Review and Recommendations of Road Design and Pavement Standards (2019)

- A Resilience Perspective -

Local Government Engineering Department

Local Government Division

Ministry of Local Government, Rural Development, & Cooperatives

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Local Government Engineering Department (LGED) approached the United Nations Office for Project Services (UNOPS) to review the Road Design and Pavement Standards (2019) from a resilience perspective and provide recommendations for incorporation into the final version. Under the National Resilience Programme, UNOPS provided technical assistance to review and enhance the design standards with resilience considerations. The Planning Commission of Bangladesh subsequently approved the Road Design Standards with the UNOPS' recommendations integrated, which was duly acknowledged in the Gazette Notification.

The NRP is a joint programme of UNOPS, UN Women, and UNDP in partnership with the Local Government Engineering Department, Department of Disaster Management, Department of Women Affairs and Programming Division of the Government of Bangladesh (GOB). The Programme is funded by the governments of the UK, Sweden, and Bangladesh.

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1. Introduction

The National Resilience Programme (NRP) aims to sustain the resilience of human and economic development in Bangladesh through inclusive, gender responsive disaster management and risk informed development. It is a joint Programme, funded by DFID, SIDA, and GOB, that consists of four sub-projects where four Government (GOB) entities [the Department of Disaster Management (DDM), the Department of Women Affairs (DWA), the Programming Division of the Planning Commission, and the Local Government Engineering Department (LGED)] are responsible for implementing their corresponding subprojects. Alongside, three UN Agencies [the United Nations Development Programme (UNDP), UN Women and United Nations Office for Project Services (UNOPS)] are the technical partners of their respective counterpart GOB entities. UNOPS is the technical partner of LGED.

The LGED-UNOPS Sub Project focuses on improving the capacity of LGED (as selected public institution) to achieve resilient outcomes through risk-informed, and gender-responsive infrastructure systems.

The rural roads – one of the drivers of change – has uplifted the socio-economic condition of the country in many ways. The rural road system of Bangladesh has connected even the remotest village to the national system, in the process enabling all economic actors to participate in an integrated national economy instead of only isolated local economies.

As mandated by the government, LGED is the custodian of the country's massive rural road network of over 350,000 km length. The present rural road design standard was approved by the Planning Commission in 2004, which considered the prevalent traffic condition at that time. Since 2004, all sectors and sub-sectors of the country have gone through huge transformational change. The change has also impacted the rural road and rural transport sub-sectors. It has been observed that road pavements constructed according to the current standard are failing at various locations before the projected design life of ten years. The main attributes to these failures are unexpected increase in traffic volume and unexpected changes in the rural traffic pattern. In this backdrop, LGED requested Bangladesh University of Engineering and Technology (BUET) to review the existing road design manual, identify issues that need to be addressed and finally, prepare a revised design manual taking these issues into consideration.

BUET, after extensive review of existing road design standard, reference publications, physical inspections, analysis of field and laboratory data including traffic, has submitted "Road Design and Pavement Standards of LGED (2019)" which is now under process of 'review and approval' by the Planning Commission.

The NRP has reviewed the new road design standards 'from a resilience perspective'. The underlying principle of this approach is based on the premise that the connectivity provided by rural roads should not be disrupted or suffer minimal disruption as a result of shocks and stresses. The results are presented as observations and recommendations. **The observations and recommendations will not be an integral part of the standards; however, those could be considered in conjunction with the new road design standards.**

2. Review of Road Design Standards

2.1 Rural Roads in Bangladesh

Rural road transport in Bangladesh is essentially a mix of motorized and non-motorized transport using the same carriageway. Heavy vehicles are accessing these roads, which need to be catered for adequately. Rural roads are also connected with national and regional highways and as a result, heavy load carrying vehicles, e.g., trucks and buses, travel on a regular basis on these rural roads, which ultimately results in deterioration of rural road structures under excessive loads.

Furthermore, other crucial factors contributing to local road deterioration appear to be related to the non-availability of the requisite quality of road materials such as coarse and fine aggregates and flawed construction procedures due to the shortage of specified construction equipment, technicians and supervision.

At locations with overlapping rural roads and merging of rural roads with national/regional highways, there is a mixture of diverse types of vehicles with variable speeds resulting in functional incompatibility. These locations are a major contributor to road traffic accidents in rural areas. In Bangladesh, the road accident fatality rate per 1000 registered vehicles is significantly higher than that of industrialized countries including developing countries of the South Asia Region. It has now become crucial for LGED to develop a strategy for economic but efficient road and pavement design standards for rural roads such that LGED can serve the rural road user customer in a safe, environmentally clean, affordable, life cycle sustainable manner.

