BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING
Department of Civil Engineering

TEXAS A&M UNIVERSITY
Zachry Department of
Civil & Environmental Engineering

Sustainability Studies and Assessments of Ground Modification Works for Civil Infrastructure

Anand J. Puppala, Ph.D., P.E., D.GE, F.ASCE, F.ICE

A.P. and Florence Wiley Chair Professor
Director, Center for Infrastructure Renewal (CIR)
Director, Center for Integration of Composites into Infrastructure (CICI) - NSF IUCRC Site
Texas A & M University, College Station, Texas, USA
Chair - ISSMGE TC307 Sustainability in Geotech Engineering

Bhaskar C. S. Chittoori, Ph.D., P.E.

Chair and Associate Professor
Department of Civil Engineering
Boise state University, Boise, Idaho, USA
Chair – ASCE GI Sustainability in Geotech Engineering

ASCE SGE Sustainability Webinar
10-5-2022

Presentation Outline

- ❑ **Introduction and Background**
- ❑ **Metrics for Sustainability and Resilience**
- ❑ **Sustainability Assessment of Ground Modification Works**
  - **Case Study 1: Pavement Stabilization with Lime and Fly Ash**
  - **Case Study 2: Dam Embankment Modification**
  - **Case Study 3: Bridge Approach Slab Repair**
  - **Case Study 4: Pavement Rehabilitation with Geosynthetics**
- ❑ **Summary**

Evolution of sustainable development

World Conservation Strategy

1980

1. Maintain essential ecological processes and life support systems,
2. Preserve genetic diversity, and
3. Ensure sustainable utilization of species and ecosystems.

Sustainability: "meets the needs of the present without compromising the ability of future generations to meet their own needs."

1987

Brundtland Commission Report

United Nations Millennium Declaration

2000

Millennium Development Goals:

1. **Eradicate extreme poverty,**
2. **Achieve universal primary education,**
3. **Promote gender equality and empower women,**
4. **Reduce child mortality,**
5. **Improve maternal health,**
6. **Combat HIV/AIDS, malaria, and other diseases,**
7. **Ensure environmental sustainability, and**
8. **Develop a global partnership.**

Defined the three pillars of sustainability: ***economics, environment, and social***

2002

World Summit on Sustainable Development

Braham and Casillas (2017). "*Fundamentals of Sustainability in Civil Engineering*", CRC Press, Boca Raton, FL.

Evolution of sustainable development

UN Conference on Sustainable Development

2012

1. Poverty eradication,
2. Changing unsustainable and promoting sustainable patterns of consumption and production, and
3. Protecting and managing the natural resource base of economic and social developments.

2015

Millennium Development Goals Final Report

- *Effort toward accomplishing these goals was the most successful anti-poverty movement in history*
- *Decreased child mortality rate by more than half*
- *Increased primary school enrollment rate in developing regions to 91%.*

Transforming Our World: the 2030 Agenda for Sustainable Development

2015

17 Sustainable Development Goals

Braham and Casillas (2017). “*Fundamentals of Sustainability in Civil Engineering*”, CRC Press, Boca Raton, FL.

