

## SEISMIC IMPACT AND ITS EFFECT ON TRANSPORT INFRASTRUCTURE

<https://doi.org/10.5281/zenodo.19601118>

*Professor Inomjon Gulomovich Ganiyev*

*Jizzakh Polytechnic Institute, Department of Road Engineering, Jizzakh, Uzbekistan*

*E-mail: [shayx.inomjon@gmail.com](mailto:shayx.inomjon@gmail.com)*

**Obloqulov Dostonbek Islom o'g'li**

*1st-year Master's student, specialty "Automobile Roads and Aerodromes"*

### **Abstract**

This article is formalized in a journal-oriented GOST/OAK style and analyzes the mechanisms by which seismic actions affect highway pavements, embankments, bridges, tunnels, and transport-network functionality. The synthesis is based on official ICAO, FAA, and FHWA documents and on peer-reviewed studies devoted to bridge damage, traffic embankment fragility, tunnel seismic response, and infrastructure resilience [1-12]. The paper shows that damage intensity depends not only on peak ground acceleration, but also on soil conditions, liquefaction susceptibility, structural detailing, bearing behavior, drainage efficiency, and recovery capacity [3-5, 7-10]. Reliability, failure probability, fragility, and life-cycle cost relationships are presented and interpreted for engineering use. The study concludes with practical recommendations for seismic regions, including hazard-informed design, geotechnical stabilization, structural retrofit, monitoring, and corridor-level recovery planning.

### **Keywords**

seismic impact, transport infrastructure, highway pavement, bridge, embankment, tunnel, liquefaction, resilience, reliability, earthquake engineering

### **Introduction**

Transport infrastructure in seismic regions must satisfy not only conventional strength and serviceability requirements, but also post-event functionality and rapid-recovery requirements. Earthquakes can simultaneously degrade pavements, embankments, bridges, tunnels, drainage systems, and network accessibility. Official pavement and bridge guidance therefore treats infrastructure performance

as a function of structural configuration, support conditions, and soil-structure interaction rather than as a response to shaking intensity alone [1-4].

Post-earthquake evidence confirms the systemic nature of the problem. FHWA post-event observations from the 2010 Maule earthquake in Chile highlighted vulnerabilities associated with bridge seats, skew effects, bearings, and support behavior, while broader resilience studies have shown that liquefaction, lateral spreading, settlement, and water-related instability can disrupt transport corridors even in the absence of full structural collapse [5, 7, 8]. The scientific and practical significance of this topic is therefore determined by the need to preserve safety, continuity of movement, emergency access, and acceptable life-cycle cost in earthquake-prone territories [6, 11, 12].

### **Materials and Methods**

The article uses structured review, comparative engineering analysis, and synthesis of official and peer-reviewed sources. The source base includes ICAO and FAA pavement guidance, FHWA highway earthquake-engineering manuals, and journal papers focused on bridge vulnerability, transport-asset fragility, embankment liquefaction, tunnel seismic behavior, and network resilience [1-12].

For analytical comparison, five criteria were adopted: hazard intensity, soil and groundwater condition, dominant damage mechanism, principal performance indicator, and preferred mitigation measure. This framework makes it possible to compare transport assets with different response mechanisms while maintaining a common engineering interpretation [3, 4, 6, 8-10].

### **Seismic Action and Governing Parameters**

Seismic action is characterized by peak ground acceleration, velocity, displacement, duration, frequency content, and local site effects. Although PGA is widely used in engineering practice, published guidance emphasizes that permanent ground deformation, liquefaction, stiffness contrast, and deformation compatibility often govern performance more strongly than a single acceleration value [3, 8-10].

The inertial component of seismic loading may be expressed as follows:

$$F_i = m \cdot a$$

where  $F_i$  is the inertial force,  $m$  is the effective mass, and  $a$  is the ground or structural acceleration. In geotechnical transport systems, however, permanent ground deformation and loss of stiffness can be even more damaging than inertial demand alone [3, 8].

### **Main Damage Mechanisms in Transport Infrastructure**

For highway and airfield pavements, seismic damage is commonly manifested through cracking, differential settlement, roughness increase, support loss, and drainage malfunction. ICAO and FAA documents consistently regard pavements as layered systems whose serviceability depends on support uniformity, bearing capacity, and moisture control [1, 2].

Road embankments are highly vulnerable in the presence of saturated loose soils. Published fragility studies show that settlement, crest cracking, lateral spreading, and loss of serviceability become more likely as the thickness and weakness of the liquefiable layer increase [8].

