UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

SUPPORTING THE POLICIES ON GREEN AND RESILIENT TRANSPORT INFRASTRUCTURE ALONG THE ASIAN HIGHWAY NETWORK

PRELIMINARY FINDINGS

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STUDY BACKGROUND

- **Study Objective:**
  - To increase the awareness and understanding amongst member countries regarding new construction and design elements including state-of-the-art engineering technologies and construction materials, which can make road infrastructure more environmentally sustainable and more resilient to natural hazards.
- **Study Scope:**
  - Overview of highway design standards across India, Kazakhstan, Philippines, Russian Federation, and Uzbekistan emphasizing their sustainability and resilience aspects.
  - Overview of selected case studies for ESCAP subregions including Cambodia (1 case), India (2), Russian Federation (2), the US (2) and Vietnam (1). The latter also addressed the gender aspects of resilience providing an example of empowering women to manage rural road maintenance.
  - Overview of selected case studies for six Small Island Developing Countries, namely: Samoa, Mozambique, Kiribati, Tuvalu, and the Coral Atolls of the Pacific Islands.
  - Overview of selected cases studies for non-ESCAP countries including Costa Rica, EU, Nicaragua, and Portugal. These were chosen for their high relevance and valuable experience of adaptation for resilience.

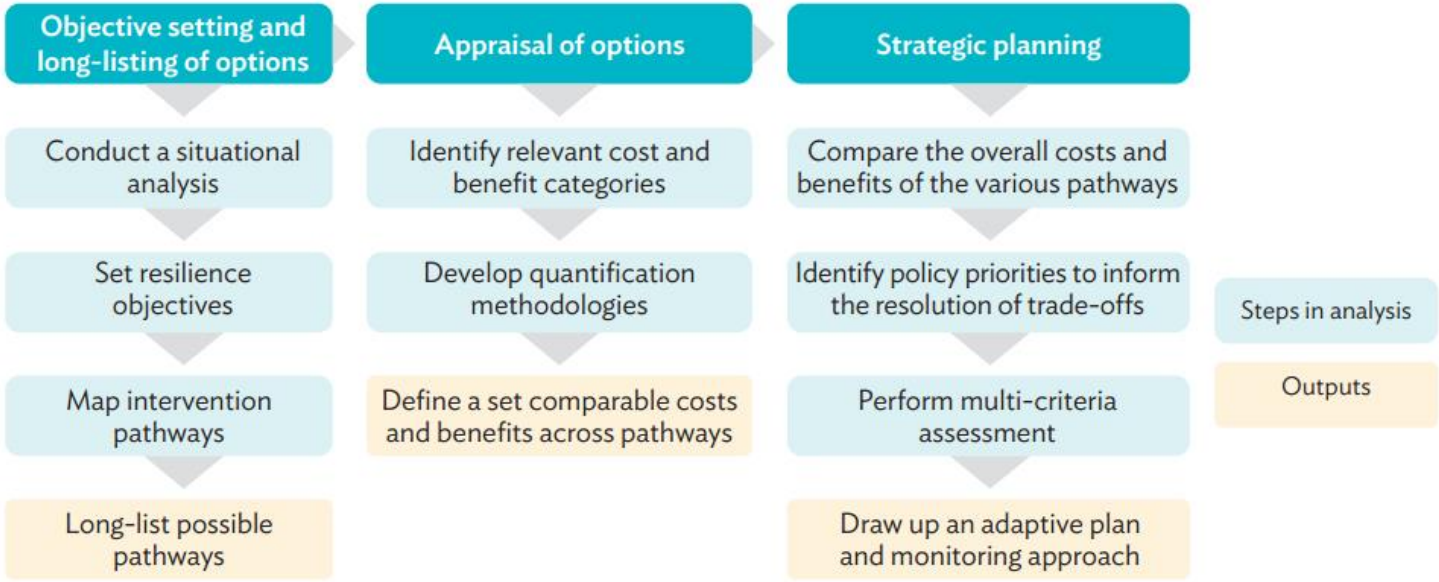
WHY RESILIENCE?

