

Design and Structural Optimization of an Adjustable Subway Platform Safety Board Using Finite Element Analysis

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Abstract

Accidents occurring at the platform–train interface remain a significant safety concern in urban railway systems due to irregular platform spacing, structural limitations, and increasing passenger density. Conventional subway platform safety boards, including fixed, sliding, and folding systems, often face limitations in structural adaptability, installation complexity, energy consumption, and maintenance requirements. To address these challenges, this study proposes a spacing-adjustable subway platform safety board that enhances passenger safety while maintaining structural stability and operational efficiency. The proposed system incorporates a passive mechanical adjustment mechanism comprising articulated supports, a ball-guided displacement structure, and a collision-prevention assembly that adapts to variable platform gaps without continuous electrical operation. Material selection was conducted through comparative tensile-strength and corrosion-resistance evaluations of multiple engineering alloys, including STS304L, STS316L, STS630, Monel 400, and Hastelloy-C. The results indicated that STS630 exhibited the most favorable combination of tensile and yield strengths and environmental durability for subway infrastructure applications. Finite element analysis was subsequently performed to evaluate deformation behavior under representative passenger loading conditions. Comparative analysis demonstrated that increasing the number of articulated supports and ball-guided components significantly improved load distribution and reduced structural deformation. The optimized configuration, incorporating five supports and five ball-guided mechanisms, exhibited the highest structural stability and minimum deformation. In addition, artificial neural network-assisted optimization was applied to improve design efficiency and determine the optimal structural configuration. The findings indicate that the proposed adjustable safety

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board provides a structurally reliable, energy-efficient, and economically feasible alternative to existing subway platform safety systems, with strong potential for future applications in urban railway infrastructure.

Keywords: *Subway platform safety board, Finite element analysis, Structural optimization, Railway safety engineering, Adjustable platform mechanism*

1. Introduction

Urban railway systems play a fundamental role in modern public transportation by improving mobility efficiency, reducing traffic congestion, and supporting sustainable urban development. As metropolitan populations continue to grow, railway operators and transportation engineers face increasing pressure to enhance passenger safety, accessibility, and operational reliability in subway environments [1]. Among the various safety concerns associated with urban railway systems, accidents occurring at the platform–train interface remain one of the most persistent engineering and operational challenges [2].

The gap between the train and the platform can create hazardous conditions for passengers during boarding and alighting operations. Such incidents include tripping accidents, wheelchair entrapment, passenger imbalance, and difficulties during emergency evacuation, particularly at curved platforms where geometric irregularities increase variations in horizontal and vertical spacing [3]. Recent studies have shown that these risks are strongly associated with platform geometry, vehicle dynamics, passenger density, and infrastructure aging [4]. Furthermore, the growing emphasis on universal accessibility and inclusive transportation systems has heightened the need for safer, more adaptable platform-protection technologies [5].

To reduce platform-related accidents, railway operators have implemented various safety facilities, including platform screen doors, warning systems, wheelchair elevators, and platform safety boards. Among these measures, safety boards installed between the train and the platform are considered an effective way to minimize passenger exposure to hazardous gaps [6]. Existing safety board systems are generally categorized into fixed, sliding, and folding mechanisms. Fixed systems employ permanently installed elastic structures, while sliding and folding systems use electromechanical actuation to dynamically reduce the platform gap during train operation [7].

Despite technological advancements, current safety board systems still present several engineering limitations. Previous investigations reported problems associated with structural deformation, mechanical malfunction, collision risk with train bodies, maintenance complexity, corrosion under humid underground conditions, and high installation costs [8]. In particular, embedded sliding and folding systems often require extensive reconstruction of platform concrete structures, leading to increased construction time and economic burden. Moreover, the variation in platform spacing among stations complicates standardization and reduces installation efficiency [9].

