GERBER: Software tool for **G**erber **E**nd **R**esistance evaluation **B**ased on **E**ngineered **R**egression

Assessment, Strengthening, and AI-Based Prediction Models for Gerber Saddles in Reinforced Concrete Bridges

Gerber saddles represent critical components for the structural safety of reinforced concrete bridges, as they are typically affected by localized degradation phenomena and stress concentrations that may compromise their structural integrity, potentially leading, in the worst cases, to the collapse of the entire structure. These vulnerabilities are also highlighted in the Italian Guidelines for the classification and management of risk, structural safety assessment, and monitoring of existing bridges[1].

This research—developed in detail within a doctoral dissertation titled "Modeling, analysis, and optimization of strengthening techniques for improving structural safety and resilience of reinforced concrete bridges with Gerber saddles"[2]—aims to investigate the structural behavior of Gerber saddles and to examine the available strengthening techniques, with the objective of proposing optimized strategies that account for structural, practical, and economic considerations, ultimately enhancing infrastructure safety and resilience.

The study was conducted following a multi-phase methodological approach. First, a comprehensive state-of-the-art review identified the main vulnerabilities of Gerber saddles, outlining their typical construction details, characteristic failure mechanisms, and the principal analytical methods available for their assessment. Subsequently, the development and detailed evaluation of an experimental database—compiled from existing literature—allowed the identification of the most recurrent failure modes, also in relation to specific construction details.

Based on these results, an in-depth analysis of strengthening techniques led to the formulation of a logical decision framework for selecting optimal intervention strategies, considering both structural performance and practical constraints related to on-site implementation and the impact on bridge operability. Particular attention was devoted to the technique based on external post-tensioning, which proved to be structurally effective, cost-efficient, and minimally invasive. Through nonlinear numerical analyses, a design procedure for this intervention was developed, enabling the optimization of external post-tensioning application and providing guidance on the expected enhancement in structural performance as a function of the applied prestress levels in the external tendons.

Finally, by employing Artificial Intelligence techniques—specifically supervised Machine Learning algorithms—a predictive model of the load-carrying capacity of Gerber saddles was developed using the data collected in the experimental database. The final model was selected following a systematic comparison of multiple supervised regression algorithms (including Random Forest and Gaussian Process Regression), evaluated through appropriate validation procedures and accuracy metrics (Table 1). The trained regression model is integrated into a user-friendly graphical software tool named "GERBER" (Gerber End Resistance Based on Engineered Regression), developed in this research by implementing

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[1]Ministry of Infrastructure and Transport. (2020). Guidelines for the classification and management of risk, structural safety assessment, and monitoring of existing bridges. Superior Council of Public Works.

[2] Picciano, V. (2025). Modeling, analysis, and optimization of reinforcement techniques for improving structural safety and resilience of reinforced concrete bridges with Gerber saddles [Unpublished doctoral dissertation]. University of Basilicata.

several Python scripts and using the Tkinter library for GUI construction. The application allows users to input the main geometric and mechanical parameters of the saddle and instantly returns the predicted load-carrying capacity (Figure 1), thereby supporting rapid preliminary safety assessments. It is, however, essential to emphasize that the computed strength value must always be accompanied by additional checks using simplified analytical methods and by the judgment of qualified engineers, in order to ensure reliable and well-informed evaluations.

The innovative nature of this procedure lies in its ability to simplify and accelerate the assessment process for Gerber saddles, reducing the need for complex numerical simulations during the initial phases and providing infrastructure managers with an immediately applicable operational tool to support decision-making regarding maintenance and strengthening of existing bridges. The research therefore offers a detailed overview of the mechanical behavior of Gerber saddles, as well as practical engineering tools, paving the way for further investigations into the effects of different degradation scenarios on saddle performance, the use of alternative post-tensioning-based strengthening configurations, and additional advanced applications of Artificial Intelligence in structural engineering.

Table 1 – Performance metrics of the trained regression algorithms.

