Structural Form of Bridges Reflecting the Construction Processes

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Flow of the Presentation

- Basic Theory
- Basic Ideas of this Thesis
- How to Illustrate the Construction Processes
- Examples (Real Construction Methods)
- Evaluation from the Analysis
- Conclusions

Introduction

Sir Ove Arup (1895-1988)

Source; Arup HP
http://www.arup.com/projects/kingsgate_footbridge

"Design without considering the construction process is nonsense."

He (Sir Ove Arup) always said this phrase when talked with us (while working).

Yuzo Mikami; Archtecture,

Source; Kenchikushiryokenkyusya (2006) "Zokei" pp 74-81

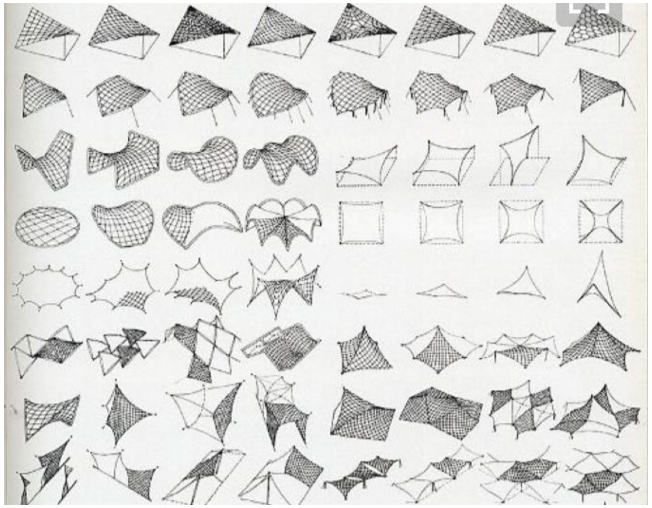
Tranlated by author

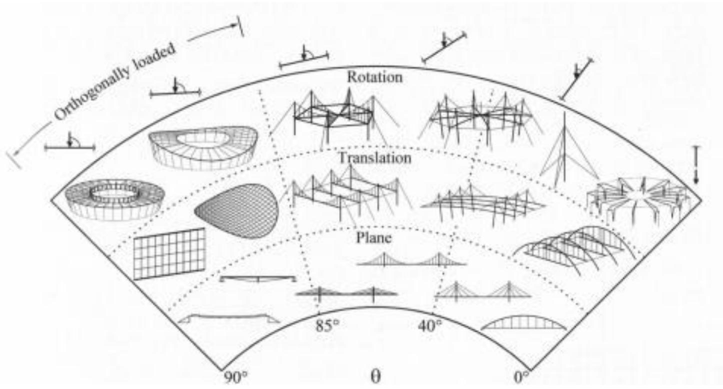
Background and Purpose of This Research

Researchers who Systematized Structures

- Frei Otto
- Mike Schaich
- Yoshiaki Kubota

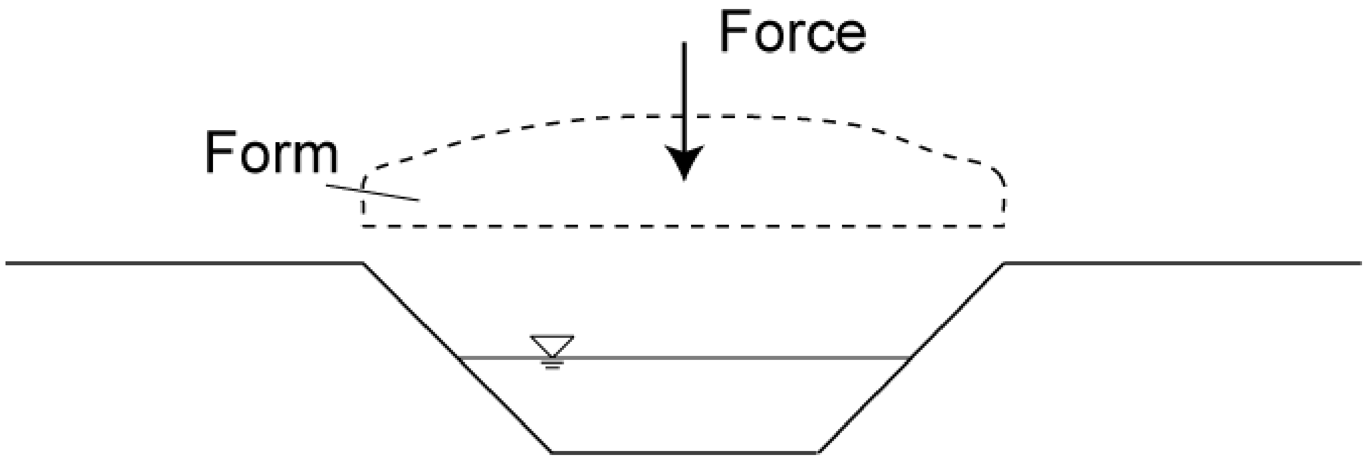
and so forth





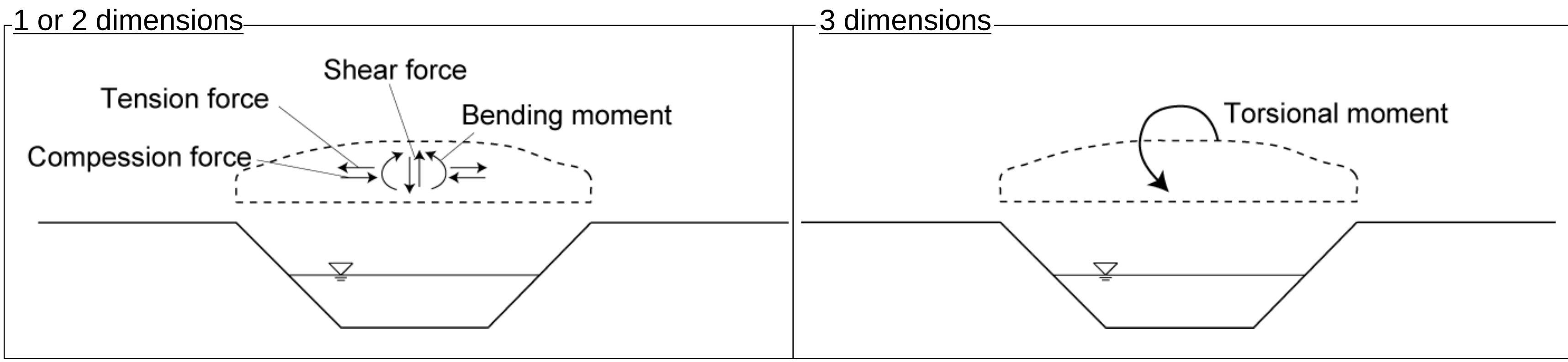
Basic Theory

- Form and Force -



Basic Theory

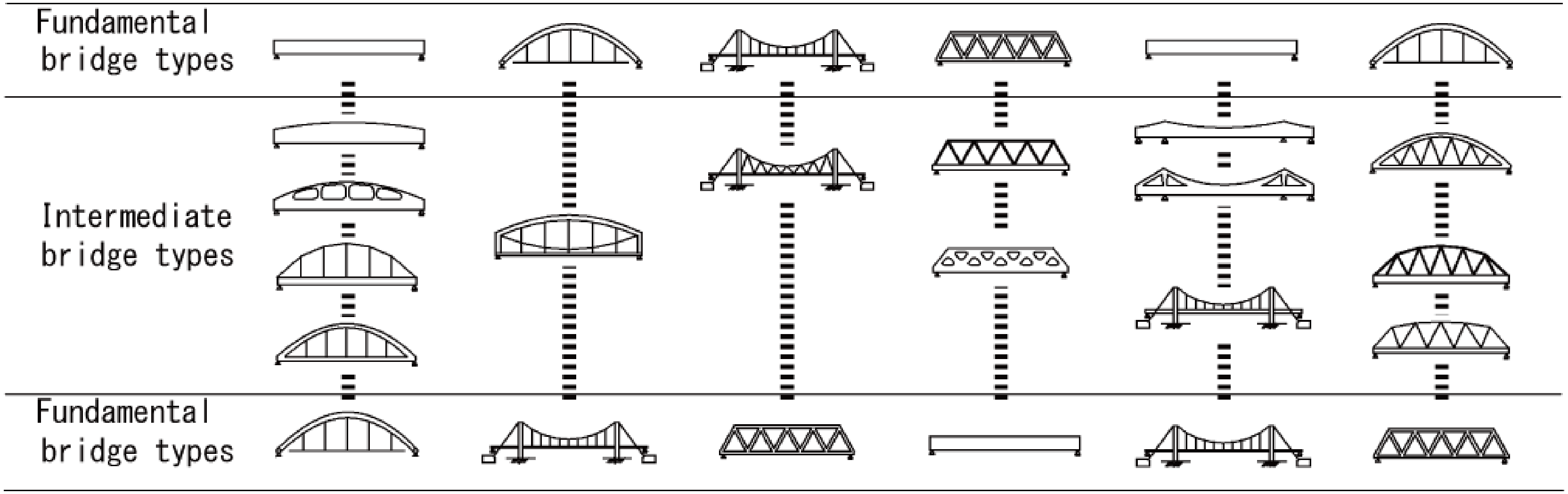
- Form and Force -



Acting force	1 dimension	2 dimensions	3 dimensions	Typical Structural systems	Fundamental bridge types
Tension force	*	*	*	Suspension system	Suspension bridge
Compression force	*	*	*	Arch system	Arch bridge
Bending moment		*	*	Beam system (Web system)	Girder
Shear force		*	*	Beam system (Diagonal system)	Truss bridge
Torsional moment			*	–	–

