OPEN ACCESS
Journal of Integrated Engineering & Applied Sciences
Volume 2, Issue 2, pp. 80-91, 2024
ISSN: 2960-2661 DOI: https://doi.org/10.5281/zenodo.13999158
Received: 27.08.2024 / Revised: 24.10.2024 / Accepted: 27.10.2024

Dynamic Analysis of Road Guardrails: The Case of Albania

Mentor Çejku[*1], Parid Milo[*1], Vasil Koça[1,2], Anis Sulejmani[1], Leonard Çomeni[1], Odhisea Koça[1]

[1] Mechanical Department, Polytechnic University of Tirana, 1001 Tirana, Albania
[2] Inspecting and Certifying Department, Ergocert Hellas, Thessaloniki, Greece
* **Corresponding Authors**: mcejku@fim.edu.al; pmilo@fim.edu.al

Abstract

Guardrails play an essential role in enhancing road safety and are extensively utilized in roadway infrastructure. In our country, the high frequency of traffic accidents and resulting injuries highlight the critical need for comprehensive studies on protective barriers. This study analysis the standards for selecting these barriers, the theoretical basis for impact testing, and presents a specific case involving the design and installation of acoustic barriers along a newly constructed route, with attention to wind load impacts. Additionally, an inspection was conducted across approximately 3,062 kilometers of main roadways in the Republic of Albania.

Keywords: Barriers; accidents; impact; inspection; safety.

1. Introduction

Nowadays, guard rails are a safety measure on the road, designed to prevent severe injuries from accidents or vehicles losing control and tending to leave the roadway [1-3]. The primary purpose of this safety construction is to prevent vehicles from exiting the roadway, acting as a protective barrier [4-6]. Figure 1 depict an inspection services of the guardrail in randomly highway roads in Albania.

(a) (b)

Figure 1. (a) Deformed guardrail after an accident, (b) On-site inspection

Guardrails, also known as protective barriers, along with temporary barriers, are among the most widely utilized road safety measures globally. These barriers are critical to traffic regulation and play an essential role in enhancing roadway safety. Their effectiveness is amplified when used in conjunction with other safety measures, such as vertical and horizontal signage, substantially reducing the risk of severe accidents. Protective barriers are available in various forms, selected based on the specific requirements of the roadway section where they are installed. The most common models include double-wave profile guardrails, often paired with red or orange reflective panels to increase visibility. These are deployed along highways, interurban roads, and both mountainous and flat areas where their presence is indispensable.

Another widely used model is the triple-wave protective guardrail, which not only enhances safety but also incorporates noise reduction features. In the event of a collision, the guardrail is designed to absorb some of the impact energy, thereby reducing potential injuries to vehicle occupants. The role of the guardrail is dual: it prevents vehicles from leaving the roadway while also acting as a barrier against vehicles crossing into oncoming traffic. While guardrails are primarily designed for four-wheeled vehicles, increasing attention is being given to designs that ensure safety for two-wheeled vehicles as well.

Over the years, numerous countries across Europe and beyond have introduced legislation governing the design, approval, and installation of road guardrails. Many of these national regulations have been aligned with EU Directive 305/2011 [7], which standardizes conditions for the marketing of construction materials across EU member states. Albania, as an aspiring EU member, has adapted its road safety legislation accordingly. In July 2023, during discussions on transport chapters, Albania engaged successfully with the respective committees of the Council of Europe.

This research focuses on analyzing the standards for selecting protective barriers, the theoretical foundation for impact testing, and presents a specific case study on the design and installation of acoustic barriers along a newly constructed route, with a focus on the effects of wind load.

