Structural Response of Bridge Structures

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Contents

- Design stress and actual stress
- Stress reduction factor for fatigue assessment
- FEM model
- Proof Load Test

Investigations on Difference between Design Stress and Actual Stress

Target Bridges : Various Types of Bridges

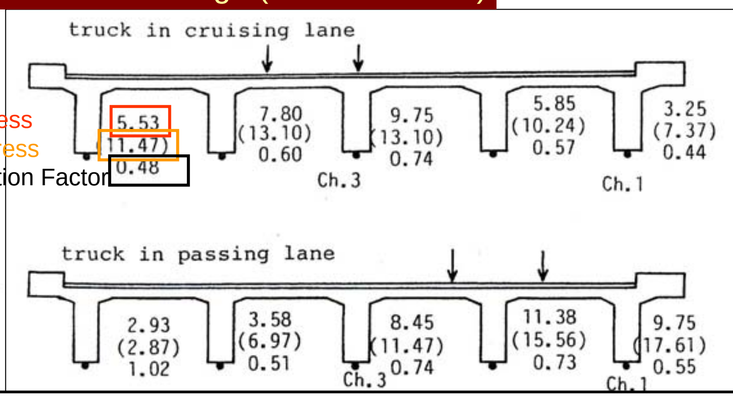
Route	Bridge	Bridge Type	Length (m)	Width (m)	Design Calculation Method
Tomei	Takamatsu No.1	PC-Post Tens. T-Section Simple Girder	27.76	13.154	Simple Supported Girder
	Katayama	Steel Composite Girder	47.30	12.60	Grid Structure Effective Width
	Katayama	3 Span Continuous Girder, RC Hollow	35.571	12.60	Grid Structure
	Sagamigawa	2 Span Continuous Girder, PC Box	73.90	16.35	Grid Structure
Chuo	Uenohara	Truss	84.115	12.101	Truss
	Uenohara	Steel Composite Girder	28.039	12.101	Grid Structure Effective Width
	Komiya	Steel Box	50.149	12.50	Grid Structure

Measured Stress, Calculated Stress, and Stress Reduction Factor

$$\text{Stress Reduction Factor} = \frac{\sigma\ \text{measured}}{\sigma\ \text{calculated}}$$

Takamatsu No.1 Bridge (PC Post-Tens.)

Measured Stress
Calculated Stress
Stress Reduction Factor



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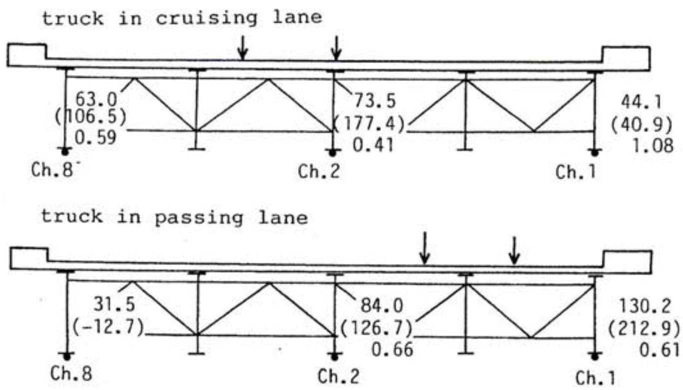
Takayama Viaduct (Steel Girder Bridge)



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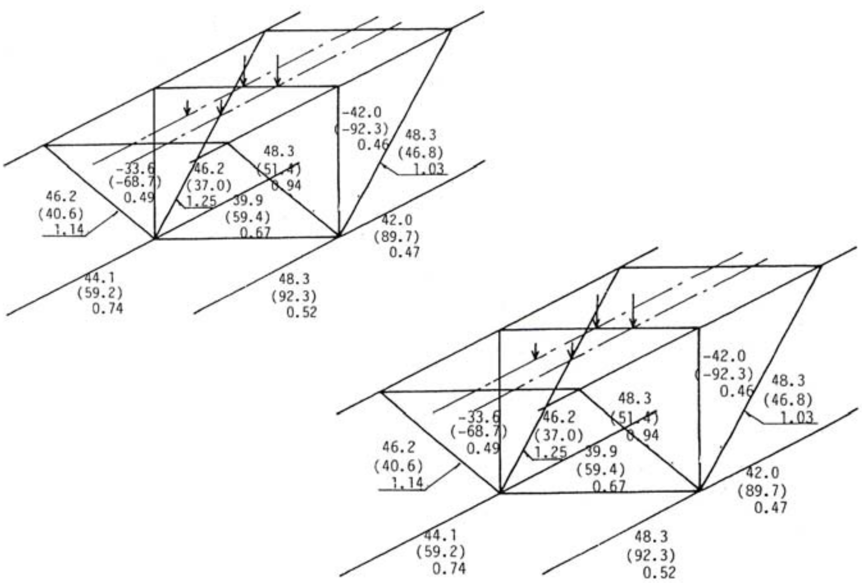
Uenohara Bridge (Truss)



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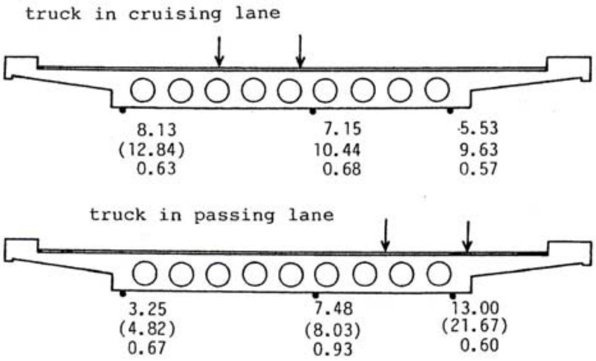
Takayama Viaduct (RC Hollow)



