



# Passive safety of railway vehicles, driver's cab structural design

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## Abstract

This paper deals with new railway vehicles for long distance and suburban service, with crashworthy design features, designed and manufactured by Costaferroviaria Company (Italy).

In the recent years the improvement of the railway vehicle crashworthiness has become a more important requirement for vehicles design, particularly for driving vehicles.

By means of quasi-static crush test, on full scale underframe of the cab, the validation of the proposed design and the measure of the amount of energy which can be absorbed reliably by the single energy absorbing components have been obtained.

## 1 Introduction

Within Europe, the requirements to ensure the structural integrity of coach bodies comes mainly from the International Union of Railways (UIC) and affiliated European Railway Research Institute (ERRI). For main line coaches, the UIC 566 OR, for the structural design of passenger vehicles, is based on minimum proof loads, 2000 kN applied at the couplers of buffers and lower loads applied at various points on the vehicle superstructure, which must resist without permanent

deformation. These standards are necessary to avoid damage in normal operating conditions.

However, in designing for dynamic resistance in collisions at higher speeds, the concept of no permanent deformation cannot be sustained. Hence, in order to provide protection in accidents, the ability of the structure to absorb energy, to a given crushing distance, is required.

For this reason the standards for dynamic resistance of driving-cab at frontal impact are still in progress.

The basic objective of crashworthy design is to manage the rapid conversion of the kinetic energy of the moving vehicles into other forms, such as structural deformation. In this way the effect of high deceleration on passengers is reduced and also the existence of a survival space remains within the collapsed vehicles, into which the deformed structure does not penetrate.

Ideally, the load to initiate the crushing should be just above the UIC 566 OR minima. Excess strength above these minima simply adds mass, and therefore more kinetic energy to moving vehicles, which should be absorbed if the collision occurs.

As literature [8] reports an important classification of trains collisions can be carried out according to energy involved ranging from 0.25 MJ to 15 MJ for impacting speeds from 10 km/h up to more than 50 km/h, corresponding to simple shunting collisions and collisions at important speed, respectively.

In this paper collision at 50 km/h of railway vehicles with one another, will be considered.

## **2 Construction philosophy**

The vehicle under investigation is a new type of railway vehicle for long distance and suburban service, designed and manufactured by Costaferroviaria Company (Italy), following a crashworthy design philosophy.

This vehicle, built from mild steel, consists of crash-resistant driver's cab, behind-cab high resistance area and passengers area (figure 1).

When the head-on collision with another railway vehicle occurs, the underframe can slide under the upper part of the cab and only little penetration of the cab space takes place with a slight deformation of

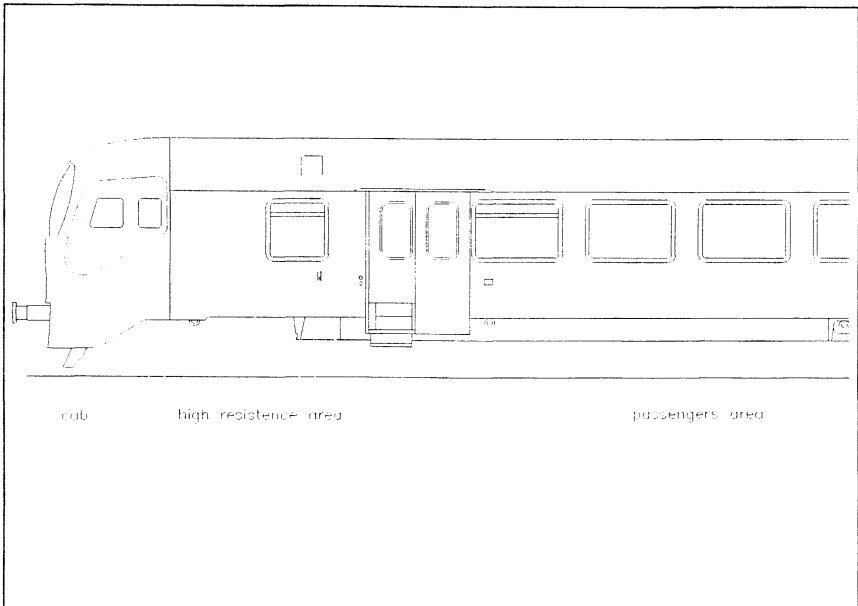


Figure 1: Railway vehicles under investigation.

the cab wall structure, on the contrary the underframe absorbs most of the collision energy.

