New Empirical Equation for Fundamental Time Period of RC Moment Resisting Frame Buildings using Machine Learning Algorithms

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**Abstract**

The fundamental time period of reinforced concrete (RC) buildings is a critical parameter in structural engineering, influencing their dynamic behaviour and response to seismic and wind loads. This study aims to propose a new empirical formula for estimating the fundamental time period of RC buildings through regression analysis. Leveraging the SAP2000 API with VBA code, a dataset comprising 200 two-dimensional RC building models was rapidly generated, allowing for efficient exploration of various building configurations.

Modal analysis was conducted for each model to determine the fundamental time period, and regression analysis was performed using both multiple linear regression and curve estimation regression techniques. The input parameters included total building height and base dimensions, while the output variable was the fundamental time period obtained from SAP2000 results. Multiple linear regression yielded two best-fit models, while curve estimation regression produced logarithmic and exponential models.

The proposed models were compared with the fundamental time period values obtained from SAP2000 results and those calculated using the formula specified in the Indian Standards (IS) code. Further the results obtained are used to develop a machine learning model that can be used to estimate the time period of RC structures for a given height. The model is chosen after the estimating the coefficient of regression for various individual machine learning algorithms and ensemble algorithms.

This research contributes to the advancement of structural engineering by providing a systematic approach to developing empirical formulas tailored to RC buildings. The proposed formula, enabled by the automation capabilities of the SAP2000 API, offers a more accurate and reliable method for estimating the fundamental time period, facilitating improved seismic design and analysis practices. Further validation and verification of the formula’s performance using additional datasets and real-world case studies are recommended to enhance its applicability and robustness.

**Keywords:** Fundamental time period, seismic performance, empirical formulae, prediction improvement.

**1. Introduction**

The fundamental time period of a structure is a key parameter in seismic design and analysis. It defines the dynamic behaviour of buildings, especially reinforced concrete (RC) moment-resisting frames (MRF), under seismic and wind loads. Accurate estimation of this parameter is crucial for developing safe and resilient buildings, as it directly influences the building’s response to external forces, particularly in earthquake-prone regions.

Traditionally, empirical formulas such as those found in the Indian Standards (IS) code have been used to estimate the fundamental time period. These formulas are simple and convenient for general applications but often fail to capture the complexities of modern building designs. For instance, variations in building height, base dimensions, material properties, and structural irregularities may significantly affect the dynamic behaviour of buildings, leading to discrepancies between actual and predicted fundamental time periods. Therefore, more accurate and adaptable methods are needed to account for these factors.

In this study, we propose a novel approach to estimating the fundamental time period of RC MRF buildings using machine learning (ML) techniques. By leveraging the SAP2000 API and automating the generation of 200 building models with varying configurations, we perform detailed modal analyses to obtain accurate time periods. Using machine learning algorithms, including linear regression and decision trees, we develop predictive models based on the building geometry and compare them with the existing IS code formulas.

This research aims to provide a more accurate and reliable method for predicting the fundamental time period of RC buildings, offering an alternative to traditional empirical formulas. The automation capabilities of the SAP2000 API and the predictive power of machine learning pave the way for enhanced seismic design practices, ultimately contributing to the safety and resilience of buildings.

The fundamental time period of reinforced concrete (RC) buildings has been extensively studied over the years due to its importance in seismic design and structural performance. Various empirical formulas have been developed and incorporated into national and international codes, including the Indian Standard (IS) 1893 (Part 1):2016, which provides simplified equations based primarily on building height. However, these traditional approaches have shown limitations in accommodating modern building configurations, such as irregular structures, and often fail to capture the impact of key structural parameters like base dimensions, material properties, and stiffness irregularities.

