6th International Electronic Conference on Sensors and Applications
ECSA-6
15 – 30 November 2019

NUMERICAL STUDY OF A MULTI-LAYERED STRAIN SENSOR FOR STRUCTURAL HEALTH MONITORING OF ASPHALT PAVEMENT

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• Introduction

- Crack initiation and propagation vary the mechanical properties of the pavement and further alter its designed function [1].

- Current sensing technology for structural health monitoring(SHM):
  Optical fibers [2]→Expensive
  Conventional strain gauges [3]→rarely used in asphalt materials
  Metal-foil-type gauges [4] →rarely used in asphalt materials

- challenges of installation conditions:
  High temperatures (up to 164 ℃)[5]
  High pressure (around 290ksi) [6]

❑ Piezoelectric materials:
Mechanical deformation→Generate electrical charges

❑ piezoelectric materials for SHM and energy harvest :

A. piezoceramic material (Lead Ziroconate Titanate, PZT)
B. piezoelectric plastic material (PVDF) [7-10]

❑ Advantage of piezoelectric-based sensors:
strong piezoelectric effects and wide bandwidth.

❑ Disadvantage of PZT:

1. suffers from saturation due to its high piezoelectric coefficient
2. too brittle to sustain high strain.

- Advantage of Piezoelectric plastic materials, such as PVDF [11-12]:

1. high sensitivity
2. good flexibility
3. good manufacturability
4. small distortion
5. low thermal conductivity
6. high chemical corrosion resistance, and heat resistance