2. Parameters and Standards for Road Guardrails

Guardrails installed in European Union countries adhere to the UNI EN 1317 standard [8], which establishes a unified approach to road safety devices. This standard defines the methods for testing and certifying safety guardrails, with a focus on three key areas:

- Performance Requirements for Guardrails: These requirements set the criteria for testing safety barriers, including their effectiveness in mitigating accident consequences, controlling vehicle behavior upon impact, and reducing risks for both vehicles and pedestrians.
- Design Requirements for Guardrails: This section specifies the technical standards that each guardrail must meet during the design phase, covering aspects such as material strength, structural flexibility and rigidity, and interaction with vehicles during collisions.
- Testing Procedures for Guardrails: These procedures ensure that guardrails meet performance and design standards through various tests, including impact tests, stability tests, and durability assessments.

- Additionally, the UNI EN 1317 standard classifies safety barriers into several stability classes (N1, N2, H1, H2, and H3), each indicating the barrier's capability to halt a moving vehicle based on extensive impact testing results.

3. Impact Theory in Barrier Testing

The precise definition of the impact phenomenon in Technical Mechanics is: "An impact is the instantaneous change of the velocity vector", see Figure 2. The duration of this process is on the order of 10^{-4} seconds.

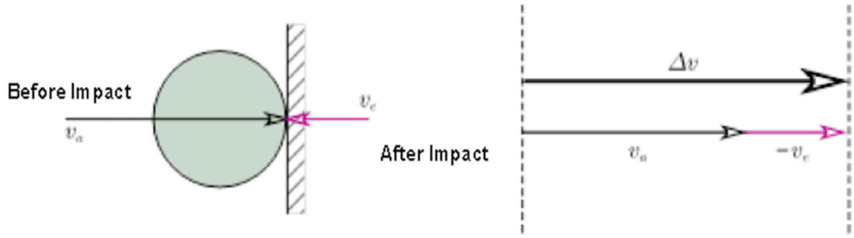


Figure 2. Velocity vector before and after impact, change in velocity.

In this context, we are dealing with very large forces, on the order of 10^{-4} times greater, see equation (1).

$$F = ma = m\frac{dv}{dt} \rightarrow Fdt = mdv \rightarrow m \cdot (v_1 - v_2) = F \cdot \Delta t \quad (1)$$

With $m \cdot \Delta v = finite\ quantity$ and $\Delta t = order\ of\ 10^{-4}$.

Impact hypotheses from the theory of impact in technical mechanics are shown as follows:

a. The duration of the impact, Δt, is so small that during this process, there is no change in the position of the bodies.
b. The forces that occur in the contact area of the bodies are on the order of 10,000 times greater, so all other forces are neglected (e.g., gravitational forces, spring forces, etc.).
c. In Mechanics, the deformations that occur during the impact are neglected, meaning that the bodies are considered quasi-rigid, while in material resistance, they are considered deformable.

Figure 3 depict a modelling accident that has been focused from mentioned impact theory.

Figure 3. An accident modelled by impact theory [9, 10].

The general case of an accident is an elastic-plastic impact. Figures 4 and 5 shown the dependence velocity and force in the impact process [11].

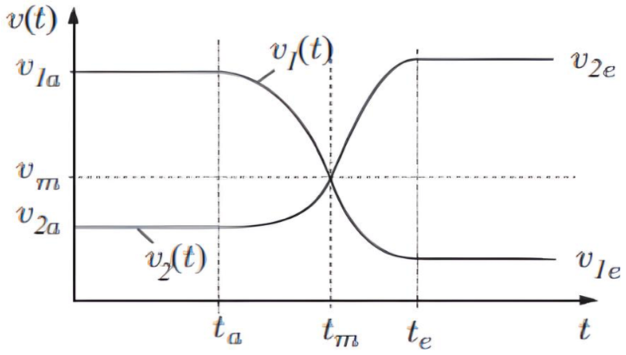


Figure 4. The dependence of velocities in the impact process.

