**Empowering Urban Infrastructure: Structural Optimization and Seismic Analysis of Metro Overpass Supports**

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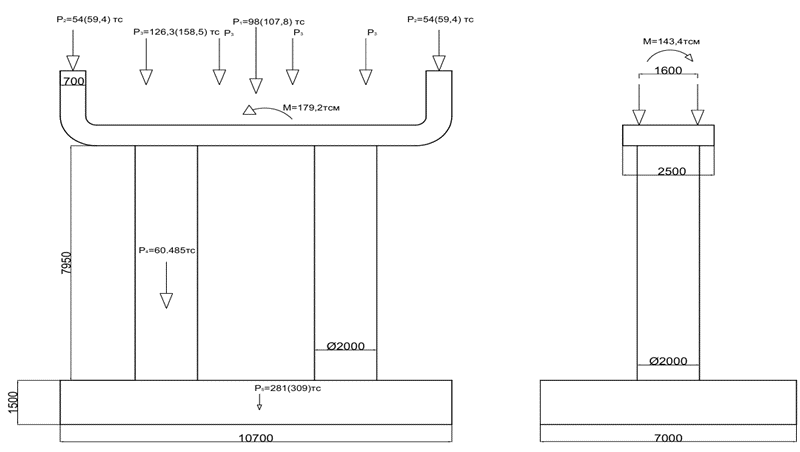
**Abstract.** This study presents a comprehensive structural analysis and design optimization of intermediate support columns used in the Sergeli aboveground metro line in Tashkent. The focus is on evaluating the existing circular reinforced concrete (RC) column design (diameter: 2000 mm) and proposing improved rectangular cross-sectional alternatives through spatial modeling and comparative assessment in LIRA-SAPR 2024. Parameters such as stress (σmax), deformation (δ), and safety factor (γ) were analyzed under static and seismic load combinations. The final proposed model includes a combined steel and carbon composite reinforcement RC column (1800x1800 mm), offering the lowest deformation   
(4.78 mm) and highest safety margin (γ ≥ 1.30), making it the most efficient and seismically resilient support configuration.

**Keywords:** Metro overpass, support column, LIRA-SAPR, deformation, seismic analysis, reinforcement optimization, composite materials

**INTRODUCTION**

The reliability and efficiency of aboveground metro viaduct systems are highly dependent on the structural integrity and rational configuration of intermediate support columns. In the Sergeli line of the Tashkent Metro, twin cylindrical reinforced concrete (RC) columns with a circular cross-section (diameter: 2000 mm) are commonly used. These supports are symmetrically arranged to ensure geometrical stability and are designed based on principles of technological simplicity, effective load distribution, and operational reliability.

The columns have a height of 7.95 meters, which provides the necessary vertical clearance between the viaduct deck and the foundation level. The selected span length of 26 meters ensures structural compatibility with dynamic and static loads from train traffic. The columns are made of heavyweight concrete of class B30, with a design compressive strength Rb = 15.3 MPa. A400 grade steel bars with a yield strength Rs provide longitudinal reinforcement = 355 MPa, and the average reinforcement ratio is approximately 1.8%, ensuring a balance between strength and ductility (Figure 1).



**FIGURE 1.** Calculation scheme of the existing support

Despite satisfying local code requirements, the existing Ø2000 mm circular support columns exhibit several drawbacks. These include excessive material usage (25.1 m³ of concrete and 1.37 t of steel per column), complexity in forming circular sections, and relatively low safety margins (γ ≈ 1.25), especially when evaluated against international standards such as Eurocode 2/8 and AASHTO LRFD [1, 2, 3, 4, 11], which recommend a safety factor of at least 1.5 for seismic regions.

Also, in [12, 13, 14], the stress-strain state of structural elements such as rods, plates and shells under alternating loading, taking into account damage accumulation, is investigated.

Three-dimensional finite element modeling of the existing support system was performed using LIRA-SAPR 2024. The spatial model consisted of 2181 elements and 2263 nodes, allowing detailed simulation of static and seismic load scenarios. Stress concentration and deformation patterns were primarily observed near the column base, aligning with known principles of structural mechanics.