Banik et al. [1] in 2022 highlighted the influence of mass, stiffness, and strength distribution on the fundamental period of multi-storey RC frames. Their work employed multiple linear regression to develop a predictive model based on 360 building models, with results indicating that factors such as bay width and the number of bays could lead to significant variations in the fundamental time period. Although this model offered improvements over traditional IS code formulas, it still relied on linear relationships and did not account for more complex building geometries. **Kewate et al. [2] in 2021** analysed 21 RC moment-resisting frame buildings in India using both finite element methods and empirical formulas. They identified significant discrepancies between the analytical results and those obtained from the IS code. Kewate proposed a modified empirical formula *T* = 0.132*h0.795*, which provided a better fit for the studied structures. However, they acknowledged that the proposed formula needed further validation and could not account for complex structural configurations such as irregular building geometries.

**Goel and Chopra [3] in 2019** refined empirical formulas for the fundamental vibration period of RC buildings based on recorded data from earthquakes like the 1971 San Fernando and the 1984 Morgan Hill earthquakes. Their findings demonstrated that the code-based formulas tended to underestimate the fundamental time period for taller buildings, particularly those over 160 feet. They emphasized the need for updated empirical formulas that better reflect the relationship between building height and period across a broader range of structures. The introduction of machine learning (ML) techniques into structural engineering has opened new avenues for improving the accuracy of time period predictions. **Dehghan et al. [4] in the year 2023** explored the application of ML algorithms, such as decision trees and random forests, to predict the fundamental time period of RC buildings. Their results demonstrated that ML-based models significantly outperformed traditional regression methods, particularly when handling large datasets with diverse building configurations. ML techniques were able to capture non-linear relationships between structural parameters and the fundamental time period, offering a more accurate and versatile solution.

Despite the advances made using regression analysis and empirical methods, these approaches still face challenges in accommodating irregular structures or accurately predicting the time period for buildings with infill walls, as shown by **Ranaweera [5] in year 2020**. His study utilized ambient vibration techniques and SAP2000 modelling to estimate fundamental time periods. The comparison between empirical formulas and experimental results revealed the limitations of traditional methods, which often underestimate the impact of structural irregularities. Khaleeluddin [6] in 2021 proposed a modified formula for setback buildings with infill walls, introducing a coefficient dependent on the aspect ratio of the building. His findings underscored the importance of considering non-structural elements like infill walls in time period estimation, further supporting the need for improved models that can integrate more variables than just height.

**P. D. Velani** [7, 8] conducted a detailed study on the seismic behaviour of RC shear wall (SW) buildings in India. The study highlighted the challenges of estimating the fundamental natural period (T) for tall buildings due to modelling complexities, such as the presence of unreinforced masonry (URM) infill walls. Through regression analysis, Velani proposed an empirical equation, *T* = 0.11*h1.1*, specifically for RC SW buildings. This equation accounted for the relationship between building height and the fundamental period, ensuring more accurate estimates compared to existing over-conservative formulas for tall buildings. Velani further emphasized the need for regularly revising these empirical formulas to keep pace with evolving building practices and seismic data. **Janaka Kumara Ranaweera** explored the complexities involved in determining the fundamental period of buildings [5], focusing on factors such as structural regularity, height, member sections, and infill panel properties. Ranaweera employed the Horizontal-to-Vertical Spectral Ratio (HVSR) method to estimate fundamental periods using ambient vibration data from 17 structures of varying characteristics [5]. The study compared empirical formulas provided by seismic design codes with experimental and numerical results, showing that the inclusion of infill walls in RC frames yielded more accurate fundamental period estimates. The study also suggested that further data from taller buildings would be necessary for comprehensive validation of the empirical formulas.

Lagomarsino [9] conducted a study on 185 buildings in Italy, of which 52 were reinforced concrete (RC) structures. The research proposed the equation *T* = *h*/55 for RC buildings and found no significant correlation between the natural period and the direction of vibration. Similarly, a team of Japanese researchers developed a comprehensive database of 205 buildings collected from various institutions across Japan [10]. Their study aimed to establish empirical expressions for the first mode, torsion mode, and damping characteristics of these structures, resulting in the proposed equation *T* = *h*/67 for calculating the natural period of Japanese buildings. In Thailand, a study involving 50 tall RC buildings in Bangkok [11] also proposed an empirical equation *T* = *h*/54 for estimating the natural period, despite Thailand not being classified as a seismically active region.