- **What is infrastructure resilience?**
  - Resilient infrastructure means adequate engineering design built to robust metrics to withstand storms and other natural disasters of a predetermined magnitude. In addition, the designs should be simplistic yet complex enough to allow modifications to be made over time as necessary as current conditions change.
- **Underpinning facts:**
  - According to a 2020 study, between 2004 and 2020, natural disasters caused more than $500 billion in losses across the Developing Asia region, affecting 2.1 billion people in total
  - Up to $1.7 trillion in annual capital expenditures will be required by developing Asia between 2017 and 2030 in order to meet infrastructure demands.
  - Regional examples show that the knock-on costs of outages can be twice as high as the cost of damaged infrastructure— admitting that costs can be up to $2 for every $1 spent on damaged assets.
- **Developing a resilient and sustainable transport infrastructure is crucial to achieve the global development goals for Asia and the Pacific**

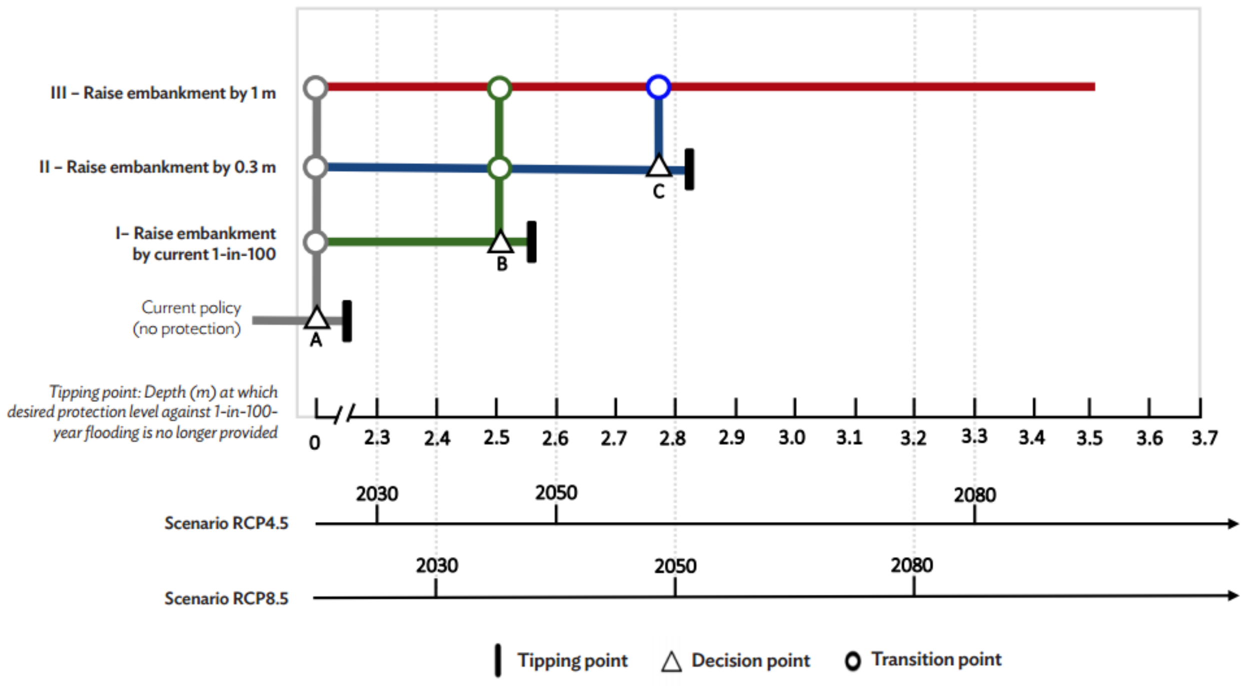
DYNAMIC ADAPTIVE POLICY PATHWAYS FOR ROAD RESILIENCE IN CAMBODIA (1/2)

