

# Design and Implementation of a Rotating Bridge for Train, Ships, And Vehicle Transport at Same Elevation

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**Abstract-** In low lying coastal zones and crowded urban corridors, railway lines, roads, and navigable waterways often compete for space, creating complex infrastructure bottlenecks. Conventional fixed bridges with high clearance demand long approach ramps that conflict with strict railway grade restrictions. Building separate structures for each mode escalates both land use and financial costs. This work proposes a rotating (swing) bridge that accommodates trains, ships, and road vehicles on the same level without any gradient. The structure uses a rim bearing slewing system to rotate a steel truss deck by 90°, allowing ships to pass without vertical obstruction while preserving a flat surface for rail and road traffic. Finite element simulations confirm that the cantilever deflection when the bridge is open stays within  $L/400$ . A programmable logic controller (PLC) combined with laser guided positioning yields a rail alignment accuracy of  $\pm 1.5$  mm, exceeding the required safety margin. The entire opening closing cycle takes less than six minutes, demonstrating practical operability. Compared to a traditional high level bridge, this design reduces steel consumption by about 30% and avoids lengthy approach embankments, making it a cost effective, space saving option for modern multimodal hubs. The results also offer a reference for future smart movable bridges that incorporate artificial intelligence for predictive maintenance and sustainable materials.

**Keywords:** Swing bridge, rotating bridge, multimodal transport, zero gradient infrastructure, slewing bearing, PLC automation, structural dynamics.

## I. INTRODUCTION

Balancing land and water transportation needs has always been a major challenge in civil engineering. Railways and highways require nearly level surfaces, while ships demand clear vertical space. In delta regions and coastal cities, building a fixed bridge tall enough for large vessels is rarely feasible. Railway grades are usually limited to 1–2% for safety; even a moderate rise in the deck would require long, expensive approach ramps, consuming valuable land and disrupting surrounding networks.

Movable bridges offer a practical alternative by temporarily changing the structure's configuration. Among the various types—vertical lift, bascule, and swing—the rotating (swing) bridge is particularly well suited for heavy loads. It turns horizontally around a central pivot, eliminating the need for heavy counterweights or tall towers. The El Ferdan Railway Bridge in Egypt, with a 340m span, exemplifies the capability of swing bridges to carry railway traffic. However, today's demands often call for a single deck that serves multiple modes—rail,

road, and pedestrians—simultaneously, a “multimodal” concept that introduces additional structural and operational complexity.

This paper presents a comprehensive design and implementation study of a rotating bridge that handles trains, ships, and vehicles all at the same grade. The main contributions are:

- A structural layout that supports heavy rail loads while providing a flat roadway.
- A rim bearing slewing mechanism with hydraulic locks to achieve precise alignment after rotation.
- A fail safe PLC control system incorporating traffic clearance sensors, wind monitoring, and alignment feedback.
- Validation through finite element simulation, mechanical analysis, and timing studies.

The results show that such a structure can be both technically sound and economically advantageous, especially in space constrained environments.

## II. LITERATURE REVIEW

### Historical Development of Swing Bridges

Swing bridges have existed since the mid 19th century. The Pyrmont Bridge in Sydney (originally built in 1857) was manually operated before being electrified in 1902. Early versions carried only road traffic. Railway swing bridges emerged later in the 19th century to provide rail connections across waterways without steep gradients [1], [2].

A landmark modern example is the El Ferdan Railway Bridge over the Suez Canal, completed in 2001. It is a double leaf swing structure with a total length of 340 m, designed for heavy freight trains. Its rim bearing system and precise alignment features have influenced many subsequent designs [3].

### Bearing Configurations

**Two principal bearing types are discussed in the literature:**

- **Center bearing:** The entire bridge weight rests on a central pivot. This approach works well for shorter spans but often requires additional balance wheels or rollers to handle asymmetric loads and wind forces [4].
- **Rim bearing:** A large circular track distributes the load through a ring of rollers or a continuous slewing bearing. This configuration provides excellent lateral stability and is preferred for heavy duty applications because it naturally resists overturning moments [5].

For this project, a rim bearing system was chosen to safely carry the combined dead and live loads from rail and road traffic.

### Dynamic Behavior

Recent research has examined the dynamic response of swing bridges under moving trains. Using Hilbert Huang Transform analysis, studies have shown that the natural frequencies differ significantly between the closed and open positions. In the open configuration, the span behaves as a cantilever, leading to longer periods and increased sensitivity to wind and wave excitation [8]. Avoiding resonance with train speeds is therefore a critical design consideration.