In order to address this requirement the underfloor structure of the driver's cab has been precisely designed to ensure that collapse occurs in a graduated and predictable manner, so as to maintain, as far as practicable, the structural integrity of the passengers area and the survival space for the driver.

The underframe of the cab includes structural elements made of standard rolled and machined sections and also components specifically intended for energy absorption.

The main energy absorbing components, shown in figure 2, are:

- special high energy absorbing buffers;
- calibrated load bolts;
- two energy-absorbing cushions of aluminium honeycomb, one for each anti-climb buffer, mounted behind each buffer, inside the headstock;
- solebars designed to induce a controlled collapse mechanism aimed to maximize energy absorption.

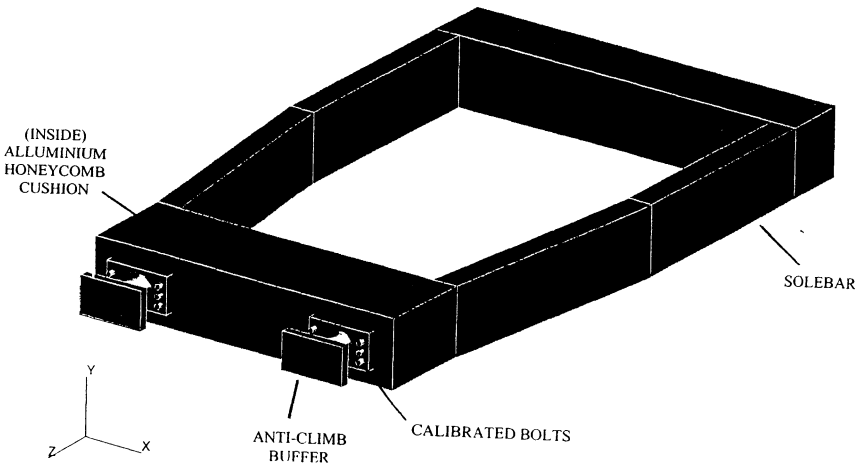


Figure 2: Collapsible structure at leading end of underframe.

In end-to-end collisions, at the beginning the collision forces always initiate on buffer level.

The buffers, high capacity energy absorbing buffer capsules, can deform up to a force level of 650 kN over a stroke of 110 mm. Each buffer is welded on a rectangular plate which in turn is connected to the headstock with six calibrated bolts.

These calibrated bolts have been specially designed and tested to fail at 133 kN. When the collision force reaches the value of 800 kN for each buffer, all the bolts fail at the same time and the rectangular plate can slide inside the headstock.

At this time the aluminium honeycomb blocks, behind the buffers and inside the headstock, will support the vehicle end load. The honeycomb core is aligned such that it will progressively collapse at a load of 800 kN for each block, in a cell crushing mode, over a nominal length of approximately 450 mm <sup>1</sup>.

At this stage of the collapse of the underframe the forces act, by means of the headstock, on the lateral solebars.

The lateral solebars are designed to work as structural components

<sup>1</sup>The honeycomb system is able to absorb energy not only in the longitudinally direction, but also in the normal direction, this permit to obtain good performance for non symmetric impact condition.

for service and exceptional load (up to 2000 kN) and as energy absorption device when the impact occurs.

The cab's solebar has the section longitudinally variable and its minimum is located where the axis of the solebar changes direction: therefore in this section results a notch.

The previously described design has been proposed in order to induce a collapse mechanism consisting in the following steps:

- plastic hinge formation in the area of minimum section in order to convert the kinetic energy of an impact into work of elastoplastic deformation;
- bending outwards to provide controlled collapse and further energy absorption;
- formation of two more plastic hinges at the solebar's ends.

This mechanism aims to maximize energy absorption on a crushing length of about 1 m. When the large deformations occurs, the force level can be considered constant and this crushing distance should be sufficient to reduce the deceleration value of the vehicle.

This type of structural design, with progressively stiffer longitudinal characteristics, let us to control the deceleration rates and also to minimize the high force and deflections of the vehicle's end, which contribute to the wedging effect and consequent catastrophic underframe climbing, as occurs in conventional railway passenger coaches. When end-to-end collisions occur, the climbing is a major cause of serious injuries and fatalities. The design of anti-climbing systems, able to keep the vehicles vertically in line throughout any further deformation, is difficult; only their principle is known<sup>2</sup>.

The climbing can be avoided by controlling the deformations in a defined way, with a defined force levels, with a progressive load-displacements characteristic.

The aim of the proposed design is to get the main collision force on the level of the underframe keeping the cab deformations independent from the one of the underframe and causing the outwards bending of the lateral solebars.

