Field Load Testing of the First Vehicular Timber Bridge in Korea

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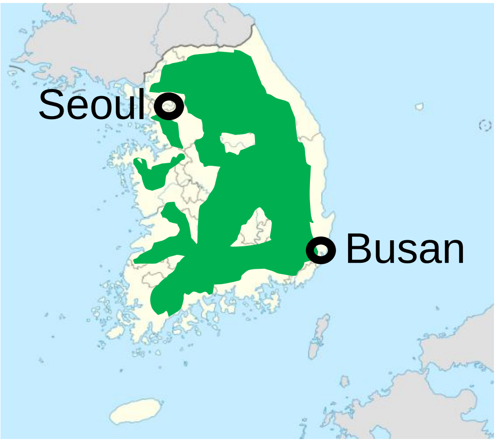
Introduction

- Korea as a mountainous country
  - 70% of territory is covered with mountains
    - → Plentiful timber resources
    - → Conventionally familiar with timber structures



<Mountain range of Korea>

- Korean traditional timber structures
  - Long history of over few thousand years
  - Numerous buildings including not only palace and temple but also typical family home were made of timber
  - Destroyed(burned) and restored over the course of many years

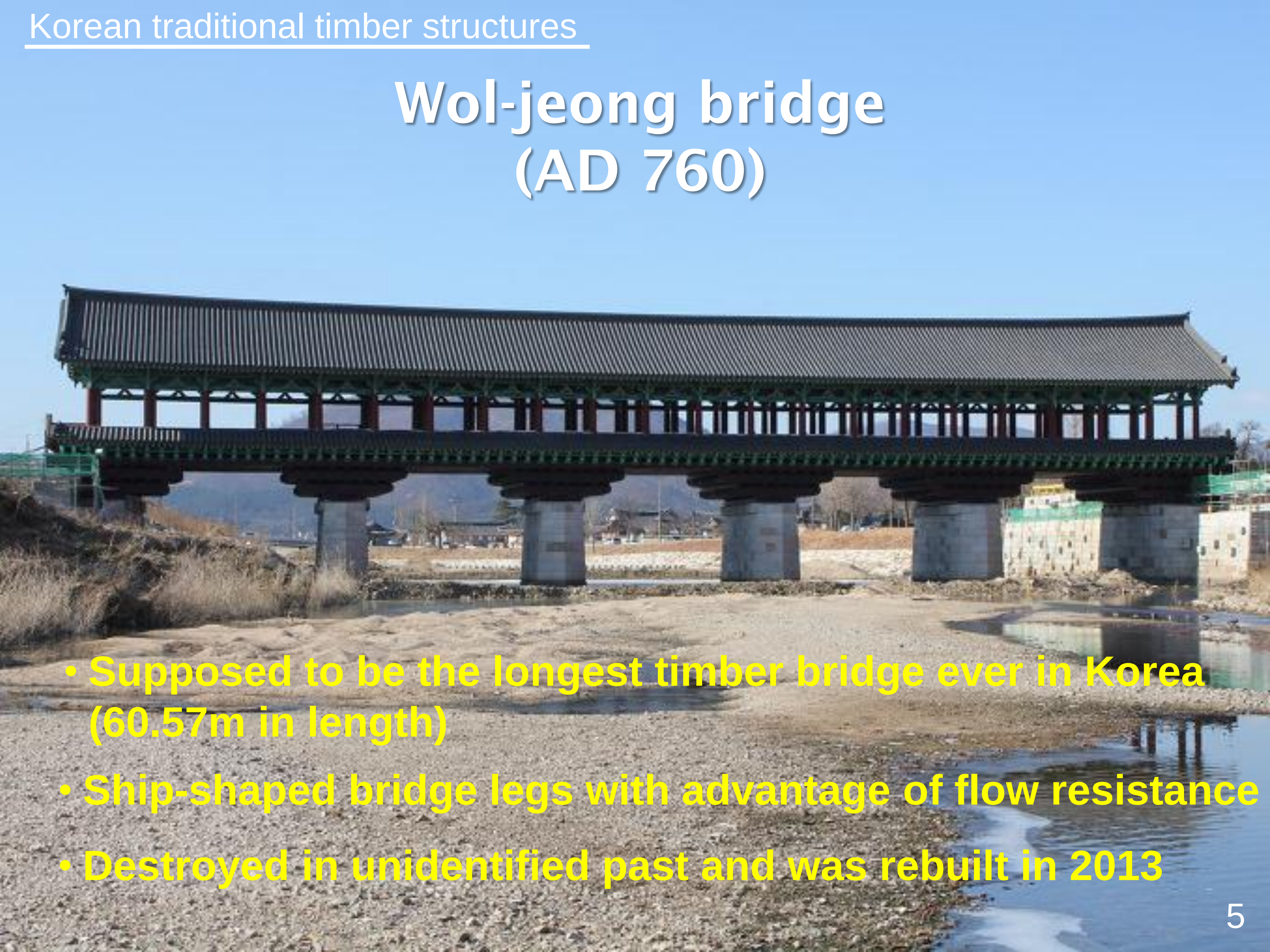
Muryangsujeon, Buseok temple (AD 660)

- Oldest timber structure among the remaining ones
- Last restoration in 1916
- Designated as a national treasure

Geunjeongjeon, Gyeong-bok palace (AD 1395)

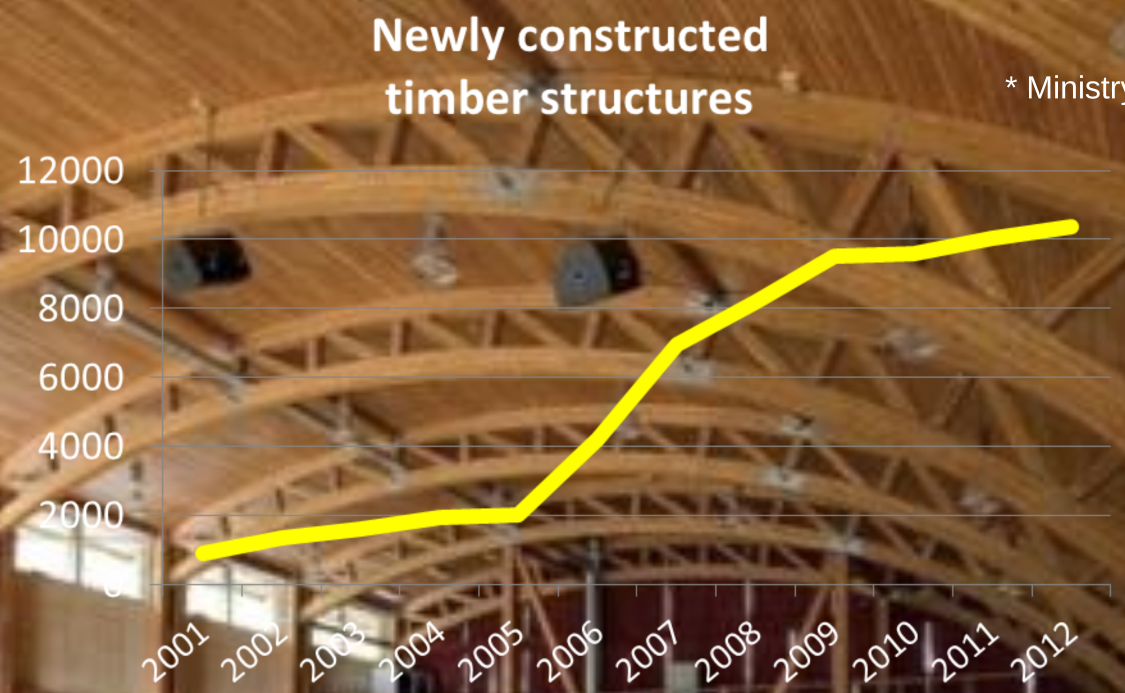
- Biggest timber structure among the remaining ones (40m in width and 24m in height)
- Burned down in 1592 and was rebuilt in 1867
- Designated as a national treasure

Wol-jeong bridge (AD 760)



- Supposed to be the longest timber bridge ever in Korea (60.57m in length)
- Ship-shaped bridge legs with advantage of flow resistance
- Destroyed in unidentified past and was rebuilt in 2013

