NEW CONCEPTS AND MATERIALS FOR PASSIVE SAFETY OF MOTORCYCLISTS

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ABSTRACT

A new type of road safety barrier for motorcyclists, that can be added to existing devices, has been evaluated by means of a *multi-body* numerical method; the results are compared, in terms of main injury criteria, with simulations of motorcyclist impacts against conventional concrete and steel barriers.

The device consists of a lower rail which can *softly* absorb a motorcyclist impact, without interfering with car and truck collisions.

Input parameters for the model are derived from experimental testing and finite element analysis.

A cost/benefit analysis is eventually performed, to evaluate the real feasibility and convenience of the solution.

PASSIVE SAFETY OF MOTORCYCLISTS has often been neglected, possibly owing to the small proportion of motorcycles in the vehicle population. But during these last years the market of motorcycles expanded (nowadays the motorcyclists constitute the 13% of road-users in Europe and 50% in emerging Asiatic countries) and consequently motorcycle traffic and number of accidents has increased (Bothwell et al., 1971).

Table 1 shows the number of fatalities due to motorcyclist accidents in Germany and the percentage over the total number of fatalities as a consequence of road accidents. Studies performed in USA and UK show that the motorcyclists have probabilities respectively 13 and 20 times higher than car occupants to be involved in fatalities.

Table 1 - Fatalities in motorcyclists accidents in Germany (Domhan, 1987)

YEAR	1970	1974	1978	1982	1984
FATALITIES	857	951	1149	1453	1206
PERCENT	4.4	6.5	7.8	12.5	11.8

The typical motorcyclist accident implies the fall, the separation from the motorcycle and the impact against obstacles: according to data collected in

Germany, 15% of motorcyclists fatalities is due to impacts against a safety barrier after ejection from the vehicle (Koch et al., 1987), and 66% of motorcyclists impacting the barrier suffer very severe traumas, such as vertebral injuries, cerebral damages or limbs amputation (Chinn et al., 1984).

Therefore conventional safety barriers, vital for car and truck occupants, can be fatal for motorcycles, mainly because the posts are harmful owing to the material and shape of the impacting area.

In this paper, some improvements to the conventional barriers will be suggested, in order to limit the severity of the injuries due to motorcyclist impacts. Through a *multi-body* numerical approach, the consequences of these impacts against concrete barriers and two conventional metallic guard-rails are analysed first; the severity of the traumas are evaluated through the application of the modern injury criteria (Newman et al., 1991). Then a new protection is developed, aimed to reduce the severity of the injuries.

The protection consists in a lower rail made of compliant composite material, connected to the posts through suitable spacers, which can *softly* absorb the motorcyclist impacts. Such a protection could be simply added to the pre-existing barriers, without compromising its effectiveness towards both light and heavy vehicles.

Finally, a cost/benefit analysis is performed, to evaluate the real feasibility and convenience of the solution.

STATE-OF-THE-ART

The technical solutions suggested up-to-now (mainly in Germany and France) to improve the passive safety of the motorcyclists are modification to the existing conventional guard-rails, aimed to damp or avoid direct impact to the post. It is evident in fact that the post is the more dangerous element in case of impact between the ejected motorcyclist and the steel barrier. On the other hand the concrete barrier, even if it is very rigid, is not so harmful, because it offers a wider impact surface and allows the sliding of the motorcyclist along the surface. Notwithstanding, the new generation of metallic barriers possesses such high safety performances, for both heavy and light vehicles, that should be always preferred to the rigid barriers.

The solutions proposed till now are as follows (Jessi, 1986):

- replacement of the conventional posts with the so-called "Σ-posts", i.e. supports having a large thin-walled Σ cross section, with rounded edges, being more compliant and less harmful thanks to the larger impact surface;
- protection of the post with polystyrene-coated polyurethane dampers, which increases the impact surface and absorbs energy thanks to its deformation; they are not very effective for velocities higher than 50-60 km/h, do not endure the environmental agents and do not withstand the rodents attack; besides, their cost is very high and their installation has to be limited to the more dangerous stretches of road;
- addition of a lower "W-beam" steel rail, lighter and more flexible than the conventional upper one, able to distribute the energy of the impact over a wider surface.

This latter installation reduced both the number and severity of the accidents, because it works as a psychological deterrent as well, but, because the kinetic energy of a motorcyclist is nearly 10 times lower than a light vehicle, the rail should be extremely compliant. To make the rail more compliant, dimensions being equal, the thickness of the steel sheet should be reduced; but a minimum attainable thickness exists, owing to reasons of production, installation, maintenance and perforating corrosion.