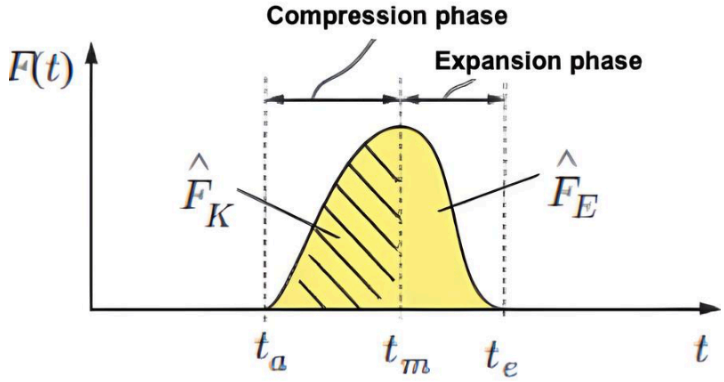


Figure 5. The dependence of force in the impact process.

Actions are performed through impulses by using equation (2) for compression impulse and equation (3) for impulse of expansion.

$$\hat{F}_K = \int_{t_a}^{t_m} F \cdot dt \quad (2)$$

$$\hat{F}_E = \int_{t_m}^{t_a} F \cdot dt \quad (3)$$

The equation of impact is in the form: $\hat{F}_E = \epsilon \cdot \hat{F}_K$ where $\epsilon \equiv$ impact coefficient. The impulse theorem for body 1 is evaluated through equation (4).

$$m_1 \cdot (v_m - v_{1a}) = -\int_{t_a}^{t_m} F \cdot dt = -\hat{F}_K \text{ and } m_1 \cdot (v_{1e} - v_m) = -\int_{t_m}^{t_e} F \cdot dt = -\hat{F}_E \quad (4)$$

The impulse theorem for body 2 is expressed by using equation (5).

$$m_2 \cdot (v_m - v_{2a}) = -\int_{t_a}^{t_m} F \cdot dt = \hat{F}_K \text{ and } m_2 \cdot (v_{2e} - v_m) = -\int_{t_m}^{t_e} F \cdot dt = \hat{F}_E \quad (5)$$

Furthermore, velocities after the elastic-plastic impact is calculated by using equation (6) and (7).

$$v_{2e} - v_{1e} = \frac{\epsilon \cdot (m_1 + m_2) \cdot (v_{1a} - v_{2a})}{m_1 + m_2} = \epsilon \cdot (v_{1a} - v_{2a}) \quad (6)$$

$$\epsilon = \frac{v_{2e} - v_{1e}}{v_{1a} - v_{2a}} \quad (7)$$

The total impulse of the impact is expressed by equation (8).

$$\hat{F} = \hat{F}_K + \hat{F}_E = (1+\epsilon) \cdot \frac{m_1 \cdot m_2}{m_1+m_2} \cdot (v_{1a} - v_{2a}) \quad (8)$$

An energy loss is calculated by equation (9),

$$\Delta E_k = E_{ka} - E_{ke} = \Delta E_k = \frac{1-\epsilon^2}{2} \cdot \frac{m_1 \cdot m_2}{m_1+m_2} \cdot (v_{1a} - v_{2a})^2 \quad (9)$$

Table 1 depict the coefficients impact in the interaction of different materials [12].

Table 1. The coefficients impact in the interaction of different materials.

Material couple	**Impact coefficient ϵ**
Wood/ Wood	≈ 0.5
Steel/Steel	$0.6 \div 0.8$
Glass/Glass	0.94
Cork/ Cork	$0.5 \div 0.6$

4. Acoustic Panels in Road Guardrails

Acoustic panels installed on road guardrails effectively absorb noise generated by vehicular traffic, particularly in high-traffic areas near residential zones, as illustrated in Figures 6 and 7. While not fully eliminating noise, these panels generally achieve a reduction in overall noise levels of approximately 10-15 dB. Panel dimensions typically include widths up to 500 mm and lengths ranging from 2000 mm to 4000 mm.

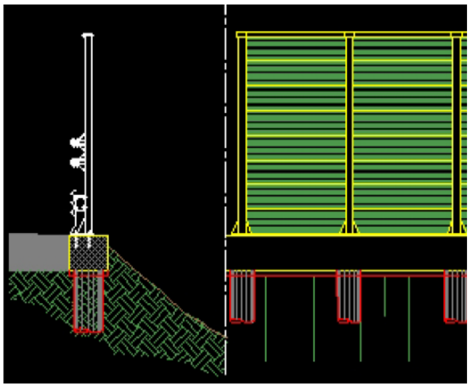


Figure 6. Acoustic panel in road guardrails.