Recent timber structures in Korea



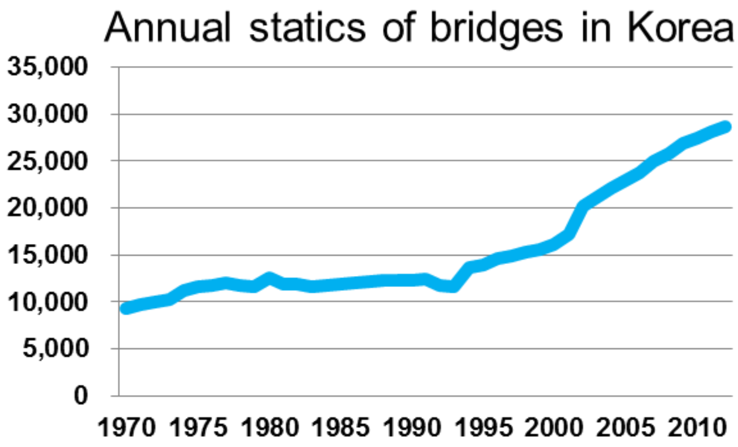
* Ministry of Land, Infrastructure and Transport (2013)

- Steep increase with a lot of merits like lightness, fine view etc.
- Mainly applied for buildings and pedestrian bridges
- Still minor or ornamental member of vehicular bridge

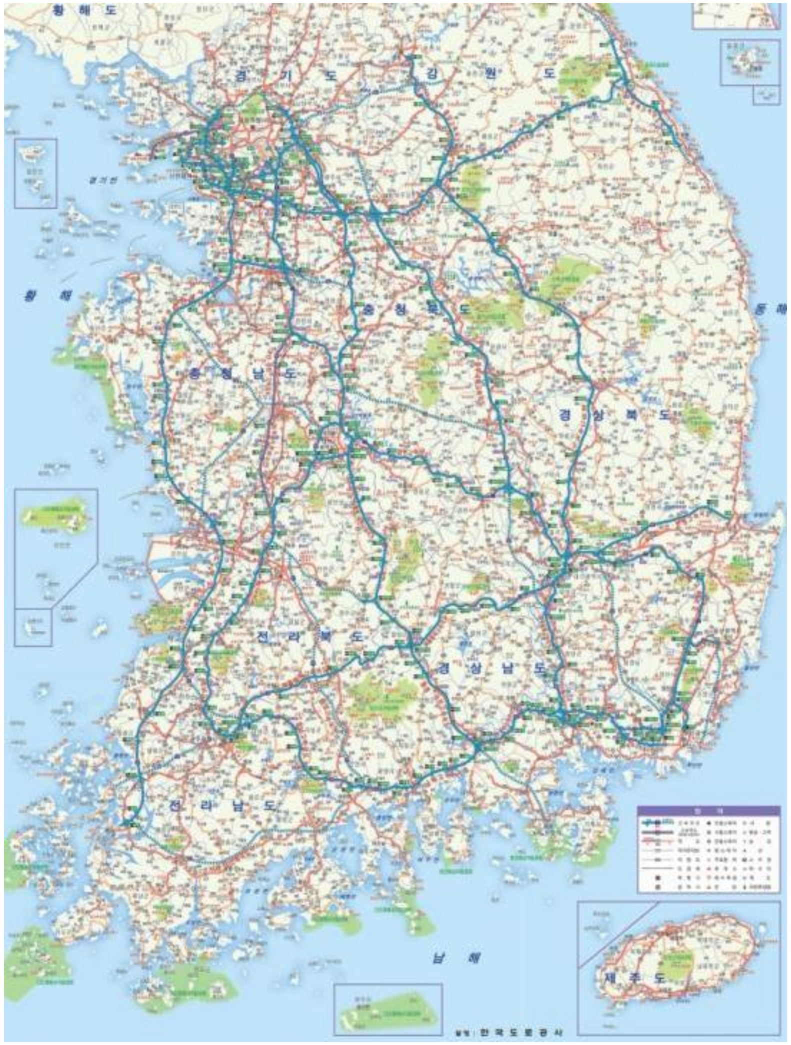
Bridges in Korea

- Bridge stock: **28,713** bridges (2,792km)
  - Expressway: 7,899 bridges (1,003km)
  - Highway: 6,743 bridges (664km)
  - Others: 14,071 bridges (1,125km)

- Numerous bridges including super long span bridges has been constructed



* Ministry of Land, Infrastructure and Transport (2012)



Yi Sun-sin Bridge (2012)

- 4th longest suspension bridge in the world
- Suspension section : 2,260m
- Main span : 1,545m
- Pylon : 207m

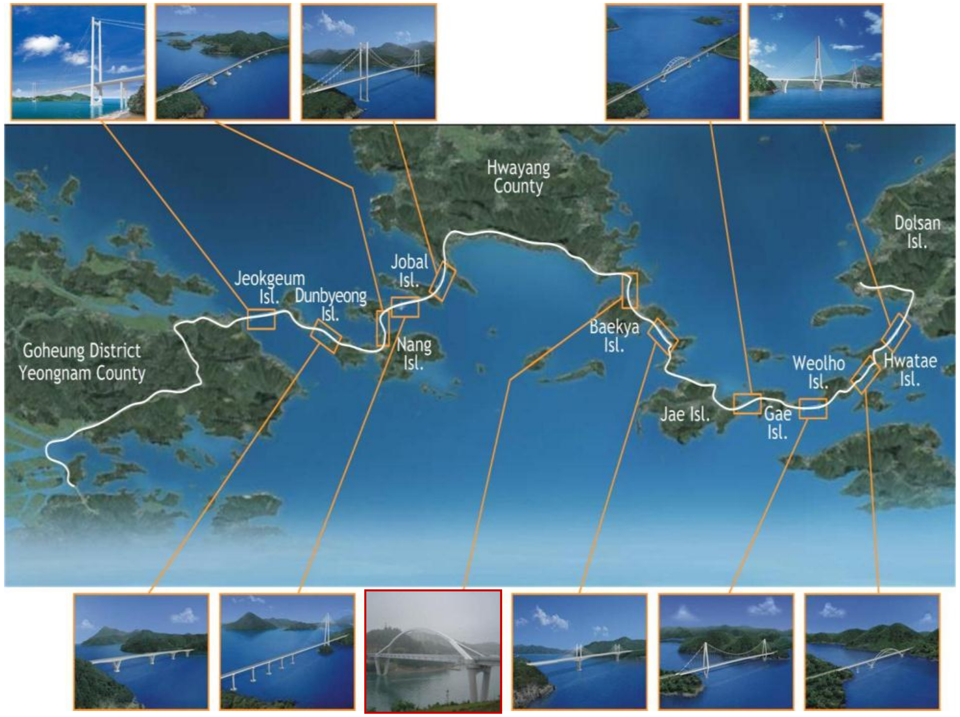
Incheon Bridge (2009)

- 8th longest cable-stayed bridge in the world
- Cable stayed section: 1,480m
- Main span : 800m
- Height of pylon : 238.5m

Recent Sea-Crossing Bridge Construction in Korea

- **Increase of sea-crossing bridge construction**
  - **A total of 102 bridges will be constructed along south-western coastal region till 2020**

Recent Sea-Crossing Bridge Construction in Korea

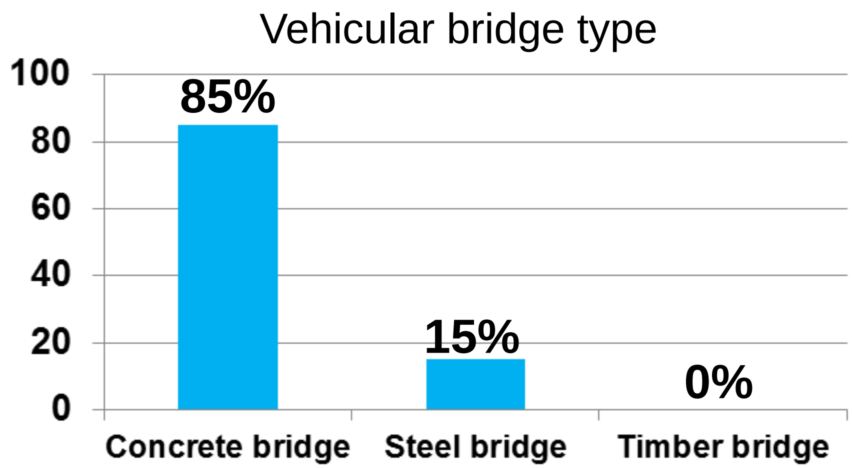


Yeosu-Goheung Sea-Belt (under construction)