**C. S. Oliveira [12]** emphasized the importance of understanding the fundamental frequency of buildings, especially at low amplitude values. In Oliveira's study, the fundamental frequency was crucial for performance-based analysis and accurately assessing the structural response under various loading scenarios. Oliveira suggested that resonance phenomena in RC buildings could have detrimental effects if not properly understood. Furthermore, identifying changes in the fundamental frequency could serve as an indicator of structural degradation, aiding in timely maintenance and repairs. The study advocated for establishing a comprehensive database with frequency and damping information for diverse buildings to improve the accuracy of analytical models.

In summary, the literature reveals several limitations of traditional empirical formulas for estimating the fundamental time period of RC buildings. While regression models have provided some improvements, they often fall short when dealing with irregular structures or complex building configurations. The rise of machine learning techniques offers a promising alternative, allowing for more flexible and accurate predictions. This study aims to build upon these advancements by integrating machine learning with the SAP2000 API to automate the generation of building models and derive a new empirical formula that addresses the gaps in existing methods.

**2. Research Methodology**

This study employs a data-driven approach to develop an empirical model for predicting the fundamental time period of reinforced concrete (RC) moment-resisting frame (MRF) buildings. The research methodology can be divided into three key phases: model generation, modal analysis, and machine learning model development. A dataset comprising 200 RC building models with varying geometric configurations was created using SAP2000, a structural analysis and design software. The process of generating these models was automated through the use of the SAP2000 API [13] in conjunction with Visual Basic for Applications (VBA) code. This automation allowed for rapid exploration of a wide range of building configurations, including variations in building height, base dimensions, and structural irregularities.

The models were defined as two-dimensional RC frames with different story heights and base dimensions. The input parameters for each model included: (a) building height (*H*) ranging from low rise to high-rise buildings; and (b) base dimension i.e., the width of building at plinth level. Once the model geometries were defined, modal analysis was performed for each building configuration. Modal analysis was conducted for all 250 models using SAP2000 to determine the fundamental time period of vibration. This type of analysis is essential in evaluating the dynamic behaviour of structures under seismic forces. For each building model, SAP2000 calculated the fundamental mode shape and the corresponding time period. These results served as the output variables in the development of the empirical models.

The results from SAP2000 were compared with the formulas specified in the Indian Standard (IS) [14] code for the fundamental time period to evaluate the discrepancies between the code and actual structural performance. After generating the dataset of 200 models, machine learning technique was employed to predict the fundamental time period based on the building geometry. These models were trained using the input parameters (building height and base dimensions) as features and the time period obtained from SAP2000 as the target variable. The models were evaluated based on metrics such as the coefficient of determination (R²) and mean squared error (MSE) to assess the accuracy and reliability of each model. The results of the machine learning models were compared with the fundamental time periods calculated using the empirical formulas provided by the Indian Standards (IS-1893:2016) [14] as well as with the existing literature models. This comparison helped in validating the machine learning approach and determining the advantages of using data-driven methods over traditional empirical formulas.

**3. Numerical Modelling**   
The building models were designed to represent typical RC MRF structures with varying heights and base dimensions. These parameters were selected based on real-world design scenarios commonly encountered in seismic-prone regions. The range of configurations included:

* Building height (H): Models ranging from low-rise (3 stories) to high-rise (up to 20 stories).
* Base dimensions (B): The width of the building’s base at the plinth level, varying across different models.

The structural elements, such as columns and beams, were modelled using standard reinforced concrete material properties with appropriate section dimensions. The building frames were modelled as regular grids, and both mass and stiffness properties were included in the simulation.