2.2 Meteorological Changes in Bangladesh

Climate change in Bangladesh is a pressing issue. According to National Geographic, Bangladesh is one the most vulnerable nations to the impacts of climate change. Bangladesh being located on the Tropic of Cancer receives fairly direct radiation throughout the year and maintains relatively high temperature. These two factors are the main catalyst to the meteorological changes. Nowadays, changing rainfall patterns and variation of temperature over the year are prominent.

The temperature data within the last 63 years period (1948-2010) from all the 35 stations of Bangladesh Meteorological Department (BMD) is analysed to determine mean monthly temperature over Bangladesh in the research paper "Change in Temperature over Bangladesh Associated with Degrees of Global Warming (Hasan 2013)" and made conclusion in way that the temperature variation between monthly maximum and minimum is (36.78-23.67)^{0}C i.e. 13.11^{0}C and monthly mean temperature has shown the highest rise of temperature of 28.71^{0}C during May.

Similarly, the annual and seasonal rainfalls of 17 stations from the period 1958 to 2007 of Bangladesh are analysed to get the time series of average annual and seasonal rainfalls of Bangladesh in the research paper "Rainfall variability and changes in Bangladesh during the last fifty years (Shahid 2012)" published in ResearchGate and it is revealed that the deviation of annual precipitation from mean precipitation is found to vary from +408 mm to -586 mm during the time period 1958-2007. Rainfall in Bangladesh varies from 1527 mm in the west to 4197 mm in the east. The gradient of rainfall from west to east is approximately 7 mm km-1.

2.3 Observations on new Road Design Standards

UNOPS has reviewed the "Road Design and Pavement Standards of LGED (2019)" prepared by the Bangladesh University of Engineering and Technology (BUET) and the major observations are as follows:

- Design philosophy/methods, parameters and code of practice are up to date to international standards like American Association of State Highway and Transportation Officials (AASHTO), Transport Research Laboratory (TRL), UK and Indian Road Congress (IRC). The design calculations, charts and catalogue are structurally adequate. Approaches, geometric and pavement design including side slope protection and road drainage (surface and subsurface) are up to date to international standards. Furthermore, the Standards include material specifications including gradation and construction methods including recycling to design climate resilient roads. The LGED Road Design and Standards is professionally written and is comparable to developed country design manuals.

- LGED Road Design and Standards has also addressed, to a limited extent, climate resilient design solutions. Climatic vulnerabilities have been taken care of in designing slope protection works and surface drainage systems. For quick run-off surface water, 2.5% crossfall in camber and 5% cross slope in shoulder are prescribed.

- LGED Road Design and Standards is a robust document with customized road design and pavement standards covering planning and alignment, geometric and pavement design including side slope protection and road drainage particularly surface drainage.

- Material specifications are suggested to be considered while designing and constructing road. Recycling method for pavement materials is discussed in this document.

- Hydrological modeling is also prescribed to carry out case-by-case to determine the drainage requirement.

- Several pavement structural design options suggested considering axle load pattern and stiffness of subgrade which seem give the flexibility to address overloading.

- LGED Road Design and Standards has adequately addressed most of the issues for designing a new road but has not addressed how to design for rehabilitation or maintenance in view of climate change effects.

- The LGED Road Design and Standards addresses the higher temperature, heavy traffic and heavy precipitation by using performance grade PG 60-10 bituminous material, raising the road foundation above the high flood level and providing adequate overflow drainage facilities as and when required.

- While PG 60-10 bitumen will mitigate high road temperature but not as effective in mitigating high traffic load rutting, cracking etc. PG 72 – 22 which is a polymer modified bitumen (PMB) (based on 72+22 = 94 > 90 is PMB as per rule of thumb) will be able to perform better.

- It is highly appreciated that the new design standards do not follow 'one size fits all'. The standards have suggested templates for structural and geometric design of pavement and carriageway corresponding to low, medium and heavy traffic with respect to different CBR value of subgrade.

- LGED Road Design and Standards appears to be a high-quality document with regards to Rural Road design which is not commonly found in many developing countries.