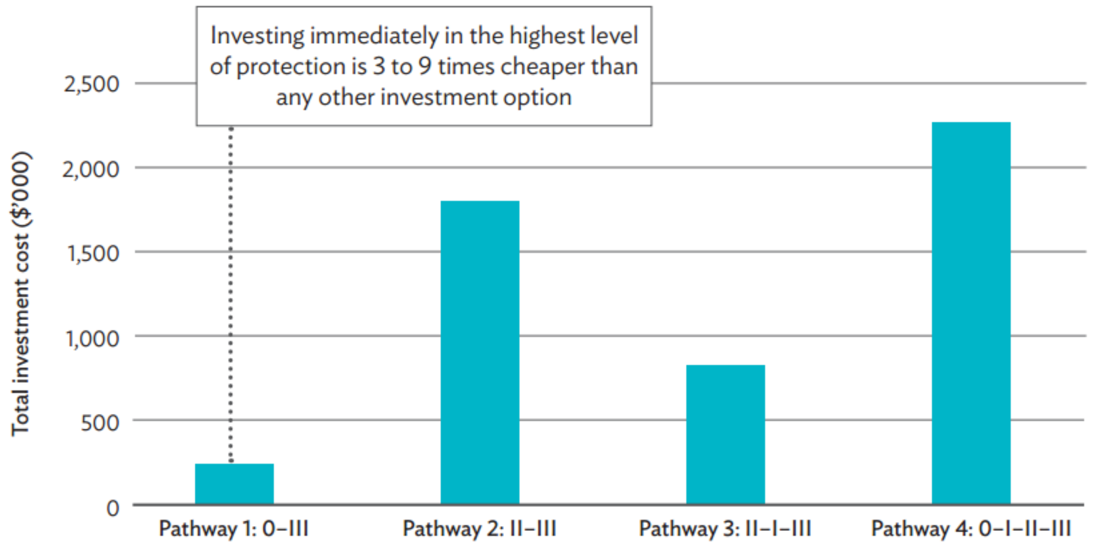
- According to WBG/ADB paper, flooding in Cambodia affects 90,000 people and causes USD 100 – 170 million in damage each year

- Determining the appropriate level of investment in resilience is complicated by **uncertainties** surrounding future **climate risk, socioeconomic outcomes, and policy options.**
- The dynamic adaptive policy pathways (DAPP) approach involves committing to lower-cost and more minor investment actions in the short term while building a framework of potential future activities. Trigger points are external changes indicating that steps need to be taken.



DYNAMIC ADAPTIVE POLICY PATHWAYS FOR ROAD RESILIENCE IN CAMBODIA (2/2)





- Analysis of three road sections most exposed to flooding was done with drawing pathways for investment decisions.

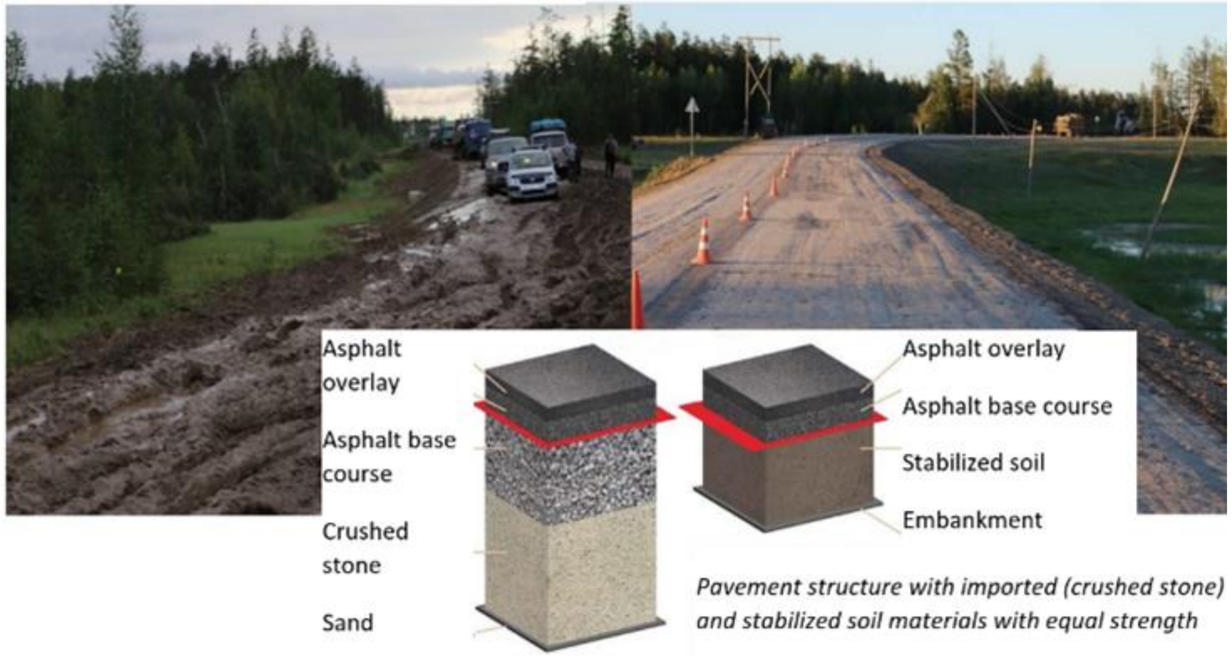
- The analysis showed that the asset can be protected against 1-in-100-year flooding through four sequences of actions. The sequences are based on combinations of the following actions:
  - The minimum level of action required in the short term is to raise the embankment to a level of protection against 1-in-100-year flooding.
  - An intermediate action level would be raising the embankment by 0.3 m.
  - The highest action level would involve raising the embankment by 1 m.

