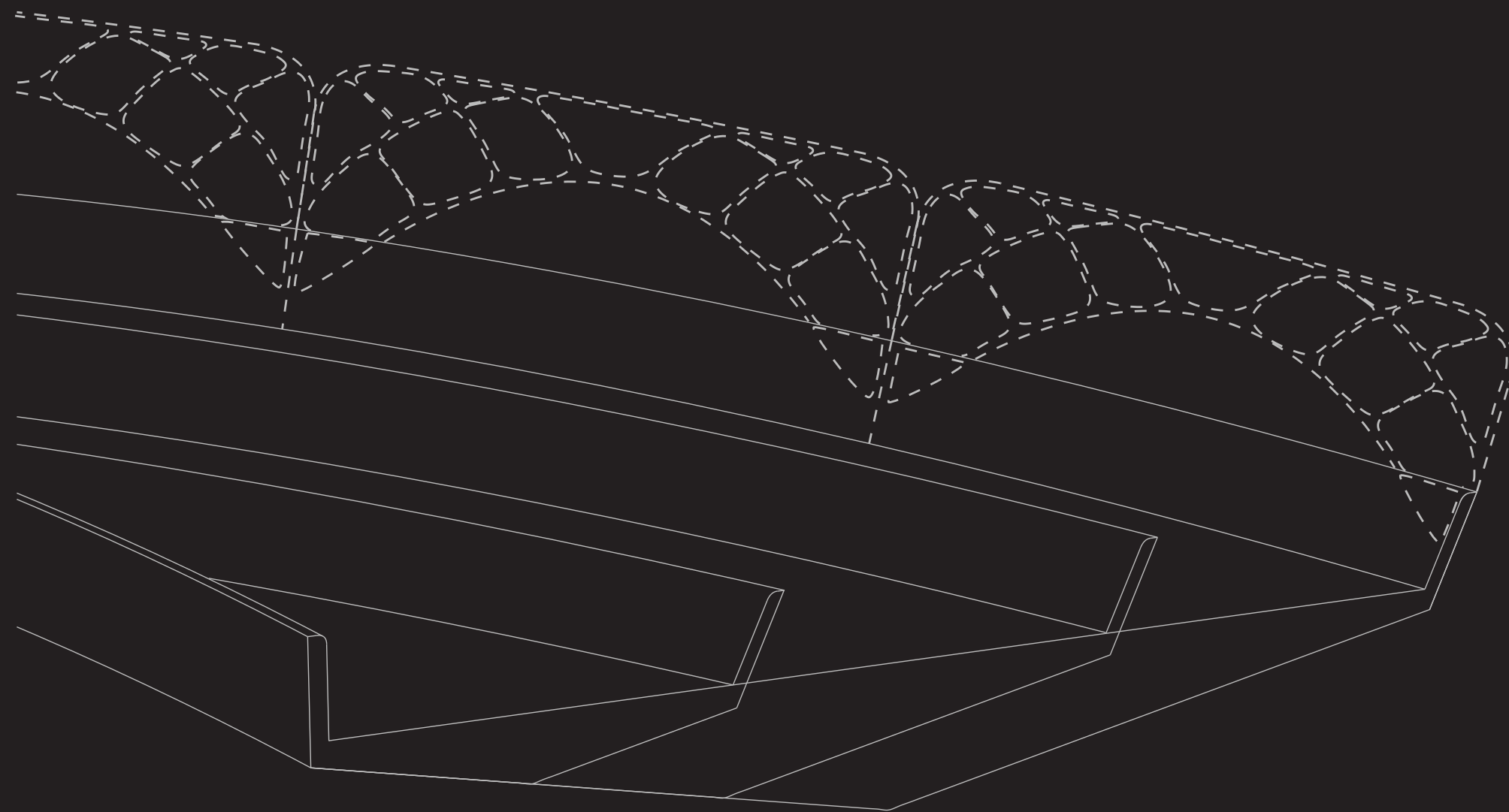


Master Graduation Thesis Presentation  
By Kalliopi Papangelopoulou

# Modular series of FRP pedestrian bridges

*The example of Tanthof Delft*



Tutors: Joris Smits (main mentor) | Fred Veer (second mentor) |  
Rafail Gkaidatzis (consultant)

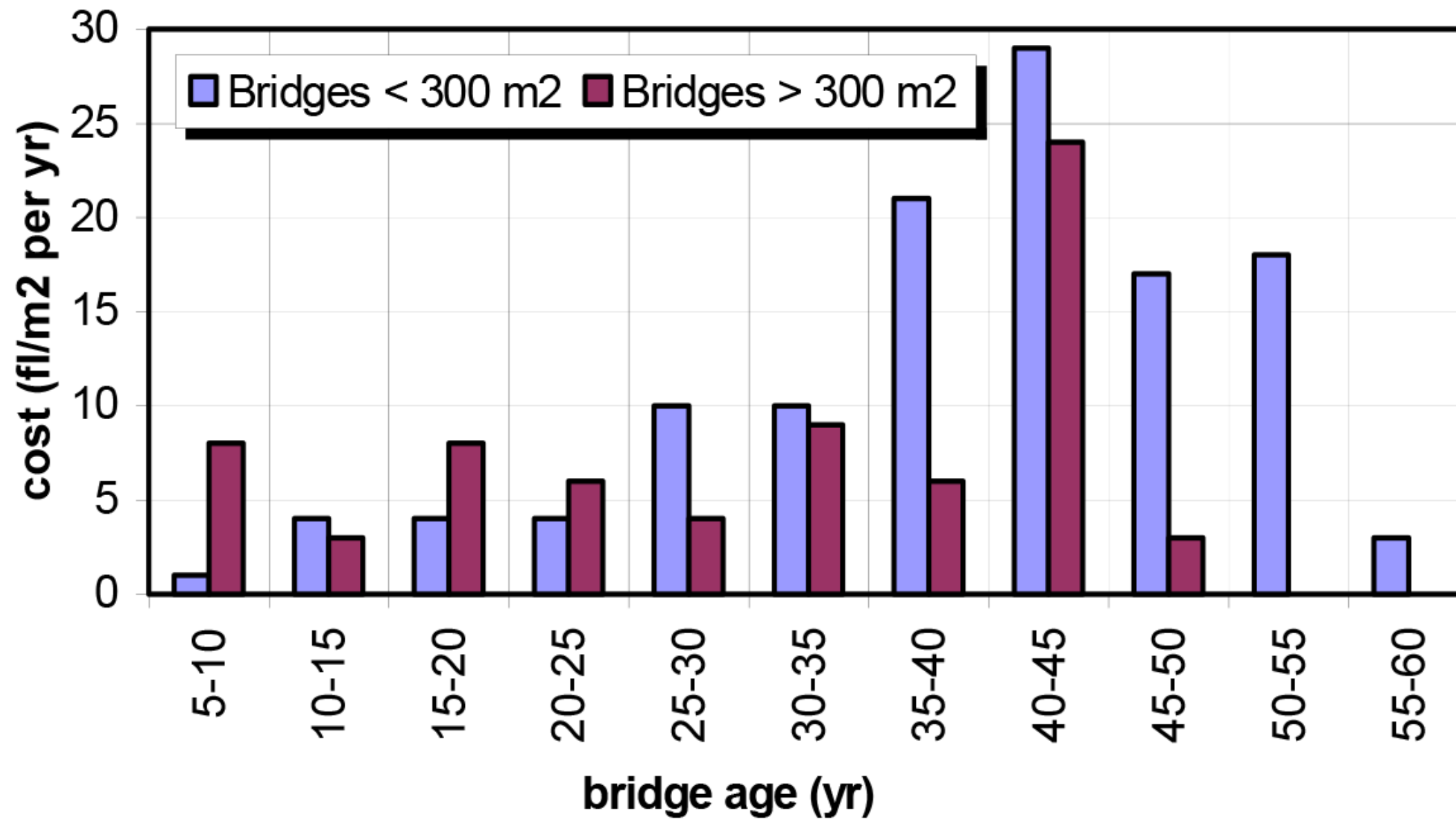








## Maintenance of bridges Overijssel



source: Klatter H.E., "Societal aspects of bridge management and safety in the Netherlands"



# PUBLIC FOOTBRIDGE'S REPLACEMENT

functional life time **+** aesthetically up-to-date

*source: Valbona M., "Bridge decks of reinforced polymer (FRP): A sustainable solution"*



**CONCRETE, STEEL, WOOD**

**or**

**FRP**

FIBER REINFORCED POLYMER

**as**

**structural material**



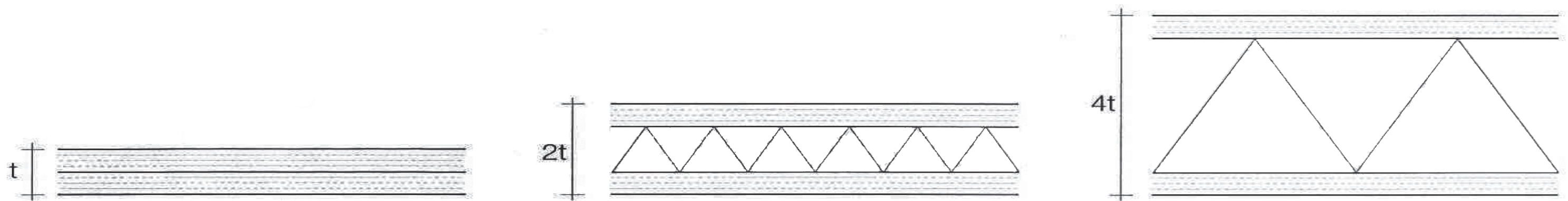


Fiberline Bridge Kolding, Denmark (1997)



# Problem statement

8



Depth of element	$t$	$2t$	$4t$
Stiffness in bending	1.0	7.0	37.0
Load-carrying capacity in bending	1.0	3.5	9.2
Weight	1.0	1.03	1.06





Zaha Hadid's Chanel Contemporary Art Container, New York's Central Park (2008)

source: <http://www.building.co.uk/>





*Prove that it is possible to design  
an **all FRP footbridge series** and  
manufacture them via a **modular  
moulding manufacturing process.***

## *Research on:*

- *FRP raw materials*
- *FRP mould manufacturing techniques*
- *bridge design principles*
- *module matrix*
- *bridge design*
- *mould design*



Modular design

Bridge design

Bridge series

Modular mould design

Bridge series  
manufacturing

Bridge series  
installation

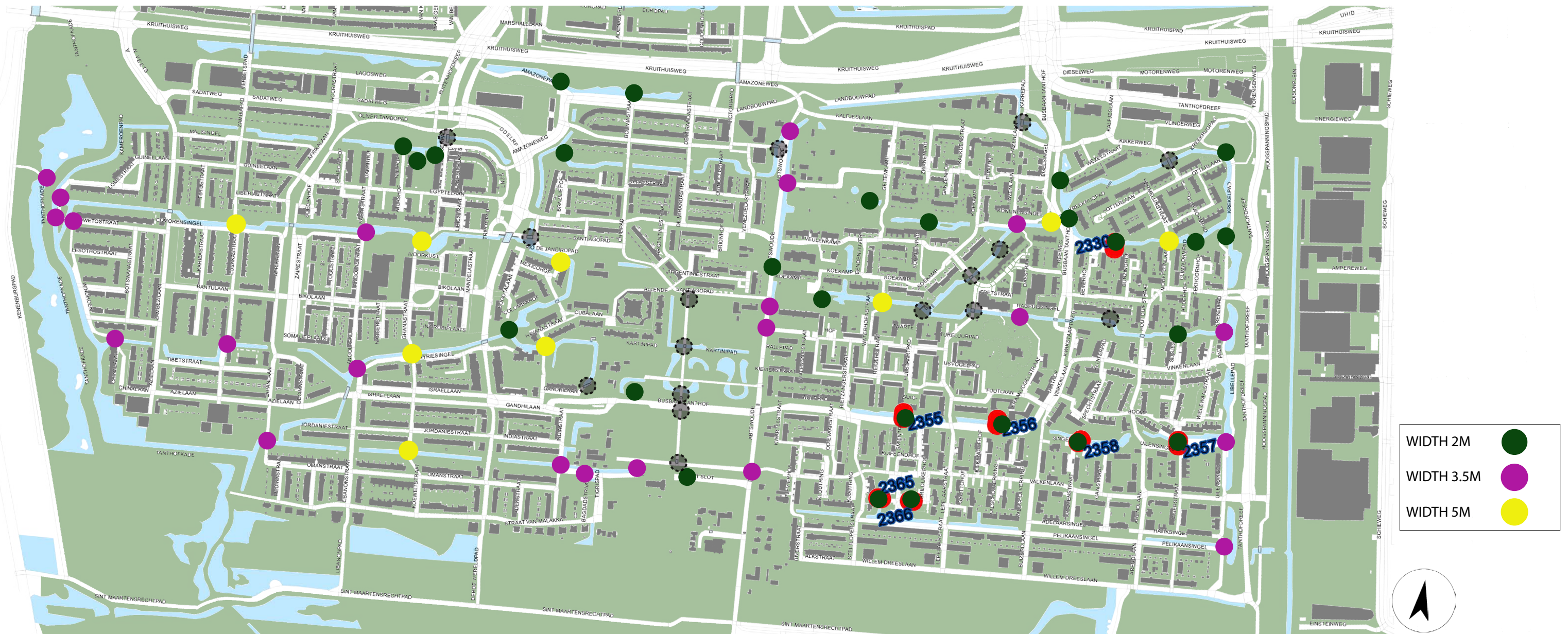








## Bridge population: 64 footbridges



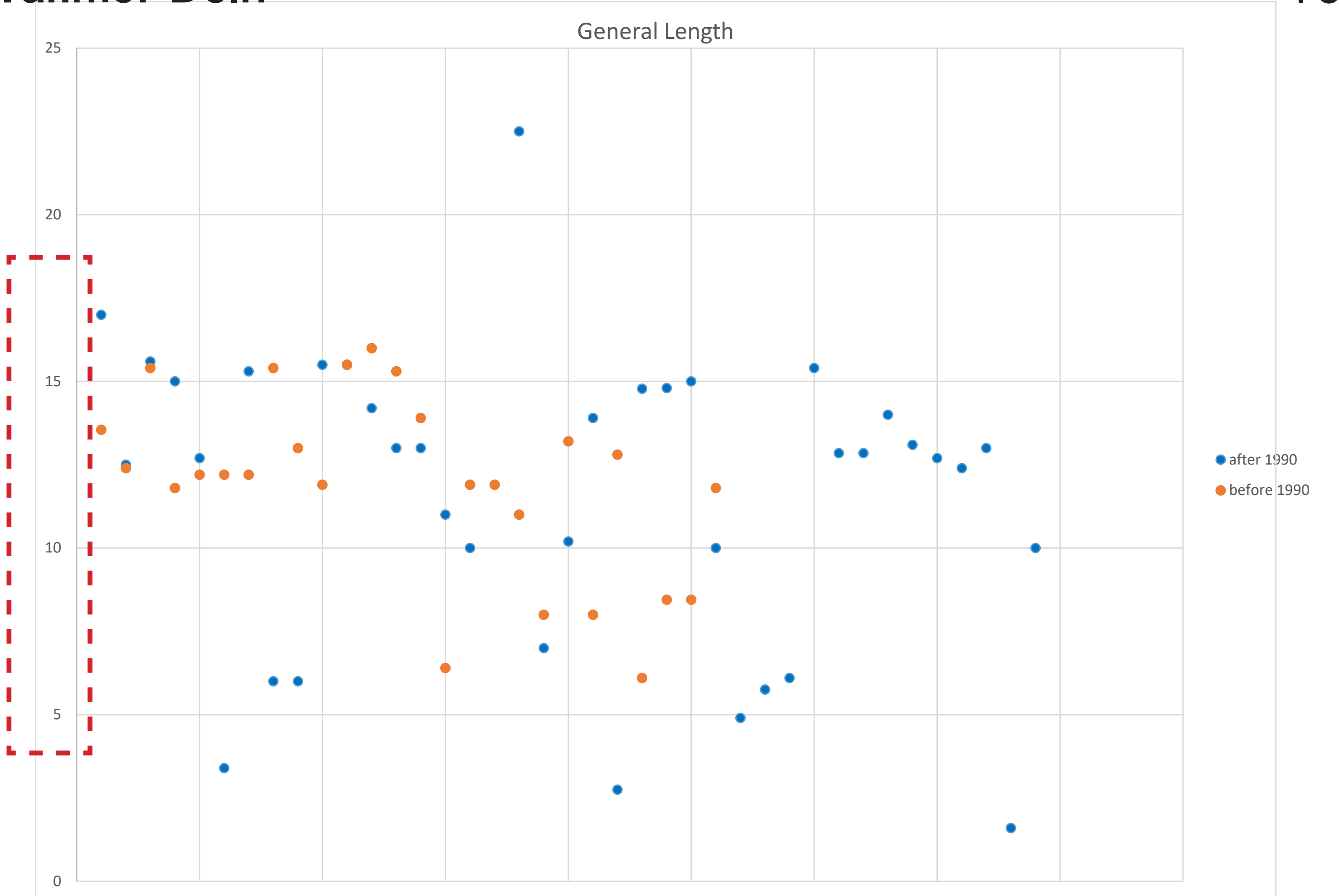


- *organic/double-curved shape*
- *monocoque structure*
- *modular mould*
- *renewable facade*
- *no extra supports*
- *integrated functions on cross-section*

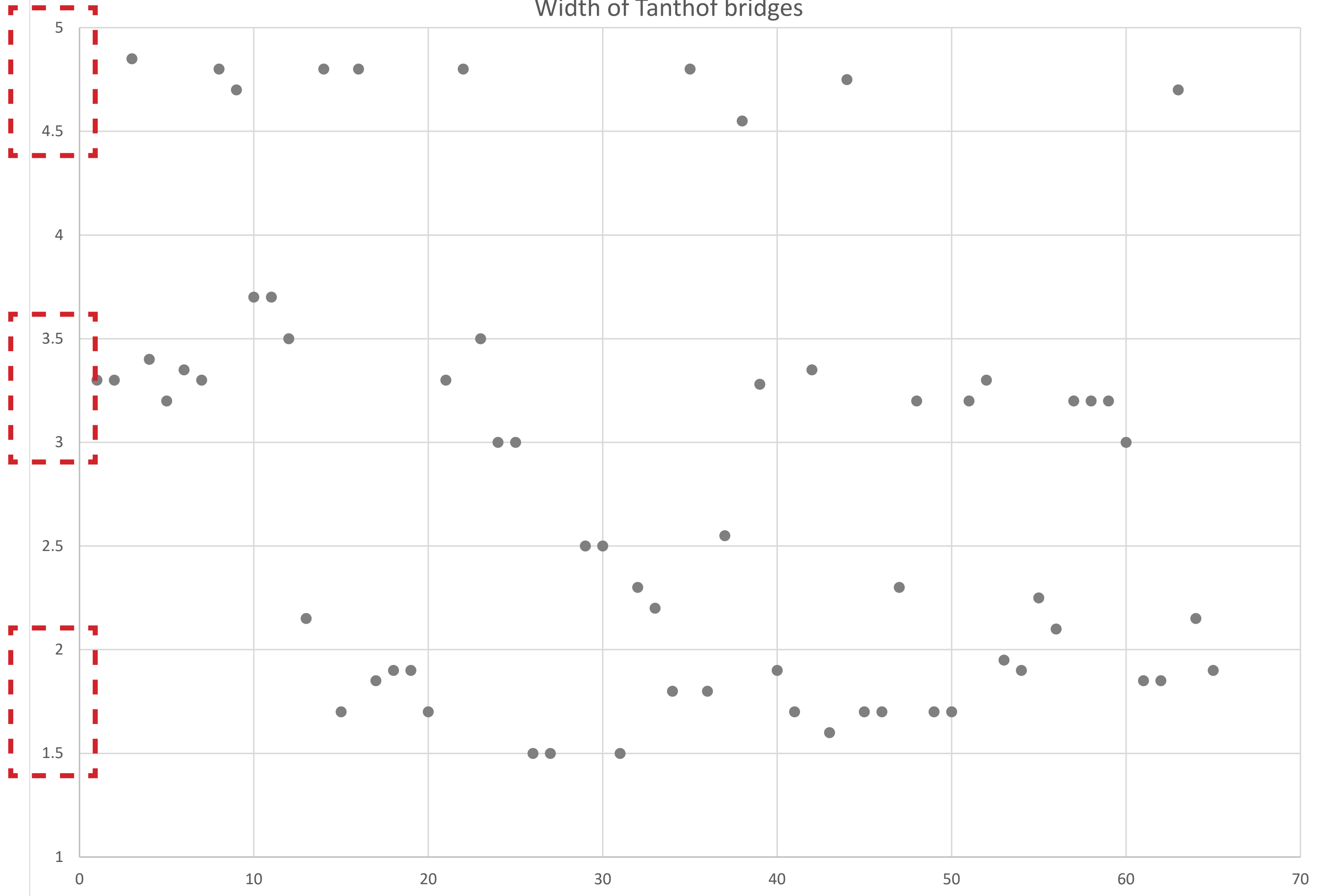
## *Design limitations:*

- *use of conventional material*
- *bridge dimensions suitable for Tanthof*
- *no height difference*
- *examined on one load case*



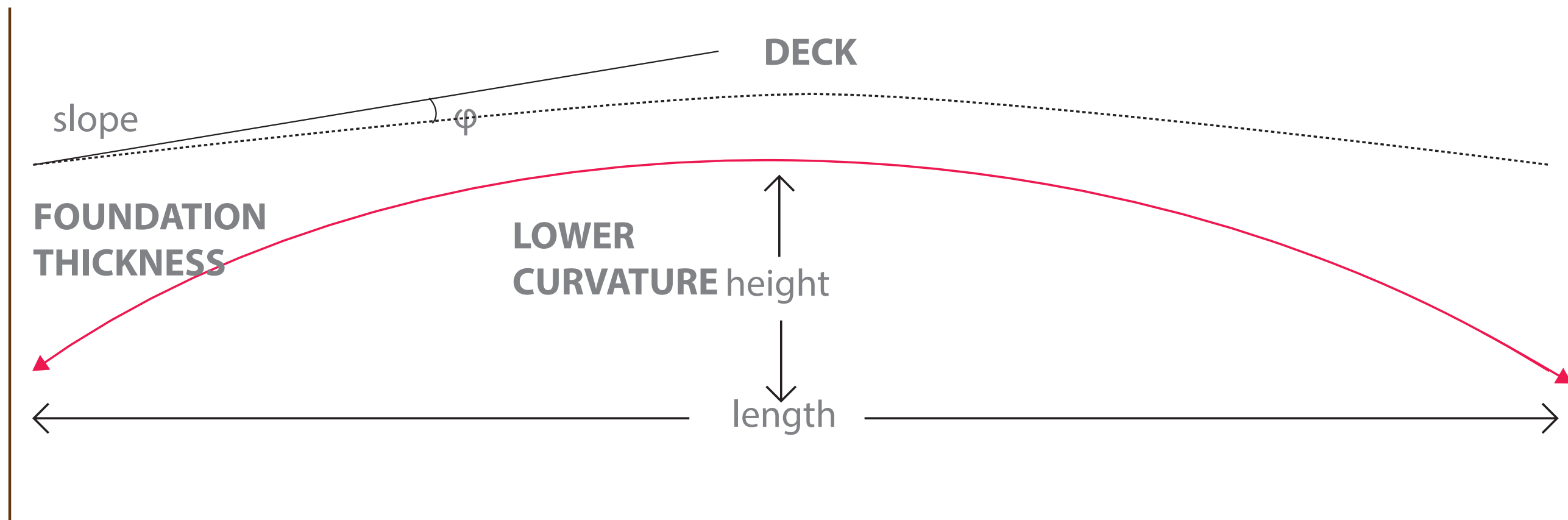


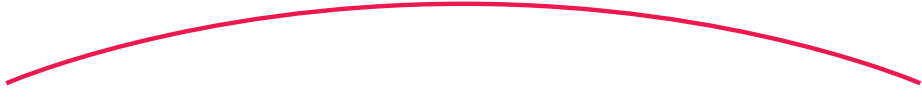
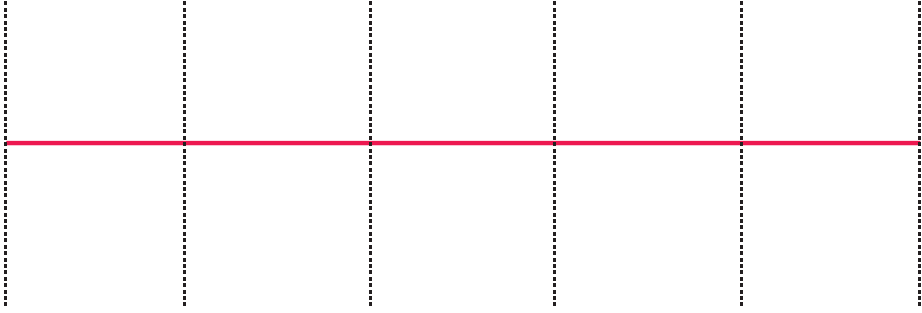
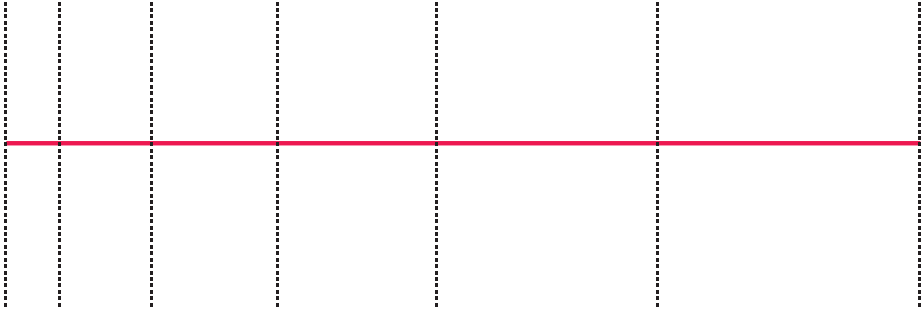
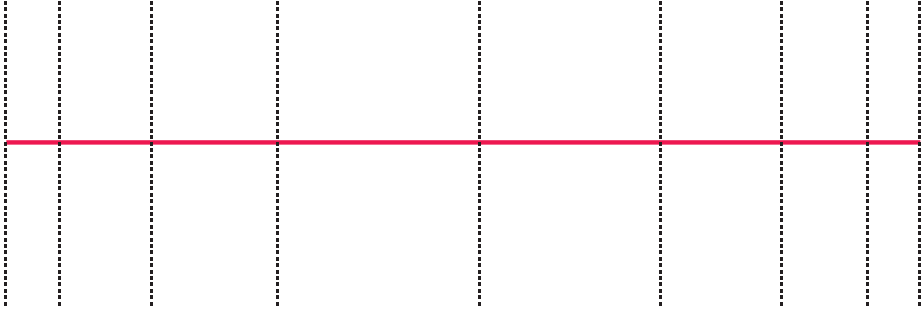
Width of Tanthof bridges



