Structural Safety and Serviceability Evaluation for the New Connection System of Hybrid Truss bridges

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GANG-CHUN BRIDGE: Hybrid Truss Bridge(HTB)

□ The bridge is the first application of the new connection systems developed in this study.

OVERVIEW OF THESIS

Chapter 1 **Introduction**

Chapter 2 **Overview of Hybrid Truss Bridges**

Chapter 3 **Development & Verification of the New Connection System**

Jung, K., Yi, J., Lee, S. and Kim, J. J. (2011), "Development and evaluation of new connection systems for hybrid truss bridges", ***Structural Engineering and Mechanics*** (submitted)

Chapter 4 **Flexural Behavior of Hybrid Truss Girders**

Jung, K., Yi, J. and Kim, J. J. (2010a), "Structural safety and serviceability evaluations of prestressed concrete hybrid bridge girders with corrugated or steel truss web members", ***Engineering Structures***, Vol. 32, No. 12, pp. 3866-3878

Chapter 5 **Fatigue Capacity verification of the New Connection System**

Jung, K., Yi, J., Lee, S., Kim, J. J. and Ha, J. (2011c), "Fatigue capacity of a new connection system for a PSC hybrid truss web girder", ***Magazine of Concrete Research*** (Accepted)

Chapter 6 **Incremental Launched Construction of Hybrid Truss Bridge**

Jung, K., Kim, K., Sim, C. and Kim, J. J. (2011a), "Verification of incremental launching construction safety for the Ilsun Bridge, the world's longest and widest prestressed concrete box girder with corrugated steel web section", ***J. of Bridge Engineering, ASCE***, Vol. 16, No. 3, pp. 453-460

Chapter 7 **Summary & Conclusions**

CHAPTER 1 and 2

- Research Significance
- Overview of Hybrid Truss Bridge
- Objectives

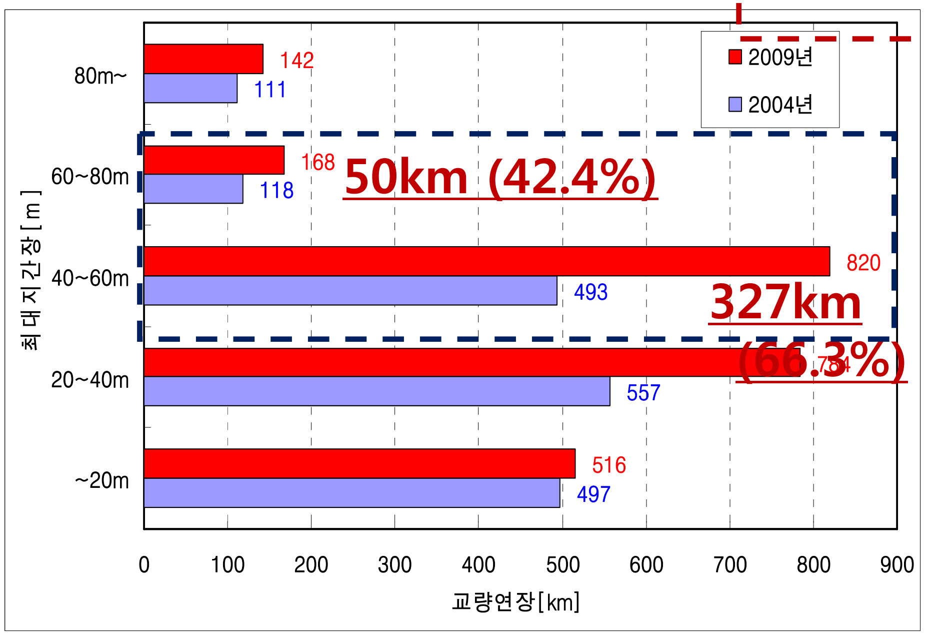
RESEARCH SIGNIFICANCE

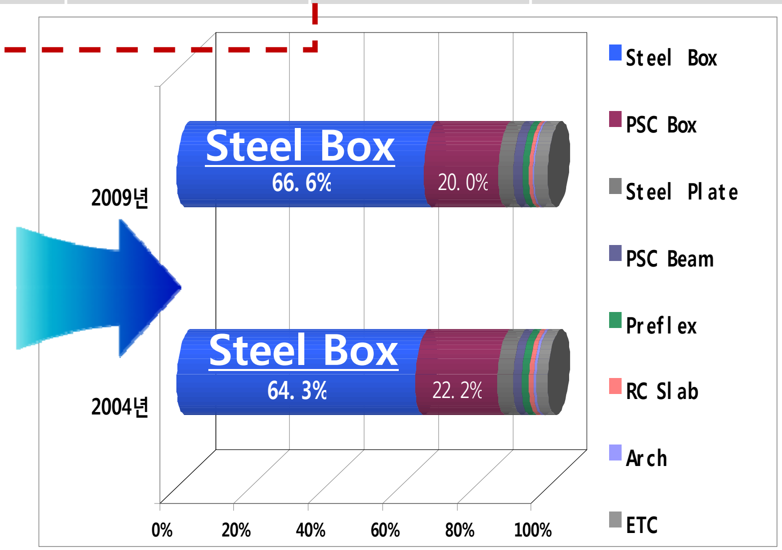
☐ The most commonly used bridge has been the medium span bridge (40-80m) in Korea.

☐ More than 65% of the medium span bridges (40-80m) have been of the steel box girder variety, due to its relatively low self-weight, in spite of its high cost.

Bridge market in Korea according to the span length

Span	~20m	20~40m	40~60m	60~80m	80~100m	100m~
Market[억원]	2,800(14%)	5,200(25%)	6,000(30%)	2,200(11%)	2,000(10%)	1,600(8%)
Typical Type	RC Slab	PSC Beam	PSC Box	Steel Box	Extradosed	Cable Bridge
Cost[만원/㎡]	50	80	140~150	240~260	400~500	Over 1,000





[MLTM 2004, 2009]

RESEARCH SIGNIFICANCE

☐ Hybrid Truss Bridge(HTB) : the prestressed concrete box girder bridges with steel truss web members instead of the concrete web

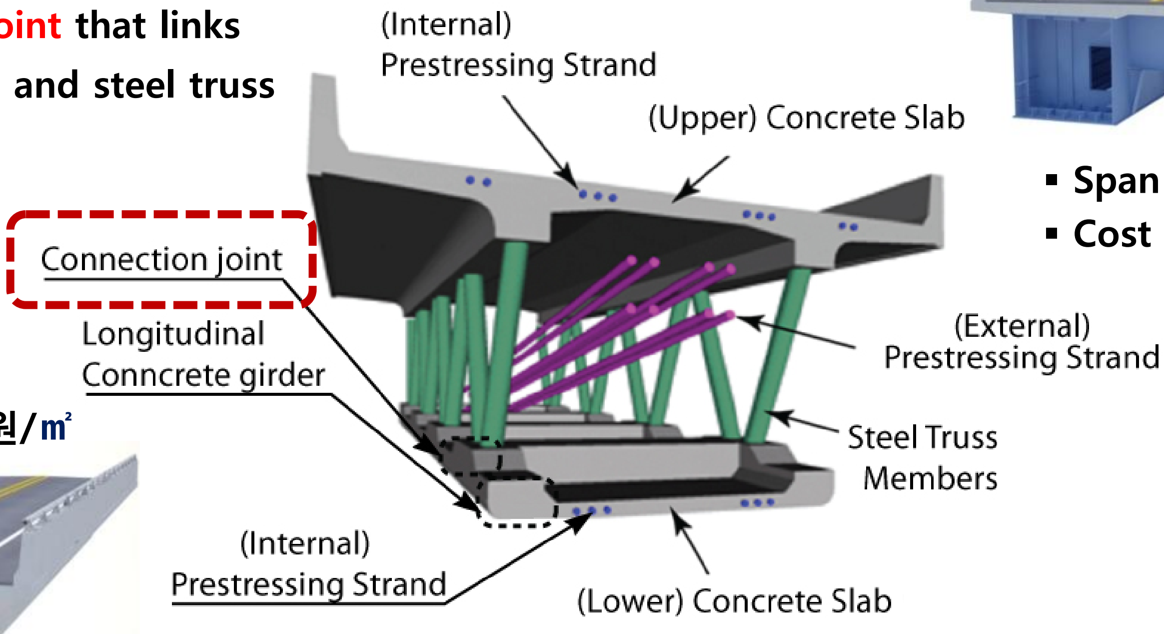
☐ Benefits of HTB

1) Reduce the self-weight about 20%, 2) High transparency, 3) Low Cost

☐ Core technology of HTB

: the connection joint that links the concrete slabs and steel truss pipes

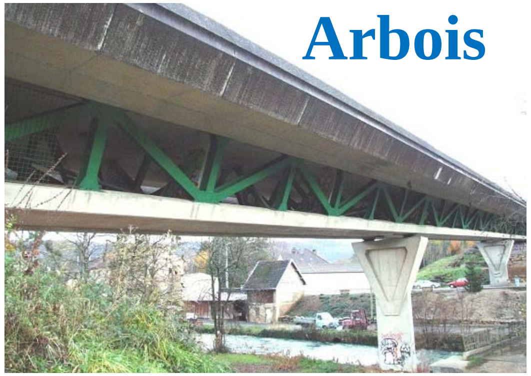
- Span : 60~80m
- Cost : 240~260만원/㎡

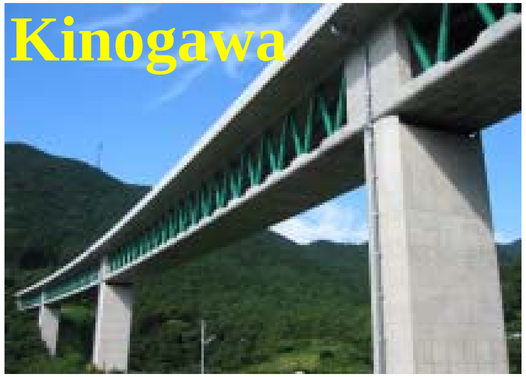


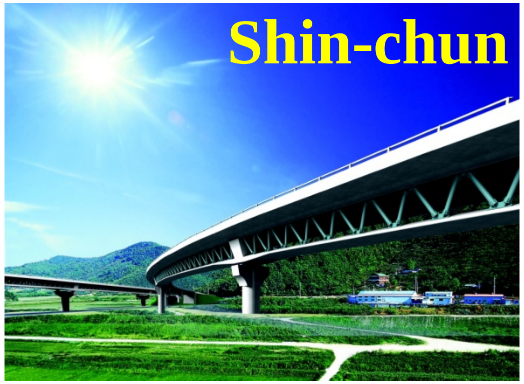
- Span : 40~60m
- Cost : 140~150만원/㎡

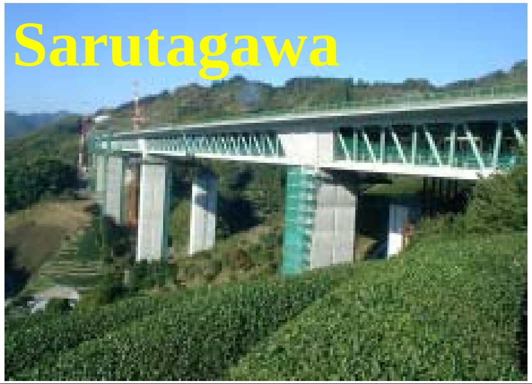
- Span : 40~80m
- Cost : 170~180만원/㎡

OVERVIEW OF HTB









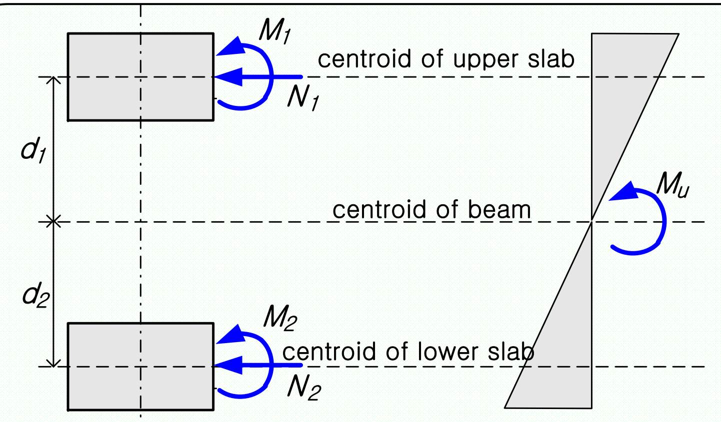
Bridge	Length (m)	Max. Span (m)	Height (m)	Construction Method	Completion (year)	Location
Arbois	100.1	40.4			1985	France
Boulonnais	474 260 1301	77 77 110	5.5 5.5 5.5~8.0	PSM	1997	France
Kinogawa	268	85	6.0	FCM	2003	Japan
Sarutagawa Tomoegawa	625 479	110 119	6.5	FCM	2005	Japan
Shitsumi Ohashi	280	75	2.5~6.5	FCM	2005	Japan
Shinchun	360	80	4.0	Seg. Lifting by Crane	Under Construction	Korea
Gangchun	485	50	3.5	ILM	2011	Korea