At the same time the proposed solution is economically favorable and

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<sup>2</sup>The function of the anti-climbing systems is to prevent any vehicle climbing to be sure that the impact on two neighboring coaches take place on the structural elements.

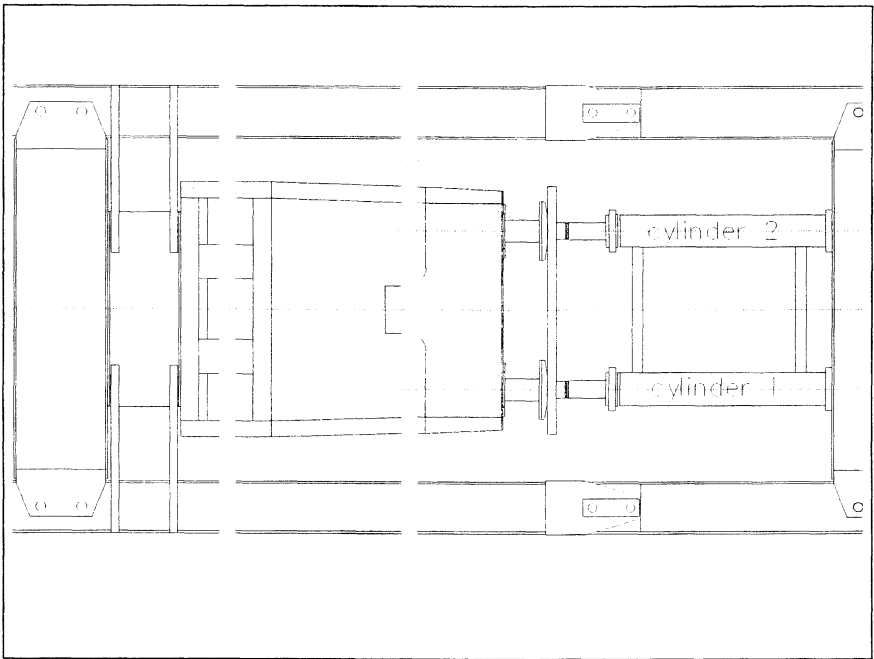


Figure 3: Experimental configuration for the test of the underframe under investigation.

particularly simple from the point of view of the structural arrangement.

Moreover, the simplicity of the structure can be also an advantage because the collapse mechanism can be reliably the same for a large range of velocity and for different impact angles.

### 3 The tests

In order to study the new railway vehicles structures, series of test has been carried out, using Costaferrviaria bench and Politecnico di Milano laboratories.

By means of experimental device, for full scale quasi-static test, experiments on structures of the same type of the cab's underframe under investigation have been carried out.

Tests and finite element calculations are in progress at Politecnico di

Milano on models of components, in order to optimize the required collapse mechanism of the energy absorbing components and estimate the amount of energy which can be reliably absorbed.

The tests has three primary objectives:

1. to validate the structural design proposals;
2. to demonstrate that a structure designed to new specification could be easily and inexpensively built;
3. to provide data for the development of computer programs able to predict the large deflection plastic collapse of similar structures.

Some preliminary full scale tests will be illustrated in the following. The first one is performed to study, by means of a simple structure, the collapse mechanism proposed for the real solebars of the underframe.

The second is a test performed on the cab's underframe under investigation in order to evaluate the performance of the complex real structure.

Tests were carried out in horizontal position: figure 3 shown the experimental device.

The load (0-3000 kN) has been applied by means of two cylinders with 2 m stroke and powered by hydraulic units: two volume displacements pumps (radial piston) with the same fixed displacement and driven by electric motor.

The displacements at strategic positions of the structure tested were monitored to check the collapse mechanism, by means of resistive potentiometers.

## 4 Simplified frame

The simplified frame tested in order to verify the proposed collapse mechanism of the solebars of the underframe is shown in figure 4, in deformed configuration after the test.