Figure 7. Acoustic panel mounted on safety guardrails.

The study focuses on the new road construction from "Thumanë" to "Kashar," a coastal flatland area, see Figure 8. The project involves approximately 5,690 meters (both directions) of acoustic panels mounted on barriers, with heights of 3 and 5 meters, see Figures 9 and 10. Placement of these panels has been analysed to mitigate noise impact from traffic on the new highway, addressing both large residential areas and individual homes. The design speed will be informed by statistics (2012-2022) and manual guidelines for maximum loads, with a calculated wind speed of 30 m/s for this study.

Figure 8. The road section under study. (Google map).

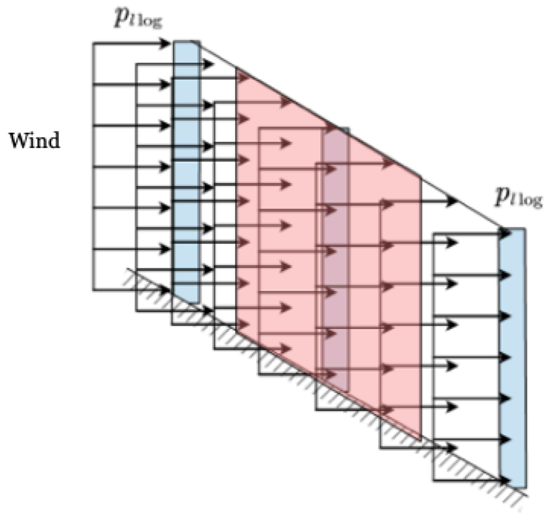


Figure 9. Wind load distributed on the panel.

From equations (10), (11) and (12), we have calculated the normalized wind pressure and maximum stress

The normalized wind pressure $\rho_{air} = 1.25\frac{kg}{m^3}, p_n = \frac{\rho_{air} \cdot v_{cal}{}^2}{2} = 562.5Pa$ (10)

The calculated wind pressure on the barrier $p_{ll} = 1.2 \cdot p_n \cdot 2 = 1350Pa$

Load per unit length on the column for width. $t = 4m$ so, $q_{col} = t \cdot 1 \cdot p_{ll} = 5400\frac{N}{m}$

First case, $h = 5m$, material S275, $Re = 275\frac{N}{mm^2}, Re_H = 280\frac{N}{mm^2}, S_M = 1.1$

The maximum stress has been calculated through equation (11).

$$[\sigma] = \frac{Re_H}{S_M} = 2.545 * 10^8 Pa \quad (11)$$

Maximum bending moment $M_{max} = \frac{q_{col} \cdot h^2}{2} = 67500\ N \cdot m$ (12)