OVERVIEW OF HTB

☐ **Basic Design Concept [1]**

✓ upper and lower concrete slabs to resist only flexural stress and the steel web to resist only shear stress

☐ **Flexural Design** *= Concrete Slab Design*



$$\phi M_n > M_u = M_1 + M_2 + N_1 d_1 + N_2 d_2$$

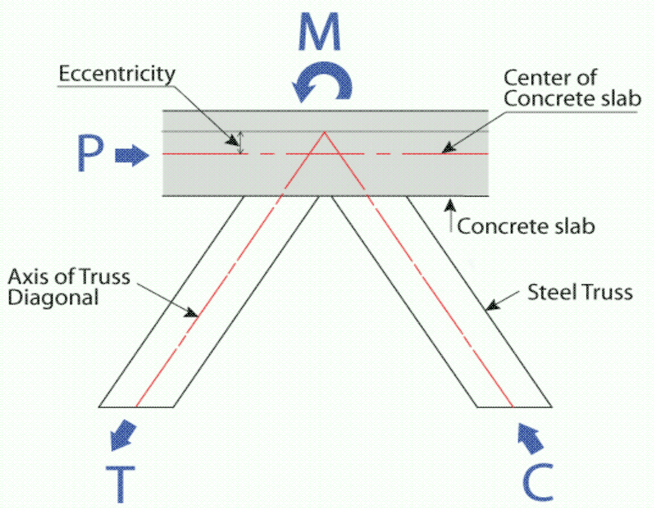
☐ **Shear Design** *= Steel Web Design*

$$f_{tr\_max} = \frac{P_{tr}}{A_{tr}} + \frac{M_{tr}}{I_{tr}}\left(\frac{d_{tr}}{2}\right) < f_{ca}$$

☐ **Basic Design Concept [2]**

✓ the connection system did not yield until the concrete slabs and steel members failed.

☐ **Connection Design**



✓must be able to fully resist these forces

✓ the connection joint safety factor of over 1.3 is recommended

OBJECTIVES

☐ Main Objective

: to develop more useful connection systems which can eliminate the need for welding procedure during construction while satisfying load carrying capacity requirements for HTBs and enhancing the construction efficiency.

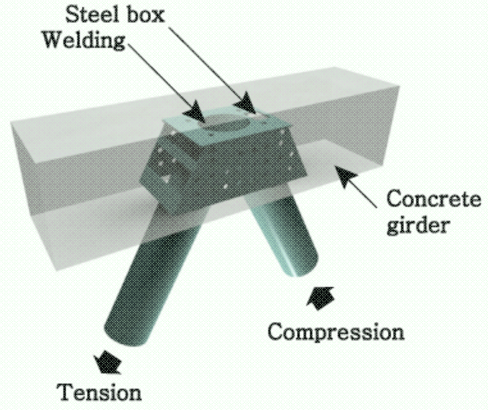
1) verify the structural safety as well as flexural behavior of HTB using the new proposed connection system through the static loading test for real scale connection joint specimens. *[Chapter 3 & 4]*
2) evaluate the possibility of using the new proposed in a HTB, both for railway and general roadway usage through the dynamic load test for a 20m bridge specimen. *[Chapter 4]*
3) verify the fatigue capacity of HTB using the new proposed connection system through the cyclic load test for both a HTB girder and a real scale connection joint specimen. *[Chapter 5]*
4) evaluate the possibility of using the incremental launching method in HTB construction through the launching nose optimization. *[Chapter 6]*
5) verify the construction safety of the new connection system through a real HTB construction of Gang-Chun Bridge. *[Chapter 6]*

CHAPTER 3

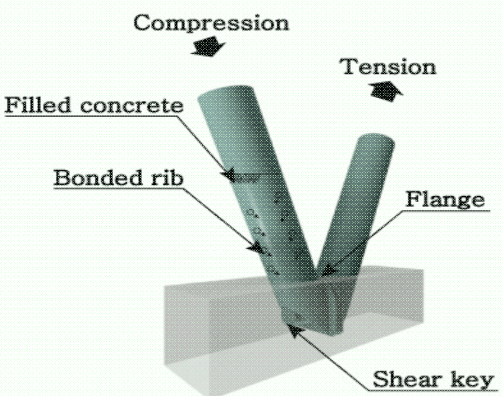
- Development of New Connection System
- Structural Capacity of New Connection

DEVELOPMENT OF NEW CONNECTION SYSTEM

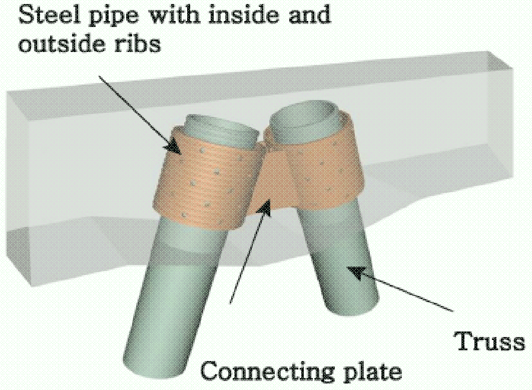
☐ Conventional Connection Systems



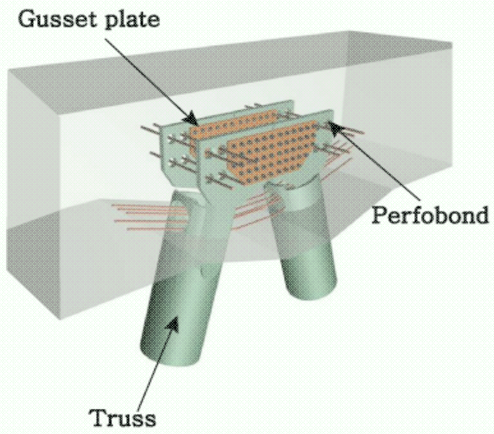
Punched box type
(Kinogawa Bridge)



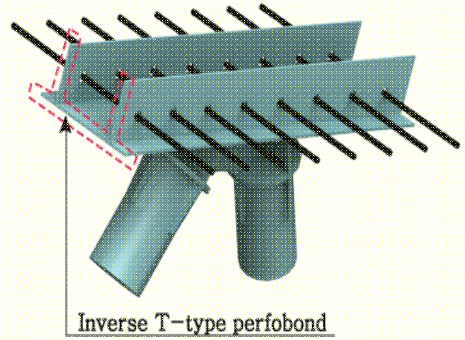
Shear key type
(Shitsumi Ohashi Bridge)



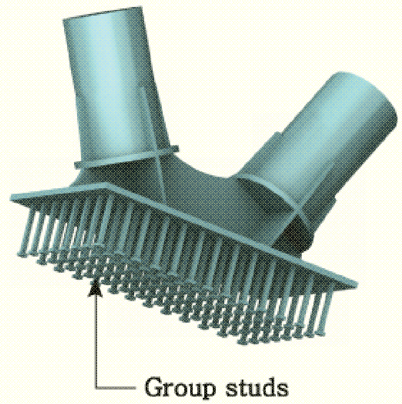
Double pipes type



Dobule gusset plates type
(Sarutagawa Bridge)



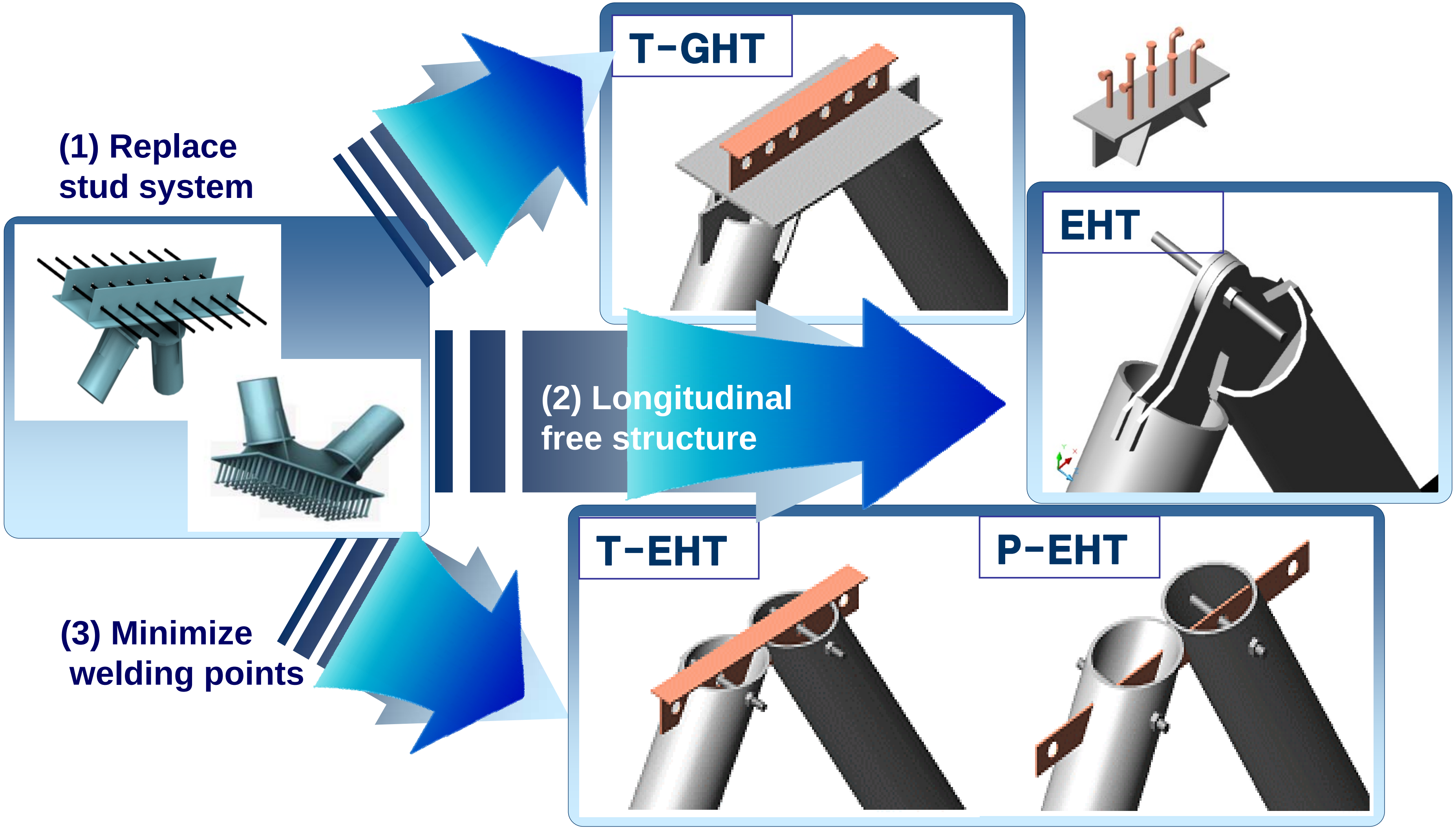
Double inverse T-perfobond



Group studs
(Shinchun Bridge)

DEVELOPMENT OF NEW CONNECTION SYSTEM

☐ Proposed Connection Systems



STRUCTURAL CAPACITY OF NEW CONNECTION

☐ Structural Capacity Tests

▪ Dimension of Specimens

(1) Slab Width: 1.6m Length: 2.2m Depth: 250mm(Hunch Depth: 250mm)

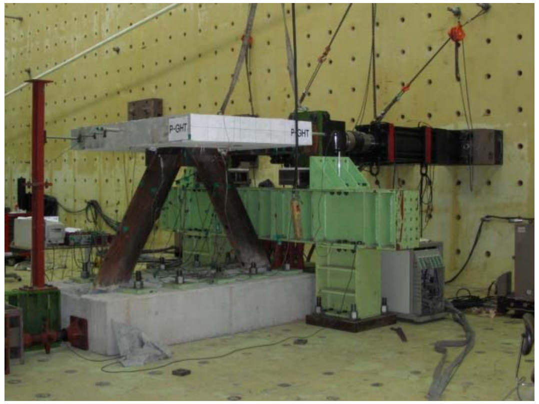
(2) Truss Steel pipe: STK490, φ318.5, 15t