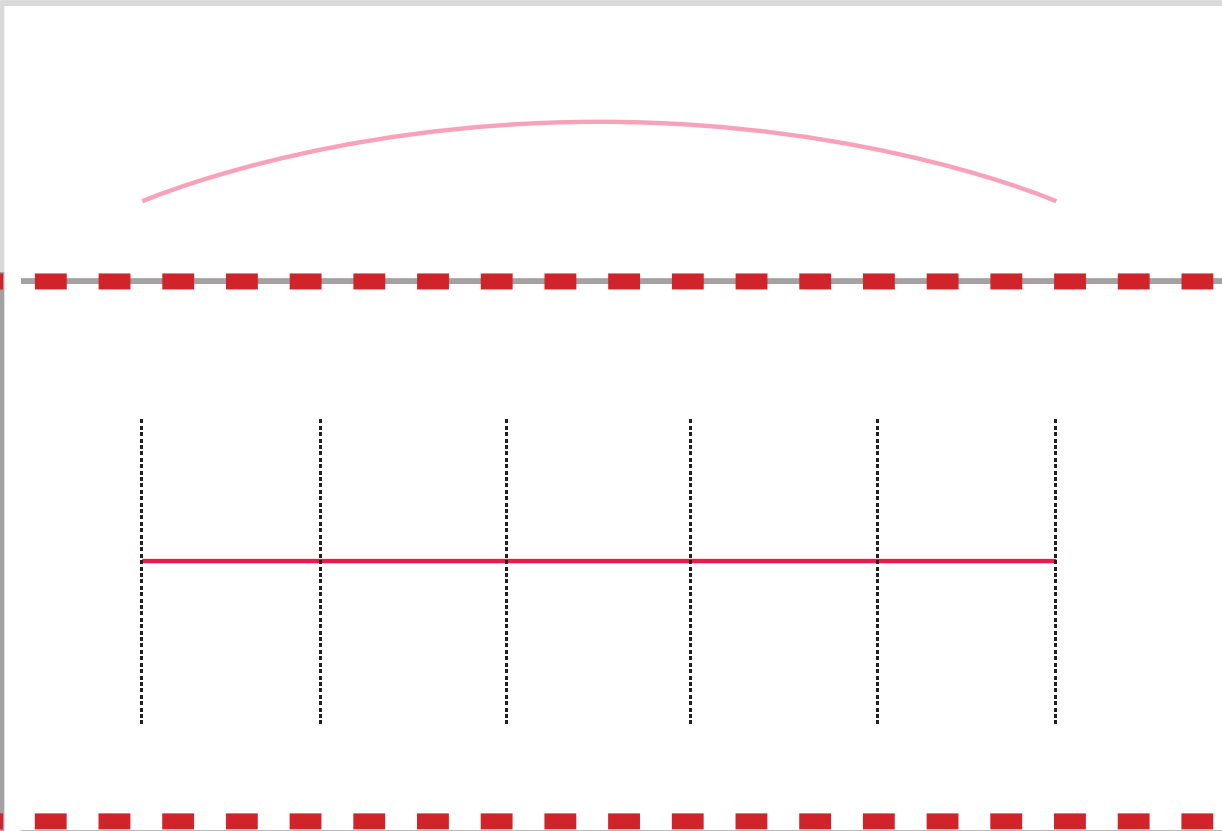

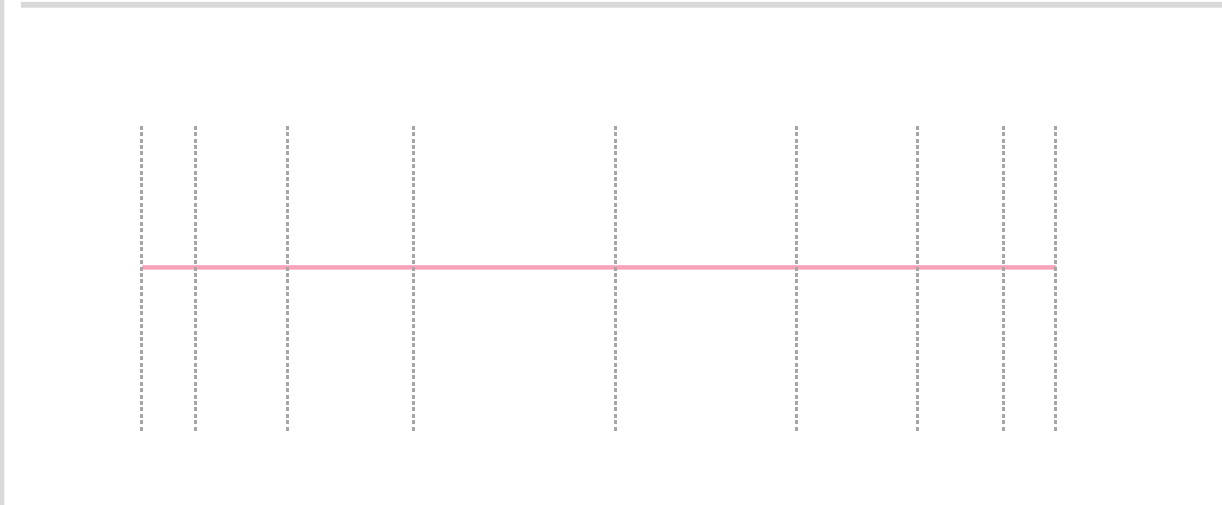


1 mould ..... bridge series

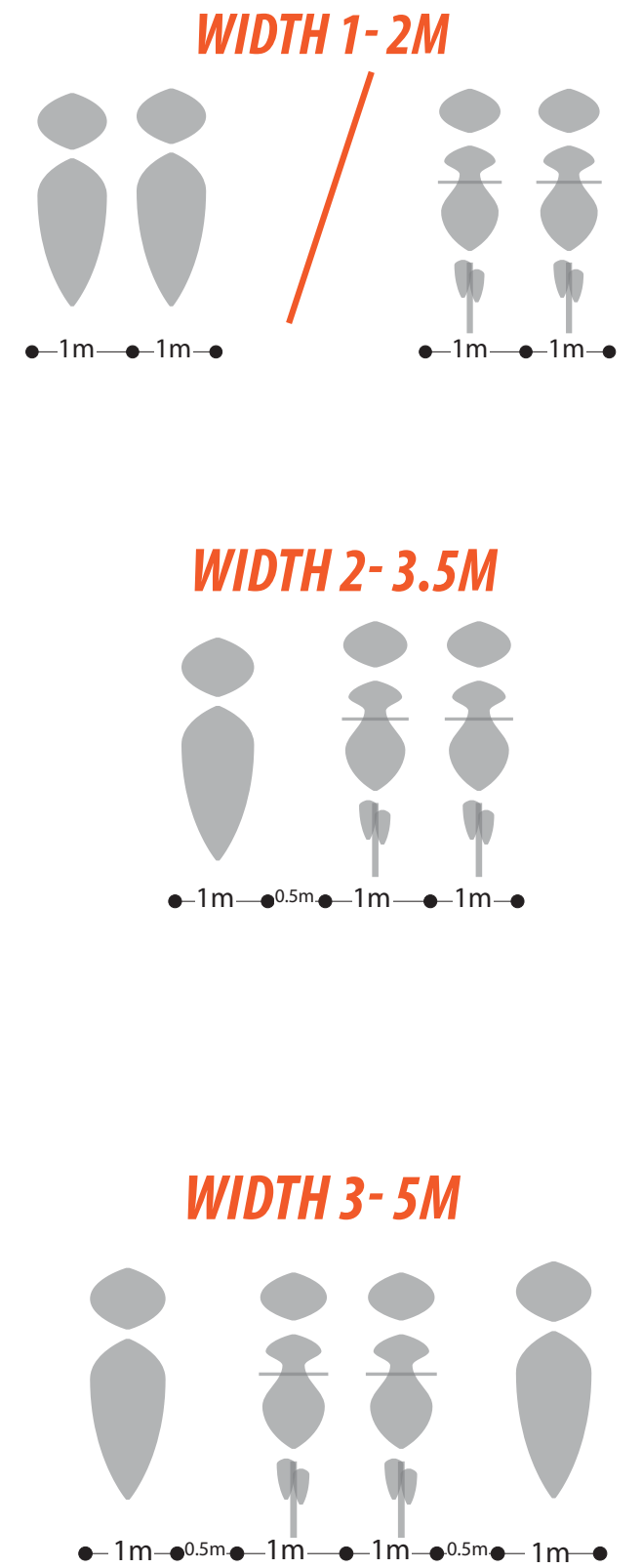
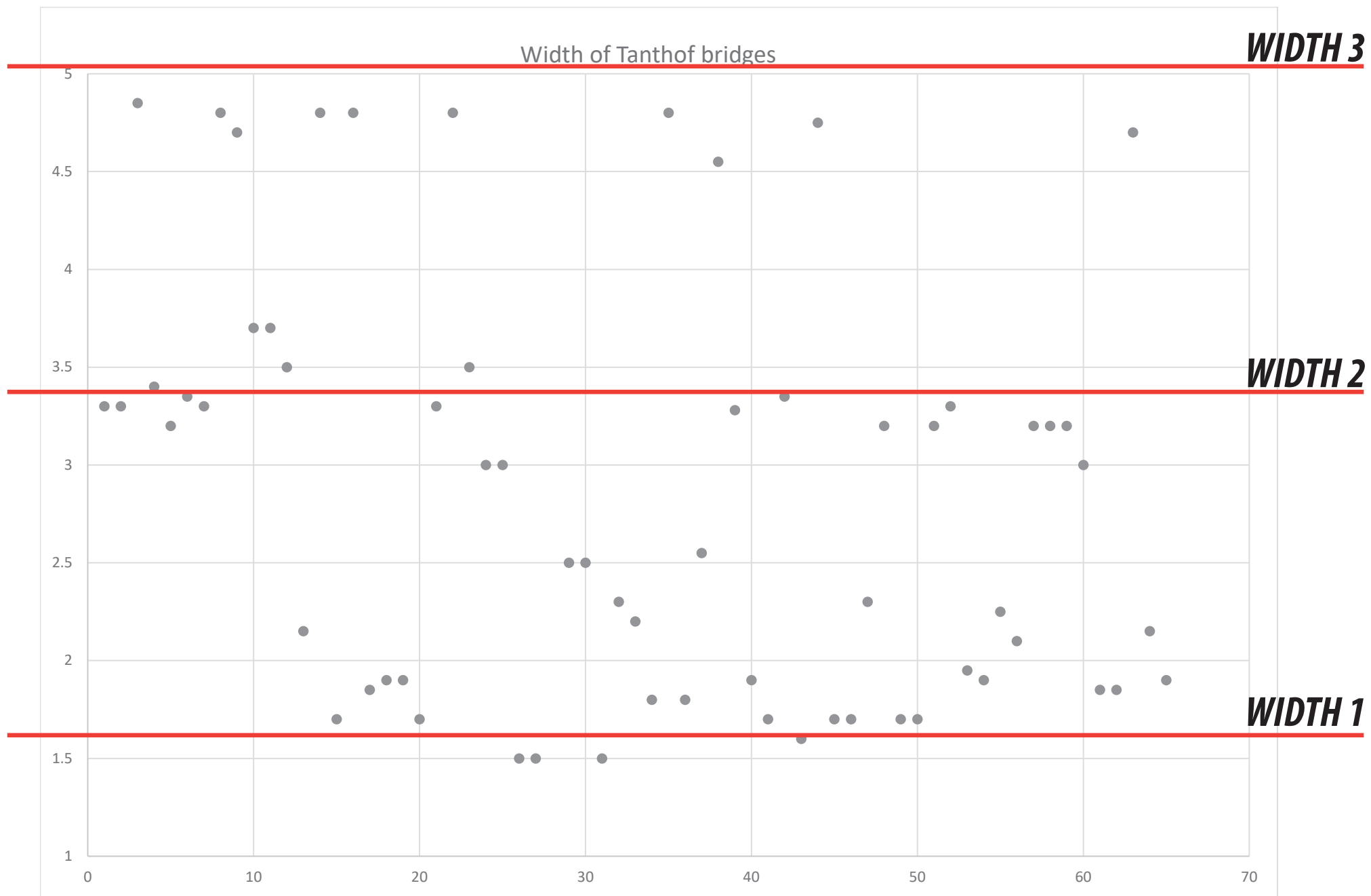


	CRITERIAS	RESULT
	possible length expansion less modules possible	
	fixed length more modules	
	fixed length more modules	



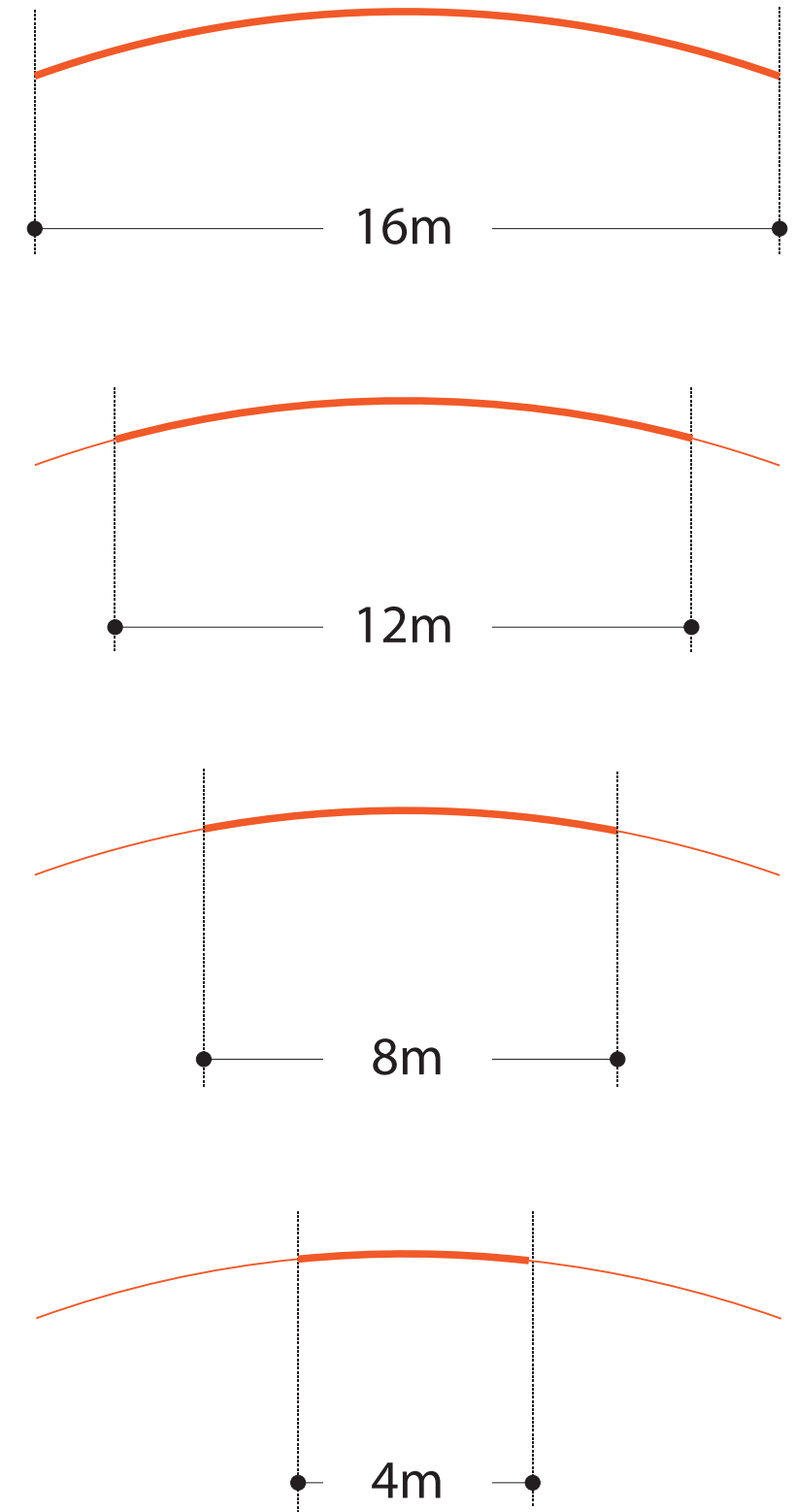
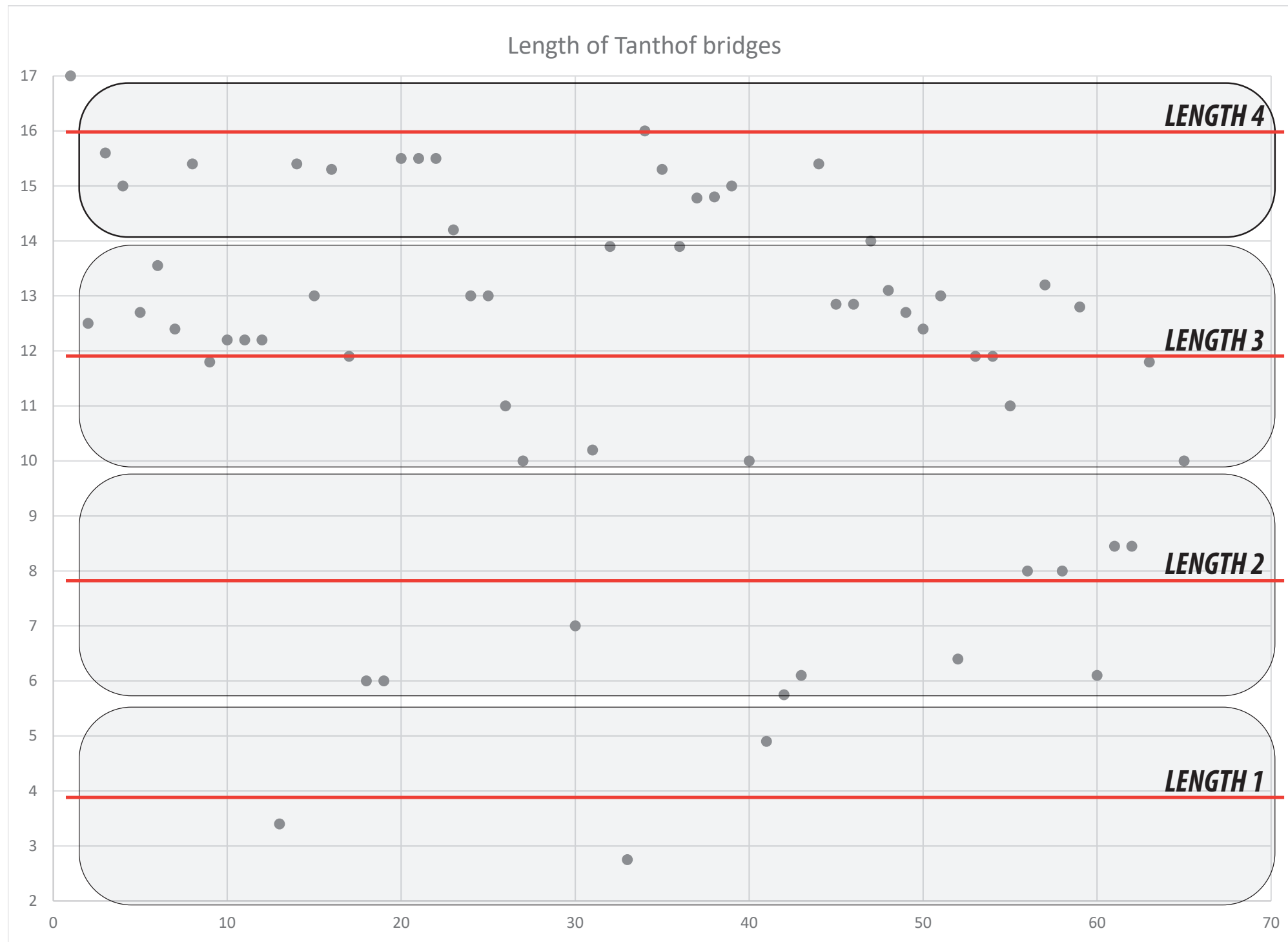
	CRITERIAS	RESULT
	possible length expansion less modules possible	+
	fixed length more modules	-
	fixed length more modules	-