In summary, although the current RC columns meet national norms, their structural and economic inefficiencies, combined with technological limitations and inadequate seismic safety reserves, indicate the necessity for an improved design. This study proposes optimized rectangular and composite-reinforced column configurations aimed at improving load-bearing capacity, reducing material consumption, and increasing seismic resilience for the Tashkent aboveground metro infrastructure.

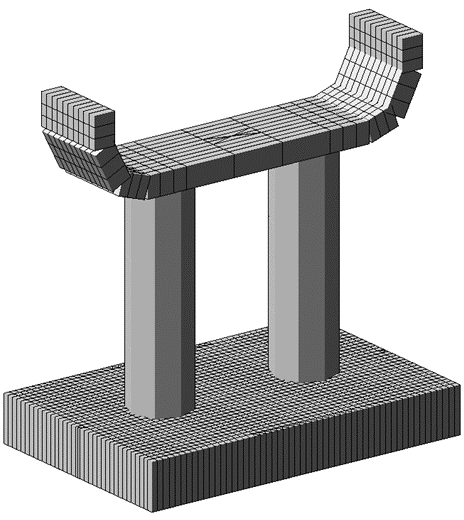
**METHODS**

To evaluate and improve the existing metro viaduct support columns, a comprehensive finite element modeling (FEM) approach was employed using the LIRA-SAPR 2024 structural analysis software [5, 10]. The methodology involved assessing the current Ø2000 mm circular reinforced concrete (RC) columns and comparing their performance with three proposed rectangular-section variants under identical load scenarios, including seismic effects.

**Finite Element Modeling of the Existing Support**

The existing twin-column system, each with a diameter of 2000 mm and a height of 7.95 m, was modeled in LIRA-SAPR using a three-dimensional frame scheme. The FEM mesh included 2181 elements and 2263 nodes, with each element representing a 10 cm linear segment. The bridge span between columns was set to 26 m (Figure 2). Material properties were defined as follows:

* Concrete class: B30 (Rb = 15.3 MPa);
* Reinforcement: A400 grade steel (Rs = 355 MPa);
* Reinforcement ratio: ~1.8%;
* Concrete volume: 25.1 m³ per column;
* Steel mass: 1.37 t per column.



**FIGURE 2.** Model of the base created using the Lira-Cad program

The model was subjected to combined dead loads, live loads (from train movement), and multi-directional seismic forces (X, Y, and Z). Load combinations followed national standards (SHNQ 2.05.03–12) and were verified for compatibility with Eurocode 8.

**Structural Performance Criteria**

The assessment of the column variants was based on the following structural performance criteria:

* Maximum vertical deformation δ ≤ 32.5 mm;
* Maximum stress σₘₐₓ < Rb;
* Safety factor γ = Rb / σₘₐₓ ≥ 1.0 (per SNIP), and preferably ≥ 1.5 (per Eurocode 2 and AASHTO LRFD);
* Minimized use of concrete and reinforcement to enhance cost efficiency.

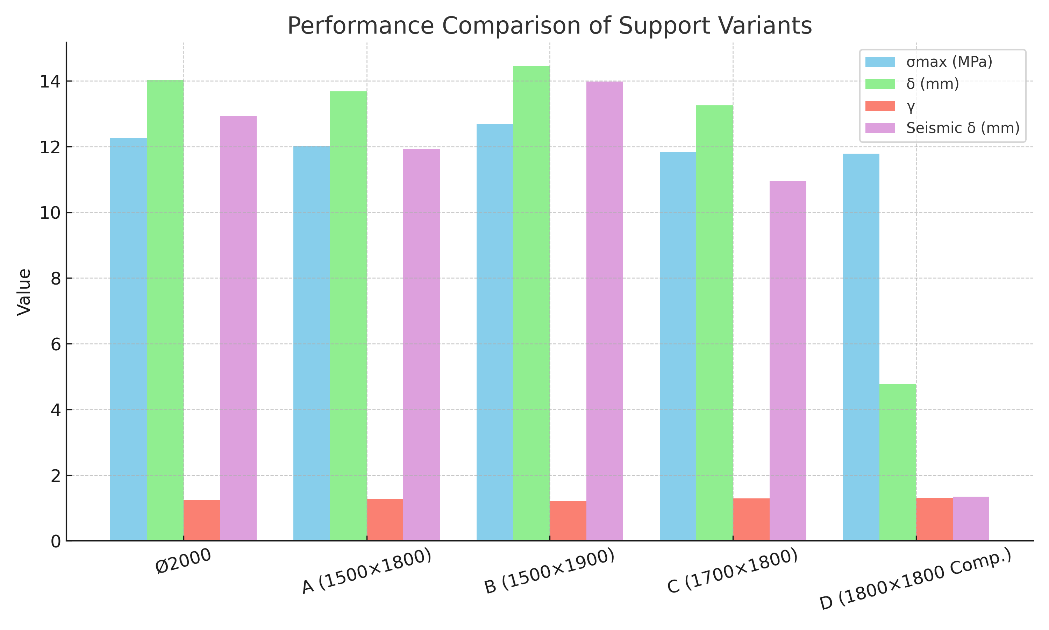
**Proposed Rectangular Column Variants**