PVDF → Key sensing unit of our strain sensor

- ## Sensor Configuration

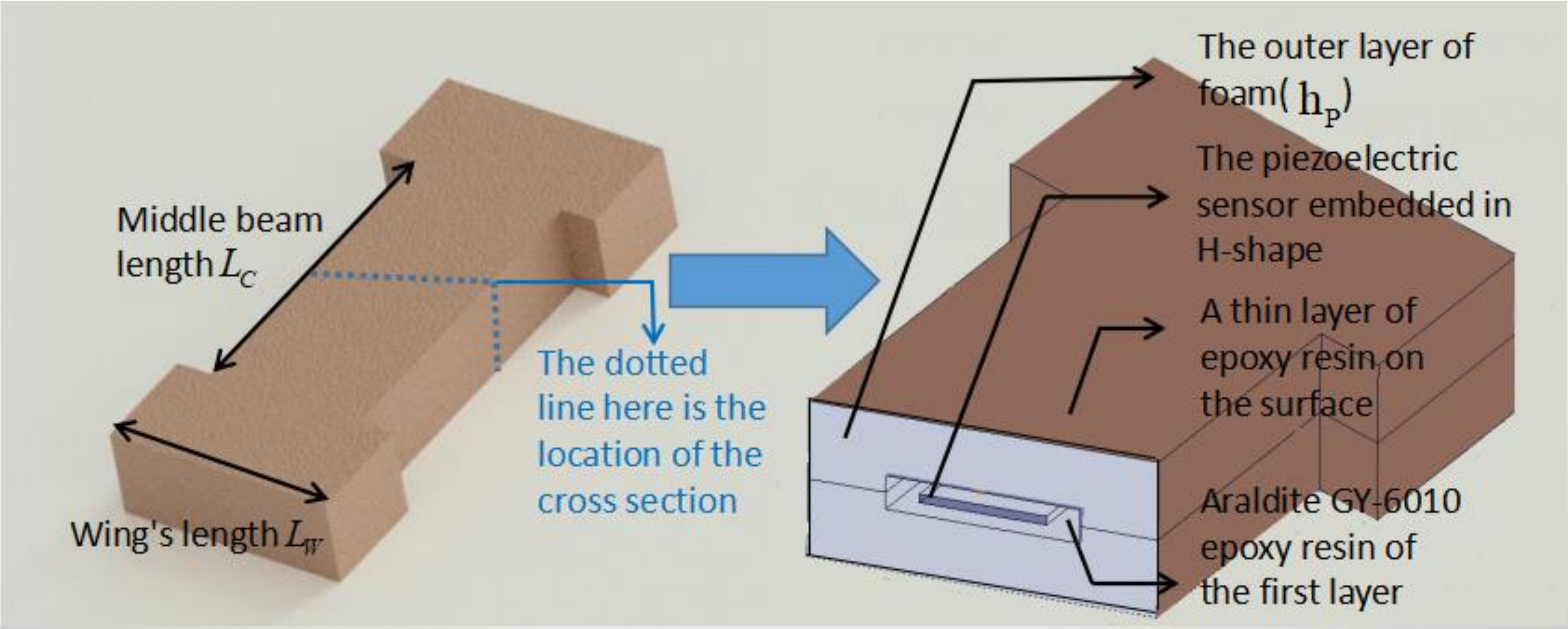
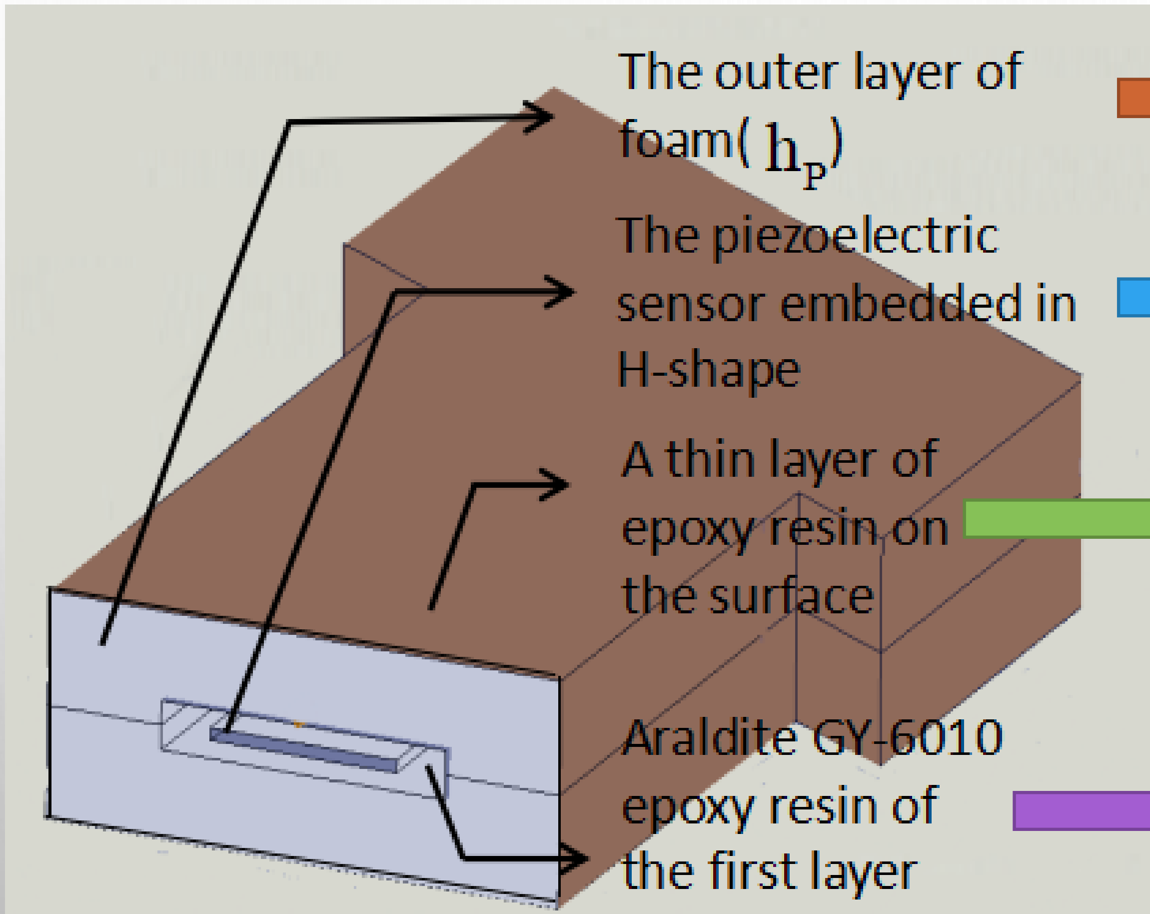


Figure 1. Configuration of the multi-layered strain sensor

• Sensor Configuration



Thermal Protection

Key Sensing Unit

Corrosion Protection

Mechanical Protection

• Thermal Analysis

	Mechanical Protection	Thermal Protection	Corrosion Protection
Material	Araldite GY-6010 epoxy	polyurethane foam	urethane casting resin
Thermal Conductivity	$0.2\ W\cdot m^{-1}\cdot K^{-1}$	$0.022\ W\cdot m^{-1}\cdot K^{-1}$	Negligible
Layer Thickness	10mm	5mm-12mm	1mm

