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Sustainable and Resilient Concrete Structures – Codes and Practices –
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Life-cycle management of concrete structures under the framework of sustainability

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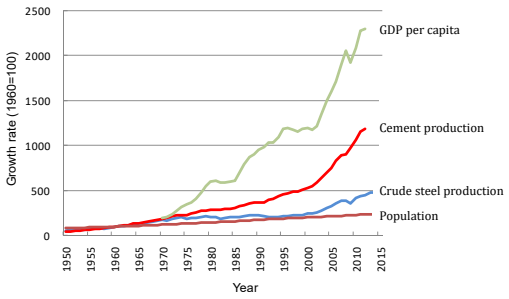
Background: Growth rates since 1950



Source
1. World steel organization: Steel year book
2. Japan Cement Association
3. UN Department of Economic and Social Affairs, Population Division
4. UN Department of Economic and Social Affairs (current USD)

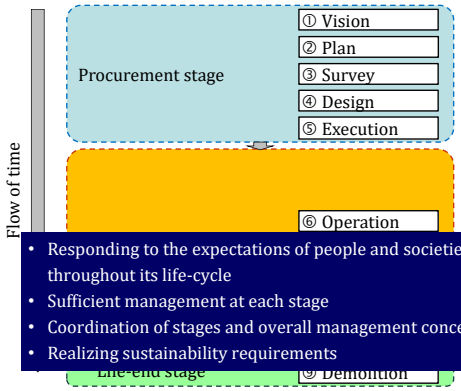
Infrastructure for society and humankind

To realize the society to have sustainability and diversity, infrastructures have to meet the expectations of people and societies.

A civil structure has its unique objectives and functions, and is socially shared by people to sustainably let them enjoy rich socioeconomic activities, ensure safety and security of life, and utilize resources.

Compatibility of infrastructure（インフラの適合性）
People and their societies can accept the infrastructure from the sustainability point of view.

Life cycle of infrastructure



- Responding to the expectations of people and societies throughout its life-cycle
- Sufficient management at each stage
- Coordination of stages and overall management concept
- Realizing sustainability requirements

International Standard on LCM

ISO 22040 *Life cycle management of concrete structures*

1. Scope
2. Normative references
3. Terms and definitions
4. General principles of life cycle management
5. General framework of life cycle management
6. Procedures of life cycle management
7. Management for each life cycle stage
8. Information transfer among management stages

ISO/TC71/WG1 Convener: YOKOTA Hiroshi (JISC)		
Sept. 2016	22nd TC71 Plenary (Cartagena, Colombia)	WG1 setup
Sept. 2017	1st WG1 & 23rd TC71 Plenary (Sapporo, Japan)	Apr. 2018 NP ballot
May 2018	2nd WG1 & 24th TC71 Plenary (Moscow, Russia)	Jan 2019 CD ballot
Oct. 2019	3rd WG1 & 25th TC71 Plenary (Birmingham, USA)	DIS ballot

Need for life cycle management

- Social infrastructure has to meet the expectations of people and societies (compatibility) throughout its life cycle consisting of different stages.
- No appropriate system has been developed regarding the basic concept and specific methods to achieve this and realize an optimal management of the infrastructure in a consistent manner.
- Consistent concepts and considerations are necessary to make infrastructure be effectively usable during its life cycle.
- Management in each stage should be appropriately coordinated, and the balance should be ensured based on sustainability considerations.

Procedures of LCM

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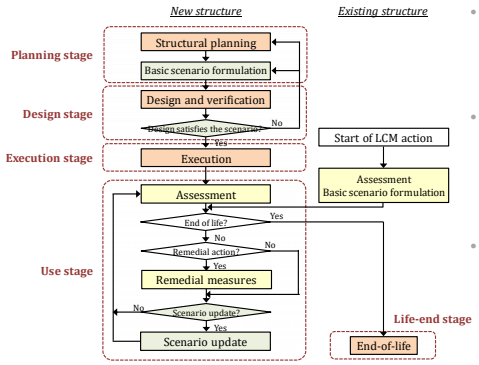

- Basic LCM scenario shall be formulated during the planning stage.
- Basic LCM scenario shall be updated if necessary at the design, execution, and/or use stages.
- Detailed scenario to apply to each stage shall be set and updated to reflect the basic LCM scenario.