Recent long-span bridges in Korea

Absence of vehicular timber bridge

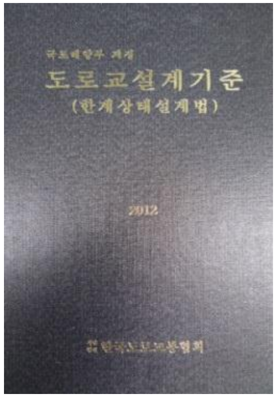
- All the vehicular bridges have been made of concrete and steel due to its reliable structural performance



* Ministry of Land, Infrastructure and Transport (2012)

- Korea bridge design code includes concrete and steel bridge
  → No timber bridge design code and specification

- Lack of researches on application of timber to vehicular bridges till nowadays



<Korea bridge design code 2012 – Limit state design>

R&D for vehicular timber bridge

*Seoul National University and
Korea Forest Research Institute

- Design of Pre-stressed glulam
- Design of timber girder bridge
- Practical design of timber arched-truss bridge
- Manufacture of timber arched-truss bridge in laboratory

Development of technology for vehicular timber bridge design and construction by SNU and KFRI*

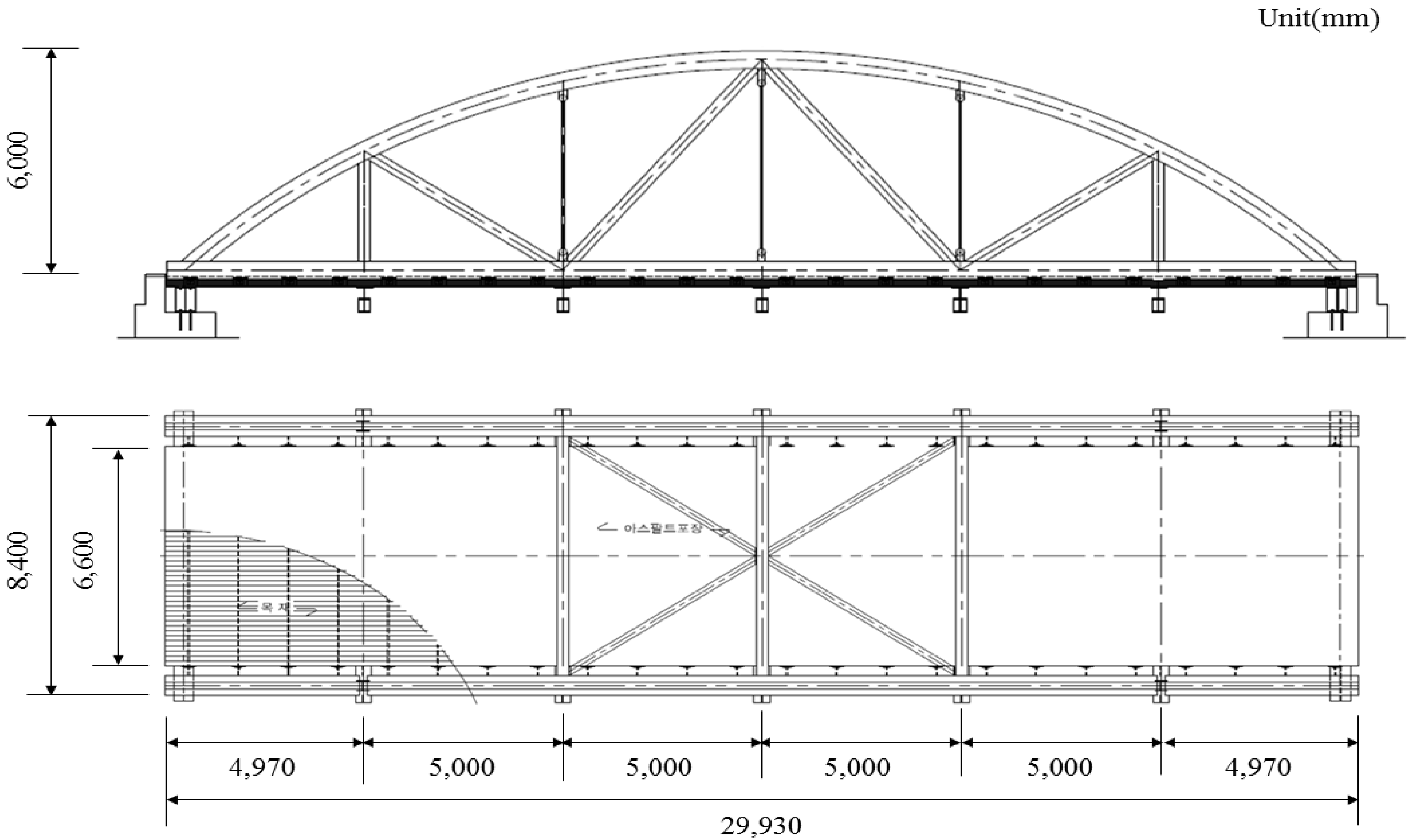
1st vehicular timber bridge in Korea (2012)

- Official name : Hanareum bridge
- Arched truss bridge
- 8.4m in width / Double lane
- 30m in length / Single span
- Material
  - Truss, Deck : Pitch pine glulam (f_{xx}=10, f_{yy}=7, f_t=6.5, f_c=7.5MPa)*
  - Cross beam : SM 490 (f_y=490MPa)

*Allowable stresses

1st vehicular timber bridge in Korea (2012)

