TOP Webinar – 25 June 2020

Closing the gap towards super-long suspension bridges using computational morphogenesis

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Suspension Bridges

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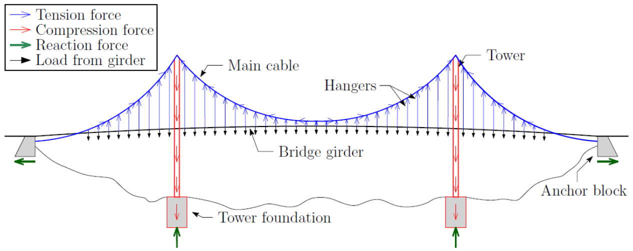
Suspension Bridges

- Girder self-weight is critical in super-long suspension bridges



- Subject to substantial fatigue issues
- Construction industry accountable for 39% of the world's CO_2-emissions

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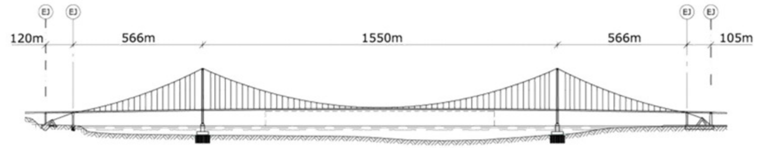
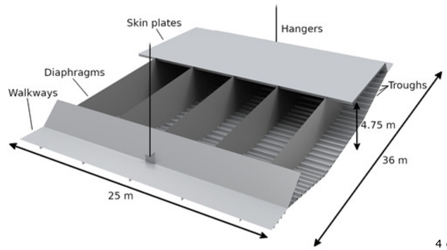
Osman Gazi Bridge (2016), Turkey





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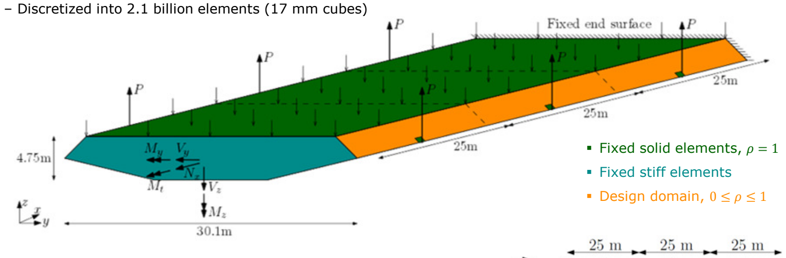
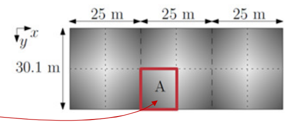
Bridge Girder Model

- FE-model: 3 sections, 75m x 30.1m x 4.75m
  - Discretized into 2.1 billion elements (17 mm cubes)



- Symmetry conditions
  - Centre x- and y-axis of each section
  - Design domain: 12.5m x 15.05m x 4.75m



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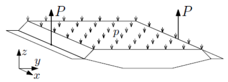
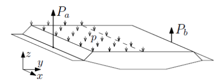
Bridge Girder Model

- Global load cases
  - Identified from global beam model of entire bridge
- Local load cases
  - Full surface load + equivalent hanger forces
  - Half surface load + equivalent hanger forces





- Optimization problem:
  - Maximize stiffness (in centre span) for given amount of material ($V^* = 3\%$)

$$\min_{\boldsymbol{\rho}} \quad \phi = \sum_{i=1}^{N_k} \alpha_i \mathbf{u}_i^\top \mathbf{K} \mathbf{u}_i \qquad \text{(Sum of compliance)}$$
$$\text{s.t.} \quad \mathbf{K}(\boldsymbol{\rho})\mathbf{u}_i = \mathbf{F}_i, \quad \forall i = 1, \dots, N_k \qquad \text{(State equations)}$$
$$\frac{V(\boldsymbol{\rho})}{V^*} - 1 \le 0 \qquad \text{(Volume constraint)}$$
$$0 \le \rho_e \le 1, \quad \forall e = 1, \dots, N_e \qquad \text{(Box constraints)}$$