Due to these limitations, a material intrinsically lighter must be used.

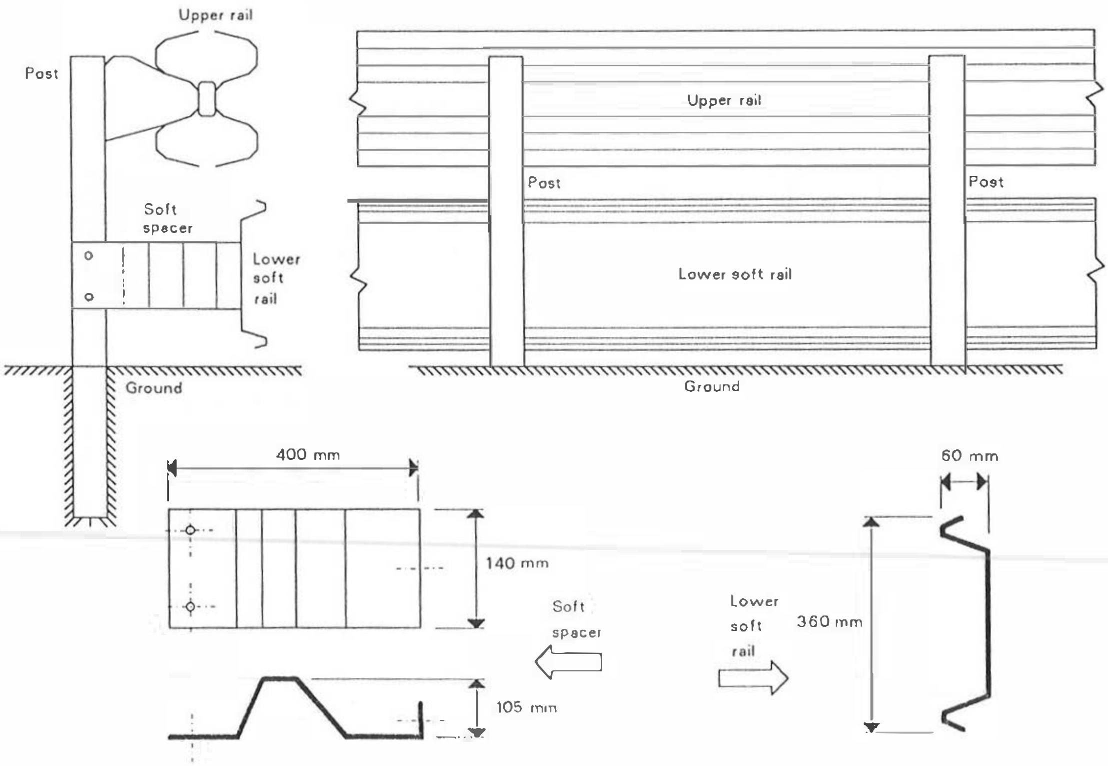
The aluminium alloys are affected by high costs and galvanic corrosion once put in contact with the main structure made of zinc plated steel sheet.

On the other hand, the composite materials are characterised by low elastic modulus (which - however - can be tailored), high damping coefficients and do not suffer corrosion; besides, (provided the adoption of low-cost fibres and resins, as well as high-production-rate technologies) they have affordable costs.

For these reasons, the new barrier solution proposed in the following consists in the addition to the conventional metallic guard-rail of a lower rail made of *pultruded* continuous glass fibres and polyester resin. Pultrusion is a relatively new technology of composite materials: continuous fibres are pulled from individual spools through a resin bath, combined and then pulled through a heated forming die, where curing takes place.

The rail must be bolted to the post through a deformable steel spacer (Astori, 1993) that absorbs the impact energy. The rail is more or less U shaped in such a way to capture the victim and reduce the risk he climbs over or under it.

Fig.1 - Metallic guard-rail, composite protection barrier set-up and general dimensions



In figure 1 a sketch of the metallic guard-rail + composite barrier assembly is showed, along with the cross sections of both the rail and the spacer and their general dimensions.

Figures 2 and 3 show the mechanical characteristics of the spacer and the pultruded rail, as a function respectively of the sheet thickness and width, as well as the laminate elastic modulus and thickness. The rail plot derives from a finite element analysis in the flexural elastic field; the spacer curves derive instead from an experimental testing and concern the complete elastic-plastic crushing of the specimen.

