



A WHITE PAPER FROM ALTICORD INFRASTRUCTURE & MOBILITY PVT LTD

Engineering for a Changing Climate: Resilience as a Design Requirement for Mountain Mobility

Why climate resilience cannot be a specification checked once at design stage — and what that means for how mountain mobility infrastructure should be built, financed and operated.

ALTICORD INFRASTRUCTURE & MOBILITY PVT LTD

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Executive Summary

Mountain regions across South Asia are experiencing climate change faster and more visibly than most other parts of the world. Extreme rainfall events in the Indian Himalayan Region have increased by an estimated 15 to 20 percent since the 1950s, and the Himalayan range as a whole already accounts for the large majority of South Asia's recorded landslides. The infrastructure that was engineered and sited for the climate of thirty years ago is, in a growing number of cases, no longer engineered for the climate it now operates in.

This paper argues that climate resilience cannot be treated as a specification checked once, at design stage, and then assumed to hold for the life of an asset. It is a continuous operating discipline — monitoring, maintenance, adaptation and, where necessary, reinforcement — that has to be sustained for decades. That has direct implications for how mountain mobility infrastructure should be designed, and even greater implications for how it should be financed and operated.

A climate-resilient design is a design that was correct for the climate on the day it was approved. Climate-resilient infrastructure is infrastructure whose operator keeps it correct for the climate it actually faces, year after year, as that climate keeps changing.

The paper sets out why road-based infrastructure bears a disproportionate share of climate-related failure in mountain terrain, what internationally recognised resilience principles imply for mobility infrastructure design, why aerial systems carry a structural resilience advantage alongside climate exposures of their own, and why the same design-build-finance-operate logic that this paper's companion pieces apply to safety and to economics applies with equal force to climate resilience: an operator with a multi-decade stake in an asset's performance has the incentive to keep adapting it: a contractor whose obligations end at handover does not.

1 A Mountain Environment Changing Faster Than Its Infrastructure

The Himalayan region is warming faster than the global average, and the hydrological consequences are already visible rather than projected. Roughly three-quarters of the region's annual rainfall arrives within a single monsoon window, and within that window, short, intense cloudburst events — heavy rain concentrated over a small area in a short time — are becoming more frequent and more severe across

the Himalayan foothills, even as broader monsoon patterns elsewhere in India show different trends.

The consequences of a single severe event illustrate the scale of exposure. In July and August 2023, an extended spell of intense rainfall in Himachal Pradesh triggered landslides that blocked roughly 1,300 roads, including five national highways, effectively isolating parts of the state from the rest of India for days. Over a thousand bus routes were suspended, tens of thousands of tourists required evacuation, and the disruption to road access delayed emergency response at the moment it was most needed. In August 2026, a glacial-lake-related flash flood in the Nepal Himalaya destroyed roads and a cross-border bridge and killed over a hundred people — a reminder that glacial and hydrological hazard, not only rainfall, is an emerging category of risk across the range.

Neither event is an isolated anomaly. Independent research bodies studying the Indian Himalayan Region have documented a measurable, decades-long increase in extreme rainfall frequency, and have concluded that the prevailing model of mountain infrastructure development has not kept pace with the change in the underlying climate risk it is exposed to.

2 Why Roads Bear a Disproportionate Share of the Risk

Not all mountain infrastructure is equally exposed to climate-driven failure, and the reason is largely geotechnical rather than climatic. A road cut into a mountainside works by removing the slope's natural support — cutting into the hillside, and often filling and compacting the downhill side — to create a level running surface. That cut and fill disturbs a slope's natural drainage and stability, and every subsequent widening or realignment repeats the disturbance. The resulting slopes are inherently more vulnerable to saturation-triggered failure than the undisturbed terrain around them, which is precisely why intensifying rainfall translates so directly into landslide risk concentrated on and above road corridors.

Aerial systems are not immune to climate risk, but their exposure is structurally different. A ropeway's land-disturbing footprint is limited to its tower foundations and terminal stations — typically a small fraction of the disturbed area of an equivalent-length road — leaving the slope beneath largely in its natural, more stable state. This does not eliminate exposure: towers must be engineered for wind loading, icing in appropriate climates, lightning strike, and foundation stability on the specific slope and soil conditions of their site, and a system's control and haulage infrastructure must be designed to detect and safely respond to extreme weather in real time. But the exposure is engineered and site-specific, rather than being a

structural feature of the transport mode itself in the way that slope-cutting is for roads.

This is an important qualification, not a claim that ropeways are immune to climate risk. It is a claim that the nature of the risk is different, and in several important respects more tractable through engineering than the risk profile of an extended mountain road corridor.

3 What Climate Resilience Actually Requires

International infrastructure and development finance institutions have converged on a common understanding of what climate-resilient infrastructure requires, most notably through the Principles for Quality Infrastructure Investment endorsed by the G20 — a six-principle framework in which climate and disaster resilience is treated as a core, non-negotiable dimension of infrastructure quality, on the same footing as economic efficiency, safety and accessibility, and applicable to projects delivered through public-private partnership as much as to those delivered by government directly.