This structure has been designed to have critical load of the longitudinal beams equal to 1000 kN and coincident with the load necessary for the plastic collapse of the section. Moreover, the central section

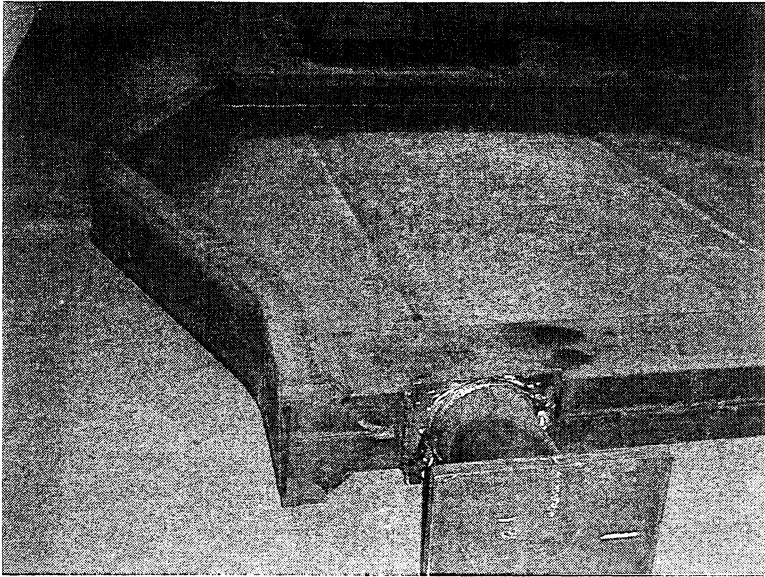


Figure 4: The simplified structure in the deformed configuration after the test.

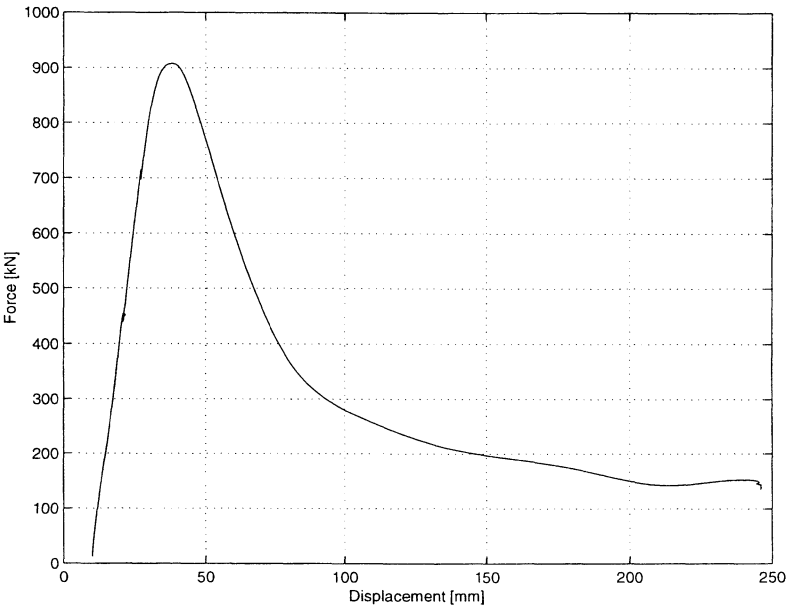


Figure 5: Measured load/displacement characteristic of the simplified structure

has been notched to localize the plastic hinge.

As expected, the lateral beams show the formation of a plastic hinge in the central section, where the notch was located, and two plastic hinges at the ends of the beams itself, when they buckled.

The measured load/displacement characteristic of the simplified frame is shown in figure 5.

For both solebars, the plastic hinge occurred in the expected sections at the designed load and at the same time the elastic instability of the lateral solebar took place.

At this time the load started to decrease and the test was stopped.

As consequence of the elastic buckling the load decreased limiting the amount of absorbed energy.

## 5 The underframe end

We the underframe end in correspondence of the cab in order to verify the behavior of the headstock's elements, the collapse mechanism of the structure and the energy absorbed by the single energy absorbing components.

### 5.1 Design specification

As before mentioned, accident collision energy must be absorbed by structural collapse of the underframe of the cab.

The peak force during collapse should not exceed 3000 kN to avoid any permanent deformation of the passengers compartment. This limit value has been established carrying out full model static tests on the vehicle under exceptional load with strain gauge measurements and also calculated carrying out finite element static analysis in the same load conditions. The two obtained value are the same.

In this more complex structure the values for the absorbed energy should be greater then 1 MJ, for this reason the section should not be slender.

The optimal section have to be calibrated in order to favor the initiation of outwards bending of the lateral solebars and to active the plastic hinges in the notched section of the solebar at load level lesser of 3000 kN. But at the same time, the section have to maximize the energy absorption.