Additional few specific findings and further opportunities are as follows:

Table 1: Opportunities for further improvement of the LGED RDS

Findings	Opportunities
On Page 19, In LGED's proposed road design and pavement standard, it is suggested that "In the design of new roads or full reconstruction of existing roads, the freeboard to the lowest edge of the pavement surface, above Highest Flood Level (HFL) shall be at least 1.0 m or height of HFL on 20 years return period (whichever is higher) and in any event the Formation Level (top of sub-grade level) should be at least 30 cm above HFL.	To prevent the subgrade saturation, this 20-year return period could be increased to 30 years in the flood prone areas like Bogra, Chandpur, Chapai Nawabganj, Gaibandha, Jamalpur, Kishoreganj, Kurigram, Manikganj, Munshiganj, and Sirajganj. From a resilience perspective there is a need to show what climate modelling is predicting in terms of the Highest Flood levels in 5 or 10 years from now, or whatever the anticipated design/operational life of the road is. The design standard should be linked to the hazard to show that it will mitigate the risk of failure as a result of this hazard occurring.
On page 118, Penetration grade bitumen (60/70) is preferred to use as binding materials for Asphalt Concrete Base Course and Wearing Course in proposed design standard.	Performance of bitumen bound pavement layers is highly dependent upon the quality and optimal use of bitumen. In Bangladesh generally, penetration grade bitumen is used in asphaltic pavement works. Penetration Grades of 60-70 and 80-100 are commonly in use. But softer grade (80-100) bitumen is more sensitive to load & temperature therefore in Bangladesh due to hot temperature and simultaneously increase of traffic load, and consequently the roads get premature rutting & cracking. Therefore, using softer grade bitumen should be avoided particularly where traffic volume is high. Again, it has been experienced by many

Findings	Opportunities
	that bitumen of same penetration grade, do not behave the same performance when the sources are different. To overcome this problem, the grade classification by penetration of bitumen has already been abolished in most countries of the world. Instead, grading based on viscosity at 60 °C has been adopted. Now it may be time to consider changes to the bitumen specification in Bangladesh. Viscosity grade bitumen has been found better in pavement performance than penetration grade bitumen in many countries, India is one of the examples. Viscosity grades bitumen is suitable for a wide range of temperatures: 25 °C for raveling / fatigue cracking; 60oC for rutting; and 135 °C for construction. Due to the generally hot weather conditions in Bangladesh, prolonged intense rainfall and high projected traffic volumes expected on major roads, it is recommended that harder grades of bitumen with higher viscosity (e.g. VC 30, VC 40) be used to overcome instability problems of asphalt mixes and to increase durability of the pavement. Same comment as above - what evidence is there to show that as a result of climate change temperatures of X Deg C are anticipated over the life of the road. Similarly, is there any evidence of the anticipated increase in traffic volumes and loads which require a change in standard to mitigate the risk of damage to the road.
On page 161, it is also suggested Superpave performance grade bitumen PG 64-10 as binding materials in selective parts of the country where variation of temperature and intense rainfall together affect or modify specification of materials.	To enhance pavement performance and durability, modified bitumen is being used extensively throughout the world. Modified bitumen is characterized by improved (i.e. higher temperature) softening point and greater durability. It is more expensive than normal bitumen per unit cost of bitumen, but it is less expensive in terms of overall pavement life cycle cost. Advantages of modified bitumen binders can be summarized as follows: Advantages of modified bitumen binders can be summarized as follows: ● They provide a stiffer binder, mixed at high temperature, hence they reduce rutting.

Findings	Opportunities
	• They provide a softer binder at low service temperatures and hence reduce low temperature cracking, • They improve fatigue resistance where high strains are imposed on bituminous mixes. • Develop elastic behavior in many folds. • Improve water resistance greatly etc. There are different types of modified bitumen. Polymer modified bitumen (PMB) has certain advantages over other types. Recent trend shows, high commercial vehicle axle load values are expected and this will require the use of stiff mixes of asphalt at high temperatures. As the use of PMB in Bangladesh is somewhat new, the construction industry and potential users have limited experience of the material, it is recommended that its use should be on a limited scale. PBM should therefore be used for all wearing courses or wearing courses at those sections of road only where extreme trafficking is expected.
On page 78, a typical subgrade typed subsurface drainage is suggested at interval of 5-7m on both sides of the subgrade.	Subgrade drainage primarily removes water from subgrades with high groundwater tables. The type, location, depth and spacing of drains depend upon the soil characteristics and depth to groundwater table. Subgrade drainage is required at locations where seasonal variation of the groundwater may raise the top of the water table to within 0.3m of the bottom of the base or subbase course. There is no provision to remove water that has infiltrated through the pavement surface and shoulder area of the pavement. The pavement cannot be resilient unless the provision of “Base and subbase drainage” is kept in the design manual to remove water from surface infiltration in the shortest possible time. Design of “intercepting drainage” is also required to incorporate to remove water that may flow laterally into the pavement structure.

3. Climate Factors

Rural Roads are the backbone of society and economy of Bangladesh. The vast majority of people have come to rely on and expect uninterrupted availability of the road network. At the same time, it is generally understood that the world's climate is changing and that this will have significant effects on the road infrastructure.