Recent engineering research from 2021 to 2025 has increasingly focused on lightweight structural systems, corrosion-resistant materials, finite-element-based structural optimization, and intelligent design methodologies for railway safety applications [9]. Advanced computational methods, including artificial neural networks and finite element analysis, have demonstrated significant potential for optimizing structural safety while reducing manufacturing and operational costs [11]. However, few studies have addressed the

development of spacing-adjustable safety board systems that adapt to varying platform conditions while ensuring structural stability, collision prevention, and economic feasibility.

Therefore, this study proposes a spacing-adjustable subway platform safety board designed to overcome the limitations of existing safety systems. The proposed structure incorporates a multi-stage adjustable mechanism, a load-support structure, and a collision-prevention component that can adapt to different platform gaps without requiring extensive platform reconstruction. In addition, material selection is investigated through tensile testing and Energy-Dispersive Spectroscopy (EDS) analysis to identify materials with superior corrosion resistance and mechanical strength suitable for subway operating environments.

To validate the proposed design, a Finite Element (FE) structural analysis is performed to evaluate deformation characteristics under distributed loading. Furthermore, neural network-assisted optimization is applied to determine the optimal structural configuration, accounting for the number of supports, ball mechanisms, and material properties.

The objectives of this study are summarized as follows:

1. To analyze the operational characteristics and limitations of existing subway platform safety board systems.
2. To develop a spacing-adjustable safety board capable of improving passenger safety under varying platform gap conditions.
3. To evaluate suitable structural materials through tensile testing and surface composition analysis.
4. To investigate structural deformation characteristics using finite element analysis under practical loading conditions.
5. To determine the optimal design configuration using neural-network-assisted structural optimization techniques.

The findings of this study are expected to contribute to the development of safer, more adaptable, and economically efficient railway platform safety systems for future urban transportation infrastructure.

2. System architecture and engineering analysis of the proposed adjustable safety board

2.1 Engineering requirements for platform safety systems

The platform–train interface remains one of the most technically challenging safety regions in urban railway systems because passengers are exposed to dynamic operational conditions during boarding and alighting activities. Variations in rail alignment, vehicle suspension displacement, track curvature, and platform geometry frequently result in inconsistent horizontal and vertical gaps between the train and platform edges [12]. These irregularities significantly increase the probability of tripping accidents, wheelchair entrapment, and passenger instability, particularly during peak operational periods characterized by high passenger density and rapid train turnover [13].

Recent transportation engineering studies have emphasized that conventional platform safety systems are insufficient to address the increasingly complex operational conditions associated with modern subway infrastructure [14]. In particular, curved platforms introduce larger geometric tolerances and dynamic vehicle movement, which complicate the implementation of standardized safety mechanisms [15]. Furthermore, aging infrastructure and repetitive cyclic loading contribute to long-term structural deterioration of platform

components, thereby reducing operational reliability and increasing maintenance requirements.

Another critical challenge involves accessibility compliance within urban railway environments. Contemporary transportation systems are increasingly required to provide safe and inclusive mobility for elderly passengers and individuals with reduced mobility [16]. Existing fixed-gap protection systems often fail to adequately accommodate wheelchair users because geometric inconsistencies remain even after installation of conventional safety devices. Consequently, there is growing engineering interest in adaptive platform technologies that dynamically improve boarding conditions while maintaining structural simplicity and economic feasibility.

In addition, sustainability considerations have become increasingly important in transportation infrastructure engineering. Current electromechanical safety systems require continuous electrical operation, frequent maintenance, and substantial structural modification of existing platforms [17]. These factors increase operational cost and reduce long-term economic efficiency. Therefore, the development of lightweight, low-energy, and adaptable safety board systems has become an important research objective in the design of next-generation railway infrastructure.

2.2. Structural configuration of the proposed adjustable safety board

To address the limitations of existing systems, this study proposes a newly designed spacing-adjustable safety board that accommodates variable platform conditions via a passive mechanical adjustment mechanism. The proposed system was developed with emphasis on structural adaptability, installation efficiency, collision prevention, and reduced maintenance complexity.

The proposed structure consists of four primary components: a fixed primary step, an adjustable secondary step, a load-support assembly, and a collision-prevention plate. The primary step is permanently attached to the platform edge and functions as the main structural support element. The secondary step is connected to the primary structure through a guided extension mechanism that enables controlled displacement according to the required platform spacing.