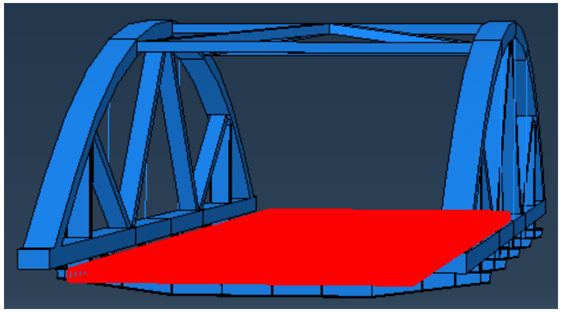
Design of the bridge



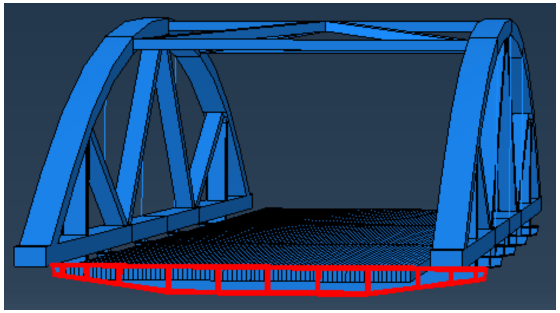
Construction of the bridge



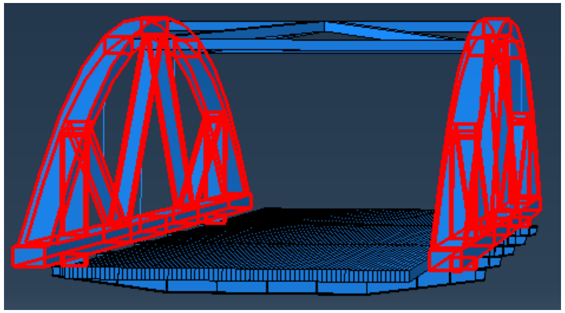

Load transfer mechanism



1. Deck floor resists the applied load and deflects

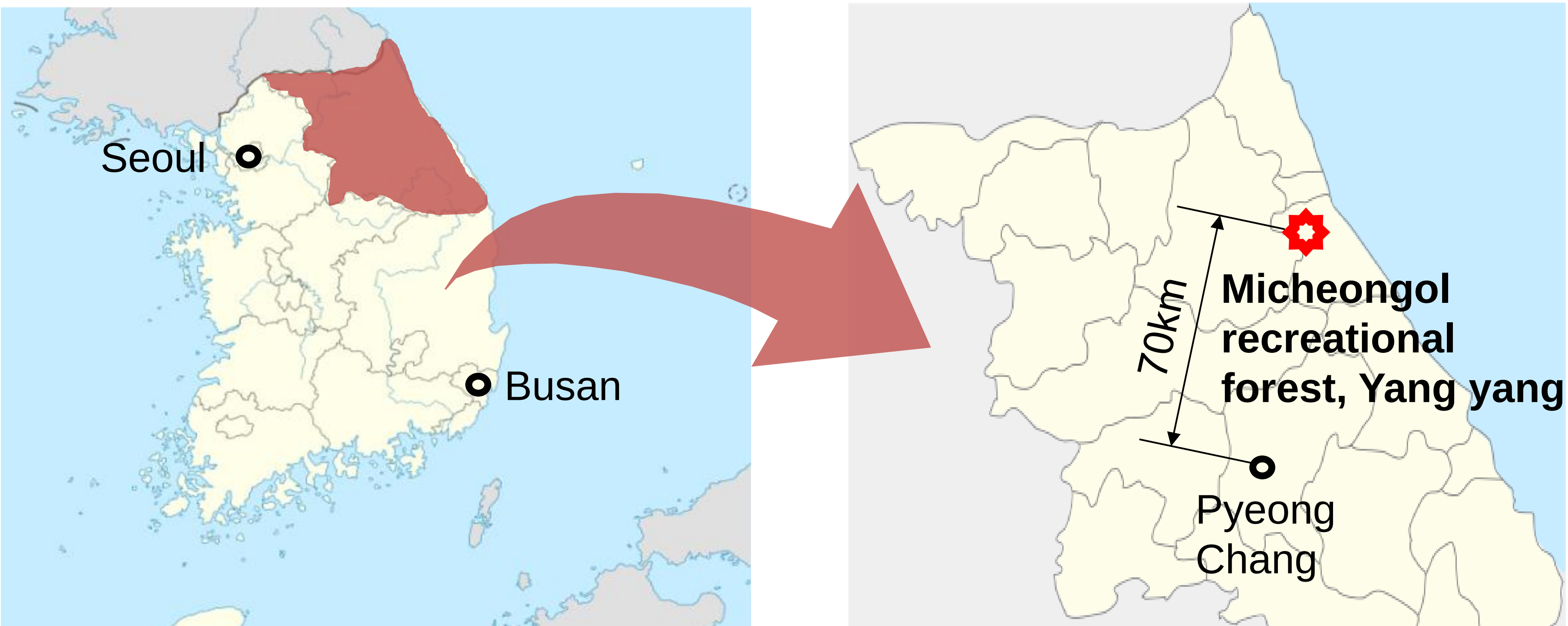


2. Cross beams support deflection of the deck floor



3. Trusses resists the load by holding the both ends of cross beams

Location of the bridge

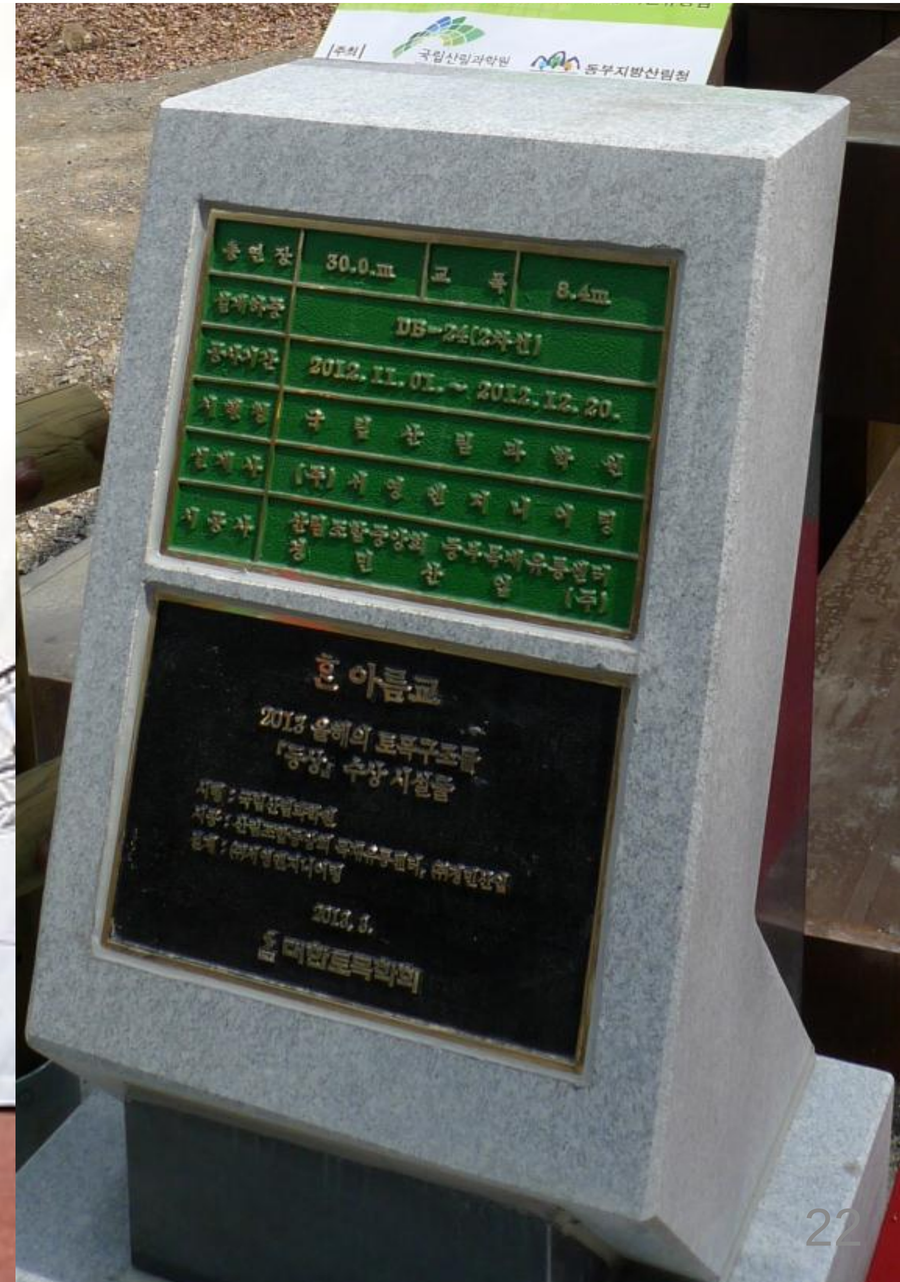


PyeongChang 2018

Micheongol recreational forest

Micheongol recreational forest

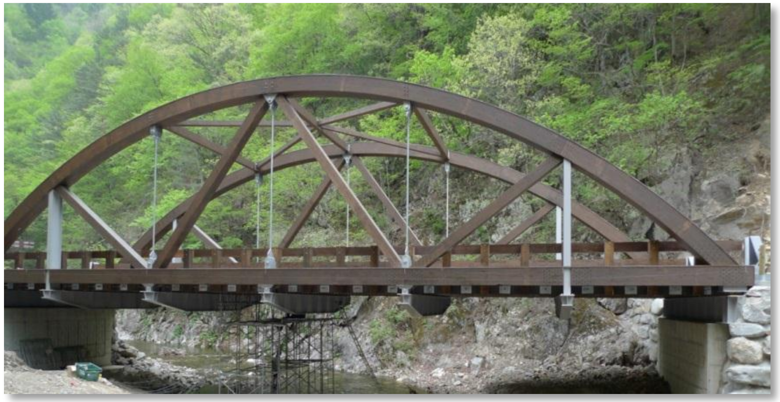
Award - Civil structure of the year (29 Mar. 2013)



