

MEASUREMENT OF DYNAMIC STRESSES ON CARRIERS WITH DETACHABLE GRIP AT STATION ENTRANCE: LA.T.I.F. EXPERIENCES AND FUTURE PROSPECTS

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Introduction

The importance of dynamic stress effects of low temperatures on fixed and mobile structures is well known to engineers in this field.

These effects are even more important when ropeway cars are considered; all the more so as car design must provide for contained sizes and weights. Dynamic stress effects on ropeway cars are extremely variable and they depend on:

- changing car loading conditions
- features of the ropeway line
- the position of the car is modified by wind pressures.

It is then very important that the designer is provided with the best possible knowledge on dynamic stresses and the relevant statistics. These information can be obtained by measuring actual stresses on different parts of the car under different loading and speed conditions.

LA.T.I.F. (The Technological Laboratory on Ropeways in Trento - Italy) is a part of the local Control Authority (Service for Ropeways) and has been in charge of tests on ropeways parts since 1971.

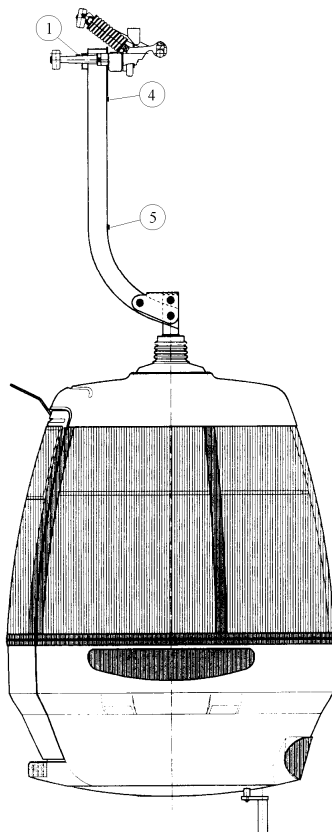
This paper is intended to highlight the following subject: "Measurement of dynamic stresses on carriers with detachable grip at station entrance". This is not a new subject for research and was already dealt with more than ten years ago. We are pleased to announce the results of more than 100 tests on ropeways chairs and gondolas performed by LA.T.I.F. over the past six years.

The tests were designed as follows:

- same test procedures;
- systematic data collection (number of measurement points and sampling);
- same processing methods on all data (tables and charts).

We had an opportunity to draw up statistics with a view to confirm running conditions: statistics are also intended as a valuable basis for future developments.

According to Italian regulations, in ropeway car design and in order that stresses on crashworthy sections are within acceptable limits, designers must apply load allowance parameters to be identified experimentally. This is done to take



dynamic stress effects on board; whenever tests are not available, stresses must be increased by at least 50%.

There is indeed a need to perform tests on dynamic stresses to:

- provide designers with a series of results to calculate reliable allowance parameters;
- provide designers with data which help in the design of prototypes of new models with a view to assess the effect of buffers on joints and connections on different parts of the car
- when the ropeway is completed, to verify whether the design reference value is consistent with that of the actual ropeway system and to allow for best adjustment of guide rollers height at station entrance.

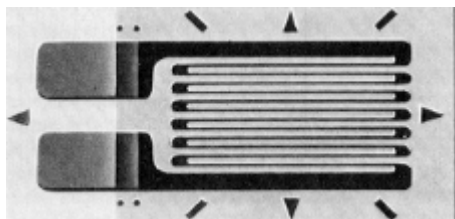
This study does not analyse the consistency between design stresses and stresses measured under static conditions.

Measurement methods and gauges

The wire strain gauge method has been used in the study, with gauges having varying strain force; this is a simple, versatile, reliable and effective method.

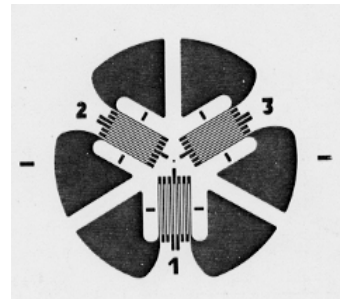
Any changes in the strain on the gauge can be measured continually and dynamically: the gauge is cemented to the structure under load. The change in strength is induced by any deformations of the part, which are induced by elastic stresses.

Single, grid-type strain gauges are used (3 - 6 mm grid, 120### strength, gage factor



single strain gauge

2.0) when the stress pattern is known; and strain gauge rosettes composed of 3 strain gauges angled at 120° when the direction of the main stresses is unknown. When the



strain gauge rosette 120°

single grid gauge was used the proportionality relationship is applied between measured deformation and the

corresponding stress along the direction where stress is applied; with strain rosettes, directions and main stresses are calculated by the Ros-Eichinger relationship.

Measurement strain gauges were always coupled with a strain gauge mounted on an unloaded metal plate which is connected to a branch of the measurement bridge to compensate for temperature changes.

The equipment has 16 dynamic channels where data can be simultaneously recorded through a remote detection system which provides for radio transmission of settings, balancing, as well as of collected data.

The latest equipment we used is very compact, solid and fully automated; it can store data on a Memory Card which can be read with a P.C. This equipment is of the modular type and can be expanded up to 256 channels, and provides for radio transmission as well.

Special care is devoted to cement strain and rosette gauges to the structure and the cabling of connections. The help of assistants is of great value.

Selection of measurement points

Strain gauges were cemented to sections which had been checked during the design stage as well as on the most relevant points where experience had shown that the highest stress increments occur. On prototypes, monitoring is performed on more points to identify any sections to be strengthened. A lower number of points is checked in case of mass-produced equipment; the choice of points shall be such to allow comparison with prototype measurements.

We were able to gather reliable statistics as strain gauges had always and systematically been applied to the very same points. The charts which will be presented always refer to stress patterns; however, what we actually measured were deformations and hence corresponding stresses could be derived: in fact, we are dealing with elastic forces and individual strain gauges were only applied where the direction of the main stress was known.

Test procedures

- Preparation of the test:

cementing the strain gauges; connection of cables; checking that strain gauges are undamaged and correctly connected; loading and unloading the car to allow bonding of the gauges; checking that bridges are back to 0-setting.

Static preliminary tests:

the car shall undergo static preliminary tests to measure static values, to confirm that the equipment is working correctly and that measurement points are as intended. Similarly, the grip is opened and then closed. Under static tests, resetting is performed with the car hanging on the line: under this condition, the car structures are subject to the stresses induced by the very weight of the parts below the section considered: in order to measure the relevant stress an additional weight shall always be added equal to the weight of the above parts. Stresses are to be measured as follows:

- on an empty car: on the strain gauge located on the suspension, with an additional weight equal to the weight of the whole car; on the other strain gauges, with the weight minus the weight of the suspension;
- on a loaded car: as above, plus the weight of passengers.

Resetting for dynamic tests:

before starting the test, strain gauge bridges are balanced under the following conditions:

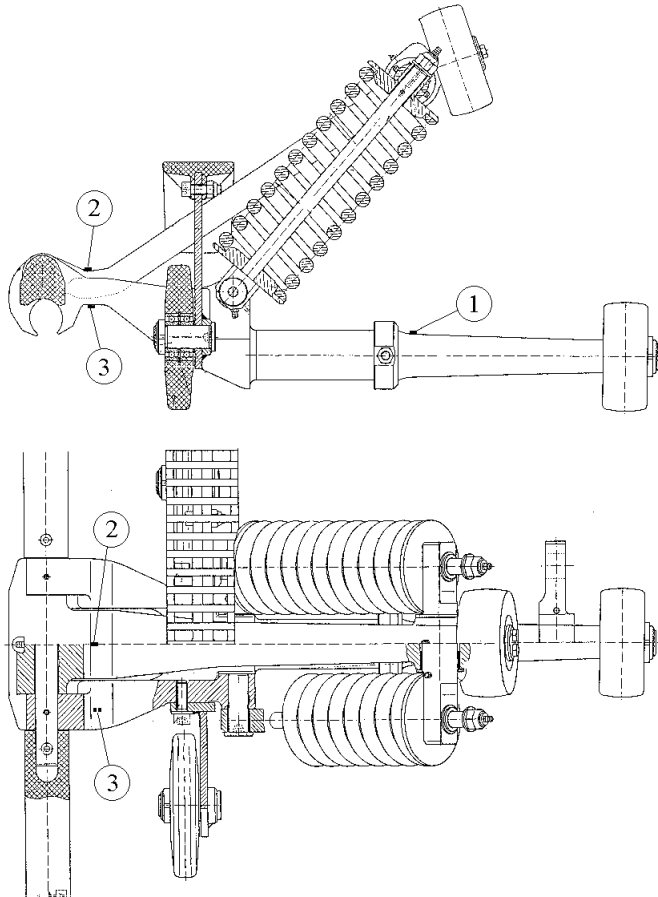
- on strain gauges located on the suspension and the car frame: measurement on the horizontal line section outside the station for ropeway cars, with closed grip and no constraints;
- on strain gauges located on the grip: car shall be on station rails, with closed grip on empty gondola, in the absence of stresses exerted by the action of springs.