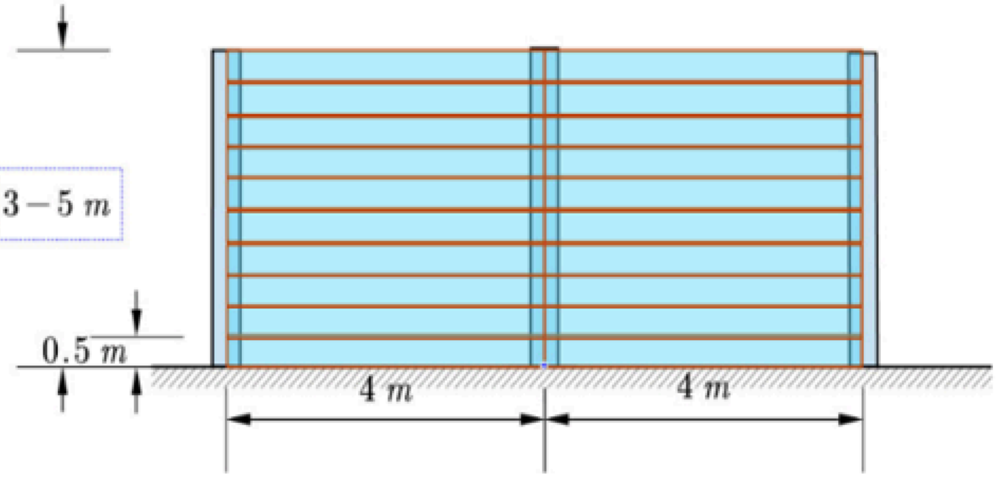


Figure 10. Acoustic panel with height of 3 and 5 meters.

Equation (13) has been used for calculation of the section modulus and afterward we have taken from standard DIN 1025-1 [12] all the parameters for finding the maximum bending moment.

Section modulus $W_x = \frac{M_{max}}{[\sigma]} = 265.179 cm^3$ (13)

From the standard we choose the *I 220* profile.

In case two, $h = 3m$, material S275, $Re = 275 \frac{N}{mm^2}$, $Re_H = 280 \frac{N}{mm^2}$, $S_M = 1.1$, $[\sigma] = \frac{Re_H}{S_M} = 2.545 \cdot 10^8 Pa$

Maximum bending moment $M_{max} = \frac{q_{col} \cdot h^2}{2} = 24300 N \cdot m$

Section modulus $W_x = \frac{M_{max}}{[\sigma]} = 95.464 cm^3$

From the standard we choose the *I 60* profile.

- *I 140* Profile is calculated,

  $W_x = 81.9 cm^3$

  $\sigma_{real} = \frac{M_{max}}{W_x} = 296.703 \cdot 10^6 \frac{N}{m^2}$

  $\frac{\sigma_{real} - [\sigma]}{[\sigma]} \cdot 100 = 16.562\% > 5\%$

In the end we choose:

a. For columns of height 5m, *I 220 profile***.**

b. For columns of height 3m, *I 60 profile***.**

5. General Inspection of Road Guardrails

In this research, inspections were carried out across nearly the entire territory of Albania, covering 3,062 km to assess and enhance the primary effectiveness of road safety measures. Observations revealed several critical issues which are as follows:

Unrepaired Damages: A significant concern identified is the presence of unrepaired damage along various road sections, see Figure 11. Many barriers damaged in past accidents have not been replaced or repaired, compromising their ability to withstand future impacts and posing increased risks for road safety.

Figure 11. Field inspection of damaged road guardrails.

Among the various issues observed, there is a lack of mounting elements and inaccuracies in installation, see Figure 12. The inspection revealed that in most cases, mounting elements for the barriers are missing, such as bolts, damping elements, and connecting components, which have been absent since the installation phase. Another issue is the inaccuracies in their installation, including the use of different types of bolts than required, the placement of vertical columns on unstable ground, the positioning of columns detached from the ground, and inadequate securing of the panels to the columns.