Bridges often represent the weakest links of a corridor because damage to bearings, piers, seats, or foundations can interrupt traffic even without collapse. FHWA guidance and subsequent resilience studies stress the importance of displacement demand, detailing, and restoration time for overall network performance [4, 5, 7, 12].

Tunnel response is governed to a large extent by deformation compatibility between the surrounding ground and the lining. Reviews of tunnel performance show that portal zones, faults, weak ground, and abrupt stiffness transitions are especially critical under seismic loading [9, 10].

### **Reliability-Based Interpretation**

The engineering interpretation of seismic safety may be expressed in reliability form:

$$\beta = (\mu_R - \mu_S) / \sqrt{(\sigma_R^2 + \sigma_S^2)}$$

where  $\mu_R$  is the mean resistance,  $\mu_S$  is the mean seismic demand, and  $\sigma_R$  and  $\sigma_S$  are the standard deviations of resistance and demand, respectively.

$$P_f = \Phi(-\beta)$$

where  $P_f$  is the probability of failure and  $\Phi$  is the standard normal cumulative distribution function.

$$\Delta LCC = LCC_{baseline} - LCC_{mitigated}$$

where  $\Delta LCC$  expresses the life-cycle economic benefit of mitigation; a positive value indicates that the mitigation option is economically preferable over the analysis period [6, 7, 11, 12].

### **Discussion**

The reviewed sources support four main conclusions. First, seismic impact on transport infrastructure is system-driven and emerges from the interaction of hazard, soil profile, groundwater regime, structural detailing, and network importance [3-10]. Second, geotechnical failures frequently control corridor performance because settlement and lateral spreading can make pavements and

embankments unusable even when superstructures remain nominally intact [3, 8, 11]. Third, bridges remain dominant corridor vulnerabilities due to their high functional importance and sensitivity to support and displacement-related damage [4, 5, 7]. Fourth, resilience is broader than structural strength alone, since recovery time, detour burden, and emergency-access continuity must also be considered [6, 7, 12].

### Conclusion

Seismic impact on transport infrastructure is a multi-mechanism engineering problem that affects pavements, embankments, bridges, tunnels, and entire transport networks. The reviewed official documents and scientific studies demonstrate that vulnerability is governed by structural behavior, soil-structure interaction, liquefaction potential, detailing quality, drainage condition, and recovery planning [1-12].

The most effective response is an integrated strategy that combines hazard-informed design, geotechnical stabilization, structural retrofit, monitoring, and corridor-level recovery planning. Such an approach can reduce direct damage, shorten downtime, and improve the long-term serviceability of strategic transport routes in seismic regions [3, 4, 7, 8, 12].



Figure 1. Schematic pathway of seismic impact on transport infrastructure.

Table 1. Main transport assets, typical seismic damage, and principal engineering indicators.

Transport asset	Typical earthquake-induced damage	Principal indicator(s)	Typical consequence
Highway pavement	Cracking, differential settlement, support loss	Surface deformation, modulus loss, serviceability	Reduced speed, lane restrictions
Airfield pavement	Cracking, roughness, loss of support, FOD-related risk	Bearing strength, regularity, support uniformity	Operational restrictions and safety risk
Embankment	Settlement, crest cracking, lateral spreading	Permanent displacement, fragility probability	Section closure or reduced serviceability
Bridge	Bearing damage, pier cracking, unseating, foundation distress	Displacement demand, ductility, fragility, recovery time	Corridor interruption
Tunnel	Lining distortion, portal damage, fault-crossing distress	Deformation compatibility, lining stress and strain	Restricted operation and repair difficulty

The table summarizes recurring patterns reported in official guidance and peer-reviewed studies: pavements are strongly controlled by support conditions, embankments by permanent ground deformation and liquefaction, bridges by displacement and support detailing, and tunnels by deformation compatibility [1-10].