∵ Thermal Conductivity: Thermal Protection<<Mechanical Protection

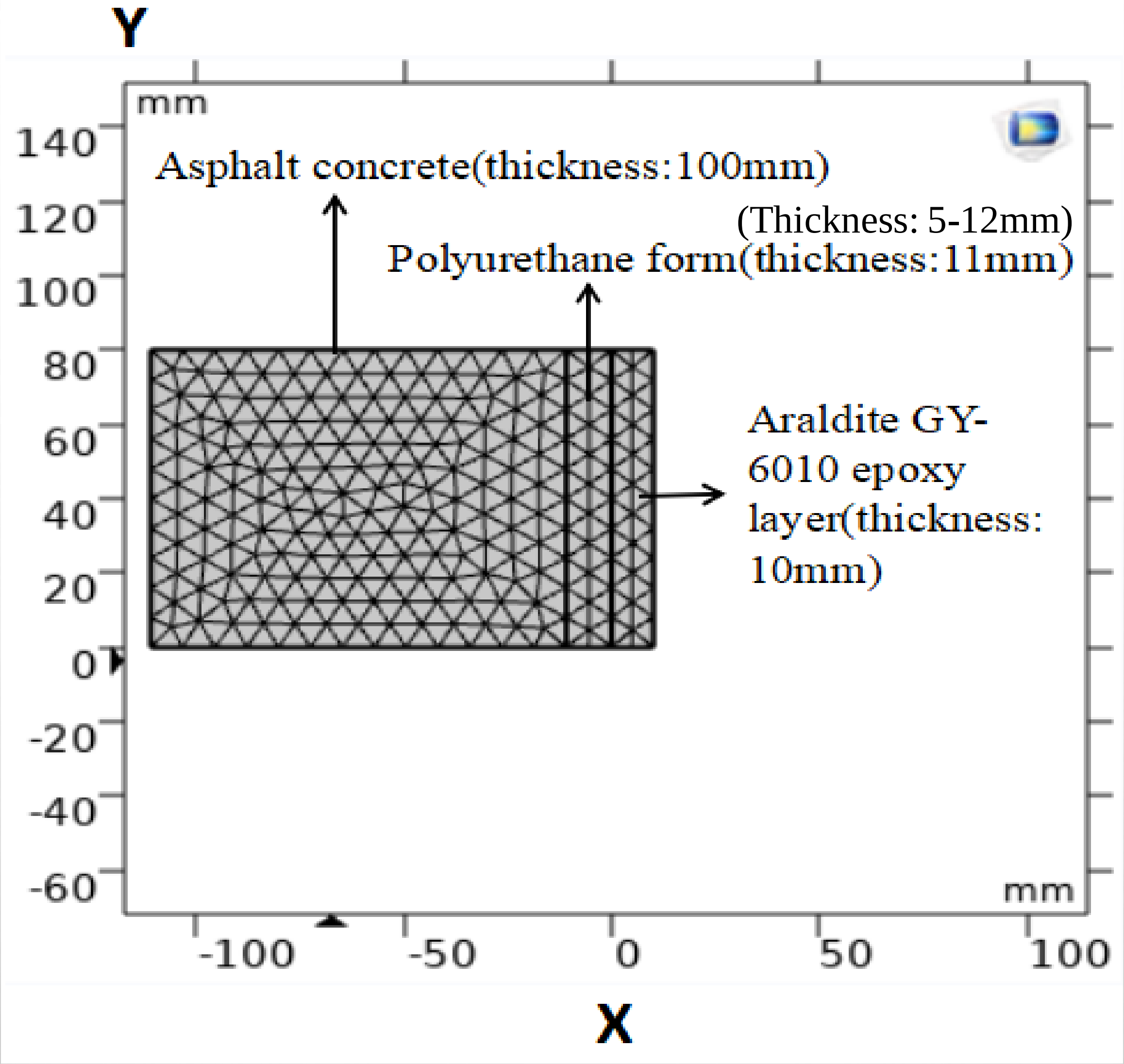
∴Thermal Analysis mainly focuses on thermal protection layer