From a resilience perspective road infrastructure should be planned, designed, constructed and maintained in a way that reduces the likelihood that the availability of the network will be disrupted by shocks and stresses. Since road infrastructure is vital to society, climate change calls for timely action. Climate change means the nature of climatic hazards or shocks and stresses, is changing and will continue to change over time. Because of the high priority of ensuring continuity of connectivity provided by road networks, this section is dedicated to climate factors and associated impact on the road networks.

The following Table presents the possible climate events and risks to roads in Bangladesh context:

Table 2: Climate Events and Risks to Roads

Climate Change and related events	Risks to the Road Assets
Extreme rainfall events	• Overtopping and wash away • Increase of seepage and infiltration pass • Increase of hydrodynamic pressure of roads • Decreased cohesion of soil compaction • Traffic hindrance and safety
Seasonal and annual average rainfall	• Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels • Adverse impact of standing water on the road base • Risk of floods from runoff, landslides, slope failures and damage to roads if changes occur in the precipitation pattern
Higher maximum temperature and higher number of consecutive hot days **(heat waves)**	• Concerns regarding pavement integrity, e.g. softening, traffic-related rutting, embrittlement (cracking), migration of liquid asphalt • Thermal expansion in bridge expansion joints and paved surfaces • Temperature break soil cohesion and increase dust volume which caused health and traffic accidents
Drought **(Consecutive dry days)**	• Consolidation of the substructure with (unequal) settlement as a consequence • Unavailability of water for compaction work

Climate Change and related events	Risks to the Road Assets
	• Drought decreases mortality of plants along road alignments
Extreme wind speed	• Threat to stability of bridge decks • Damage to signs, lighting fixtures and supports • Increase of wind speed causes the dynamic force of water generated by waves on road embankments

There are two aspects to Climate change to consider:

1. Mitigation - can we design roads so that they will contribute to a reduction in the factors driving climate change? e.g. greenhouse gas emissions, using construction materials and methods that don't produce greenhouse gasses.

2. Adaptation - take action across the asset lifecycle (planning, design, construction, maintenance) to minimise the impact of climate change on the roads.

Among various climate change events the most common event in Bangladesh is 'Heavy Rain for Longer Periods'. The suggested **mitigation** measures to minimize the risks associated with this climate event are as follows:

Table 3: Heavy Rain for Longer Periods, Risks and General Mitigation Measures

Risks	General Mitigation Measures
• Water overtopping on road crest • Increased capacity of moistures and decreased cohesion of soil and increased seepage and infiltration across road body • Drainage system over capacity of and increase drainage erosion • Embankment instability or loss, road wash away	• Increase road level to at least 0.5 m over the maximum flood level • Erosion protection • Increase capacity of culverts Build up weirs and spillways • Increase capacity of compaction (lower moisture percentage) • Decrease hydrodynamic force of water through planting • Use resistant materials for building roads

As the options for mitigation are limited, the rural roads in Bangladesh should go for **adaptation** measures. Adaptation in this context means making changes to the way roads are planned, designed, constructed and maintained to mitigate the risk of damage as a result of changing climatic hazards. With regards to climate change impacts, some mitigation measures are proposed to reduce the possible impact of changing climatic events, especially flooding, which always causes damage to rural roads in Bangladesh:

Table 4: General Adaptation Measures for Rural Roads

Item	Adaptation Options
Road Embankment	● Raising embankment level ● Adjusting side slope ● Paving unpaved sections (for earthen roads)
Drainage	● Improvement of cross drainage (culverts, bridges and spillways) ● Ditches and drains ● Permeable road ● Underdrain ● Scour checks (in hilly terrain)
Erosion	● Retaining walls ● Rip-Rap Protection ● Groynes (stream or longitudinal erosion conditions)
Maintenance	● Dust control ● Inspection and repairs of road surface deformation ● Clearing and cleaning culverts and drains ● Inspection and Repair of erosion protection and scour checks
Planning	● Realignment ● Revised road design standards ● Monitoring

It is to be noted that there are great uncertainties involved in both the projections of to what extent the climate will change and how this will manifest in climate related events (rainfall intensity and severity, sea level rise) plus their impacts on the road infrastructure and related socio-economic developments. In the meantime, there is a constant need for on-going development of the road transport system which requires data or best estimates of data to inform the planning and design processes. This means that in the absence of clear data we cannot stop development but we should be fully aware of what we don't know and what is uncertain. This will inform good risk management practices in respect of risk mitigation or risk acceptance, if we are not clear on the exact nature of the climatic hazards the road system will face in the future.

The following table with threats and related climate variables has been constructed from the ROADAPT document (*ROADAPT: Roads for today, adapted for tomorrow Climate data requirements of National Road Authorities for the current and future climate, May 2015*) taking only the elements relevant to Bangladesh context.