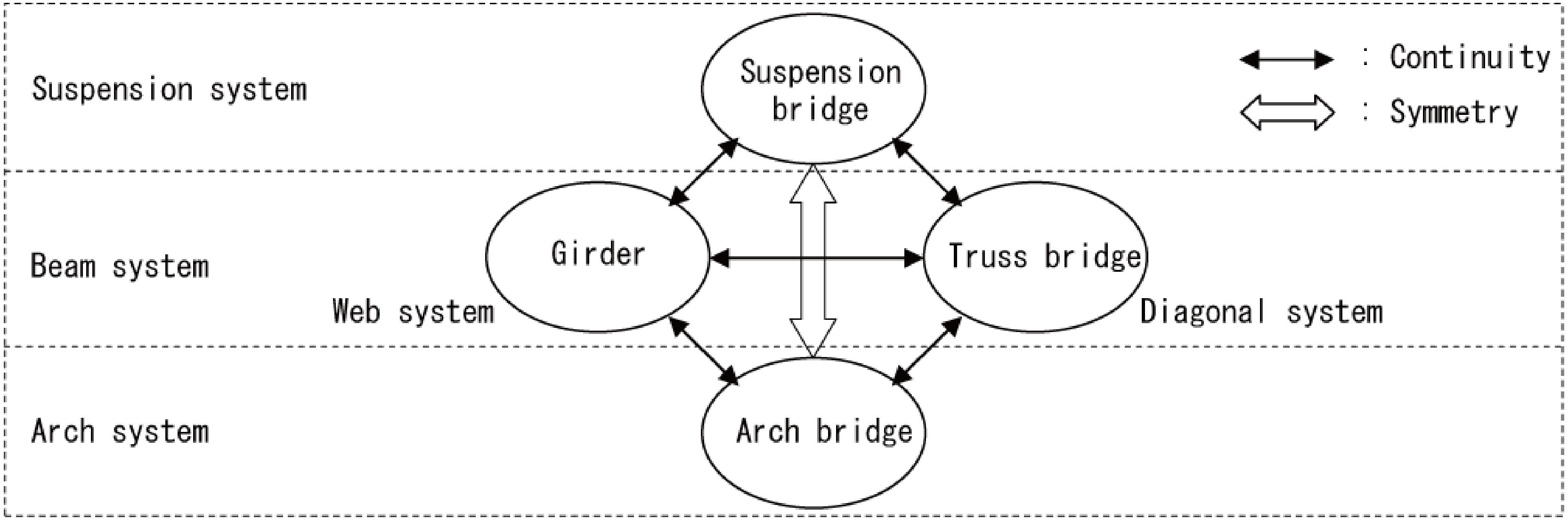
Basic Theory

- Continuous relationships between fundamental bridges -



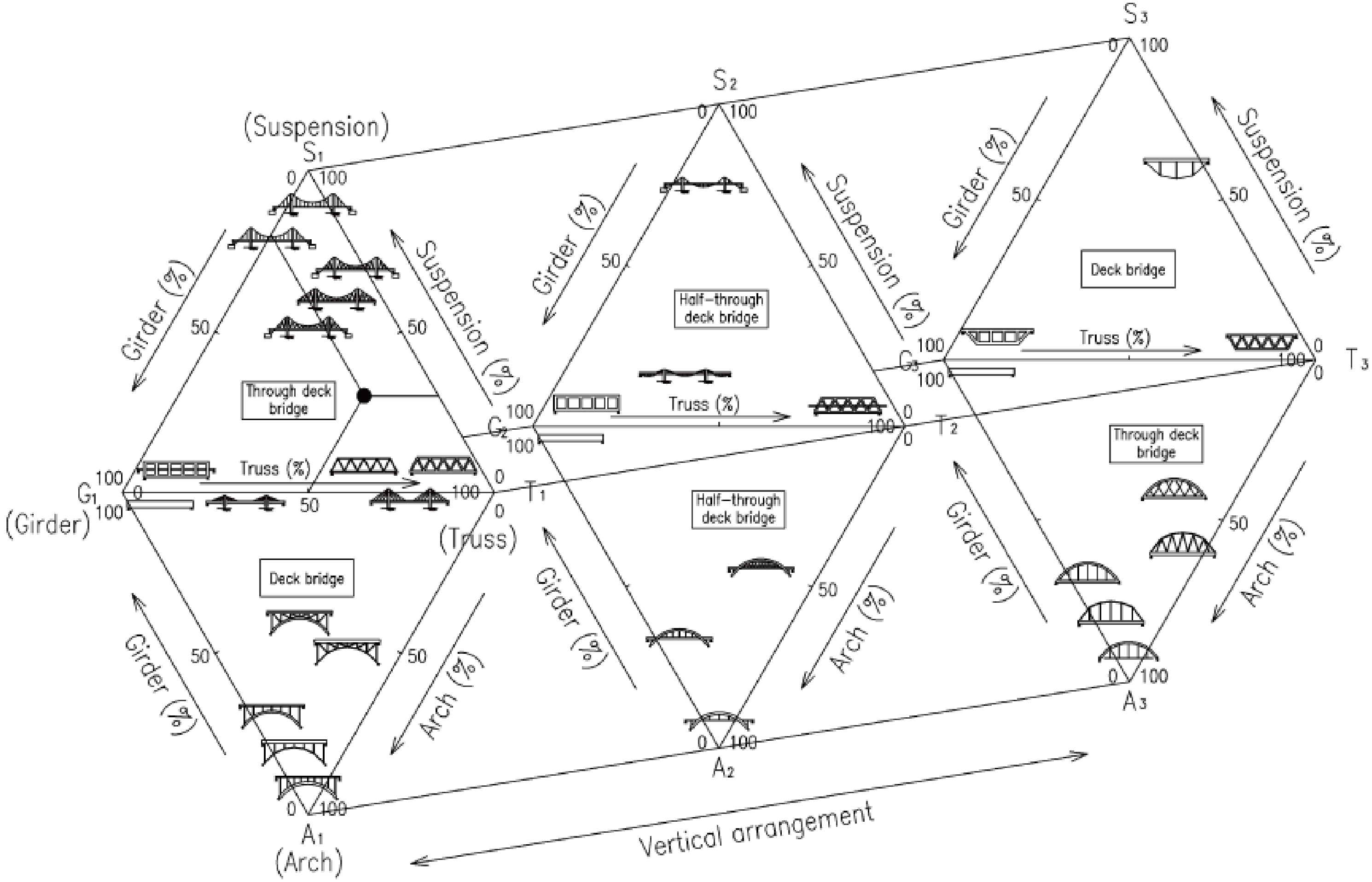
Basic Theory

- Relationships between fundamental bridges -



Basic Theory

- Structural Form Correlation Chart -



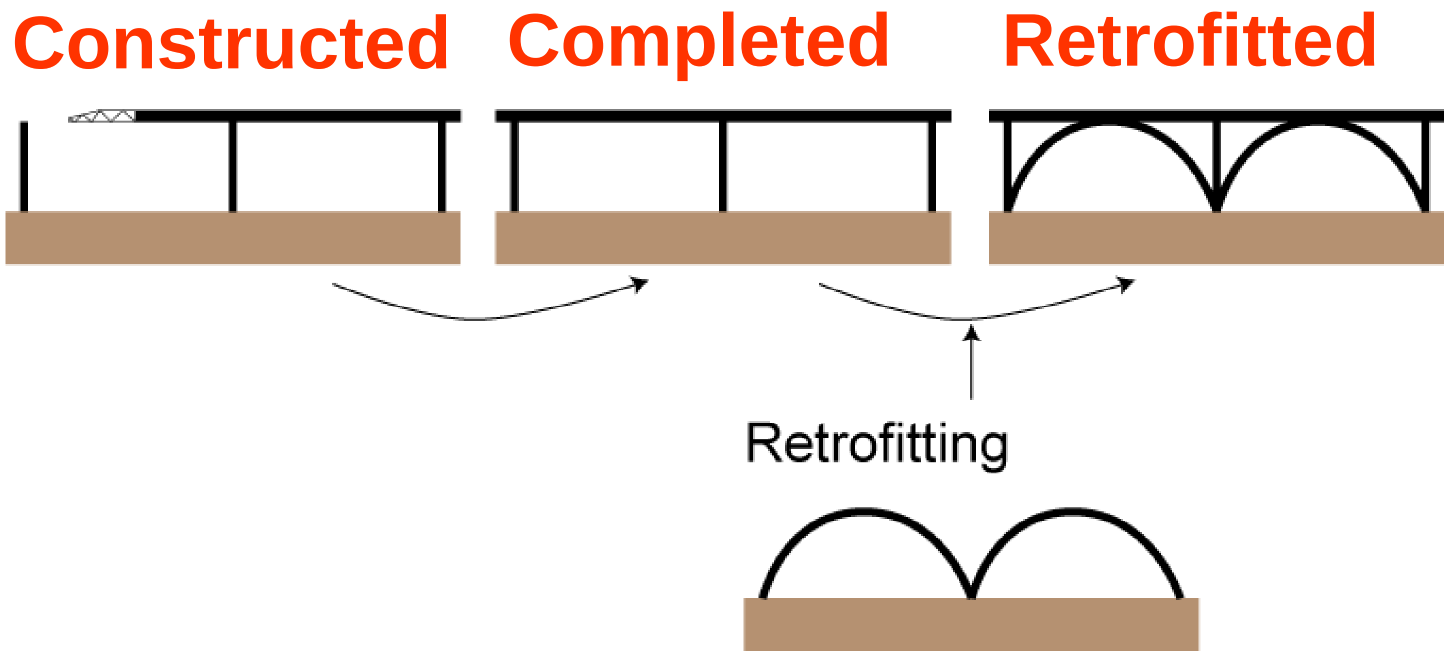