Opening ceremony and symposium (19 Apr. 2013)

Requirement of load testing

- 1st vehicular timber bridge with variable uncertainties



Guarantee the systemic safety and serviceability of constructed bridge

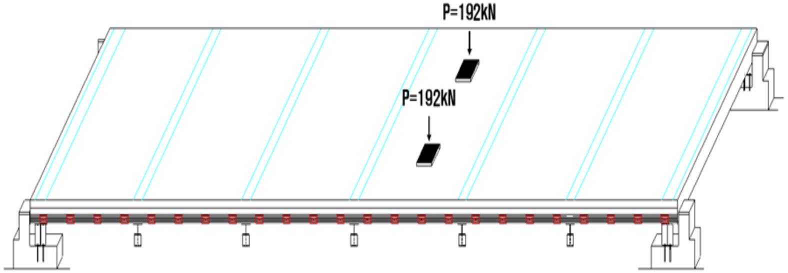
Investigation on structural behaviors through load tests

Verification of long term behavior for proper and timely maintenance

Finite element model update using the responses of load tests

Static and dynamic load tests were required

Laboratory load test



- Static load test to examine the bridge performance
- Comparison of measured data with design value

Maximum deflection of cross beam and deck floor

Member forces (strain) of truss, cross beams, and deck floor

- Check the symmetric condition for verifying the manufacture and fabrication error

Laboratory load test


Laboratory in Myongji Univ.


Assembling process of the truss


Complete assembly of the bridge

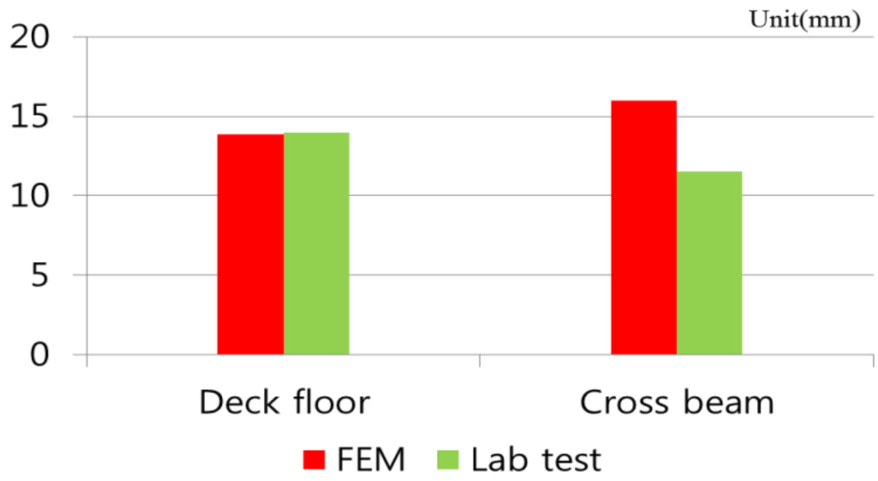

Load testing in laboratory

Result of the load test

① Member forces < Design values → Safe side

② Maximum deflection

- Deck floor : Almost same with design value
- Cross beam : Lower than design value



③ Symmetry condition was satisfied well

Field load test

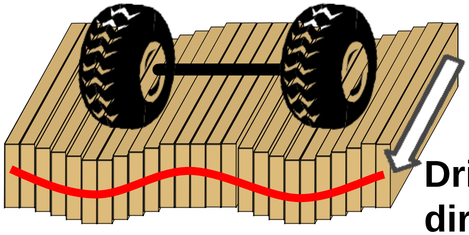
- Static and dynamic load test to verify the bridge performance
- Comparison of measured data with design value and lab test

Maximum deflection of cross beam and deck floor	Member forces (strain) of trusses and deck floor	Mode frequency (acceleration) of deck floor

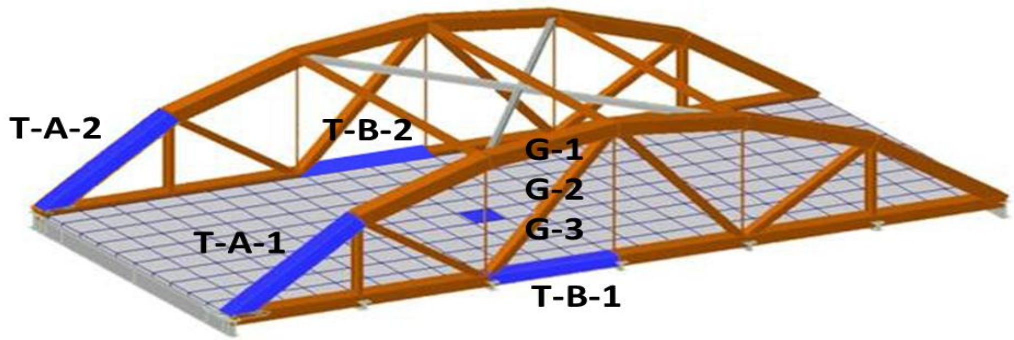
- Check the symmetry and linearity condition for verifying the construction error
- Check the integrity condition of pre-stressed glulam deck floor

Location of LVDTs

Cross beam	Deck floor
• Three sensors : Deflection shape of center cross beam	• 13 sensors : Located densely considering the chance for separation behavior of laminated timbers



Location of strain gauges



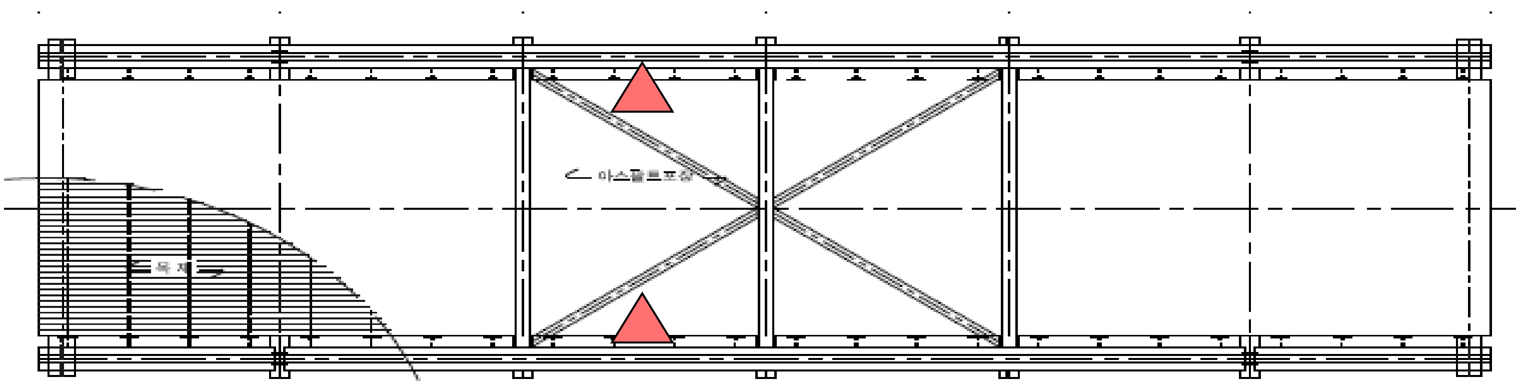
<T-A-1, T-A-2>

<T-B-1, T-B-2>

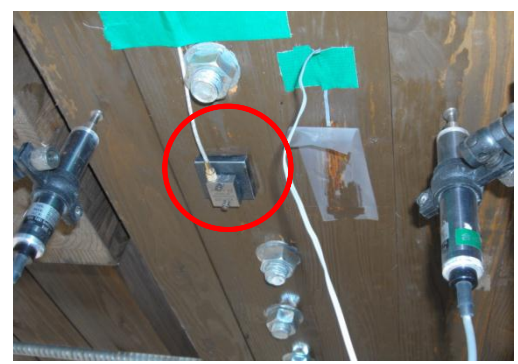
<G-1, G-2, G-3>

- 7 elements of largest(or smallest) strain were selected through FEA
  - Upper chord(2) : Maximum compression
  - Lower chord(2) : Maximum tension
  - Deck floor(3) : Maximum tension