In practice, applying this standard to a mobility asset means at minimum:

- Designing to forward-looking climate projections for the specific site and structure lifetime, rather than to historical rainfall, wind and temperature records alone — because, as Section 1 illustrates, the historical record increasingly understates current and future risk in Himalayan geographies.
- Conducting a site-specific geotechnical and hydrological risk assessment for every tower foundation, station site and access route, not only for the headline alignment.
- Building in structural and operational redundancy — backup power, redundant braking and communication systems, and defined safe-shutdown protocols for extreme wind, lightning or seismic activity.
- Installing real-time monitoring for the conditions most likely to require an operational response — wind speed, precipitation, seismic activity and, where relevant, upstream glacial or hydrological hazard indicators — feeding into a defined early-warning and evacuation protocol.
- Treating the initial design-basis climate assumptions as provisional rather than permanent, with a defined process for reviewing and, where necessary, retrofitting the asset as climate data and site experience accumulate over its operating life.

The last of these is the point most easily lost in a construction-only mindset, and the one this paper returns to in Section 5: resilience engineered to a fixed specification at the design stage degrades in relative terms as the climate continues to shift, unless someone remains responsible for revisiting that specification over the asset's life.

4 The Economic Logic of Building for Resilience

The financial case for investing in resilience up front, rather than accepting climate-driven disruption and rebuilding after the fact, is by now well established in international infrastructure finance. The OECD estimates that meeting global climate and development goals will require on the order of USD 6.9 trillion a year in sustainable infrastructure investment through 2030 — a figure that reflects, in large part, the recognition that climate-resilient infrastructure investment is markedly more cost-effective over an asset's life than the combined cost of repeated climate-driven failure, emergency repair and service interruption.

This logic applies with particular force to mountain mobility corridors, where a single severe monsoon event can close a road for days or weeks, and where the true cost of that closure is rarely limited to repair expenditure. It includes lost tourism and pilgrimage revenue for every business along the corridor, delayed emergency response for local communities, and the second-order damage to a destination's reputation for reliable access — the same reputational and economic effect, working in reverse, that this paper's companion piece on the economics of mobility describes as the multiplier effect of reliable access.

Resilience investment, in other words, is not a cost layered on top of a mobility project's economic case. For mountain corridors exposed to intensifying climate risk, it is a precondition for that economic case holding up over the life of the concession.

5 Why This Is an Operating Discipline, Not a Design Milestone

A resilience specification approved at financial close reflects the best available climate science and site data at that moment. In a region where extreme rainfall frequency has already shifted measurably within living memory, that specification does not stay current on its own. Someone has to keep it current — revisiting risk assessments as new data arrives, upgrading monitoring systems as better technology becomes available, and in some cases physically reinforcing towers,

foundations or drainage as conditions evolve beyond what the original design anticipated.

Nobody retrofits an asset they no longer have a financial stake in. This is the same incentive gap this paper's companion piece identifies for safety and maintenance — and it applies with equal, perhaps greater, force to a hazard that is itself actively getting worse.

This is why Alticord treats climate resilience as inseparable from its design-build-finance-operate concessionaire model, rather than as a construction-phase specification. An entity that will be operating and maintaining a mountain mobility asset for a multi-decade concession term has a direct, continuing commercial interest in the asset performing safely through whatever the climate does over that period — an interest that a construction contractor, whose obligations are substantially resolved at handover, structurally does not share to the same degree.

In practice, this means resilience monitoring, review and adaptation is treated as a standing operational function for the life of the concession, not a one-time deliverable signed off before construction begins.

6 A Framework for Climate-Resilient Corridor Design

Alticord evaluates the climate resilience of a potential mobility corridor alongside its transport and economic case, using a consistent set of questions:

- Forward-looking exposure: what do climate projections, not only historical records, suggest for extreme rainfall, wind and temperature at this specific site over the asset's intended operating life?
- Comparative footprint: how does the land-disturbance footprint of an aerial alignment compare with the road-based alternative, and what does that imply for landslide and slope-failure exposure?
- Geotechnical specificity: has every tower and station site received individual geotechnical assessment, rather than relying on a single corridor-level study?
- Redundancy and monitoring: does the design include the structural and operational redundancy, and the real-time monitoring, that current international resilience guidance treats as standard?
- Institutional durability: is the project structured so that the entity responsible for the asset has a multi-decade incentive to keep revisiting and upgrading its resilience posture, rather than a one-time obligation that ends at handover?

Corridors that score well against this framework are markedly better positioned to remain safe, reliable and economically viable across a multi-decade concession term, in a climate that is not expected to stop changing.

Conclusion

Mountain regions across South Asia are living through a measurable, accelerating shift in the climate risk their infrastructure was built for. Roads bear a disproportionate share of the resulting failure because of how they are physically built into unstable terrain; well-engineered aerial systems carry a structurally different, and in important respects more manageable, risk profile — provided that profile is actively engineered and continuously managed, not assumed.

The central argument of this paper is that climate resilience is fundamentally an operating discipline rather than a design milestone. It has to be revisited, monitored and adapted for as long as the asset is in service, in a climate that continues to change after the day the asset opens. That is precisely the discipline a design-build-finance-operate concessionaire model is built to sustain, and precisely what a construction-only delivery model structurally struggles to guarantee.

This is why Alticord treats resilience not as a line item in a technical specification, but as a core and continuing responsibility of the concessionaire role it has set out to play — for as long as it remains accountable for the mountain infrastructure it builds.