USE OF HEAT-INSULATING SHEETS IN ROAD CONSTRUCTION IN THE RUSSIAN FEDERATION

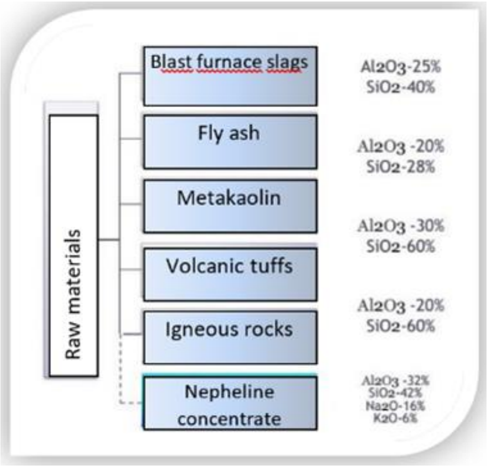
- Most of the Russian territory is located in the zone of seasonal freezing of soils characterized by frost heaving.
- The freezing moisture accumulated in the soil increases soil volume by up to 9% leading to the destruction of the road.

- The use of extruded polystyrene foam has proven that it can withstand evenly distributed pressure from a moving traffic load up to 70 t/m^2
- Rigid water-, bio- and frost-resistant layers in the pavement prevent the frost hive and function as a barrier that ensures uniform load distribution.
- The introduction of extruded polystyrene foam in the embankment makes it possible to distribute static and dynamic loads more evenly and reduce the destructive effect on the subgrade.
- Traditional embankment construction technology requires about three years to stabilize settlement while using extruded polystyrene foam to replace the embankment soil helps reduce the stabilization period to 3–6 months.
- According to expert estimates, using extra-thick heat-insulating sheets for subgrades on weak soils reduces labor costs by up to 20%, and construction costs can be reduced by 10–20%. The construction period is also reduced significantly.

GREEN MATERIALS FOR RURAL ROADS IN THE RUSSIAN FEDERATION



Pavement structure with imported (crushed stone) and stabilized soil materials with equal strength



- Cheap and green methods for improving rural roads and hydraulic construction have been tested that are using alternative materials and technologies for soil stabilization in remote regions of the Russian Federation.

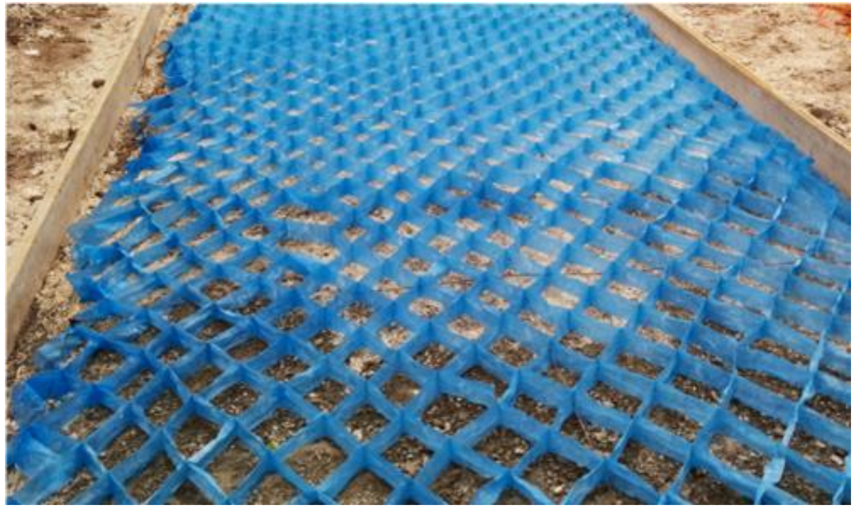
- Geopolymer binders are hydraulic binders most suitable for soil stabilization. Critical properties of geopolymer-based concrete mainly include:
  - Compressive strength up to 130 MPa;
  - Curing rate - 20 MPa after 4 hours;
  - Low shrinkage during curing - less than 0.05%;
  - Frost resistance - loss of strength after 180 cycles - less than 5%;
  - Water resistance (minimum permeability);
  - Chemical resistance and strengthening in seawater.
- The use of marine cement in port and hydraulic engineering construction allows to optimize the entire cycle of hydraulic engineering works:
  - Minimized energy consumption and limited need for cargo transportation;
  - The use of materials from nearby the construction site (sea sand, sea water) avoids the need to bring washed sand and fresh water for the production of the mixture;
  - The unit cost and volume of the binder are 1.5 times less than that of Portland cement.