Theoretical Model

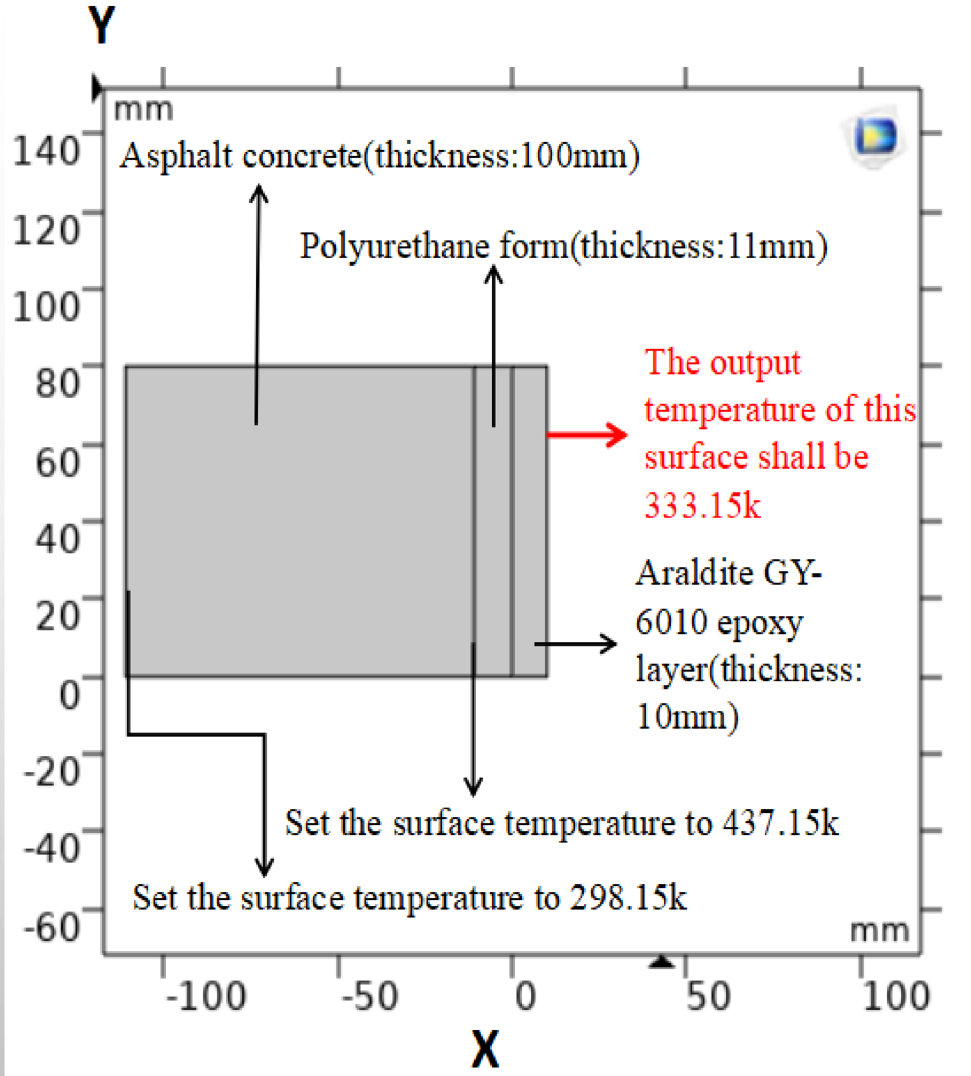
$$d_z \rho C_p \frac{\partial T}{\partial t} + d_z \rho C_p u \cdot \nabla T + \nabla \cdot q = d_z Q + q_0 + d_z Q_{ted}$$

$$\mathrm{q} = -d_Z k \nabla T$$

Q --heat content, J
k--thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
q-- local heat flux density, $W \cdot m^{-2}$
ρ -density of each material, $kg \cdot m^{-3}$
C_p--heat capacity, $J \cdot kg^{-1} \cdot K^{-1}$.
∇T is the temperature gradient, $K \cdot m^{-1}$.
t time,s



2D Finite Element Model with 422 elements;