Conceptual framework of LCM

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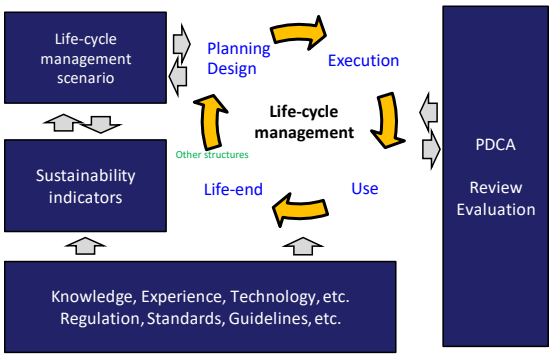

Sustainability

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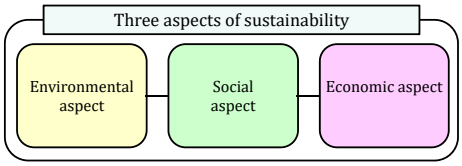
Sustainability

Activities of humankind can be appropriately sustained or not.

Finite resources and space ⇨ Equally shared among generations
Equally shared among regions

Ability of a structure or structural element to contribute positively to the fulfilment of the present needs of humankind with respect to social, economic and environmental aspects, without compromising the ability of future generations to meet their needs in a similar manner (*fib* MC 2020).



Scenario evaluation with sustainability indicators

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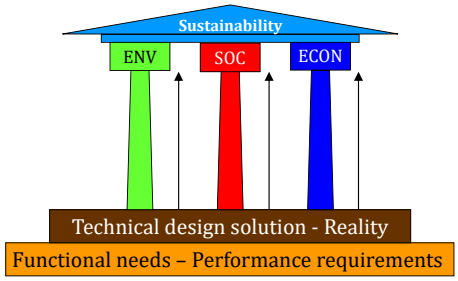

ENV: Climate change, Resources consumption, Pollution, Biodiversity, Ecological system, etc.
SOC: Quality of infrastructure, Safety and security, Accessibility, Users' satisfaction level, Cultural preservation, etc.
ECON: Direct and indirect costs, Benefit, Efficiency, Values, etc.

Examples of sustainability indicators

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ENV

- Climate change
- Resource consumption
- Pollution
- Biodiversity
- Etc.

⇨

- Input energy
- Resourse consumption
- Greenhouse gas emission
- Pollution, noise, vibration, etc.
- Industrial waste etc.

SOC

- Quality of infrastructure
- Safety・Comfort ・Serviceability
- Easiness of access to service
- Culture ・Cultural heritage
- Social unification
- Quality of life, satisfaction, etc.

⇨

- Safety
- Serviceability
- Accessibility
- Adaptability
- Health・Comfort
- Creating job
- Population, etc.

ECON

- Performance
- Location
- Energy efficiency
- Maintenance
- Function, etc.

⇨

- Direct cost
- Asset value
- Direct benefit
- Indirect economic effect
- External cost, etc.

Principal sustainability indicators

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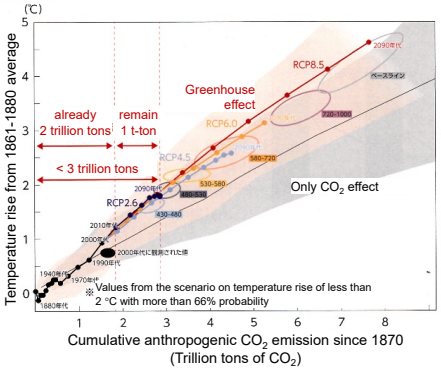
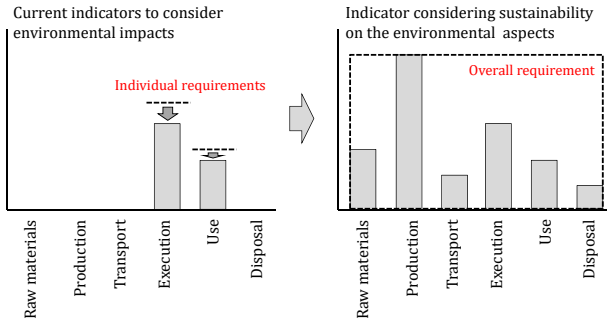
- Environmental aspect
  - Greenhouse gas emission
  - Resources and energy consumption
  - Environmental burdens to lives and properties, etc.
- Social aspect
  - Safety and serviceability (overall safety margin)
    Robustness and Resiliency
    Risk, etc.
- Economic aspect
  - Life cycle cost
  - Benefit
  - Asset value, etc.