Table 5: Threats and related climate parameters, imposing risks to the road infrastructure

Threats	Climate Parameter	Unit	Time Resolution
Main Threat: Flooding of road surface (assuming no traffic is possible)			
Sub Threats 1: **Flooding due to failure of flood defense system of rivers and canals, caused by snow melt, rainfall in catchment area, extreme wind**	Temperature (in catchment area)	°C, days Temp avg>0 °C	days
	Extreme rainfall (long periods with rain in catchment area)	mm/days	days-week
	Extreme wind speed	m/s	days-week
	Wind direction	degrees	hours-days
Sub Threat 2: **Pluvial flooding (overland flow after precipitation, increase of ground water levels, increase of aquifer hydraulic heads)**	Extreme rainfall events (heavy showers)	mm/h	minutes-hours
	Extreme rainfall events (long periods with rain)	mm/days	days-week
Sub Threat 3: **Inundation of roads in coastal areas, combining the effects of sea level rise and storm surges**	Sea level (rise)	cm	year(s)
	Extreme wind speed (-> storm surge)	m/s	hours-days
	Wind direction (-> storm surge)	degrees	hours-days
Main Threat: Erosion of road embankments and foundations			
Sub Threat 1: **Overloading of drainage systems crossing the road**	Extreme rainfall events (long periods of rain)	mm/days	days-weeks
	Extreme rainfall events (heavy showers)	mm/h	minutes-hours
Sub Threat 2: **Erosion of road embankments**	Sea level (rise)	cm	year(s)
	Extreme wind speed (-> storm surge)	m/s	hours-days
	Wind direction (-> storm surge)	degrees	hours-days
	Extreme rainfall events (long periods of rain)	mm/days	days-weeks
	Extreme rainfall events (heavy showers)	mm/h	minutes-hours

Threats	Climate Parameter	Unit	Time Resolution
Sub Threat 3: **Bridge scour**	Sea level (rise)	cm	year(s)
	Extreme wind speed (-> storm surge)	m/s	hours-days
	Wind direction (-> storm surge)	degrees	hours-days
	Extreme rainfall events (long periods of rain)	mm/days	days-weeks
	Extreme rainfall events (heavy showers)	mm/h	minutes-hours
Main Threat: Landslips			
Sub Threat 1: **External slides, ground subsidence, affecting the road**	Extreme rainfall events (long periods of rain)	mm/days	days-weeks
	Extreme rainfall events (heavy showers)	mm/h	minutes-hours
	Drought (consecutive dry days)	consecutive days	multiple days-months
Sub Threat 2: **Slides of the road embankment**	Extreme rainfall events (long periods of rain)	mm/days	days-weeks
	Extreme rainfall events (heavy showers)	mm/h	minutes-hours
	Drought (consecutive dry days)	consecutive days	multiple days-months
Main Threat: Loss of road structure integrity			
Sub Threat 1: **Impact on soil moisture levels (increase of water table), affecting the structural integrity of roads and bridges.**	Seasonal and annual average rainfall	mm/season, mm/y	season-year
	Sea level (rise)	cm	year(s)
	Extreme wind speed (-> storm surge)	m/s	hours-days
	Wind direction (-> storm surge)	degrees	hours-days
Sub Threat 2: **Weakening of the road embankment and road foundation by standing water**	Seasonal and annual average rainfall	mm/season, mm/y	season-year
Sub Threat 3: **(Unequal) settlements of roads by consolidation**	Drought (consecutive dry days)	consecutive days	multiple days-months

Threats	Climate Parameter	Unit	Time Resolution
Main Threat: Loss of pavement integrity			
Sub Threat 1: **Cracking, rutting, embrittlement**	Maximum and minimum diurnal temperature	°C	days
	Nr. of consecutive hot days (heat waves)	consecutive days	days
Sub Threat 2: **Thermal expansion of pavements**	Maximum and minimum diurnal temperature	°C	days
	Nr. of consecutive hot days (heat waves)	consecutive days	days
	Nr. of consecutive hot days (heat waves)	consecutive days	days

The above table is not an exhaustive list of Hazards but provides guidance for areas to be considered in good risk management. The Center of Excellence (CReLIC - Climate Resilient Local Infrastructure Center) established in LGED with the support from GCF-KfW-GOB Project (CRIMP) can consider the above table for its further enhancement and adaptation for the Bangladesh context taking into consideration climate modelling specific to Bangladesh.