Bridges in use

Bridges under construction





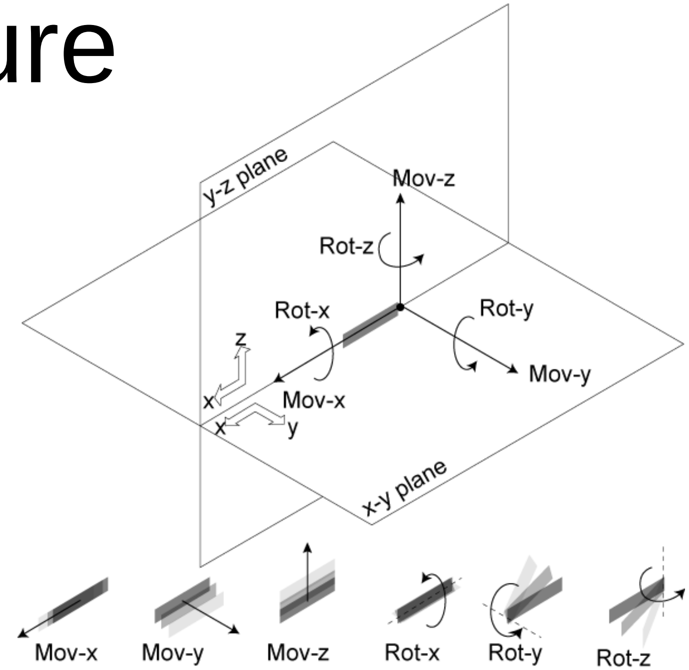
Three steps in Life Cycle of Bridges and Retrofitting state



Retrofitting members are seen in the construction process such as reinforcement or repair, but not in the continuous life cycle of one particular bridge.