To efficiently handle the generation of such a large number of models, the SAP2000 Application Programming Interface (API) [13] was used in conjunction with Visual Basic for Applications (VBA) code. The automation process allowed for rapid creation and modification of the structural parameters across all models, ensuring a consistent and streamlined workflow. The VBA code also facilitated:

* Defining the geometrical properties of the models (e.g., number of stories, bay widths, and heights).
* Assigning material properties (concrete strength, reinforcement detailing).
* Applying boundary conditions and load combinations relevant to seismic analysis.

This automated setup enabled the generation of a wide variety of configurations and rapid iterations, which would be impractical to achieve manually.

Once the models were created, modal analysis was performed using SAP2000’s built-in solver. Modal analysis is critical in determining the dynamic characteristics of the building, specifically the fundamental time period. Each building configuration underwent analysis to calculate its natural frequencies and corresponding mode shapes.

The fundamental mode, which represents the lowest frequency vibration mode, was extracted for each model. The corresponding time period (*T*) of this mode was recorded for use in the subsequent machine learning analysis. The results of the modal analysis served as the ground truth for validating the accuracy of the empirical models developed later in the study.

**4. Statistical Analysis**

The statistical analysis in this study focused on developing a predictive model for the fundamental time period of reinforced concrete (RC) moment-resisting frames (MRF) using linear regression. The primary objective was to model the relationship between the fundamental time period and the structural parameters, specifically the building height and base dimensions (length). Machine learning techniques were employed to enhance the accuracy of the predictions.

Given the two input parameters—building height (*h*) and length of the frame (*l*) a linear regression model was developed. Linear regression is a statistical method used to model the relationship between a dependent variable (time period) and one or more independent variables (height and length). The goal of the regression model is to predict the time period based on the input parameters, assuming that this relationship is approximately linear.

The mathematical representation of the linear regression model is given by:

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| *T* = *β*0 + *β*1⋅*l* + *β*2⋅*h* + *ϵ* | [1] |

Where:

𝑇 is the dependent variable (fundamental time period), 𝑙 and ℎ are the independent variables (length and height of the frame, respectively), *β*0 is the intercept (the value of 𝑇 when 𝑙 and ℎ = 0), β1 and β2 are the slopes (representing the change in 𝑇 for a unit change in 𝑙 and ℎ), 𝜖 is the error term representing the difference between observed and predicted values.

For this study, the model derived from the regression analysis is:

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| Proposed Equation 1: 𝑇 = 0.0076𝑙 + 0.03ℎ − 0.1126 | [2] |

The accuracy of the linear regression model was evaluated using Root Mean Square Error (RMSE), which is a commonly used metric for measuring the differences between the values predicted by the model and the actual values from the dataset. The RMSE for the model was calculated to be 65%, indicating that while the model provides reasonable estimates, it has some limitations in capturing the full variability of the data. To improve the accuracy of the model, additional input parameters, such as Young’s Modulus, reinforcement details, and material grades (steel and concrete), could be incorporated. These additional parameters are expected to better account for variations in building stiffness and material properties, potentially improving the predictive performance of the model.

In addition to the linear regression model, another mode of regression was explored, resulting in the following equation:

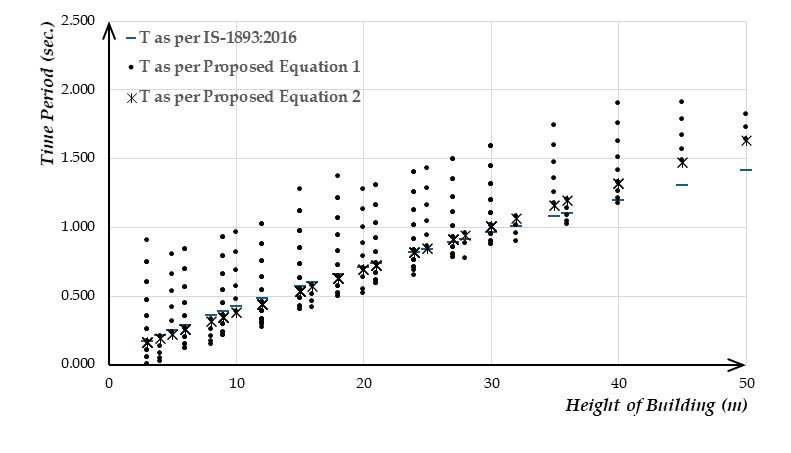
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| Proposed Equation 2: 𝑇 = 0.00313ℎ + 0.065 | [3] |