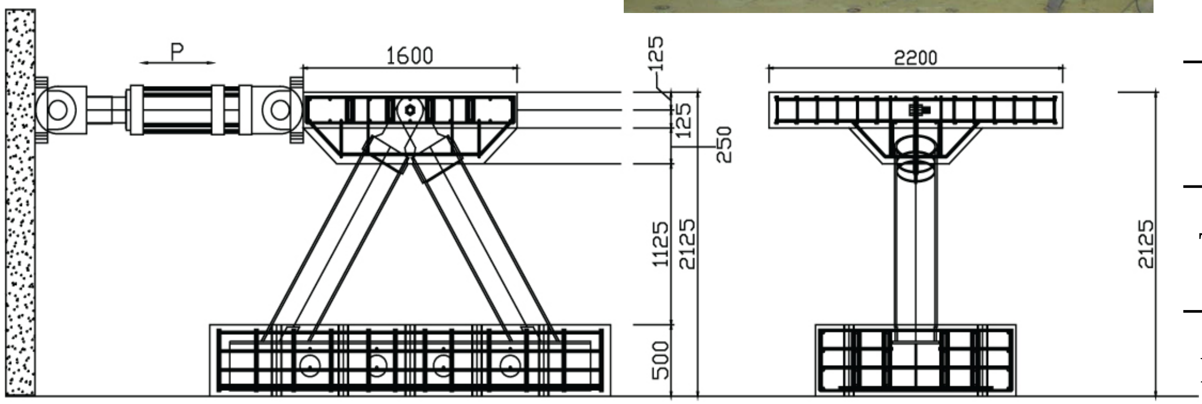
(3) Base Block H-Beam(SM400, H:344×B:348, φ150hole) + Concrete Block

▪ Loading System

- Actuator(2,000kN) : 2EA
- Control :0.02mm/sec
- Unloading Points :

  200kN, 400kN, 800kN





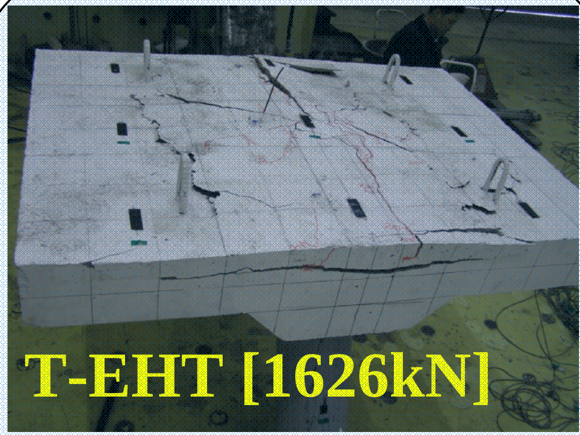
Index	Connection System	Concrete Hunch
T-GHT	T-type Perfobond + Gusset Plate	No
EHT	Hinge system + Perfobonds	Yes
T-EHT	T-type Perfobond + Connection Bolts	Yes
P-EHT	Perfobond + Connection Bolts	Yes
T-EHT-1	T-type Perfobond + Connection Bolts	No
P-EHT-1	Perfobond + Connection Bolts	No

STRUCTURAL CAPACITY OF NEW CONNECTION

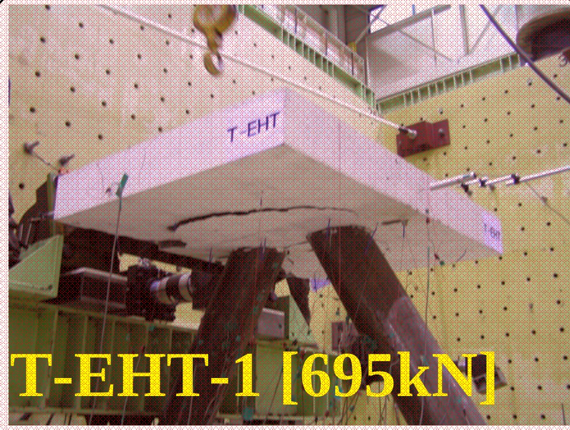
☐ **Failure Mechanism**

Design Load : 1000kN

Crack on the slab

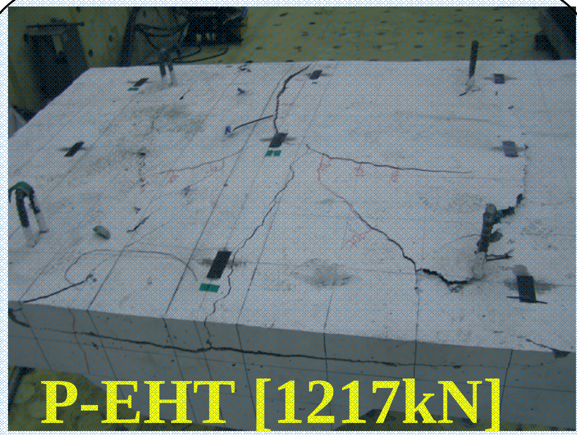


Compressive failure of slab



Punching failure of slab

Crack on the hunch



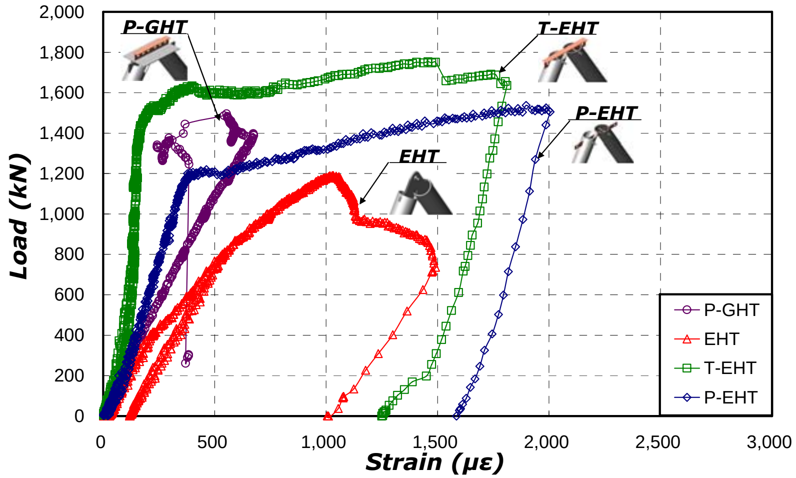
Compressive failure of slab

Punching failure of slab

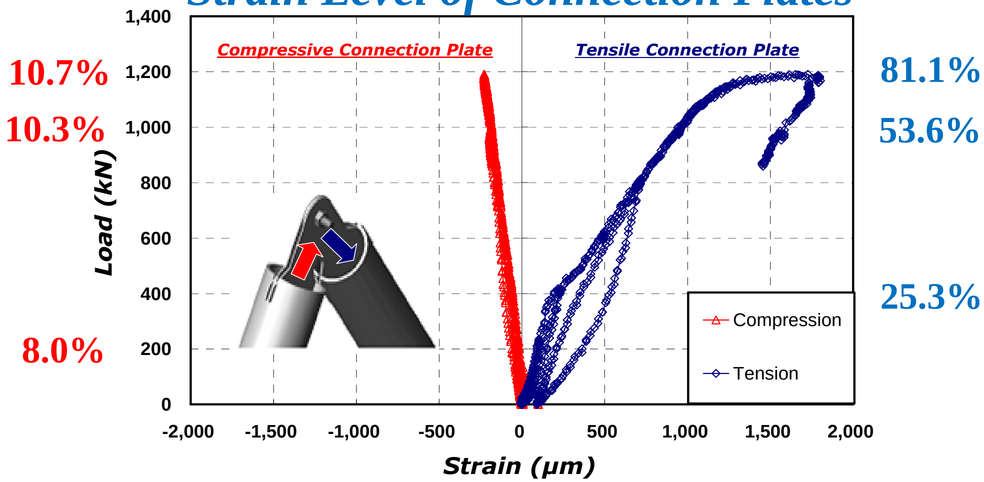
STRUCTURAL CAPACITY OF NEW CONNECTION

☐ Load Transfer Mechanism of EHT

Strain of Truss Members

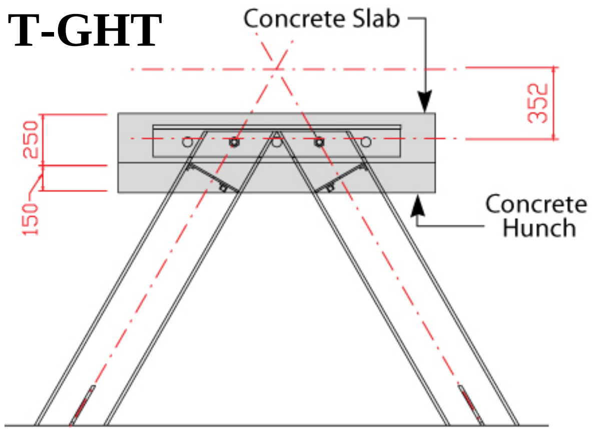


Strain Level of Connection Plates



Compressive LDR: 8.0~10.7% Tensile LDR: 25.3~81.1%

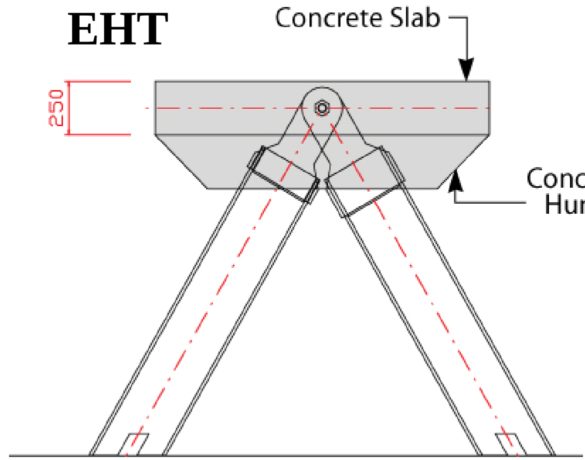
T-GHT



Load indirectly transfer to members

$$Q_u = 1.45\{(d^2 - \phi^2) f_{ck} + \phi^2 f_y\} - 26.1 \times 10^3 = 1077 kN$$

EHT



Load directly transfer to members

$$P_u = f_{yield} \cdot A_{plate} = f_{yield} \cdot (w_{plate} \cdot t_{plate}) = 1006.6 kN$$

CHAPTER 4

- Flexural Behavior of HTB Girders

- Behavior of HTB Bridge Specimen

FLEXURAL BEHAVIOR OF HTB GIRDERS

☐ What is the role of the flange plates ?

As is : PCT

▪ Span Length vs. Height

50m	60m	70m	80m
2.5~3.0m	3.0~3.5m	3.5~4.0m	4.0~4.5m

▪ Amount of main materials for Gangchun

Index	Specifications	Unit	Amount
Concrete	40~45MPa	㎥	1,539
Tendons	SWPC7B 15.2mm	ton	140
Steel Truss	SM520, D355.6	ton	168
Steel Plates	SM520, 22t	ton	306

▪ Cost : 191만원/㎡ × 10m × 485m = 약 93억원

To be : HTB

▪ Span Length vs. Height

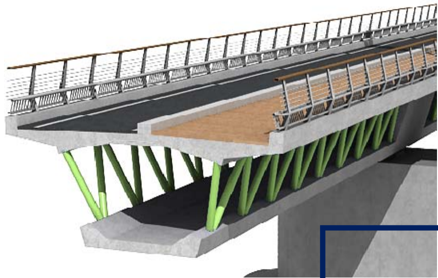
50m	60m	70m	80m
3.0~3.5m	4.0~4.5m	5.0~5.5m	6.0~6.5m

▪ Amount of main materials for Gangchun

Index	Specifications	Unit	Amount
Concrete	45MPa	㎥	1,620
Tendons	SWPC7B 15.2mm	ton	135
Steel Truss	SM520, D355.6	ton	210
Steel Plates		ton	0

▪ Cost : 157만원/㎡ × 10m × 485m = 약 76억원

close to Steel Box Bridges



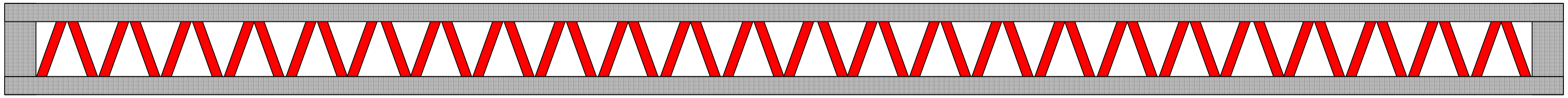
close to PSC Box Bridges

FLEXURAL BEHAVIOR OF HTB GIRDERS

☐ Height vs. Transparency

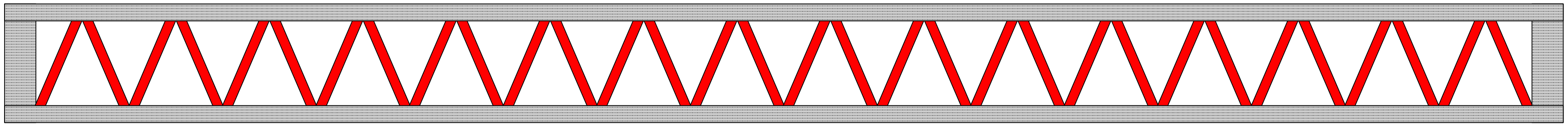
As is :