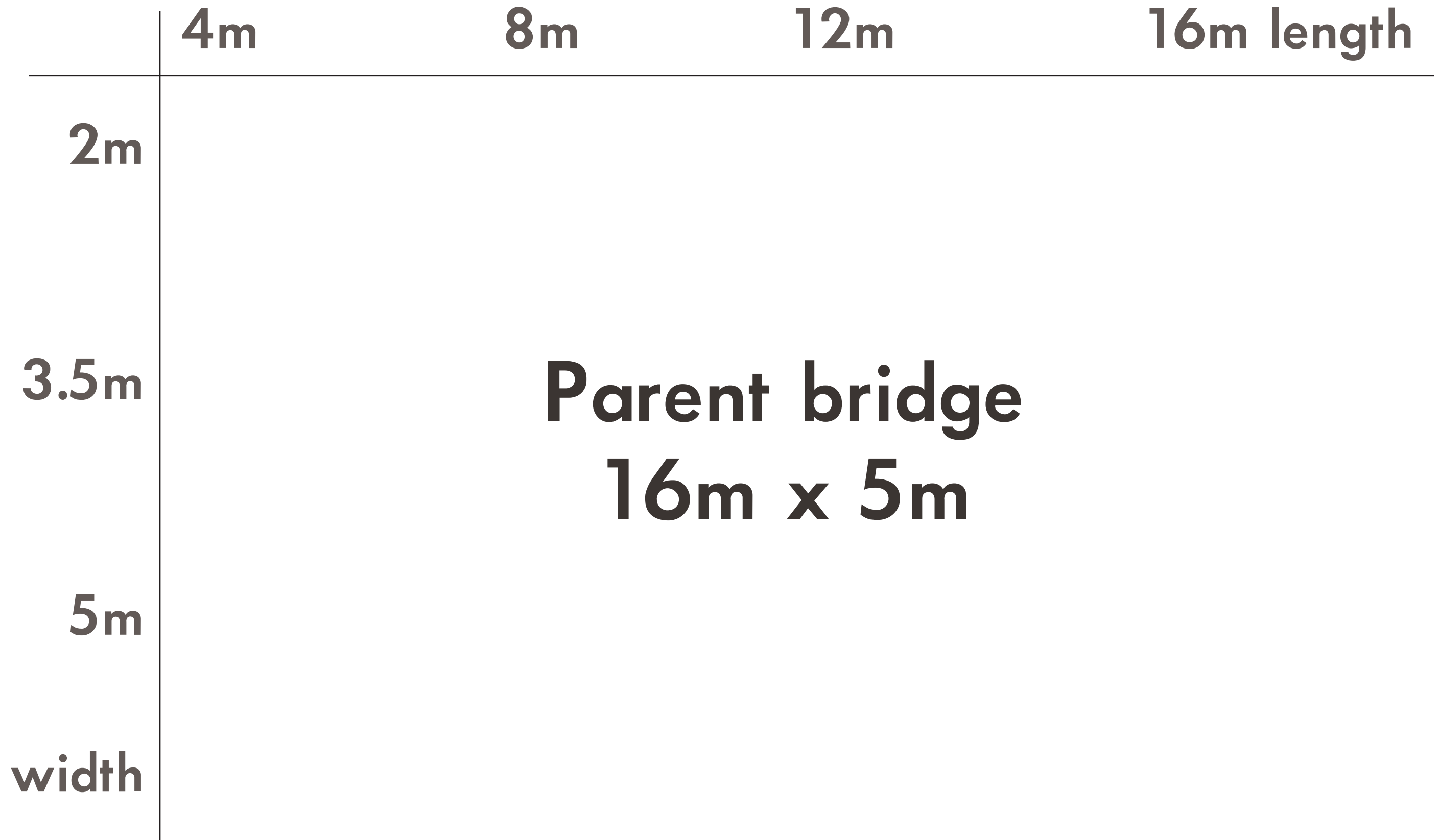
# Modular design



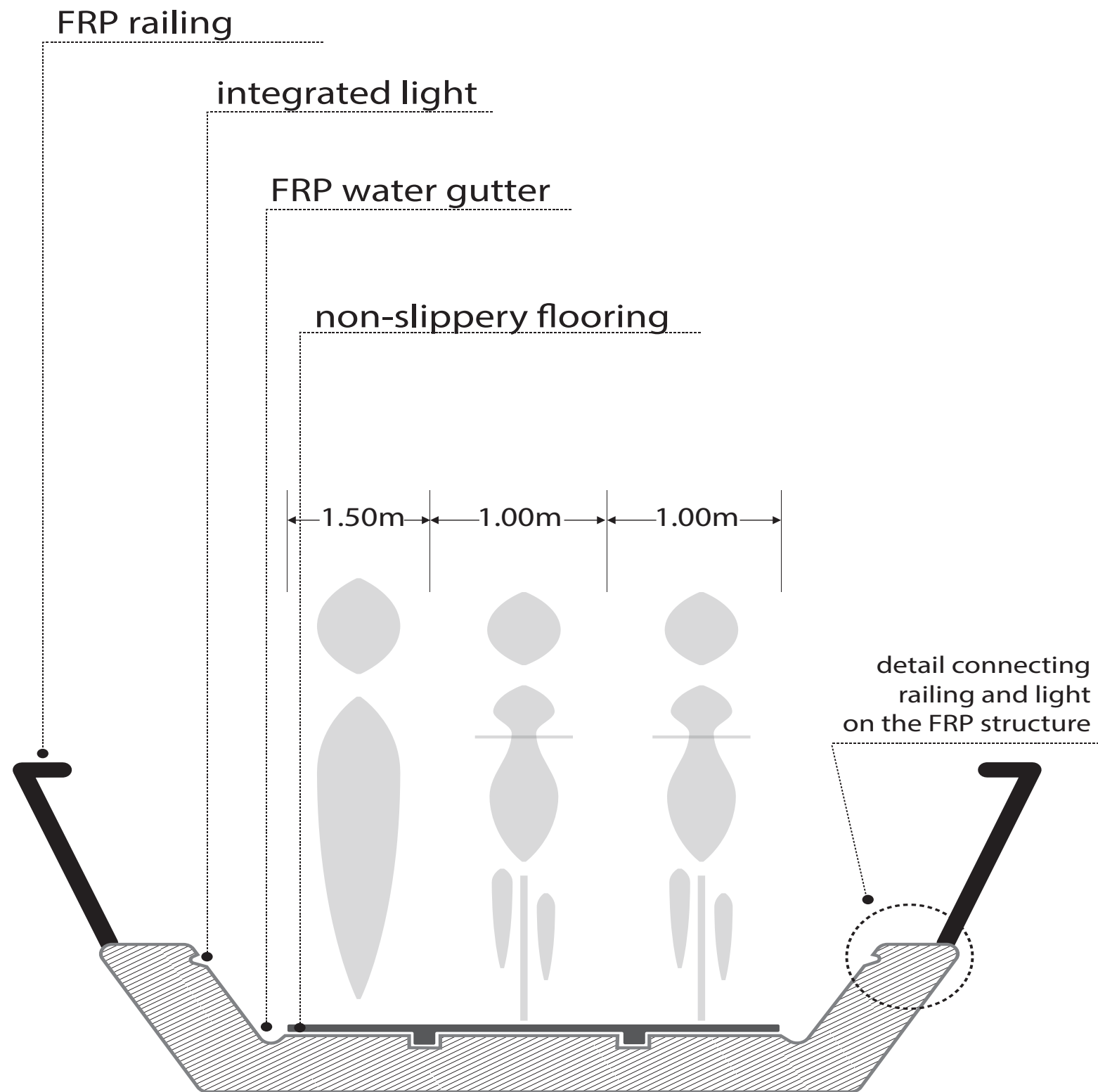


# Modular design

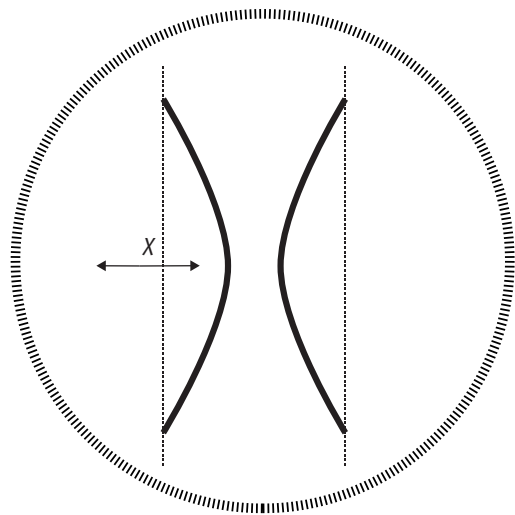




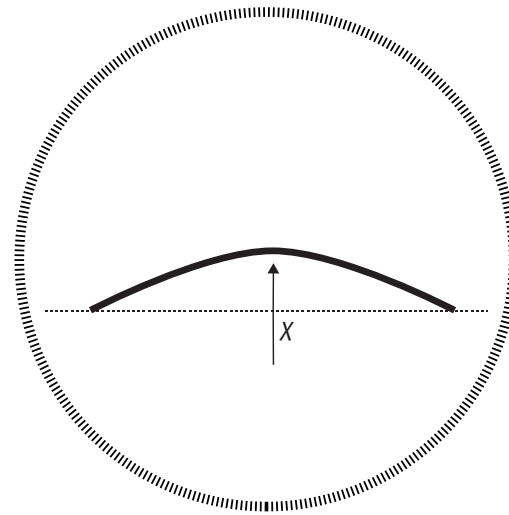




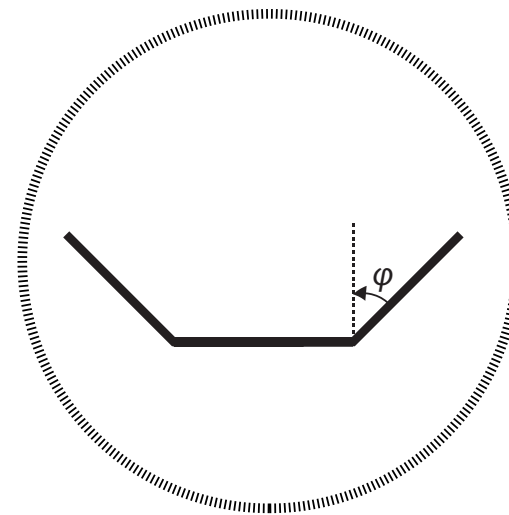
## GEOMETRICAL VARIABLES



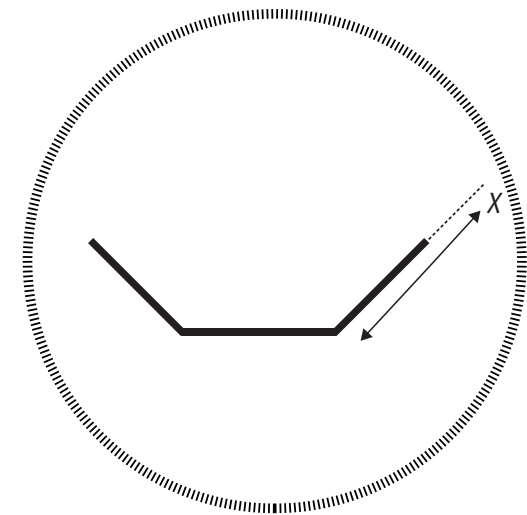
plan curve



side curve

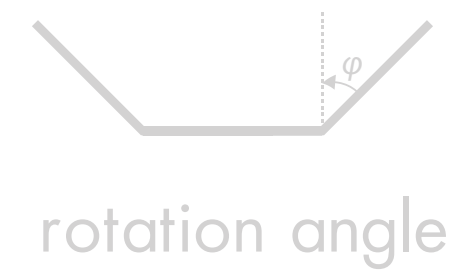
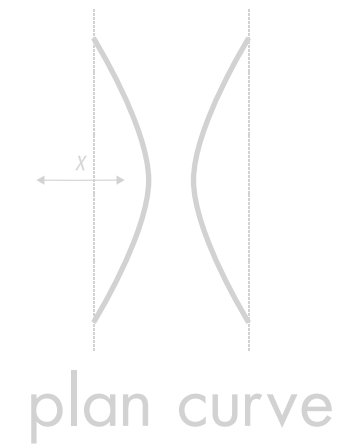
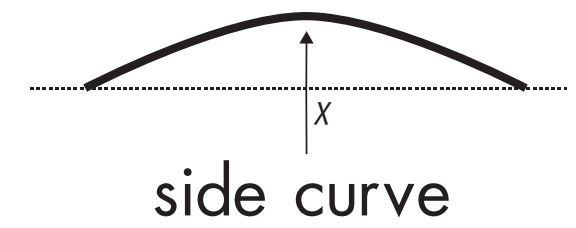
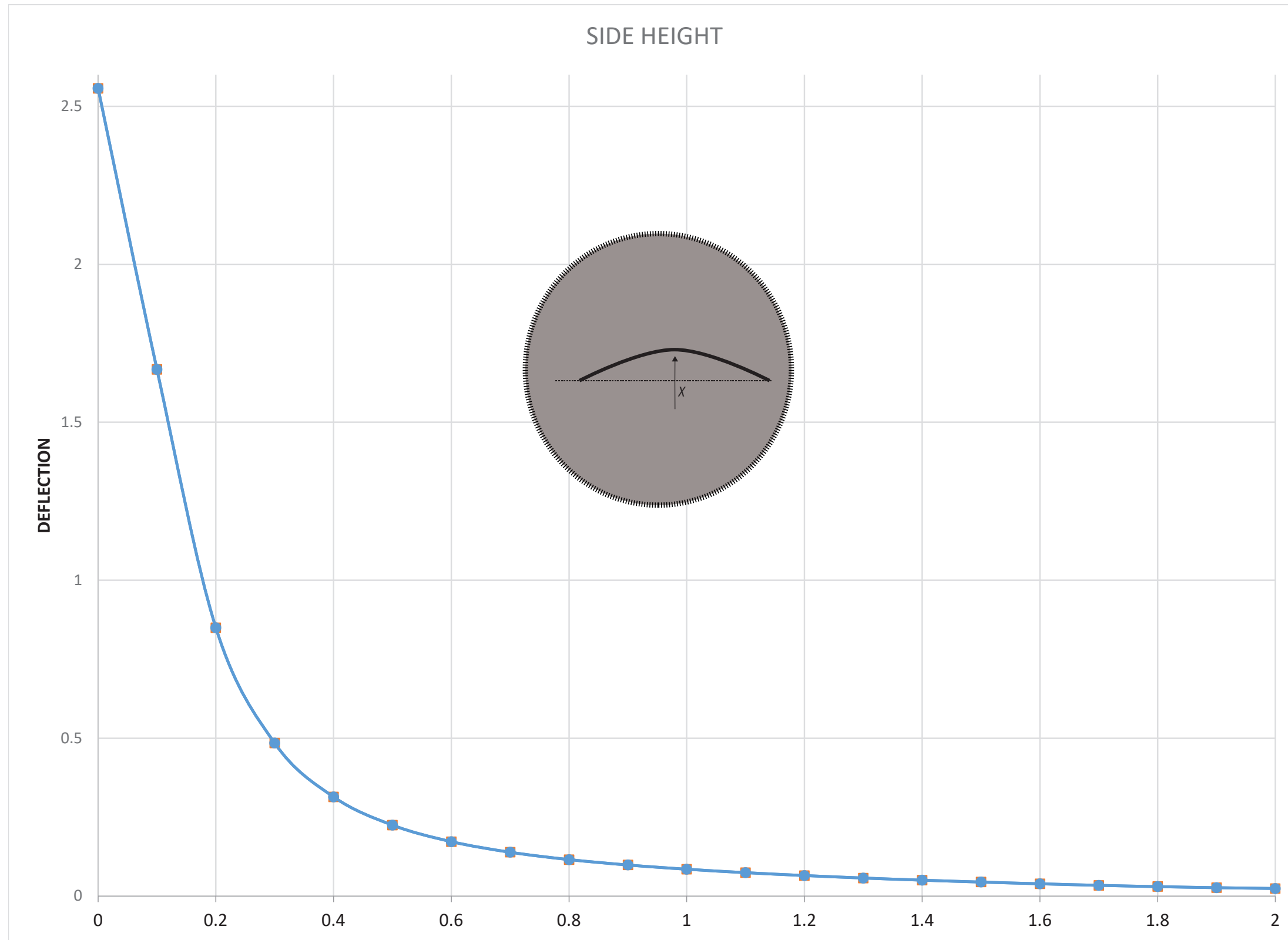


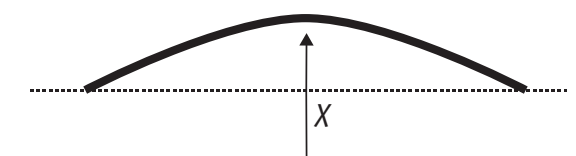
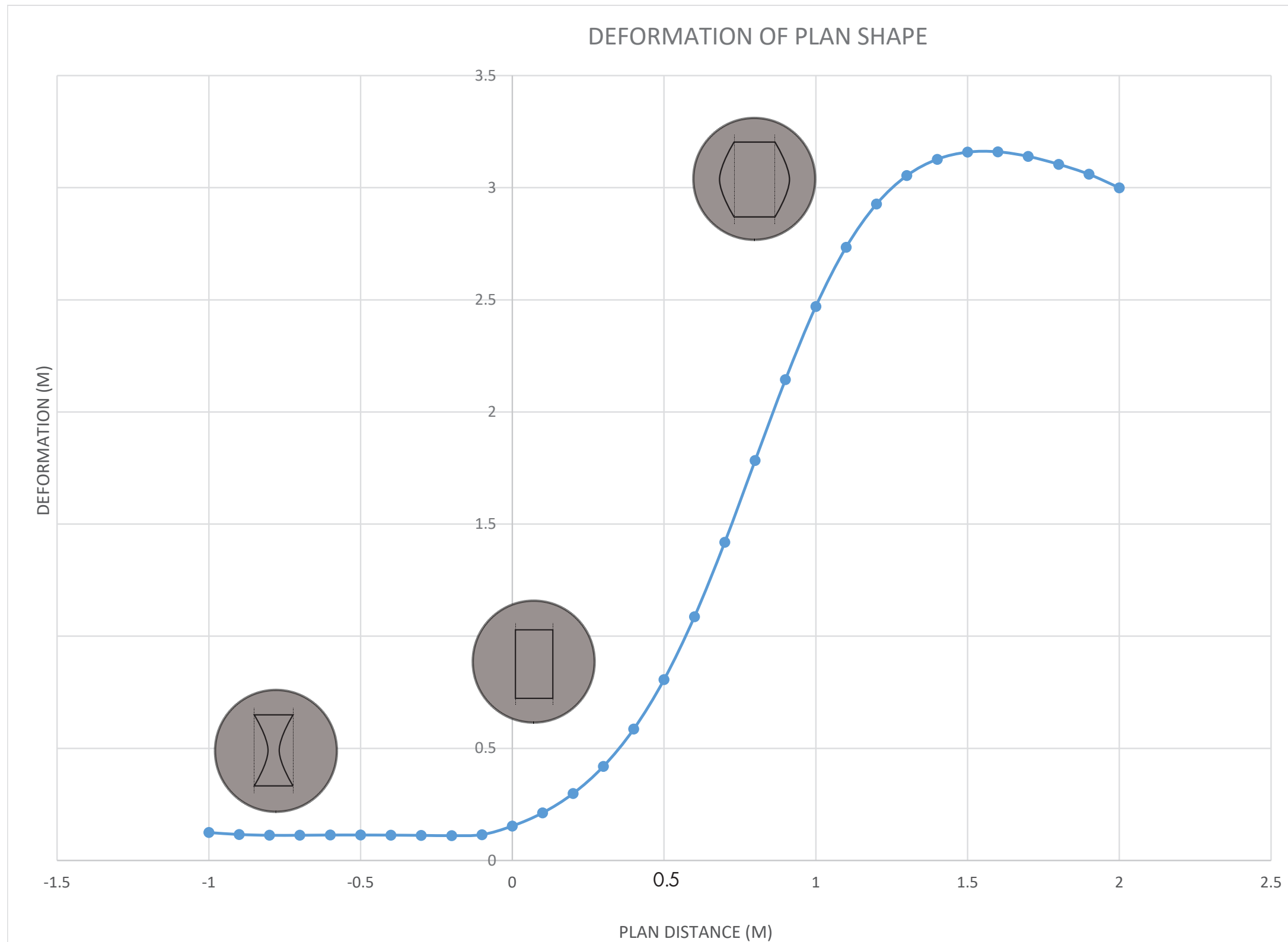
rotation angle



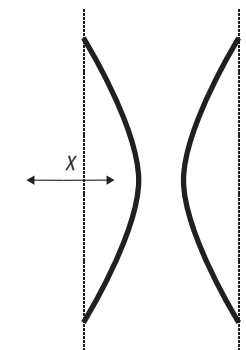
flange height







side curve



plan curve

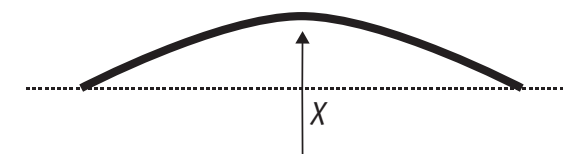
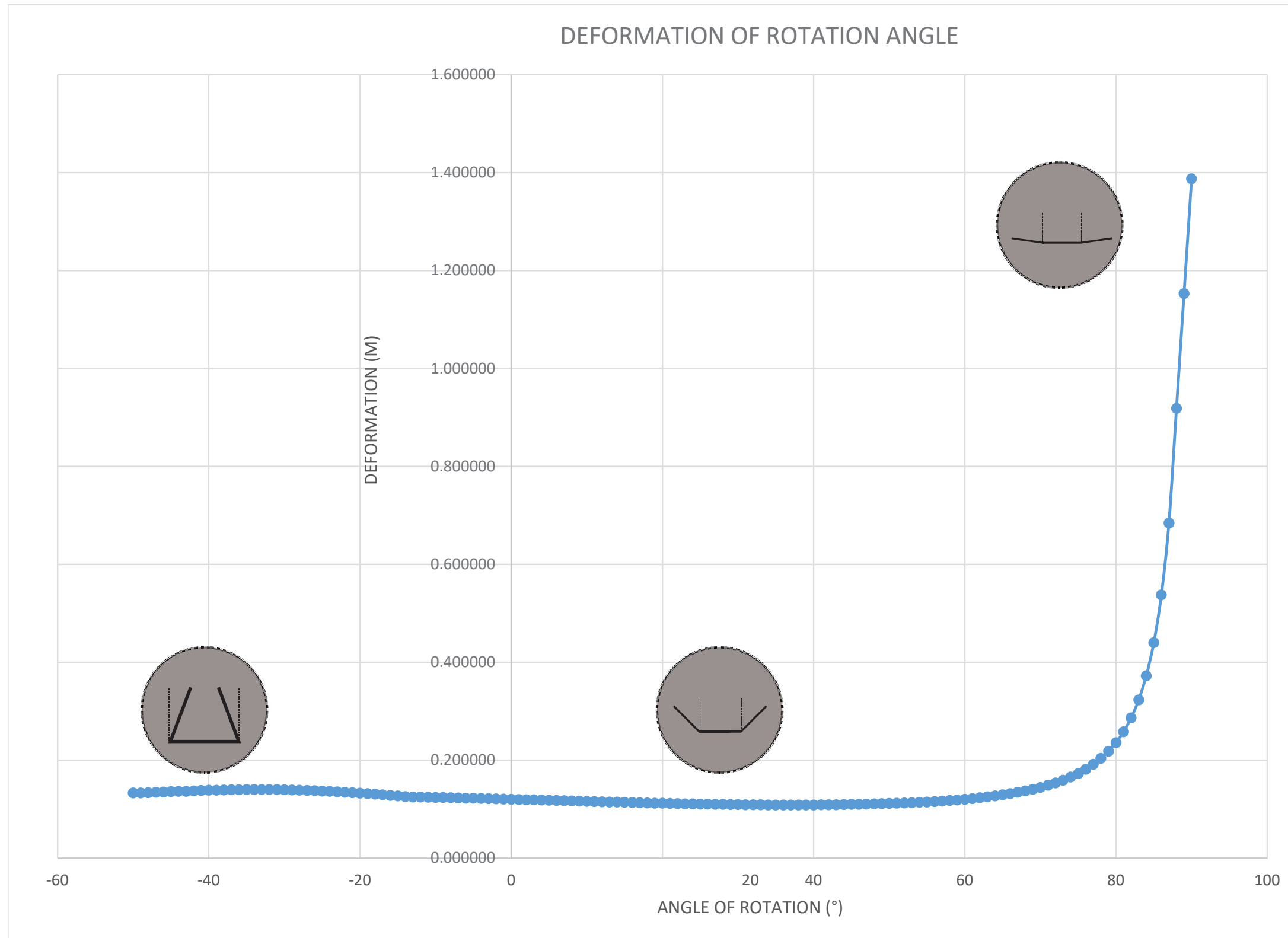


rotation angle

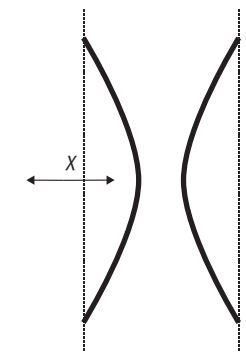


flange height





side curve



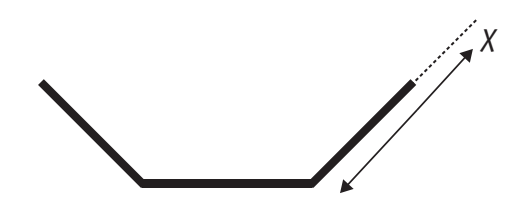
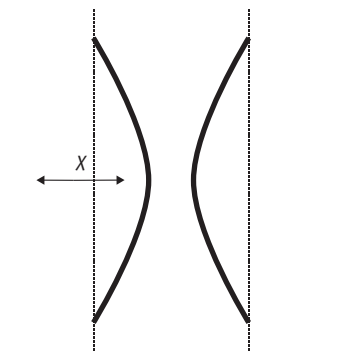
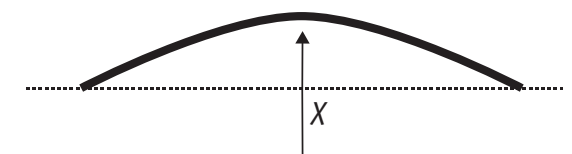
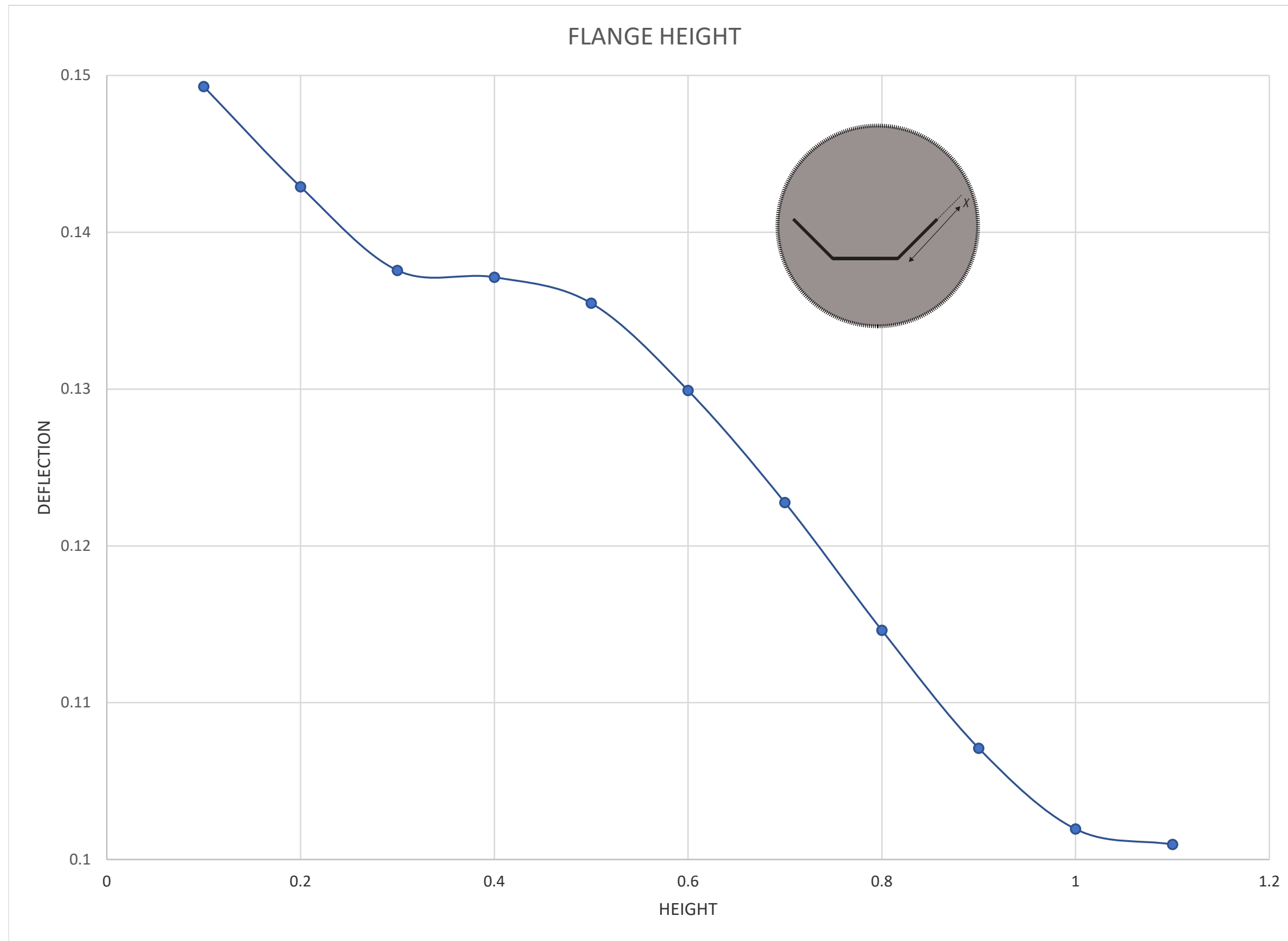
plan curve



rotation angle



flange height

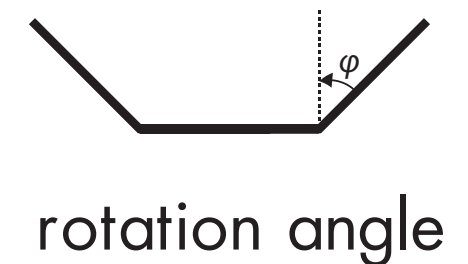
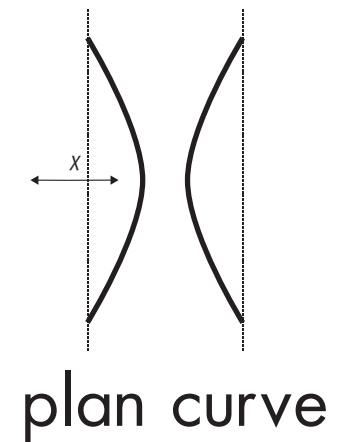
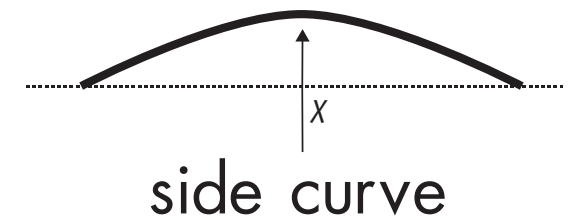