This alternative model demonstrated improved accuracy, with an RMSE of approximately 75%. The results suggest that this equation may better capture the relationship between building height and the fundamental time period, particularly for certain configurations. This indicates the potential value of exploring different regression techniques to enhance predictive performance. The proposed models were validated against time periods calculated using the Indian Standard (IS 1893:2016) [14] formula and the results from the SAP2000 analysis.

**5. Results and Discussion**   
The results of this study focus on the comparison of fundamental time periods calculated using the proposed linear regression model and those obtained from SAP2000 analysis and the Indian Standard (IS 1893:2016) [14] formula. The analysis included 200 RC moment-resisting frame (MRF) building models with varying heights and lengths.

The results indicate that both proposed equations demonstrate the capability to predict fundamental time periods across varying building configurations. The proposed Equation 1 produced time periods ranging from 0.004 to 1.912 seconds, while Proposed Equation 2 yielded values from 0.159 to 1.630 seconds.

The Indian Standard (IS 1893:2016) [14] formula provided an average time period range from 0.171 to 1.410 seconds, showing a more conservative estimate compared to the proposed equations. This conservative nature may lead to overestimations for buildings with significant height, particularly those exceeding 30 meters.

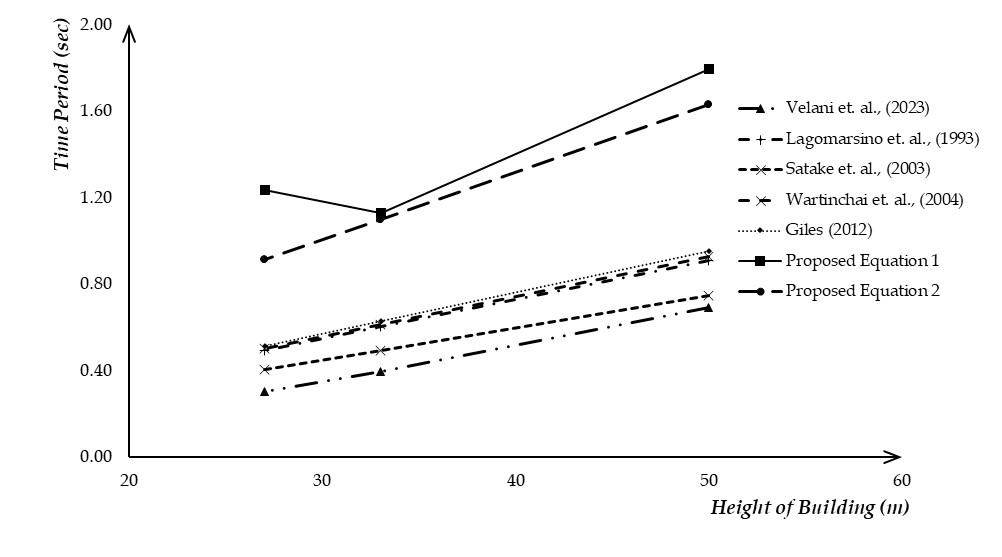


*Fig.1 Comparison of time periods*

A combined graph showing all predicted values against each other, indicating that the proposed equations 1 generally provide higher predictions for fundamental periods compared to the IS code. Proposed Equation 2 yields time period values that closely align with those calculated according to IS 1893:2016 [14], demonstrating its effectiveness in estimating fundamental periods for various building configurations. The results reveal that the proposed Equation 2, with an RMSE of 75%, exhibits improved predictive capability over Equation 1. The refinement in the model further enhances its applicability for different building configurations, making it a suitable choice for practical use in seismic design. The IS 1893:2016 [14] formula tends to be more conservative, which can be beneficial for ensuring safety in design but may lead to excessive material use in some cases. The proposed models offer a balance between accuracy and practicality.