Strain gauges located on the grip are reset under different conditions as compared with the other strain gauges and hence dynamic stress also includes the static stress; percentage increases shall be calculated on the difference between the two and shall then be referred to static stress. The remaining strain gauges directly provide the magnitude of dynamic stress only.

Note that on grip parts under spring load the dynamic stress induced when the car is running along the line and at the entrance of the station are negligible as compared with the stress exerted by the grip closing force.

Available data and statistical criteria.

The results of app. 100 tests performed between 1993 and 1998 have been included in the statistics. Tests were performed on chairlifts (4 and 6-seaters) and gondola lifts (6, 8, 12 and 15 posts) with detachable grip, and station entry speed of 4.5 -5.0 m/sec.



A large number of data is available upon completion of a dynamic test with multi-channel data recording. Although measurements were performed at station entrance only, numerical data which are very useful with a view to statistics are obtained under the following circumstances and depend on:

- number of tests performed;
- number of strain gauges used, usually 7 or 8, and arranged as follows:

- two on the grip (n. 2 and 3 on the drawing)

- one on the carrying wheel pin ("third wheel" - n. 1 on the drawing)

- two on the suspension (n. 4 and 5)

- one/two on the suspension/car frame connection (n. 6)

- two/three on the car frame, on most relevant points (n. 7 and 8); the following measurements were

performed on each measurement point:

- preliminary static measurement, with gradual increments in load;
- dynamic measurement, under four different loading conditions (empty, full load, 1/2 load unbalanced either on the outer or inner side) with car entering both top and valley stations.

Data are processed and continuously tracked into charts; highest and lowest values are calculated for each curve: more than 10,000 data were collected.

The survey and the relevant statistics were confined to a single and significant measurement point and quality performance was provided for some other measurement points.

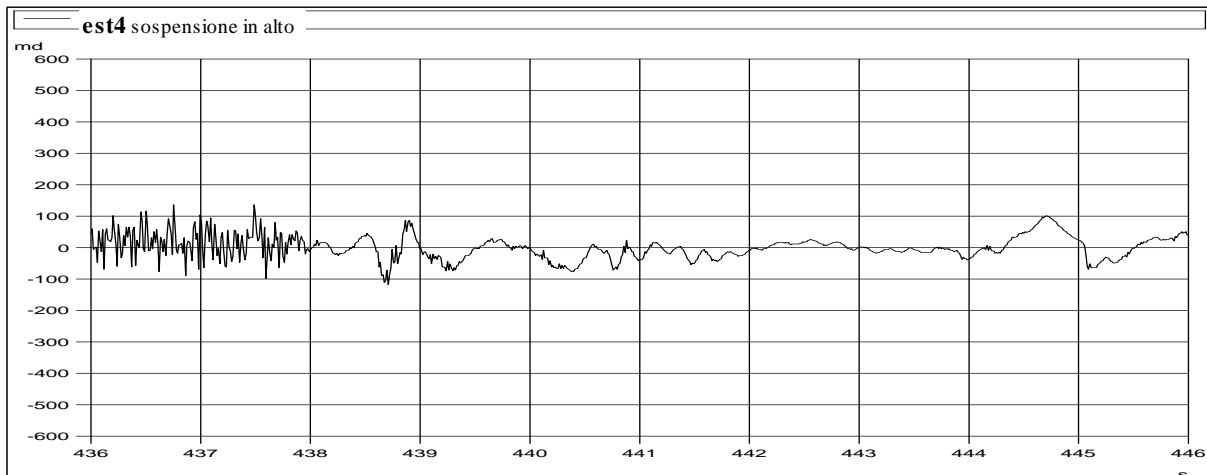
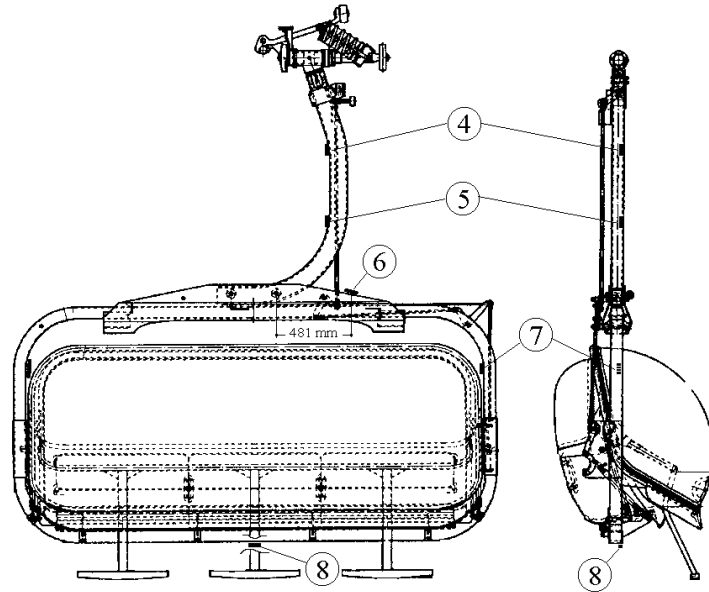
The strain gauge under the suspension head - inner side of the line - was the most relevant measurement point because it is undoubtedly under the effects of the impacts against the station guide rollers because of the distance from the system centre of gravity and as there are no buffers upstream.

Data processing provides the following information:

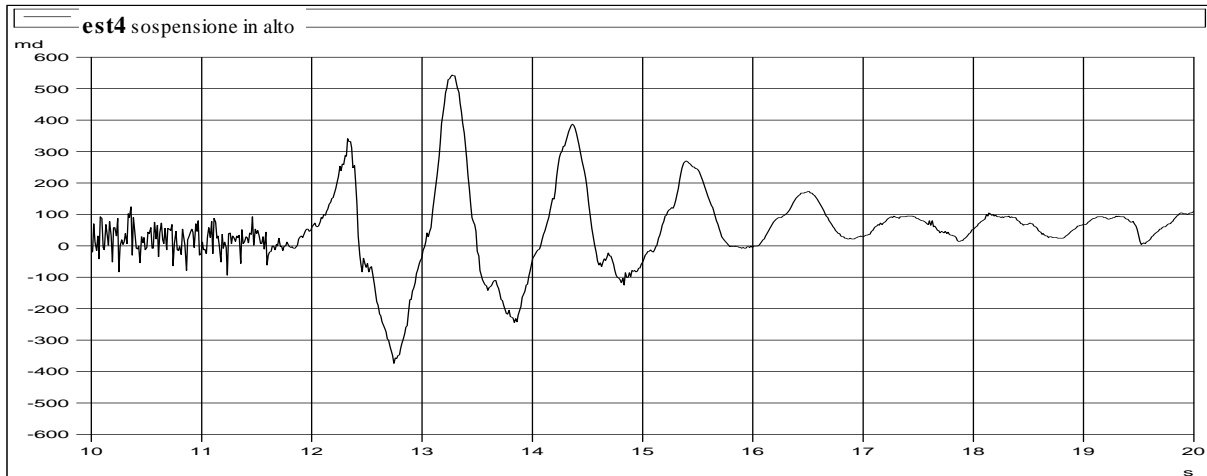
- dynamic stresses as a percentage of static stresses on the same point, with empty, fully loaded and unbalanced 1/2 loaded cars;
- the highest stress, as a sum of static and dynamic stresses having the same sign to confirm that the values are within acceptable limits (this is not really important during this stage; indeed, it is key to confirm that design sizes are correct).

The following charts were obtained on a chairlift, at the entrance of a valley station, at a speed of 5.0 m/sec, as follows:

balanced full load:



1/2 load, 2 passengers on the inner side:



changes at the beginning of the curve indicate that the car is passing on the rollers before the station.