PCT



To be :

HTB



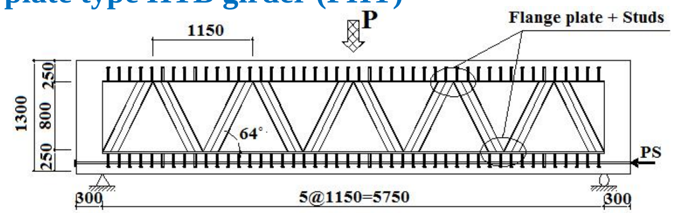
Index	Span	Height	Truss angle	No. of truss	Truss length	Amount of truss	No. of joints
PCT	50 m	2.5 m	60°	48 EA	2.24 m	14.5 tonf	49 EA
HTB	50 m	3.5 m	60°	32 EA	3.25 m	14.1 tonf	33 EA

FLEXURAL BEHAVIOR OF HTB GIRDERS

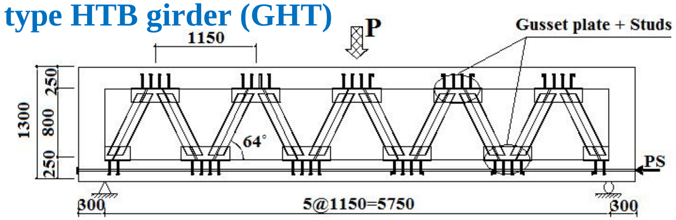
☐ Static Loading Tests for HTB Girders

Design Ultimate Load : 917kN

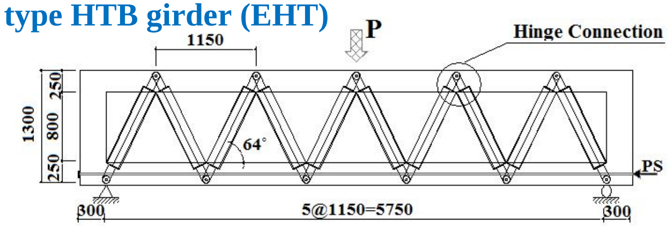
Flange plate type HTB girder (FHT)

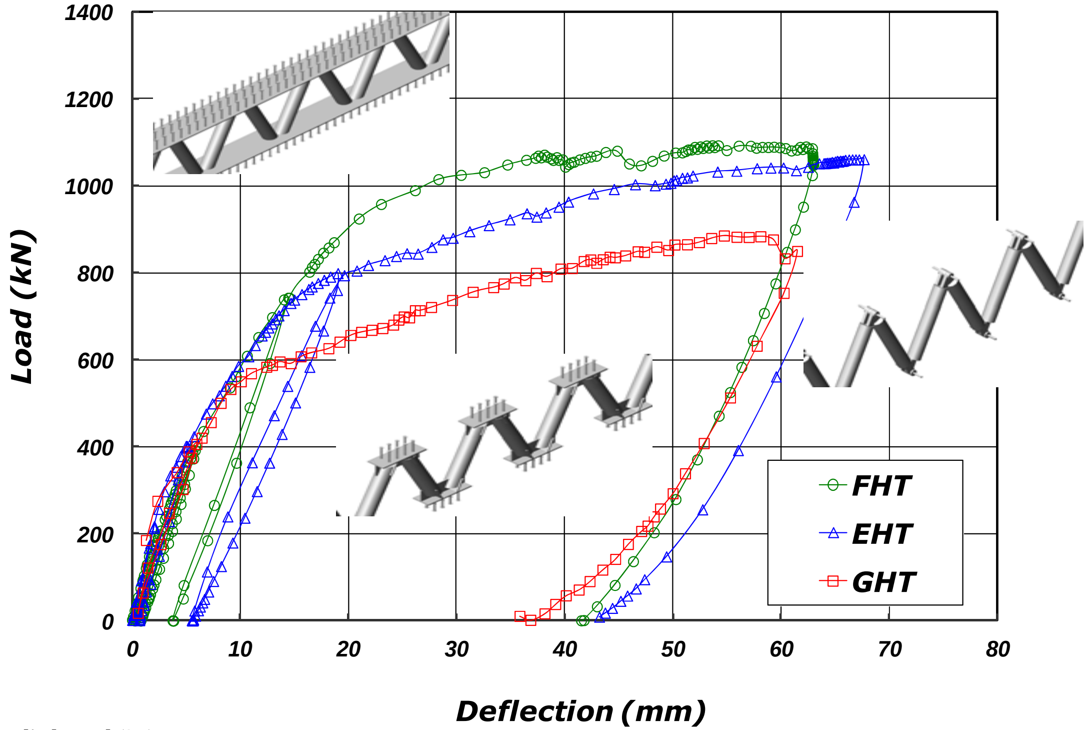


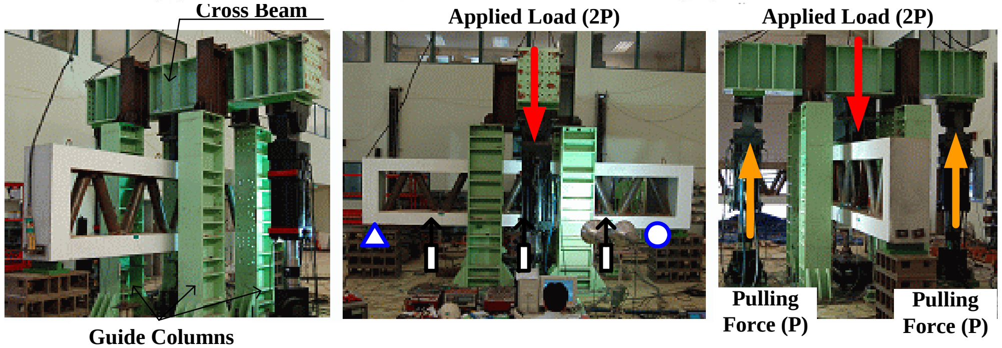
Gusset type HTB girder (GHT)



Hinge type HTB girder (EHT)



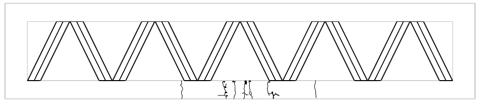
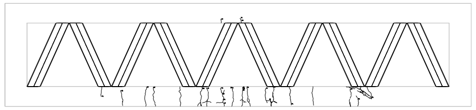
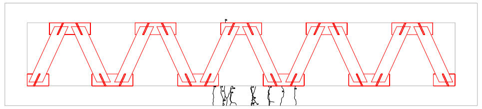
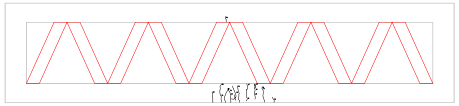
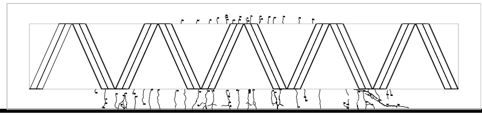
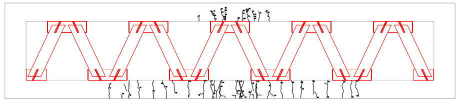
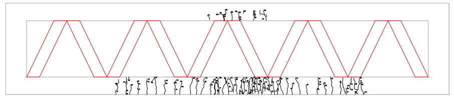




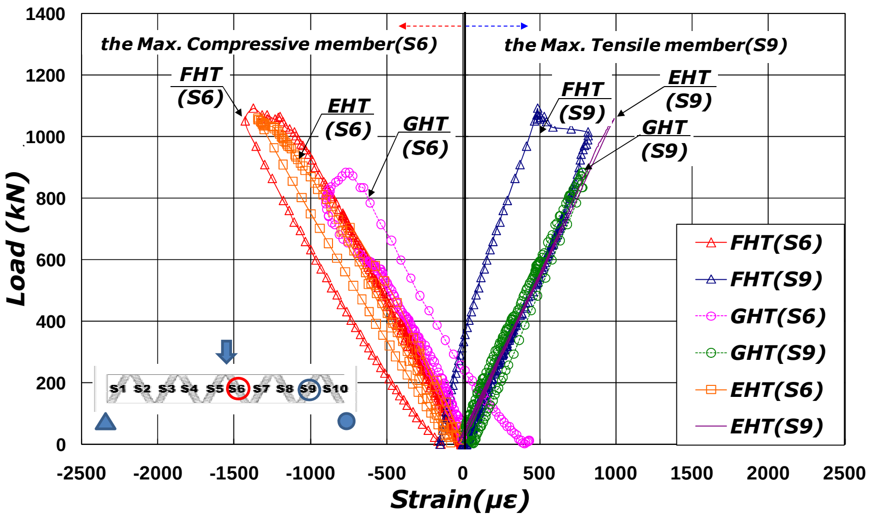
Index	FHT	GHT	EHT
Yielding Load	924.5	595.9	794.2
Ultimate Load	1089.2	883.7	1060.9

FLEXURAL BEHAVIOR OF HTB GIRDERS

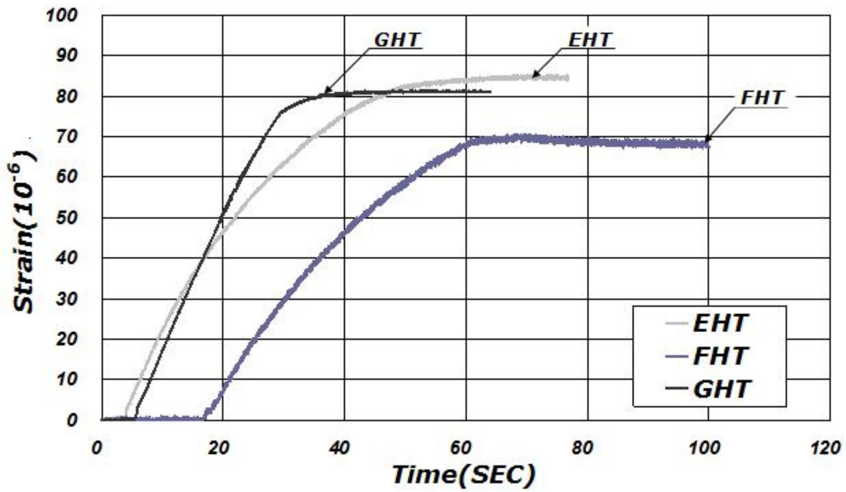
□ Serviceability Evaluation

Load	FHT	GHT	EHT
200 kN			
400 kN			
800 kN			

Max. stress level of truss members: 150.7MPa

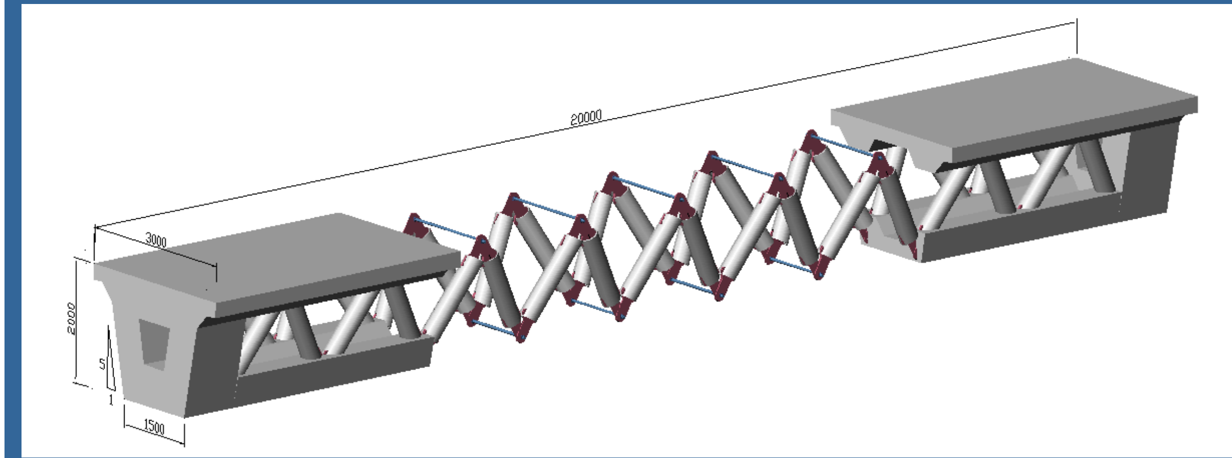


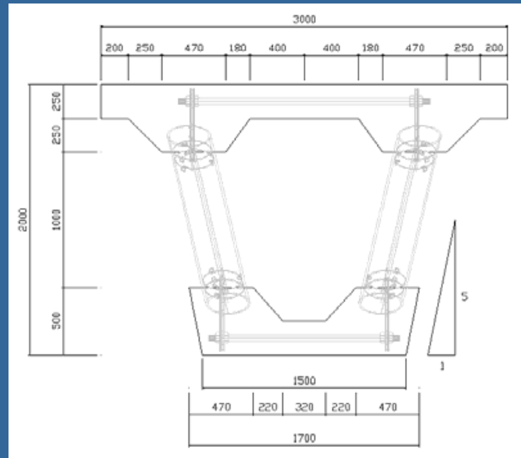
Prestressing efficiency



BEHAVIOR OF HTB BRIDGE SPECIMEN

☐ Bridge Specimen (Railway Bridge : 20m)

