation of passengers must be possible if the system cannot be moved anymore. In such case passengers must be evacuated and moved to a safe place, preferable to one station of the cable car line. The evacuation process must be safe and shall not lead to hazardous exposures of passengers to freezing temperatures or heats, etc.

The main considerations are:

- Nature of passengers (skiers, visitors, and handicapped people): For instance on installations transporting skiers only, it can be expected that their protection against the environment is much better compared to visitors.
- Environmental conditions such as temperature, wind, rain, etc.: Hence, limiting the maximum time for evacuation is of essence. Wind is a matter of special consideration. Many times picking up of wind may just be the reason, that something goes wrong and evacuation becomes necessary. It is therefore recommended to design any rescue facilities for a higher in-operation design stagnation wind pressure than defined for operating the cable car, e.g. 1,5 times greater.
- Adequate public address system to quickly and accurately inform passengers to avoid hazardous action in panic in case of a breakdown, or an extended interruption of operation. For monocable gondolas with tower spacing up to about 300 m, loudspeakers, placed on the towers, are the means to inform passengers in case of a breakdown. For bicable or tricable cable cars with large tower spans loudspeakers on towers are no more adequate. They require a public information system in the cabins.
- Cable car type: There is a huge difference from an open chairlift to a tricable gondola.
- Cabin, standing or seated passengers: It is a big difference if passengers are jammed in a cabin with 0,18 m^2 floor space per passenger or having ample space with 0,25 m^2 per passenger.

Time requirement for evacuation

The evacuation procedure must be started if the cable car system cannot be operated within half an hour after an unscheduled stop. The total evacuation time is counted from the time of immobilization of the installation until the last passenger arrives at a safe place. It must be guaranteed that all passengers can be evacuated safely and healthy which is a parameter for the maximum tolerable evacuation time. According to CEN standards the evacuation process shall not last more than 3,5 hours. The evacuation time should be limited according to the circumstances. If for instance means are provided for quick supply of blankets, food, etc. the evacuation time may be extended. The same is true if favorable climatic conditions prevail.

Evacuation Equipment

Important is the proper storage of all rescue equipment in a lockable room with check list to verify completion. There must be a person appointed to periodically verify completeness and workable condition of the equipment. The same is true for rescue equipment carried in the passenger vehicles.

Evacuation plan

A detailed evacuation plan is most important (requirement by CEN). Such plan shall define the hierarchy of the rescue team, telephone numbers of individuals, detailed procedure description etc. There are a number of different concepts in use.

Training

All the above is of little help, if evacuation is not practiced on site periodically.

8.2 Common evacuation concepts

a) Rope down passengers (applicable for most aerial cable cars)

Roping down the passengers from the vehicle is the most common procedure and is standard as long the terrain and ground clearance permits this type of evacuation. Accessing vehicles by rescue workers along the rope is a routine maneuver. Well designed and practical equipment is available in abundance.

b) Evacuation by turntable ladder trucks (preferred option)

Wherever the terrain allows for an evacuation procedure via turntable ladders this evacuation procedure has to be applied.

c) Evacuation by helicopter (preferred option)

An evacuation plan for most cable cars should include the evacuation procedure by helicopter. Helicopter evacuation is the most efficient procedure, and is applied any time permitted by the weather conditions. The problem is that adverse weather conditions may prevent helicopter evacuation. Hence, alternative means must be available.

d) Winch propelled rescue car

This evacuation procedure is mainly applicable for systems with track ropes (aerial tramway but not for tricable gondola)

e) Rescue tram with spliced rescue rope to a loop

Such system is mostly propelled by a diesel hydrostatic drive and used with aerial tramway systems. The rescue rope is permanently installed mostly at the track centerline above the track ropes. This type of system should be avoided whenever possible, since it is complicated, expensive and has inherent disadvantages.

The following conditions usually require this concept:

- Rescue of passengers to the lower station is a requirement
- Trams with positive and negative slopes as for instance the former Roosevelt Island Tramway in Manhattan

f) Towing of main cabins on circulating systems (no preferred option)

The big advantage is that passengers may remain in the main cabin at least until a suitable location for roping down is reached. In the best case the main cabins may be towed all the way into a terminal. Preferably, winch driven vehicles are applied which approach the main cabins. The rescue vehicle (towing carrier) is designed to attach the main cabin to it and open its grips. Depending on the profile, a continuous haul rope loop may be required to haul the passenger cabins to a tower to rope them down.

Circulating cable cars with track ropes (tricable gondola systems)

The towing carrier must be lifted up from the track rope(s) and reset the other side of a towed in main cabin to move on and pick up the next main cabin. The accessibility of lifting equipment to reach the towing carrier may become a **problem**. This solution was never realized so far.

Monocable detachable gondolas

Things are easier since the towing carrier travels on the haul rope and may override the grips of a main cabin. After detaching a cabin from the haul rope, the cabin should be supported by a couple of rollers to avoid sliding on the haul rope and improve guidance.
Application: Providing evacuation of critical spans within inaccessible terrain with drives and rescue ropes according to the initial description.

General

The loading of any accumulation of towed in carriers if applicable, must be considered when designing the supporting structures.

g) Rescue carrier for monocable circulating systems

As a rescue carrier approaches the main cabin, the passengers may deboard the main cabin and enter the rescue carrier. Then passengers can be hauled all the way into a station. On monocable cable cars a rescue carrier can be designed to override the rope grips of a main cabin.

h) Self-propelled rescue carriers

If moderate slopes prevail and icing is no issue, a self-propelled rescue carrier may be applicable. Alternatively a rescue carrier would have to be moved by a circulating haul rope loop as described under e). Hence, the undesired haul rope loop can be eliminated.

i) Integrated rescue (preferred evacuation procedure for tricable gondola system)

Particularly for tricable and monocable gondola systems the so-called "integrated rescue system" nowadays becomes more and more popular. The integrated rescue system basically consists of back up equipment in case of any failure of equipment which is involved in moving the haul rope.

The recovery concept is a series of redundant drive-line systems that ensures the cabins will return to a station in the event of a mechanical or electrical failure of the primary drive-line.

Major features of this concept include:

- Main drive mechanism has an auxiliary motor in case of primary motor failure
- Coupling can be detached from bullwheel to allow emergency drives to take over in case both primary and auxiliary motors fail
- Each bullwheel is equipped with an emergency bearing allowing rotational movement between emergency drives on either side
- Special tools installed which lifts the cable back to normal position in case of tower derailment
- Special tools, such as permanent crane facilities, to remove blocked cabins

The recovery concept has been installed in several urban cable cars including the Koblenz Cable Car (Germany), and the Emirates Air Line Cable Car (UK).

However, despite all the fancy provisions, a problem on the cable car line such as a tree falling on the line, cabin stuck on a tower, tangle up of haul rope with track ropes, applied track brake which cannot be opened, hang glider tangled up on track etc. may still lead to an extended interruption of operation. Hence, the list of the remaining "tolerable" risks appears still somewhat extensive.

On the other hand, the mentioned incidents may also impair the functioning of the evacuation methods d) thru h).

j) Various rescue systems

E.g. for a specific aerial tramway the rescue winch tram was designed with extra track ropes to be fully independent of the main tram.
For accessing tramway cabins a radio controlled lift may bring up a rescue worker from the ground to the cabin.
There are numerous methods available which are not mentioned. Innovations on rescue procedures are abundant.