Three rectangular RC column designs were developed:

* Variant A: 1500×1800 mm;
* Variant B: 1500×1900 mm;
* Variant C: 1700×1800 mm.

Each design used B30 concrete and A400 steel reinforcement, maintaining similar reinforcement densities and boundary conditions as the existing column for valid comparison.

All models were analyzed under identical load combinations in LIRA-SAPR. Output data included maximum stress (σₘₐₓ), vertical deformation (δ), safety factor (γ), seismic displacements, and structural behavior visualizations such as epures and moment diagrams (Figure 3).



**FIGURE 3.** Performance comparison of Support Variants

**Sensitivity Analysis for Concrete Grade**

For Variant A (1500×1800 mm), a sensitivity study was conducted by varying the concrete class (B25, B30, B35) while keeping all-geometric and load parameters constant. The effect on safety factor γ and deformation δ was evaluated to identify the optimal material selection in terms of structural and economic performance.

**Composite Reinforced Column Modeling**

An additional model was created with a square cross-section (1800×1800 mm), reinforced using carbon-fiber composite bars (ABK800). The FEM included 1273 nodes and 1282 elements. Composite reinforcement was modeled with enhanced tensile strength and elastic modulus, following international standards. This model was subjected to the same load combinations, and its performance was compared against conventional RC alternatives.

**RESULTS**

The numerical simulations carried out in LIRA-SAPR 2024 provided detailed comparative insights into the behavior of the existing and proposed support column variants. Key performance indicators such as maximum stress (σₘₐₓ), vertical deformation (δ), and safety factor (γ) were computed for all configurations under combined static and seismic loads.

**Existing Ø2000 mm Column Performance**

The current twin circular column system (Ø2000 mm) demonstrated the following characteristics:

* Maximum vertical deformation: **δ = 14.02 mm;**
* Maximum stress: **σₘₐₓ = 12.25 MPa;**
* Safety factor: **γ = 1.25;**
* Concrete volume: **25.1 m³;**
* Reinforcement mass: **1.37 t;**
* Seismic displacement (Z-direction): **12.94 mm.**

Stress distribution was predominantly concentrated near the base of the column, which aligns with theoretical expectations. Though structurally sufficient per SNIP, the safety factor remained below international standards (Eurocode and AASHTO recommend γ ≥ 1.5 for seismic zones) [1, 8, 9, 10].

**Rectangular Column Variants Comparison**

The performance of three proposed rectangular reinforced concrete columns was evaluated using identical modeling assumptions. Table 1 presents the computed stress, deformation, and safety factor for each variant.

**TABLE 1.** Structural performance of rectangular support variants

| **Variant** | **Size (mm)** | **σₘₐₓ (MPa)** | **δ (mm)** | **γ** | **Seismic δ (mm)** |
| --- | --- | --- | --- | --- | --- |
| A | 1500×1800 | 12.02 | 13.68 | 1.27 | 11.92 |
| B | 1500×1900 | 12.68 | 14.45 | 1.21 | 13.98 |
| C | 1700×1800 | 11.83 | 13.25 | 1.29 | 10.95 |

All rectangular variants satisfied the deformation limit of 32.5 mm. Variant A achieved a **14% reduction in concrete volume** compared to the original, demonstrating material efficiency and economic potential. Variant C showed the best balance of low stress and deformation, with γ = 1.29 [2].