UN'S SUSTAINABLE DEVELOPMENT GOALS

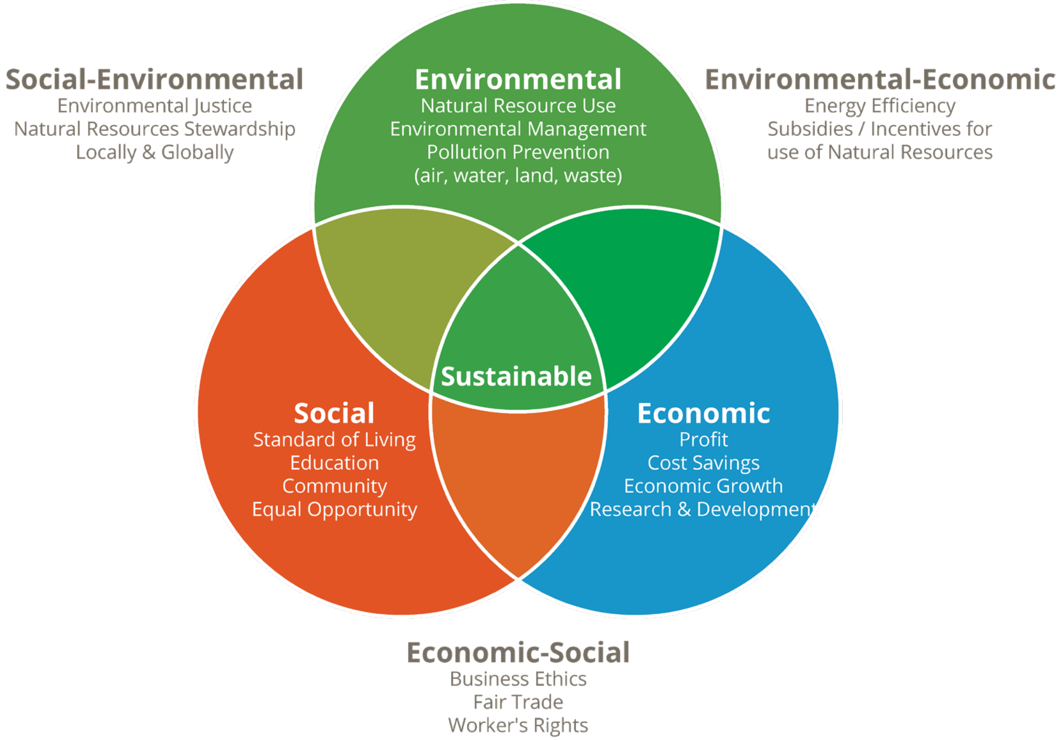
- Adopted in 2015 by UN
- Targeting 2030
- COVID19 pandemic has huge impact on all of these goals

Sustainability

- **ASCE's definition of sustainability**
  - **"a set of environmental, economic, and social conditions - the "Triple Bottom Line"- in which all of the system has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural, economic, and social resources"**

- **Triple bottom line**

  People, Planet, Profit



(https://sustainableinfrastructure.org/)

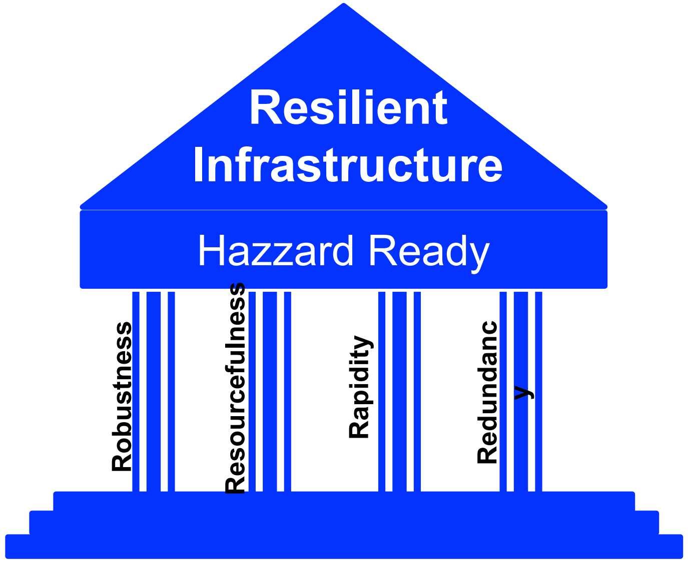
Resiliency

- **Definition**

  the measure of a system that undergoes a loss in functionality due to an event that has low probability but high impact, and that system regaining functionality within a specified time.

- **Four pillars of resiliency**

  Robustness, Resourcefulness, Rapidity, and Redundancy



Sustainability and Resiliency

- Assessing sustainability and resiliency of a infrastructure is essential for a holistic design
- Several methods exist to perform these assessments separately
- However, sustainability and resiliency assessments have several similarities (Bocchini et al. 2013)
  - Both analyses require life cycle assessments to study the impacts
  - Both analyses study the impact from economic, environmental and societal aspects

Sustainability and Resiliency

- Limited research on unified assessment methods for sustainability and resiliency
- Existing frameworks are often overly complex, or specialized
- Value in assessing both sustainability and resiliency with the ever increasing risk of catastrophic events
- Work performed consisted of discrete analysis of both resiliency and sustainability, then unified analysis incorporating risk
- Initial work as foundation for further research