Results

Based on the above results the following table has been made, which is divided as to include chairlifts and gondola lifts because:

- the connections between suspension bar and gondola frame in gondola lifts usually differ from connections in chairlifts (where single or "double swivel" joints are used)
- in gondolas, when the load is unbalanced, impact stresses when gondola enters the station entrances are lower;

The table shows that:

- increments are much higher in the case of chairlifts: when a passenger is sitting on a side seat and there is a need to reduce side-to-side oscillation inside the station, the connection between the suspension bar and the seat frame must be stiffer to resist the effects of side-to-side movements;

	empty	1/2 load unbalanced	full load
chairlift average increments	189%	84%	100%
gondola lift average increments	108%	31%	63%

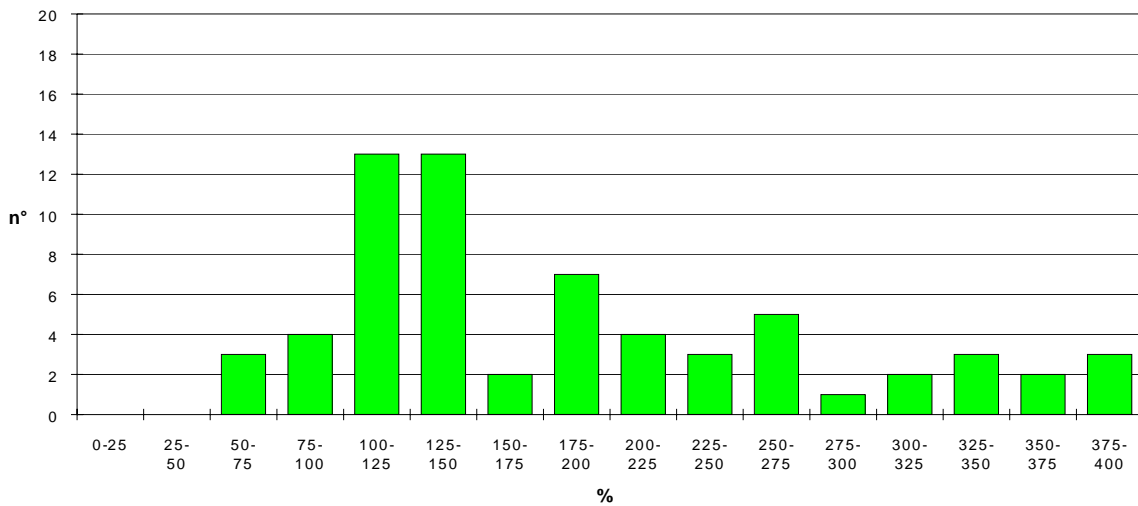
- increments when the structure is empty are nearly double as compared a loaded car; however, as the static stress is lower, total stress is lower than stress induced when the car is fully loaded.

Statistical distribution of dynamic stresses (in percentage)

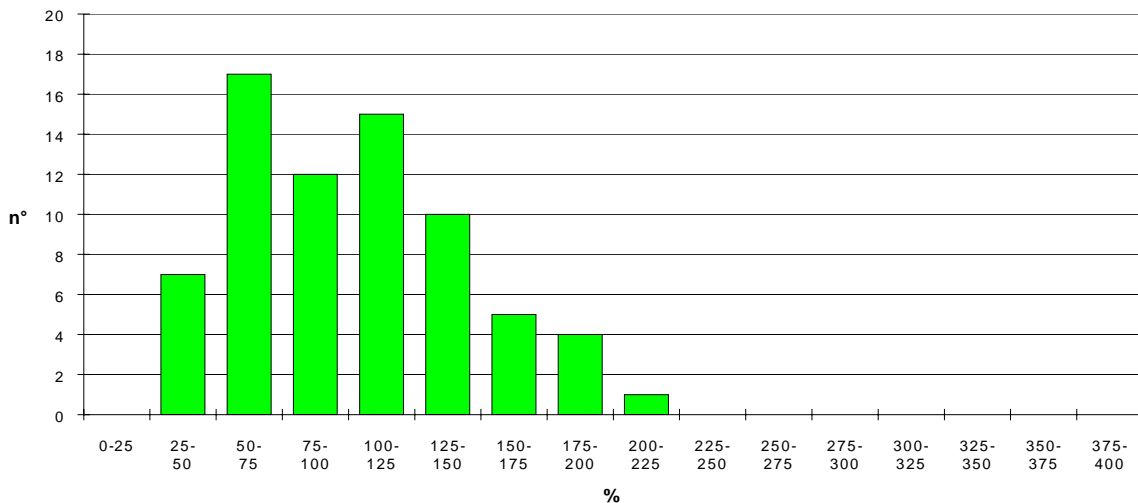
During the test, the gondola is driven to perform a round trip under all loading conditions and, when entering the station, conditions might be affected by random parameters such as lateral pressure from winds, bay oscillations, etc. which may bring about unusual increments.

Once the average values of dynamic stresses are calculated, it is maybe worth checking the percentage range where highest stresses occur. The distribution is traced as follows:

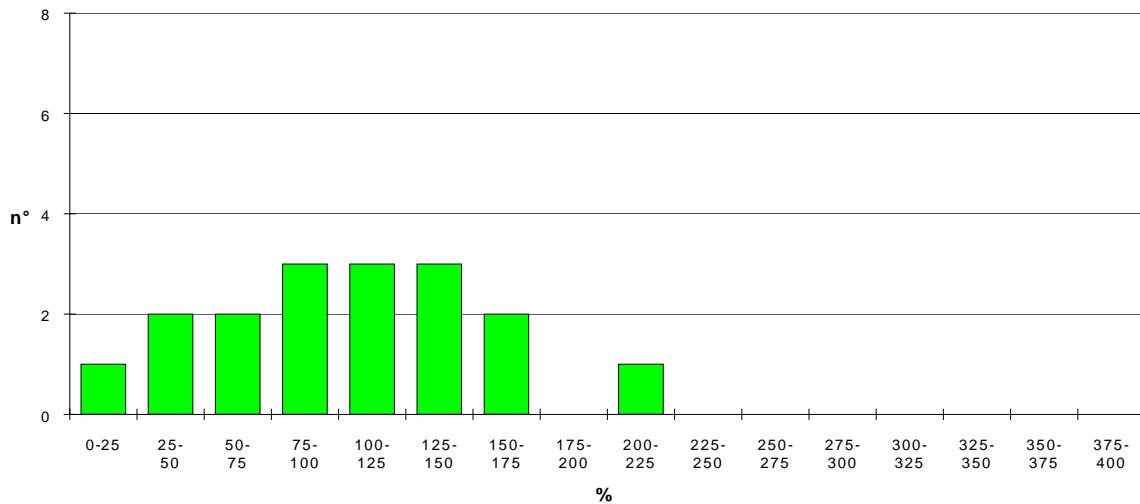
empty chair



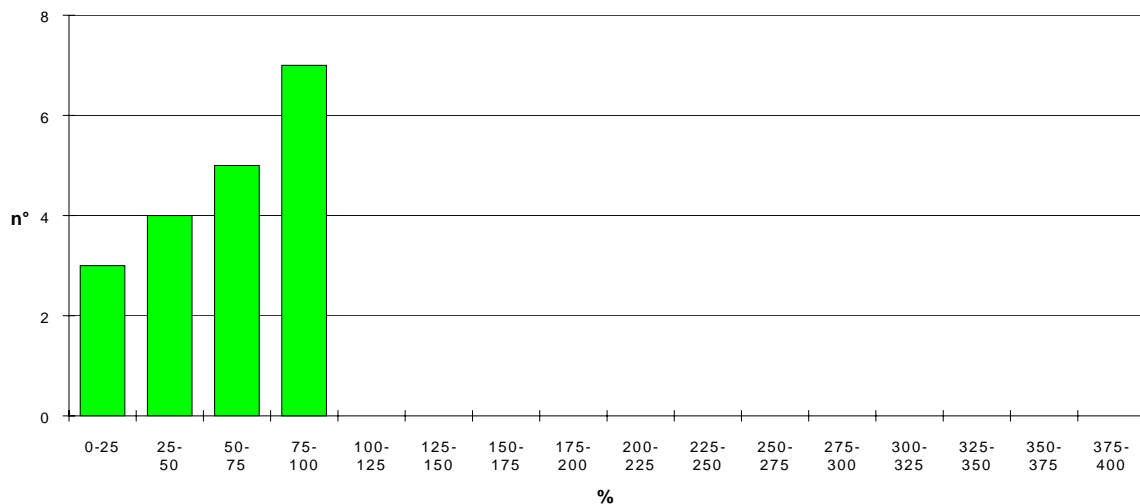
fully loaded chair



empty gondola



fully loaded gondola

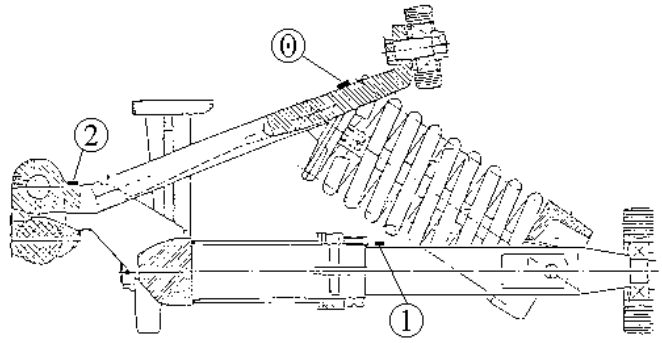


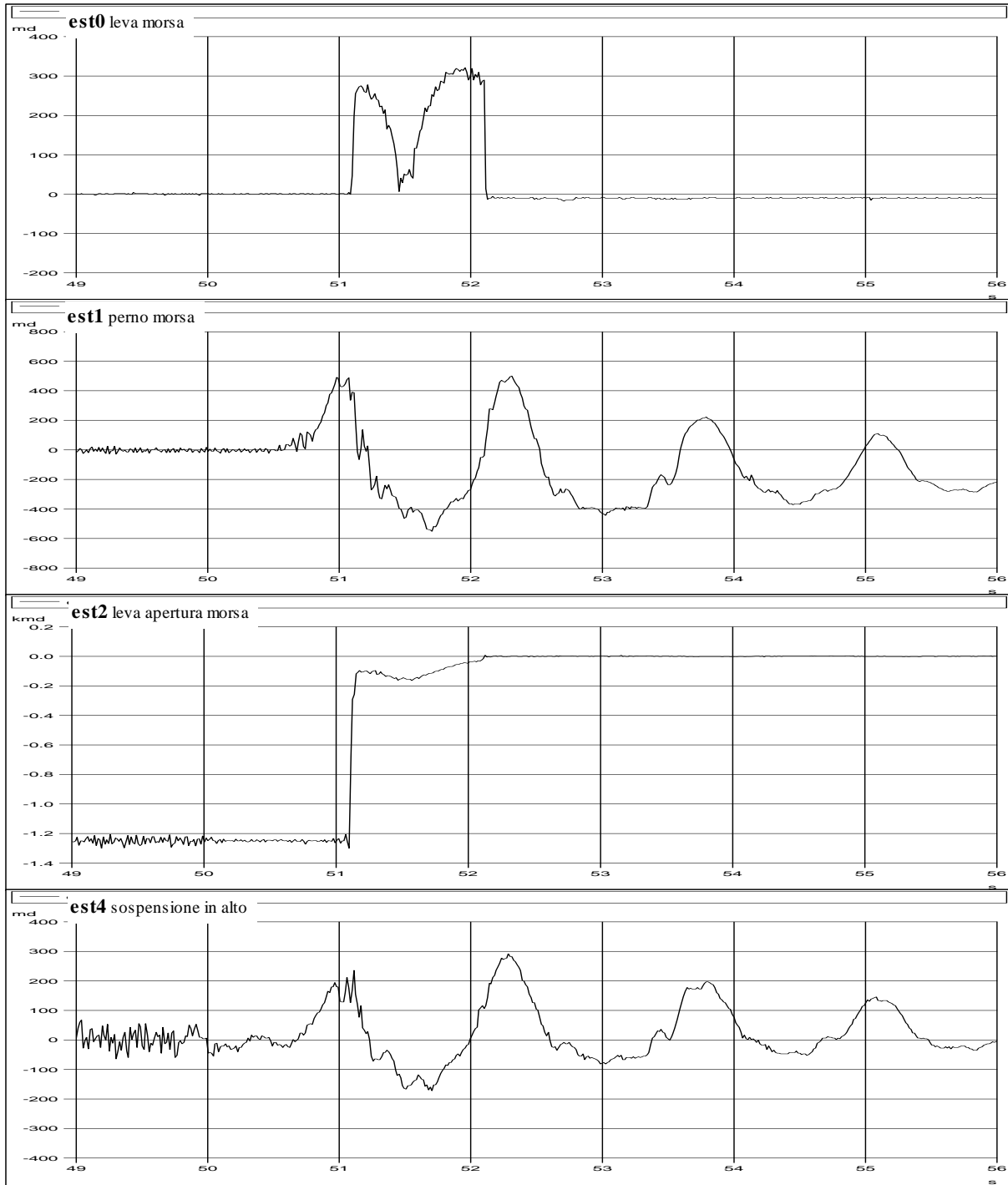
Detailed analysis of tests with unbalanced load at station entrance

Tests are performed with 50% of rated load, to be arranged on the outer or inner side of the car as to the direction of the carrying-haulage cable.

The unbalanced load effect is such that the rest car is tilted to the side as to the vertical: upon entering the station, the impact against slide rails cannot be avoided. The following charts shows the deformation/stresses detected by the strain gauges:

- n. 0: on the bearing lever, the opening wheel providing data on the contact with the relevant guide;
- n. 1: on the stabilising wheel bearing pin;
- n. 2: on the lever where the mobile jaw is mounted ;
- n. 4: on the suspension head, which is the selected measurement point;





Comment to charts:

- on the first chart we can see the exact moment when the impact occurs and the grip opening guide is detached: note that the bending stress decreases until the grip is fully open, which is then opened again once the cable has detached:

- second chart: when the third wheel impacts against the upper guide, the strain gauge on the pin is tensioned; compression/tension cycles follow which are due to side-to-side oscillations;

- the third chart represents the discharge of the mobile jaw, at the end of the opening guide rail;

- the fourth curve is like the second one: however, here the highest stress is exerted when the first impact occurs (which is buffered by elastic guides); the highest stress is indicated by the second peak when the car is already on fixed rails and its position cannot be changed.

Note the first part of the fourth chart: it shows the stress induced by the rollers before the station.

In general, stress exerted when the gondola has an unbalanced 1/2 load is lower than in case of full load.

Effects of roller guide height adjustment on dynamic stresses

During a test performed on a 4-seater chairlift with wind shield, very high dynamic stresses have been detected at station entrance at a speed of 5.0 m/sec - chair with balanced full load - even though the chair was in a perfectly vertical position. The builders adjusted the height of elastic guide rollers at the entrance and replaced the guide supporting buffers.

Response curves at three measurement points (to be superimposed) are reported and comments are provided.

Before adjustment:

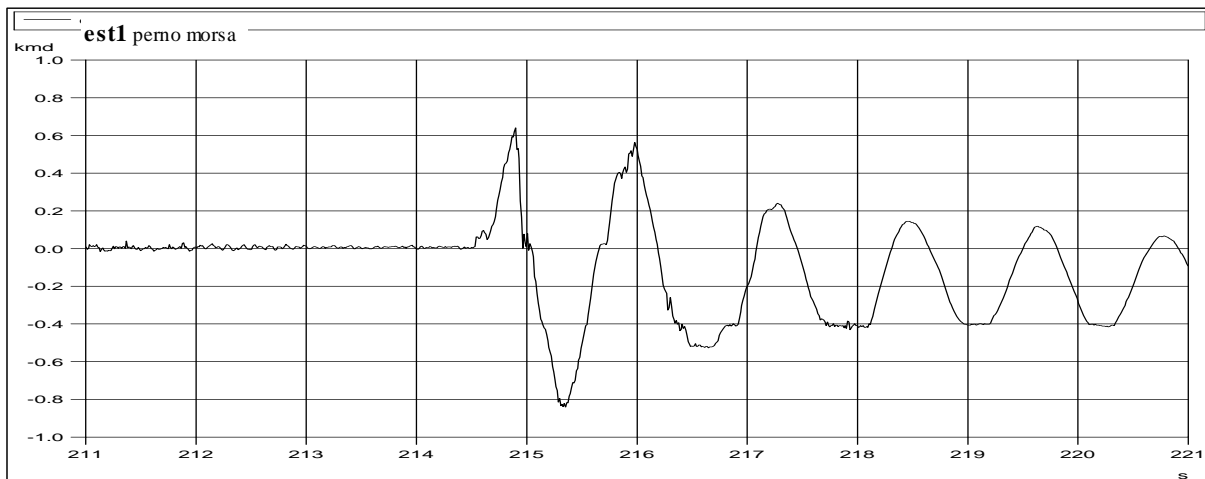


Chart 1 (strain gauge located on the third wheel bearing pin - see grip previous drawing): the pin is not loaded along the line; after impacting against the upper section of guide rollers the pin is tensioned, and is subject to alternate cycles - with decreasing intensity - of compression and tensioning due to the side-to-side oscillations of the chair. In the stress cycles which follow the first one, the average compression value is below zero which is due to the vertical load exerted by the haulage wheels of guide rollers.