Model	**Mean R^2**	**Mean RMSE**	**Mean MAE**
Random Forest	0.938	56.86	34.10
GPR (Rational Quadratic)	0.936	57.01	31.96
Decision Tree	0.915	65.38	40.98
KNN	0.870	82.19	50.33
Linear Regression	0.864	84.65	56.36
Mean R^2 (coefficient of determination): quantifies the goodness-of-fit of the model to the data. Values closer to 1 indicate a better fit.			
Mean RMSE (Root Mean Square Error): quantifies the average quadratic error. Lower values indicate better model performance.			
Mean MAE (Mean Absolute Error): quantifies the average absolute error. Lower values indicate better model performance.			

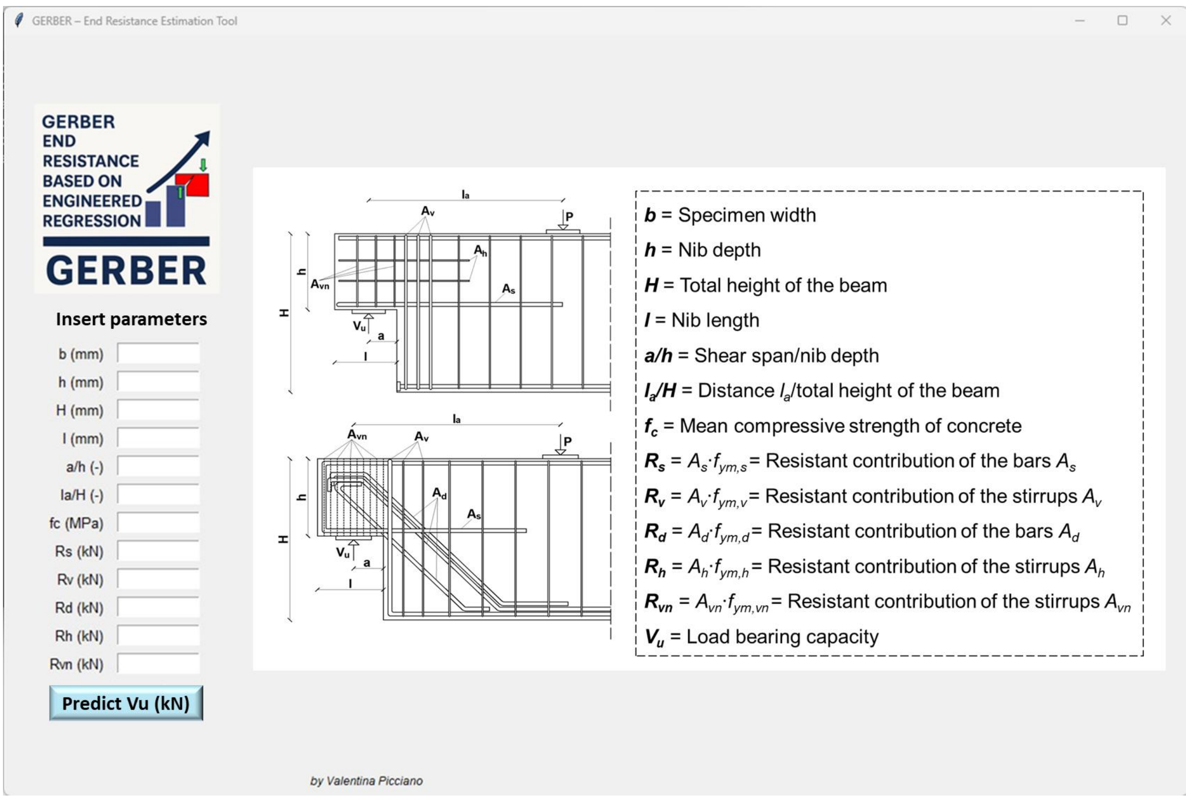

Figure 1 – Graphical user interface of the “GERBER” application.