Role of Transportation Infrastructure

- Critical engineered systems
- Important driver of nation’s economy
- Connect supply chains
- Provide access to healthcare and education
- Offer employment opportunities

Challenges

- Rapid industrialization
- Population growth
- Human-induced disturbances
- Natural hazards
- Aging and durability issues

ASCE Infrastructure Report Cards

GRADING SCALE

A — EXCEPTIONAL, FIT FOR THE FUTURE

The infrastructure in the system or network is generally in excellent condition, typically new or recently rehabilitated, and meets capacity needs for the future. A few elements show signs of general deterioration that require attention. Facilities meet modern standards for functionality and are resilient to withstand most disasters and severe weather events.

B — GOOD, ADEQUATE FOR NOW

The infrastructure in the system or network is in good to excellent condition; some elements show signs of general deterioration that require attention. A few elements exhibit significant deficiencies. Safe and reliable, with minimal capacity issues and minimal risk.

C — MEDIOCRE, REQUIRES ATTENTION

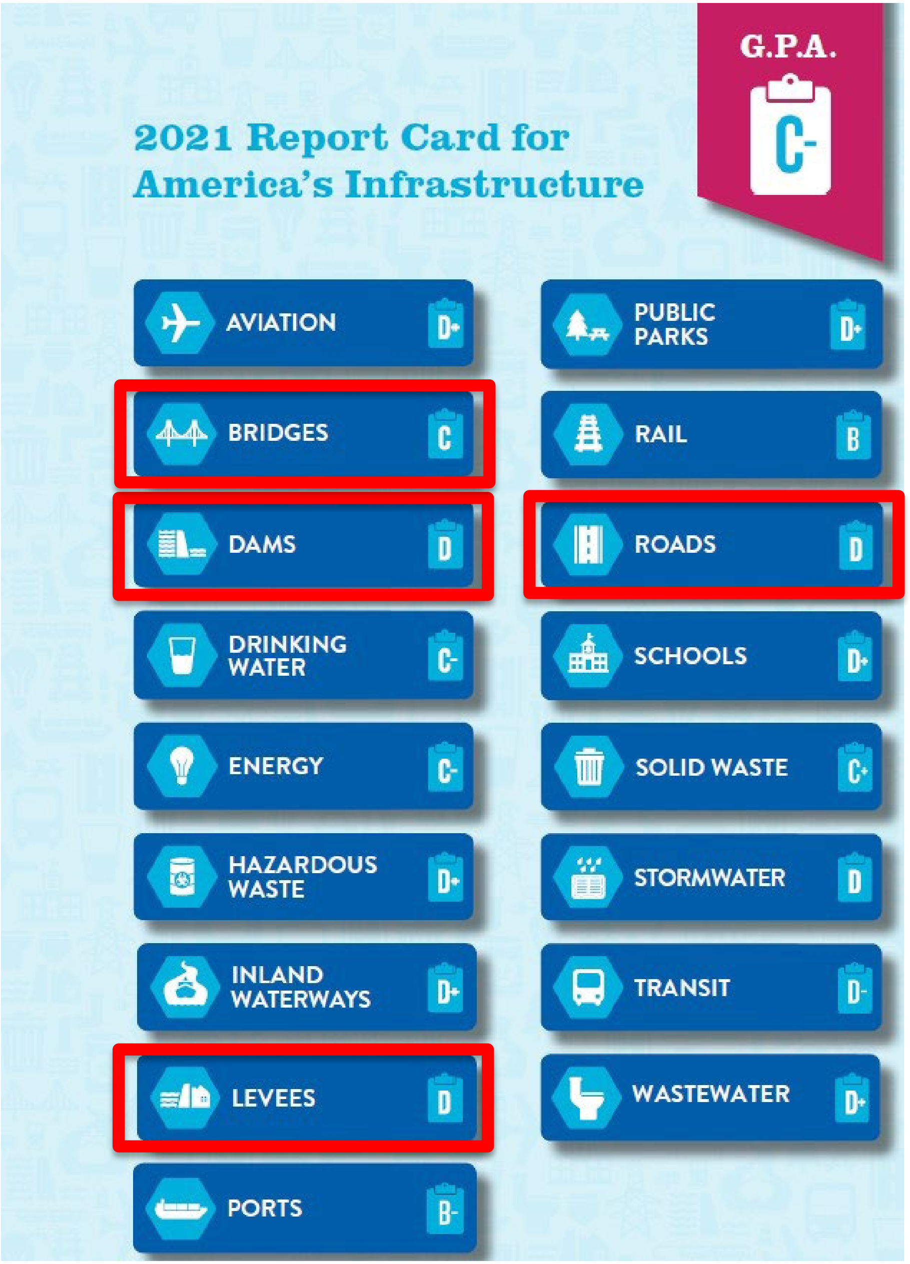
The infrastructure in the system or network is in fair to good condition; it shows general signs of deterioration and requires attention. Some elements exhibit significant deficiencies in conditions and functionality, with increasing vulnerability to risk.