Unlike conventional sliding safety systems that rely on motor-driven actuation, the proposed design utilizes a mechanically linked support structure combined with spring-assisted adjustment. During operation, the support assembly changes its angular configuration according to the required extension length. Simultaneously, ball-guided linear grooves positioned beneath the secondary step enable smooth translational motion while minimizing frictional resistance and localized stress concentration.

A collision-prevention mechanism is additionally incorporated into the front section of the safety board. In the event of unexpected contact between the train body and the safety board, the collision-prevention plate rotates and transfers impact force to the articulated support structure through a connected linkage system. This mechanism allows temporary structural deformation that absorbs impact energy and reduces the likelihood of severe mechanical damage [18].

Compared with conventional embedded systems, the proposed structure offers several engineering advantages. First, the design can be externally attached to the platform without extensive demolition of existing concrete structures, thereby reducing installation time and construction complexity. Second, the passive adjustment mechanism eliminates continuous electrical energy consumption, improving sustainability and reducing operational expenditure.

Third, the adjustable configuration enables standardized manufacturing despite differences in platform geometry among stations, improving scalability and reducing fabrication cost [19].

2.3. Material selection and surface characterization

Material selection is a critical factor in the structural reliability of railway safety systems because subway environments expose components to cyclic mechanical loading, humidity, particulate contamination, and long-term vibration [20]. Therefore, the proposed safety board requires materials that provide high strength, fatigue resistance, corrosion resistance, and dimensional stability under continuous operational conditions.

In this study, several engineering alloys commonly used in transportation infrastructure applications were comparatively evaluated, including STS304L, STS316L, STS630, Monel 400, and Hastelloy-C. Material performance assessment focused on tensile strength, yield strength, and corrosion resistance characteristics.

Recent materials engineering research demonstrated that precipitation-hardened stainless steels exhibit superior fatigue performance and environmental durability in underground transportation systems [21]. Among the investigated materials, STS630 showed particularly favorable mechanical properties due to its high yield strength and resistance to stress-induced deformation. Furthermore, chromium-rich surface layers enhance corrosion resistance under humid operational conditions.

To further evaluate material suitability, Energy-Dispersive Spectroscopy (EDS) analysis was considered to investigate elemental surface composition and corrosion-related characteristics. Surface elemental distribution is closely associated with long-term environmental durability because subway systems continuously expose structural materials to oxidation, moisture accumulation, and abrasive contaminants generated during train operation [22].

Based on the comparative evaluation, STS630 was identified as the most suitable material for the proposed safety board, offering the best balance of structural strength, corrosion resistance, and manufacturing feasibility.

2.4. Finite element structural analysis and optimization strategy

Structural stability evaluation is essential for verifying the operational safety of railway platform systems subjected to repeated passenger loading conditions. Accordingly, a finite element (FE) analysis was employed to investigate the deformation characteristics, stress distribution, and load-transfer behavior of the proposed safety board structure.

The analysis considered multiple design variables, including the number of support members, the number of ball-guided mechanisms, and the thickness of the supporting plate. Distributed loading conditions representing passenger traffic and wheelchair loading were applied to evaluate practical operational performance [23].

Previous structural engineering investigations demonstrated that increasing the number of support elements improves load distribution uniformity and reduces localized deformation within modular transportation structures [24]. Similarly, ball-guided mechanisms contribute to smoother displacement transfer and reduced stress concentration during extension and retraction operations.

To improve optimization efficiency, Artificial Neural Network (ANN)-assisted structural optimization was integrated with finite element analysis. The ANN model was trained using simulation-generated datasets that correlated design variables with deformation responses and stress distributions. This methodology enabled rapid prediction of structural performance

while significantly reducing the computational cost associated with repeated numerical simulations [25].

The optimization process aimed to identify the structural configuration that minimizes deformation while maintaining simplicity of manufacture and economic feasibility. Through this integrated design methodology, the proposed adjustable safety board was developed as a lightweight, adaptive, and structurally reliable platform safety system suitable for advanced urban railway infrastructure applications.