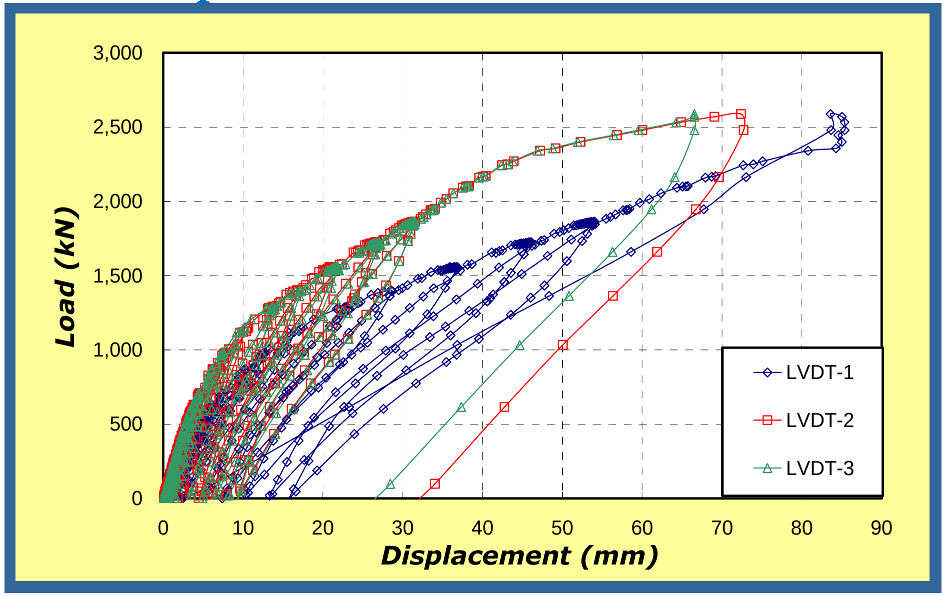




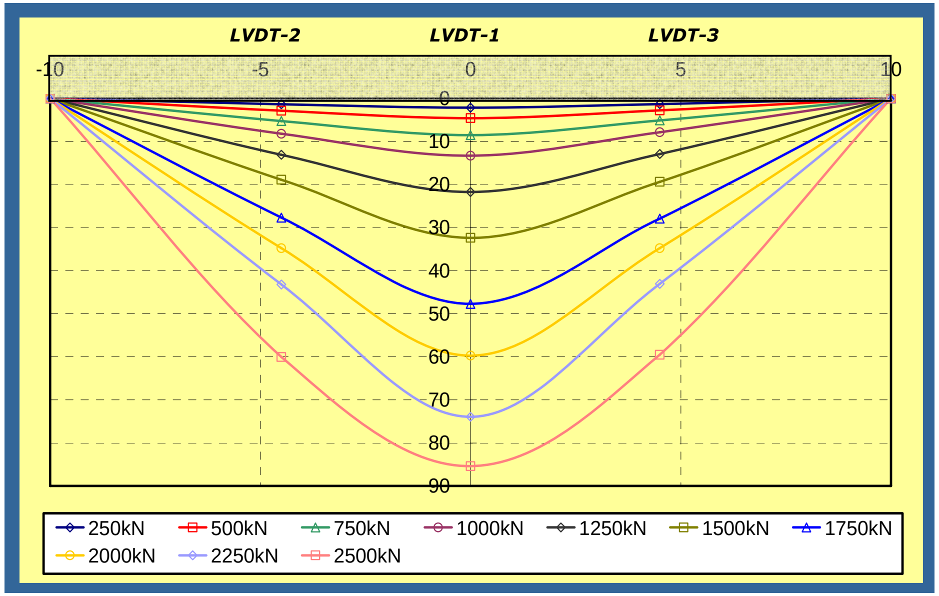
BEHAVIOR OF HTB BRIDGE SPECIMEN

☐ Static Test Results

Load-displacement curve



Deflection shape



➢ ***Failure mechanism***

- typical flexural behavior

- cracks occurred in the lower slab

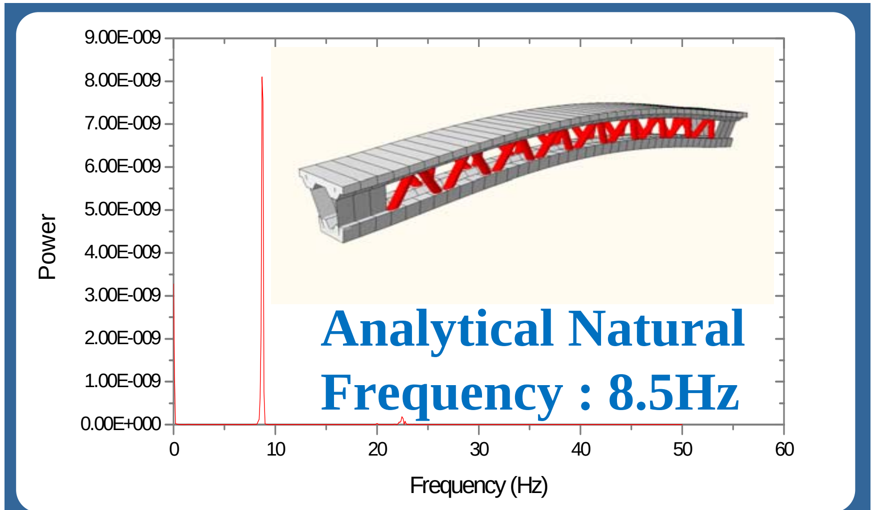
- failure of the middle concrete deviator for external tendon

Flexural Failure in the lower Slab

Failure of the middle concrete deviator

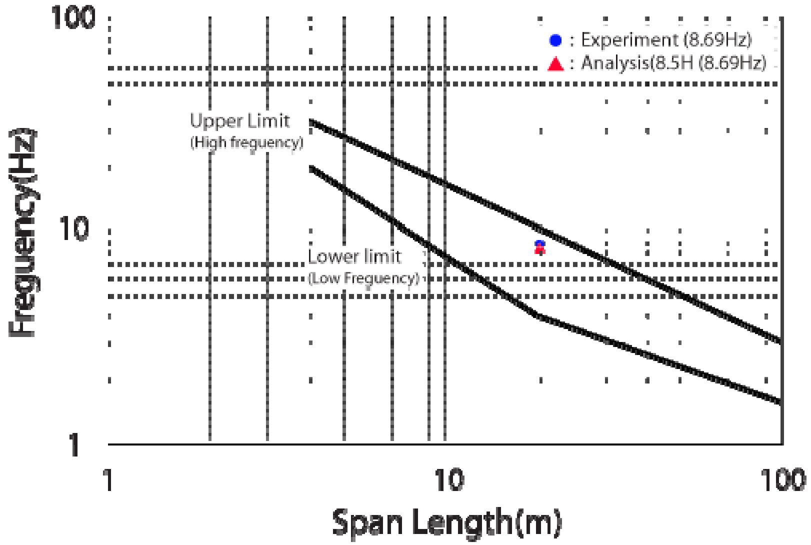
BEHAVIOR OF HTB BRIDGE SPECIMEN

☐ Dynamic Test Results



Exciter

FEM Model



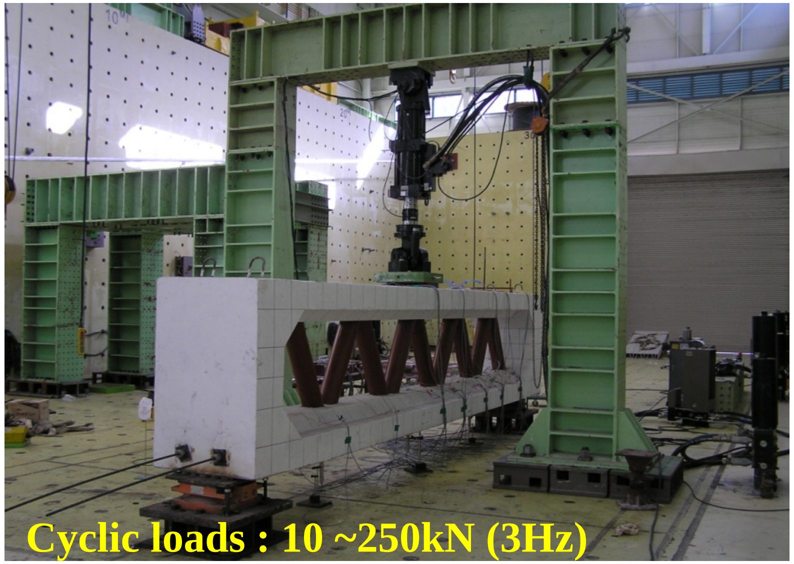
Natural frequency limits for railway Bridges