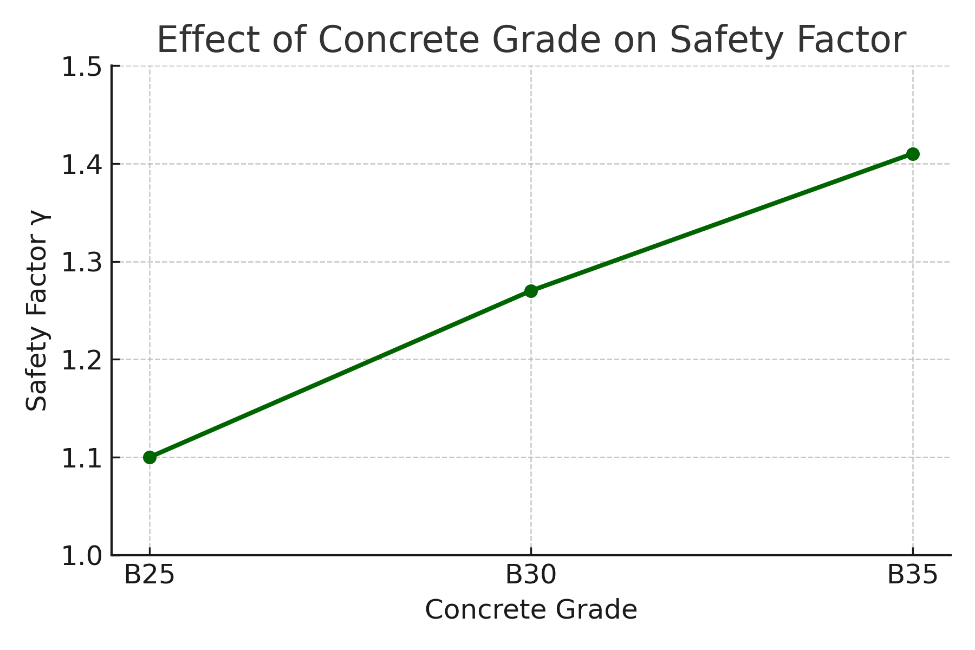
**Sensitivity of Concrete Strength (Variant A)**

A parametric study on concrete grade was conducted for Variant A (1500×1800 mm), and results are shown in Table 2.

**TABLE 2.** Sensitivity of safety factor to concrete strength

| **Concrete Grade** | **Rb (MPa)** | **σₘₐₓ (MPa)** | **γ** | **δ (mm)** |
| --- | --- | --- | --- | --- |
| B25 | 13.2 | 12.02 | 1.10 | 13.68 |
| B30 | 15.3 | 12.02 | 1.27 | 13.68 |
| B35 | 17.0 | 12.02 | 1.41 | 13.68 |

Higher strength concrete resulted in greater safety margins without changing the deformation, due to constant geometric and loading parameters (Figure 4).



**FIGURE 4.** Effect of changing concrete grade on strength reserve (γ)

**Composite-Reinforced 1800×1800 mm Column**

An advanced model was created using carbon-fiber composite reinforcement (ABK800) in a 1800×1800 mm square column. Key results included:

* **σₘₐₓ ≤ 11.78 MPa;**
* **δ = 4.78 mm;**
* **γ ≥ 1.30;**
* **Seismic δ = 1.345 mm;**
* **Concrete volume: 22.4 m³;**
* **Reinforcement mass: 0.92 t.**

This variant significantly outperformed the other alternatives in both static and seismic performance.