- Solver: Method of moving asymptotes (MMA)
- Filter: Density with radius 1.5 x element size
- 400 iterations over 85 hours on 16,000 CPUs

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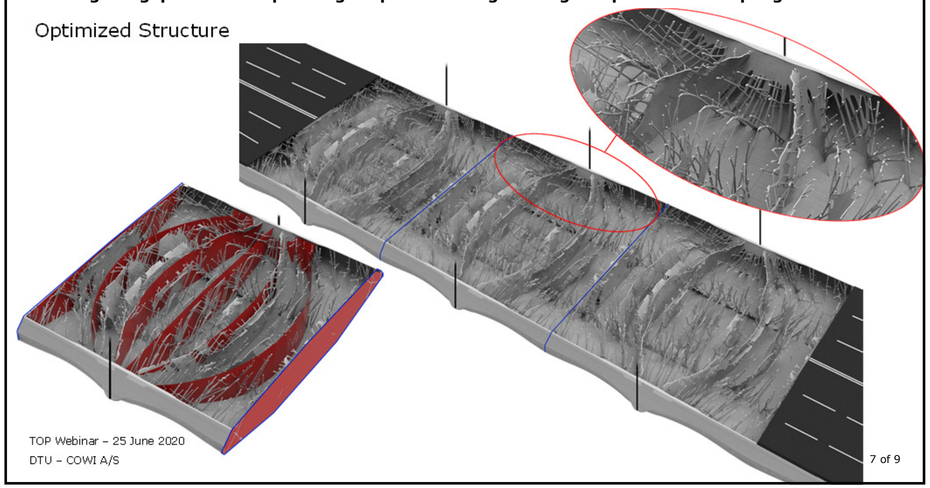
Optimized Structure



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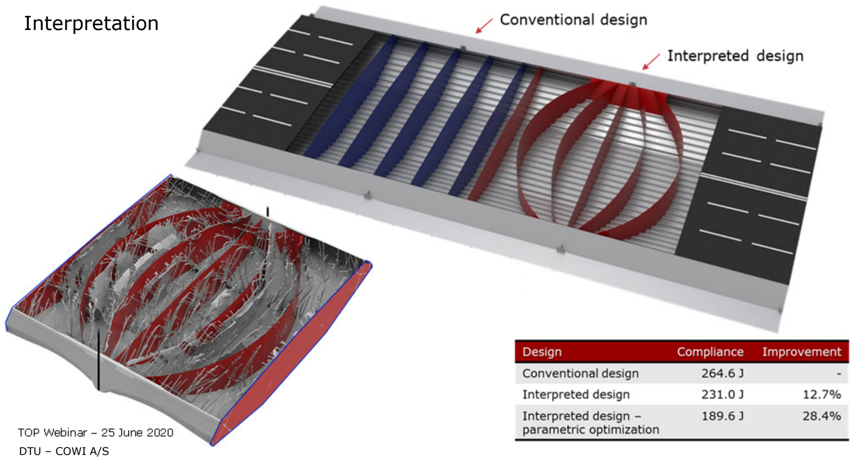
Interpretation



Design	Compliance	Improvement
Conventional design	264.6 J	-
Interpreted design	231.0 J	12.7%
Interpreted design – parametric optimization	189.6 J	28.4%

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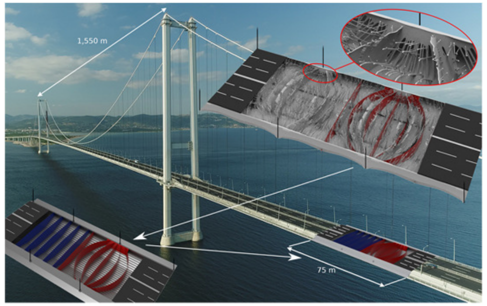
Conclusions

- Possible weight savings of 12.7%-28.4%
  - Equivalent to a reduction in CO_2 of 8.5%-18.5% (entire bridge)
- Interpreted design
  - Increase in number of diaphragms
  - Diaphragms curved towards hanger anchorages
  - Longitudinal support panels
- Demonstration of topology optimization in civil engineering
  - Interpretation of complex results to simple designs
  - Beneficial in early design stage



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