CHAPTER 5

- Fatigue Capacity of EHT Girder
- Improvement of EHT Details

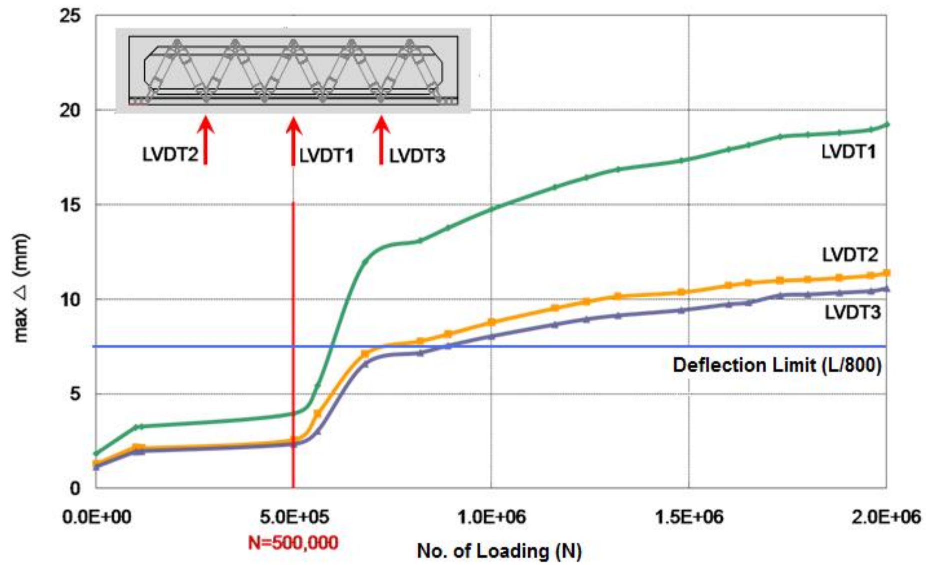
FATIGUE TEST FOR EHT GIRDER

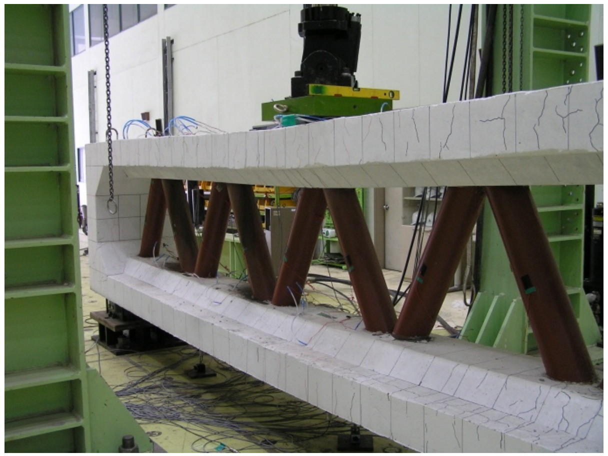
☐ **Fatigue Test Summary**



240kN : 30% of the elastic limit load of 800kN

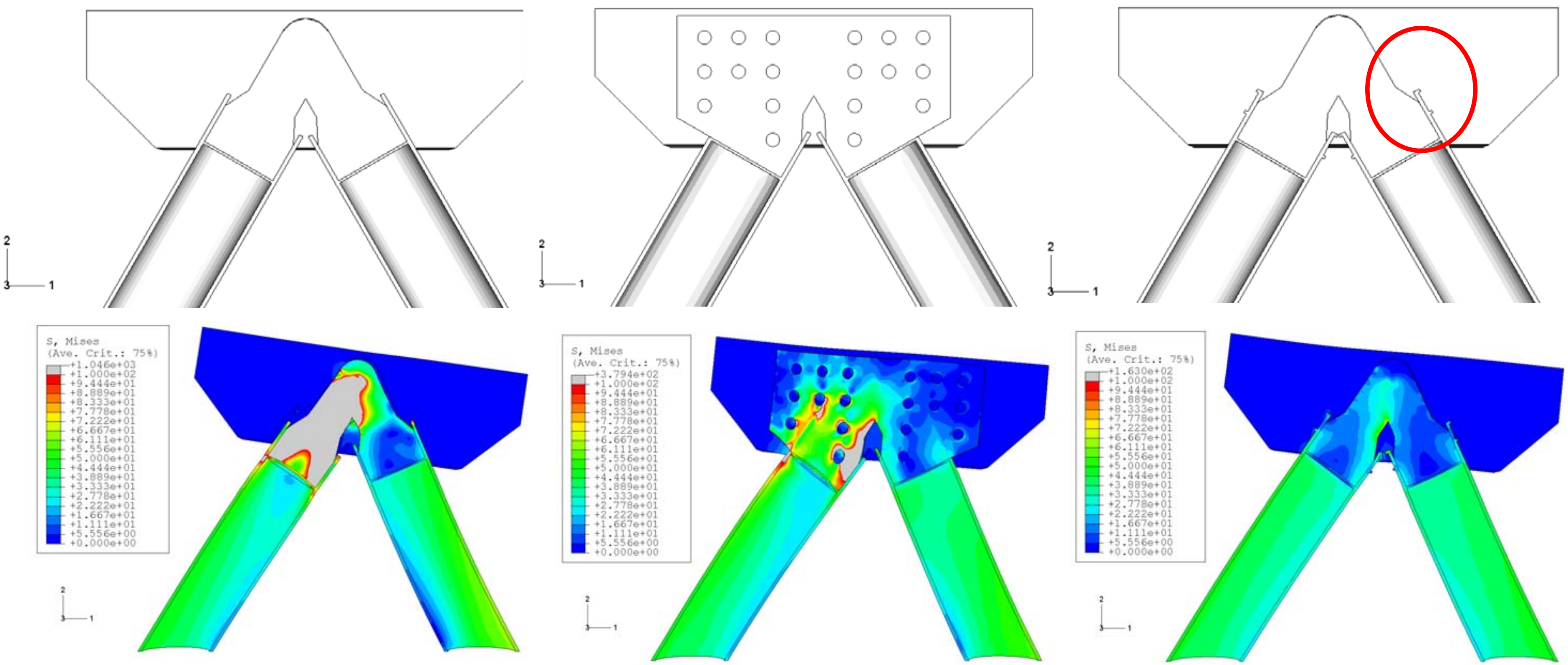
Max. Deflection vs. No. of Loading





IMPROVEMENT OF EHT DETAILS

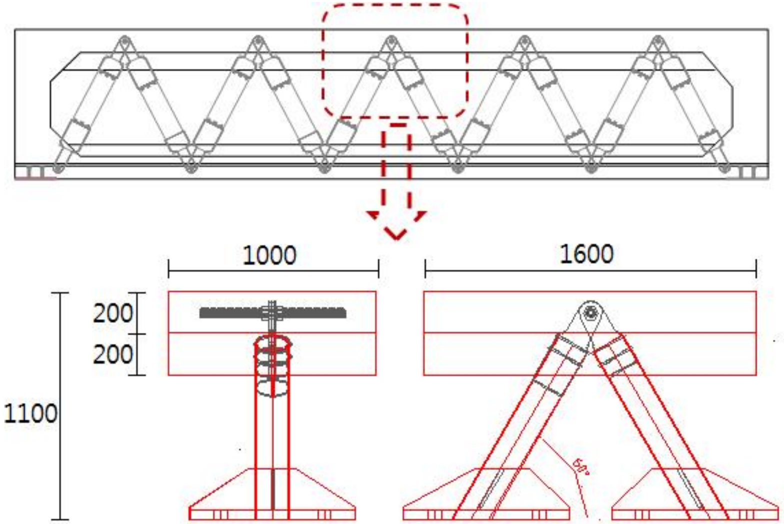
☐ **Two Proposed Details**



Index	Conventional type	Perfobond type	Circular rib type
Max. stress	104.6 MPa	37.9 MPa	16.3 MPa
Reduction ratio of Max. stress	-	63.8%	84.4%

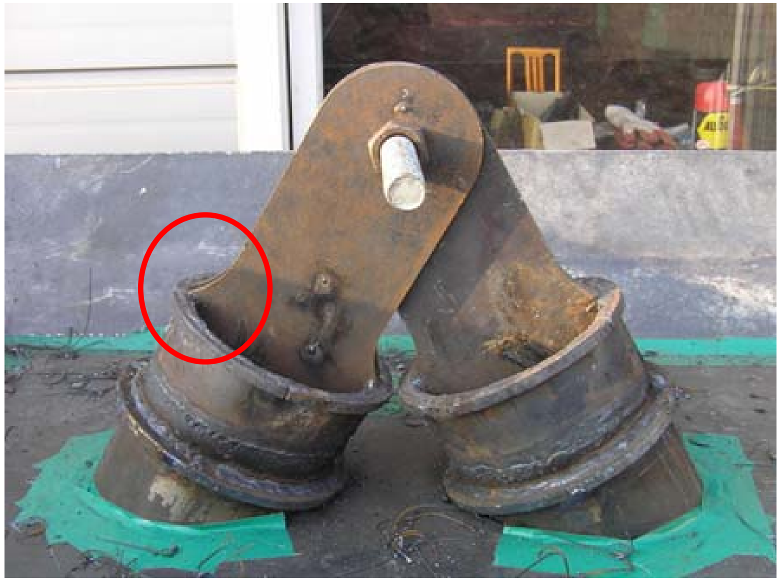
IMPROVEMENT OF EHT DETAILS

☐ **Verification Test**



125kN : about 50% of the previous test

Improved detail of EHT



➤ **Detail improvement**

1)Circular ribs

2)Curved shape connection plates

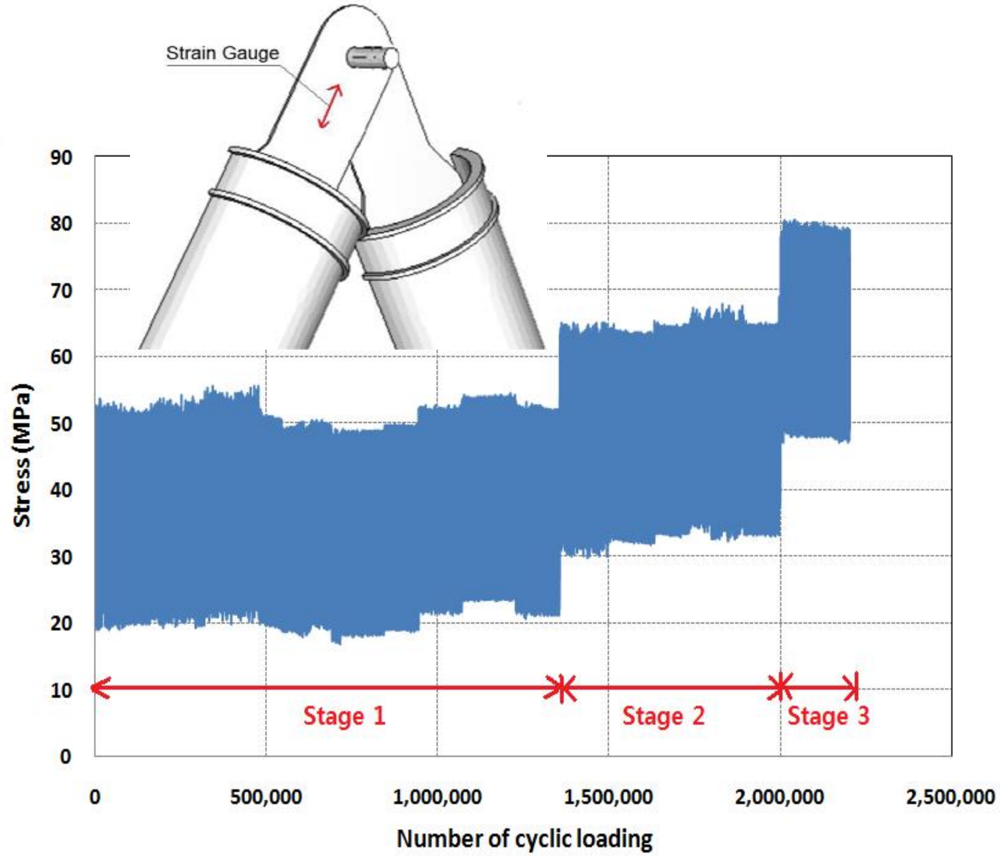
3) Increase the hunch height

(150mm ⇨ 200mm)

IMPROVEMENT OF EHT DETAILS

☐ Verification Test Results

Stress variation of the connection plate during the fatigue test



CHAPTER 6

- Incremental Launching Construction
- Nose-Deck Interaction

INCREMENTAL LAUNCHING CONSTRUCTION

□ *"GangChun Bridge"* **project in the NamHan river**

- ✓ Weir maintenance bridge / DB-24
- ✓ Construction Limit : 12month

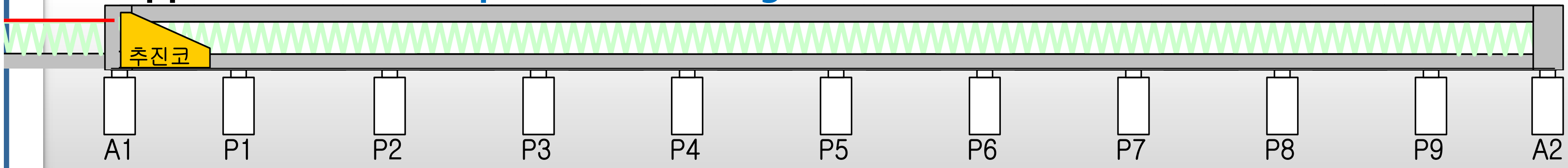
- ➢ Span : 42.5+8◎50+42.5 = 485m
- ➢ Width : 10m
- ➢ Height : 3.3m