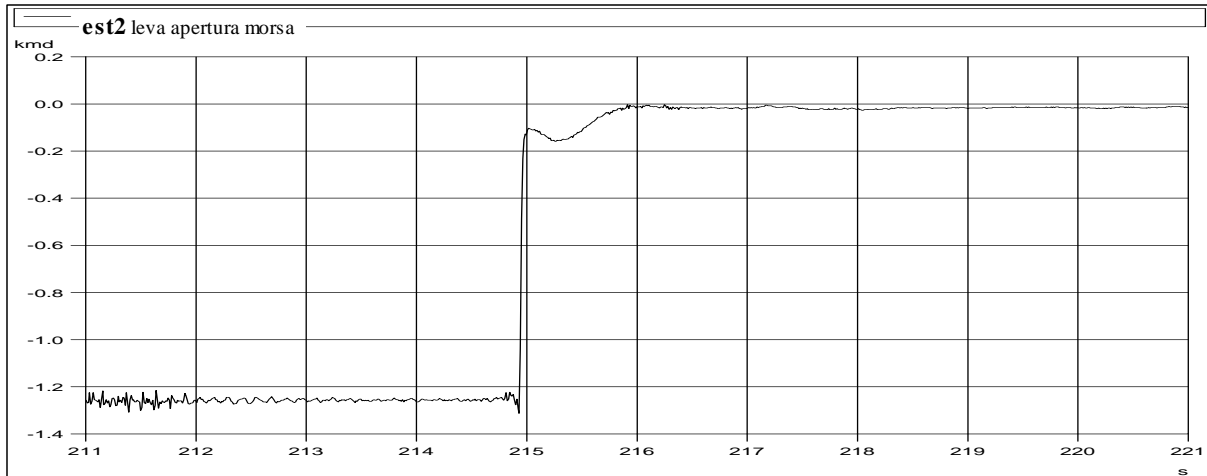


Chart 2 (strain gauge on the mobile jaw lever): this element is only affected by the load exerted by the closing forces and is not due to impacts occurring when the chair enters the station; as a matter of fact, the tracing of the curve is unchanged: the peak values (lever unloading) are delayed if compared with the previous chart as the grip opening blade follows guide rollers before the entrance of the station.

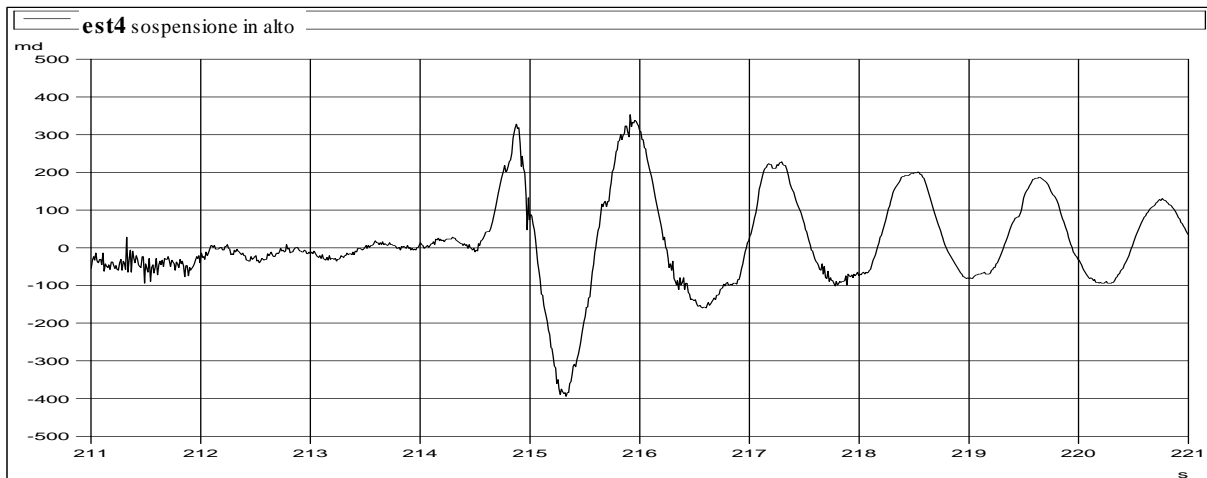
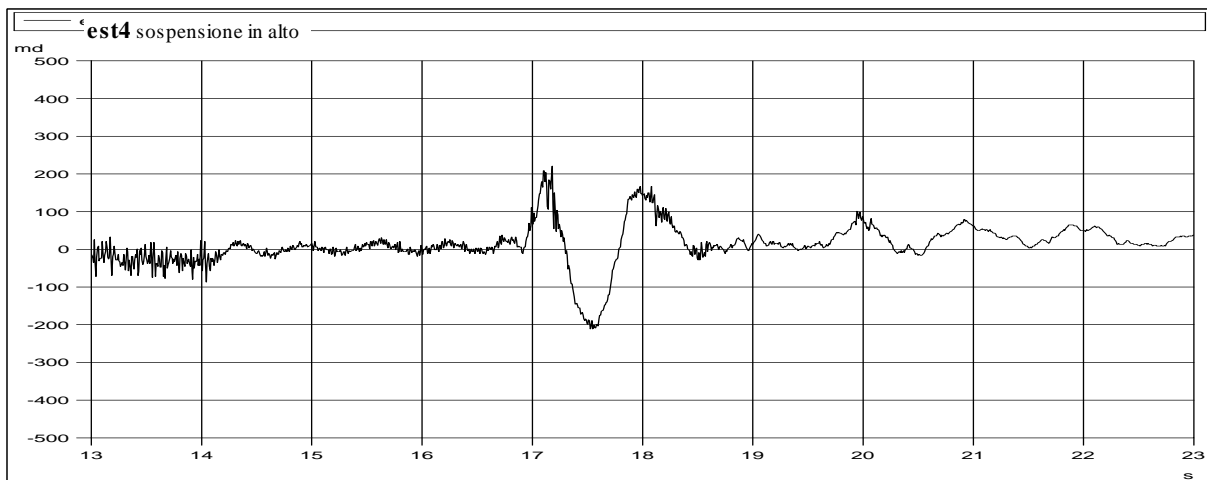
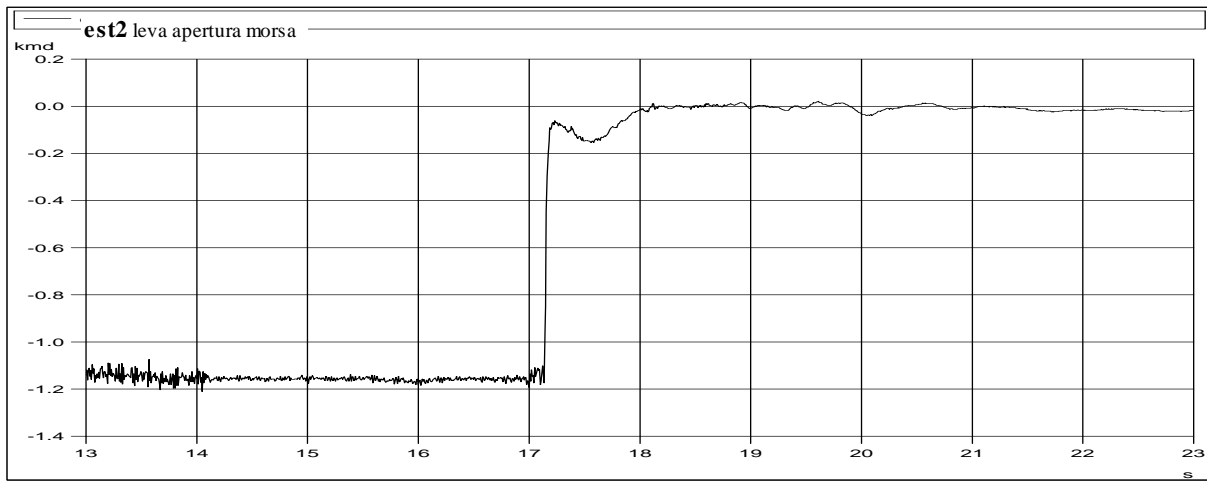
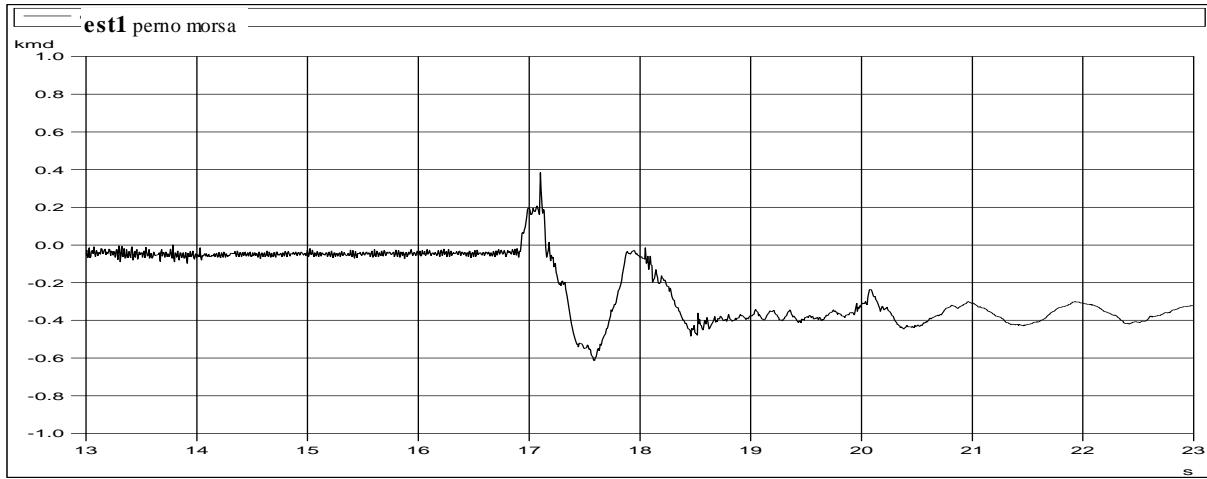