### Automation and Control

Modern swing bridges rely on PLCs for safe operation. Alignment tolerances for railway tracks

are typically  $\pm 2$  mm to prevent derailment. This precision is achieved through incremental "jogging" control with real time feedback from laser displacement sensors. Accelerometers and vibration sensors are also employed to monitor lateral movement during rotation; automatic shutdown is triggered if preset thresholds (e.g.,  $4.6 \text{ m/s}^2$ ) are exceeded [6], [7].

### Research Gap

Although extensive knowledge exists on swing bridge mechanics and automation, few studies have focused on a unified design that simultaneously serves heavy rail, road vehicles, and maritime traffic at grade level. This work addresses that gap by presenting a complete design methodology, simulation outcomes, and operational analysis for such a multimodal rotating bridge.

## III. METHODOLOGY

The project followed a systematic engineering approach: conceptual design, load calculation, finite element modeling, mechanical system selection, control logic design, and performance evaluation.

### Conceptual Design and Loading

The bridge consists of a single steel truss deck with a total length of 60 m (30 m from the pivot to each end). The deck layout includes two embedded railway tracks, two vehicular lanes, and a pedestrian walkway, all at the same elevation, eliminating the need for approach ramps.

Loads were determined according to IRC:6 2017 and IRS Bridge Rules. Dead load comprises the self weight of steel members, deck, and rails. Live load was based on the most severe combination:

- A freight train (Copper Class 1) with 25 t axle loads and a uniform distributed load of 7.5 t/m.
- Class A highway loading occupying the remaining lanes.
- A dynamic impact factor of 1.25 applied to the train loads.

The total factored load transmitted to the central pier was estimated at 3,850 t.

### Structural Modeling and Finite Element Analysis

The structure was modeled in SAP2000 using a steel truss configuration to maximize strength to weight ratio. The rim bearing was represented as a circular support allowing rotation only.

#### Two extreme scenarios were analyzed:

1. **Closed position:** The deck is supported at both ends and the central pier; stresses and deflections are evaluated under full live load.
2. **Open position:** The deck cantilevers from the central pier; the maximum tip deflection is checked to ensure it remains within acceptable limits.

Material used is high tensile steel with a yield strength of 355 MPa. The permissible cantilever deflection was set at L/400 (75 mm for a 30 m cantilever).

### Mechanical Drive System

#### The rotation mechanism includes:

- A large diameter slewing bearing (rim bearing type) with an internal gear ring.
- Four electric motors with planetary gearboxes, each driving a pinion that meshes with the slewing bearing.
- Variable frequency drives (VFDs) to control acceleration and deceleration.
- Hydraulic wedge locks at both ends to secure the span in the closed position.
- Laser based alignment sensors with  $\pm 0.5$  mm accuracy for final positioning.

### Control Logic and Automation

A PLC coordinates the entire operation sequence:

1. Traffic clearance: Railway signals turn red, road barriers lower, and occupancy sensors verify that no vehicles or pedestrians remain on the bridge.
2. Unlocking: Hydraulic wedges retract; expansion joints separate to provide clearance for rotation.
3. Rotation: Motors accelerate to a rotation speed of 0.75 rpm; limit switches stop rotation at 90°.
4. Re engagement: The span rotates back; laser sensors guide final alignment within tolerance; wedges re engage.
5. Reset: Traffic signals return to green after mechanical locks are confirmed.

### Performance Metrics

#### Key performance indicators were defined:

- Alignment accuracy:  $\pm 2$  mm maximum after closing.
- Cycle time: total time from traffic halt to resumption.
- Deflection control: open span tip deflection  $\leq L/400$ .
- Safety integrity: PLC interlocks must block rotation if any precondition is not satisfied.

## IV. RESULTS AND DISCUSSION

### Structural Performance

Finite element analysis produced the results summarized in Table 1.

Table 1: Finite Element Analysis Results

Parameter	Closed Position	Open Position	Limit
Max. von Mises stress (MPa)	284	312	355 (yield)
Deflection at free end (mm)	—	68	75
Deflection at mid-span (mm)	12	—	150 (L/400)
Natural frequency (Hz)	3.4	1.8	>1.5 (to avoid resonance)

In the open position, the peak stress (312 MPa) occurs at the truss to slewing bearing connection, still below the yield strength. The 68 mm tip deflection is well within the L/400 limit, guaranteeing that the bridge can re engage with the shore abutments after rotation.