INCREMENTAL LAUNCHING CONSTRUCTION

Conventional Method

Cost : 93억원 **Period : 300day**

Upper slab : Cast-in-place / Air curing

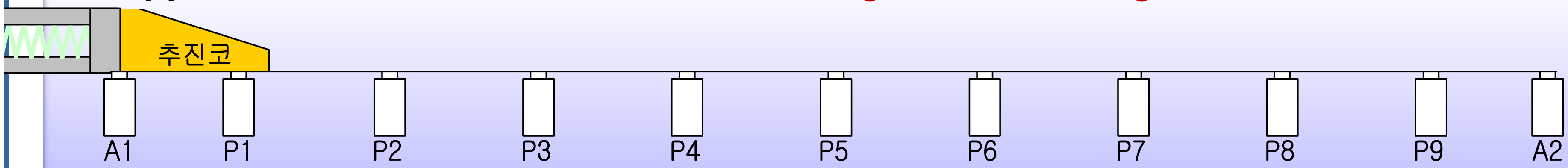


Nose : 30m

Gangchun Bridge

Cost : 76억원 **Period : 240day**

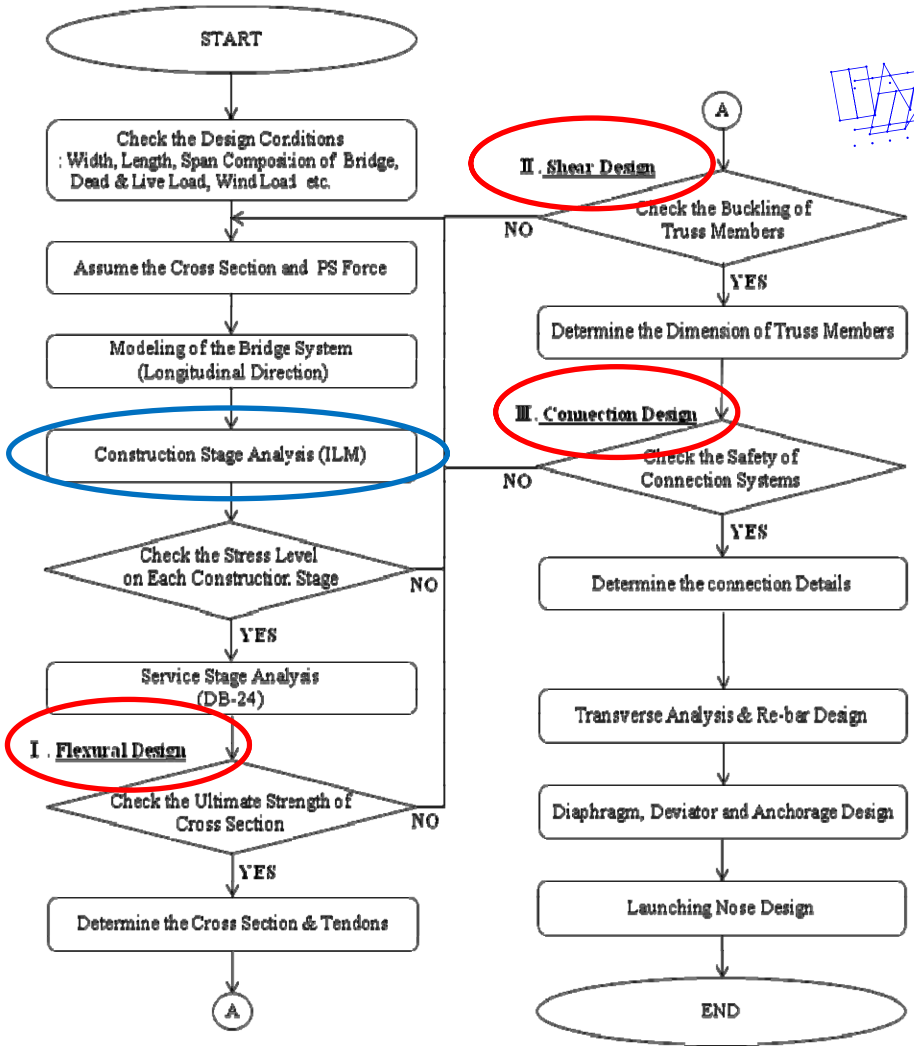
Upper & lower Slabs : Simultaneous casting / Steam curing

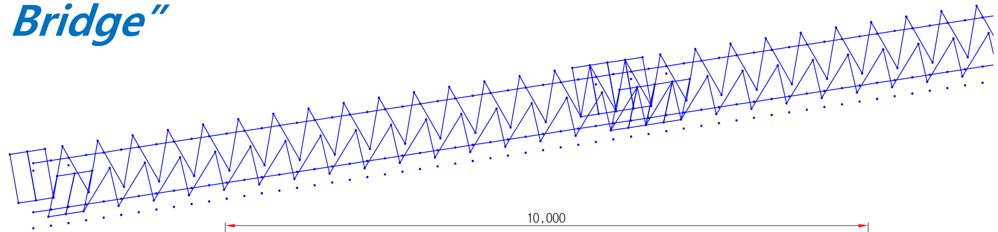


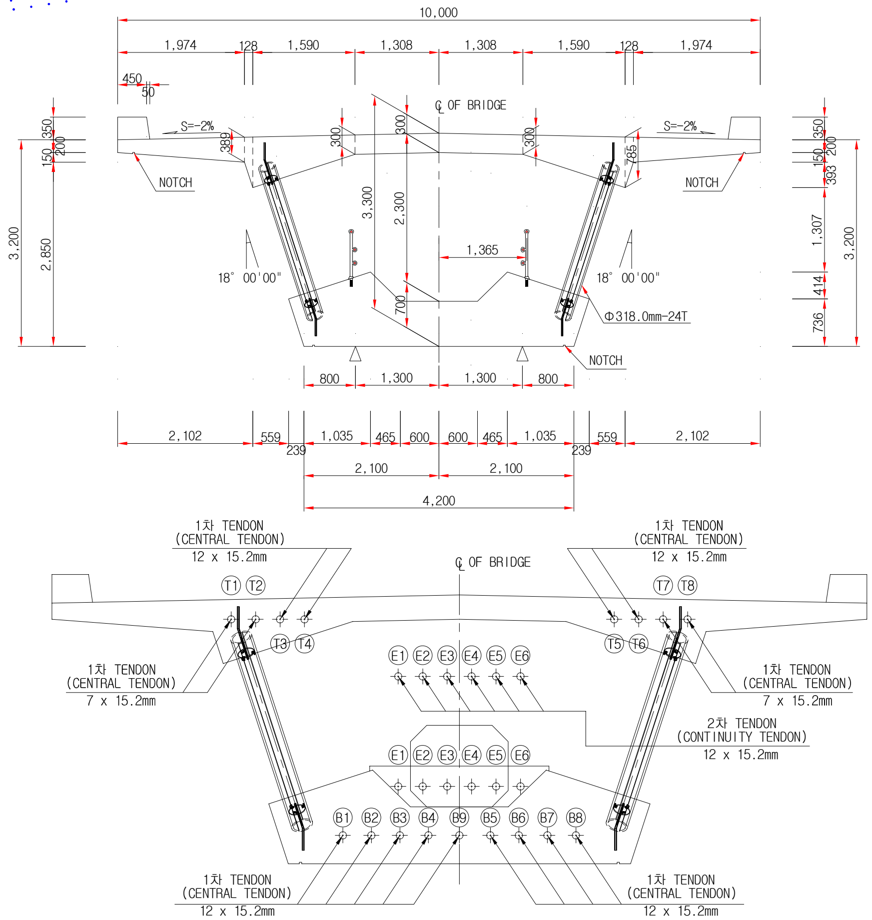
Nose : 50m

INCREMENTAL LAUNCHING CONSTRUCTION

☐ **Design Procedure of HTB** *"GangChun Bridge"*

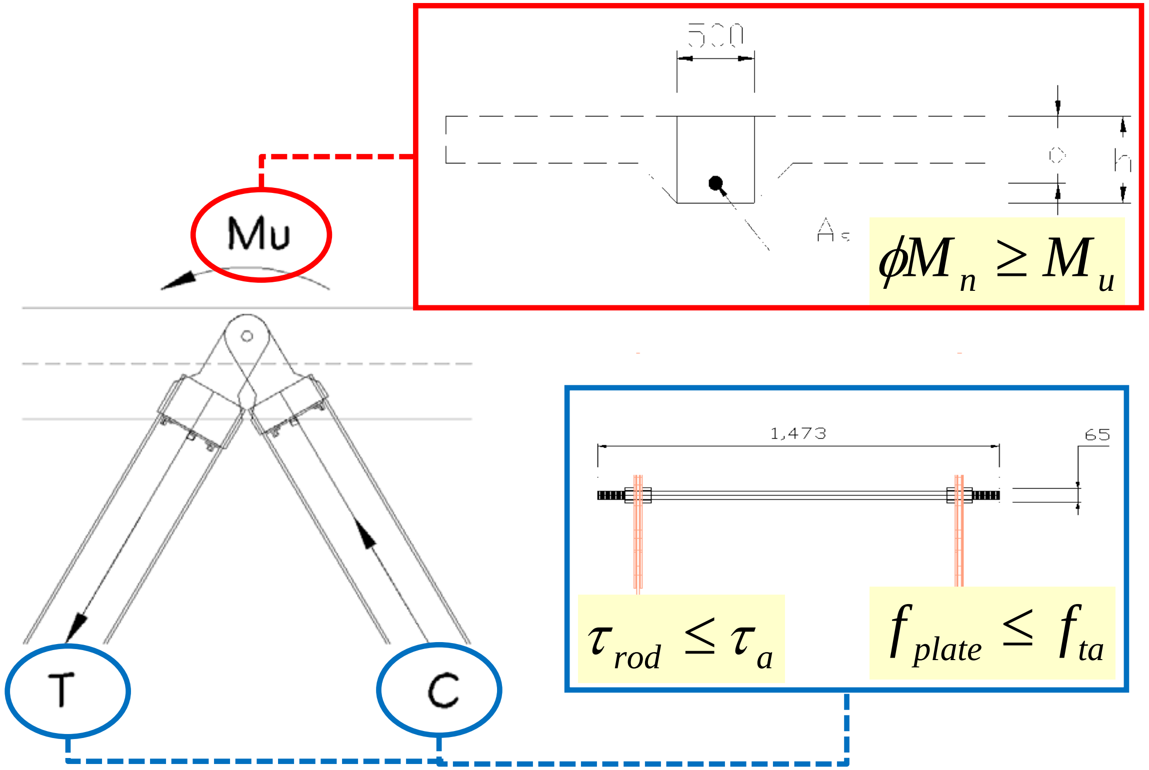






INCREMENTAL LAUNCHING CONSTRUCTION

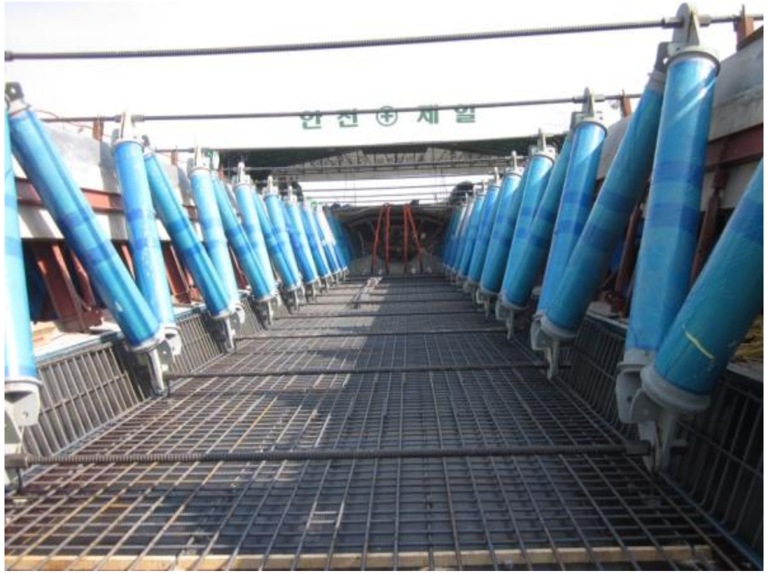
☐ Connection Design of *"GangChun Bridge"*

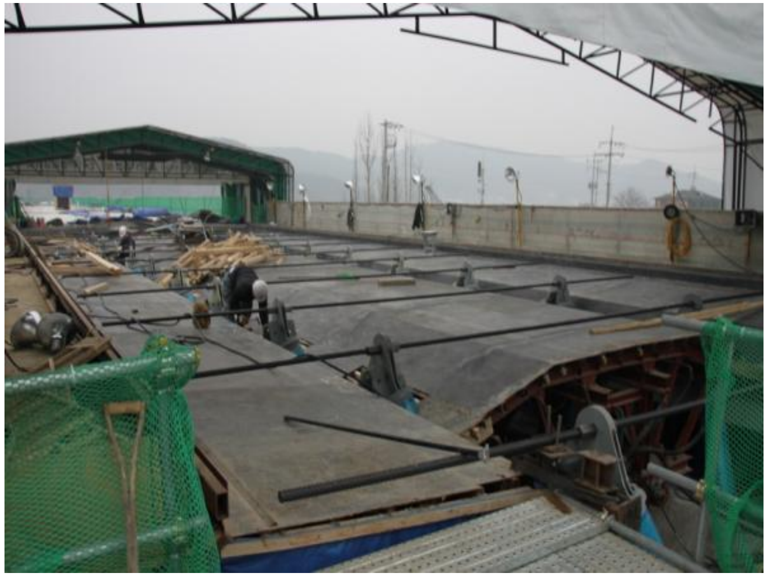


Applied loads at the connection joints

Index	Axial Force (kN)		Local Moment (kN-m)	
	Tension	Compression	Tension	Compression
Construction Stage	2236.3	-2512.4	69.24	-69.70
Service Stage	1853.9	-2515.1	60.63	-61.08