4. Roads: Enhancing Resilience through Asset Management

4.1 Resilience in General: Infrastructure

Infrastructure underpins almost all development. It has two main functions:

1. Facilitator of development - It facilitates the flows of goods and services and is thus an enabler of development
2. Protector of development - It protects the built environment and people from hazards, such as landslides, floods, tsunamis, earthquakes etc.

As a facilitator of development which enables the flows of goods and services, Infrastructure and the service delivery it facilitates is essential for quality of life and livelihoods. Billions of people are exposed to the consequences of vulnerable infrastructure, and disruptions to delivery of services when the infrastructure fails; which costs the global economy billions of dollars every year. Natural hazards are one of the main causes of damage to or destruction of infrastructure resulting in service disruptions. A major share of the financial cost of such natural events arises from damage to or destruction of critical infrastructure. Beyond the direct costs of rebuilding, there are also substantial indirect costs associated with the loss of the services that the infrastructure was enabling. The loss of such services affects businesses, communities and the broader economy via delays, interruption, financial losses, loss of customers and broader social impacts such as stress and anxiety. As such, the total cost or loss resulting from damage or destruction of infrastructure is substantially higher than the direct replacement costs of the infrastructure assets The total loss can be described as a 'loss of development gains'

Resilient infrastructure plays a critical role in supporting communities to withstand, respond to and recover from shocks and stresses. In essence it is thus about ensuring the continuity of the services that the infrastructure is enabling. In many cases authorities do not consistently consider the resilience of infrastructure and the associated continuity of services, when making investment decisions, nor are there specific requirements to do so. Usually, the authorities overinvest in post-disaster reconstruction and underinvest in mitigation strategies across the infrastructure asset lifecycle that would limit the impact of natural hazards or other hazards in the first place. The World Bank, in its report 'Lifelines: The Resilient Infrastructure Opportunity' notes that increasing resilience of infrastructure is not very expensive. It would only increase the overall investment needs by around 3% - resulting in fewer disruptions with lower economic impact. It is estimated that the net benefit of investing one dollar in resilient infrastructure gives a benefit or return on investment of four dollars saved as a result of reduced loss of development gains.

The term 'Resilience' has been defined in many ways. The widely accepted UN definition for resilience is:

"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". (UNISDR, 2009)

Another definition of Infrastructure Resilience is: *"the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event." (NIAC 2009 Critical Infrastructure Resilience: Final Report and Recommendations).*

A similar definition can be found in the IPCC 2012 Glossary of Terms, *"The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions"* (IPCC 2012 Glossary of Terms)

All pillars of these definitions are captured in Figure 1 which shows that resilience adopts the assumption that a system always tends to reach a systematic status after a disruptive event that equals the status before the event or become stable in a new equilibrium.

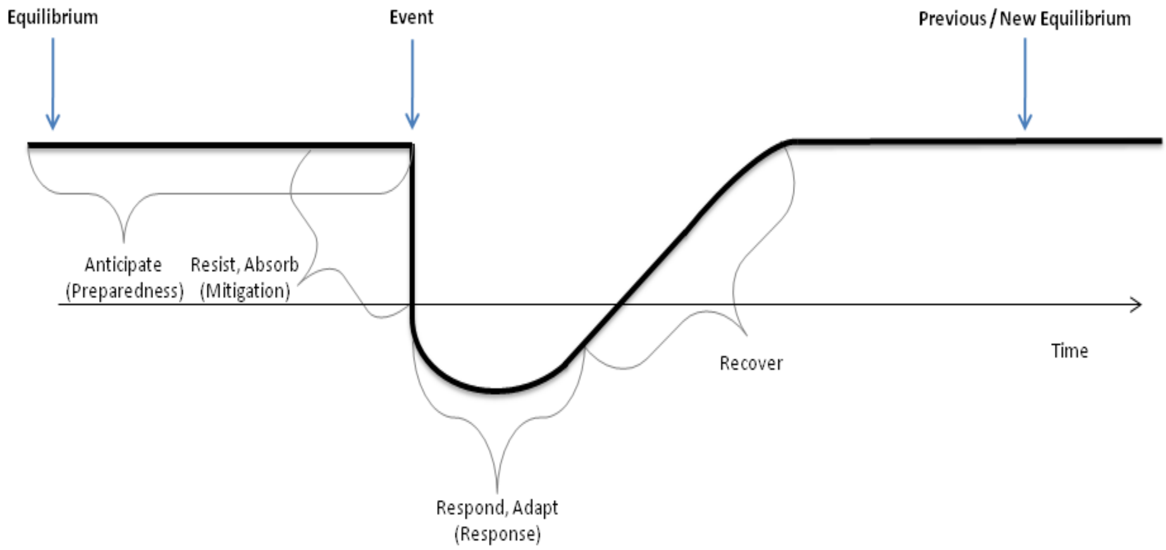

Figure 1: Components of Resilience and the Timing of an Adverse Event (Carlson et al. 2012)

The above definitions are a kind of formal, structural, and official. The informal but easy and applicable definition for the practitioners could be:

"Resilience is about maintaining the continuity of a service in the face of disruptive events". It means that if infrastructure is delivered or built, it should maintain its continuity of providing services even when things go wrong.