Fig.2 - Composite rail: curves of force vs. mid-span displacement

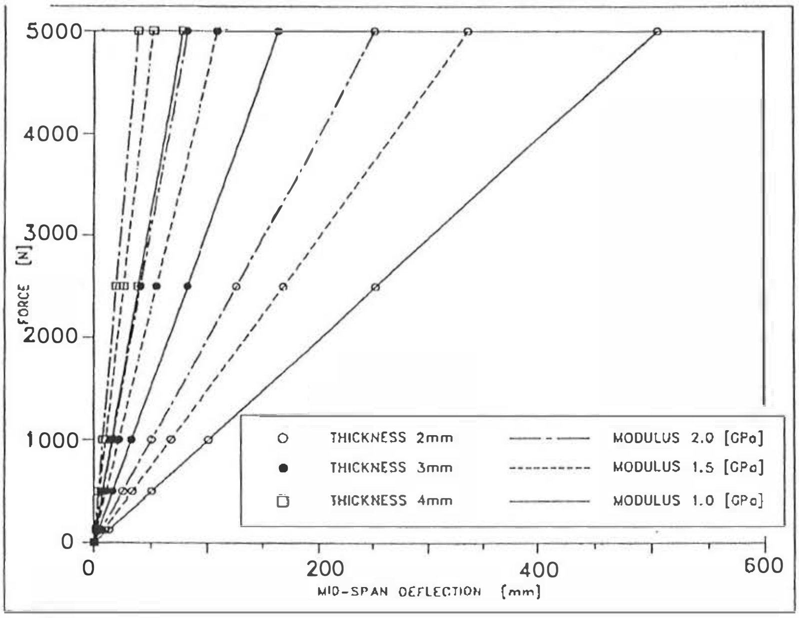
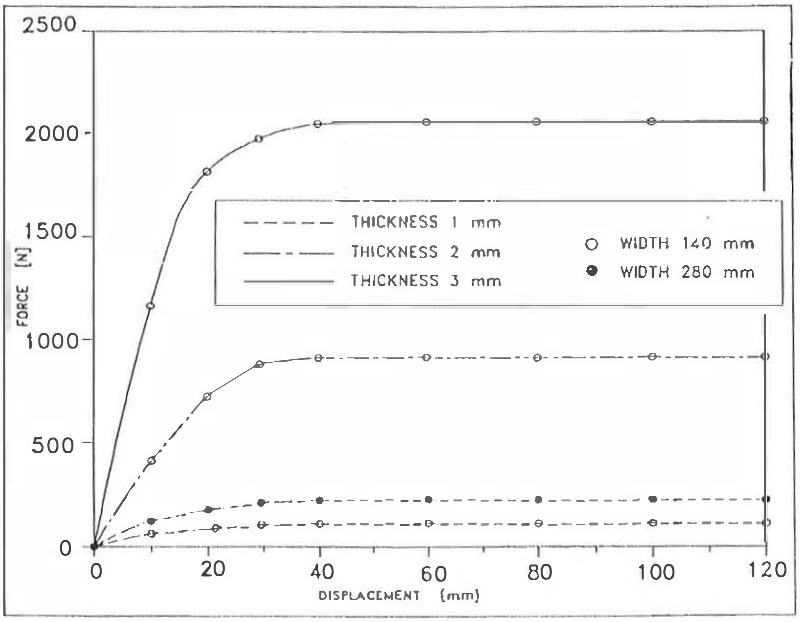


Fig.3 - Spacer: curves of force vs. displacement (compression test)



METHOD

At the initial stage of design, a numerical approach can be conveniently adopted, which allows to perform a cost-effective parametric analysis.