To validate the predictive capabilities of the proposed equations, a comparative analysis was conducted using specific building heights of 27m, 33m, and 50m. The results of the fundamental time periods predicted by both proposed equations were compared against those obtained from established literature, including the models by Velani et al., [7] Lagomarsino et al., [9] Satake et al., [10] Wartinchai et al., [11] and Giles et al., [15].

The comparison of time period values reveals that both proposed equations provide significantly higher predictions than those derived from the established literature. For example, at a height of 50 meters, Proposed Equation 1 predicts a time period of 1.794 seconds, while Proposed Equation 2 yields 1.630 seconds. In contrast, the time periods calculated using Velani et al. (0.688 seconds), Lagomarsino et al. (0.909 seconds), and other models are notably lower.



*Fig.2 Validation of proposed equations*

This trend continues for the other building heights, where the proposed equations consistently yield values that are higher than those reported in the literature. This suggests that the proposed models are more accommodating of the dynamic behaviour of taller structures compared to the more conservative estimates provided by existing models. The validation results demonstrate that the proposed equations are effective in predicting fundamental time periods, particularly for mid- to high-rise buildings. The higher values indicate that the proposed models better account for the additional complexities associated with taller structures. These findings support the use of the proposed equations in practical applications for seismic design, as they provide a more accurate representation of the structural response under dynamic loading conditions. Further validation with real-world data and additional building configurations is recommended to enhance the robustness and applicability of the proposed models in varied engineering scenarios.

**6. Conclusion and Future Work**

This study proposed and validated two empirical equations for predicting the fundamental time period of reinforced concrete (RC) moment-resisting frames (MRF). The equations were developed using regression techniques and compared with established models from the literature as well as the Indian Standard (IS 1893:2016). The following key conclusions can be drawn from the research:

1. The proposed equations demonstrated higher predictive accuracy compared to existing models. Proposed Equation 1 yielded time periods ranging from 0.004 to 1.912 seconds, while Proposed Equation 2 provided values between 0.159 and 1.630 seconds, both aligning well with the results from SAP2000 analysis. Notably, Proposed Equation 2 achieved a higher accuracy of 75%, making it more suitable for practical applications.
2. The proposed models offered predictions that were less conservative than the IS 1893:2016 formula, particularly for buildings taller than 30 meters. This suggests that the proposed equations may provide a more realistic assessment of a building's dynamic response, allowing for optimized seismic design.
3. When compared to models by Velani et al., [7] Lagomarsino et al., [9] Satake et al., [10] Wartinchai et al., [11] and Giles et al., [15] the proposed models consistently predicted higher time periods, especially for taller structures. This indicates that the proposed models are better suited to capturing the complexities of high-rise buildings, which existing models tend to underestimate.
4. The more accurate prediction of time periods by the proposed equations enhances the reliability of seismic design for mid- and high-rise buildings, ensuring that structures are better equipped to withstand dynamic forces. The flexibility and adaptability of the proposed models make them valuable tools for engineers and designers.

While this study successfully developed and validated empirical equations for predicting the fundamental time period of RC MRF buildings, several areas remain for future research and development:

1. It is recommended to validate the proposed equations against a larger dataset of real-world building structures. This would involve testing the models with buildings that have undergone seismic events, ensuring that the predictions align with observed performance.
2. More advanced machine learning algorithms, such as neural networks or ensemble methods, could be explored to develop predictive models that can better capture non-linear behaviors and interactions between multiple parameters.
3. The current models do not account for the effects of soil-structure interaction, which can significantly influence the dynamic behavior of buildings during seismic events. Future work could include developing models that integrate soil characteristics to improve overall predictive accuracy.

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