INCREMENTAL LAUNCHING CONSTRUCTION





INCREMENTAL LAUNCHING CONSTRUCTION

NOSE-DECK INTERACTIOM

☐ **Rosignoli`s Eq. :** *"Nose optimization"*

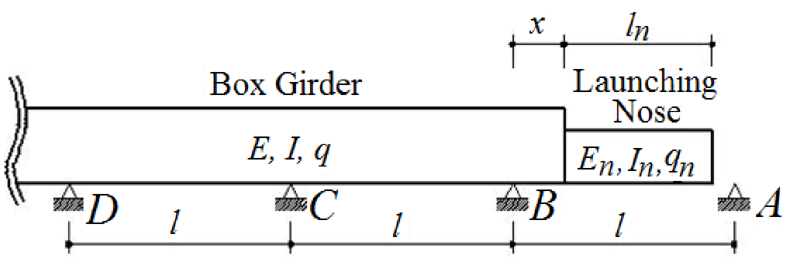
- *[Stage 1] :* ***Negative moment at the pier when the launching starts***

$$\frac{M_B^*}{ql^2} = -\frac{\alpha^2}{2} - \frac{q_n}{q}\frac{l_n}{l}\left(\alpha + \frac{1}{2}\frac{l_n}{l}\right)$$

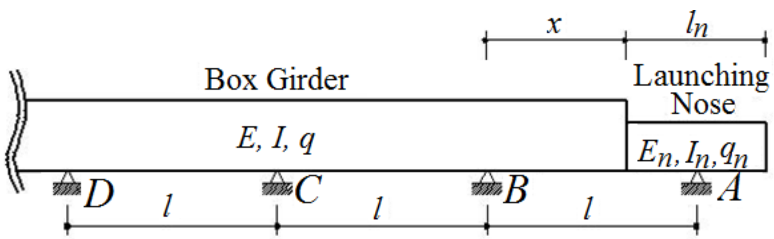
- *[Stage 2] :* ***Negative moment at the pier when the launching nose reaches the next pier***

$$\frac{M_B^*}{ql^2} = \frac{\{[(C_5 + C_4)/(C_3 + C_1)]C_2 - C_4 - C_8\}(1/ql^2) + (1/2)(q_n/q)C_7(l_n/l + \alpha - 1)^2}{C_1 + C_6 - C_2^{\ 2}/(C_3 + C_1)}$$

$$Herein, C_1 \sim C_8 = f(E_n I_n / EI)$$



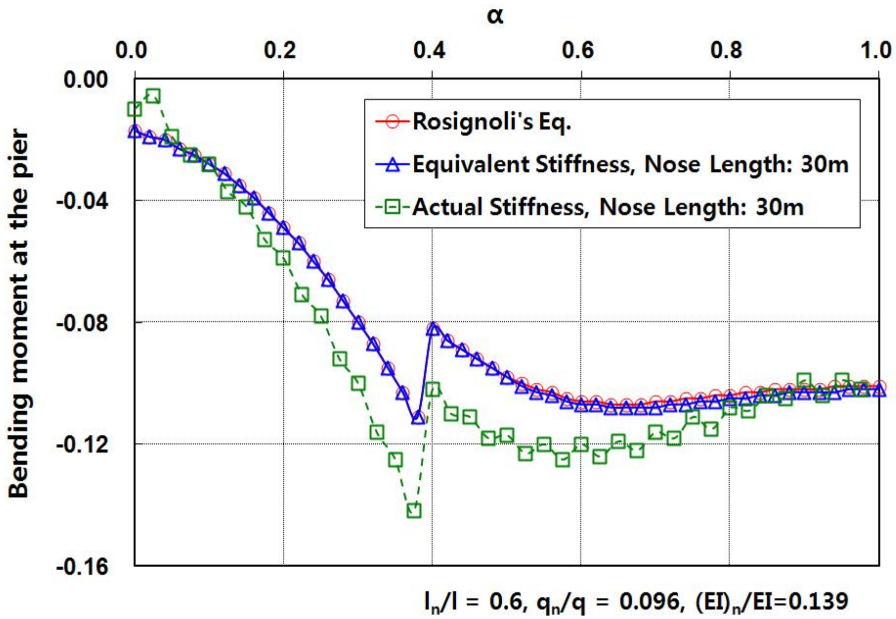
[Stage 1]



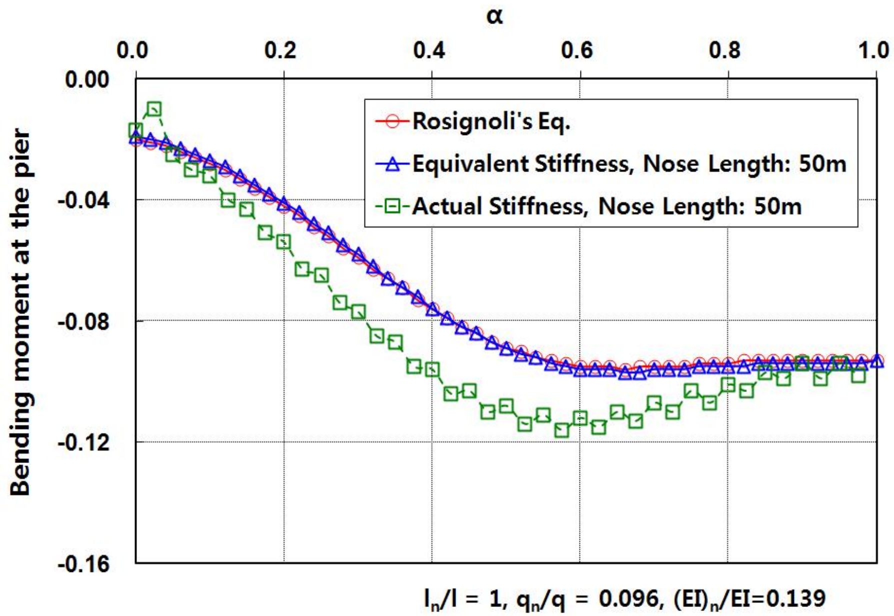
[Stage 2]

NOSE-DECK INTERACTIOM

☐ Determination of the Nose Length



[Nose Length : 30m]



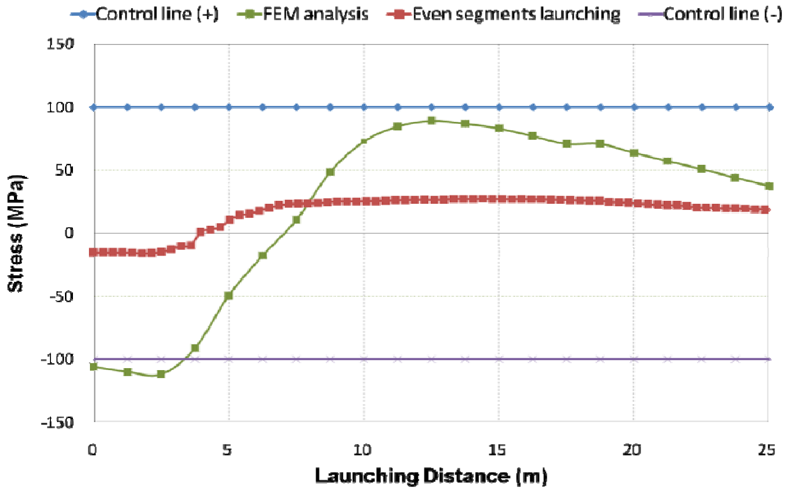
[Nose Length : 50m]

In order to *reduce the negative bending moment* during the launching procedure, *the launching nose length was extended to a span length of 50m*, and additional temporary shoes was installed at the piers.

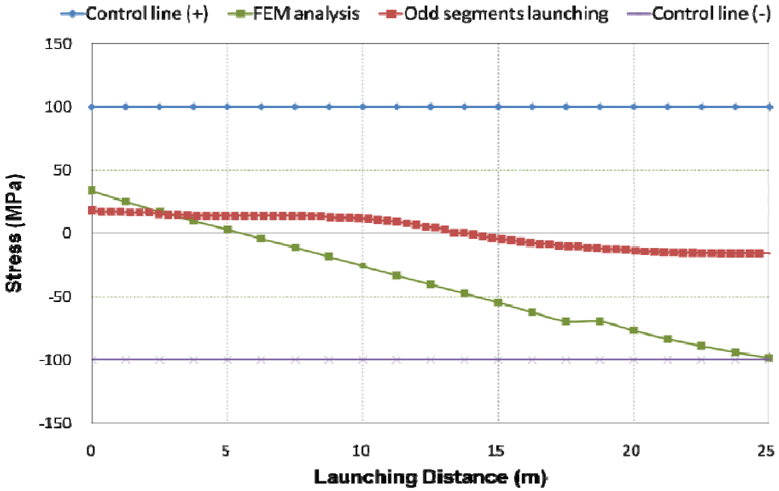
NOSE-DECK INTERACTIOM

☐ Construction Monitoring : *Stress levels*

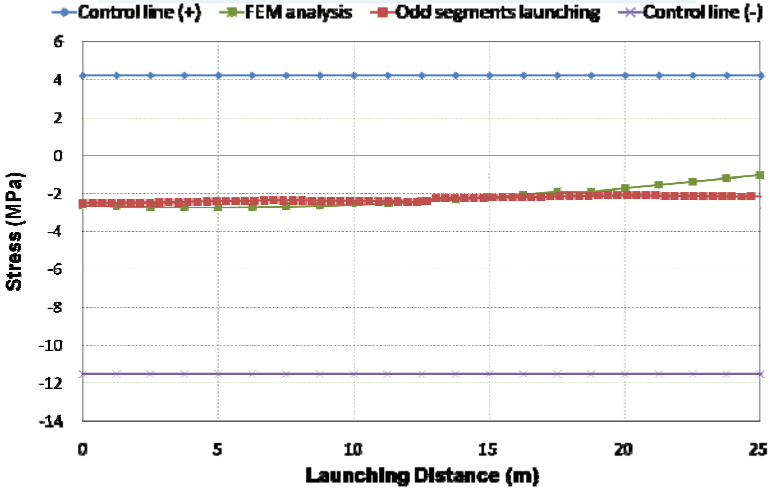
Steel Truss (Tension)



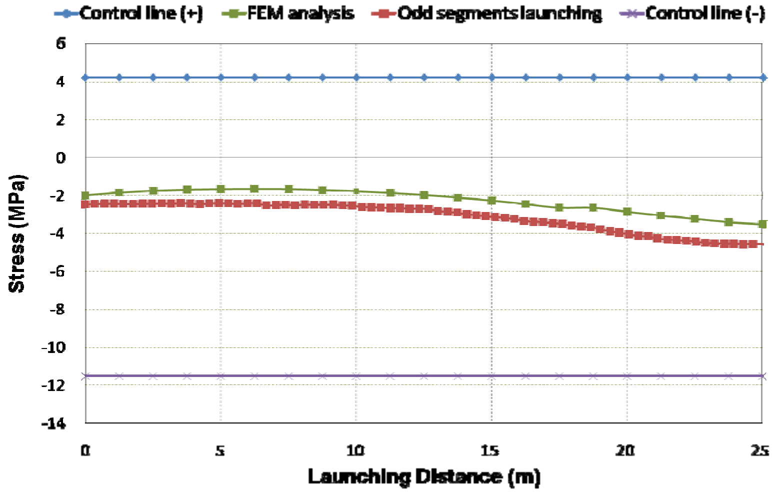
Steel Truss (Compression)



Upper Concrete Slab



Lower Concrete Slab



CHAPTER 7

- Conclusion

CONCLUSIONS

- **In this study, several new connection systems for HTB (P-GHT, EHT, T-EHT, P-EHT) using hinge devices or T-type perfobonds are proposed and evaluated, in order to improve the assemblage convenience and eliminate welding during construction.**
- ✓ However, the local moment resisting members at the connection joints, such as concrete hunches (EHT, T-EHT and P-EHT) and a steel base plate (P-GHT), require careful selection.
- ✓ The use of concrete hunches may enhance the local moment resisting ability and increase the initial stiffness.
- **With respect to EHT, the applied load at the connection joint was directly transferred to the steel truss members, eliminating eccentricity due to discordance between the center of the slab and the cross point of two truss axes.**
- **The validity of EHT is verified through the static and dynamic loading tests for the real scale bridge specimen.**

CONCLUSIONS

- **Two ideas for connection details were proposed in order to guarantee a fatigue capacity of this hinge type connection system**

  [1] an extension of a connection plate & an application of multiple punched holes

  [2] an addition of circular ribs around the embedded truss pipes

- **The 3D elastic analyses results for these ideas showed that a circular rib type is more efficient than a perfobond type in terms of the stress reduction ratio and total amount of steel plates.**
- **The launching process safety of the HTB applied this connection system is evaluated by the monitoring results of the Gangchun Bridge during the construction.**
- **Finally, it is recommended that it is better to design a longer launching nose to ensure that the nose reaches subsequent piers early enough to decrease the negative moment, using incremental launching method for HTB.**

GANG-CHUN BRIDGE: Hybrid Truss Bridge(HTB)