Chart 3 (strain gauge on the suspension bar, upper section): at the beginning of the curve, signal changes refer to the chair passing on the rollers before the station and then indicate the vertical oscillations of the bay and the impact against the guide rails.

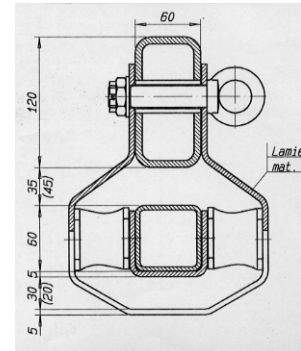
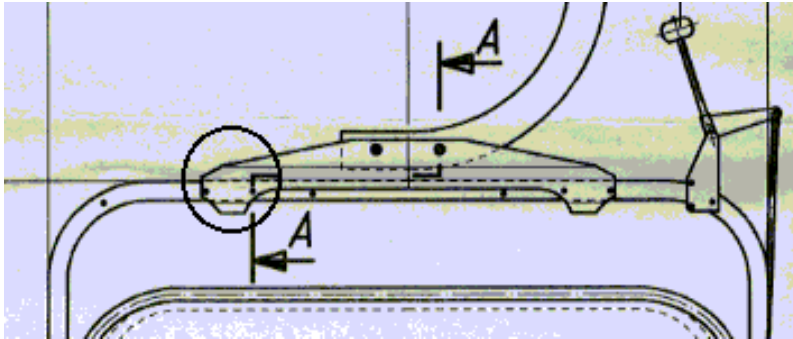
Guide roller height was reset and the constraining buffer parts were replaced:



dynamic stresses on the suspension bar were then remarkably lower, from 214% to 113% increments, as compared with static stresses. The signal provided by the strain gauge on the mobile jaw is unchanged.

Effects when replacing car components

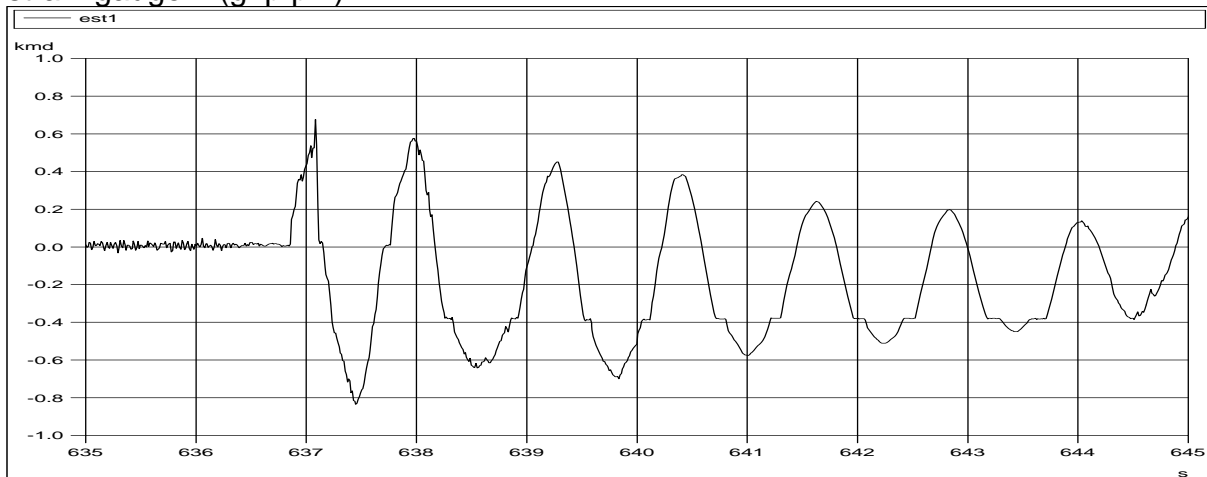
The test is performed to assess the effects of replacing rubber buffers on the suspension bar/seat-bearing frame joint on the above chair. Softer rubber buffers were used and located in a different position.



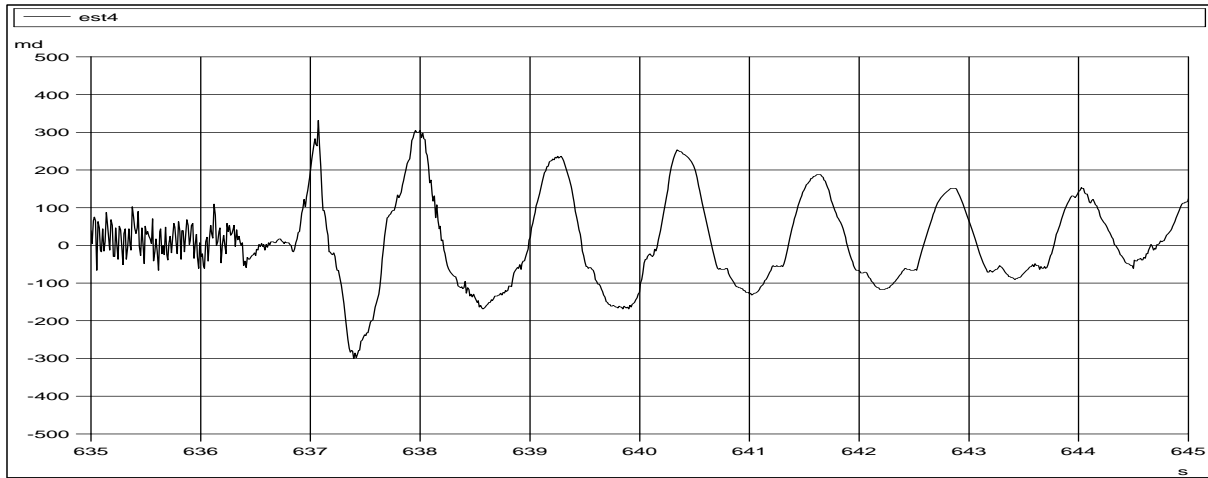
original buffers

Charts - balanced full load - entry speed 5.0 m/sec

strain gauge 1 (grip pin)