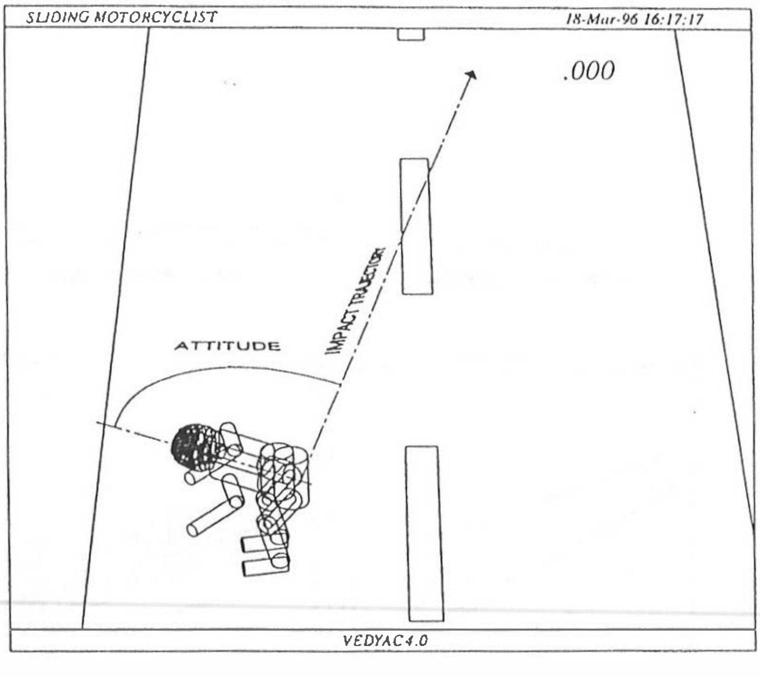
Both the *finite elements* and the *multi-body* approaches are based on the subdivision of the system into discrete elements, which - in the case of *multi-body* - are large and not very numerous; this implies simpler models and shorter computing times than a finite element approach, to the detriment of the geometry detail, not of the results accuracy.

Because in the present work the global dynamics of the accidents is going to be studied, which involves the computation of the forces and accelerations of just some meaningful parts of the human body, a *finite element* code should be too detailed and onerous; so, the *multi-body* code VEDYAC (VEhicle DYnamics And Crash) will be adopted (Giavotto et al., 1983). It was born at the Department of Aerospace Engineering in the 80's and, being very flexible in application, it has been used very extensively for more than 15 years to optimise the design of roadside barrier, including crash victim injury prediction and vehicle dynamics analysis.

THE MODELS

The biomechanical model, already existing and validated in VEDYAC database, represents a 50-percentile anthropometric test dummy HYBRID II (figure 4).

Fig.4: - The dummy model and the impact attitudes



It is composed of 13 rigid bodies: Head/Helmet, Neck, Chest, Abdomen, Pelvis, Arms, Forearms/Hands, Thighs, Legs/Feet. These rigid components are mutually connected by hinges reproducing the actual dummy articulations:

each hinge has rotational restraints, elastic and friction reactions taken from dummy data. The rigid bodies are associated to cylinders having contact properties close to the dummy response.

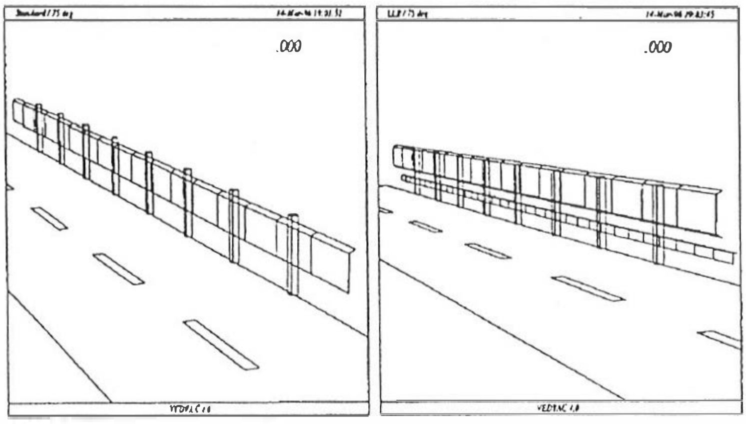
The model of the concrete barrier consists in a hard polyhedron fixed to ground (figure 5).

The model of the conventional simple guard-rail is made of rigid bodies representing the posts and the sequence of rail sections (figure 5). Each post is connected to the ground through a massless beam reproducing the flexural characteristics of the actual post constraint; it is also connected to one rail body by means of a massless beam simulating the spacer. The rail bodies are connected each other through massless beams having the elastic characteristics of the rail itself.

The model of the conventional guard-rail with lower rubbing rail (useful for wheels re-direction) is close to the previous one, but has a greater number of rigid bodies to represent the lower beam, following the same pattern used for the main upper rail (figure 5).