GENDER ASPECT OF RESILIENCE:
EMPOWERING WOMEN TO MANAGE RURAL ROAD MAINTENANCE IN VIETNAM

- In steep, mountainous areas of Vietnam costs of road maintenance are very high due to the challenging terrain and heavy rainfalls.
- The low-income communities lack resources to cover maintenance costs, and poor road conditions limit access, constrain economic opportunities, and exacerbate poverty—particularly for women.

- Background:
  - In 2010, the World Bank's "Third Rural Transport Project (RTP3)" initiated a small pilot routine road maintenance (RRM) activity for ethnic minority women in five communes in mountainous Lao Cai Province
  - The Provincial Women's Union (PWU), under the Vietnam Women's Union (VWU), managed the pilot with technical guidance from the Provincial Department of Transport (PDOT) and the District Urban Management Department
  - Based on very positive outcomes of the pilot, a Women-Managed Routine Rural Road Maintenance Program was then developed to cover more districts and two additional provinces
- Key outcomes:
  - The Union managed 2,293 people who planted 39,235 trees along 87.4 kilometers of roads that were maintained by women-managed groups
  - Specific gains included:
    - greater access to markets and market information, leading to expanded crop production;
    - increased opportunities for employment and small business development;
    - lower costs for fuel, vehicle maintenance, farm inputs, and consumer goods; and
    - shorter travel times and fewer road accidents.
  - A policy has been enacted to include commune road maintenance in the official budget
  - New coordination mechanisms were established between provincial and district transport staff and the Women's Union, providing a model for collaboration with other social organizations

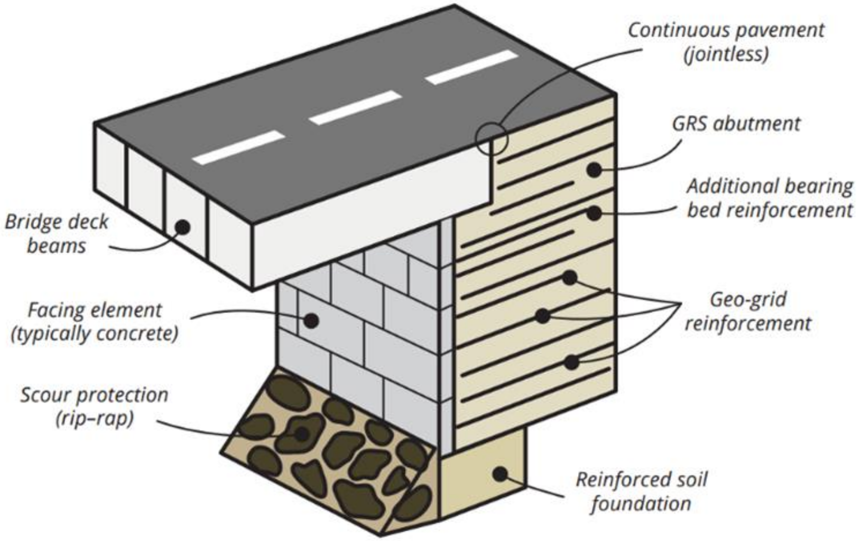
CLIMATE AND DISASTER RESILIENT ROADS USING GEOCELL CONCRETE PAVEMENTS IN KIRIBATI AND TUVALU



- Geocell concrete pavement is a solution that allowed small island states to have technologies that can be readily implemented without importing substantial equipment.