3. Development and functional evaluation of the adjustable safety board

3.1. Design concept and engineering objectives

The development of the proposed adjustable safety board was motivated by the growing need for adaptive platform safety systems that reduce passenger accidents while maintaining structural simplicity and economic feasibility. Limited adaptability, complex installation procedures, high operational costs, and vulnerability to mechanical failure under repetitive subway operating conditions generally constrain the effectiveness of conventional platform safety mechanisms. In particular, embedded electromechanical systems often require extensive reconstruction of platform infrastructure, resulting in increased maintenance complexity and operational interruptions.

To overcome these limitations, this study proposes a spacing-adjustable safety board with a passive mechanical adjustment mechanism that adapts to variable platform gaps without requiring continuous electrical power. The proposed design was developed according to four primary engineering objectives:

1. Reduction of passenger accident risk at the platform–train interface.
2. Improvement of structural adaptability under varying platform geometries.
3. Minimization of installation and maintenance complexity.
4. Enhancement of operational sustainability through low-energy system operation [26].

Unlike conventional automated systems, the proposed structure operates through mechanically linked motion components that utilize geometric displacement rather than motor-driven actuation. This approach simplifies the structural configuration while improving long-term reliability under cyclic operational loading conditions.

The design additionally emphasizes modularity and scalability. Subway platforms often exhibit substantial geometric variation due to differences in rail curvature, vehicle dimensions, and infrastructure age. Consequently, a standardized fixed-dimension safety board cannot effectively satisfy operational requirements at all stations. The proposed adjustable system, therefore, incorporates variable extension capability to improve compatibility across diverse platform environments [27].

3.2. Structural configuration of the proposed safety board

The proposed adjustable safety board consists of four major structural components: a fixed primary platform, a movable secondary extension plate, articulated support members, and a collision-prevention mechanism. Each component was designed to perform a specific structural and operational function while maintaining overall system stability.

3.2.1. Primary platform structure

The primary platform functions as the main load-bearing component and is permanently attached to the existing subway platform structure. This component supports passenger loading and transfers operational forces to the platform foundation. The primary structure was designed using a reinforced plate configuration to minimize bending deformation under distributed loading conditions.

Unlike embedded safety systems that require substantial demolition of platform concrete structures, the proposed design allows external attachment through modular fastening systems. This installation approach significantly reduces construction complexity, installation time, and operational disruption during deployment [28].

The primary platform additionally serves as the guide base for the movable secondary extension mechanism. Structural reinforcement ribs were incorporated beneath the plate surface to improve stiffness and maintain dimensional stability during repeated loading cycles.

3.2.2. Adjustable secondary extension plate

The secondary extension plate is the primary adaptive component of the proposed safety board system. This structure extends toward the train body to reduce the effective platform gap during boarding and alighting operations.

The extension mechanism operates through a passive translational displacement system connected to articulated support members. As the support angle changes, the secondary plate moves horizontally along predefined guide paths. This design enables continuous adjustment according to different platform spacing requirements without requiring electric motors or hydraulic actuators.

The extension plate was designed to maintain smooth translational motion while minimizing frictional resistance and stress concentration. To achieve this objective, ball-guided motion components were integrated beneath the extension structure. Ball-supported motion systems have been shown to provide superior displacement stability and reduced wear compared with conventional sliding contact systems [29].

The adjustable configuration also improves manufacturing efficiency, as a single standardized structural design can accommodate multiple platform geometries through mechanical adjustment rather than through customized fabrication.

3.2.3. Articulated support mechanism

The articulated support mechanism plays a critical role in maintaining structural stability and enabling adaptive displacement of the secondary extension plate. The support members were designed using rotational linkage geometry to distribute operational loads uniformly while permitting controlled extension movement.

During operation, the support members rotate according to the required extension distance. Simultaneously, the connected ball-guided system converts rotational displacement into translational movement of the secondary plate. This integrated mechanism allows smooth extension and retraction while minimizing localized deformation.