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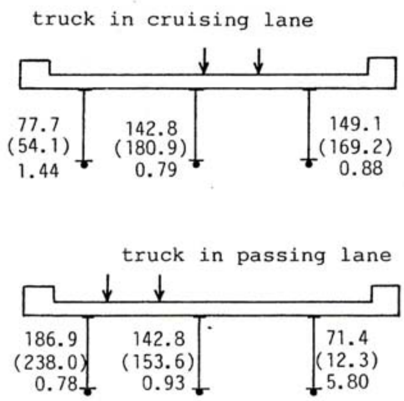
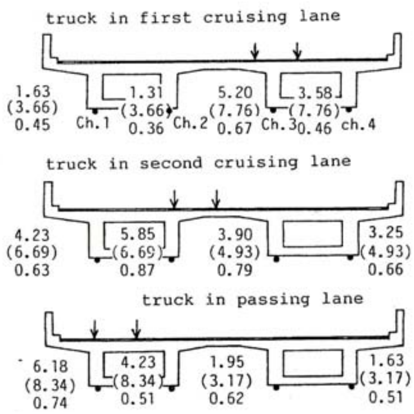
Uenohara Bridge (Composite Girder)



Sagamigawa Bridge (PC Box)



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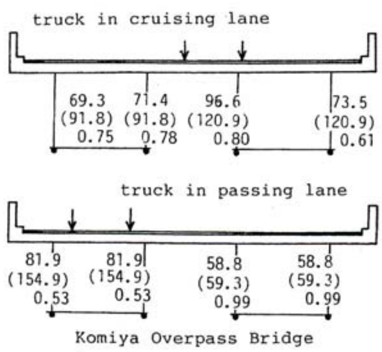
Komiya Overpass Bridge (PC Box)



Mean Values of Stress Reduction Factor

BRIDGE	IMPACT FRACTION	STRESS REDUCTION FACTOR	
		WITH IMPACT	WITHOUT IMPACT
Takamatsu No.1	0.260	0.64	0.81
katayama(steel)	0.207	0.67	0.81
Katayama(R.C.)	0.235	0.68	0.84
Sagamigawa(R.C.)	0.231	0.60	0.75
Uenohara(steel)	0.259	0.85	1.07
Komiya	0.200	0.75	0.90
Toyoda(steel)*	0.253	0.64	0.81
Muramatsu(steel)**	0.250	0.65	0.82

*Tomei expressway, 3 span continuous girders with three girders
28.62 + 29.00 + 28.63m

**Tomei expressway 3 span continuous girders with four girders
3 x 30m

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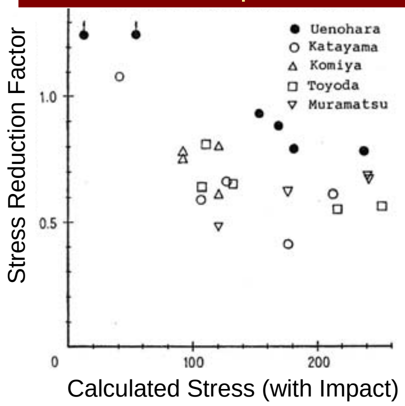
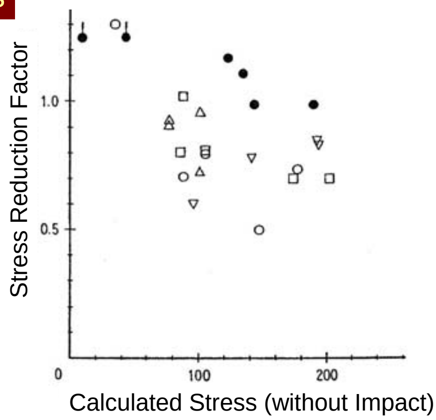
Stress Reduction Factor