D — POOR, AT RISK

The infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of serious concern with strong risk of failure.

F — FAILING/CRITICAL, UNFIT FOR PURPOSE

The infrastructure in the system is in unacceptable condition with widespread advanced signs of deterioration. Many of the components of the system exhibit signs of imminent failure.



Some Statistics

- Losses due to delays (Petroski, 2018)
  - Traffic congestion on roadways: $120 billion
  - Trip delays at airports: $35 billion
- Percent GDP spent on transportation infrastructure (McBride, 2018)
  - China ~ 9%
  - Europe ~ 5%
  - India ~ 5%
  - US ~ 2.4%
- Chronic under investment: $800 Billion
- 2021 Infrastructure Investment and Job Act - $550 Billions on New Infrastructure next five years
- Livable communities by reducing carbon pollution from the transportation and other infrastructure sectors – Focus on sustainability and resilience

Survey at 2018 ASCE GeoCongress

An informal survey was attempted by Das and Puppala (2018) to understand what they prefer…Sustainability and Resilience?

- **50 questionnaires handed to attendees at IFCEE 2018, Orlando, FL.**
- **26 responded (~ 50%)**

Research Survey

Dear Participant,

This survey is part of a research undertaken to study the sustainability of civil infrastructure. Your response would be helpful in developing models to assess the feasibility and profitability of infrastructure projects.

Thank you.

Sustainability focuses on socio-economic impacts and environmental stewardship. For an infrastructure project, sustainability can be enhanced by reducing resource consumption, limiting carbon footprint, and containing greenhouse gas emissions from the project.

Resilience is the capacity of an infrastructure to withstand, recover, and adapt in response to extreme events such as earthquakes, hurricanes, terrorist attacks etc. This can be achieved by ensuring the safety, reliability, and serviceability of the project components.

At times, the pusuit of sustainability can be in conflict with the pursuit of resilience. An engineering design with excessive focus on the environmental impact may lead to a marginally safe structure.

In your opinion, what weightage should be given to the sustainability aspects and resilience elements? Please choose ***only one*** option.

- [ ] 100% Sustainability, 0% Resilience
- [ ] 90% Sustainability, 10% Resilience
- [ ] 80% Sustainability, 20% Resilience
- [ ] 70% Sustainability, 30% Resilience
- [ ] 60% Sustainability, 40% Resilience
- [ ] 50% Sustainability, 50% Resilience
- [ ] 40% Sustainability, 60% Resilience
- [ ] 30% Sustainability, 70% Resilience
- [ ] 20% Sustainability, 80% Resilience
- [x] 10% Sustainability, 90% Resilience
- [ ] 0% Sustainability, 100% Resilience

Name:

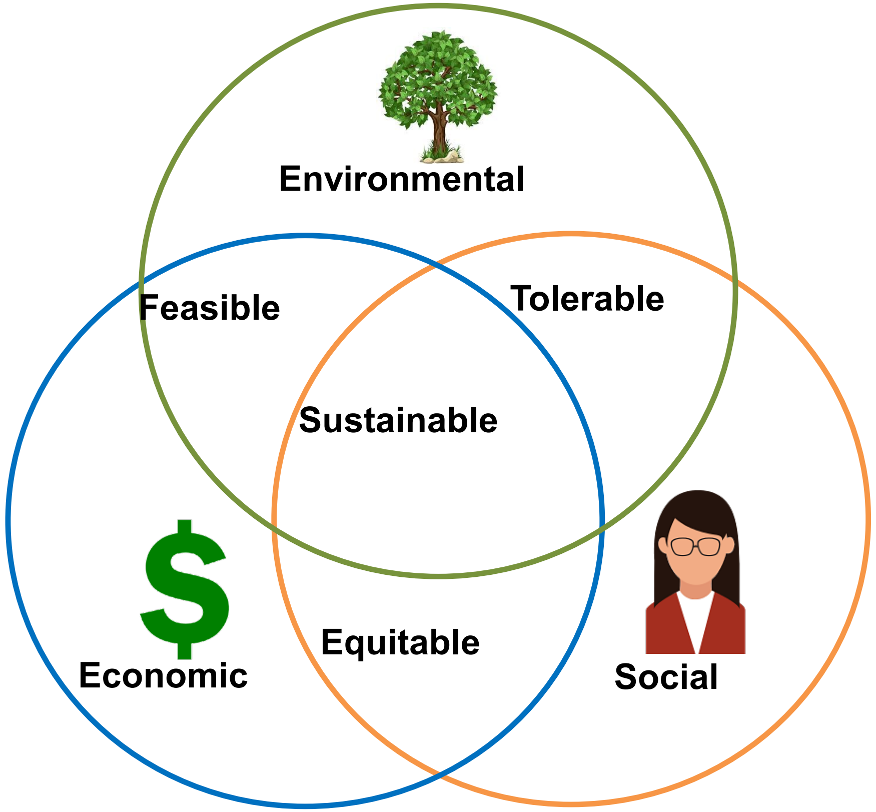
Position:

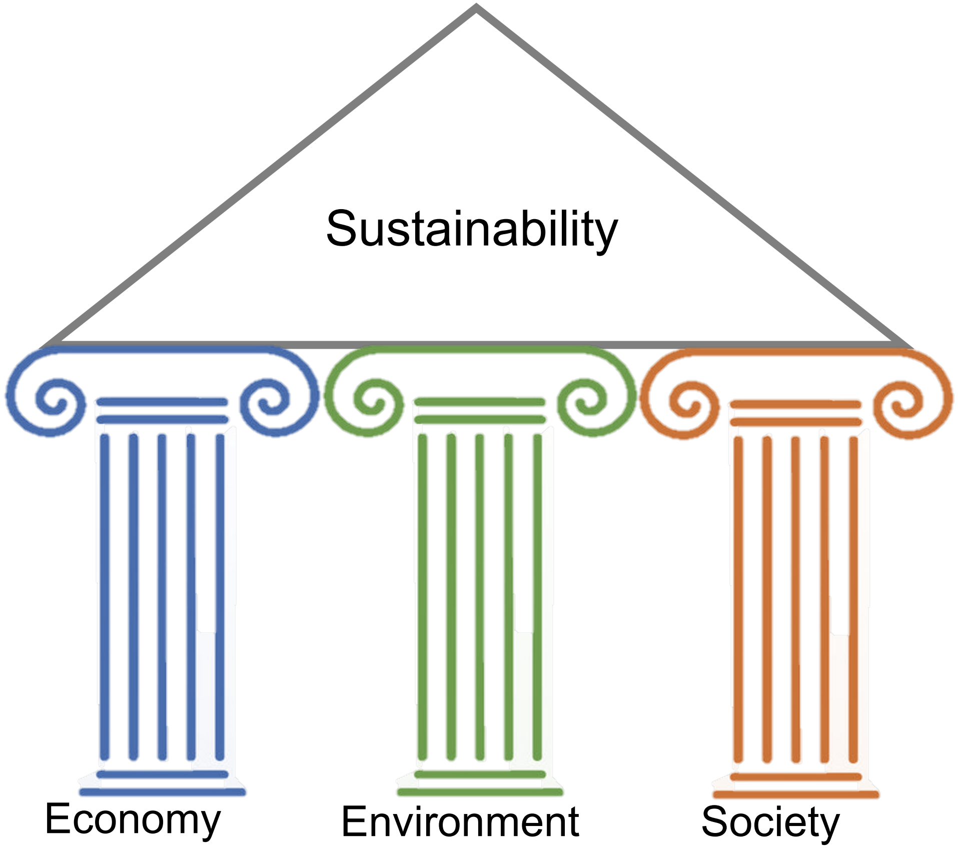
Company

Survey Statistics	
No. of questionnaires handed	50
No. of respondents	26
Average weightage to Sustainability	0.25
Average weightage to Resilience	0.75

What is Sustainability?