Movement of Structure

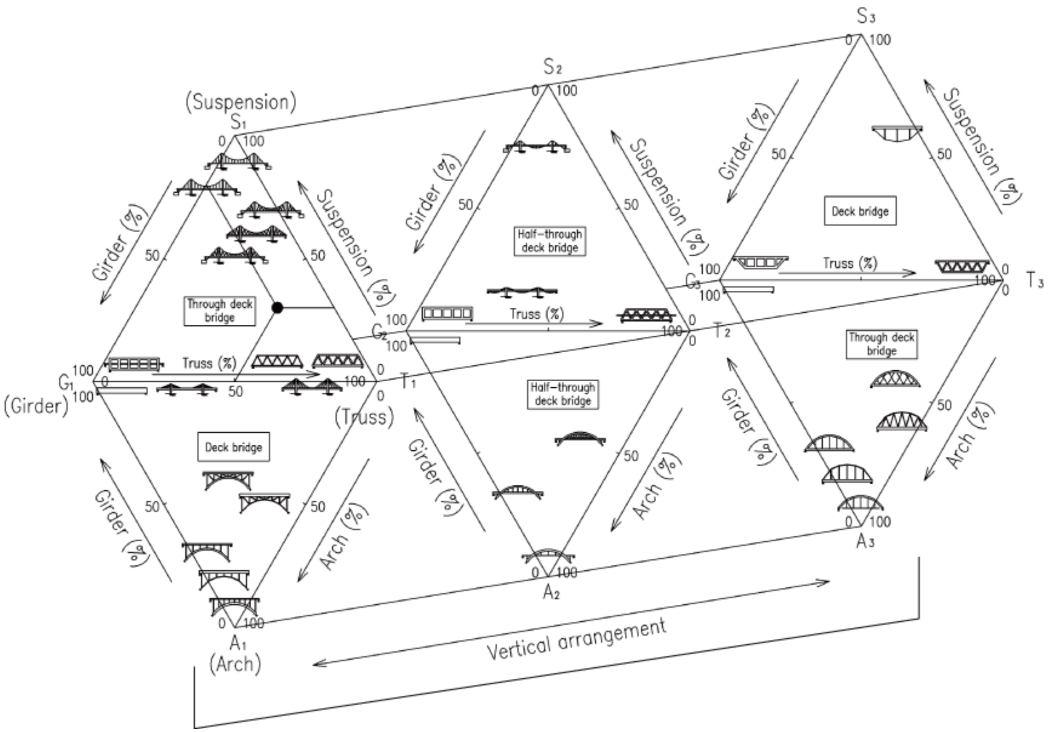
A coordinate system for bridge incorporates the boundary condition, spaning/cantilever condition and the movement which occurs when the bridge is under construction.



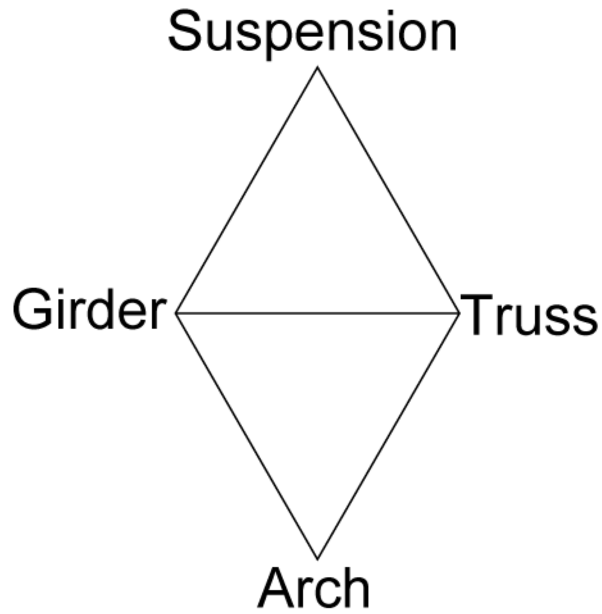
Structure system \ The Elements		Spaning System Boundary Condition: Rot	Spaning System Boundary Condition: Fix	Cantilever System	Mov-x	Mov-y	Mov-z	Rot-x	Rot-y	Rot-z
Suspension System		○	×	×	×	○	○	△	△	×
Beam System	Web System	○	○	○	○	○	○	△	○	○
Beam System	Diagonal System	○	○	○	○	○	○	△	○	○
Arch System		○	× (*)	×	×	○	○	△	△	×

- ○ ; avilable, × ; unavilable, △ ; aviilable under the specific condition
- Though Arch Bridge can transfer bending moment at the endpoints because of the bending rigidity, column (*) is filled with "I" because a pure arch system can transmit only axial compression force.