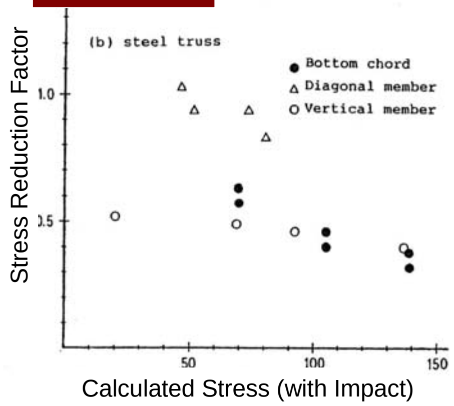
Steel and Composite Girders

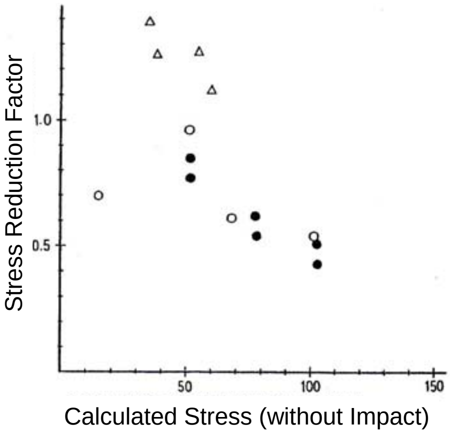




Stress Reduction Factor

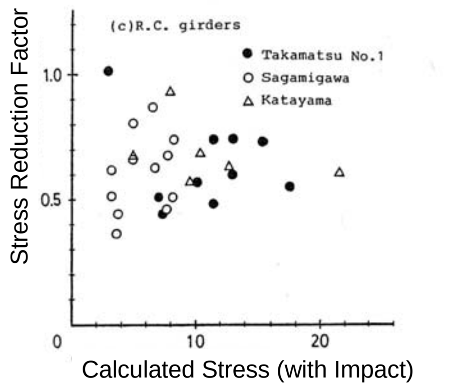
Steel Truss

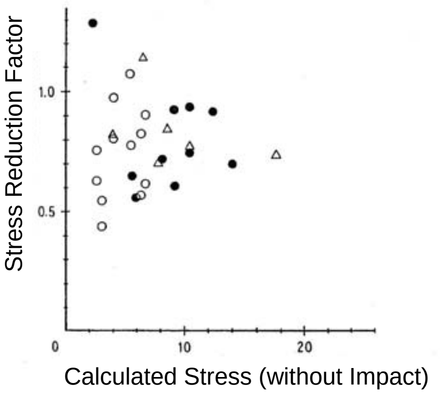




Stress Reduction Factor

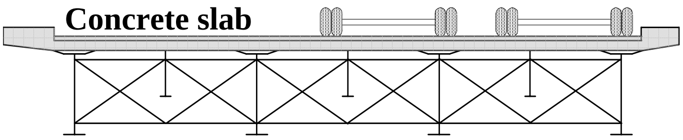
RC Girders





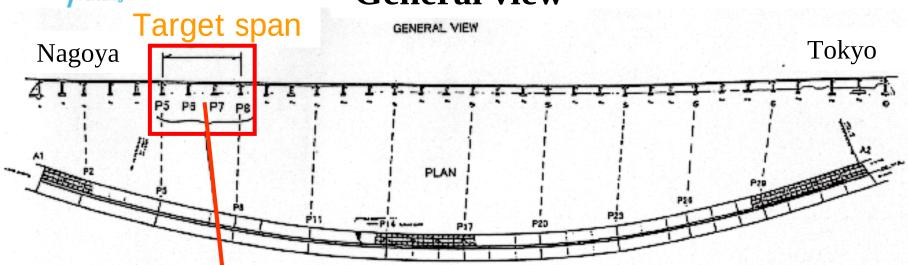
Proof Loading Test of Existing Bridge

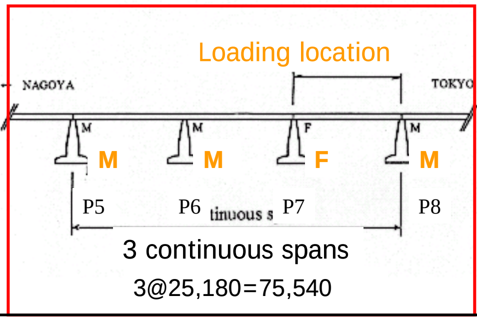
Target Bridge

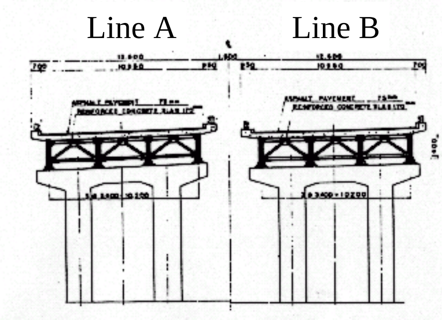


Steel girder

General view







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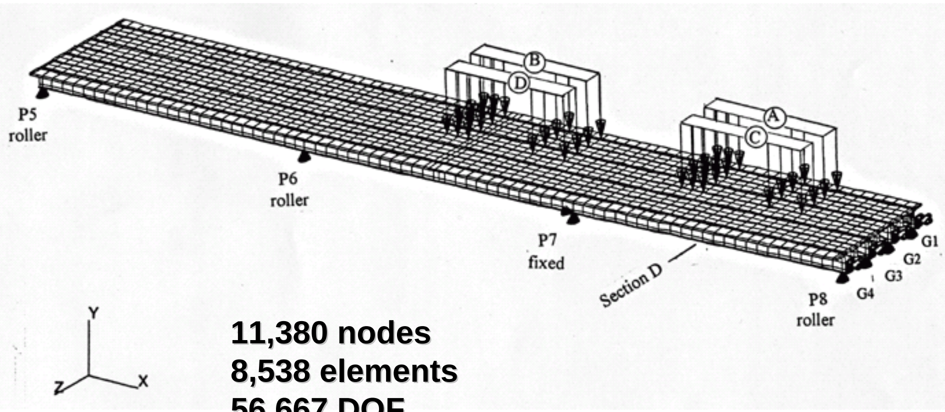
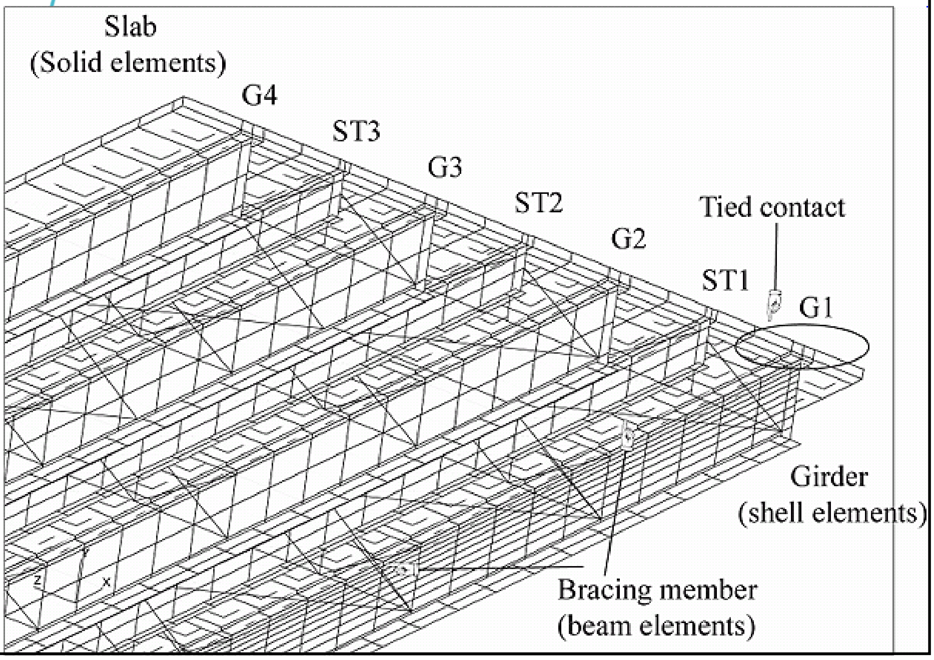
FEM Model