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." **Brundtland Report for the World Commission on Environment and Development (1992)**





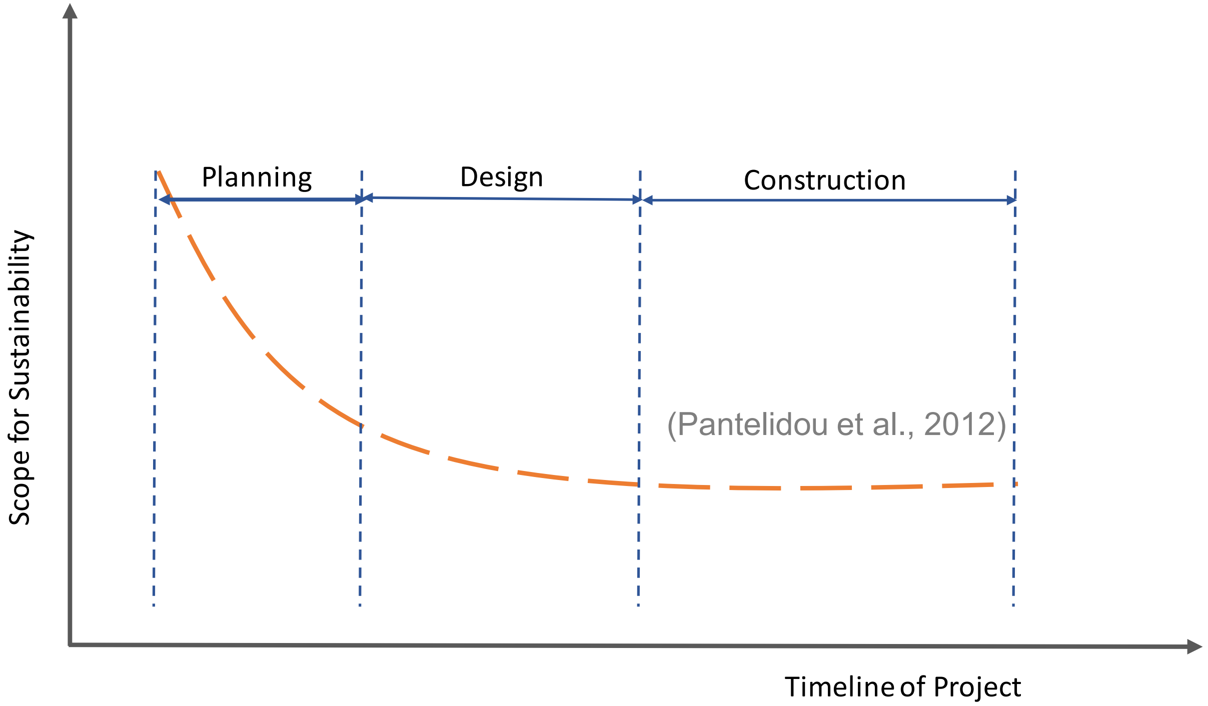
Goals for Sustainable Development

ASCE – 6, 7, 11 and 13

http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Geotechnics and Sustainability

- Integral component of many constructed systems
- Interface through which the human society and the built environment interacts (Puppala et al., 2017)
- Being positioned at the incipient stages, influences project sustainability in the subsequent stages (Abreu et al., 2008)