**Summary Comparison of All Variants (** Table 3).

**TABLE 3.** Comparative summary of all variants

| **Variant** | **δ (mm)** | **σₘₐₓ (MPa)** | **γ** | **Concrete (m³)** | **Steel (t)** | **Seismic δ (mm)** |
| --- | --- | --- | --- | --- | --- | --- |
| Existing Ø2000 mm | 14.02 | 12.25 | 1.25 | 25.1 | 1.37 | 12.94 |
| Rectangular A (1500×1800) | 13.68 | 12.02 | 1.27 | 21.6 | 1.21 | 11.92 |
| Rectangular B (1500×1900) | 14.45 | 12.68 | 1.21 | 23.4 | 1.29 | 13.98 |
| Rectangular C (1700×1800) | 13.25 | 11.83 | 1.29 | 23.5 | 1.29 | 10.95 |
| Composite (1800×1800) | 4.78 | ≤11.78 | ≥1.30 | 22.4 | 0.92 | 1.345 |

The composite 1800×1800 mm column exhibited the **lowest deformation**, **highest safety factor**, and **best seismic performance**. It also required the **least amount of steel**, enhancing cost-effectiveness and structural resilience.

**DISCUSSION**

The comparative structural analysis conducted in this study highlights critical insights regarding the behavior of various support column configurations used in the Sergeli aboveground metro system. While the existing Ø2000 mm circular reinforced concrete columns fulfill the minimum national code requirements (SHNQ 2.05.03–12), they exhibit multiple limitations in terms of material consumption, construction complexity, and seismic safety margins [6].

**Structural Safety and Seismic Performance**

Seismic resilience is a primary design criterion in Tashkent, a region characterized by high seismicity (8–9 MMI). According to the simulation results, the existing circular columns show a seismic displacement of **12.94 mm**, which is relatively high. Additionally, the safety factor **γ = 1.25** is below the internationally accepted thresholds (Eurocode 2/8 and AASHTO LRFD recommend **γ ≥ 1.5** for seismic design). This indicates that the existing design, although compliant with local norms, may be insufficient for extreme seismic events{3],[4].

Among the proposed variants, the **1700×1800 mm rectangular column** demonstrated the lowest seismic displacement (**10.95 mm**) among the conventional RC designs, while the **1800×1800 mm composite-reinforced column** achieved the best overall performance with a seismic displacement of only **1.345 mm** and a safety factor **γ ≥ 1.30**.

**Material Efficiency and Construction Practicality**

Material consumption was significantly optimized in the rectangular variants. The **1500×1800 mm** configuration reduced concrete volume by **14%** compared to the original design, equating to a saving of over **350 m³** of concrete across 100 columns. Similarly, steel usage decreased by approximately **12%**, directly reducing structural weight and cost. From a construction standpoint, rectangular cross-sections offer advantages in formwork standardization and reinforcement placement. Unlike circular columns that require complex, custom-made formwork and curved reinforcement cages, rectangular columns can utilize prefabricated templates and straight bars, which simplifies on-site operations and speeds up the construction cycle.

**Code Compliance and International Standards**

A comparative review of safety factors reveals that all rectangular columns satisfy **local norms (γ ≥ 1.0)**, yet only the composite-reinforced column approaches the **internationally recommended level of γ ≥ 1.5**. Table 4 provides a summary comparison against global standards.

**TABLE 4.** Comparison with International Standards

| **Parameter** | **SHNQ (Uzbekistan)** | **Eurocode 2/8** | **AASHTO LRFD** |
| --- | --- | --- | --- |
| Concrete class | B30 | C30/37 | 30 MPa |
| Reinforcement grade | A400 | B500B | Grade 60 (420 MPa) |
| Required safety factor γ | ≥ 1.0 | ≥ 1.5 | ≥ 1.5 |

The use of advanced reinforcement techniques, such as **carbon-fiber composite bars**, is well aligned with modern seismic retrofitting practices used globally. These materials enhance ductility and energy dissipation, which are essential for ensuring post-elastic structural behavior during earthquakes.

**Recommended Design Selection**

Considering deformation behavior, safety reserves, material efficiency, and seismic resistance, the **1800×1800 mm composite RC column** stands out as the optimal choice. It achieves the lowest deformation (δ = 4.78 mm), the highest safety factor (γ ≥ 1.30), and the smallest seismic displacement. Additionally, it requires the least reinforcement (0.92 t) and less concrete (22.4 m³) than the existing design [7].