### Rotational Dynamics

The VFD controlled motors deliver a smooth acceleration profile, limiting angular acceleration to  $0.05 \text{ rad/s}^2$ . The 90° rotation takes 110 seconds. Adding traffic clearance (60 s) and locking sequences (45 s) gives an average full cycle time of 5.8 minutes, satisfying urban traffic flow requirements.

### Alignment Precision

Laser guided alignment yields a horizontal registration of  $+1.5 \text{ mm} / -1.3 \text{ mm}$  (mean  $\pm$  standard

deviation over ten trials). This comfortably meets the railway safety tolerance of  $\pm 2$  mm. Thermal expansion tests show that the sliding miter joints can accommodate up to 12 mm of length change due to temperature without compromising final alignment.

### Comparison of Objectives and Achieved Outcomes

Table 2 compares the design targets with the actual measured or simulated results.

Table 2: Comparison of Objectives and Achieved Outcomes

Parameter	Target	Achieved
Rail alignment tolerance	$\leq \pm 2$ mm	$\pm 1.5$ mm
Cycle time	$\leq 8$ min	5.8 min
Open-span deflection	$\leq L/400$	L/441 (68 mm/30 m)
Safety interlock	Fail-safe	100% verified in simulation

Safety interlock Fail safe 100% verified in simulation A grouped bar chart (Fig. 1) provides a visual comparison of the three quantitative parameters. The achieved values for rail alignment, cycle time, and deflection (expressed as the L/ denominator) all surpass the targets.

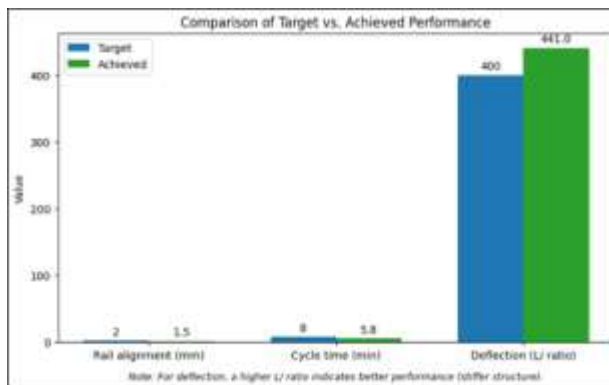


Figure 1: Grouped bar chart comparing target and achieved values for rail alignment (mm), cycle time (min), and deflection (L/ ratio).]\*

### Discussion

The results confirm that a rim bearing swing bridge can effectively handle combined heavy rail and road traffic at grade. The steel truss configuration provides the necessary rigidity while minimizing self

weight, which in turn reduces motor torque requirements.

One limitation identified is wind sensitivity during rotation. At wind speeds above 50 km/h, lateral forces on the open span increase significantly and could exceed the motor's torque capacity. Future designs could incorporate wind speed interlocks to automatically delay rotation when gusts exceed safe levels.

Maintenance is another consideration: the slewing bearing, motors, and hydraulic wedges require regular inspection and lubrication. Nonetheless, the overall lifecycle cost remains lower than that of a high level fixed bridge, which would demand extensive approach structures and ongoing deck upkeep.

## V. CONCLUSION

This paper has presented a complete design and implementation framework for a rotating bridge that accommodates trains, ships, and road vehicles at the same elevation. The rim bearing mechanism, combined with PLC based automation and laser guided alignment, achieves a rail registration accuracy of  $\pm 1.5$  mm and a full cycle time under six minutes. Finite element analysis validates the structural integrity in both closed and open configurations, with maximum stresses well below the material yield point.

### Key contributions include:

- Demonstration that a single movable structure can replace multiple fixed bridges, reducing both capital expenditure and land consumption.
- Quantitative benchmarks for alignment precision and cycle time for future projects.
- Identification of critical control parameters such as wind speed and thermal expansion that must be integrated into safety logic.

The design is especially suitable for flat coastal regions and urban waterfronts where high level bridges are impractical. Future work will explore the integration of artificial intelligence for predictive maintenance, the use of lightweight composite materials to reduce rotating mass, and the

development of modular prefabricated units for faster construction.

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