## CONCLUSIONS

Important aspects of the shape:

- Curved side shape
- Negative plan curvature
- Existence of flange
- Flange height

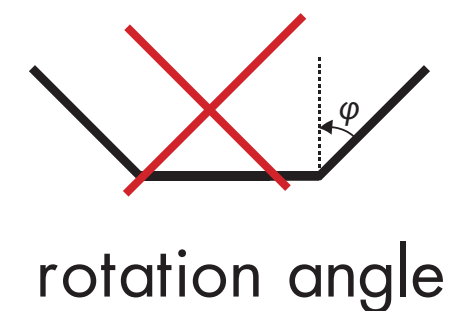
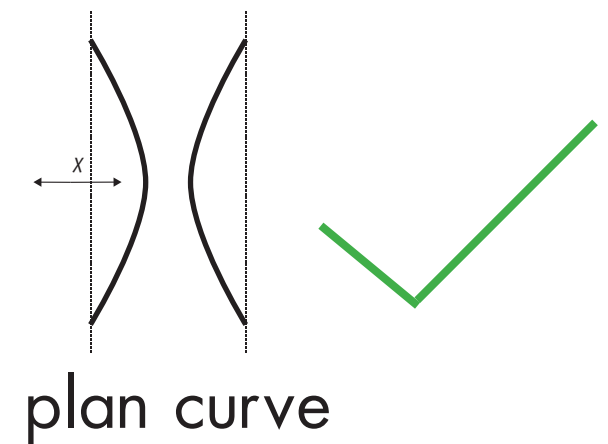
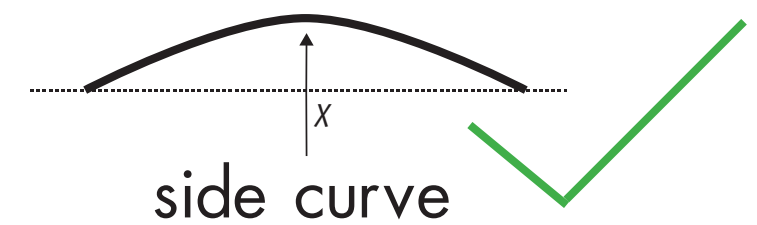


## CONCLUSIONS

Important aspects of the shape:

- Curved side shape
- Negative plan curvature
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- Flange height

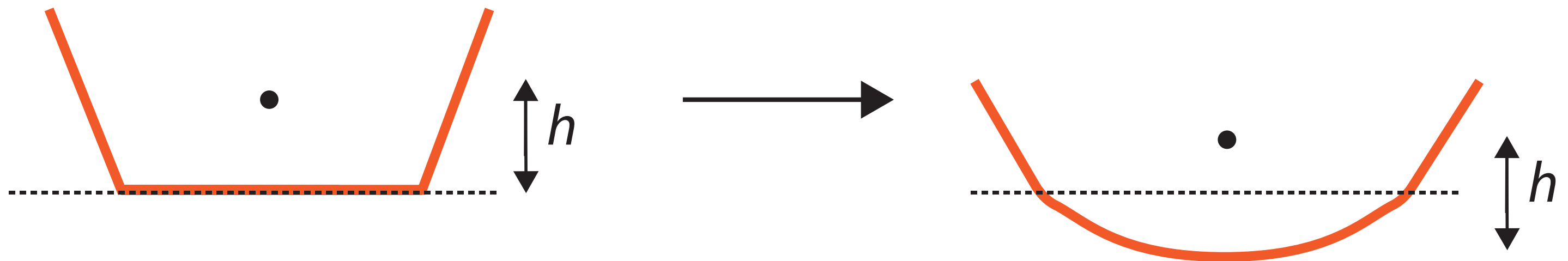
*structural railing*

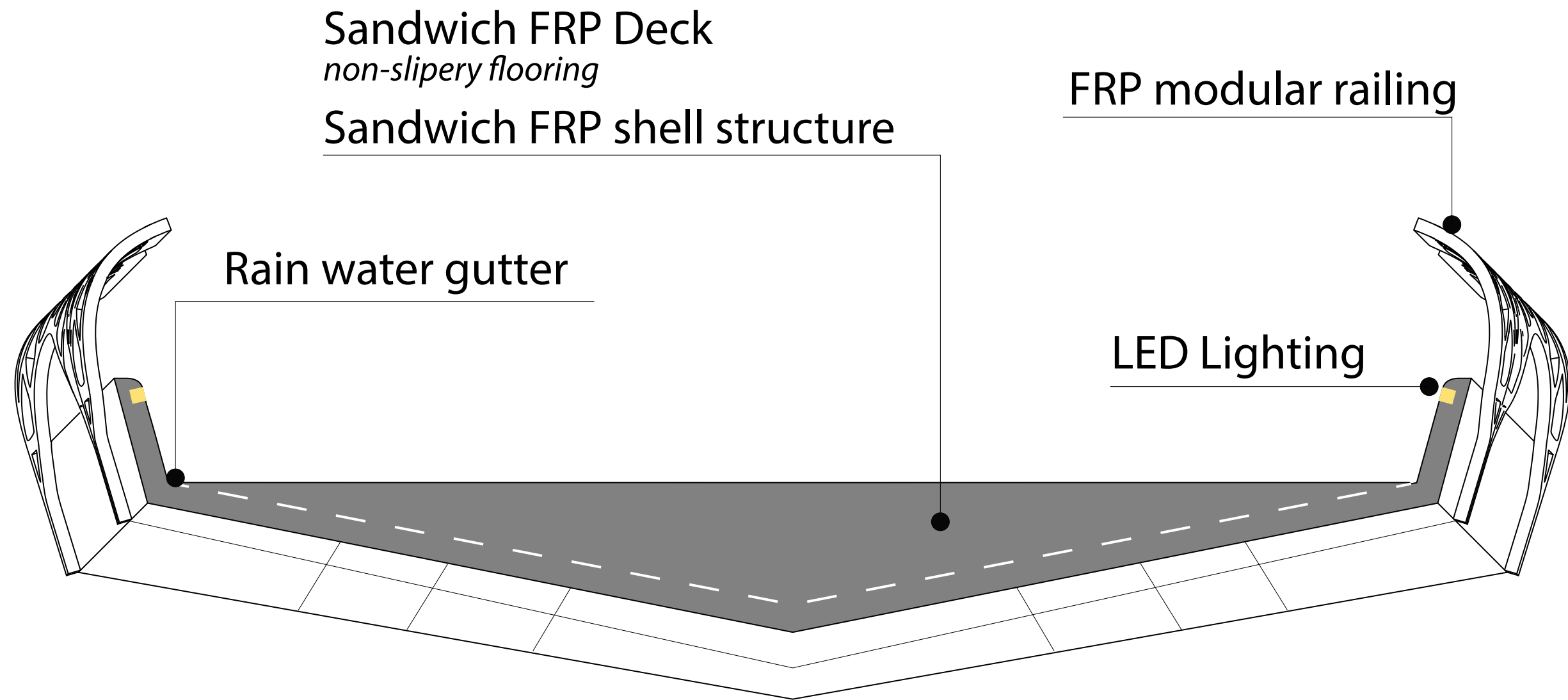




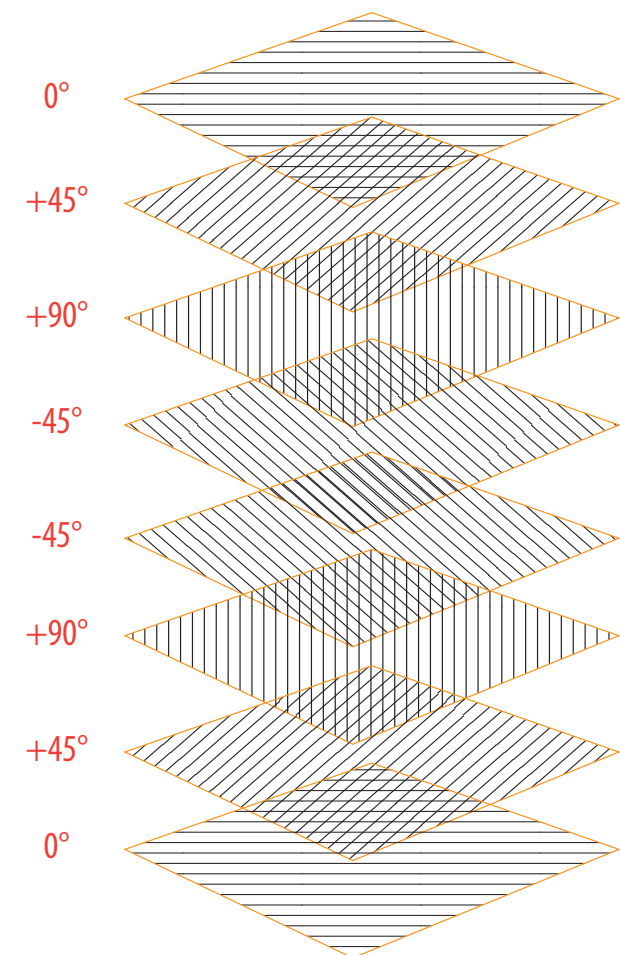
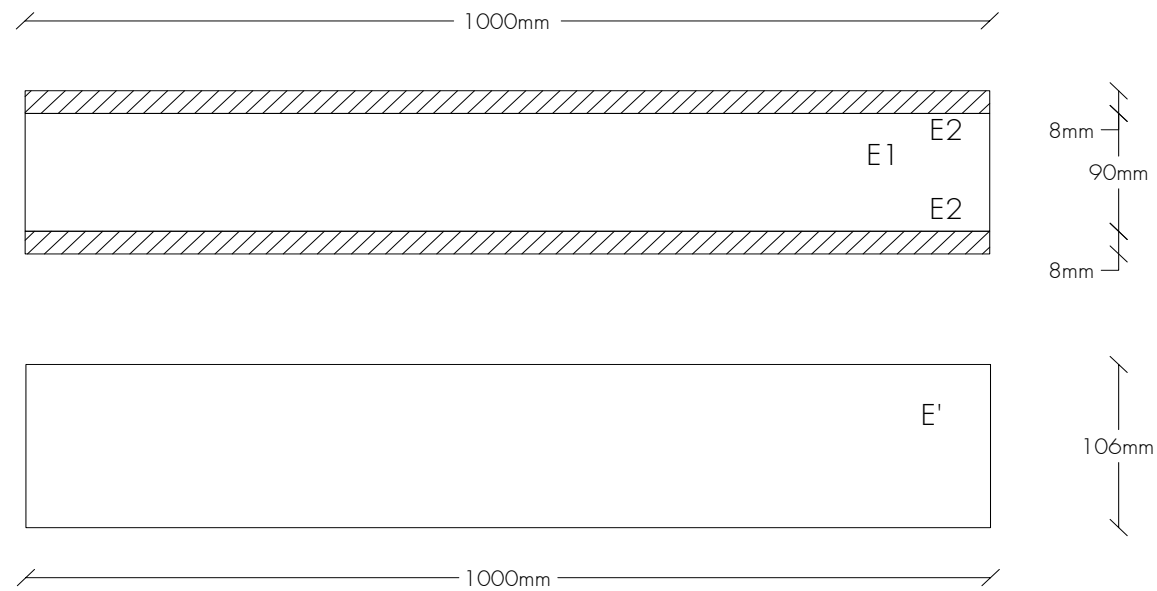
## EQUIVALENT STRUCTURAL HEIGHT

$$I = (1/12) * b * h^3$$









$$I_i = \left(\frac{1}{12}\right) \times (\omega_i \times (h_i^3)) + (A_i \times d_i^2)$$

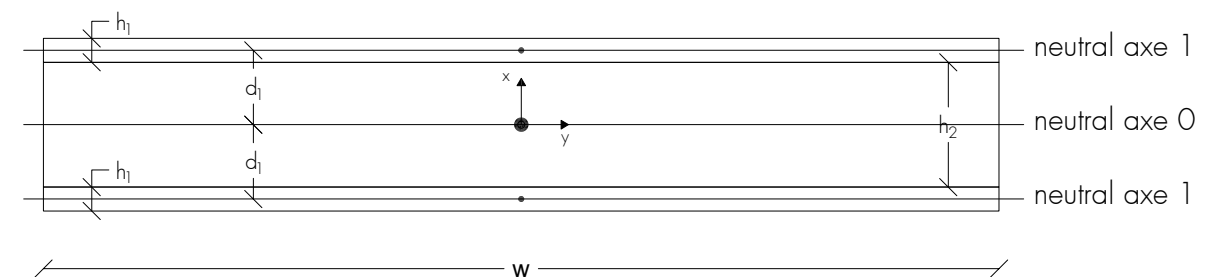
$$E_0 * I_0 = E * I$$

$$E_0 = E * \frac{I}{I_0}$$

$$G_0 = \frac{E_0}{2 \times (1 + \nu_0)}$$

Resin epoxy polymer  
 +  
 E-glass fibres  
 +  
 PVC cross-linked foam  
 =  
 new sandwich FRP material

**I= 0.019 m4**  
**E= 15.86 GPa**  
**G= 6.95 GPa**

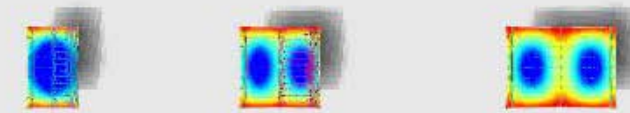


# Bridge design

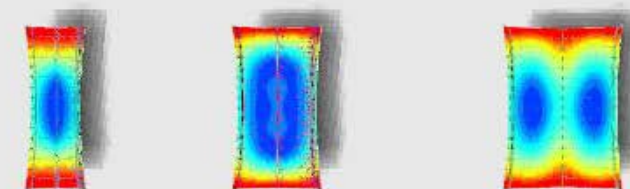
maximum deformation:  
**7mm < 53mm (1/300)**