11,380 nodes
8,538 elements
56,667 DOF

ABAQUS v.5.8



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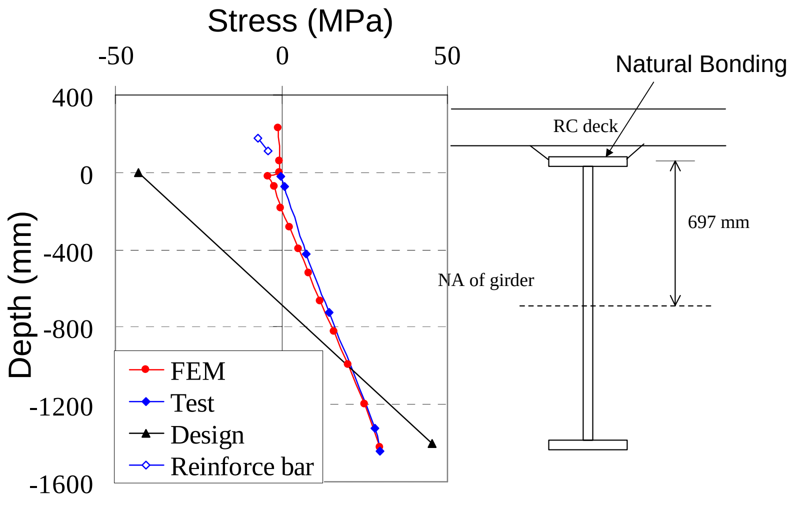
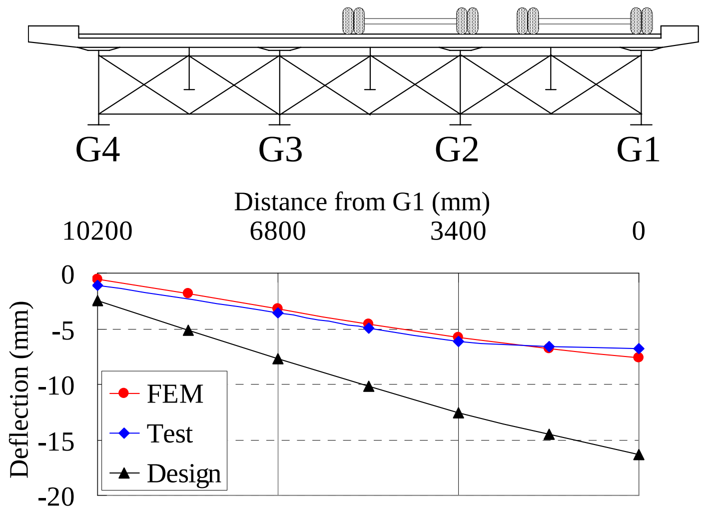
Stress distribution at midspan of girder G1



Deflection at midspan of each girder



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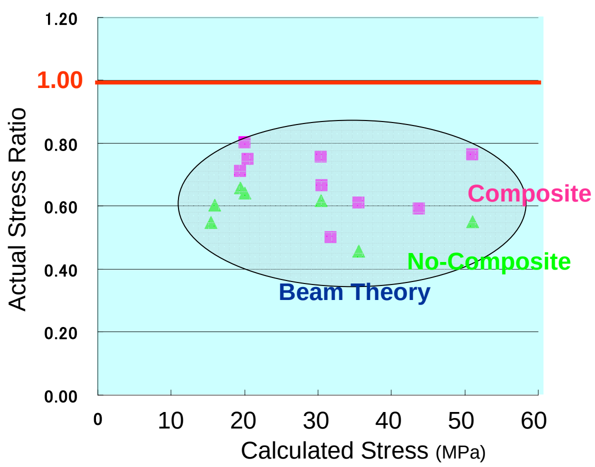
Accuracy of Beam Theory

Actual Stress Ratio
(Stress Reduction Factor)

$$= \frac{\sigma \text{ measured}}{\sigma \text{ calculated}}$$



Measured stress is a half of design stress.

Excessive Design !

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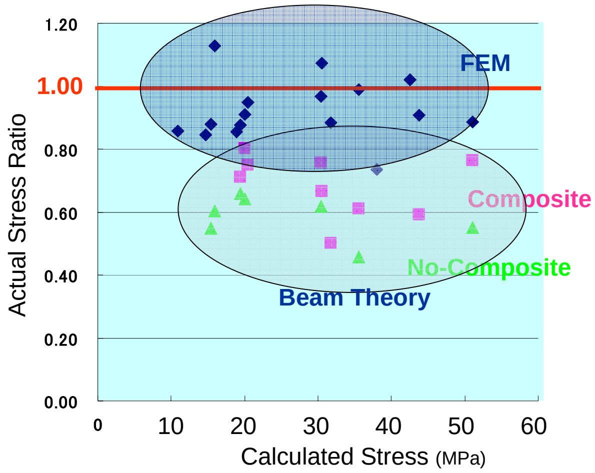
Accuracy of FEM

Actual Stress Ratio

$$= \frac{\sigma \text{ measured}}{\sigma \text{ calculated}}$$



Measured stress is a half of design stress with beam theory.

Excessive Design !