Structural optimization of the support geometry was performed to reduce stress concentration at the rotational joints. Previous transportation engineering studies demonstrated that articulated support systems improve load distribution efficiency and reduce localized bending deformation under distributed loading conditions [30].

The number of support members additionally influences structural stiffness and deformation behavior. Increasing the number of supports improves load distribution uniformity and enhances structural stability under concentrated passenger loading conditions.

3.2.4. Collision-prevention mechanism

One of the major safety concerns associated with conventional platform safety boards involves accidental collision between the train body and malfunctioning safety structures. To address this issue, the proposed design incorporates a collision-prevention plate positioned at the outer edge of the safety board.

During abnormal contact conditions, the collision-prevention plate rotates and transfers impact forces to the articulated support structure through a connected linkage mechanism. This controlled deformation process absorbs impact energy and reduces stress concentration at critical structural regions.

The collision-prevention mechanism therefore functions as an impact mitigation system that minimizes severe mechanical damage to both the train and the platform structure. In addition, the rotational response reduces the likelihood of catastrophic structural failure during accidental collision events [31].

This mechanism represents a significant improvement over conventional rigid safety boards, which often experience severe structural damage when subjected to direct train impact.

3.3. Functional characteristics and operational advantages

The proposed adjustable safety board offers several important operational and engineering advantages compared with conventional fixed, sliding, and folding systems.

3.3.1. Adaptability to variable platform conditions

One of the most significant advantages of the proposed system is its ability to adapt to varying platform gap conditions. Conventional fixed safety boards cannot effectively accommodate differences in train alignment or platform geometry. In contrast, the proposed extension mechanism enables controlled adjustment according to operational spacing requirements.

This adaptability improves passenger safety while reducing the need for station-specific customized manufacturing procedures [32].

3.3.2. Reduction of energy consumption

Existing sliding and folding systems generally rely on motors, sensors, and automated control systems for operation. These components increase operational energy consumption and maintenance requirements.

The proposed safety board instead operates through passive mechanical displacement generated by geometric linkage motion. Consequently, continuous electrical power is unnecessary during normal operation. This characteristic improves sustainability and reduces long-term operational expenditure [33]

3.3.3. Simplified installation and maintenance

Installation complexity is another important limitation of existing embedded safety systems. Conventional designs often require demolition and reconstruction of platform concrete structures, leading to prolonged construction periods and operational interruption.

The proposed externally mounted modular structure significantly simplifies installation procedures. In addition, the major structural components remain easily accessible for inspection and maintenance. This accessibility improves maintainability and reduces lifecycle maintenance cost [34].

3.3.4. Improved structural safety

The proposed design also improves structural safety by optimizing load distribution and enhancing collision mitigation. The articulated support structure distributes passenger loading more uniformly, reducing localized deformation and stress concentration.

Furthermore, the collision-prevention mechanism improves structural resilience during abnormal operational conditions by absorbing impact energy through controlled rotational deformation [35].

These characteristics collectively improve operational reliability and reduce the probability of severe infrastructure damage.

3.4. Preliminary structural feasibility evaluation

Preliminary structural evaluation was conducted to assess the feasibility of the proposed safety board under representative passenger loading conditions. Distributed vertical loading corresponding to passenger crowding and wheelchair operation was considered during conceptual analysis.

Initial observations indicated that increasing the number of articulated supports reduced localized deformation at the extension plate edges and improved load transfer uniformity. Similarly, increasing the number of ball-guided components improved displacement stability and reduced friction-induced stress concentration.

Material evaluation additionally confirmed that precipitation-hardened stainless steel structures provide favorable resistance to cyclic deformation and environmental degradation under subway operating conditions [36].

Based on these preliminary observations, detailed finite-element structural analysis and optimization procedures were subsequently performed to determine the optimal configuration that satisfies safety, durability, and economic performance requirements.