width 2m    width 3.5m    width 5m

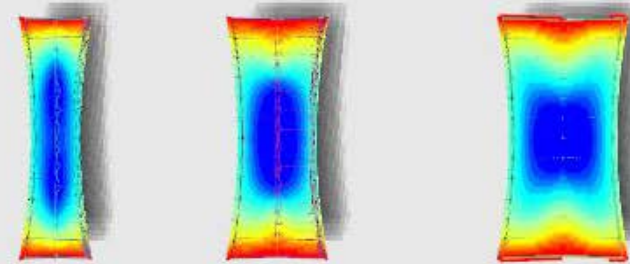
length 4m



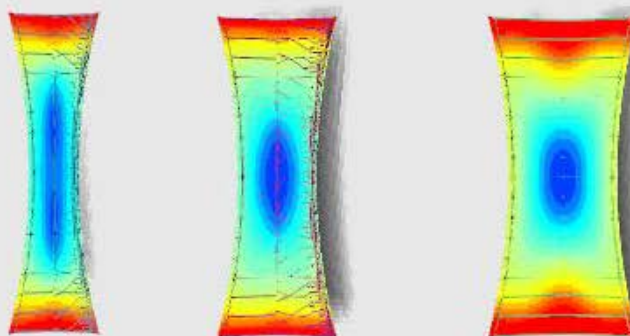
length 8m



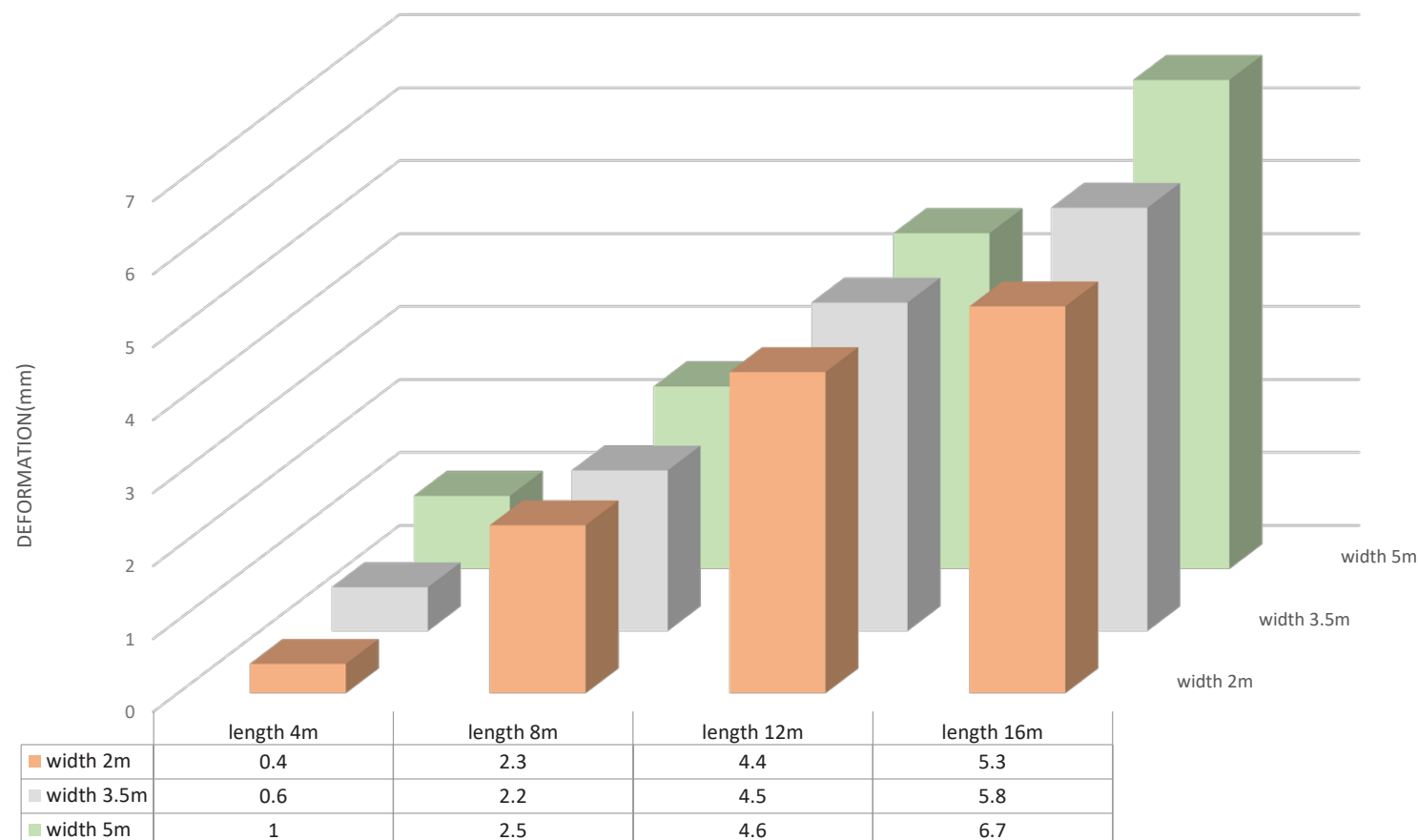
length 12m



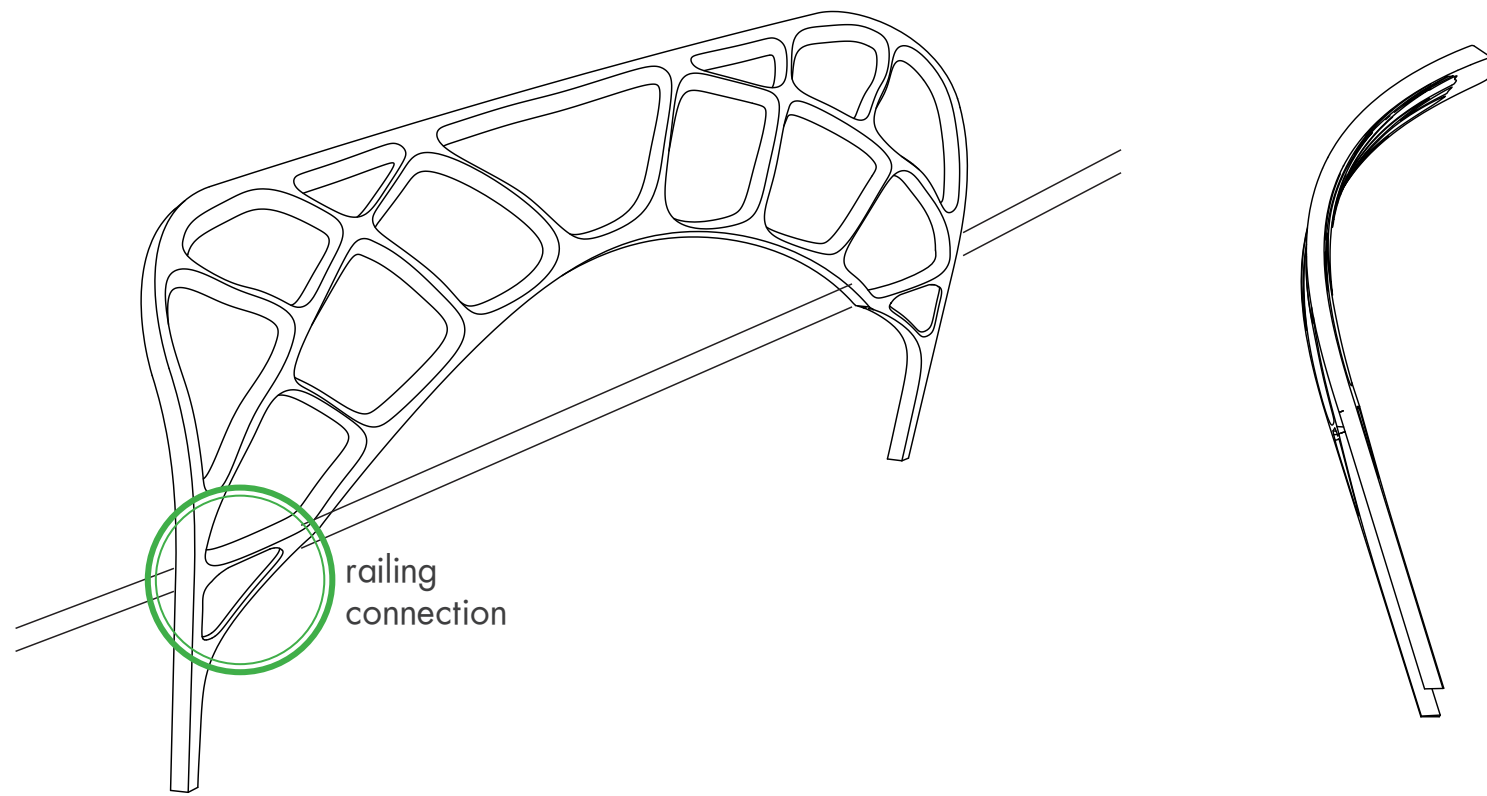
length 16m



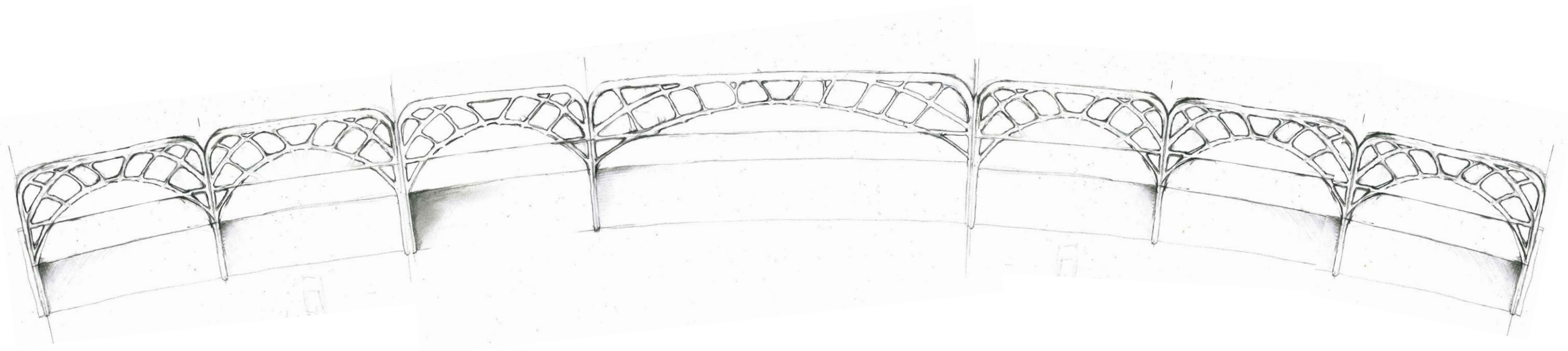
Bridge series deformation





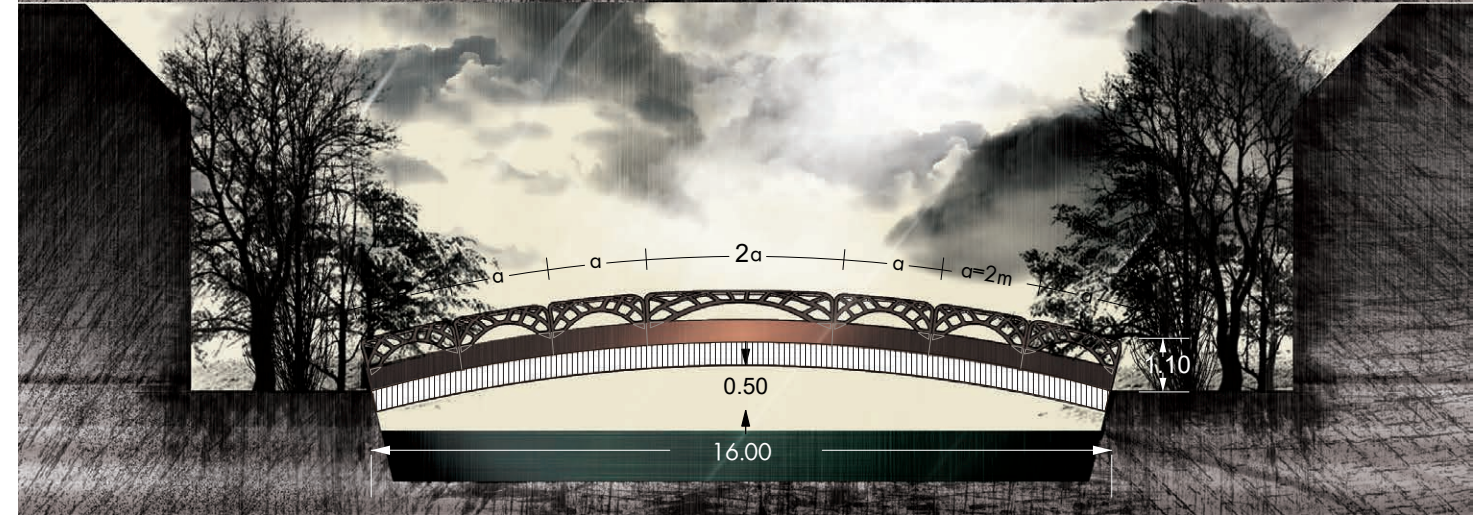
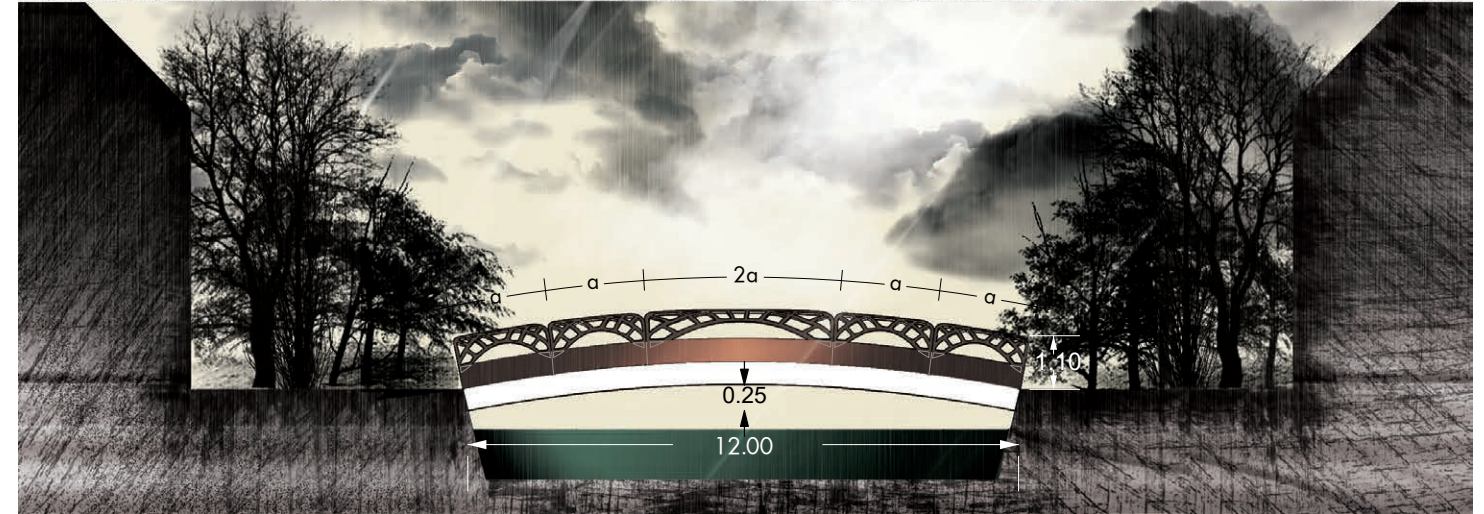
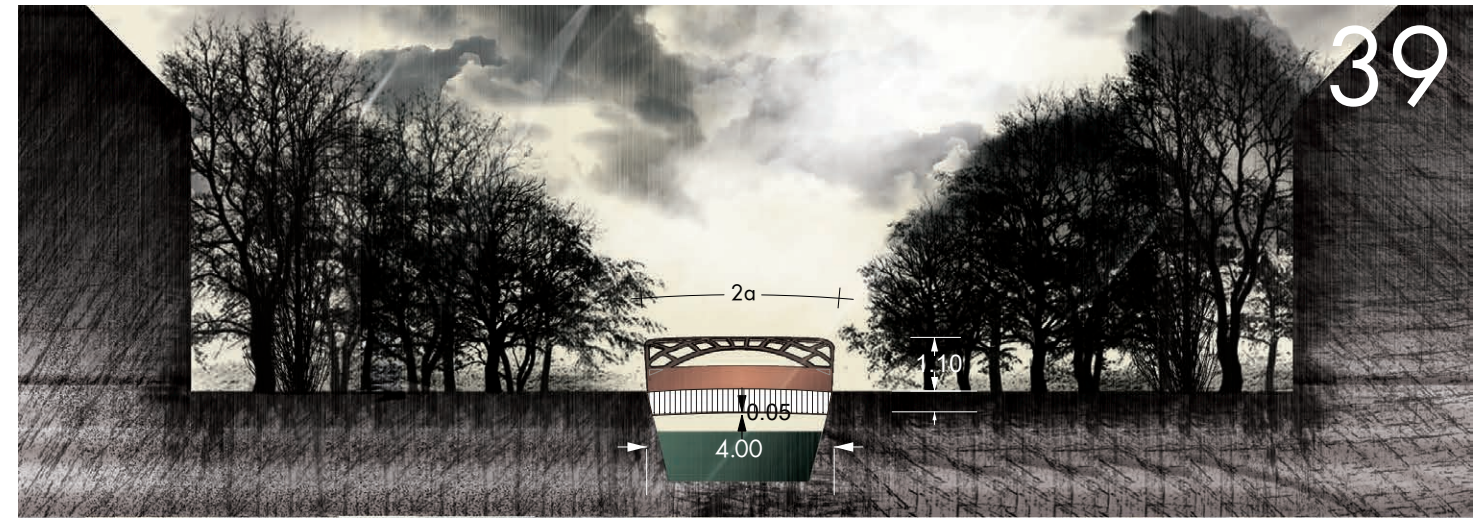


- modular elements
- easy replacement
- max. opening 0.5m diameter
- railing height 1.00 m



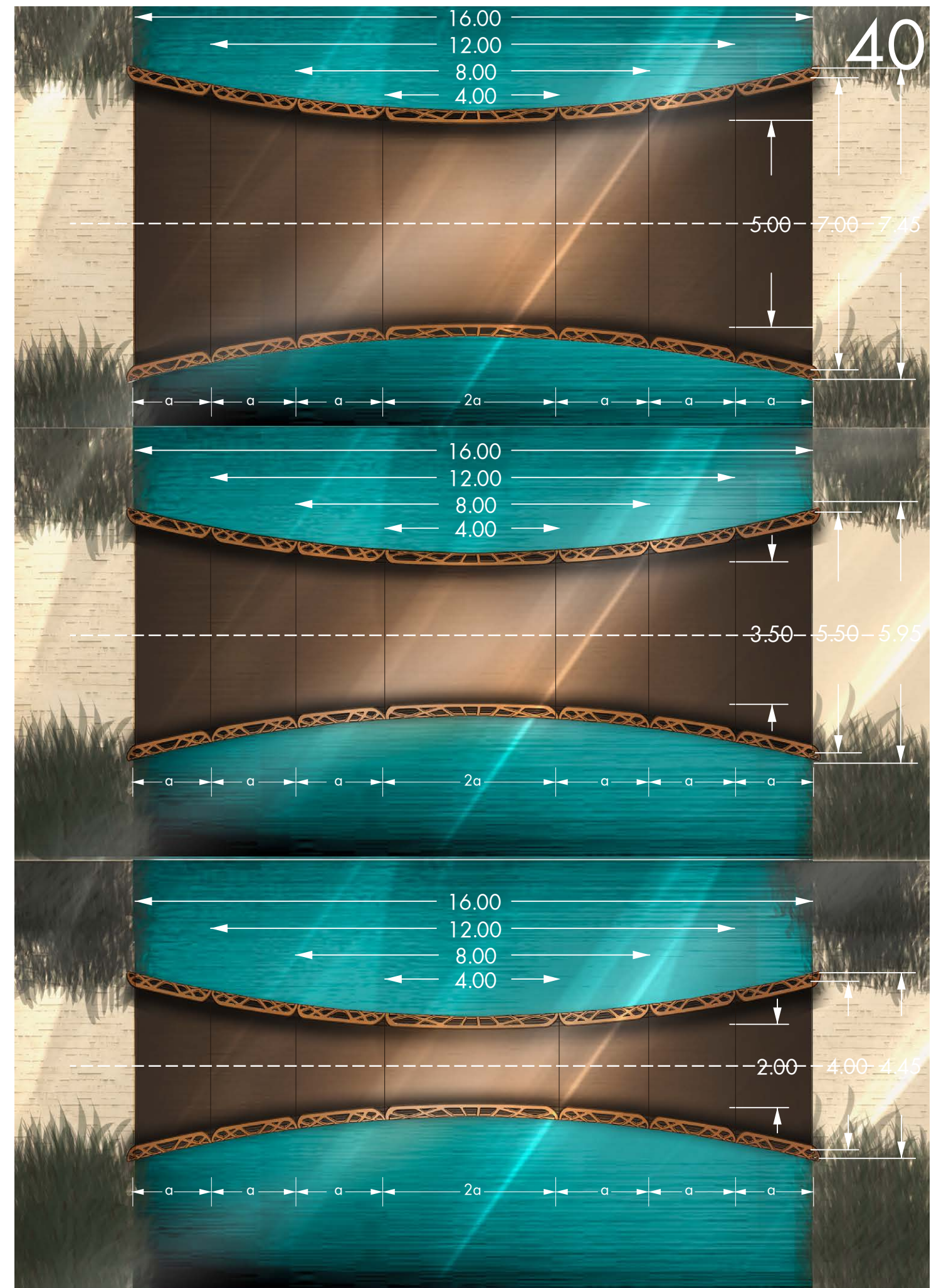
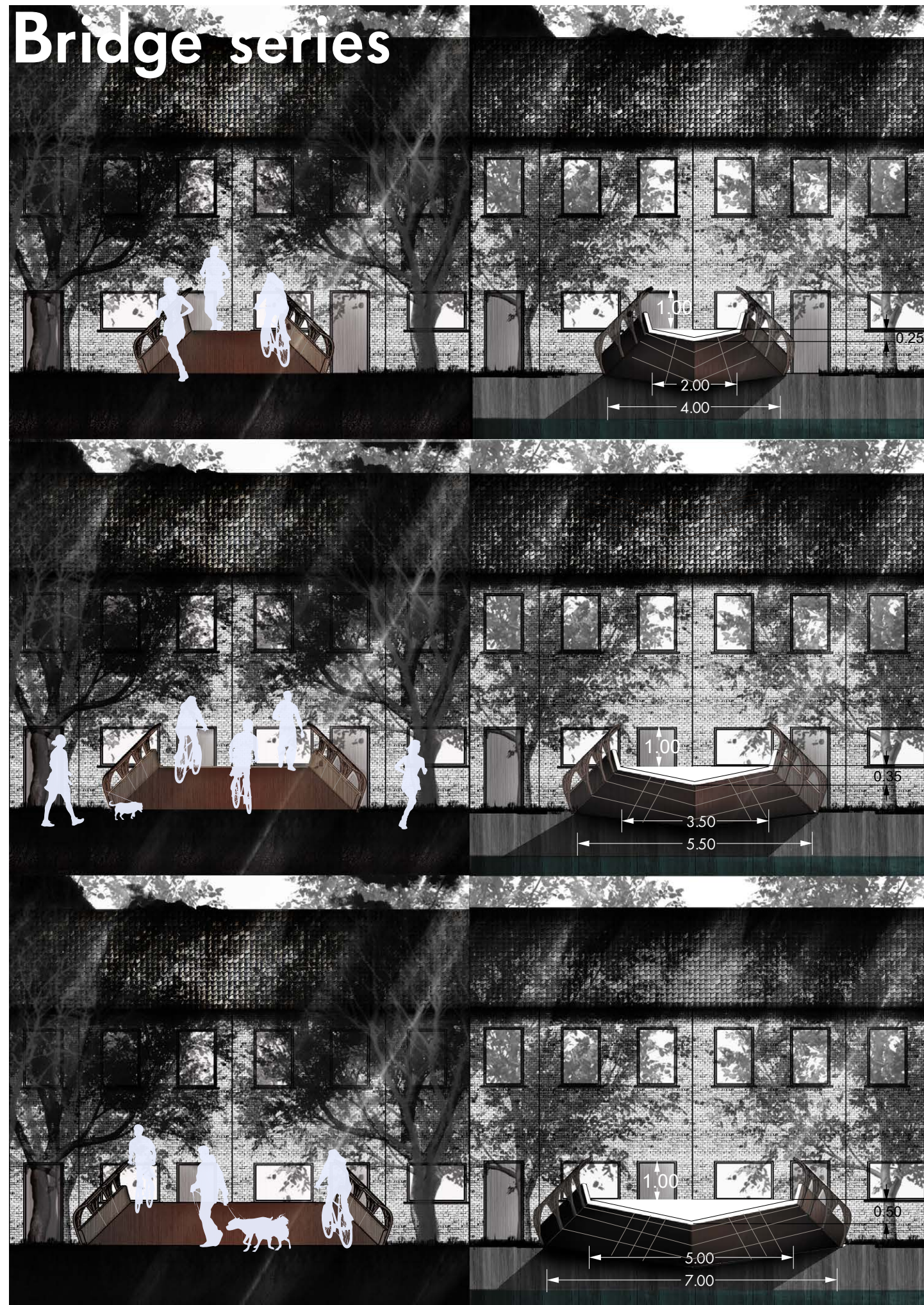