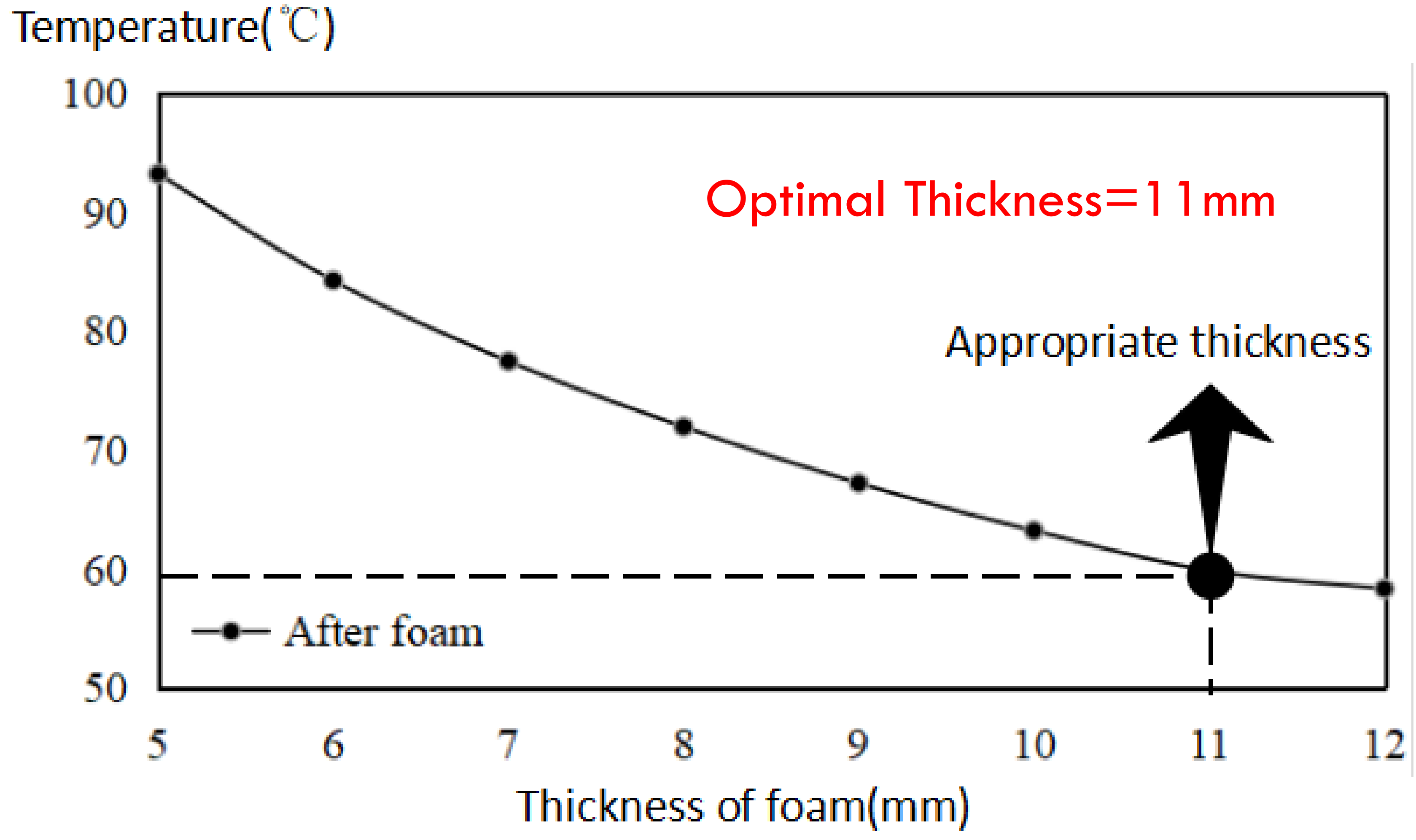
∵Max operation temp of PVDF equals to 333.15K

∴ output temp T_{out} ≤333.15K

∴ Aim:

Find optimal thickness of Polyurethane foam for T_{out} =333.15K

Schematic of 2D model with boundary conditions.