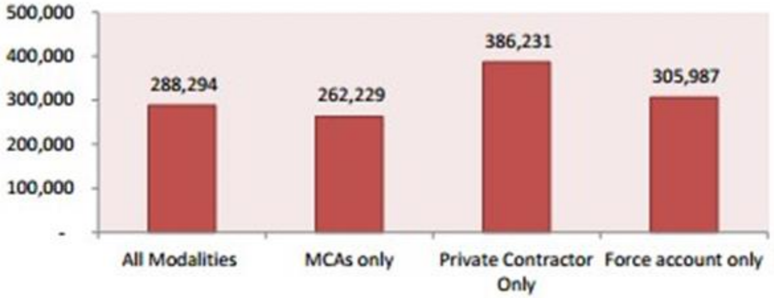
- Cement concrete geocell pavements were introduced to Kiribati and Tuvalu to provide climate and disaster resilient low-volume roads.
- Geocell pavements consist of an interlocking set of unreinforced concrete blocks formed by pouring cement concrete into a thin plastic lattice. The resulting composite structure serves as a flexible but impermeable pavement surface.
- Ranging from 75 to 150 mm thick, and 150 mm to 300 mm square, the cells are shaped by a high-density polyethylene (HDPE) sacrificial formwork that remains in the final pavement.
- Geocell pavements are ideally suited to remote islands because they can be constructed using labor with portable equipment, and the HPDE formwork is light and easy to transport.
- The ease of construction, climate and disaster resilience, and long-term performance make it an effective option for constructing resilient low-volume roads in small island states.

GEOSYNTHETIC REINFORCED SOILS FOR RAPID AND LOW-COST BRIDES IN SRI LANKA



- Sri Lanka's bridges serve as critical links in the transport network, taking road and rail traffic across rivers, but this aging infrastructure is typically in poor condition, with 50 percent of the country's bridges suffering from significant deterioration.
- To address these challenges, the study looked at applying innovative Geosynthetic Reinforced Soil (GRS) technology to the bridges of Sri Lanka with promising results, finding that locally sourced material could be used in conjunction with GRS to construct bridges faster and at a lower cost than traditional piled abutments.
- Concept designs were produced for a sample of four bridges, with a conclusion that the GRS approach could result in savings of 30 to 50 percent, not to mention a shorter construction time and added resilience.
- While the benefits of this technology have been clearly demonstrated in Sri Lanka, many other locations could put GRS to good use and enjoy similar benefits.

GREEN, INCLUSIVE, AND COST-EFFECTIVE ROAD PROGRAM IN NICARAGUA



- Nicaragua is subject to destructive earthquakes, volcanoes, landslides, and hurricanes. Roads to main cities may be impassable for a few hours during heavy rains. Secondary roads often get severely damaged by torrential rains.

- To propose an integrated solution for rural infrastructure delivery, the study aimed to expand the use of green technologies in road construction, promote social inclusion, and increase cost-effectiveness in the following key directions:
  - To challenge business-as-usual choices on pavement surface type (usually defaulted to asphalt) and contracting modalities;
  - To make extensive use of locally sourced and environmentally friendly road surfacing elements;
  - To adopt the use of the block stones on long sections of rural roads not limiting to the traditional use in urbanized areas;
  - To extend the application of the labor-based model to paved roads and not limit it to the historical roles on unpaved roads without compromising quality or undermining project budgets;
  - To enable widespread integration of local authorities and households in the road prioritization and construction phase.

- The community-based model (MCA) has proved to be a well-suitable approach to rural road infrastructure delivery in Nicaragua that is worth exploring for adaptation and use in similar conditions.