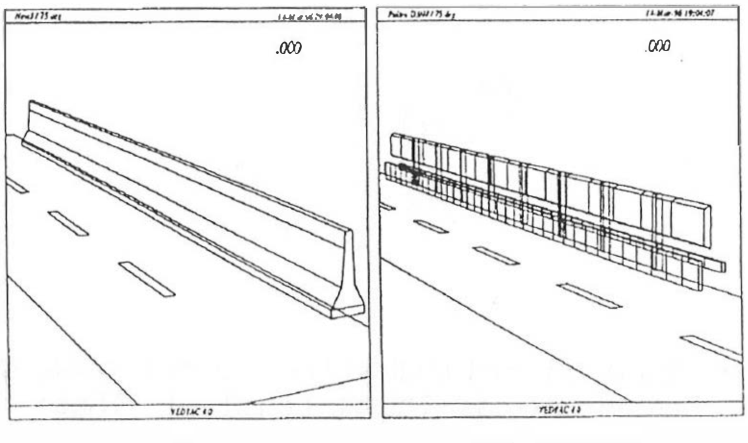
The model of the composite rail, to be added to the previous guard-rail barriers, is modelled as a sequence of rigid bodies joined together as well (figure 5).

Fig.5: - The models of the different types of barrier



STEEL - NO RUBBING RAIL

STEEL - RUBBING RAIL



CONCRETE

STEEL / COMPOSITE

THE INJURY RISK PARAMETERS

The simulations reported in the following concern the final history of the accident, that is the impact of the motorcyclist against the barrier, after he is ejected from the vehicle.

Reasonably, the worst attitude of the motorcyclist occurs when he is in contact with the pavement on his side, and slides backward until impacting the barrier with the back part of the body (figure 4). In this condition in fact the head and torso impact directly the barrier, since there is no protective action of the upper and lower extremities. No friction is here simulated, in order to avoid any chaotic motion of the victim, that will not be studied here.

The most severe injuries that can be generated are related to head, chest, abdomen and spinal cord (Glaister, 1979).

Head injuries are here evaluated through the *Head Injury Criterion* (HIC), by accepting HIC = 1000 s as the threshold for brain trauma.

Chest injuries are evaluated according to the *60 g's Criterion*, thanks to its simplicity.

The main abdomen injury criterion is based on acceleration as well, its maximum allowable value being equal to 130 g.

The spinal cord is divided into two sections of interest: the lumbar spine and the cervical spine. While for the lumbar section only a compressive limit is specified (6670 N) (USAAVSCOM, 1989), the injury criteria for the cervical spine are based on tension, compression, shear and bending moment (Shirazi et al, 1989, Yoganendan et al, 1991 and 1992): the tensile and the fore/aft shear load limits both assume the value of 1100 N (duration > 45 ms); the compressive limit is assumed to be 5700 N (Careme, 1990), while the bending limits are 190 Nm in flexion and 57 Nm in extension.

RESULTS

The model of the dummy was considered to slide along the pavement at a velocity of 15 m/s and to impact the barriers with a trajectory angle of 15°.

The dummy attitudes with respect to the impact trajectory were as follows (figure 4):

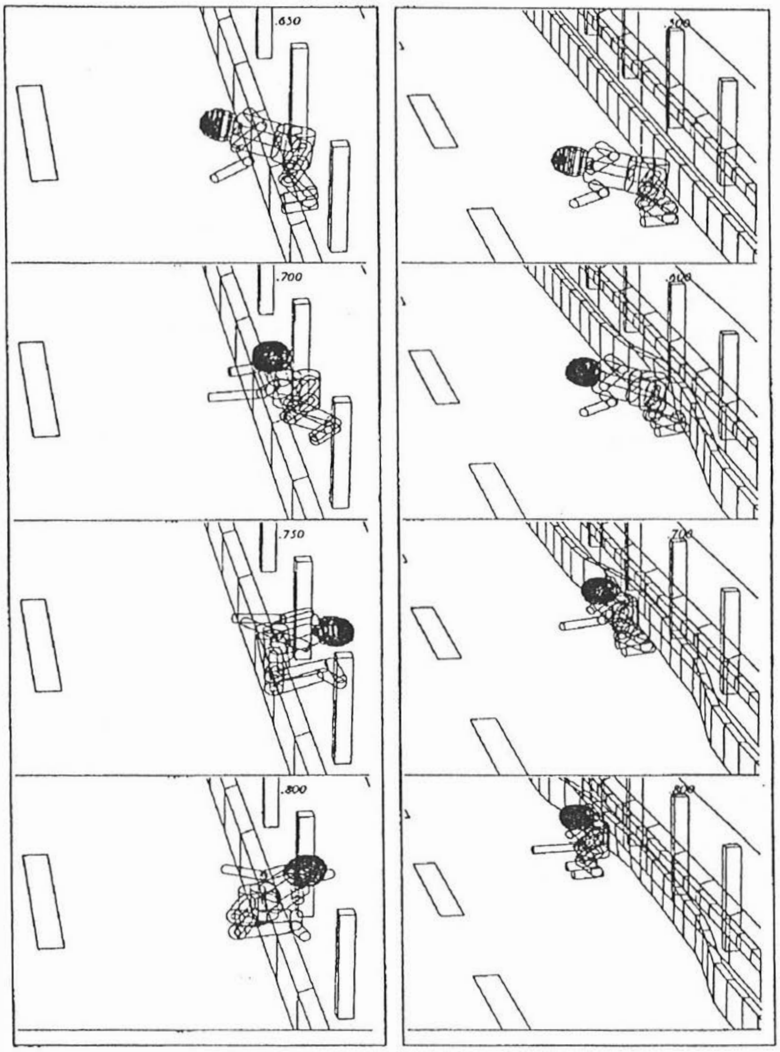
- 0°: head impact mainly;
- 15°: back parallel to barrier;
- 30°, 45°, 60°, 75° and 90°: bottom impact mainly.