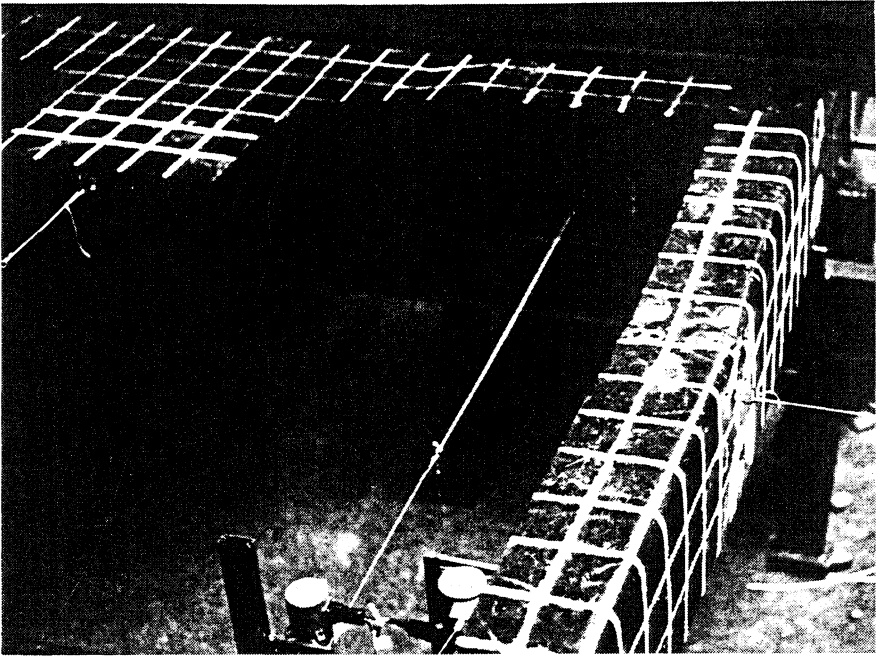


Figure 6: The underframe under investigation, mounted in the experimental device, is visible the lateral solebar.

## 5.2 Test

The underframe under investigation, mounted in the experimental device is shown in figure 6 and 7.

In figure 7 two resistive potentiometers for displacements measure are also visible. The displacement transducers has been applied on the anti-climb buffers and symmetrically at front end of the underframe and at the both ends of the solebars.

The buffer capsules and the calibrated bolts have not been included in the underframe tested. The first have been repeatedly tested and certified, at the same time the calibrated bolts were separately tested and the load of failure of the all bolts, for each buffer, was, as expected, 800 kN.

As far as the underframe is concerned, the load was initially applied through the anti-climber buffers until the honeycomb was totally crushed. At this point, the face of the buffers became co-planar with the front face of the underframe and the increasing load acting directly on the headstock caused, at first, the local instability of the upper plate of the headstock and then the collapse of the solebars

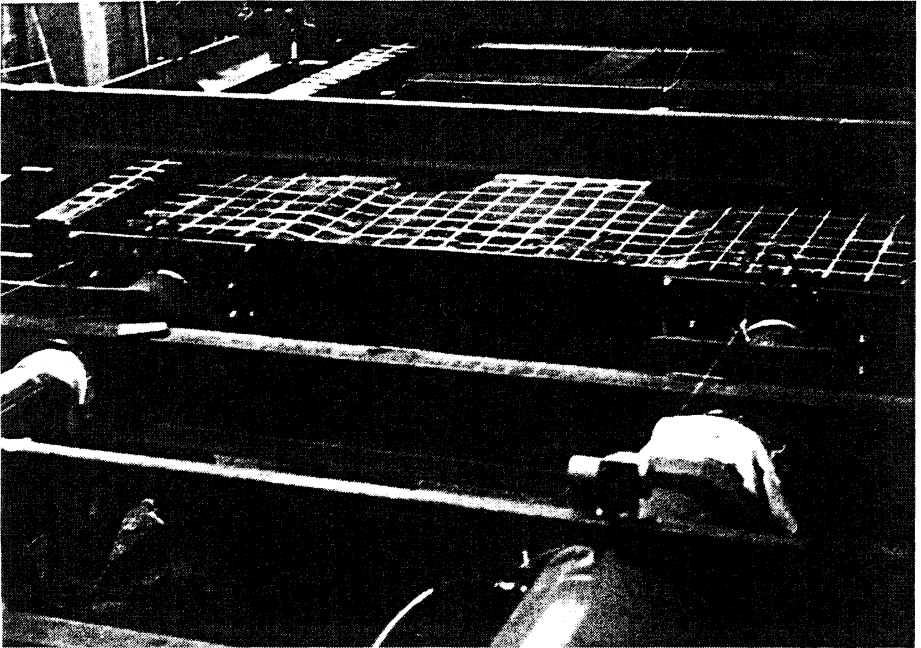


Figure 7: The underframe under investigation, mounted in the experimental device, is visible the headstock.

initiated.