Figure 12. Lack of mounting elements and inaccuracies installation

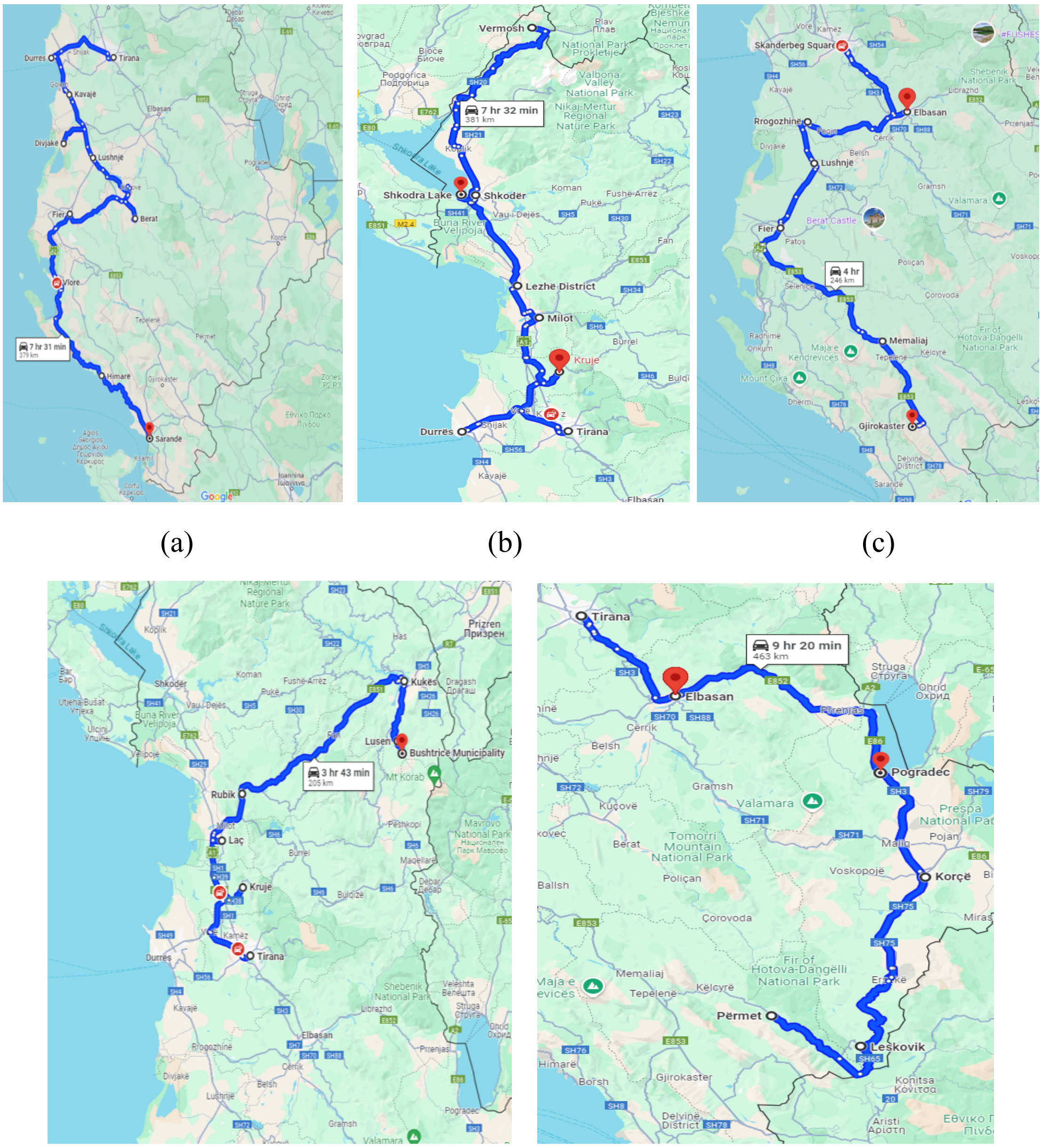
Use of welding in guardrails: Welding is not a permissible method for joining components in barriers, as it lacks the durability required to withstand impacts from vehicle collisions with the barriers, see Figure 13. This joining method should be categorically avoided, yet observations indicate that welding is frequently used in barrier construction.

Figure 13. Use of welding in road guardrails.

A recognized issue is the improper placement of the end elements of barriers as can be seen in Figure 14. These end elements are often not implemented according to established standards, which can lead to increased accident risk. They should not protrude or create significant impact forces during collisions, as demonstrated in the examples provided. To enhance safety, it is recommended that these end elements be designed to be more forgiving and that impact-absorbing features, such as fluid buffers, be installed

Figure 14. Ending elements of road guardrails.

The study examined approximately 3,062 km of roads across various categories, including highways, interurban routes, urban streets, and local roads. Several specific routes where these investigations were conducted have been documented. Figure 15 depict some journey routs that we have done in this research work.



(a) (b) (c)

(d) (e)

Figure 15. Inspection journey routes in Albania. (a) Southwest, (b) Northwest (c) South (d) North-eastern (e) Southeast. (Google map).