FEM: Steel bridge design could be rationalized drastically

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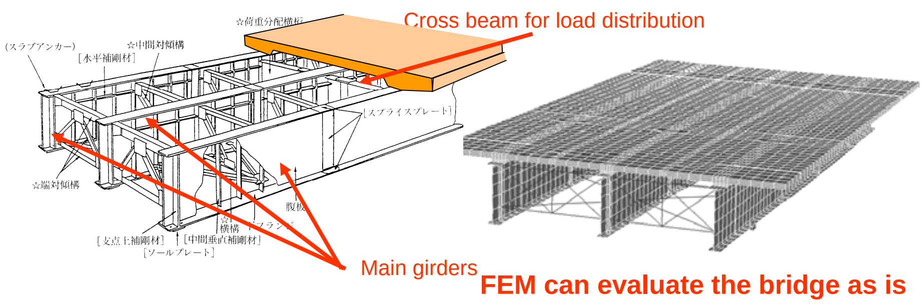
Assumptions of beam theory

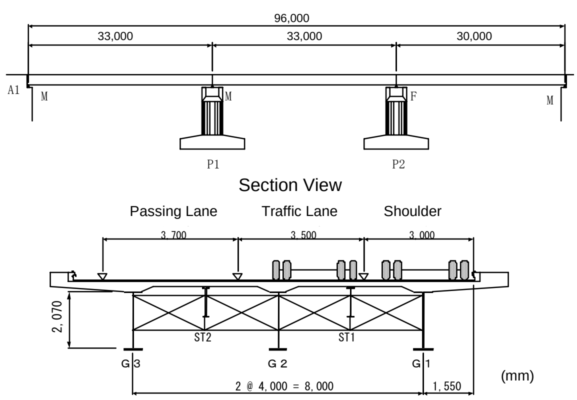
The conventional analysis method = Beam theory

- Ignorance of interaction between main members and minor members
- Underestimate of composite effect between upper flange and concrete slab
- Adaptation of effective width



FEM can evaluate the bridge as is

Target Bridge



3-continuous span
3 main girders.

Typical type of Toumei-Highway bridge

- **Additional bracings for slab refinement**

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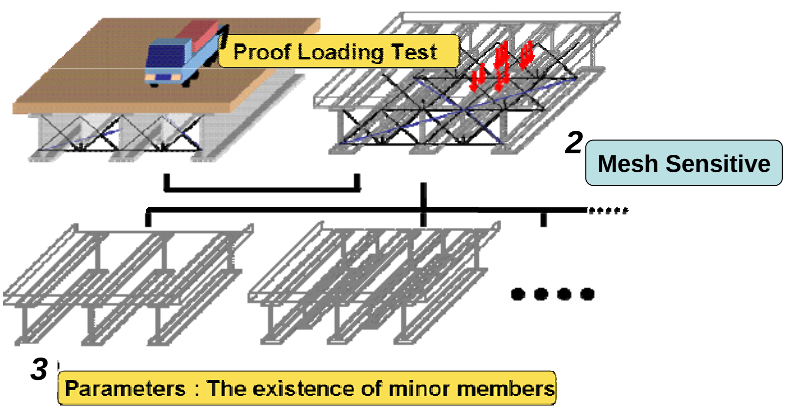
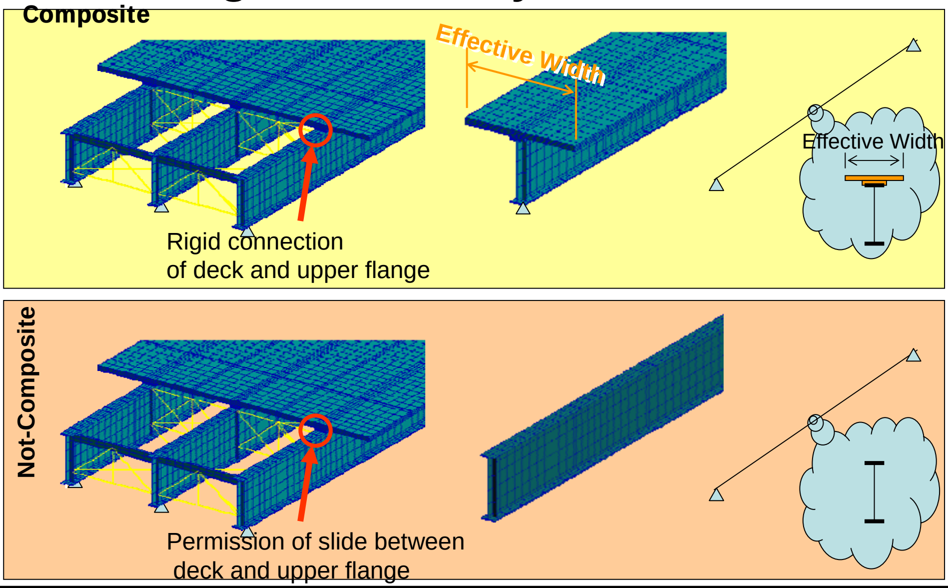
Analysis Procedure

Requirement of time and effort for modeling



Stages of Analysis Models



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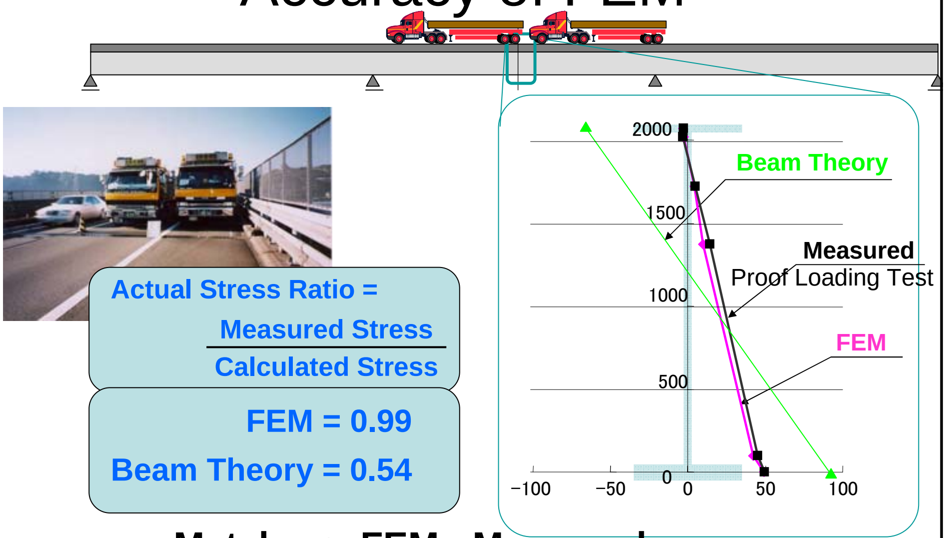
Accuracy of FEM