Simplification of Illustration of Triangular Coordinate System

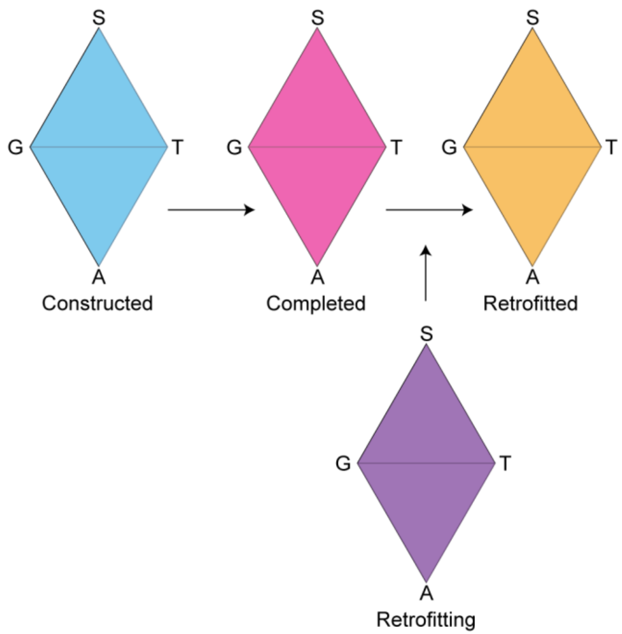


Ignoring the Layers

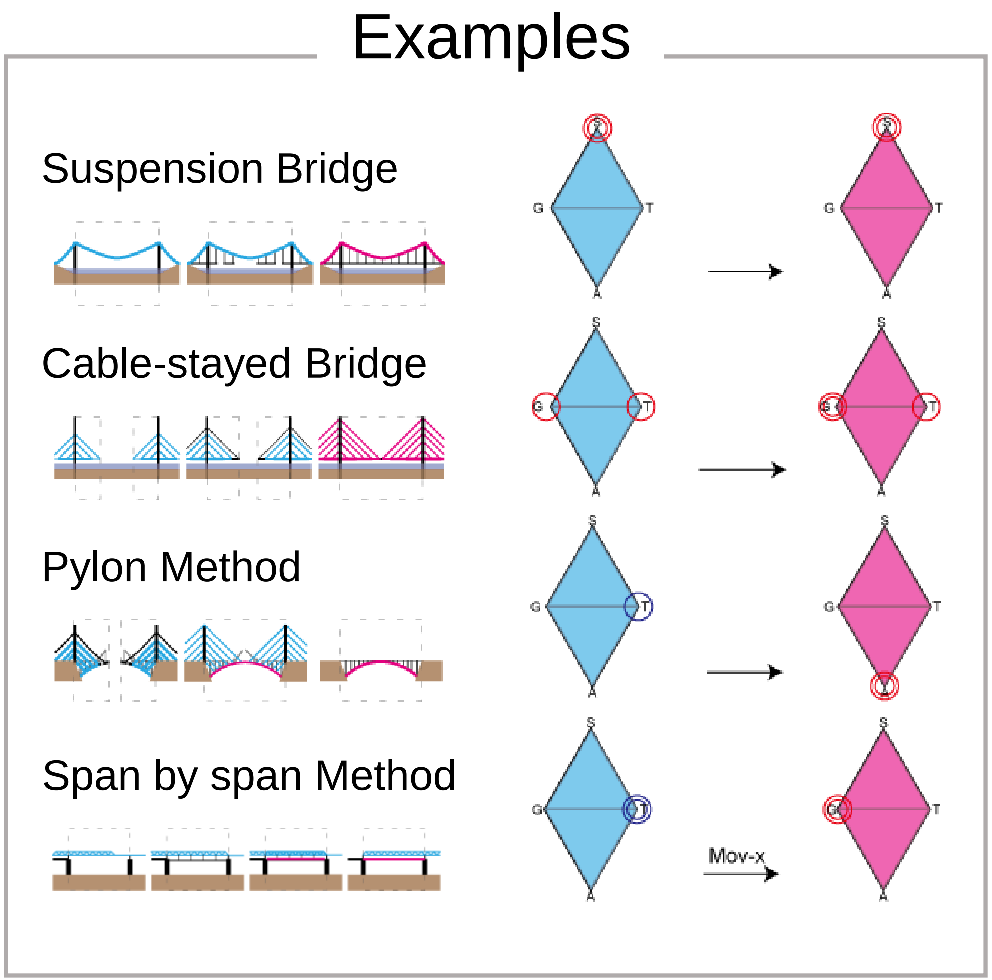


Simple Illustration

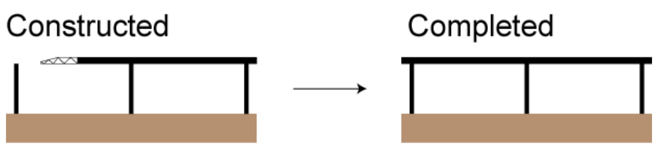
The way of Analysis