Resilient infrastructure is not about roads or bridges or power plants alone. It is about the people, the households and communities for whom this infrastructure is lifeline to better health, better education and better livelihoods through the services it enables. Now, there is an increasing international discussion on improving the resilience of infrastructure. The UN Sustainable Development Goals (SDG) set a target to provide resilient infrastructure. Resilient infrastructure also links with ***Goal 9:*** Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; and ***Goal 11***: Making cities and human settlements inclusive, safe, resilient and sustainable.

4.2 Resilience: Specific to Roads

Effective and efficient road network underpins the economic and social functions of society. On the other hand, disruption results in a cascade of impacts including limiting or preventing access to jobs, education and leisure, and essential services such as healthcare. Road transport disruptions can even affect the GDP of a country. Many transport organisations are working to improve resilience, however, consistently including it throughout the value chain is challenging.

Within the road industry improving resilience constitutes both increasing the ability of infrastructure to withstand potential threats and also the capability of the system to rapidly recover from disruptive events. Main components of resilience are 4Rs *(Resilience Primer: Roads – An Industry Guide to Enhancing Resilience: TRL Publication)*:

Figure 2: Major components of resilience

- Resistance: Physical robustness
- Reliability: Ability to operate under a variety of conditions
- Recovery: Respond and recover from disruption
- Redundancy: Spare capacity or diversion routes

Appropriate Road Design standards is definitely a vital tool, but the standards alone cannot ensure the resilience components. Resilience factors need to be considered throughout the stages of the value chain – from proposal to delivery.

Table 6: Various stages of value chain and corresponding considerations

Stages	Considerations
Initial proposal stage	The case for investment, the benefits expected from the project and the major options available e.g. on alignment. This is an important stage in the value chain.
Planning and appraisal stage	The economic, social and environmental impacts. The resilience of both the infrastructure being built/ upgraded and the impact the project has on the resilience of other infrastructure and communities should be considered.
Detailed design	Resilience can be embedded by using more robust materials and design better able to withstand different hazards, by incorporating features which make it easier to repair if damaged, or update if conditions change.
During construction	The planned design and materials may need to be adjusted to fit the actual conditions. Although, most major decisions have been made by this phase of the project there are still opportunities for modifying designs to increase resilience. Also care needs to be taken that aspects included in the design to increase resilience are not eroded due to pressures on time and budget. Quality construction must be ensured.
Maintenance and operation	Decisions relating to the maintenance of deteriorated infrastructure and the operation of the network. Resilience can be included in prioritisation of maintenance and improving response to incidents.

Improving resilience to the variety of hazards facing road networks requires integration into decision-making at all points of the infrastructure lifecycle.

The TRL publication has divided opportunities for increasing consideration of resilience into six areas for action:

Figure 3: Six areas of action for increasing consideration of resilience

Changing mind-sets (Reeves 2019)

Increasing resilience requires changing mind-sets in a number of ways:

REINFORCING THE RIGHT BEHAVIOUR: *Authorities usually take efforts to deal with and recover from events. The approach should be for effective planning so that events do not occur.*

PROMOTING LONG-TERM THINKING: *Generally, emphasis is given on reducing initial costs and shot-term solutions rather than considering whole life costs. Following good practice in asset management, by considering the infrastructure over its life cycle and identifying future risks will make infrastructure more resilient.*

BEING PROACTIVE WHEN CONSIDERING POTENTIAL HAZARDS: *When a large-scale disaster or catastrophe happens, the authorities make money available to address the situation and focus on instigating improvements. A more proactive approach where all potential hazards are considered and mitigation actions identified is more effective and less costly. This requires consistent long-term funding rather than funding that is only available for a short-time following a disaster.*

CHALLENGING CURRENT PRACTICES: *The normal tendency is to become complacent when an event has not occurred for a period of time. People often follow what has always been done, rather than thinking of future considerations and investing in better preparation and more robust infrastructure.*

Current practices need to be challenged and constantly questioned in order to be improved for example through stress testing current practice with different scenarios.