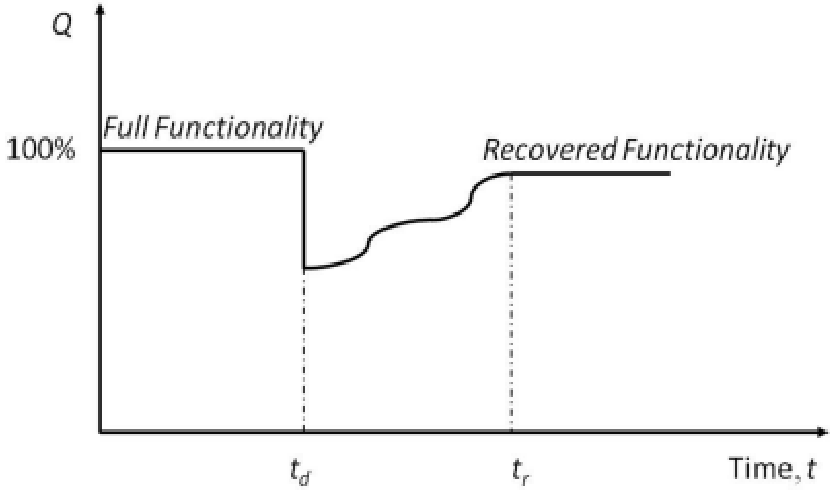


Resilience

Conceptual Definition

Resilience is the ability of human communities to withstand external shocks or perturbations to their infrastructure and to recover from such perturbations (Timmermann, 1981).

Analytical Definition

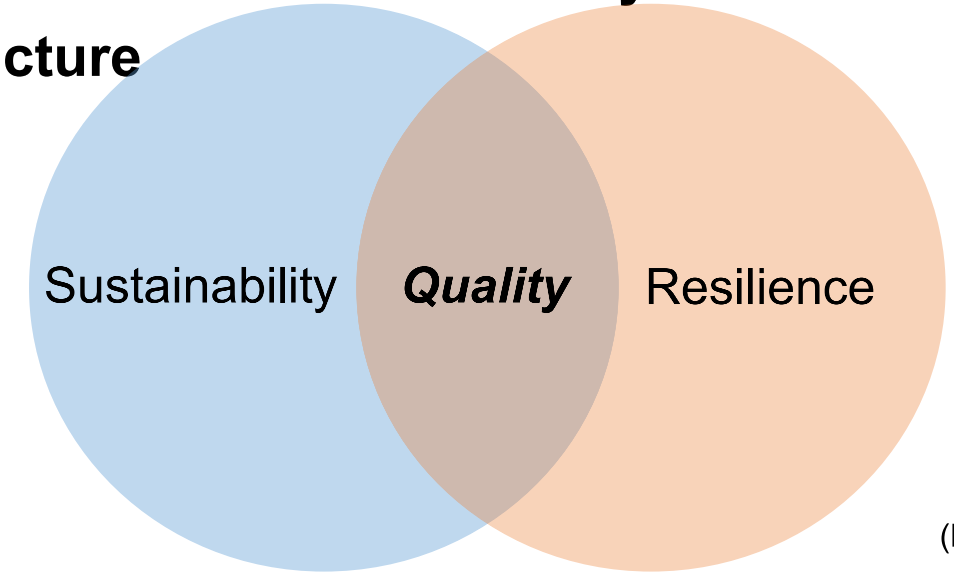


$$R = \int_{t_d}^{t_r} [100 - Q(t)]\, dt$$

(Bruneau et al., 2003)

In a Nutshell…

- **Sustainability and resilience are two complementary attributes of an infrastructure**
- **Sustainability deals with the steady impacts on environment, economy and society over the service life of an infrastructure**
- **Resilience chiefly addresses the resistance to sudden impacts due to unanticipated failure**
- **A holistic consideration of both sustainability and resilience is indicative of the quality of an infrastructure**



(Bocchini et al., 2013)

Many Geo-Infrastructure Areas

- Use of recycled and alternate materials in geotechnical construction
- Geosynthetics for soil reinforcement
- Innovative and energy-efficient ground improvement techniques; bioslope engineering
- Sustainable foundations, retrofitting and reuse of foundations, geothermal pile foundations
- Energy and mining geotechnics
- Environmental protection, waste management, and preservation of geodiversity
- Socioeconomic impact of geo-activities
- Geohazard monitoring and mitigation

- Development of sustainability assessment tools in geotechnical engineering

Combined Sustainability-Resilience (S-R) Framework