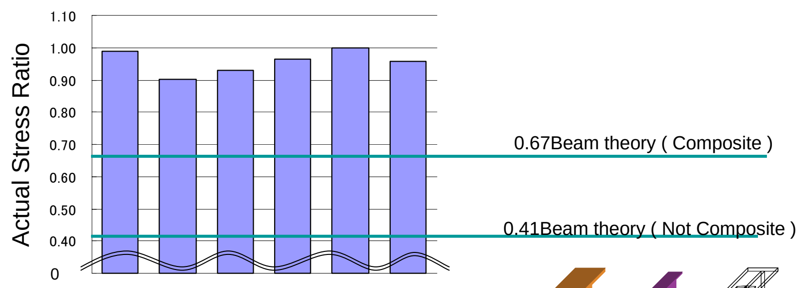


Actual Stress Ratio = Measured Stress / Calculated Stress

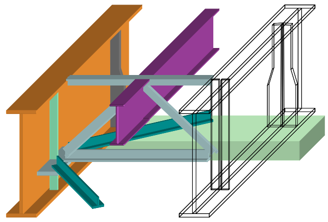
FEM = 0.99
Beam Theory = 0.54

Match up: FEM - Measured
Our Model : Good Performance

Effects of Members



Omitted Members						
Lateral Brace	◎	✖	◎	◎	◎	◎
Brace	◎	◎	✖	◎	◎	◎
Stringer	◎	◎	◎	✖	◎	◎
V-Stiffener	◎	◎	◎	◎	✖	◎
V-Stiffener on Supports	◎	◎	◎	◎	◎	✖



Members that connect girders are high efficiency for Stress distribution

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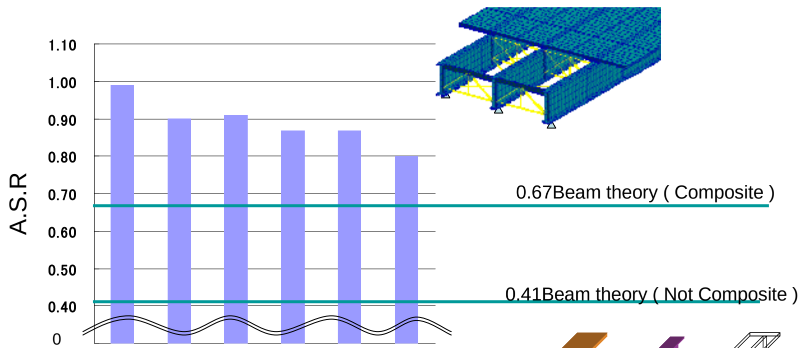
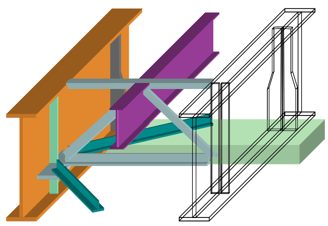
Effects of Members



Omitted Members						
Lateral Brace	◎	✖	✖	✖	✖	✖
Brace	◎	◎	✖	✖	✖	✖
Stringer	◎	◎	◎	✖	✖	✖
V-Stiffener	◎	◎	◎	◎	✖	✖
V-Stiffener on Supports	◎	◎	◎	◎	◎	✖



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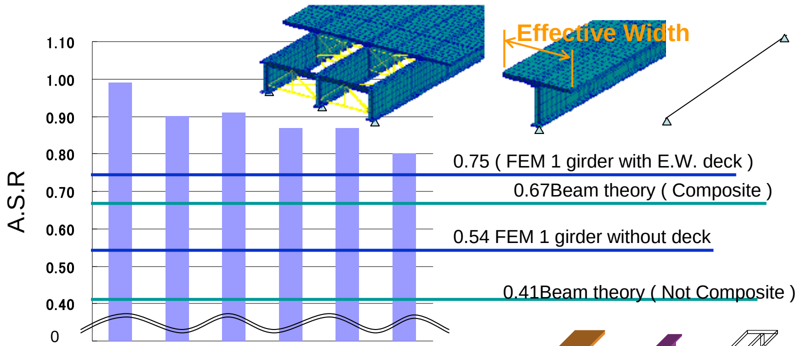
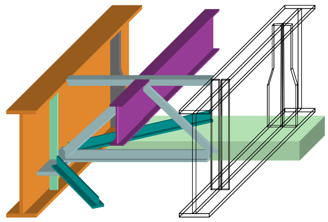
Effects of Members



Omitted Members

Lateral Brace	◎	✖	✖	✖	✖	✖
Brace	◎	◎	✖	✖	✖	✖
Stringer	◎	◎	◎	✖	✖	✖
V-Stiffener	◎	◎	◎	◎	✖	✖
V-Stiffener on Supports	◎	◎	◎	◎	◎	✖