Location of accelerometers



<Floor plan of deck floor>



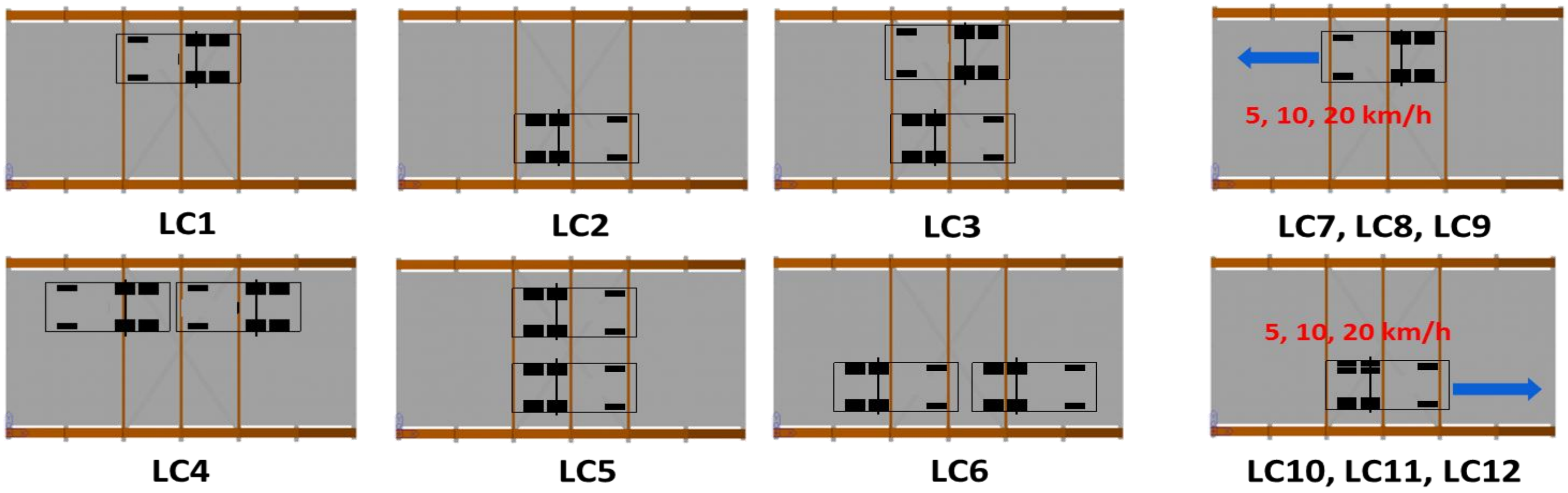
Loading trucks

- Two gravel loaded 27 ton trucks

Car No.	5389	5509
Load(kg)	26,700	27,030

- 62.5% of design load(43.2ton) → To be calibrated for comparison

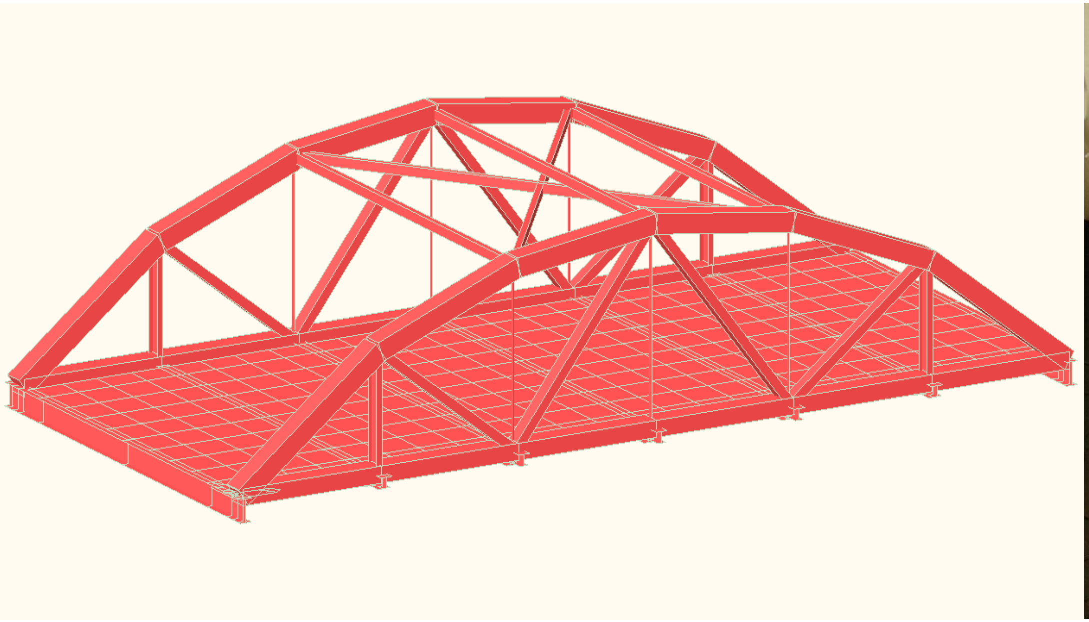
Load cases

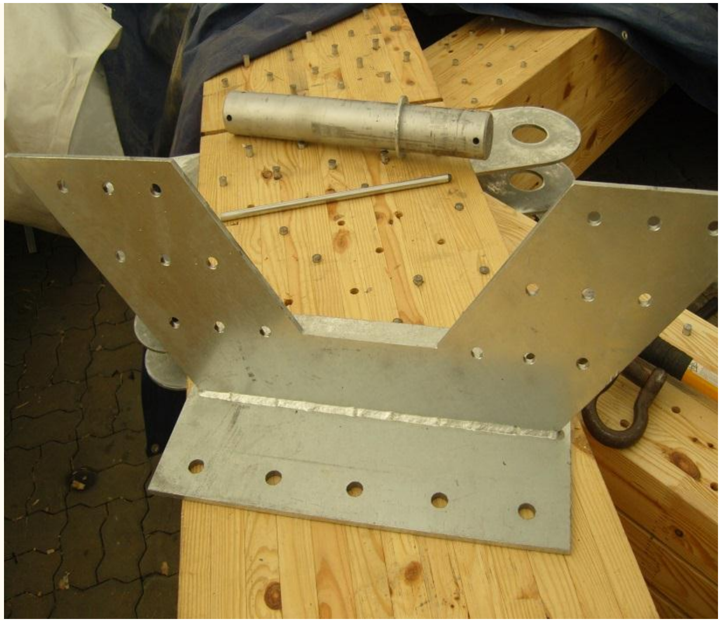


- Total 12 load cases
  - Static cases : LC1 – LC6
  - Dynamic cases : LC7 – LC12