# Bridge series

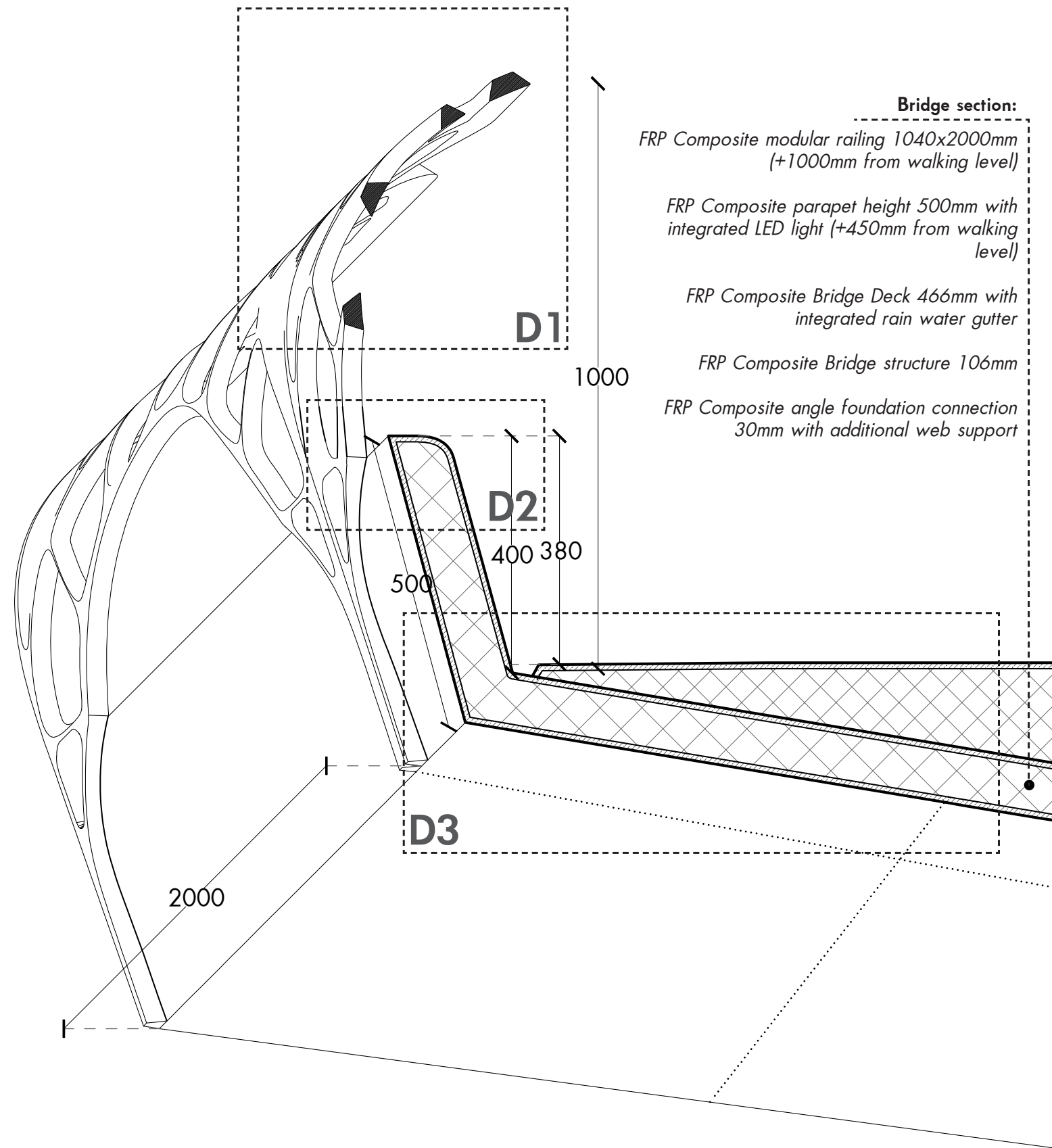




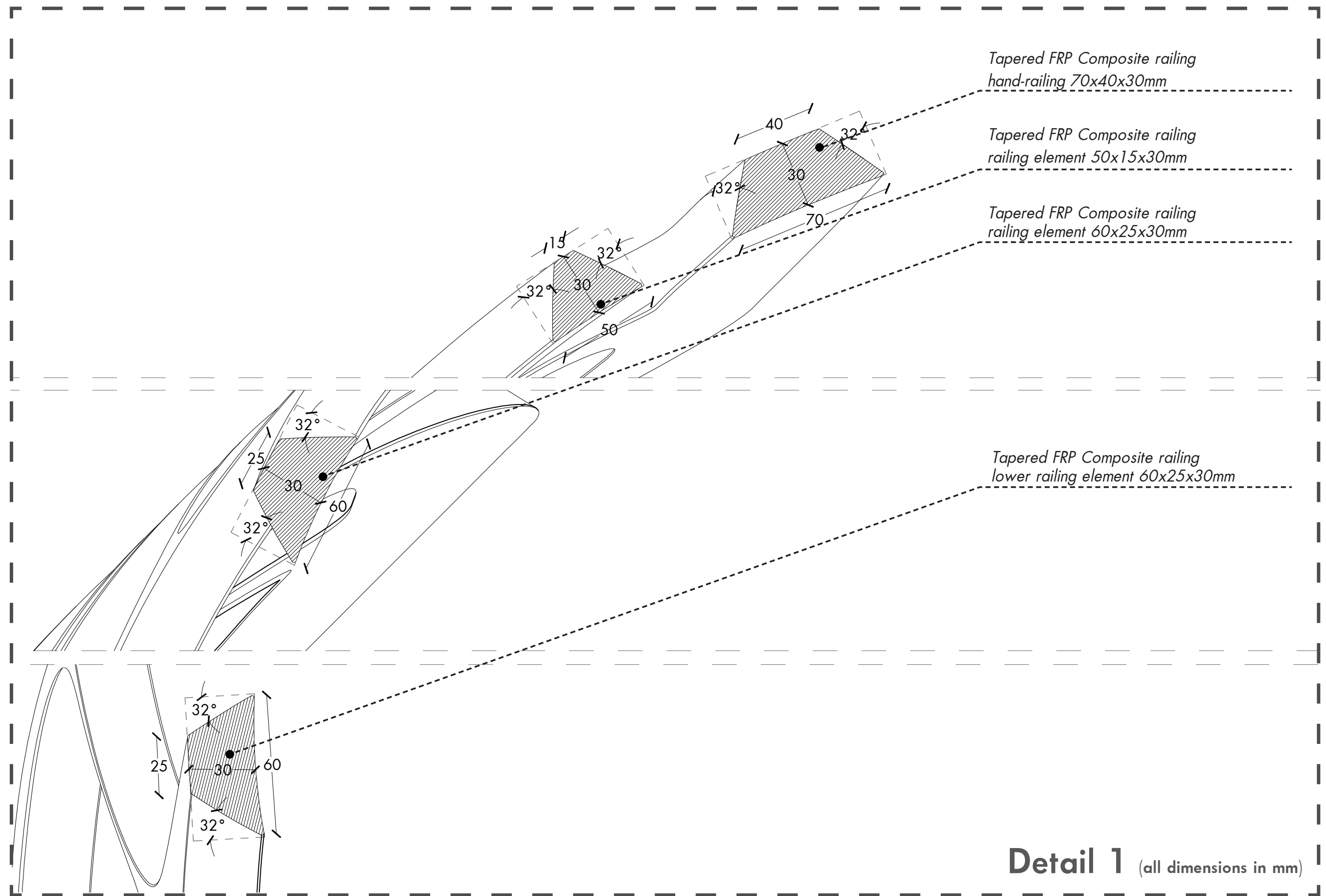
# Bridge series



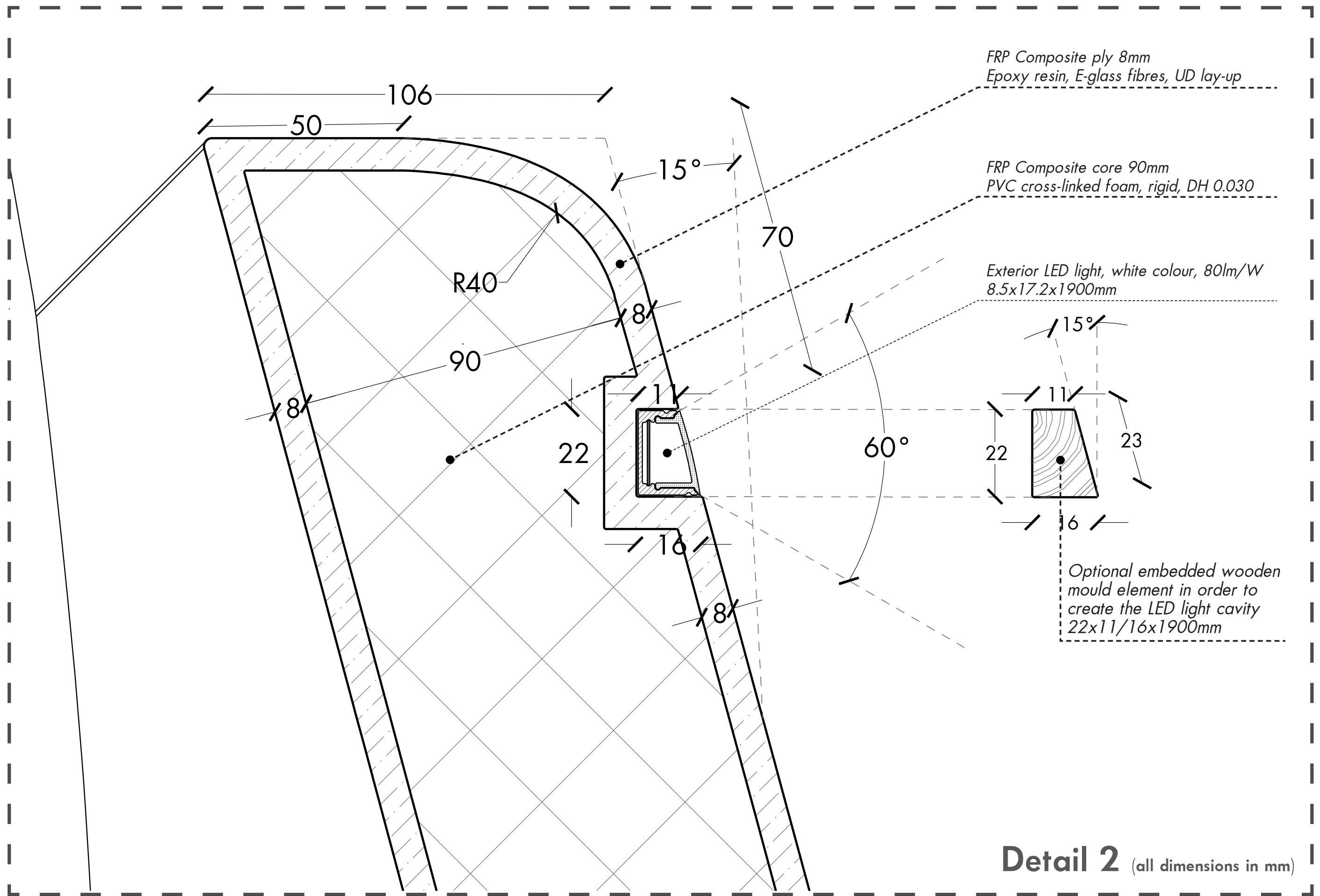


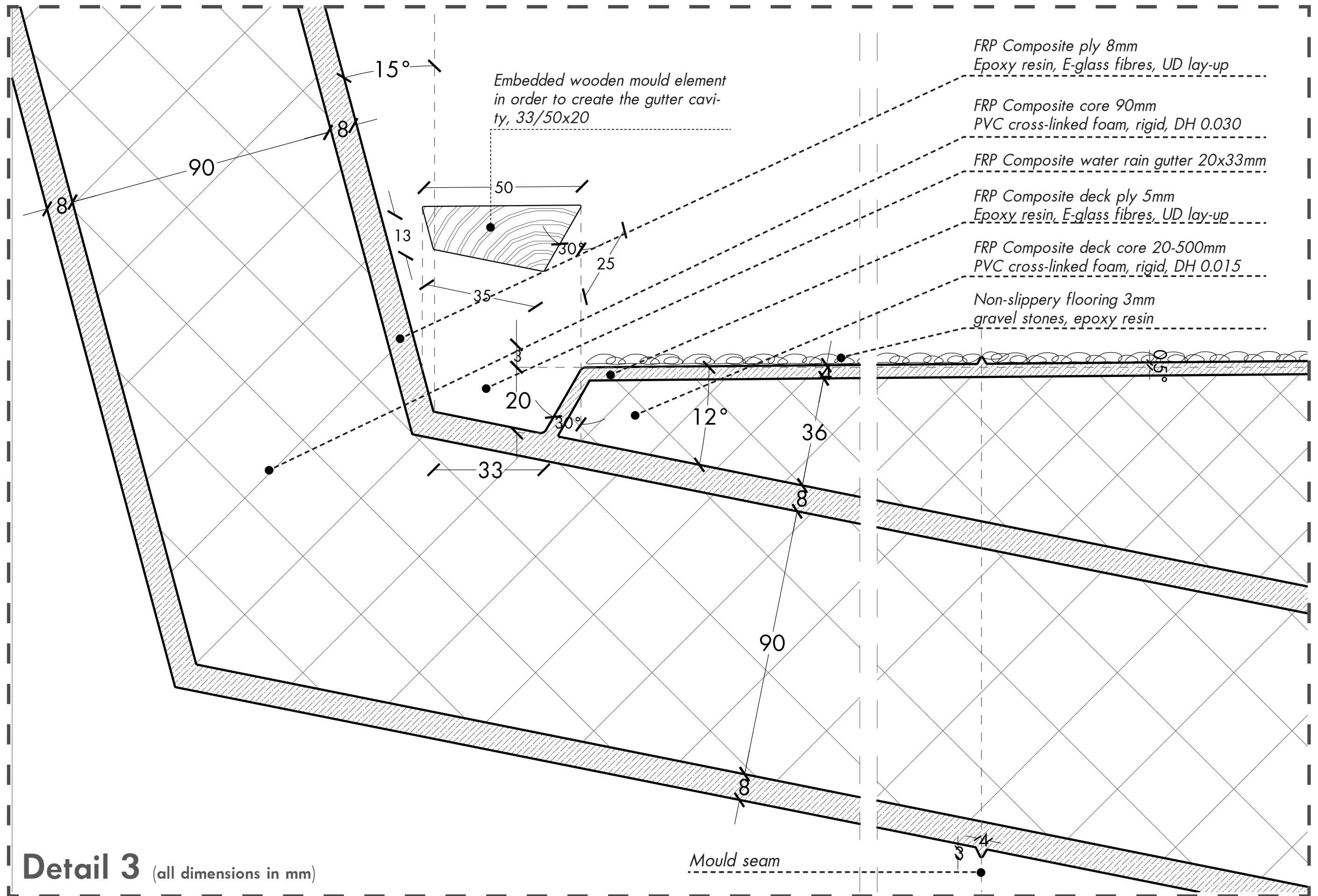


Final cross-section with railing









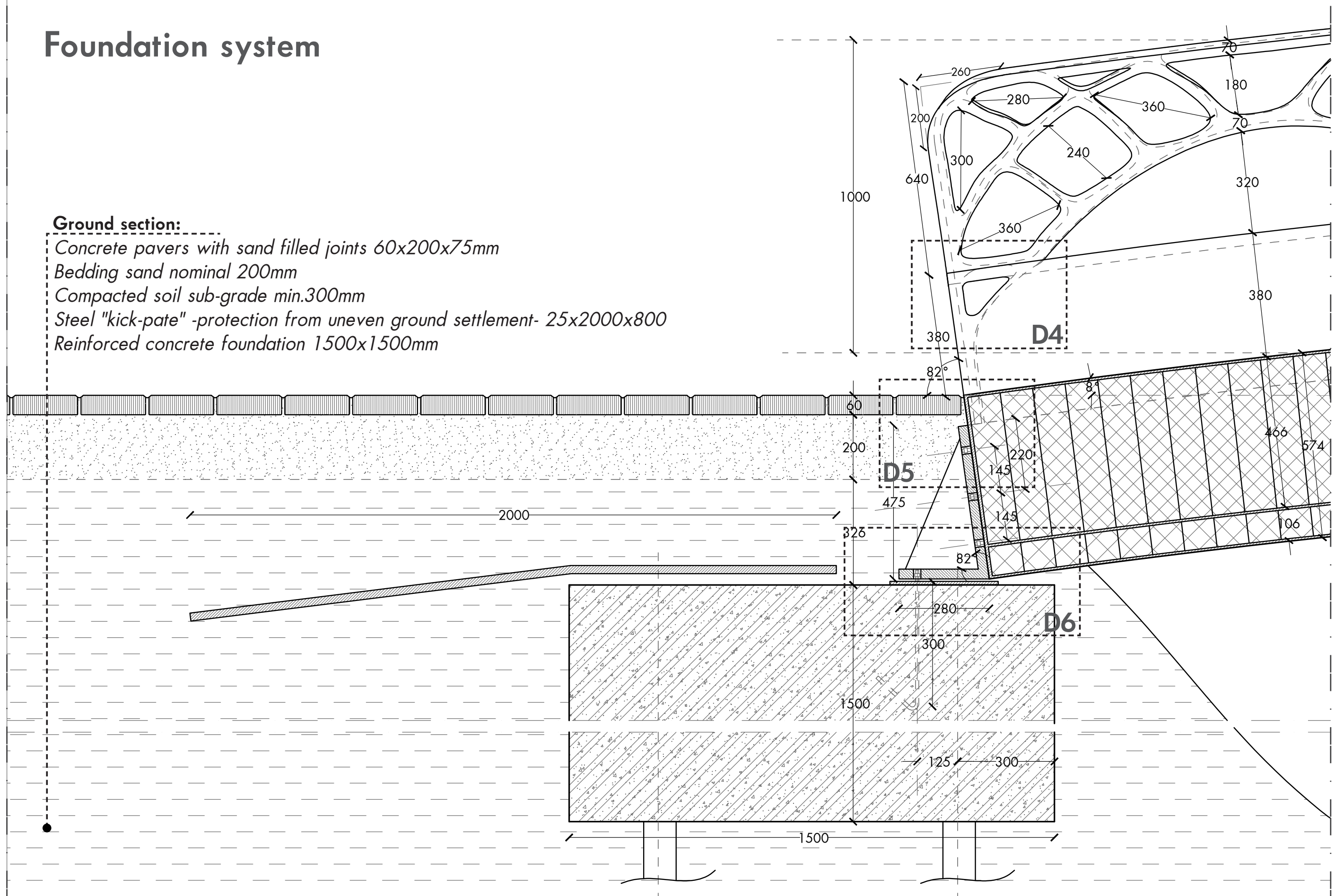
**Detail 3** (all dimensions in mm)

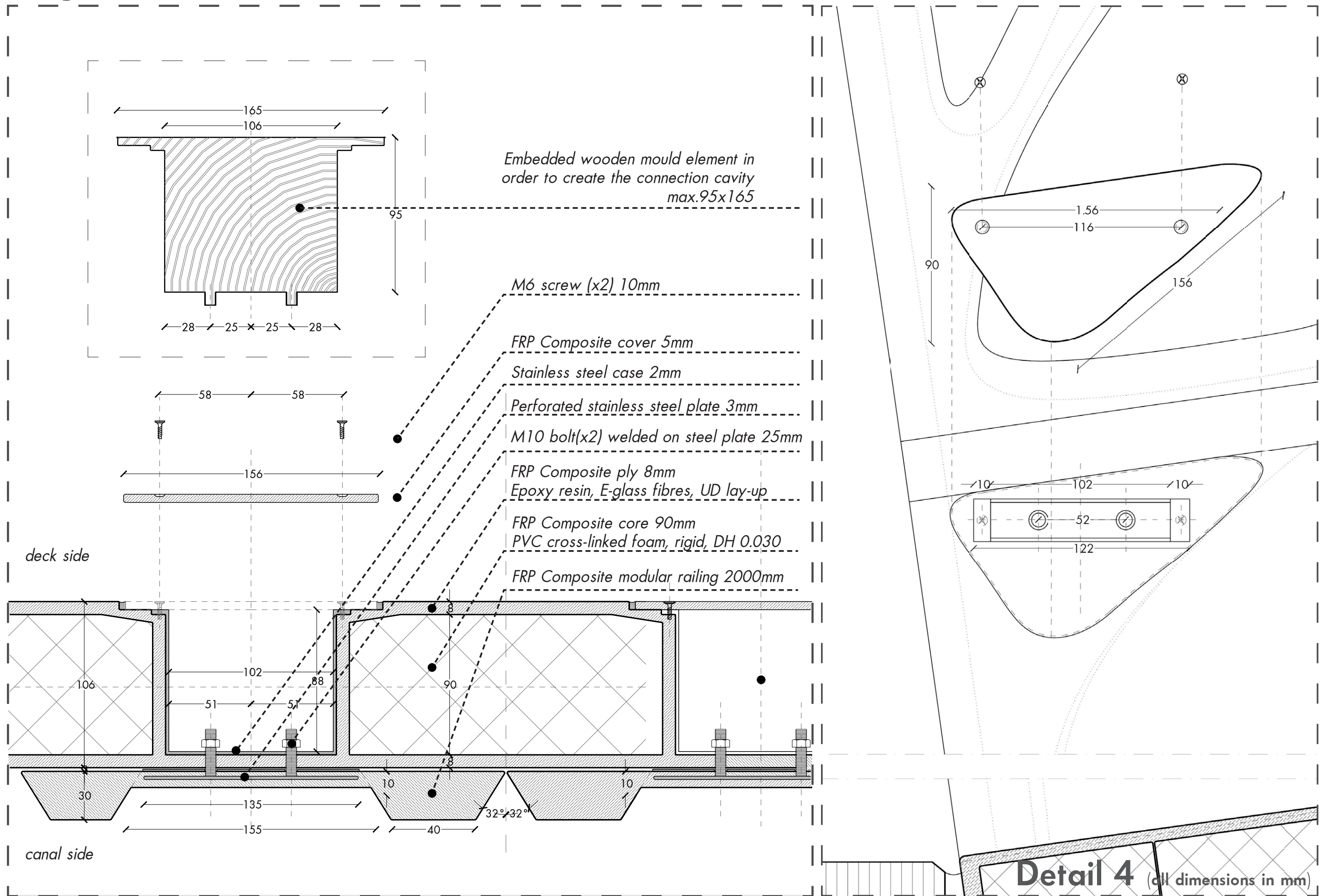


## Foundation system

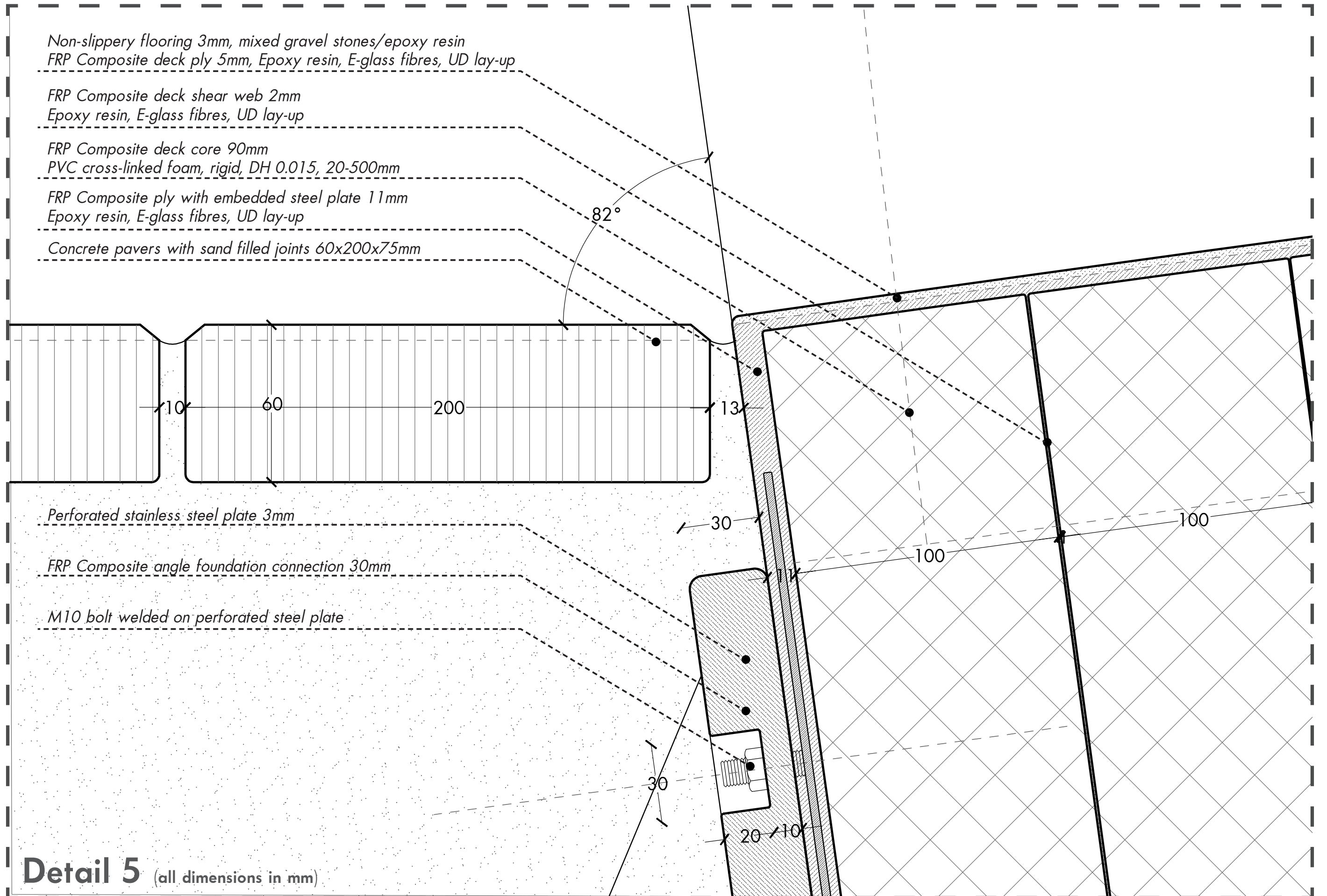
**Ground section:**

- Concrete pavers with sand filled joints 60x200x75mm
- Bedding sand nominal 200mm
- Compacted soil sub-grade min.300mm
- Steel "kick-pate" -protection from uneven ground settlement- 25x2000x800
- Reinforced concrete foundation 1500x1500mm