As expected the crushing of two cushions of aluminium honeycomb took place a load level equal to 1600 kN.

After, the formation of the plastic hinge at section notched of the solebar took place.

When the load reaches to 3000 kN (maximum load for the passengers compartment) the maximum bending angle of the solebar has been about 20 degrees, the corresponding maximum crushing distance of the underframe about 450 mm.

The result of the test showed that the adopted typology of headstock behaves correctly and the reliability of the performed calculations of the behavior of the honeycomb cushions have been demonstrated.

Moreover, it can be stated that the collapse of the single elements occur in the designed sequence (buffers, calibrated bolts, honeycomb cushions, solebars).

The energy absorbed by each element of the such structure is also evaluated.

The collapse characteristics are given in table 1. The measured

load/displacement characteristic is shown in figure 8, where the design collapse characteristic is also shown.

The energy expected to be absorbed by the buffers is not included. Since they are made in steel, are characterized by high level of plastic deformation and high absorption of energy. But for the solebar the bending angle resulted too lesser and consequently the energy absorbed is lower then the expected value.

The evaluation of the solebar's behaviour have steered the research towards the refinement of their design, with the aim of inducing the formation of more plastic hinges, able to absorb the collisions energy.

## 6 Conclusion

The experiences and the tests reported in the paper are part of extensive research program about crashworthiness, carried out at Politecnico di Milano and Costaferroviaria Company.

The obtained results outline same important topics considered in the following.

The test on the simple structure let to point out the feasibility of the proposed collapse mechanism.

In the steps of the crash sequence of the complex structure, the levels of resistance of the single components have verified. As far as the certified elements are concerned (buffers and calibrated bolts), their behavior have been experimentally validated, as well as the correct sequence of collapse, the design of the headstock and the correct constrain of the honeycomb cushions.

|                        | collapse load [kN] | load requirement                | crushing distance [mm] | energy absorption [MJ] |
|------------------------|--------------------|---------------------------------|------------------------|------------------------|
| Buffers                | 640                | verified                        | 110                    | 0.2                    |
| Calibrated loads bolts | 800                | verified                        | —                      | —                      |
| Typology of headstock  | greater then 3000  | verified with local instability | —                      | —                      |
| Constrain of honeycomb | greater then 3000  | verified                        | —                      | —                      |
| Honeycomb cushions     | 800                | verified                        | 400                    | .640                   |
| Solebars               | 2500-3000          | verified                        | *                      | *                      |
| Passengers area        | greater then 3000  | verified                        | —                      | —                      |

Table 1: Collapse performance of components, (\*) This values have to be optimized by means of the next tests.

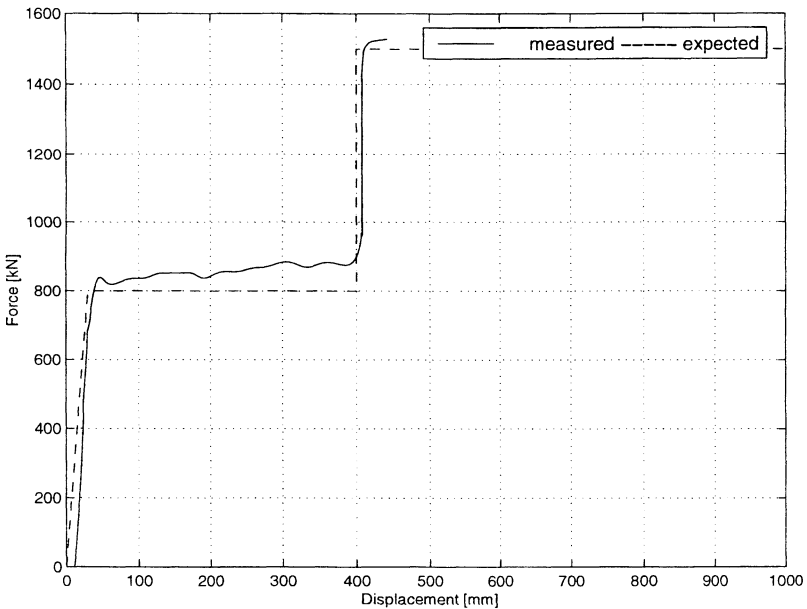


Figure 8: Measured load/displacement characteristic of cab's under-frame



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