- Accurate data acquisition by averaging three trials for each cases

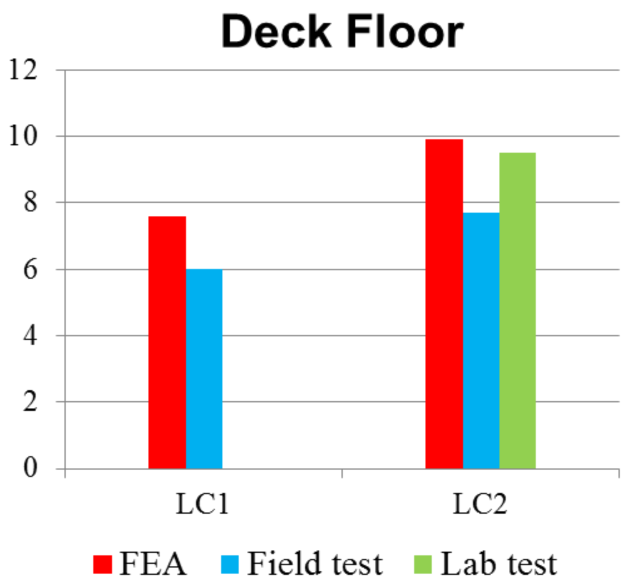
Static load test - Deflection

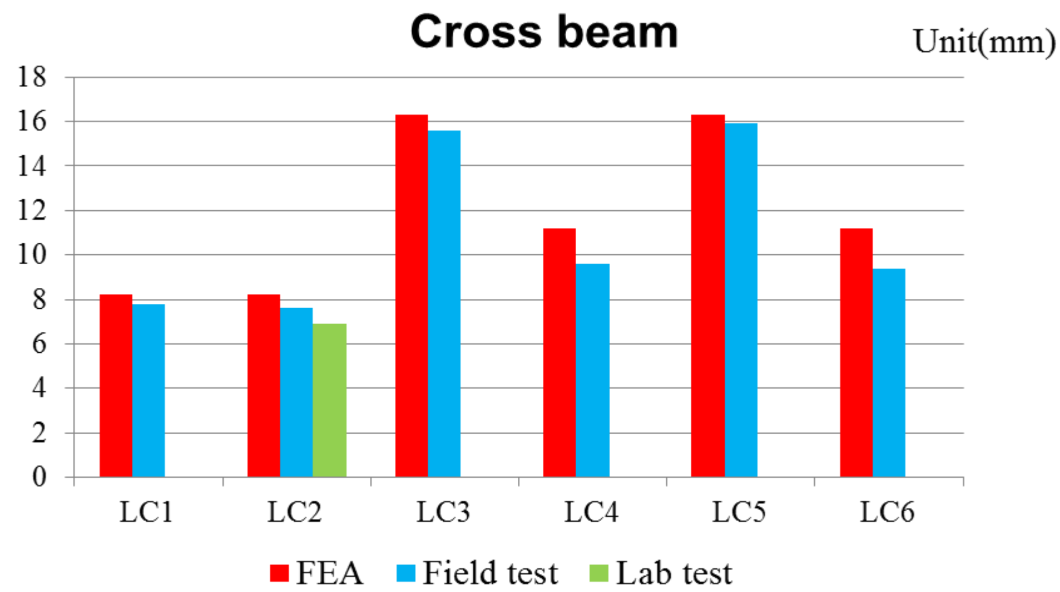




1. For all load cases, deflections were smaller in tests than in FEA, especially for deck floor
   - Design FE model had the connection between timbers as hinge (truss) while the bridge has strong connections with dowel plates and bolts
   - Stiffness of asphalt and fence on deck floor were neglected in FEA

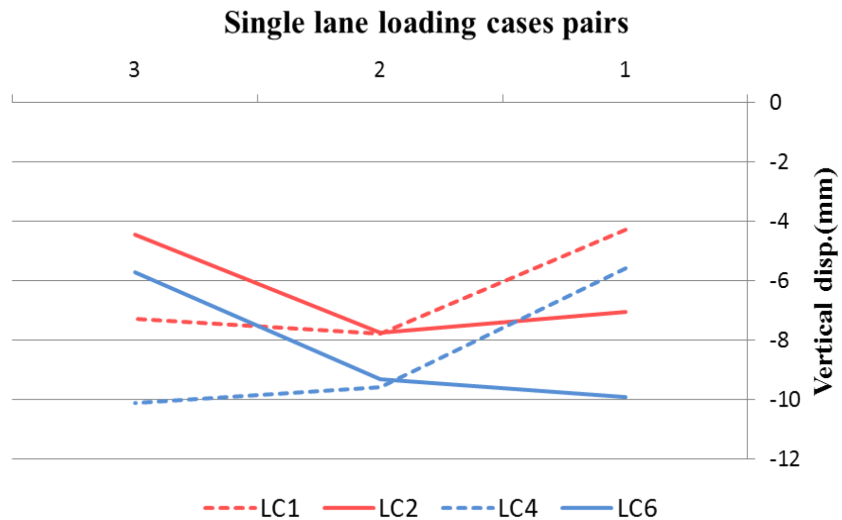
Static load test - Deflection

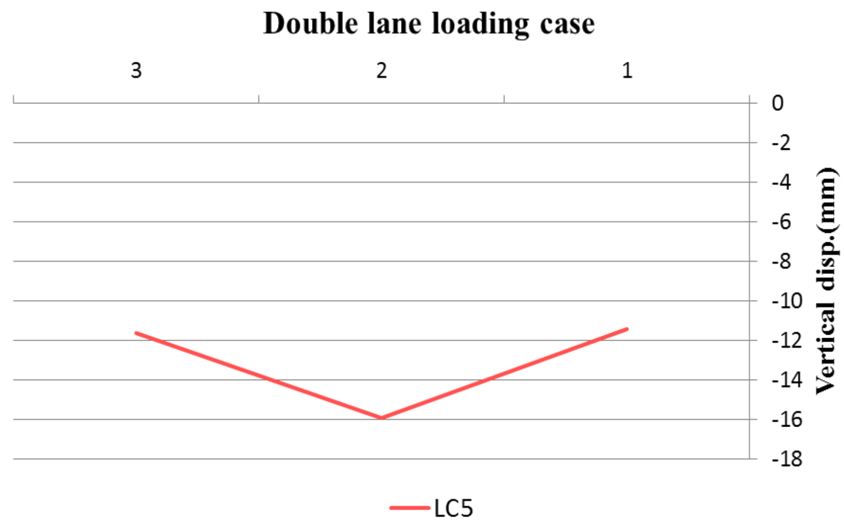


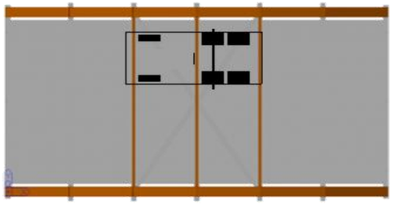


2. For LC2, deflection was quite smaller than lab test for deck floor while a little bit larger for cross beam
   - Small error due to different location of loading points and values
   - Fence and asphalt installed on deck <u>at field</u> would have strengthened the stiffness of deck