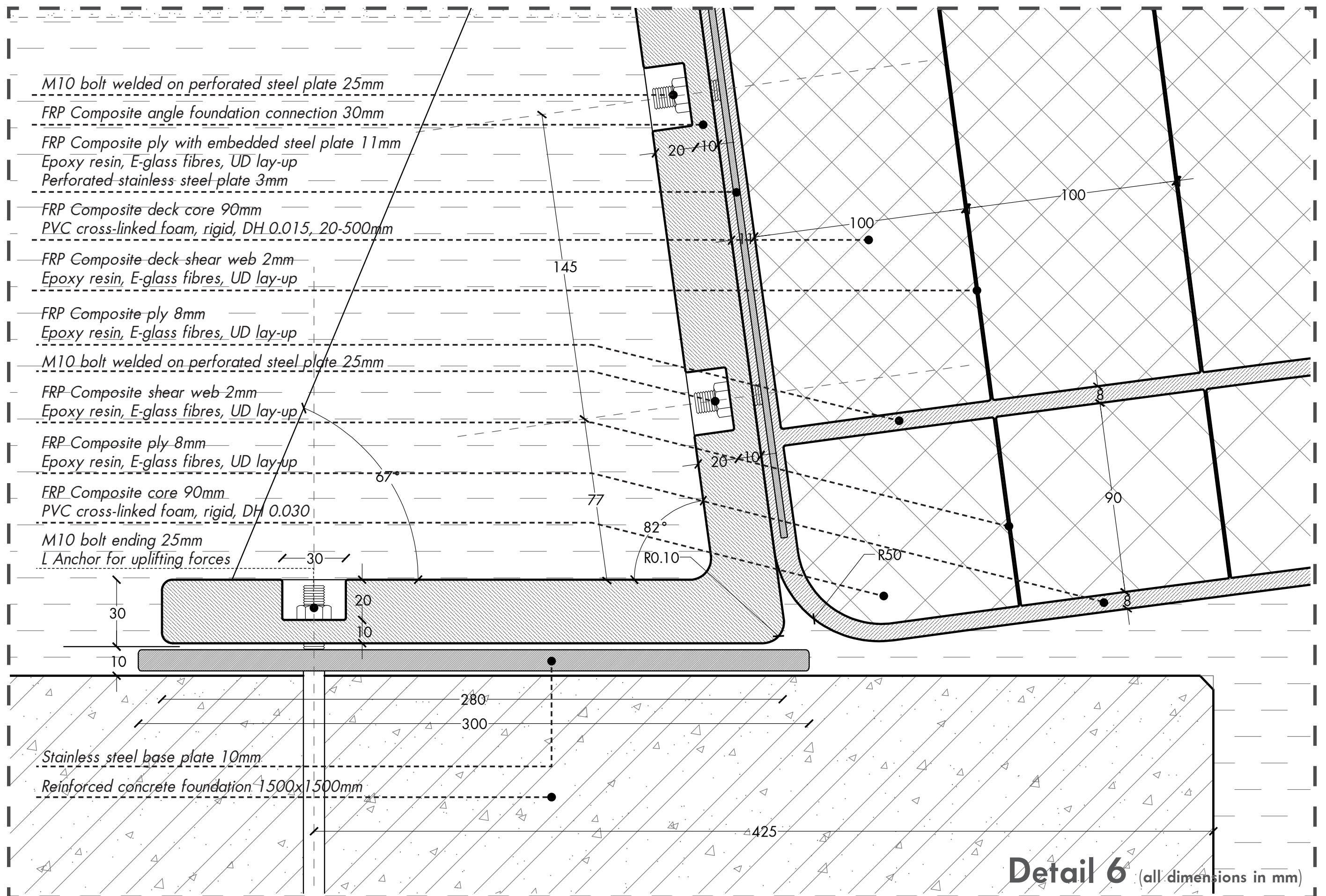








**Detail 5** (all dimensions in mm)







## Tanthof area—small housing context





Tanthof area- urban context



# Bridge series



**Delftse Hout area- natural context**



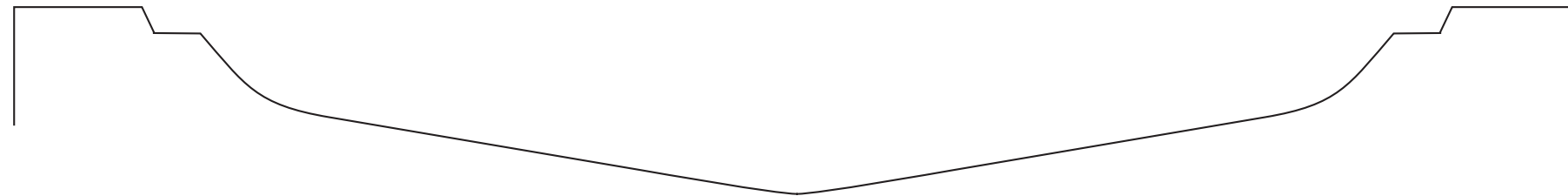


Voorhof area- Multiplex housing context



*How is the bridge series  
manufactured ?*

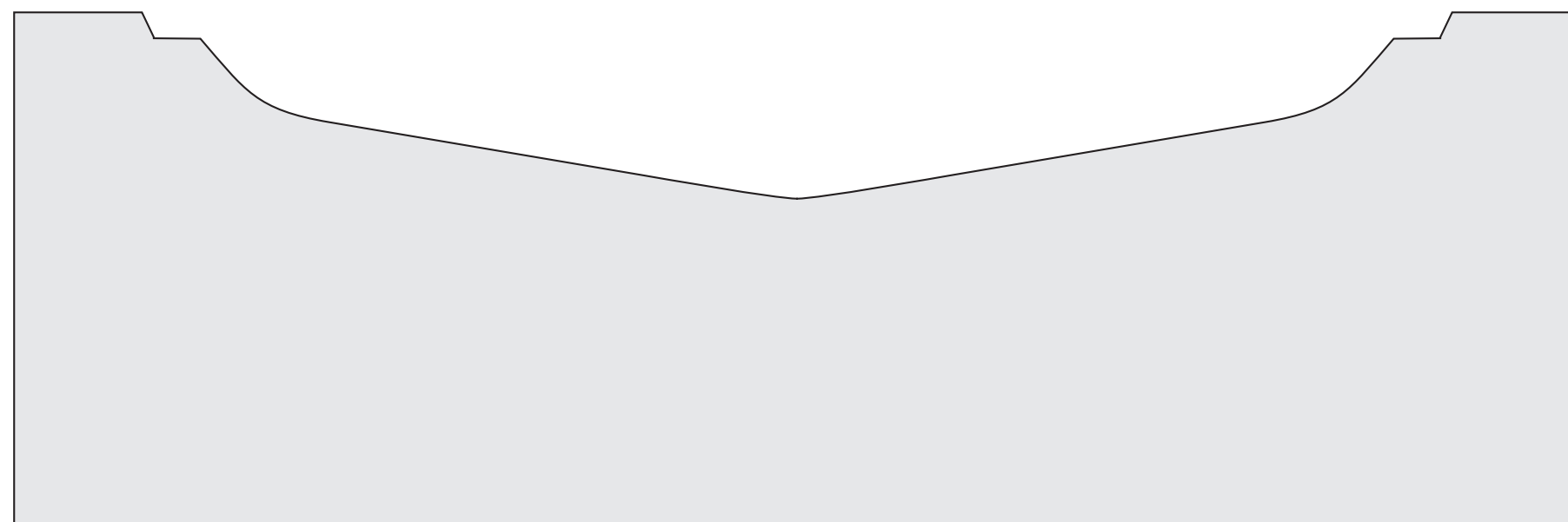




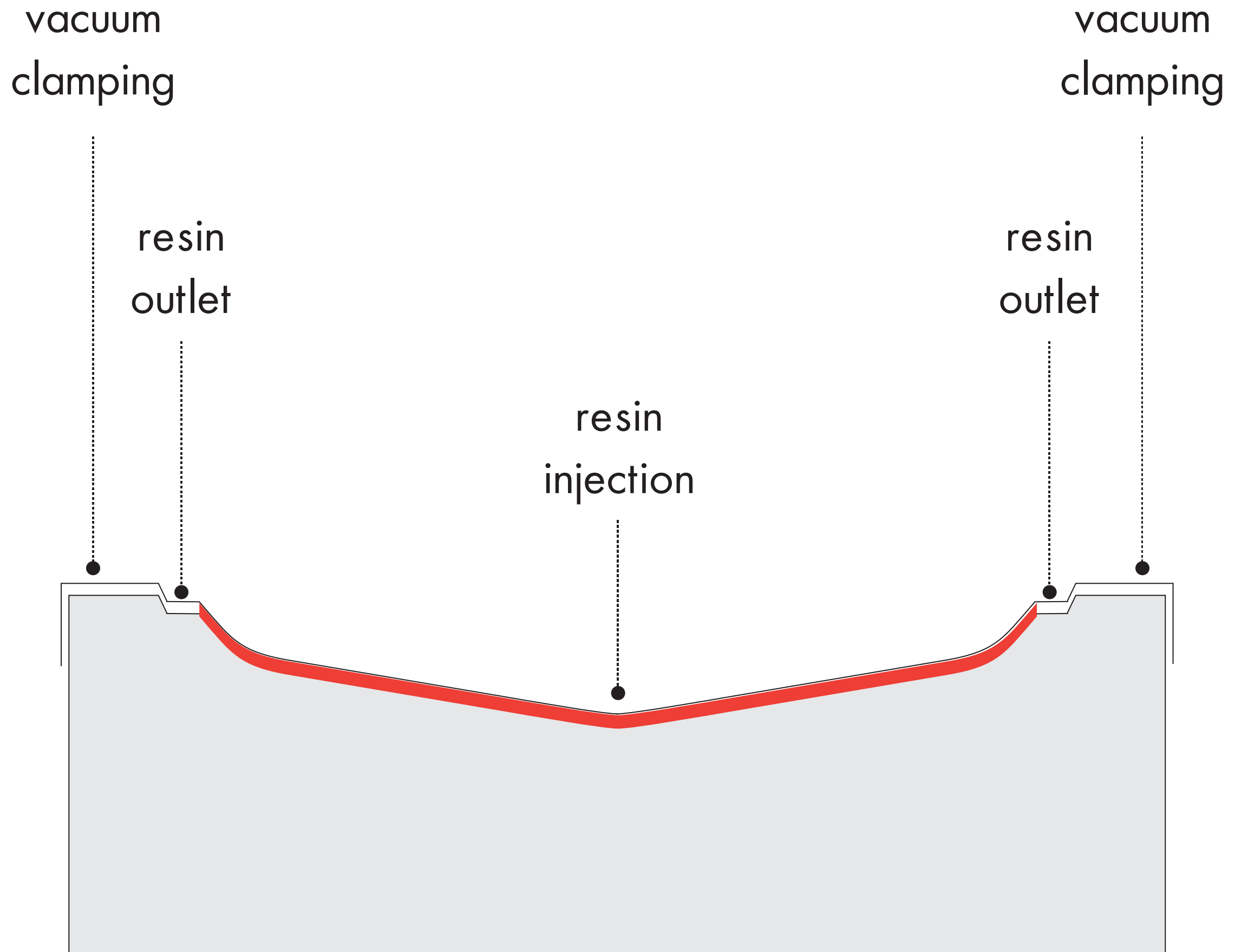
male mould  
● *FRP sheet*



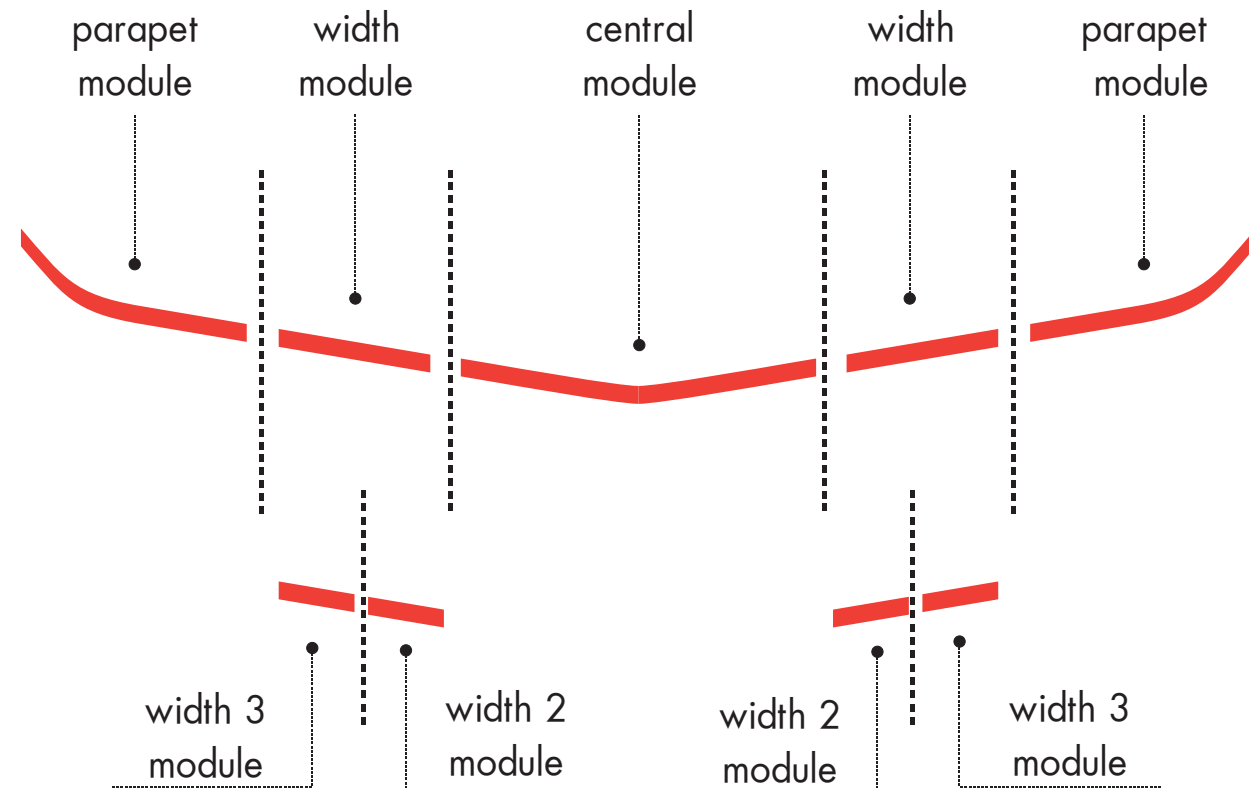
product  
● *FRP sandwich*



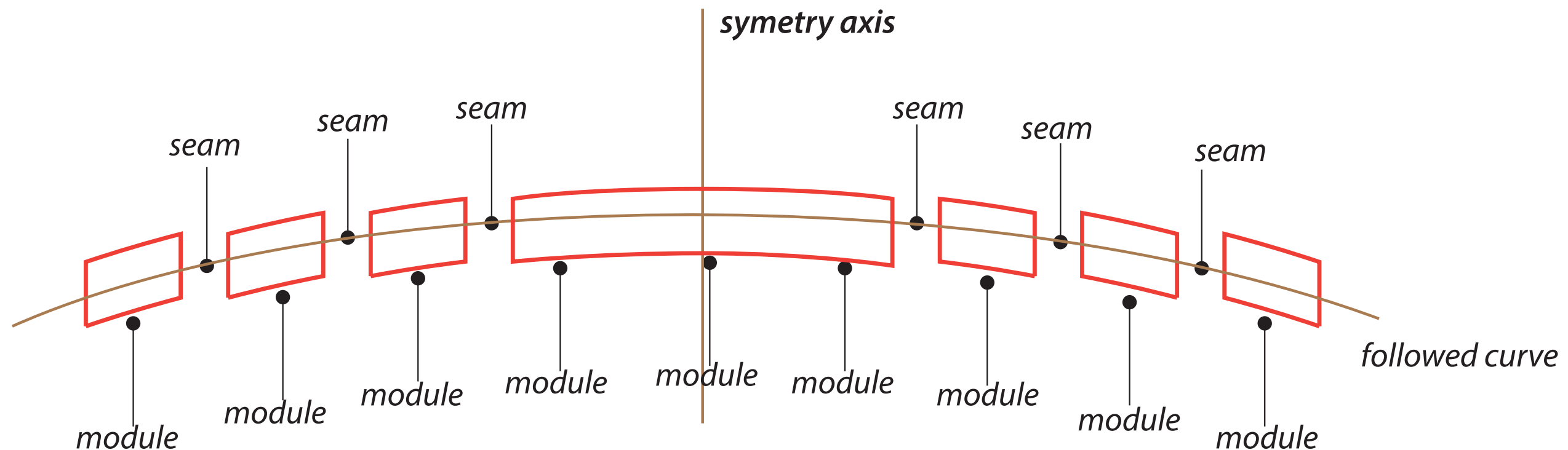
female mould  
● *FRP sandwich*



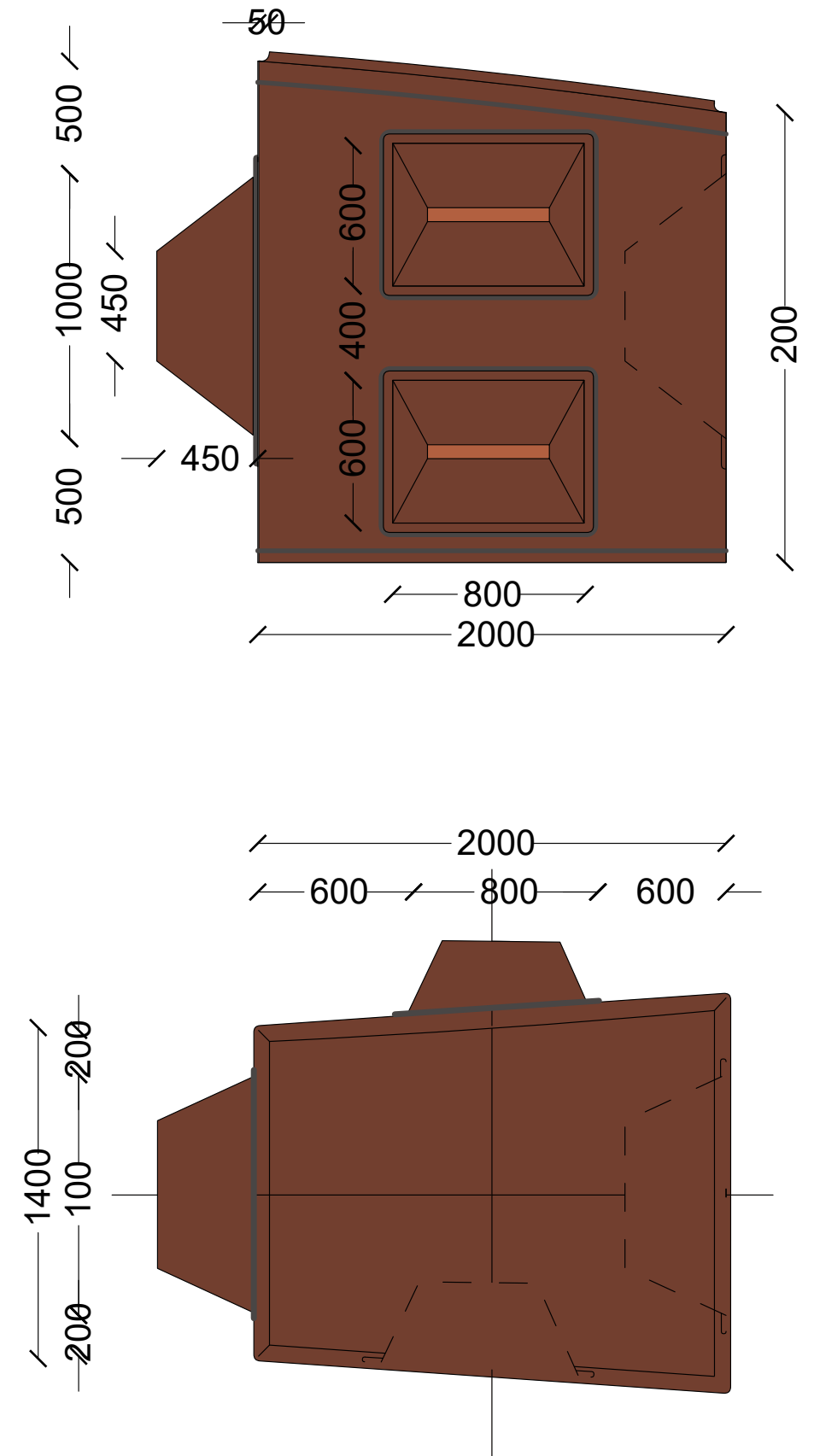
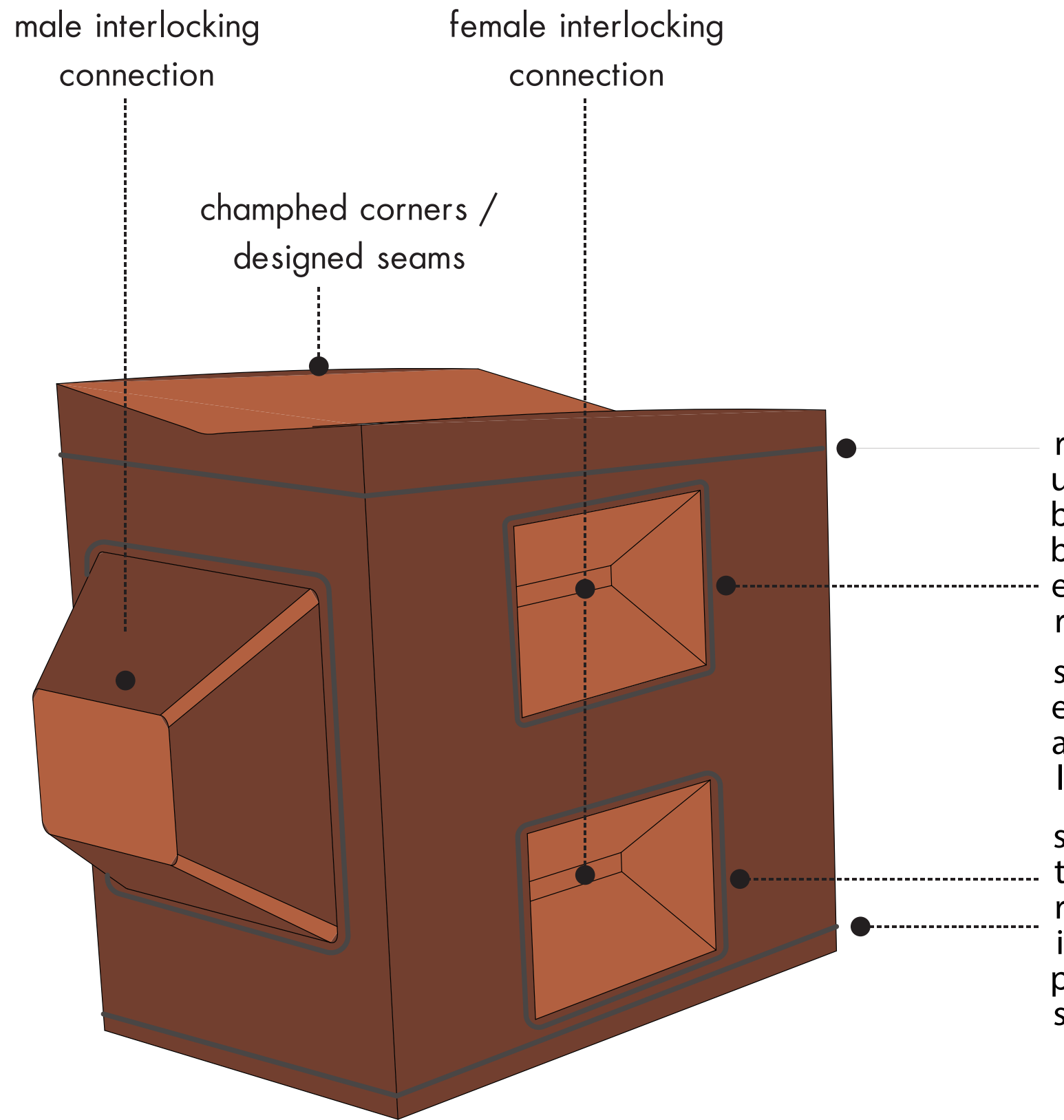




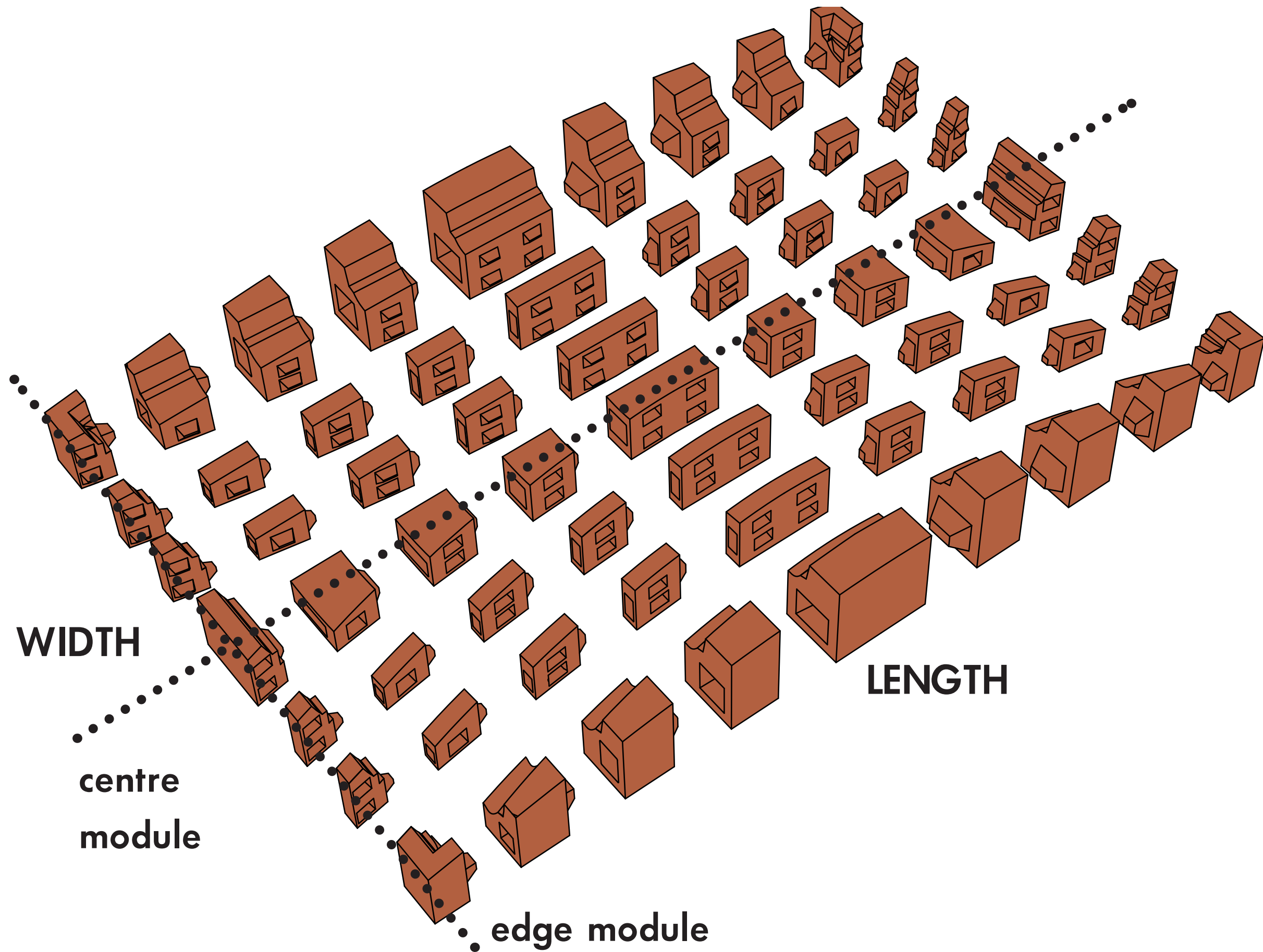
**Width: 7 modules**  
**Length: 7 modules**  
**Edge part: 2 modules**