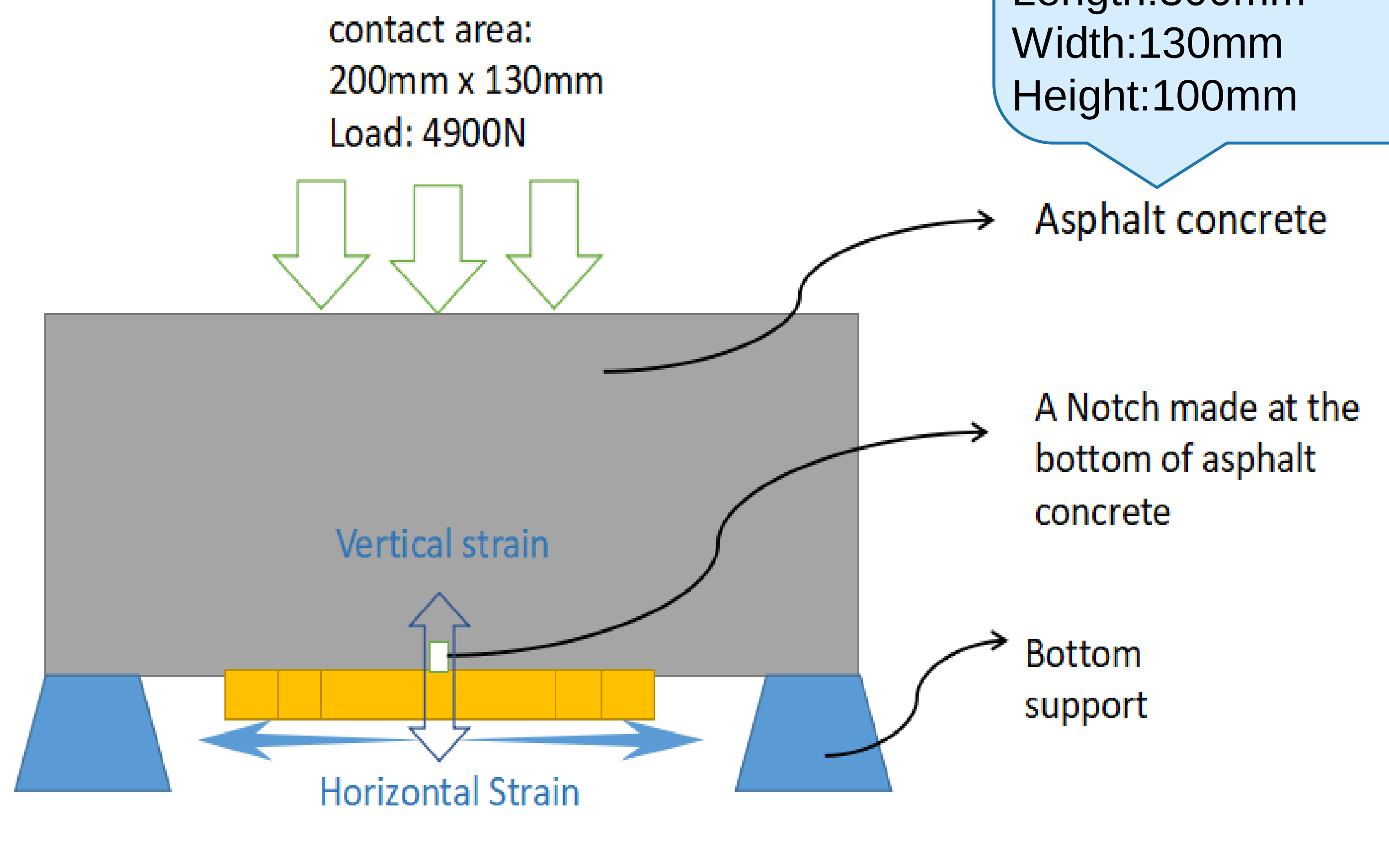


The relation between the foam thickness and output temperature

• Solid mechanics model

Three-point Bending Test

Elastic modulus: 1200 MPa
Density: 2.6g·cm^{-3}
Poisson's ratio: 0.35
Length:300mm
Width:130mm
Height:100mm



Determine the optimal ratio of the wing length to the center beam length for the H-shape sensor structure

Goal: highest sensitivity with the lowest material cost

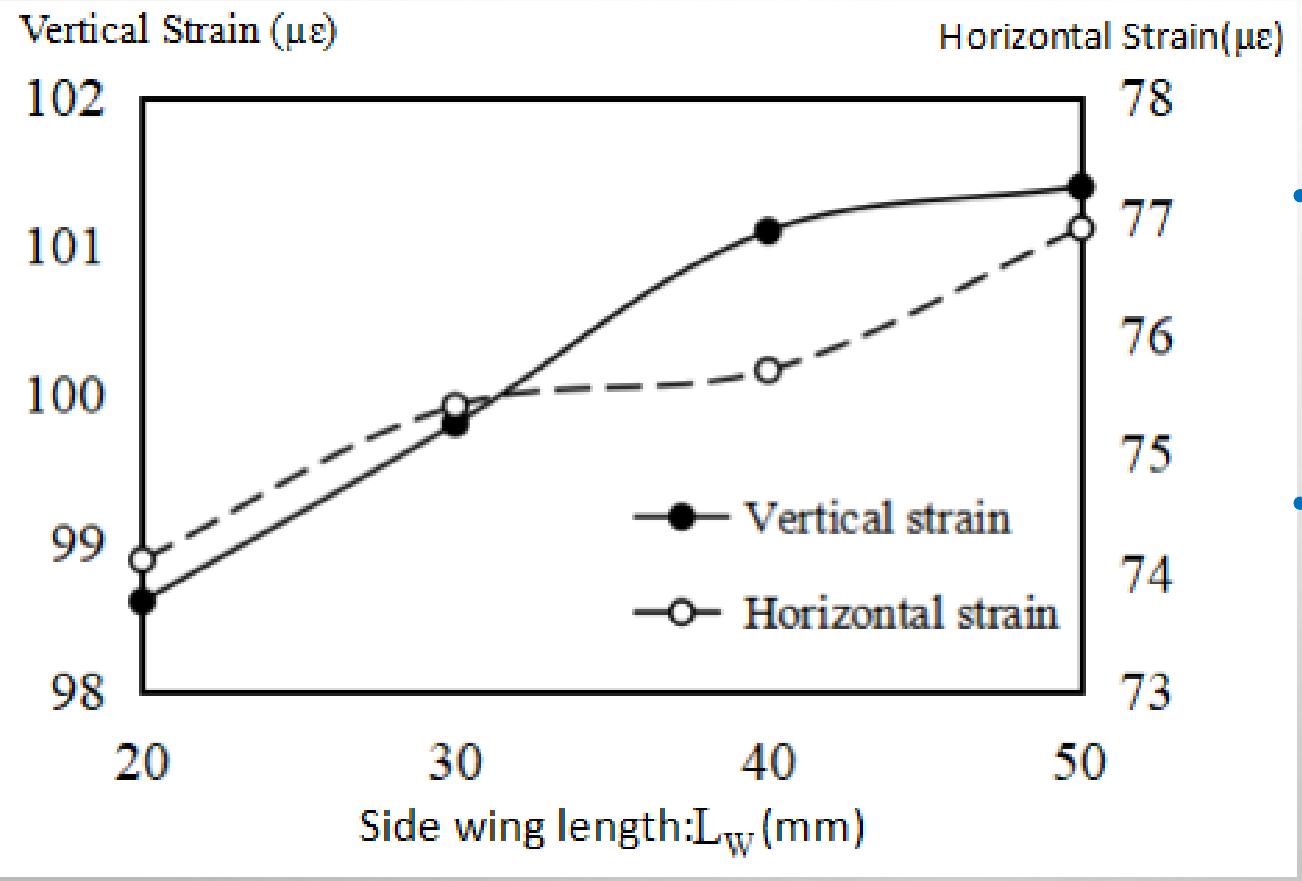
Method:

Step 1: Find optimal L_W for highest vertical/horizontal strain

Fix: length of the center beam, L_C=160 mm

Independent Variable： wing length, L_W= 20mm,30mm,40mm, 50mm

Dependent Variable: Horizontal strain, Vertical Strain

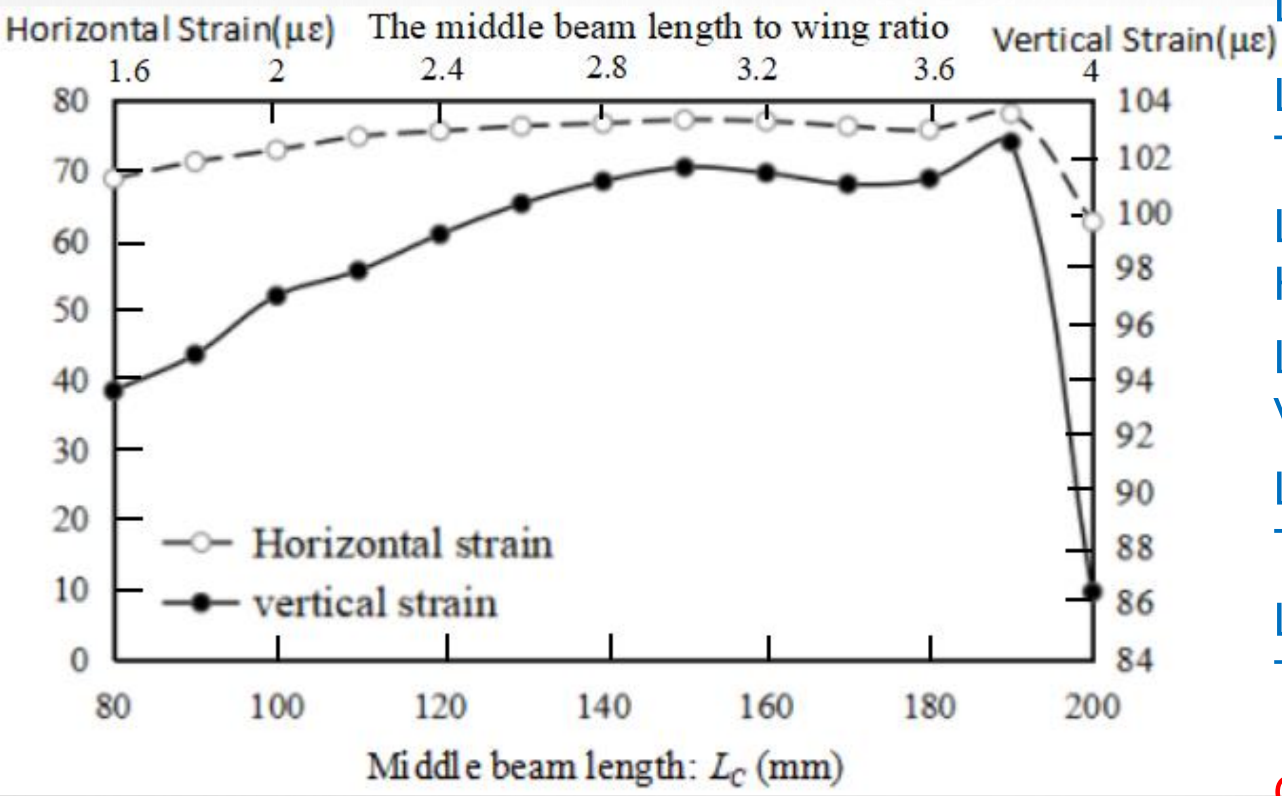


When L_W=50 mm

- vertical strain curve begins to flatten and it stabilizes at around 101με
- horizontal strain first shows a gentle trend and then shows a sharp upward trend

Step 2: Find optimal ratio of the wing length to the center beam length for highest vertical/horizontal strain