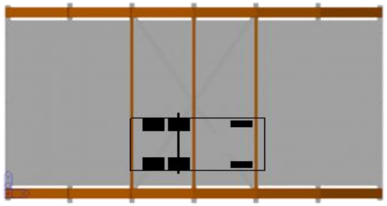
Static load test - Symmetry check



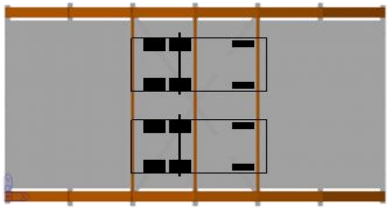




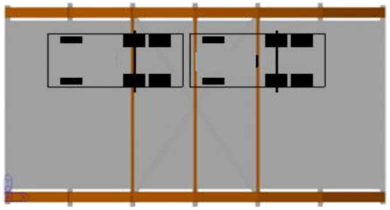
LC1



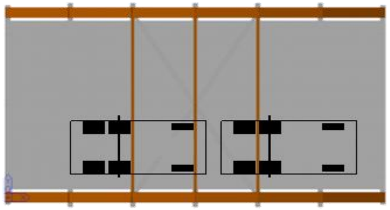
LC2



LC5

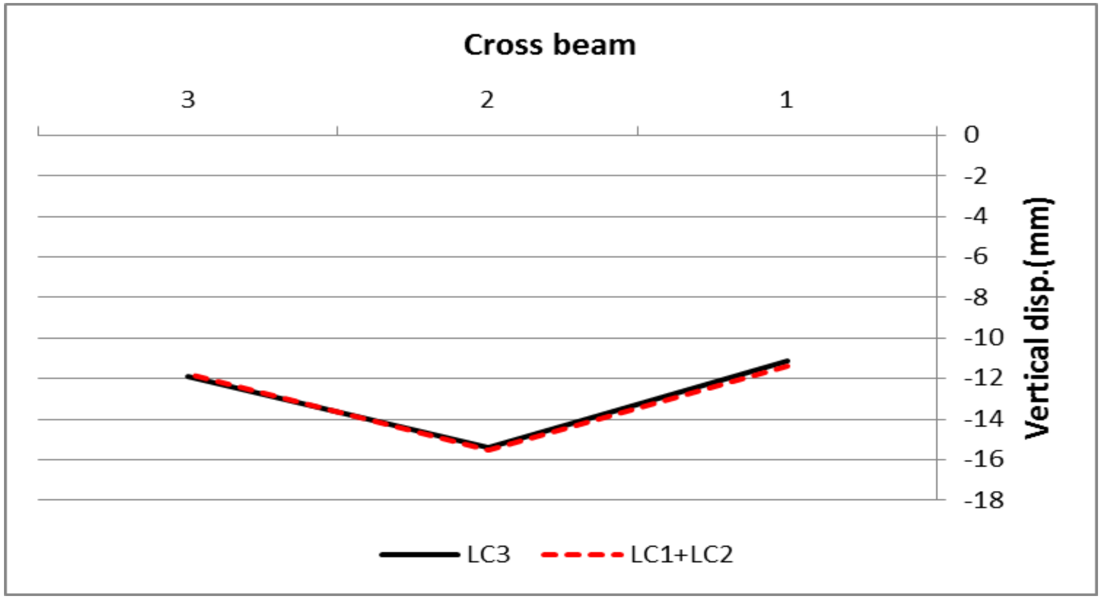


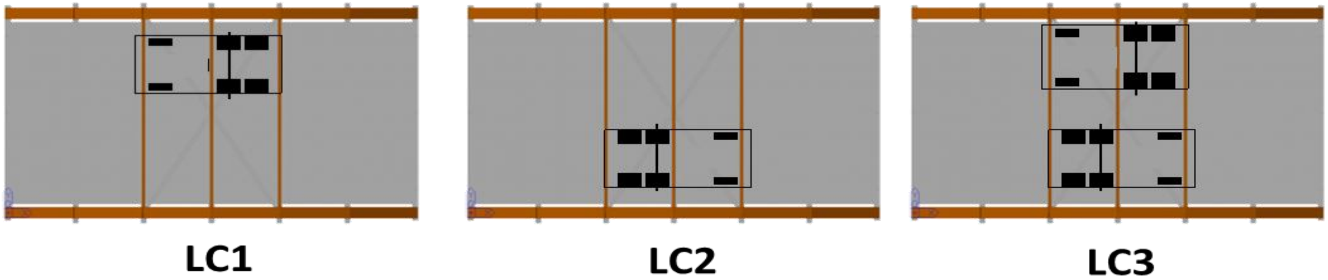
LC4



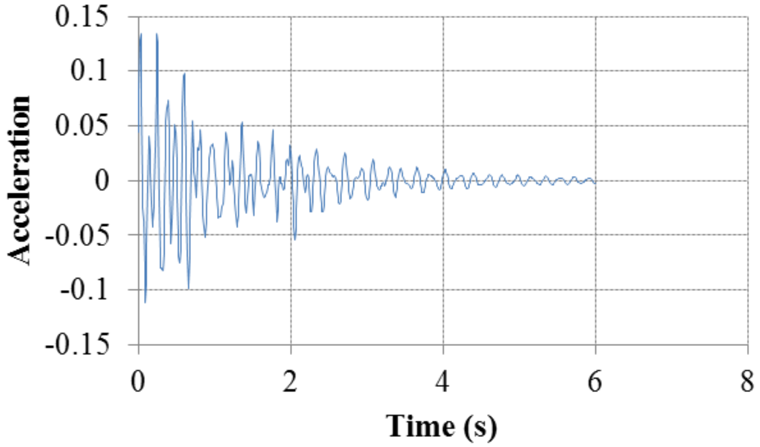
LC6

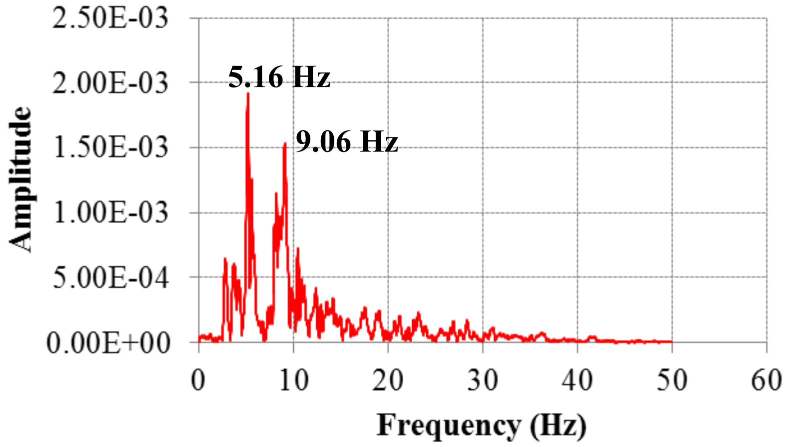
Static load test - Linearity check





Dynamic load test - Frequencies

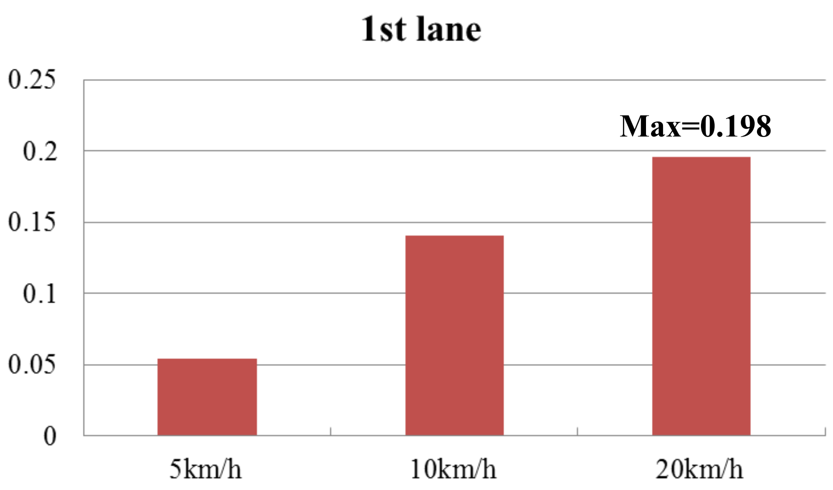


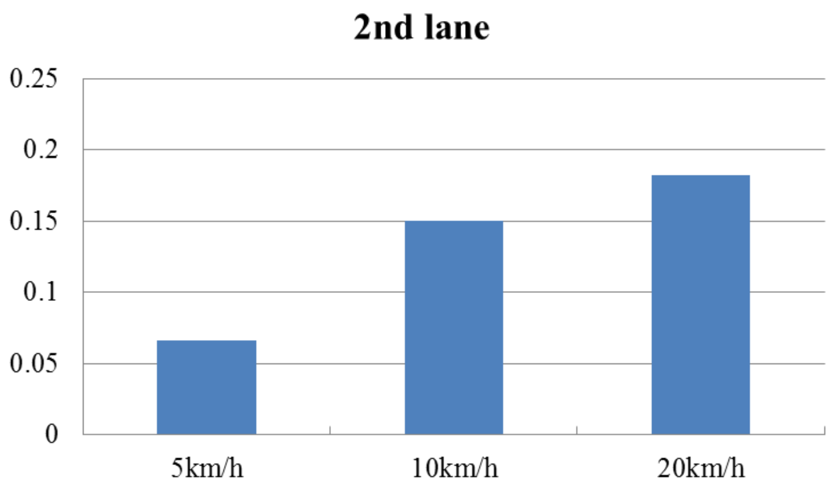


- Mode frequencies of deck floor
  - 1st mode : 5.16 Hz
  - 2nd mode : 9.06 Hz

- Results will be verified through a refined finite element analysis in further research

Dynamic load test – Impact factor





$$Impact\ \ factor = \frac{Maximum\ \ dynamic\ \ disp.}{Maximum\ \ static\ \ disp.} - 1$$

- Too large impact factor indicates the reduction of load carrying capacity and fatigue capacity of the bridge

- Calculated impact factor by the specification* : $\frac{15}{(40+L)} = 0.214 \approx 0.198$

*Korea bridge design specification (2012)

Concluding remarks

- 1st vehicular timber bridge in Korea was constructed successfully following several years of R&D project
- Results of the tests indicates that
  - manufacturing and fabrication quality is excellent
  - the bridge can perform as designed
- Periodic load testing is planned and FE model will be established based on the results to establish an appropriate maintenance plan for the bridge
- New design specification for timber bridge in Korea is in the planning stages

Thank you for your attention

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