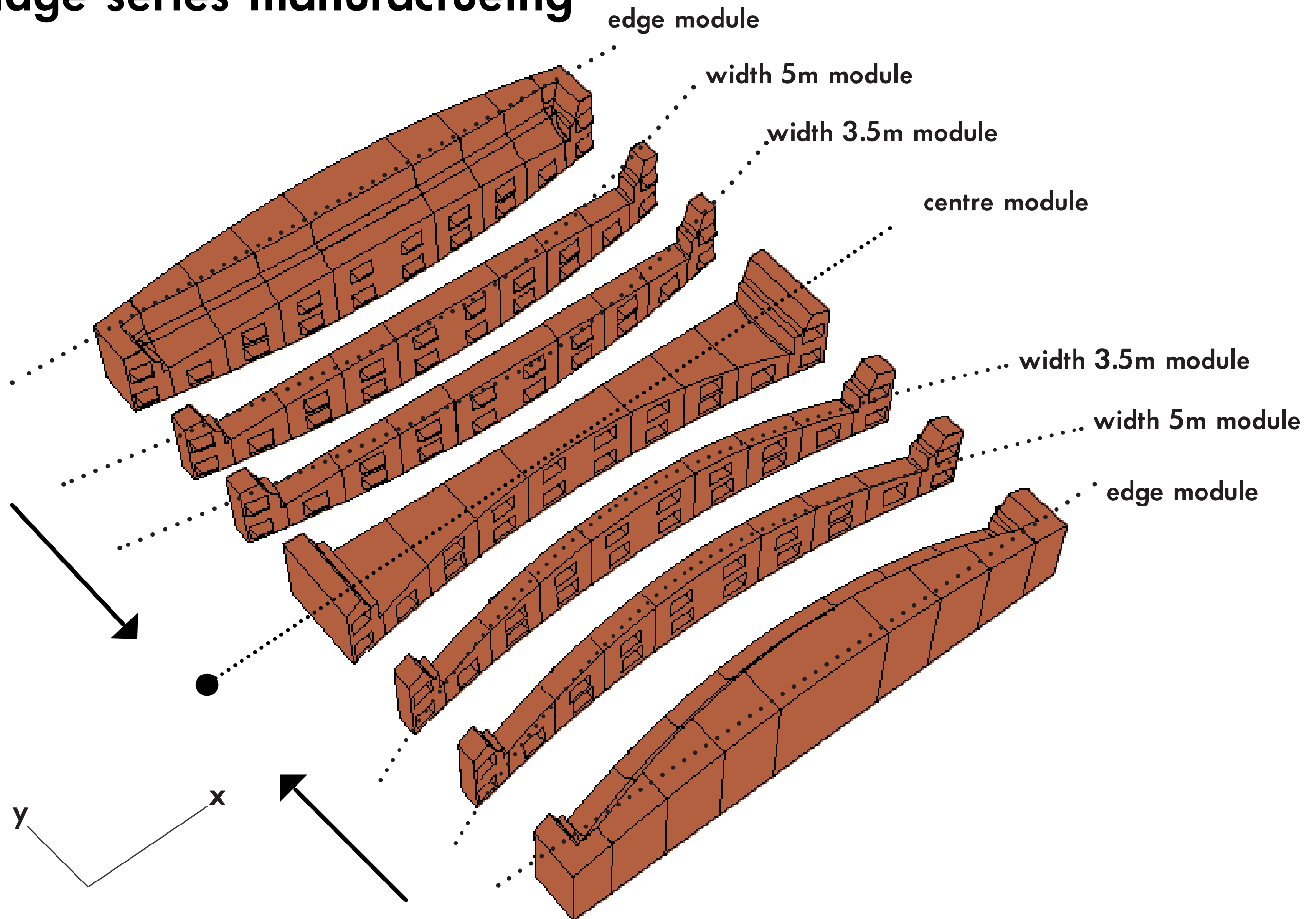
# Modular mould design



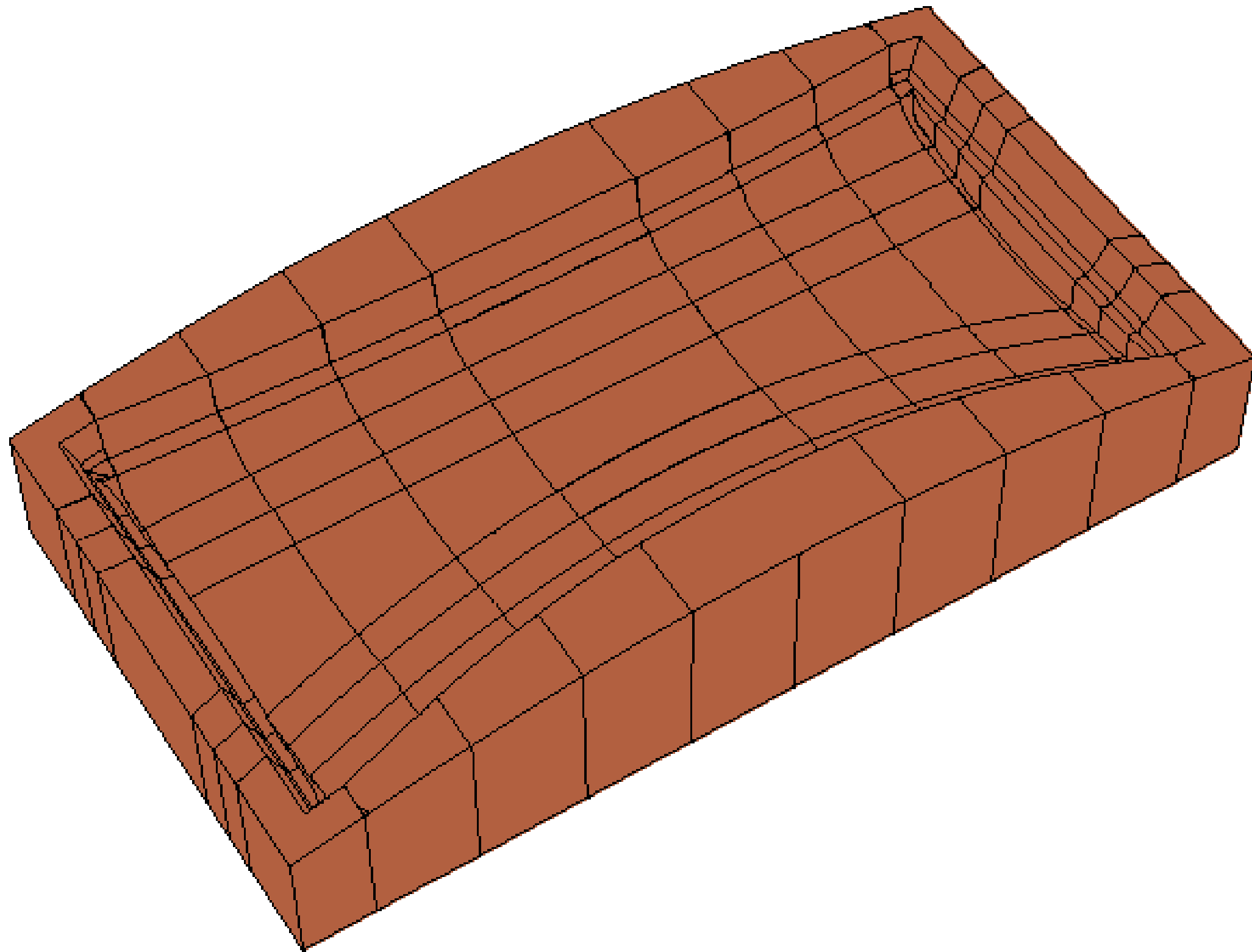




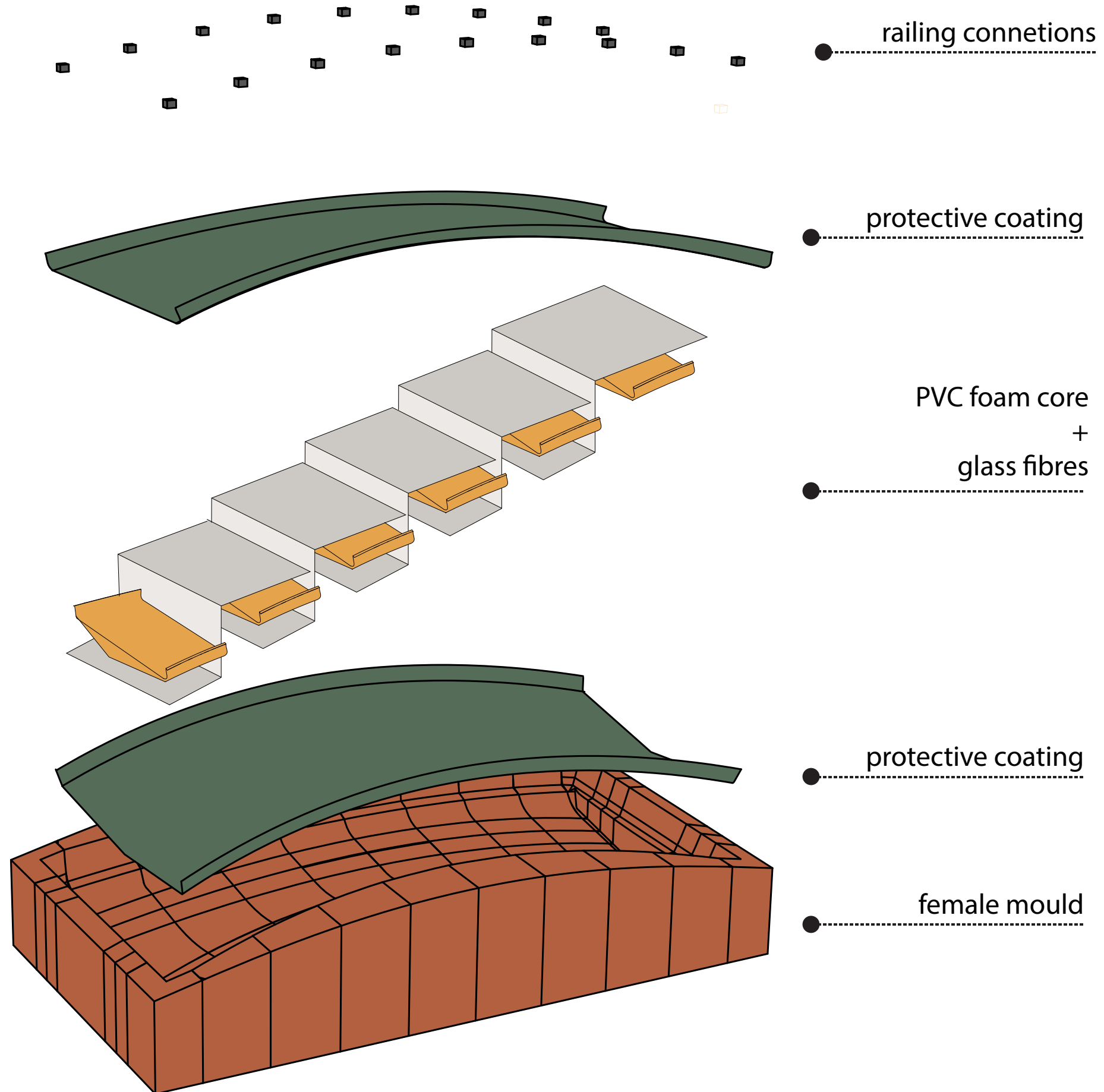
# Bridge series manufacturing



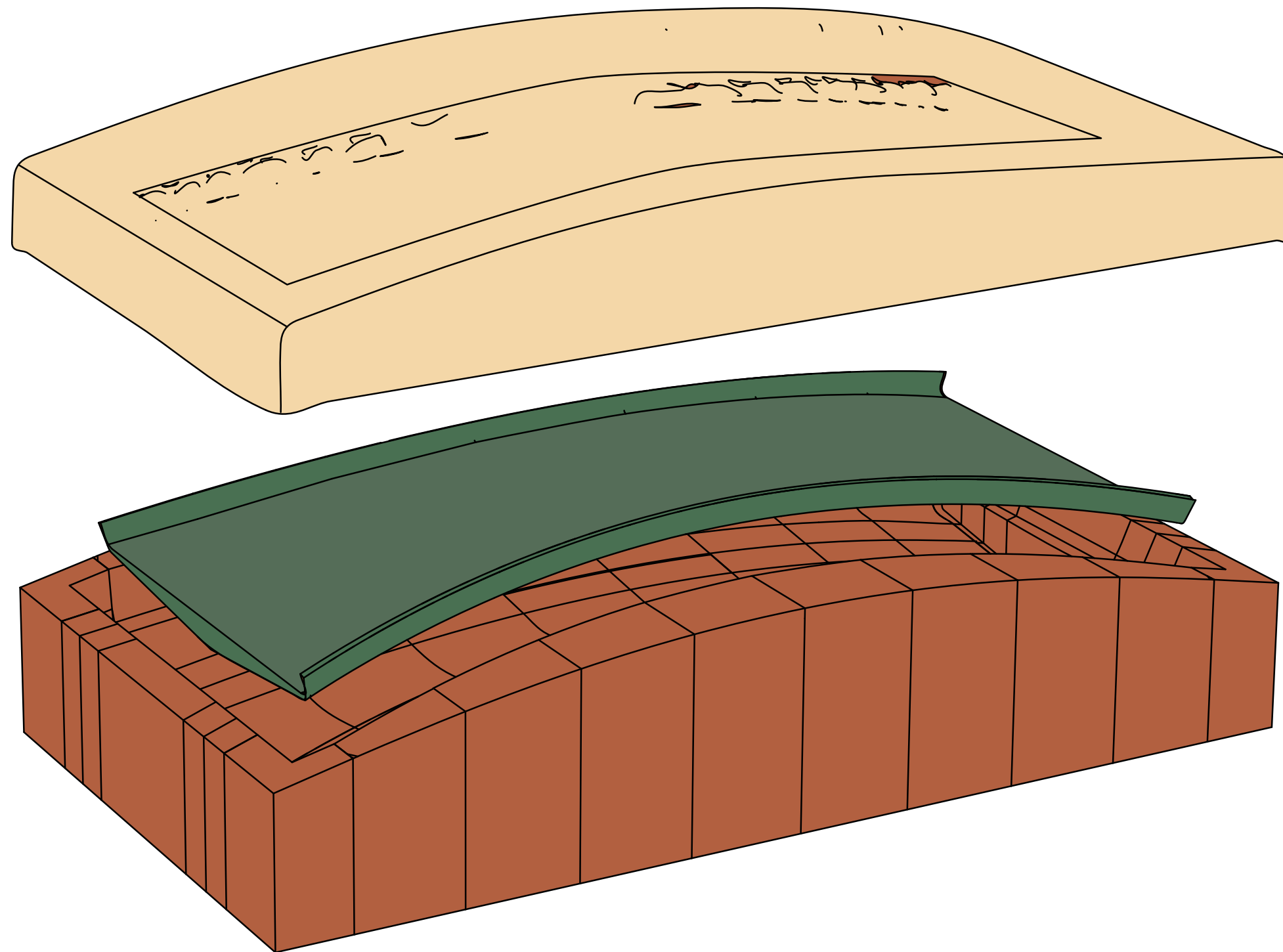


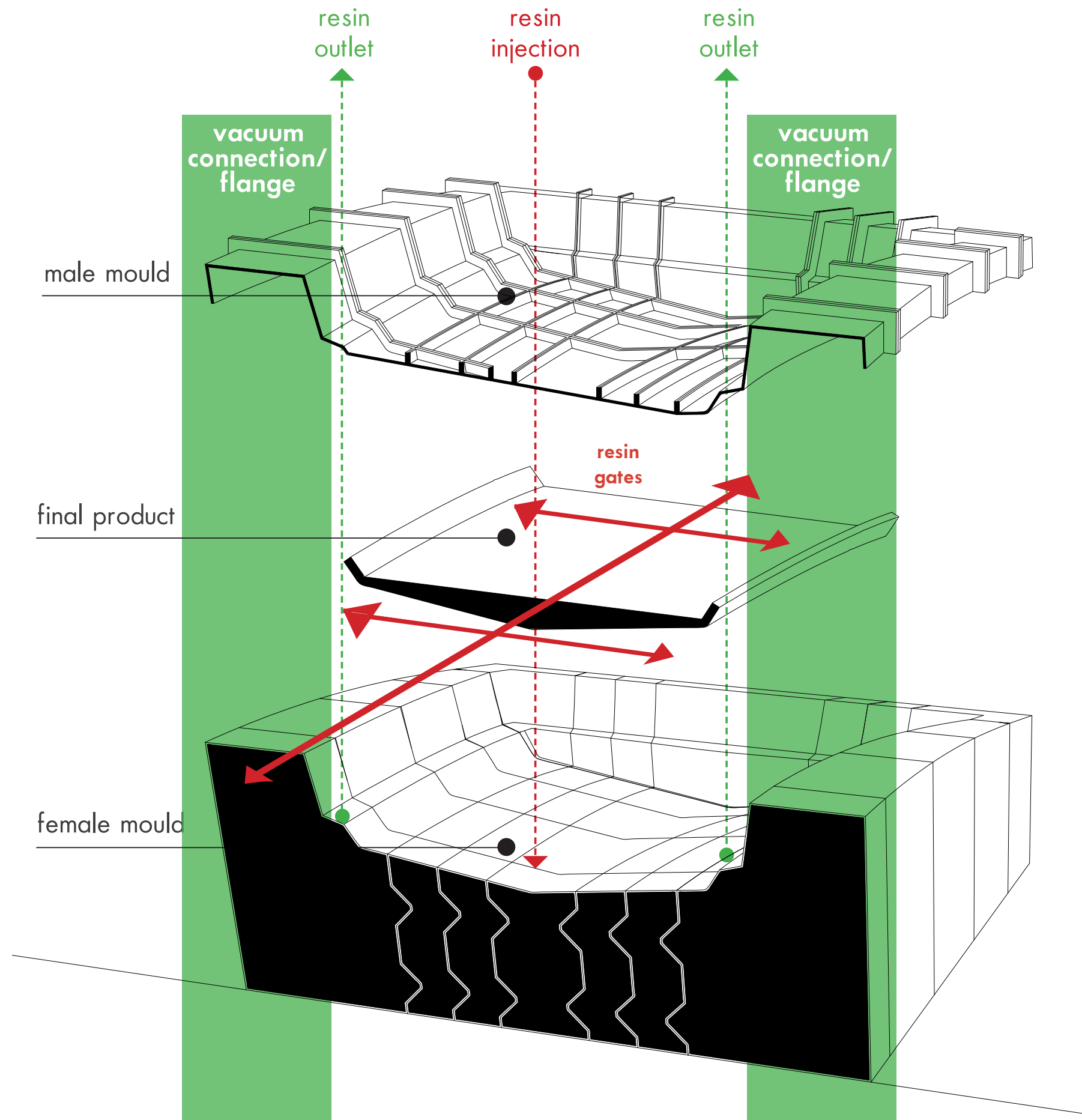


# Bridge series manufacturing

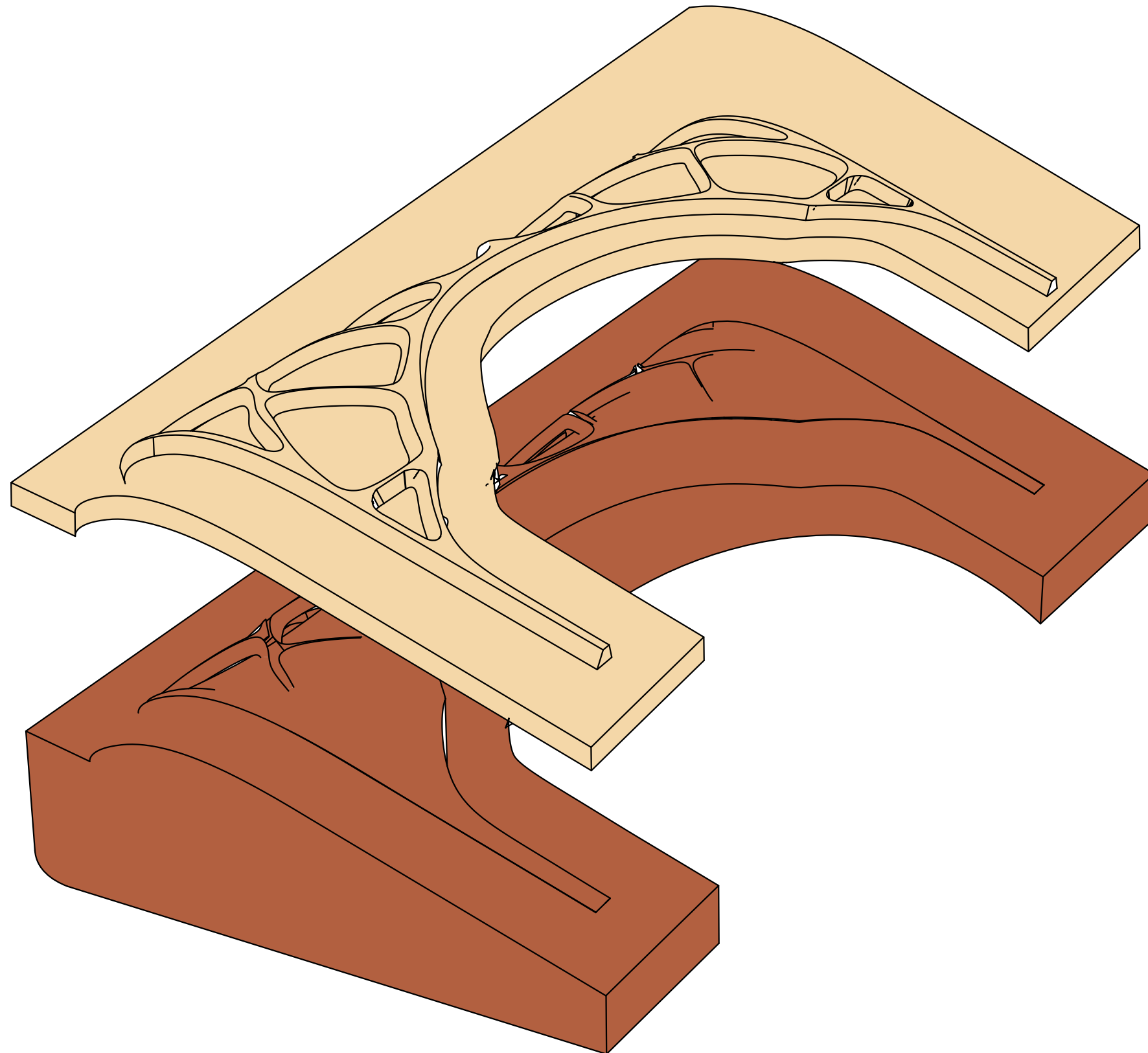






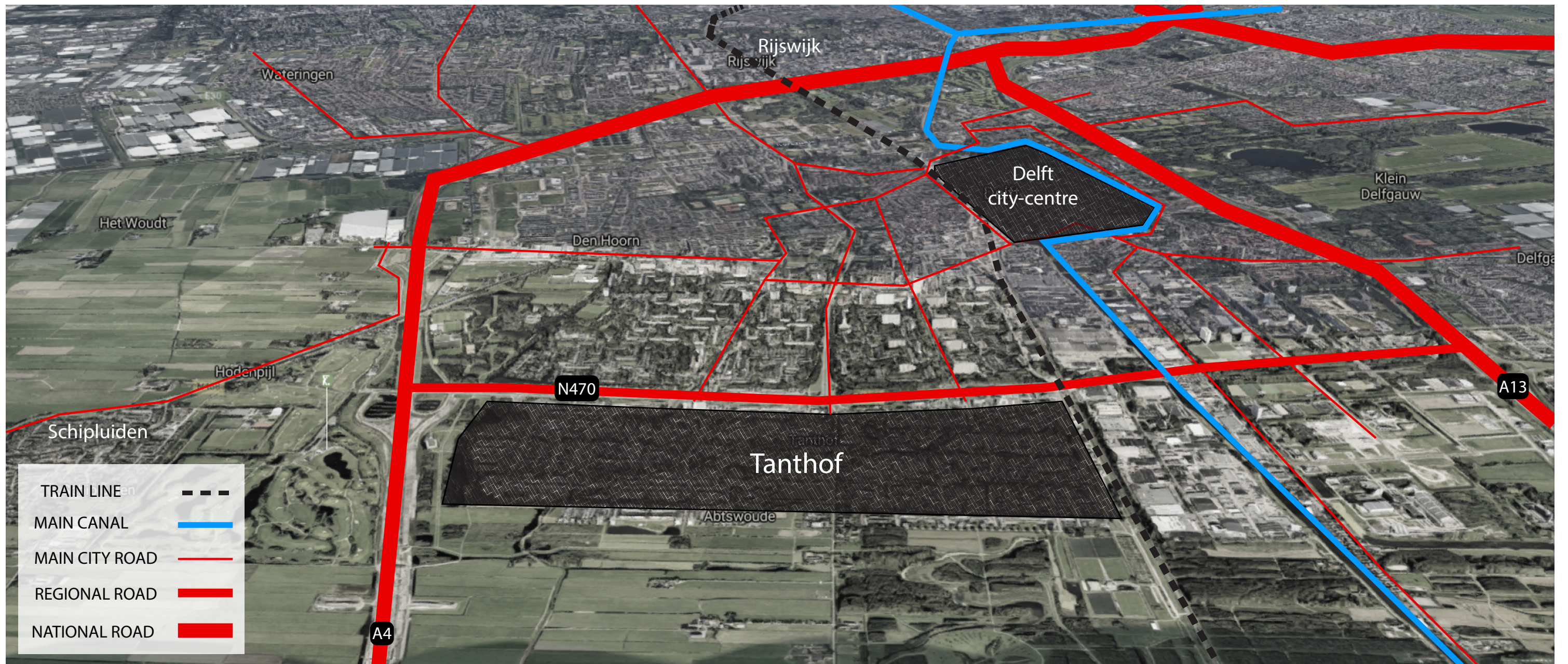






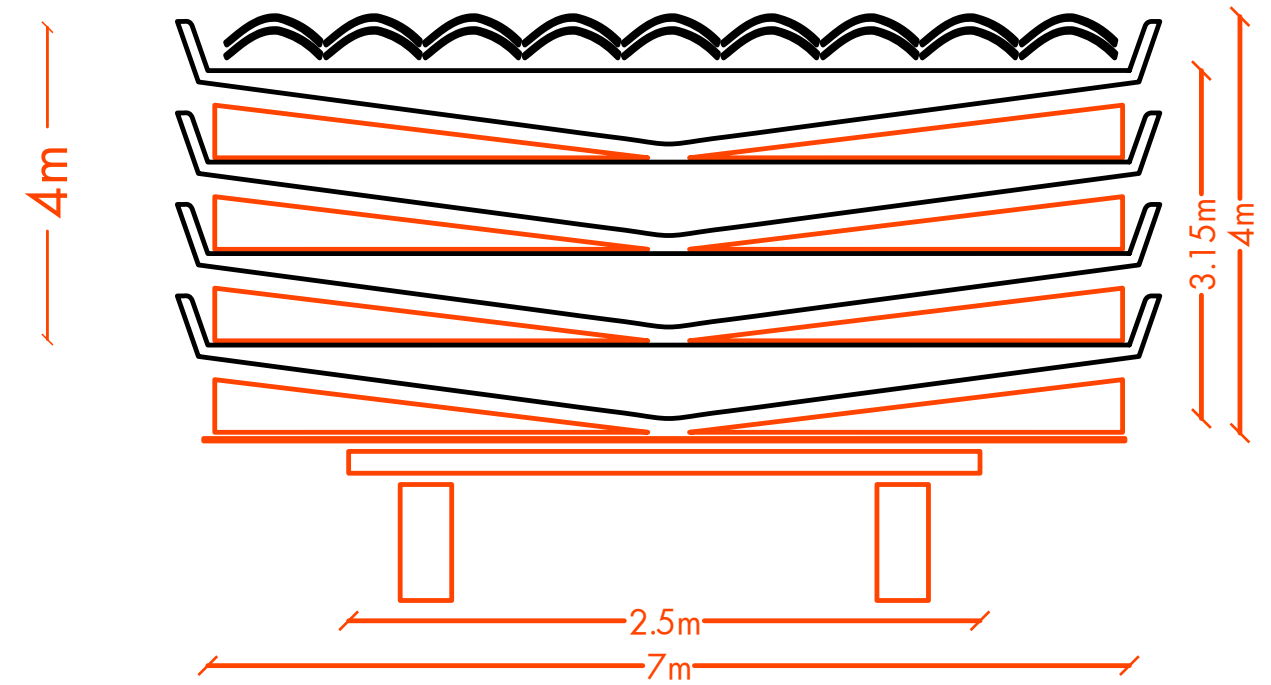
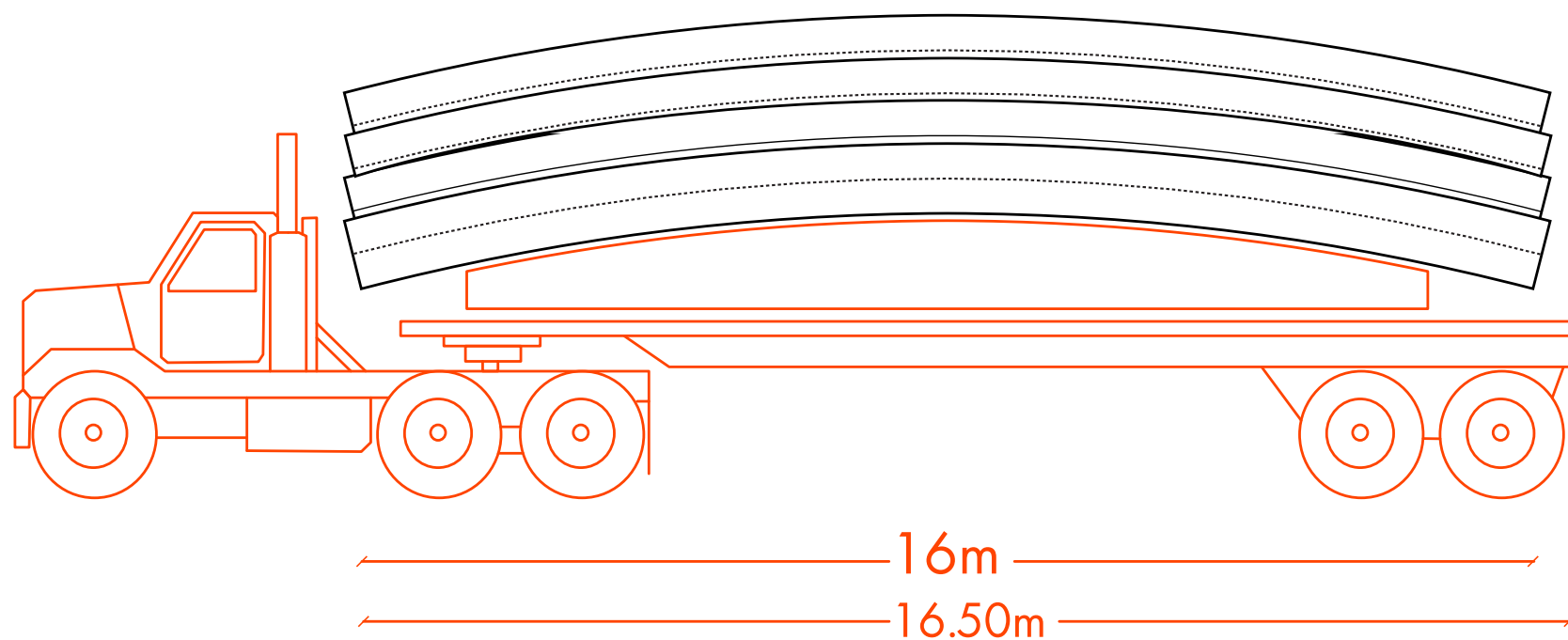


# Bridge series installation





# Bridge series installation



length 4m  
length 8m  
length 12m  
length 16m

9 bridges  
9 bridges  
30 bridges  
15 bridges

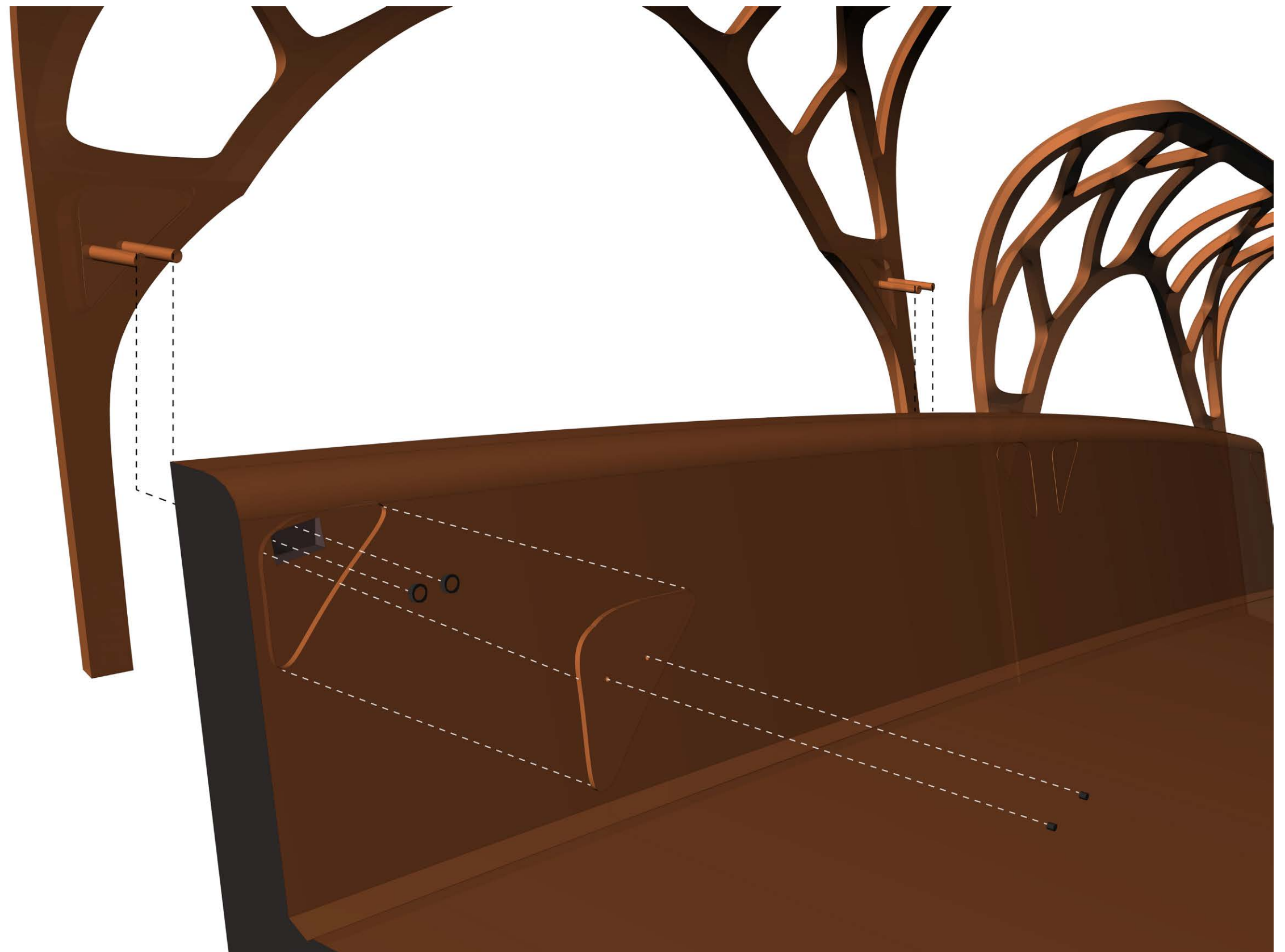
**63 bridges**

54 bridges / 4

**14 trucks**







- combination of multiple research topics
- free-form design appropriate for large structures or individual elements
- Light RTM is not appropriate for bio-resins
- modularity in connections for larger structures





# THANK YOU