Fix: Lw=50mm
Independent Variable： Lc=0-200 mm(20mm increment)
Dependent Variable: Horizontal strain, Vertical Strain



L_C↑

L_C=0-160mm,
Two Strains increase

Lc=160-200mm,
Horizontal Strain flat

Lc=160-180mm,
Vertical Strain drop

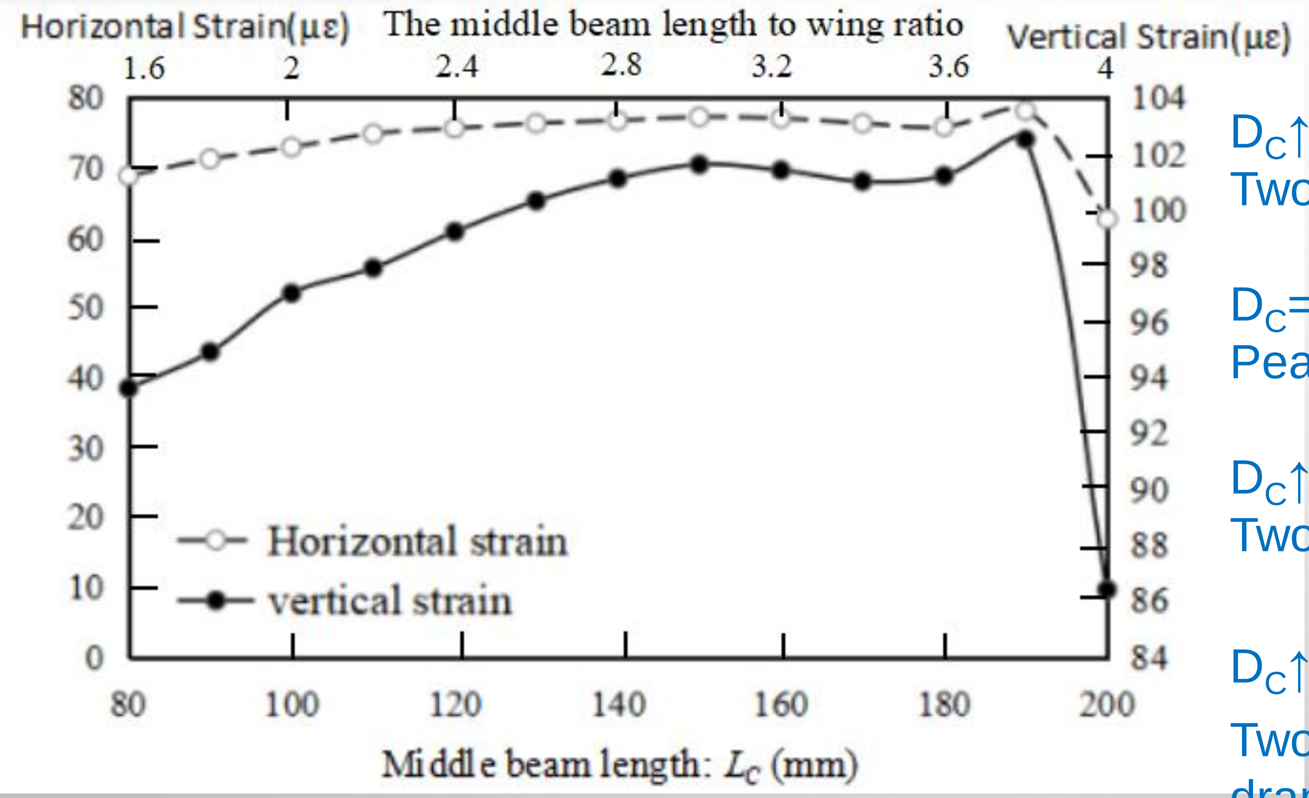
L_C=190mm,
Two Strains both have peak

Lc=200mm,
Two Strains decrease sharply

Opitical length: 160mm
Optimal Ratio: Lc/Lw=3.2

Method: Determine sensor's capability of capturing the pavement crack

Fix: Height of asphalt pavement D=100mm
Independent Variable： Crack depth Dc=0-100 mm(10mm increment)
Dependent Variable: Horizontal strain, Vertical Strain



D_C↑ From 0 mm to 50mm
Two strains increase

D_C=50mm
Peak of Two strain curves

D_C↑ From 50 mm to 90mm
Two strain curves drop slightly

D_C↑ From 90 mm to 100mm
Two strain curves drop dramatically

• Conclusion

- Optimal Ratio of the wing length to the center beam length for the H-shape sensor structure:3.2
- Optimal wing length: 50mm
- Optimal the center beam length: 160mm
- Sensor is capable to detect the horizontal/vertical strains changes with the crack initiation and propagation.

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Thank you for your attention