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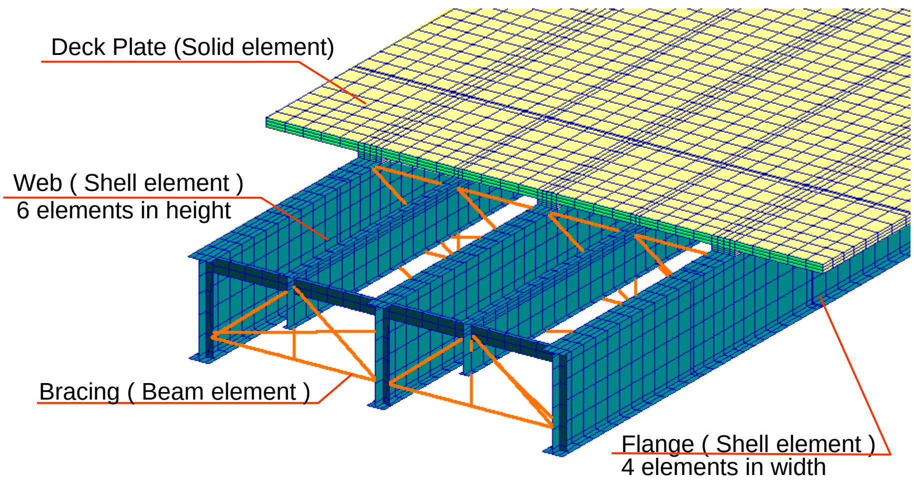
Proposed FEM Model for Actual Stress Evaluation



Unnecessary members
・Vertical Stiffener

Capacity evaluation with proof load test

Concept of proof load test

- loading the bridge up to the required load level
- If the target load level is reached without distress, the bridge is proved to have capacity up to the target load level

Procedure

- FEM analysis
  - Calculate the capacity required by B-live load
  - Design proof load patterns (weight, number, arrangement of test trucks)
- Field load testing
  - Gradually load the bridge with designed proof load patterns
  - Monitor and collect the bridge responses (stresses and deflections)

Target Bridges

- Monoi Bridge
  - Since 1971 (32 yrs)
  - Composite plate girder
  - 5 main girders
  - Simple span, 29.5 m

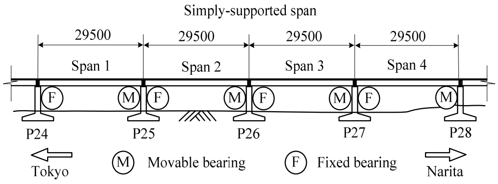
- Sakabe Bridge
  - Since 1968 (35 yrs)
  - Non-composite plate girder
  - 4 main girders
  - 3-continuous span, 3@25.1 m

- Hirono Bridge
  - Since 1968 (35 yrs)
  - Non-composite plate girder
  - 3 main girders
  - 3-continuous span, 30.4~33.0 m

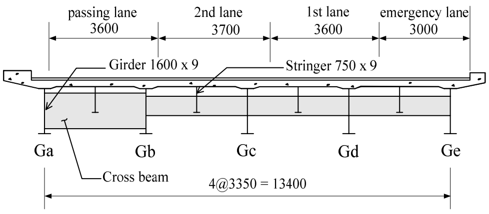
The Monoi Bridge

- Since 1971 (32 yrs.)
- Composite RC slab-on-girder
- Multi simple span
- Designed for **L20** (1964 code)
- Current **B-live load** (heavier)

Elevation



Cross section



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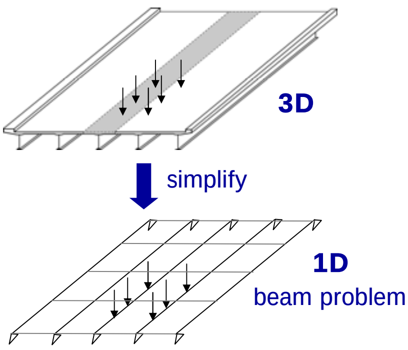
Capacity evaluation based on grid analysis

Grid analysis



Assumptions in grid analysis:

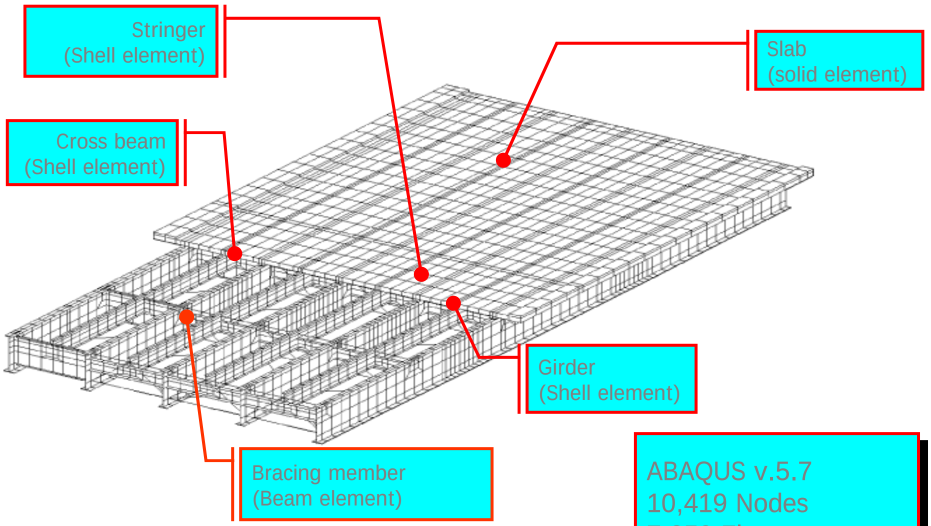
- Effective slab width
- Equivalent section
- Load distribution

Stress produced by design live loads
By grid analysis

Exceed allowable stress (σa)