Providing leadership and accountability

Resilience has to compete with other priorities for resources and attention. High level organisational leadership on resilience could provide powerful incentives to move resilience up the agenda. Some actions which can help to do this are:

ASSIGNING A CHAMPION(S): *There needs to be someone in a high-level position in the organisation to champion resilience and be accountable for improvements.*

IMPROVING AWARENESS AND UNDERSTANDING OF RESILIENCE: *Whilst it is important to have someone accountable for resilience, there needs to be awareness and understanding of resilience throughout the organisation. Often outside the team involved in resilience, people do not understand what resilience is, why it is important or their role in improving it. Changes in staff or organisational structure can add to the problem, by leading to loss of knowledge and disruption of plans to improve resilience. Actions to increase awareness include providing workshops, guidance, case studies, role specific training and including objectives in an individual's appraisals.*

DEMONSTRATING THAT RESILIENCE IS IMPORTANT: *Leaders need to be visible in resilience discussions and actions in order to demonstrate the value they place on resilience. For example, speaking at external and internal events on resilience, asking staff questions on resilience and being involved during events.*

ESTABLISHING POLICY, TARGETS AND ACTION PLANS: *By including resilience in organisational policy and developing appropriate action plans, it demonstrates its importance internally and externally.*

PROVIDING RING-FENCED FUNDING FOR RESILIENCE: *Lack of funding is seen as a major barrier to increasing resilience. To address competing priorities and prevent focus on the short-term issues, funding specifically for actions to improve resilience may be required.*

HAVING ASSURANCE PROCEDURES IN PLACE: *Often after an event, recommendations to improve resilience are made, but there also needs to be a process in place to ensure these have been addressed.*

Systems thinking and collaboration

Resilience requires a cross-asset, cross-sector approach which involves collaboration between organisational functional units (e.g. Planning Unit, Design Unit, Quality Control Unit) and different organisations (e.g. RHD, LGED, BWDB). Resilience needs to be addressed at the system level, rather than solely focusing on individual assets. There are opportunities to improve resilience through less siloed working and greater awareness of external interdependencies.

Understanding and mitigating risk

In order to prioritise maintenance and upgrades to improve resilience, identification of the areas of highest risk is required. Data collection and analysis is required to support hazard and risk assessments, and decision-support tools and standardized methodologies provide a consistent methodology so that comparisons can be made between projects, areas of the network and hazards.

The requirement to carry out a risk assessment can be embedded in the planning process for new build and asset management processes for existing networks.

Improving disaster management

Preparation for different types of events should include plans to deal with disruption, contingency plans and recovery plans.

Embedding resilience

No single lever can embed resilience within the road industry. There needs to be inclusion of multiple specific actions to support resilience integrated in existing procedures at all major decision points and involving all stakeholders. For example, the road agencies need to include clauses relating to resilience in contract agreements."

4.3 Resilience: Beyond design standards

The preceding sections clearly show that to address the major components of resilience (Resistance, Reliability, Recovery, Redundancy and Reflection) can never be addressed with Technical Standards alone. Although the road design standard is one of the most critical elements of resilience, however, the resilience concept goes well beyond the technical aspects. The reasons for this are:

1. Resilience is an outcome - it is the consequence of a series of actions and not an end in itself
2. Resilience is a 'state of being' - By this we mean it is inherent in a system, it is the characteristics of a system that result from how the system is planned, designed constructed, operated and maintained
3. Resilience is not static - Resilience is the ability to withstand shocks and stresses (Hazards), which are continually changing, so this ability will change depending on how the shocks and stresses change. Similarly, resilience is a characteristic of the system so as the system changes its resilience will also change e.g. the resilience of a road will change if the road is damaged or deteriorates through lack of maintenance.

The resilience approach encompasses a wide range of activities that cannot be 'done once and forgotten', it requires on-going management of the system to ensure it remains resilient. It is therefore more about policy, strategy, regulations, improved decision making, providing finance, changes in business process, system reform, and changes in work culture, than simply building 'bigger or stronger infrastructure assets' It is about a new approach to preparation and appraisal of road projects with new methods of calculating the Cost Benefit ratio. On the technical side, resilience demands for lifecycle delivery including sound technical design standards. All these elements are well incorporated in the Asset Management System ISO 55000. In terms of the Asset Management approach, the focus is thus on the way in which assets are managed across the entire lifecycle, so that they can deliver the value they were created to deliver. Continuity of service is a key value that the asset should deliver, which will only be realised if the entire system is resilient. This requires a holistic approach, not just a focus on building more resistant assets.

LGED is in the process of developing its Asset Management System (AMS) in line with ISO 55000, with the support of National Resilience Programme (NRP). The new Road Design Standards (RDS) should be embedded into the LGED AMS as an integral part of the system. Then, the RDS, in conjunction with other elements of the LGED AMS, will be extremely helpful to achieve resilient outcomes in LGED road network.

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