4. Finite element analysis and material performance evaluation

4.1. Material selection and mechanical characterization

Material selection is a critical aspect of subway platform safety board design because the structure is continuously exposed to cyclic passenger loading, vibration, humidity, particulate contamination, and long-term environmental degradation. Therefore, the selected material must provide high tensile strength, corrosion resistance, dimensional stability, and fatigue resistance while remaining economically feasible for large-scale transportation infrastructure applications.

To identify the most suitable structural material for the proposed adjustable safety board, five engineering alloys commonly used in transportation and structural systems were comparatively evaluated:

- STS304L
- STS316L
- STS630
- Monel 400
- Hastelloy-C

The material evaluation process focused on three major criteria:

1. Tensile strength
2. Yield strength
3. Corrosion resistance characteristics

Tensile testing was performed to investigate the stress–strain behavior and mechanical stability of each material under loading conditions representative of subway platform operation. The experimental evaluation also considered long-term structural durability, as repeated loading cycles may induce fatigue-induced deformation over extended service periods.

Among the investigated materials, precipitation-hardened stainless steel STS630 demonstrated superior mechanical performance, with high tensile strength and excellent yield resistance. Furthermore, the material exhibited favorable corrosion resistance, associated with a chromium-rich surface composition and a precipitation-hardening microstructure.

Table 1. Mechanical properties of candidate materials

Material	Tensile Strength (MPa)	Yield Strength (MPa)	Corrosion Resistance	Structural Suitability
STS304L	766.31	542.77	High	Moderate
STS316L	674.05	509.74	Very High	Moderate
STS630	1117.60	1014.80	High	Excellent
Monel 400	565.78	361.03	Excellent	Moderate
Hastelloy-C	811.38	490.13	Excellent	High

The results in Table 1 indicate that STS630 exhibited the highest tensile and yield strengths among the investigated materials. Although Monel 400 and Hastelloy-C demonstrated excellent corrosion resistance, their mechanical performance and economic feasibility were less favorable for structural railway applications.

Consequently, STS630 was selected as the primary material for the proposed adjustable safety board structure.

4.2. Surface composition and corrosion resistance analysis

In underground railway environments, corrosion resistance is particularly important because subway systems are continuously exposed to humidity, airborne particulates, and chemically reactive contaminants generated during train operation. Surface degradation may reduce structural reliability and increase maintenance frequency over time.

To evaluate corrosion-related characteristics, Energy-Dispersive Spectroscopy (EDS) was used to analyze the elemental surface composition of the candidate materials. The analysis focused on identifying the distribution of chromium, nickel, iron, and other alloying elements associated with corrosion resistance performance.

The EDS evaluation confirmed that STS630 possessed a stable chromium-rich surface layer that enhanced oxidation resistance and environmental durability. In addition, the precipitation-hardened microstructure contributed to improved surface stability under cyclic operational conditions.

Table 2. Comparative surface performance evaluation

Material	Chromium Content	Oxidation Resistance	Moisture Resistance	Overall Durability
STS304L	Moderate	High	High	High
STS316L	High	Very High	Very High	Very High
STS630	High	High	High	Excellent
Monel 400	Low	Excellent	Excellent	High
Hastelloy-C	Moderate	Excellent	Excellent	Very High

Although STS316L and Hastelloy-C demonstrated excellent environmental resistance, STS630 provided the best balance of structural strength, corrosion resistance, and manufacturing feasibility. Therefore, the material was selected for detailed finite element structural analysis.

4.3. Finite element modeling procedure

Finite Element (FE) analysis was conducted to evaluate the structural stability and deformation characteristics of the proposed adjustable safety board under representative passenger loading conditions. The numerical analysis was performed to investigate stress distribution, displacement behavior, and load transfer efficiency throughout the structural system.

The FE model incorporated the following structural components:

- Primary support platform
- Adjustable secondary extension plate
- Articulated support members
- Ball-guided displacement mechanisms
- Collision-prevention structure

Distributed vertical loading conditions representing passenger crowding and wheelchair loading were applied to the safety board's upper surface. Boundary conditions were defined in accordance with practical constraints for subway platform installation.

The analysis focused on three principal design variables:

1. Number of articulated supports
2. Number of ball-guided components
3. Supporting plate thickness

Structural deformation and stress concentration were evaluated for each design configuration.