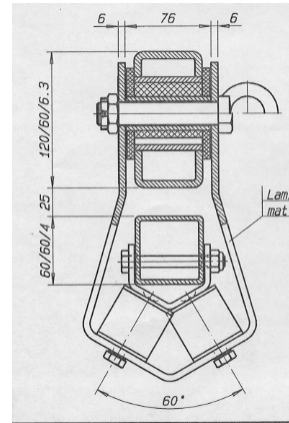


strain gauge 4 (suspension bar)

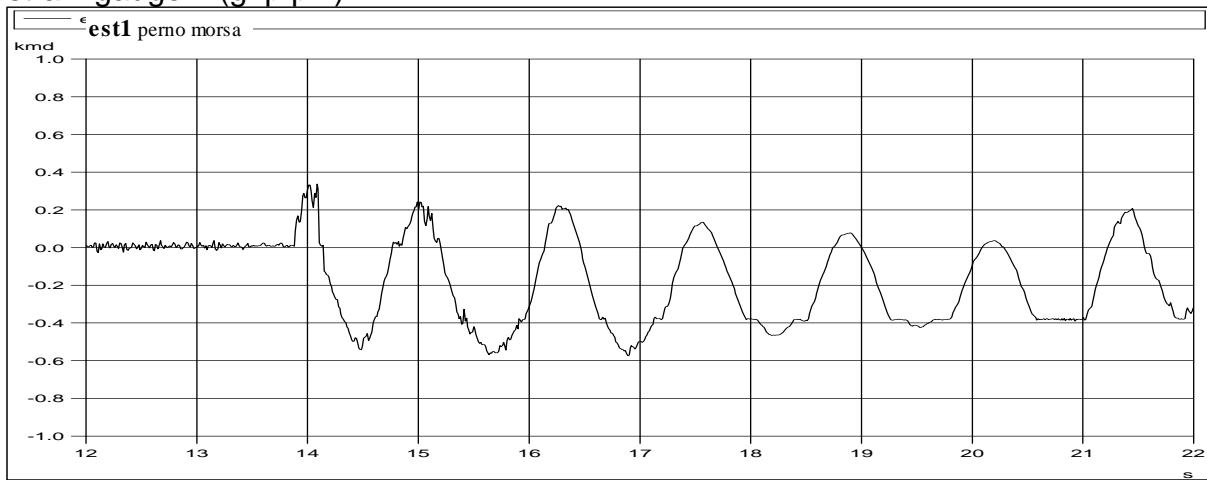


Same parameters

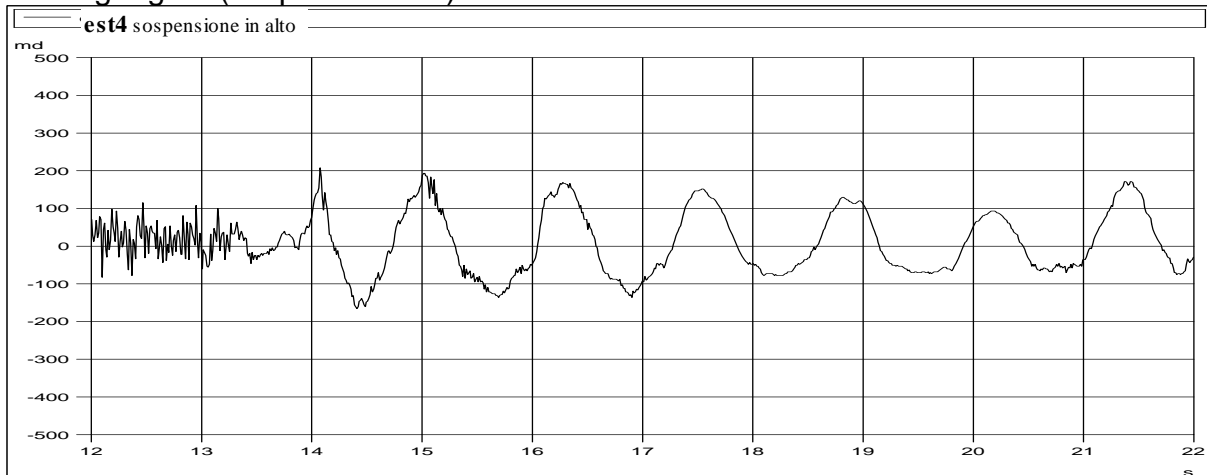
with new buffers:



strain gauge 1 (grip pin)



strain gauge 4 (suspension bar)



Dynamic stresses decrease by 40-50%.

Tests at station entrance under fixed lateral inclination

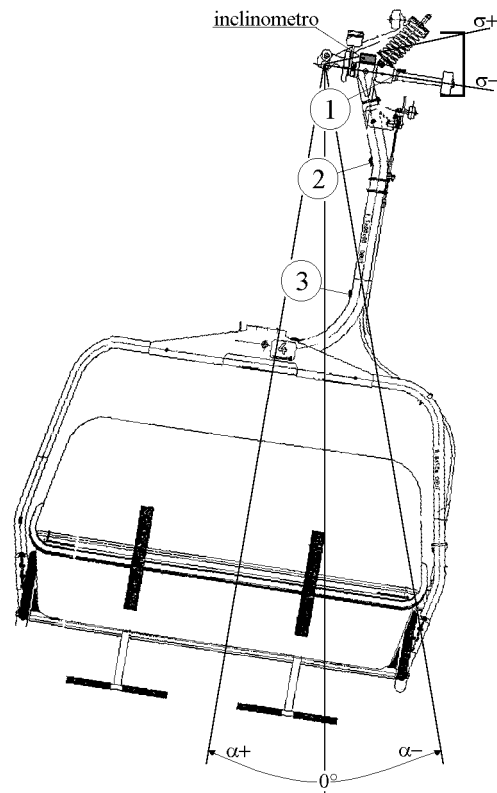
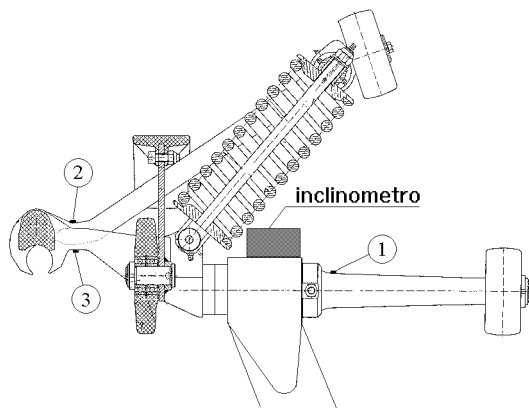
The results reported so far were collected under test conditions where the car had a "natural" position when entering the station, i.e. its position was determined by loading conditions and line-induced oscillations only. In order to take thrust effects on board, which are due to lateral pressure from winds equal to the highest value under service conditions, tests were performed where the car was in a fixed laterally inclined position before entering the station

Builders were requested to provide lateral inclination values due to wind pressure effects on each loading condition to define the following test parameters (angle to be achieved):