6. Summary and Conclusion

In this research, we analyzed the current condition of road guardrails in Albania. For the acoustics road guardrails is calculated 5m the height of column for I 220 profile and 3m for I 60 profile. Based on our findings, we recommend that private companies responsible for maintaining these barriers establish a close partnership with law enforcement to stay informed about accidents and hazardous locations. Regular inspections of the barriers should be conducted, with prompt reconstruction of any damaged sections. Key recommendations include:

- Installation of buffers at the beginning and end of the barriers.
- Recalculation and reconstruction of damaged components [13].
- Replacement of damaged barriers to ensure safety and functionality.
- Addressing the issue of the shoulder where vertical posts of the barriers are installed. The shoulder's integrity and dimensions are often inadequate, and the underground foundation lacks sufficient solidity.
- Adaptation of barriers to the specific conditions of the roads in our country, ensuring that standards are tailored to local requirements. Different types of roads necessitate different types of barriers.
- Conducting laboratory tests with various vehicles of differing heights and weights, including assessments for two-wheeled vehicles.
- Assembling all missing elements in accordance with the original design specifications.
- Avoiding the use of welding as a method of connection; instead, connections should be made using bolts or other appropriate fastening methods.

Acknowledgement

Authors gratefully acknowledge the Albanian National Agency for Scientific Research and Innovation (NASRI) which supports financially our research project.

Conflict of Interests

The authors would like to confirm that there is no conflict of interests associated with this publication.

References

[1] Khanum H., Garg A., Faheem I. Accident severity prediction modeling for road safety using random forest algorithm: An analysis of Indian highways. F1000research, 2023; 12; 494.

[2] Shala K., & Dorri A. Identification of the Accidents Causes and their Engineering Analysis: The Case of Albania. *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2021; 4(2); 706–715.

[3] Musa M., Hassan S., & Mashros N. The impact of roadway conditions towards accident severity on federal roads in Malaysia. *PloS ONE*, 2020; 15(7); e0235564.

[4] Shala K., & Dorri A. Analysis of the motor vehicle fleet as a way to reduce air pollution in the Republic of Kosovo. *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2021; 4(2); 685–690.

[5] Siswanto J., Syaban A.S.N., Hariani H. Artificial intelligence in road traffic accident prediction. *Jambura Journal of Informatics*, 2023; 5(2); 77-90.

[6] Vu T.M. Automatic Control of Clutch Engagement and Slip for Hybrid Vehicle. *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2019; 2(1); 49–61.

[7] EU Directive 305/2011. Regulation (EU) No 305/2011 of the European Parliament. Available at https://eur-lex.europa.eu/legal-

content/EN/TXT/?uri=celex%3A32011R0305. Accessed on 15 July 2024.

[8] UNI EN 1317: 2010. Road restraint systems - part 1: terminology and general criteria for test methods. European Union.

[9] Shealy J.E. Impact of Theory of Accident Causation on Intervention Strategies. Proceedings of the Human Factors Society Annual Meeting, 1979; 23(1); 225-229.

[10] Yang S.X., Haugen S. Implications from major accident causation theories to activity-related risk analysis. *Safety Science*, 2018; 101; 121-134.

[11] Voinea R.P., Stroe I.V., Predoi M.V. Technical Mechanics. 2nd edition book. 2010; Bucharest, Romania.

[12] DIN 1025-1: 2009. Hot rolled I-sections - Part 1: Narrow flange I-sections, I-series - Dimensions, masses, sectional properties. Germany.

[13] Dhoska, K., Sakaj, E., & Moezzi, R. Enhancement of Road Construction by Using Recycled Tire Rubber Modified Bitumen. *Journal of Transactions in Systems Engineering*, 2023; 1(1); 1–9.

Cite this article as: Cejku, M., Milo P., Koca, V., Sulejmani A., Comeni L., Koca O. Dynamic Analysis of Road Guardrails: The Case of Albania, *Journal of Integrated Engineering and Applied Sciences*. 2024; 2(2); 80-91.