4.4. Deformation analysis according to the number of supports

The number of articulated supports significantly influences structural stiffness and load distribution behavior. To investigate this effect, comparative FE simulations were performed using configurations containing three, four, and five support members.

The results demonstrated that increasing the number of supports improved load transfer uniformity and reduced localized deformation at the extension plate edges. Additional support members distributed passenger loading more evenly across the structural system, thereby improving overall stiffness.

Table 3. Deformation analysis according to the number of supports

Number of Supports	Maximum Deformation (mm)	Stress Distribution	Structural Stability
3 Supports	0.001387	Moderate	High
4 Supports	0.001351	Improved	Very High
5 Supports	0.001314	Uniform	Excellent

The results indicate that the five-support configuration reduced maximum deformation by approximately 5.5% compared with the three-support configuration. In addition, the five-support model exhibited more uniform stress distribution throughout the support structure.

4.5. Deformation analysis according to the number of ball-guided components

The ball-guided displacement mechanism additionally influences structural deformation and displacement stability during extension operations. A comparative FE analysis was therefore performed using configurations with three and five ball-guided components.

The analysis demonstrated that increasing the number of ball-guided components reduced localized stress concentration and improved translational stability of the extension mechanism.

Table 4. Deformation analysis according to the number of ball-guided components

Number of Balls	Maximum Deformation (mm)	Motion Stability	Load Distribution
3 Balls	0.001824	Moderate	Moderate
5 Balls	0.001618	Excellent	Uniform

The five-ball configuration reduced maximum deformation by approximately 12.7% compared with the three-ball model. Furthermore, smoother load transfer and improved displacement uniformity were observed during simulated extension movement.

4.6. Neural-network-assisted design optimization

To improve design efficiency and reduce computational cost associated with repeated FE simulations, Artificial Neural Network (ANN)-assisted optimization was integrated into the structural evaluation process.

The ANN model was trained using FE-generated datasets containing relationships between design variables and structural responses. Input parameters included:

- Number of supports
- Number of ball-guided components
- Material properties
- Plate thickness

Output variables consisted of:

- Maximum deformation
- Stress concentration
- Structural stability index

The neural network optimization process enabled rapid prediction of structural performance and identification of optimal design configurations.

Based on the optimization results, the final design configuration incorporated:

- Five articulated supports
- Five ball-guided components
- STS630 structural material
- Minimum support plate thickness of 4.3 mm

The optimized model demonstrated excellent structural stability, minimal deformation, and improved load distribution characteristics under representative operational loading conditions. Furthermore, the selected configuration satisfied both safety and economic performance requirements while maintaining simplified manufacturability and installation feasibility.

5. Discussion

The present study investigated the structural feasibility and operational applicability of a spacing-adjustable subway platform safety board developed to overcome the limitations of conventional fixed, sliding, and folding safety systems. The results obtained from material characterization, finite element analysis, and structural optimization demonstrated that the proposed design provides improved adaptability, structural stability, and operational efficiency under representative subway loading conditions.

One of the major findings of this study is that passive mechanical adjustment mechanisms can effectively reduce reliance on electromechanical systems while maintaining adaptive functionality. Existing automated safety boards typically require motors, sensors, and control systems to adjust platform spacing, which increases operational complexity and maintenance requirements. In contrast, the proposed design achieved adaptive displacement through articulated supports and ball-guided translational motion, thereby reducing energy consumption and simplifying structural configuration.

The deformation analysis further demonstrated that the number of articulated supports and ball-guided components significantly influences structural behavior. Increasing the number of supports improved load transfer uniformity and reduced localized deformation within the extension structure. Similarly, additional ball-guided mechanisms enhanced displacement stability and reduced stress concentration during extension. These findings indicate that distributed support geometry is essential for maintaining structural reliability under repetitive passenger loading conditions.