This bridge should be replaced or strengthened

FEM model



ABAQUS v.5.7
10,419 Nodes
7,850 Elements

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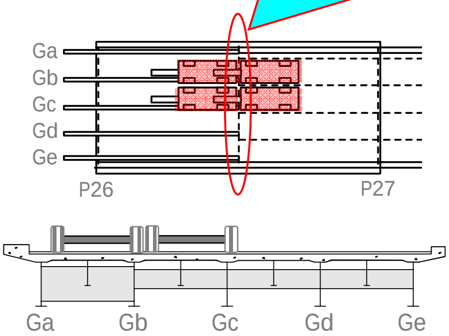
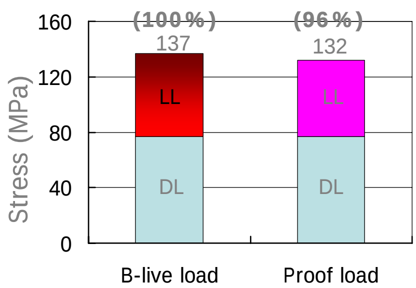
Design of proof load

Maximum force effect at midspan



Test truck = 34.7 ton (4 trucks)

Stress produced by B-live load & Proof Load
(Based on FEM)

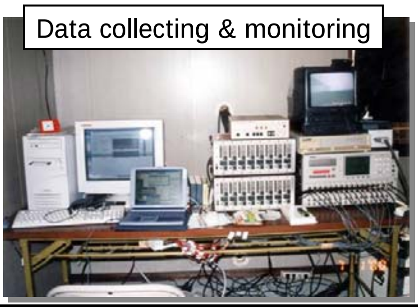


Stress produced by proof load is almost equal to required stress

Proof load test results

Loading

Data collecting & monitoring



Monitoring results

- The proof load was successfully reached without any distress
- The stress and deflection rebound to the initial conditions after load removal

The bridge was proved to have enough capacity to safely carry load up to proof load level

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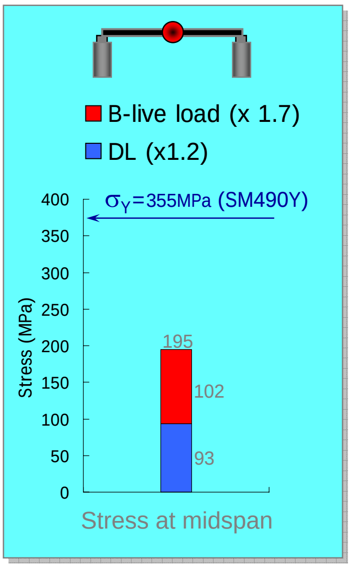
Safety verification *(1)*



Safety condition

$$\varphi \bullet \sigma_r \geq \gamma_D \bullet \sigma_D + \gamma_L \bullet \sigma_L$$

σ_r = Stress of limit state (σ_Y or σ_{cr})

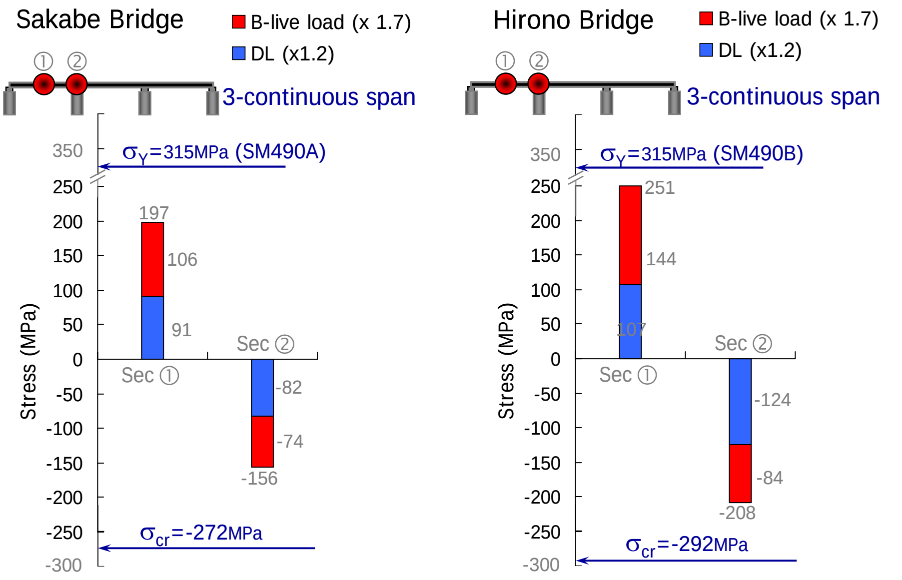
$\sigma_{D,L}$ = Stress due to dead load and live load

$\gamma_{D,L}$ = Factor for dead load and live load (γ_D=1.2 γ_L=1.7)

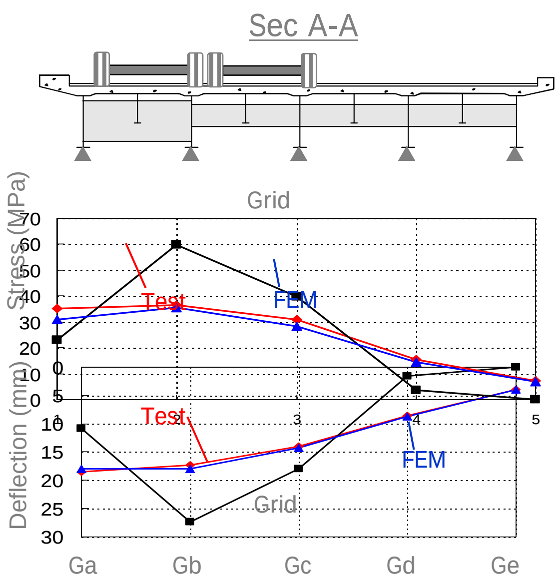
φ = resistance factor = 1.0

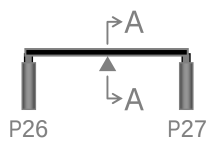
- Strength of structure ≥ force effects from load

Safety verification (2)



Test & analytical results





- Grid analysis overestimate the bridge responses
- FEM can well predict the bridge responses