The analyses of these impact conditions were performed considering the four above mentioned types of barrier.

For a best understanding of the impact biodynamics, figure 6 reports the sequences of the 75° attitude collisions with the conventional guard-rail and the pultruded protection.

The results of the 28 simulations are summarised in figures 7 to 16, where the values of each injury risk is reported vs. the 7 dummy attitudes, for the 4 different types of barrier; the injury threshold is plotted as well. Head acceleration is included as first plot.

Fig.6 - Collision against the conventional guard-rail and the new protection



STEEL- NO RUBBING RAIL

STEEL / COMPOSITE

Fig.7 - Head resultant acceleration

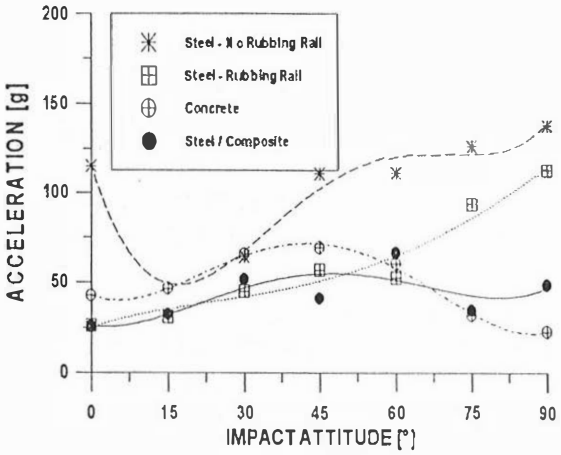


Fig.8 - HIC

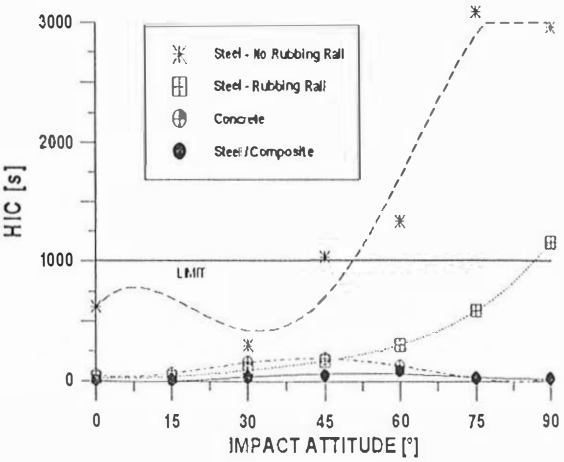


Fig.9 - Neck tensile load

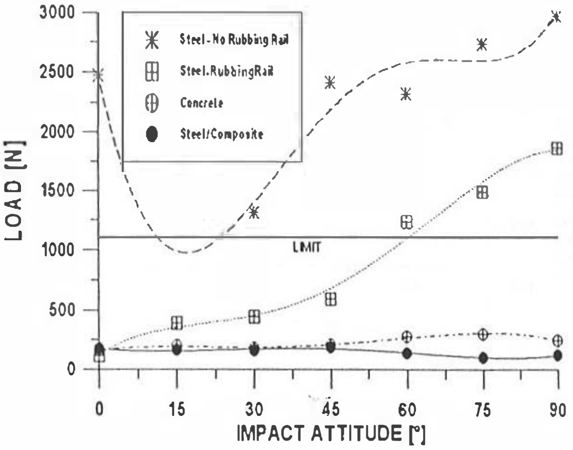


Fig.10 - Neck compressive load

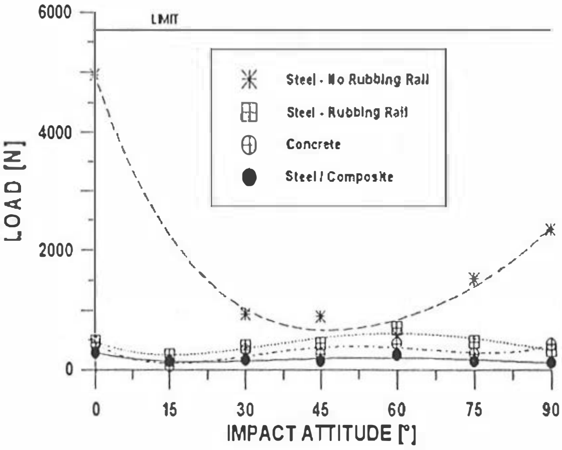


Fig.11 - Neck extension moment

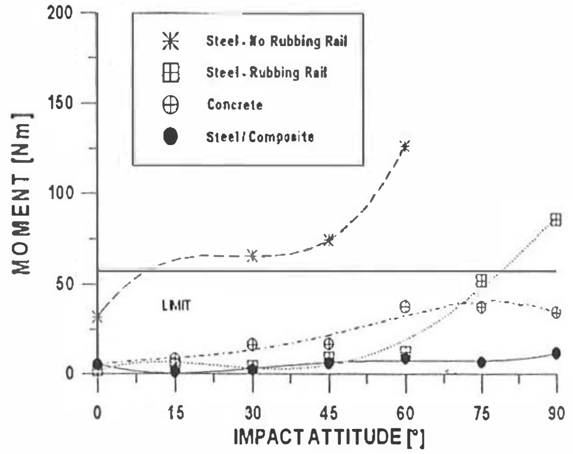


Fig.12 - Neck flexional moment

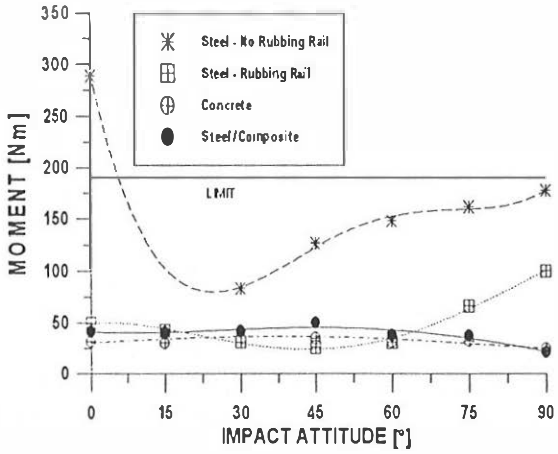


Fig.13 - Neck shear load

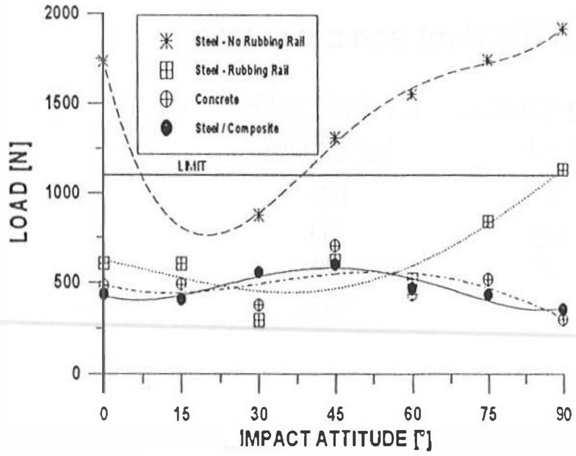


Fig.14 - Lumbar spine compressive

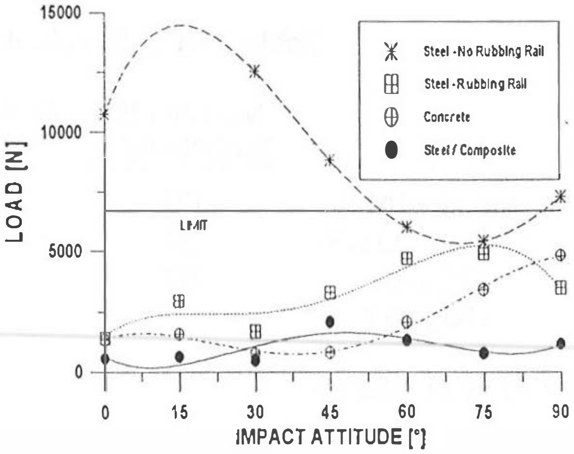


Fig.15 - Chest resultant acceleration

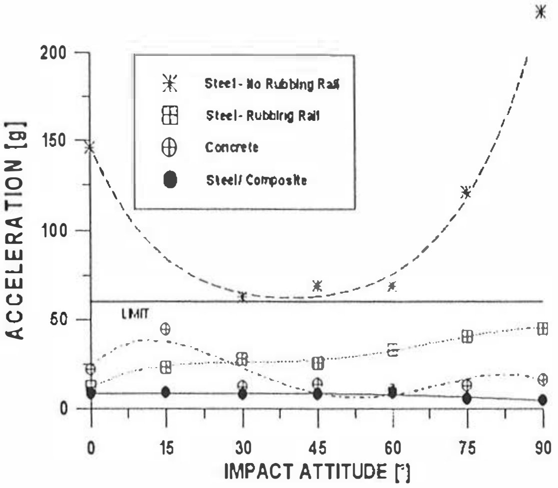
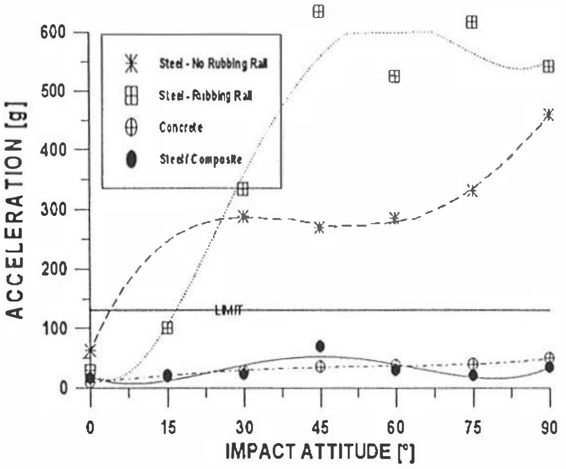


Fig.16 - Pelvis resultant acceleration



DISCUSSION