The optimized structural configuration incorporating five supports and five ball-guided components exhibited the most favorable deformation characteristics among the evaluated models. The reduction in deformation suggests that the proposed system can maintain structural stability during long-term subway operation while reducing the likelihood of localized fatigue failure. Uniform stress distribution additionally contributes to improved durability and reduced maintenance frequency.

Material selection also played an important role in the overall structural performance of the safety board. A comparative evaluation of candidate materials confirmed that STS630 provided the best balance among tensile strength, yield strength, corrosion resistance, and manufacturing feasibility. Subway environments continuously expose structural systems to vibration, humidity, and environmental contaminants, all of which accelerate material degradation. The precipitation-hardened stainless steel structure demonstrated superior resistance to cyclic deformation and environmental deterioration, indicating strong suitability for long-term transportation infrastructure applications.

Another important contribution of the proposed system is the integration of a collision-prevention mechanism. Conventional rigid safety boards are vulnerable to severe structural damage when accidental train contact occurs due to synchronization failure or mechanical malfunction. The rotating collision-prevention plate developed in this study reduces impact concentration through controlled deformation behavior, thereby improving operational safety and minimizing infrastructure damage during abnormal events.

From a practical implementation perspective, the proposed modular structure offers significant advantages in installation and maintenance. Conventional embedded safety boards often require demolition and reconstruction of platform concrete structures, leading to high construction costs and operational disruption. In contrast, the externally mounted configuration proposed in this study can be attached directly to existing platform systems without major structural modification. This approach simplifies installation procedures, reduces construction time, and improves maintainability during future inspections and replacements.

The integration of artificial neural network-assisted optimization additionally demonstrated the effectiveness of combining numerical simulation with intelligent prediction techniques for transportation infrastructure design. The optimization framework enabled efficient evaluation of multiple design configurations while reducing the computational cost associated with repeated finite element simulations. This methodology may provide a useful design approach for future adaptive transportation safety systems.

Despite the favorable findings, several limitations remain. The present investigation primarily considered static distributed loading conditions and did not fully account for dynamic operational effects such as train-induced vibration, impact loading variability, thermal expansion, and long-term fatigue behavior. Furthermore, the current study relied mainly on numerical analysis and preliminary material characterization rather than full-scale experimental validation. Therefore, future research should focus on prototype fabrication, dynamic structural testing, and long-term environmental durability evaluation under actual subway operating conditions.

6. Conclusion

This study proposed a spacing-adjustable subway platform safety board to improve passenger safety while overcoming the operational and structural limitations of conventional platform safety systems. The proposed design incorporated a passive mechanical adjustment mechanism, an articulated support structure, a ball-guided displacement system, and a collision-prevention assembly to achieve adaptive platform gap reduction without requiring continuous electrical operation.

Comparative material evaluation demonstrated that STS630 exhibited superior structural suitability due to its high tensile strength, excellent yield strength, and favorable corrosion resistance. The material also showed strong potential for long-term use in subway infrastructure due to its resistance to cyclic deformation and environmental degradation.

Finite element analysis confirmed that the number of articulated supports and ball-guided components strongly influenced structural deformation. Increasing the number of supports and ball-guided mechanisms improved load distribution uniformity and reduced localized deformation within the safety board structure. Among the evaluated configurations, the optimized model incorporating five supports and five ball-guided components demonstrated the most stable structural performance under representative operational loading conditions.

The proposed collision-prevention mechanism additionally improved structural safety by reducing impact concentration during abnormal contact conditions between the train body and the safety board. Furthermore, the externally mounted modular configuration simplified installation procedures and reduced maintenance complexity compared with conventional embedded safety systems.

The neural network-assisted optimization framework successfully identified an efficient structural configuration while reducing the computational cost of repeated numerical

simulations. The integration of finite element analysis and artificial intelligence-based optimization, therefore, demonstrated strong potential for future applications in transportation infrastructure design.

Overall, the findings indicate that the proposed adjustable safety board provides a structurally stable, energy-efficient, and economically feasible alternative to existing subway platform safety systems. The developed system demonstrates strong potential for improving passenger safety, operational reliability, and maintenance efficiency in future urban railway infrastructure applications.

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