**CONCLUSION**

This research aimed to evaluate and optimize the design of intermediate support columns for the Sergeli aboveground metro viaduct through advanced numerical modeling and comparative analysis using LIRA-SAPR 2024. The study assessed the existing Ø2000 mm circular reinforced concrete columns and compared their performance with several alternative rectangular-section and composite-reinforced variants.

Key conclusions are as follows:

* The existing columns, although compliant with Uzbek construction standards (SHNQ 2.05.03–12), exhibited limitations in seismic resilience and material efficiency. The safety factor (γ = 1.25) falls short of Eurocode and AASHTO recommendations (γ ≥ 1.5) for seismic zones.
* Among the conventional rectangular options, the **1500×1800 mm** and **1700×1800 mm** columns demonstrated improved performance in terms of stress distribution, reduced material usage, and better seismic behavior, with safety factors ranging from **1.27 to 1.29**.
* Sensitivity analysis showed that increasing the concrete grade from B25 to B35 improves safety margins without significantly affecting deformation, suggesting B30 as a balanced, cost-effective choice.
* The most significant improvements were achieved with the **1800×1800 mm square column using ABK800 carbon-fiber composite reinforcement**. This configuration provided:
  + Lowest deformation (δ = 4.78 mm),
  + Highest safety factor (γ ≥ 1.30),
  + Minimum seismic displacement (1.345 mm),
  + Lowest reinforcement mass (0.92 t),
  + Optimized concrete volume (22.4 m³).
* The composite-reinforced column satisfies both local and international structural safety requirements, while also offering practical benefits in terms of weight reduction, construction efficiency, and seismic performance.

**Recommendation:**

The 1800×1800 mm composite-reinforced RC column is recommended as the optimal solution for future implementations in seismically active urban metro systems. Its structural reliability, economic efficiency, and compatibility with modern construction technologies make it the most appropriate design alternative for sustainable infrastructure development.

**REFERENCES**

1. Uzbekistan Construction Standards, SHNQ 2.05.03–12 “Bridges and Pipes” (Tashkent, 2012).
2. Eurocode 2: EN 1992-1-1:2004, Design of concrete structures – General rules and rules for buildings (2004).
3. Eurocode 8: EN 1998-1:2004, Design of structures for earthquake resistance – Part 1: General rules (2004).
4. AASHTO, AASHTO LRFD Bridge Design Specifications, 9th ed. (American Association of State Highway and Transportation Officials, Washington, DC, 2020).
5. LIRA-SAPR, Structural Analysis Software. User Manual (Softline Group, 2024).
6. A. M. Neville, Properties of Concrete, 5th ed. (Pearson Education, London, 2011).
7. Fédération Internationale du Béton (fib), Structural Concrete, Vol. 1, Bulletin 55 (2010).
8. ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-19) (American Concrete Institute, Farmington Hills, MI, 2019).
9. P. K. Mehta and P. J. M. Monteiro, Concrete: Microstructure, Properties, and Materials, 4th ed. (McGraw-Hill Education, New York, 2014).
10. R. Zarnic and S. Gostič, “Seismic behavior of reinforced concrete columns with composite reinforcement,” Eng. Struct. **25**, 487–500 (2003). https://doi.org/10.1016/S0141-0296(02)00177-0
11. M. Dolšek and P. Fajfar, “Soft storey effects in uniformly infilled reinforced concrete frames,” Earthq. Eng. Struct. Dyn. **30**, 813–833 (2001). <https://doi.org/10.1002/eqe.42>
12. A. Abdusattarov, F. E. Abdukadirov, and N. X. Sobirov, “Numerical calculation of elements of thin-walled structures under alternating loading taking into account damage,” *J. Phys.: Conf. Ser.* **1479**, 012143 (2020). <https://doi.org/10.1088/1742-6596/1479/1/012143>
13. F. E. Abdukadirov and T. Khasanov, “Design and calculation of surface road conductors,” *AIP Conf. Proc.* **3265**, 050011 (2025). <https://doi.org/10.1063/5.0265355>
14. A. Ibrokhimov, K. Djumaev, B. Artikova, and F. Abdukadirov, “RETRACTED: Numerical study of particle motion in a two-dimensional channel with complex geometry,” *BIO Web Conf.* **84**, 05037 (2024). <https://doi.org/10.1051/bioconf/20248405037>