ENV: Cumulative CO_2 emission

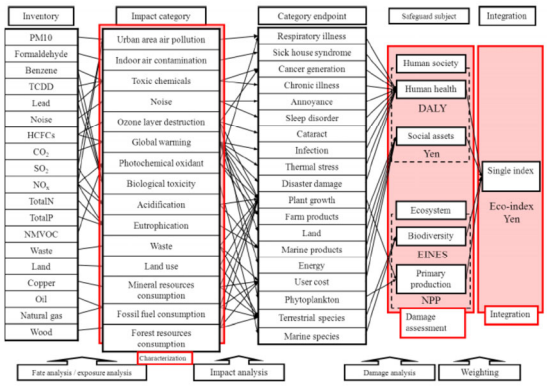


White paper (2018), Ministry of the Environment

ENV: Indicator of environmental aspect



ENV: Life cycle impact assessment Method based on Endpoint modeling



LIME2, Life Cycle Assessment Society of Japan

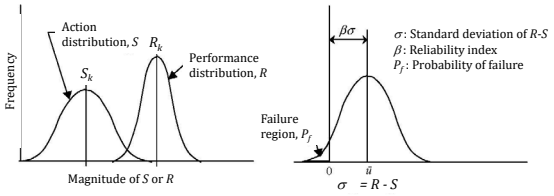
SOC: Verification on social aspect (structural capacity)

$$\gamma_i S_d / R_d \le 1.0$$

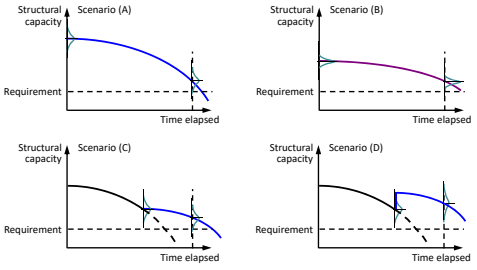
γ_i : Structure factor (overall safety margin)

S_d : Design action

R_d : Design performance (capacity)



SOC: LCM scenarios



(A) (B) Scenario at the design stage

(C) (D) Scenario for repair at the use stage

Which scenario should be selected?

SOC: Indicators for sustainability design

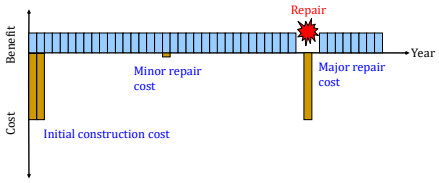
- Safety and serviceability
  - Robustness: structural insensitivity (Ability of a structure to withstand accidental events or consequences of human errors without being damaged to an extent disproportionate to the original cause [ISO 2394])
  - Resilience: ability to resist, adapt, or quickly recover from potentially disruptive events or conditions, whether natural or manmade, in order to maintain or restore the intended service
  - Redundancy
  - Direct or indirect risk caused by structural failure

ECON: From Cost (LCC) to Value (Value)

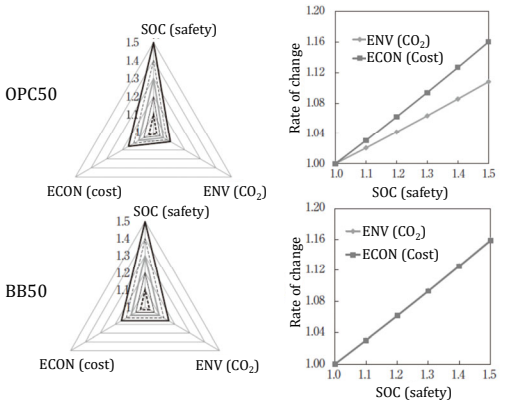
$$LCC = \sum_{i=1}^{t} \frac{C_i}{(1+r)^i}$$

$$NPV = \sum_{i} \frac{(B_i - C_i)}{(1+r)^i}$$

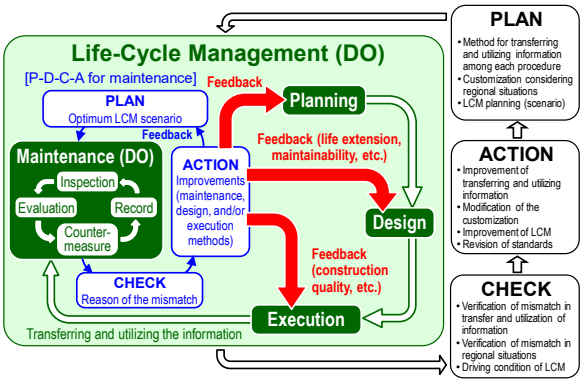
B_i: Benefit at time i
C_i: Cost at time i
r: Discount rate



Estimating sustainability indicators



Information transfer during LCM



Conclusions 1

- Thorough coordination is necessary between the planning, design, execution, use and end-of-life stages of structural life-cycle.
- Sustainability considerations are required for the life cycle management with the appropriate balance between social, environmental and economic indicators.

Conclusions 2