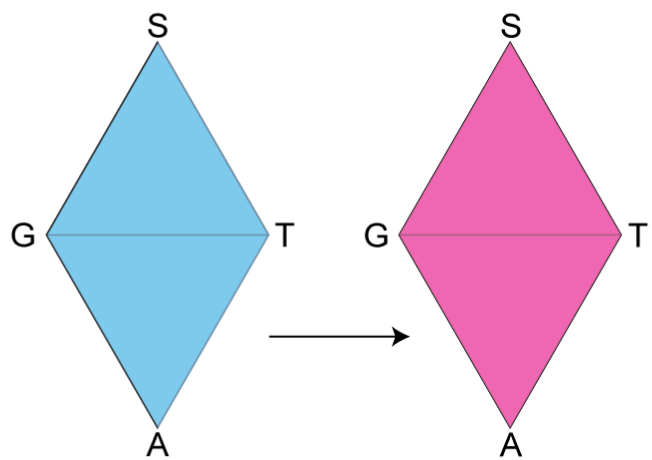


	Permanent	Removal
Spanning	◎	◎
Cantilever	○	○



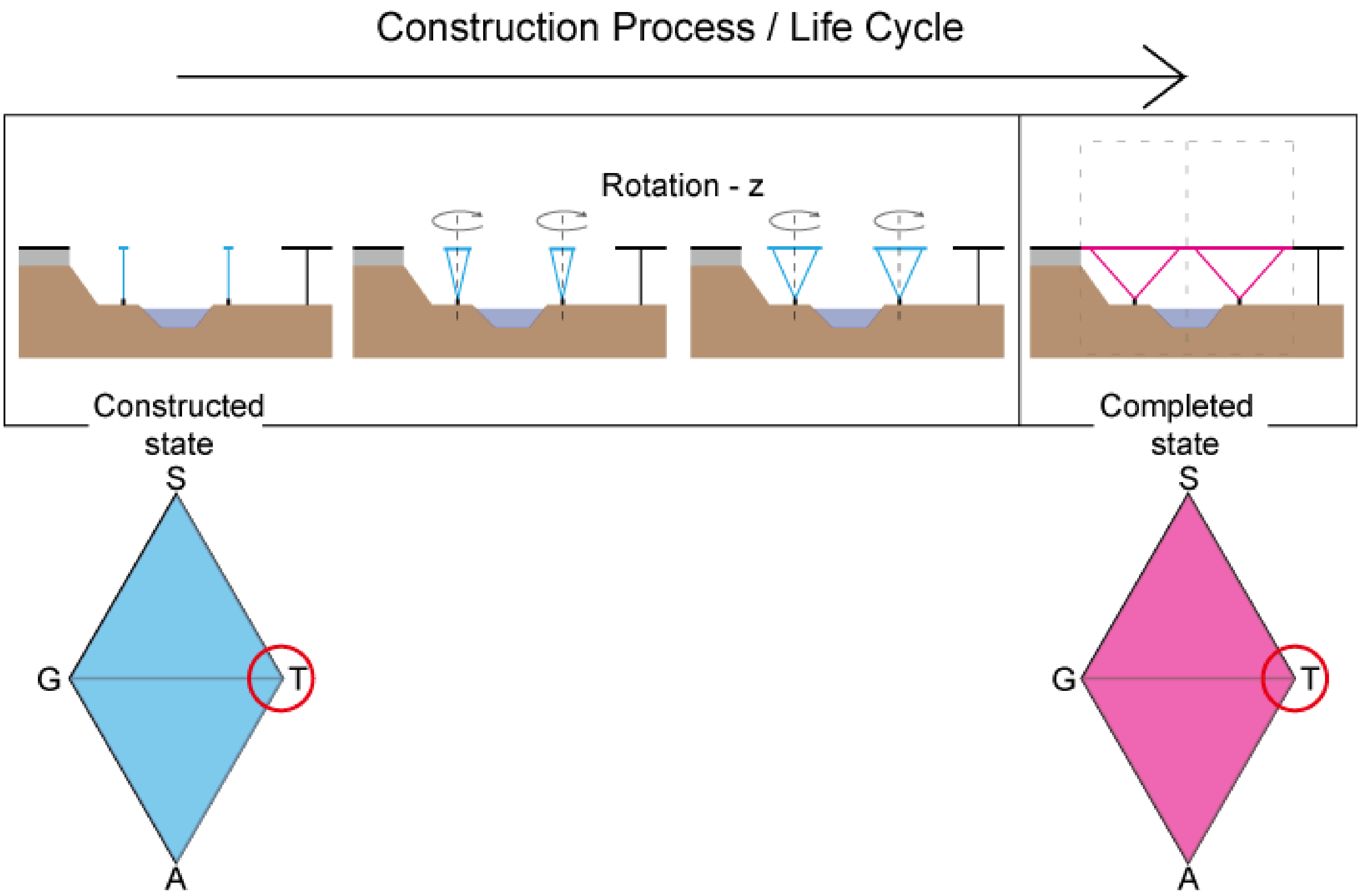
New Construction



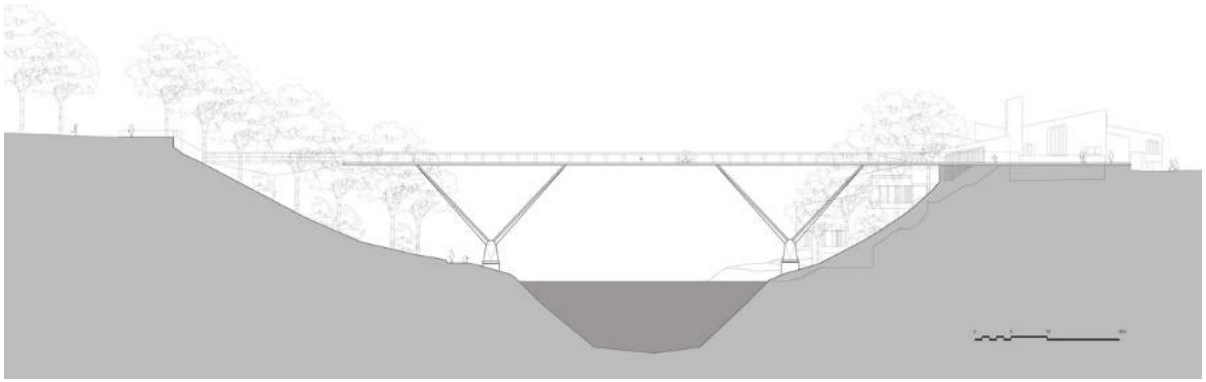


In new construction, bridges are defined as completed when they become available.