SUMMARY OF ENGINEERING OPTIONS FOR INCREASING INFRASTRUCTURE RESILIENCE

Type	Natural hazard: Hazard	Natural hazard: Intensity	Component	Critical system/component: Engineering improvement	Critical system/component: Quality improvement	Damage probability: Baseline	Damage probability: Improved	Total cost (including QC)
Highways on grade	EQ motion	PGD 0.5 m	Embankment	Provide geogrid reinforcement	Construction inspection, use of approved material	0.1	0.05	0.1
	Liquefaction	--	Embankment	Soil improvement	Geotechnical testing, construction inspection and testing	0.1	0.05	0.05
	Wind	--	--	--	--	--	--	--
	Flood	--	--	--	--	--	--	--
	Landslide	--	Road surface	Add retaining wall, stabilize sloe, shotcrete, soil nails	Construction monitoring	0.2	0.02	0.1
Highway bridges	EQ motion	Mw 7 PGA 0.4g	Bridge superstructure, column, foundation	Use CA or Japan seismic design, columns as fuse	Construction inspection, testing, qualify contractors	0.4	0.05	0.1
	Liquefaction	PGD 250 mm	Bridge foundation	Use pile foundation	Geotechnical testing, construction inspection	0.3	0.05	0.2
	Wind	Small events	Steel bridge members and connections	Use details with longer fatigue life during bridge design life	Inspection of welded connections, reduce section loss by corrosion prevention	0.05	0.01	0.05
	Flood	Large floods	Bridge foundation	Use riprap	Hydrological report, construction inspections	0.05	0.02	0.05
	Landslide	PGD = 14 in., 7 in.	Bridge foundation	Soil improvement	Apply Higher level of QA (assume (E) is on Standard level)	0.5	0.16	0.15
Secondary urban roads on grade	EQ motion	Mw 7 PGA 0.4g	Road surface and underlying material	Provide seismic reinforcement, compact the underlying material	Use earthquake resistance foundations	0.1	0.05	0.05
	Liquefaction	Large PGD: more than 0.3 m	Road surface and underlying material	Provide reinforcement against large ground displacement	Soil improvement, avoid areas subjected vulnerable to liquefaction	0.1	0.05	0.05
	Wind	--	--	--	--	--	--	--
	Flood	Large floods	Road surface	Provide barriers, improve drainage	Construction inspection, testing, qualify contractors	0.1	0.05	0.03
	Landslide	--	--	--	--	--	--	--
Urban (roadway) bridges	EQ motion	Mw 7 PGA 0.4g	Bridge superstructure, abutments, footings	Use CA or Japan seismic design, columns as fuse	Construction inspection, testing, qualify contractors	0.35	0.04	0.2
	Liquefaction	PGD 250 mm	Bridge foundation	H pile or pre-stressed pile foundation	Geotechnical testing, construction inspection	0.4	0.1	0.3
	Wind	Small events	Connection of diaphragms to steel girders	Reduce dissertation-induced fatigue cracking, redundant non-fracture critical design	Inspection of welded connections, reduce section loss by corrosion prevention	0.1	0.03	0.05
	Flood	Large events	Pier and abutment foundations	Mitigation of local scour, use rocks or pier walls	Regular inspection, construction quality control	0.03	0.02	0.01
	Landslide	--	--	--	--	--	--	--
Unpaved tertiary roads	EQ motion	Mw 7 PGA 0.4g	Road surface and underlying material	Provide seismic reinforcement, compact the underlying material	Use earthquake resistance foundations	0.1	0.05	0.1
	Liquefaction	Large PGD: more than 0.3 m	Road surface and underlying material	Provide reinforcement against large ground displacement	Soil improvement, avoid areas subjected vulnerable to liquefaction	0.1	0.05	0.05
	Wind	--	--	--	--	--	--	--
	Flood	Large floods	Road surface	Provide barriers, improve drainage	Elevate the roads	0.1	0.05	0.03
	Landslide	--	Road surface	Add retaining wall, stabilize slope, shotcrete, soil nails	Construction monitoring	0.2	0.02	0.05
Wooden bridges	EQ motion	Acceleration = 0.4g	Wood bridge trusses	Truss strengthening & connection retrofit	Apply Higher level of QA (assume (E) is on Standard level)	0.35	0.03	0.2
	Liquefaction	PGD = 10 in.	Bridge foundation	Pile addition (foundation retrofit)	Apply Higher level of QA (assume (E) is on Standard level)	0.44	0.13	0.3
	Wind	Connection fatigue category	Truss connections	Connection retrofit/replacement	Apply Higher level of QA (assume (E) is on Standard level)	0.15	0.05	0.1
	Flood	Flood return period (1,000 to 100 yr.)	Foundation ground	Scour mitigation by ground strengthening (riprap, rock, etc.)	Apply Higher level of QA (assume (E) is on Standard level)	0.06	0.02	0.03
	Landslide	PGD = 14 in., 7 in.	Bridge foundation	Soil improvement	Apply Higher level of QA (assume (E) is on Standard level)	0.63	0.25	0.25

Overview of Engineering Options for Increasing Infrastructure Resilience (Vol. 2) : Technical Annex (English). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/620731560526509220/Technical-Annex