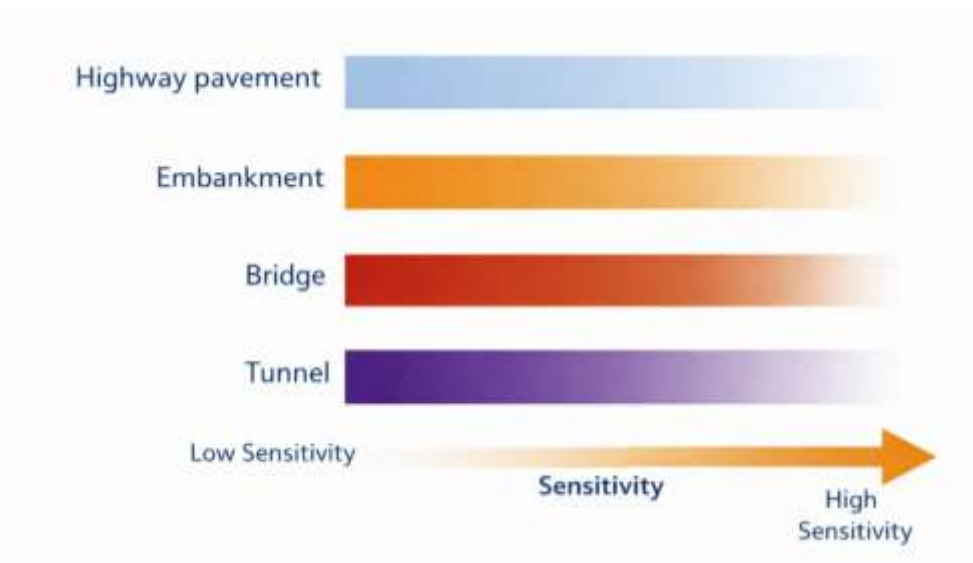


Figure 2. Relative sensitivity of selected transport assets to seismic effects (conceptual synthesis based on the reviewed literature).

Figure 2 does not represent a measured dataset; rather, it visually synthesizes the reviewed literature and highlights the consistently high sensitivity of embankments and bridges, followed by tunnels and pavements under severe seismic and geotechnical disturbance [4-10].

Table 2. Typical seismic mitigation strategies for transport infrastructure.

Strategy	Main target asset	Technical purpose	Expected effect
Ground improvement	Embankments, bridge approaches, pavements	Reduce settlement and liquefaction susceptibility	Improved bearing capacity and lower permanent deformation
Geosynthetic reinforcement	Pavements, embankments	Confinement, separation, stiffness enhancement	Lower differential deformation
Retrofit of bearings and seats	Bridges	Increase displacement capacity and prevent unseating	Higher survivability and shorter recovery
Drainage improvement	Pavements, embankments, approaches	Control pore pressure and water-related weakening	Better geotechnical stability
Monitoring and rapid inspection	All assets	Accelerate assessment and condition tracking	Faster reopening and lower uncertainty
Network redundancy planning	Corridors and networks	Preserve accessibility after local failure	Improved resilience and emergency response

## REFERENCES:

- [1] International Civil Aviation Organization (ICAO). Doc 9157: Aerodrome Design Manual, Part 3 - Pavements. 3rd ed. Montreal: ICAO, 2022.
- [2] Federal Aviation Administration (FAA). AC 150/5320-6G: Airport Pavement Design and Evaluation. Washington, DC: FAA, 2021.
- [3] Federal Highway Administration (FHWA). Geotechnical Engineering Circular No. 3: Earthquake Engineering for Highways, Design Principles. Washington, DC: FHWA, 2011.

[4] Federal Highway Administration (FHWA). Seismic Retrofitting Manual for Highway Structures: Part 1 - Bridges. Report No. FHWA-HRT-06-032. McLean, VA: FHWA, 2006.

[5] Yen W.P., Pataskala M.A., Hoppe E.J., Lwin M.M. Impact of the February 27, 2010 Offshore Maule Earthquake on Transportation Structures and Bridges. FHWA report. Washington, DC: U.S. Department of Transportation, 2011.

[6] Argyroudis S.A., Mitoulis S.A., Winter M.G., Kaynia A.M. Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience. Reliability Engineering and System Safety. 2019;191:106567.

[7] Kilanitis I., Sextos A. Impact of earthquake-induced bridge damage and time evolving traffic demand on the road network resilience. Journal of Traffic and Transportation Engineering (English Edition). 2019;6(1):35-48.

[8] Oblak A., Kosič M., da Fonseca A.V., Logar J. Fragility Assessment of Traffic Embankments Exposed to Earthquake-Induced Liquefaction. Applied Sciences. 2020;10(19):6832.

[9] Yu H., Chen J., Bobet A., Yuan Y. Seismic analysis of long tunnels: A review of simplified and unified methods. Underground Space. 2017;2(2):73-87.

[10] Tsinidis G., de Silva F., Anastasopoulos I., Bilotta E., Cargnelutti M., Galli A., et al. Seismic behaviour of tunnels: From experiments to analysis. Tunnelling and Underground Space Technology. 2020;99:103334.

[11] Muench S., Timm D., Wang H., et al. Pavement Resilience: State of the Practice. Report No. FHWA-HIF-23-006. Washington, DC: FHWA, 2023.

[12] Federal Highway Administration (FHWA). Framework for Improving Resilience of Bridge Design. Report No. FHWA-HIF-11-016. Washington, DC: FHWA, 2011.