It is evident from the sequenced drawings and also confirmed by the curves, that the impact against a non-continuous barrier results in concentrated loads acting on the body of the motorcyclist, due to the direct interaction with the posts. This generates high flexion/extension movements of the body, as well as high decelerations and inertial loads, which, in some conditions, are well above the human tolerance limits.

Viceversa, the concrete barrier and mostly the compliant composite rail are the best solution for the motorcyclist protection. In fact, both the devices have a continuous surface that distributes the contact forces on a large body area and allows a sliding and soft redirection of the motorcyclist. In particular, the compliant composite rail barrier damps the impact thanks to the energy absorbing spacers and to the low flexural stiffness of the rail, so that the injury risk parameters are reduced to minimum values.

The economic feasibility and convenience of the proposed system appears from the figures reported in table 2.

Table 2 - Cost evaluation (ECU/m) and comparison

	METALLIC GUARD-RAIL	COMPOSITE RAIL	COMPLETE SYSTEM	RETROFIT
MATERIALS	60	8	68	68
INSTALLATION	20	20	20	40
TOTAL	80	28	88	108
OUTLAY	-	-	10%	35%

CONCLUSIONS

The impact between the ejected motorcyclist and the barrier, here studied by means of the *multi-body* code VEDYAC, can produce severe injuries, mainly in the case of impact against the post of a conventional metallic guard-rail without lower rubbing rail.

The development and the application of a new type of protection, made of a pultruded fibreglass composite rail, placed beneath the main metallic rail and connected to the posts through deformable steel spacers, gave encouraging results.

The global characteristics of both the rail and the spacers were determined in advance by means of experimental tests and detailed FEM analyses, to be successively used as input data for the *multi-body* dynamic analysis.

For many accident conditions, and according to different injury criteria, the solution so modified seems to be extremely more effective than the solution nowadays commonly adopted. Furthermore, this solution could be even more convenient in the case of high impact angles.

However, these results, obtained through numerical analyses, should be validated by means of full-scale experimental testing on dummies.

The feasibility and the cost/benefit analyses demonstrated that the outlay for the installation of the new protection is acceptable in case of addition to a pre-existing guard-rail, very profitable if they are installed at the same time.

However, the additional protection could be installed only where accidents are more likely to happen: so doing, it could provide a danger signal as well, inviting to drive with caution and contributing to reduce the number of accidents.

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