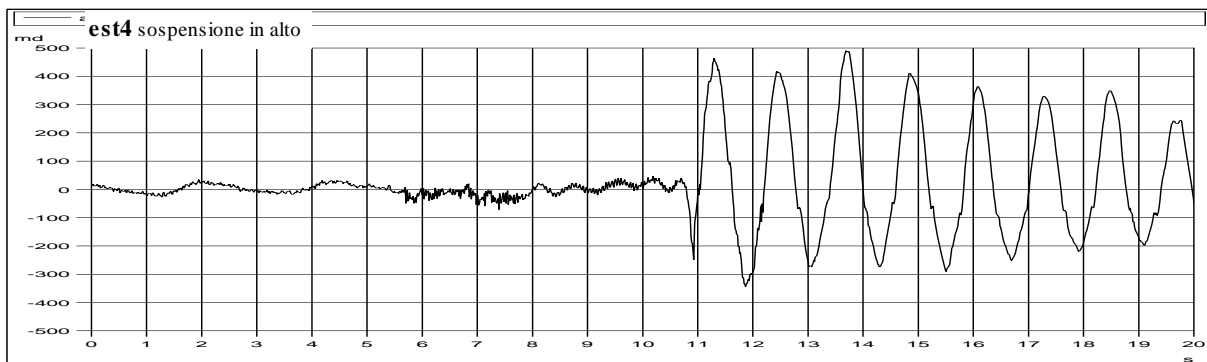
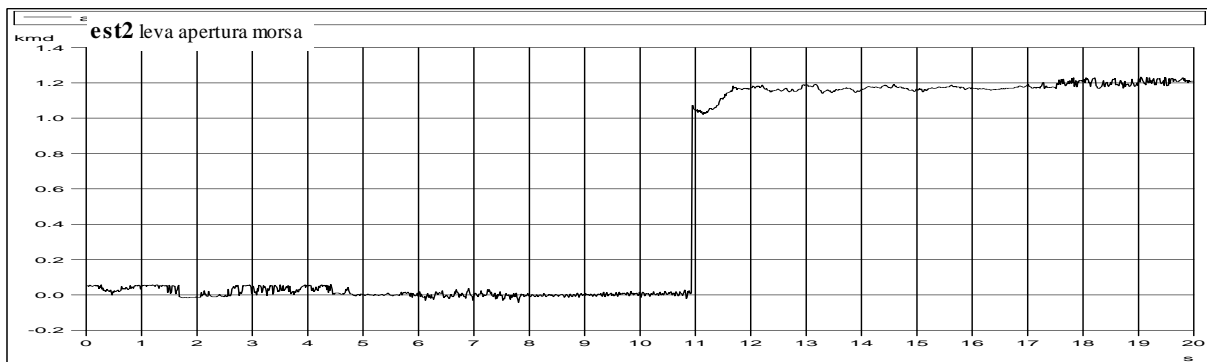
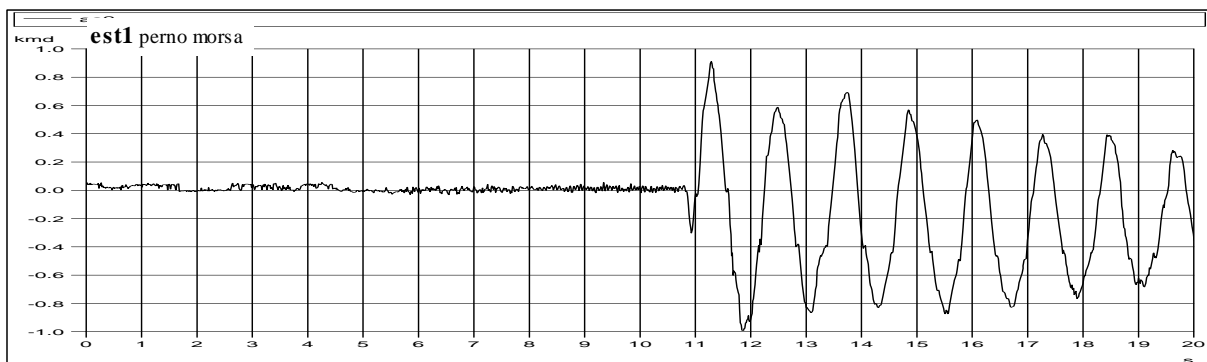
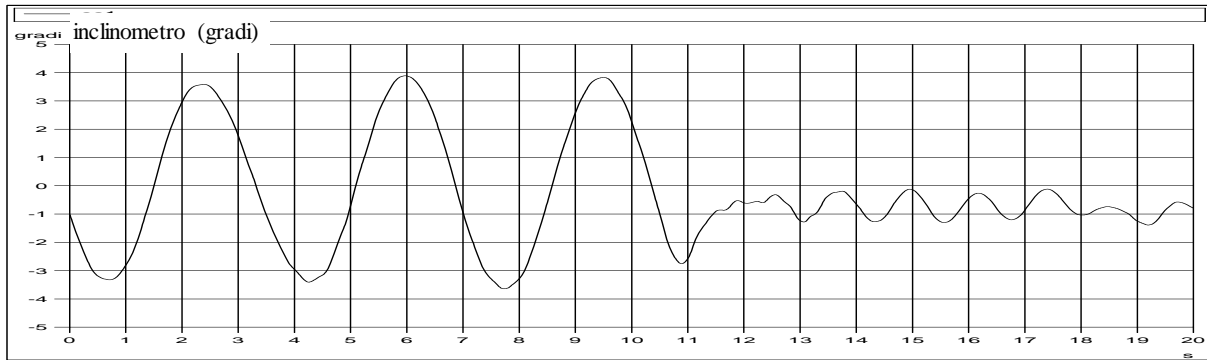
- empty car: 12° ;
- 1/2 unbalanced load: the natural angle plus the value corresponding to the highest lateral pressure from winds;
- full load: 6° .

This test is rather dangerous so it was performed on a limited number of car models only.

The car was driven outside the station at a distance that it could be fully started and could enter the station at the maximum running speed; at the same time, the car was swung laterally so that it reached the desired angle when impact occurs. Tests were performed with the car at desired angles, inwards and outwards the line.



A recording channel line was connected to a pitch indicator mounted on the head of the suspension to measure the lateral inclination.



A comparison between the percentage dynamic increments measured on a 4-seater chair with wind shield and a 6-posts gondola is provided, under normal conditions and under lateral inclination, which were measured on the strain gauge on the suspension head.

dynamic increments. as to static stress	empty		1/2 unbalanced load		full load	
	chair	gondola	chair	gondola	chair	gondola
fixed lateral incl. tests	428%	513%	-	31%	151%	225%
dynamic tests	111%	167%	-	23%	48%	81%
ratio between the two incr.	3,8	3.1	-	1,34	3,1	2,77

The last row shows the ratio between the magnitude of the impact force in the presence of lateral pressure from winds and the impact force with no wind, when entering the station.

These are clearly two completely different phenomena; in the hardest situation the minimum level of safety degrees mandated by regulations is not complied with (3 as to the unit yield point of the material and 4 as to the unit breaking strength, measured under standard loading conditions and with a 50% increase).

We therein provide a table comparing:

- design stress values (static + dynamic equal to 50%)
- stress values (static + dynamic) measured under a "natural" angle
- stress values (static + dynamic) measured under a "fixed" angle

including the relevant degrees of safety as to the unit breaking strength of the suspension material (steel Fe510D UNI 7806)

(Stresses in N/mm²) - 4-seater chair with wind shield

	design stress	safety degree	measured stress (natural angle)	safety degree	measured stress (fixed angle)	minimum safety degree before failure	minimum safety degree before yielding point
empty	-	-	59	8.6	148	3.4	2.3
full load	72.1	7.0	86	5.9	143	3.5	2.4

Lower values of safety degrees were measured on other ropeway systems, which were however always higher than 1.5.

Based on the following:

- low incidence of this event, which as such cannot be evaluated in the framework of the fatigue effect,
 - extremely rare event, so that lower degrees of safety can be adopted;
- under such circumstances, the Control Authority has accepted that the minimum degree of safety can be reduced to 1.5 as to the unit yield point of the material.

Dynamic stresses on other points of the carrier

Whenever static stresses are known, we can confidently speak of a dynamic increment, i.e. the magnitude of the thrust effect. Whenever the car/chair is empty, under static conditions, absolute stress values - generated by impacts - is measured (see stabilising pin, known as the "third wheel").

Signals coming from the strain gauges on the seat frame, below buffers, may be remarkably out-of-phase - under specific loading and speed conditions - as to signals sent by the strain gauge on the suspension, especially when the frame passes under the guide rollers before the station entrance.

It may well be that the highest stresses are induced at speeds lower than the top speed. It must be noted that on structures below buffering parts, dynamic stresses are considerably decreased and safety degrees are largely respected even at remarkable lateral inclinations.

Conclusions

The wire strain gauge method to measure dynamic stresses proved of value as it is reliable, it provides reliable impact curves and is easy to use.

Whenever timely and exhaustive information on stresses are available:

- builders can easily undertake type approval procedures of a car type, with improvement of production processes (no need to continuously modify the model series)
- designers can select the best and most suitable crashworthy sections, technical solutions for parts connections and joints;
- builders and installers can adopt best solutions for station parts touching car parts;
- the Control Authority is provided with an effective control method to monitor compliance of design and erected structures and as a valuable data base to any amendments of the regulations in force.

Future prospects

We advocate that testing procedures are harmonised in different countries and in those on the Alps mountain range in particular.

Having confirmed the value of such methods, we foresee further development in the future owing to technology development of instruments so that we could:

- perform wider monitoring, with more points of measurement to be thoroughly controlled;
- have compact equipment to monitor the performance of parts touching the car and which are at present not easily reached (line rollers, station cable pulleys);

- wider data collection and processing.

A more thorough knowledge on stresses and the use of fatigue tests performed under actual stresses conditions will enable to confidently reduce degrees of safety. Cars will then be lighter, with less strong impacts and a lower live load as to the pay-load available.

LA.T.I.F. is fully committed to pursue further tests to include measurement of stresses along ropeway lines.