Horizontal Rotation Method



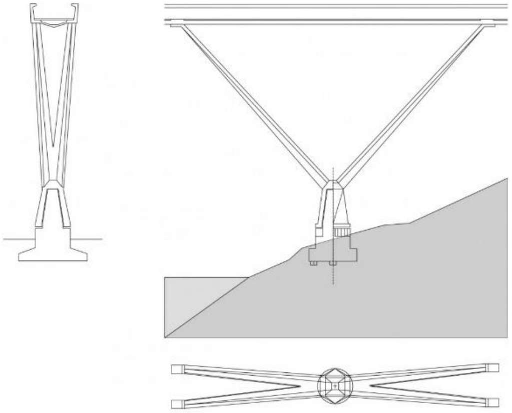
Ex, Kingsgate Bridge



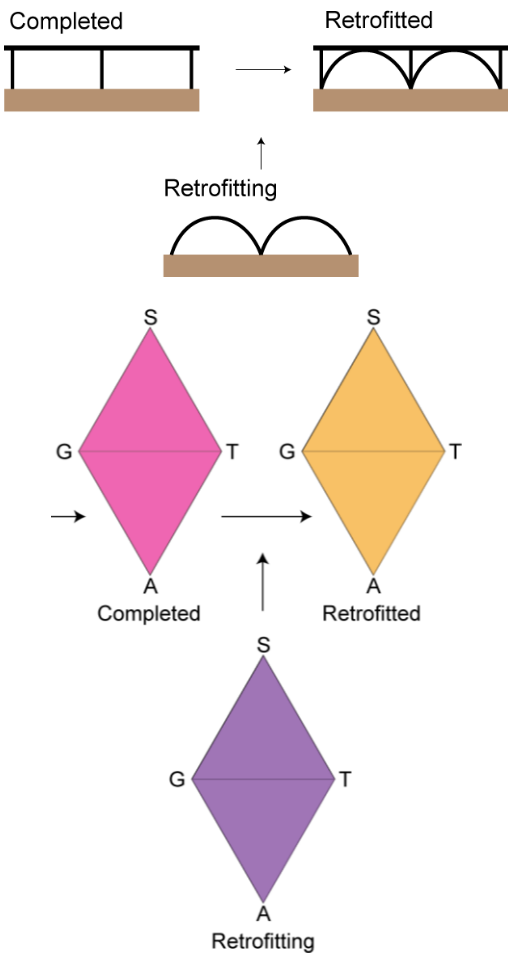
Span
20m,20m,20m,20m,12m

The Completion
1966

Country
United Kingdom

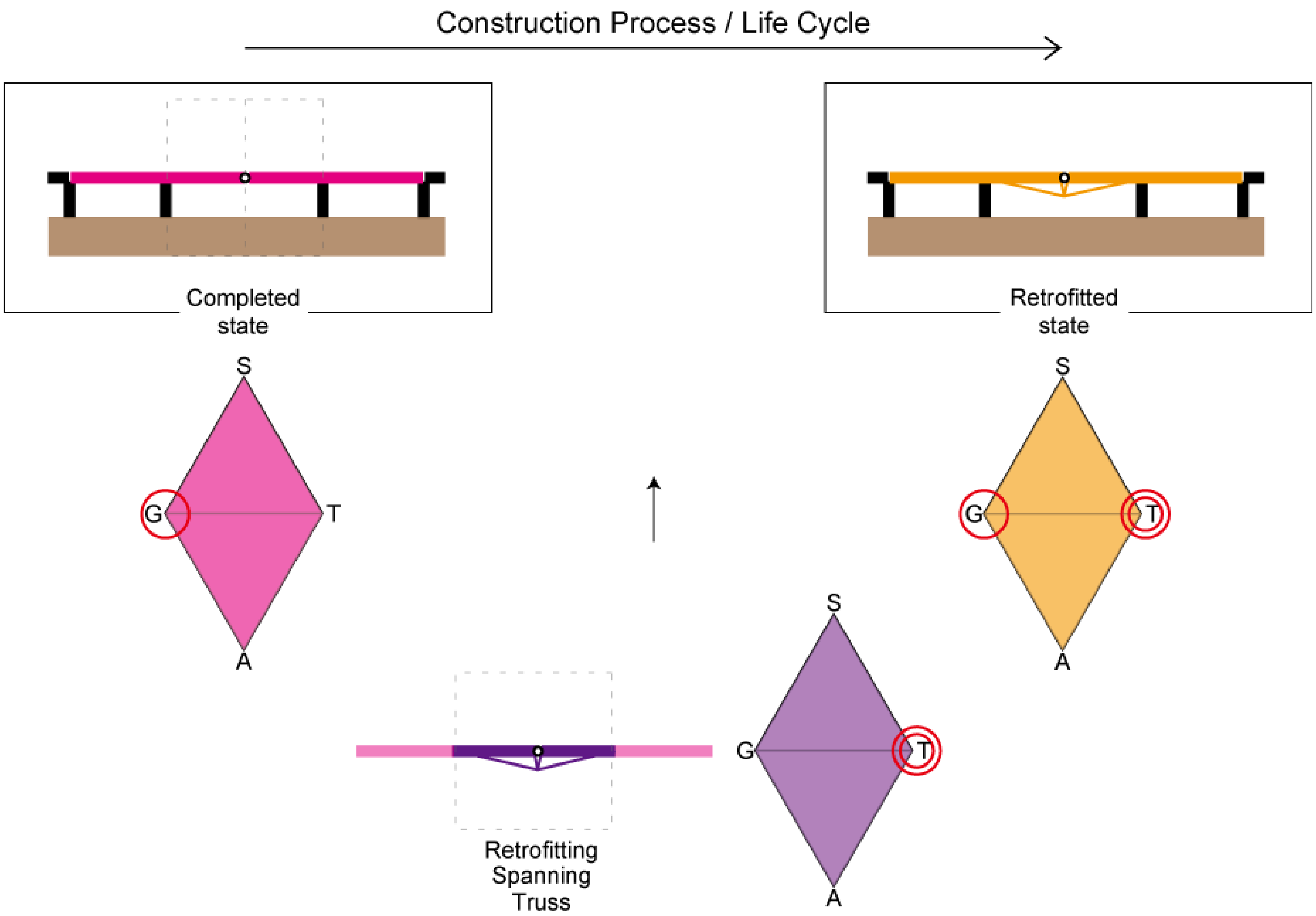


Retrofit (reinforce, repair, widening)



In retrofit process, bridges are completed when they are improved and become available again.

Reinforcement of the Middle Hinge PC Bridge with String Beam Structure



Ex, Kireuriwari Bridge




Span

154m

The Completion

1979 (Repaired in 2003)

Country

United Kingdom

Evaluation

- Applicability

  The likelihood that a structural system will change to another system.

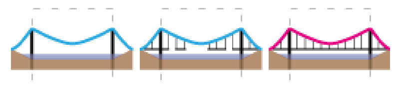
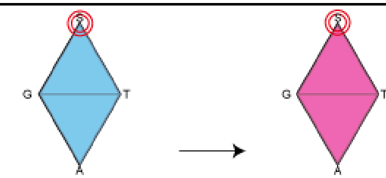
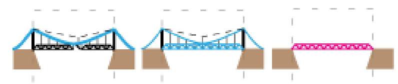
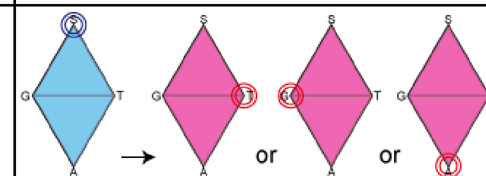
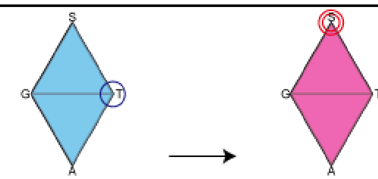
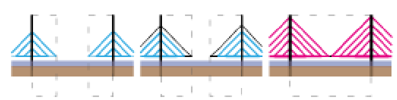
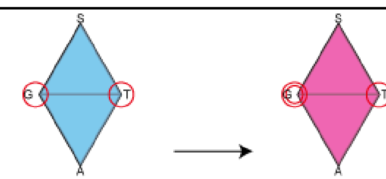
- Material Efficiency

  Quantity of the material including temporary structures in consideration of bridges' scale.

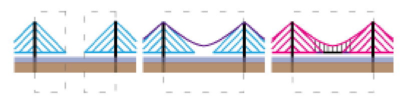
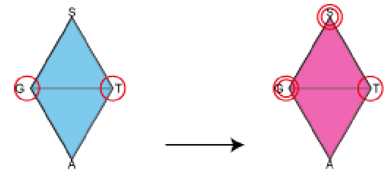
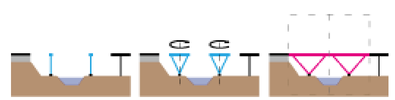
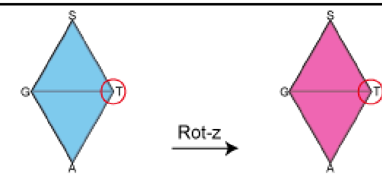
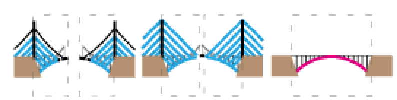
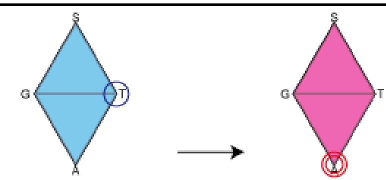
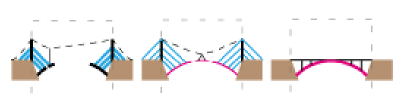
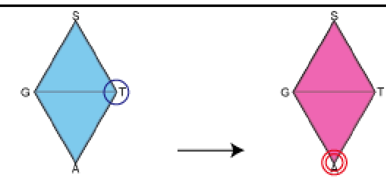
- Time Efficiency

  Speed of the construction in consideration of bridges' scale.

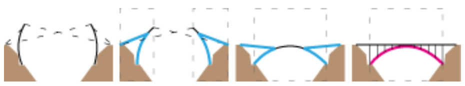
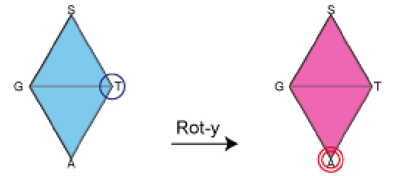
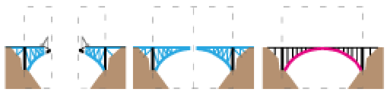
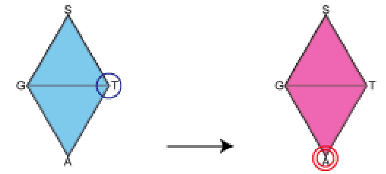
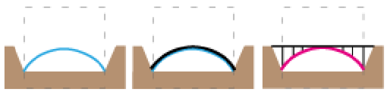
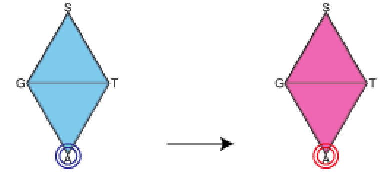
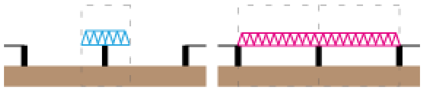
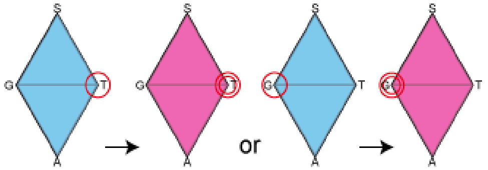
Evaluation

Construction Method / Names of Completed Bridge	Efficiency (Dimensionless)		Construction Process / Life Cycle	Transition
	Material	Time		
Suspension Bridge	◎	○		
Vertical Cable Erection Method	×	△		
Single-operation Method of the Suspension Bridge	○	◎		
Cable-Stayed Bridge	◎	×		

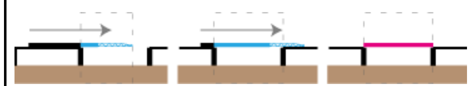
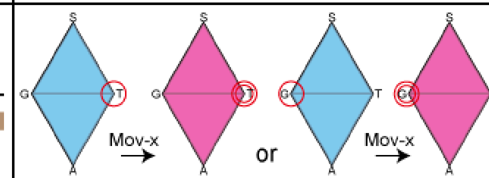
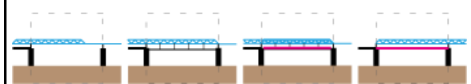
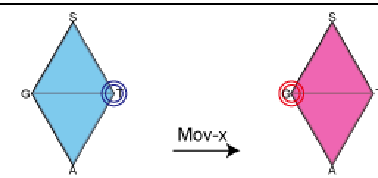
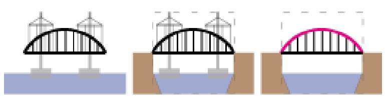
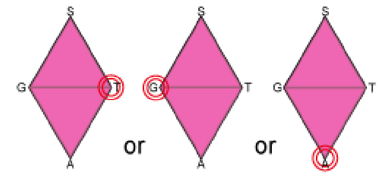
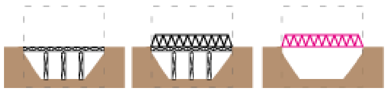
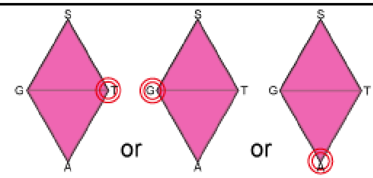
Evaluation

Construction Method / Names of Completed Bridge	Efficiency (Dimensionless)		Construction Process / Life Cycle	Transition
	Material	Time		
Dischinger-Type Bridge	◎	×		
Vetrical Rotation Method	○	○		
Pylon Method	×	△		
Diagonal Cable Erection Method	×	△		

Evaluation

Construction Method / Names of Completed Bridge	Efficiency（Dimensionless）		Construction Process	Transition
	Material	Time		
Lowering Method	○	△		
Overhanging Arch Erection Method with Truss	○	×		
Arch Center Method	×	○		
Balanced Cantilever Method	◎	△		

Evaluation

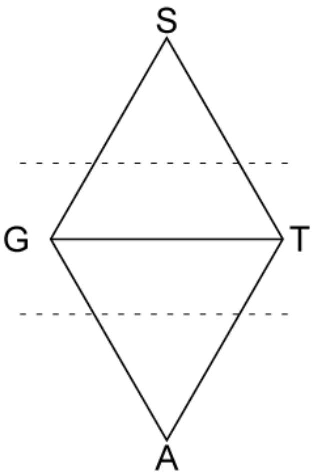
Construction Method / Names of Completed Bridge	Efficiency (Dimensionless)		Construction Process	Transition
	Material	Time		
Launching Erection Method	△	◎		
Span by Span Construction Method	×	◎		
Single-Operation Method with Floating Crane or Pontoon	×	◎		
Fixed Timbering Erection Method	×	◎		

Applicability and Efficiency

	Applicability of Structural System		Time Efficiency
	Constructed State	Retrofitted State	
Suspension System	Quite Good	Poor	Good
Diagonal System	Good	Good	Good with Parallel translation
Web System	Not Good	Good	Good with Parallel translation
Arch System	Poor	Good	Poor

Material Efficiency becomes good if the structural system doesn’t change while the construction process. For example, suspension bridges and cable-stayed bridges are quite good at material efficiency.

Conclusion

<table>
<tr><th colspan="3">Triangular
Coordinate System</th><th>Constructed</th><th>Completed</th><th>Retrofitted</th><th>Retrofitting</th></tr>
<tr><td colspan="2">Suspension System
(Spanning System)</td><td rowspan="3">
</td><td>Efficient because of the material efficiency</td><td>More efficient because of the material efficiency</td><td>Low efficiency</td><td>Efficient because of the material efficiency</td></tr>
<tr><td>Web System
(Beam System)</td><td>Diagonal System
(Beam System)</td><td>Efficient at both time and material because of being used as a cantilever</td><td>Efficient because of the material efficiency</td><td>Efficient</td><td>Efficient if being used as a diagonal system</td></tr>
<tr><td colspan="2">Arch System
(Spanning System)</td><td>Low efficiency</td><td>More efficient because of the material efficiency</td><td>Efficient</td><td>Efficient for Supporting exisiting spanning systems</td></tr>
</table>

- Suspension system is always good at material efficiency.
- Efficiency in constructed and retrofitted state is different.
- In retrofitting state, all systems except web system are efficient.

Future Research

- Examination of the analysis method
- Quantification of the analysis of efficiency
- Evaluation of the application in the retrofit process
- Development of the design method using this theory