Curved Concrete Elements:

Rheological Parameters used for Deliberate Deformation of a Flexible Mould after Casting

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RILEM Paris Conference

Goal: make curved concrete

Outline

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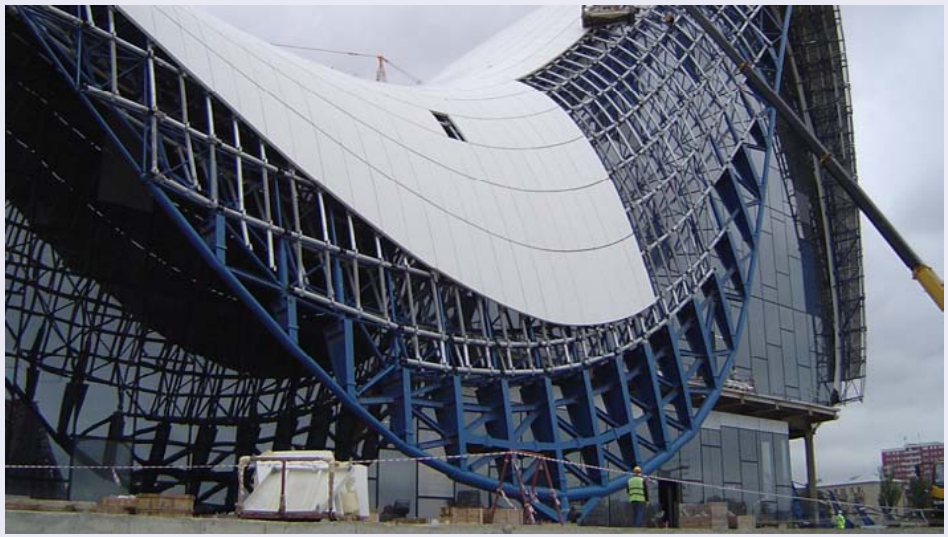
Curved Elements in Freeform Architecture

Trends in precast concrete:

- More and more buildings with complex geometry
- Manufacturing is expensive:
  - limited repetition
  - high mould costs
  - complex shape
- Reconfigurable Mould System

Heydar Aliyev Cultural Centre Baku (Zaha Hadid Architects)



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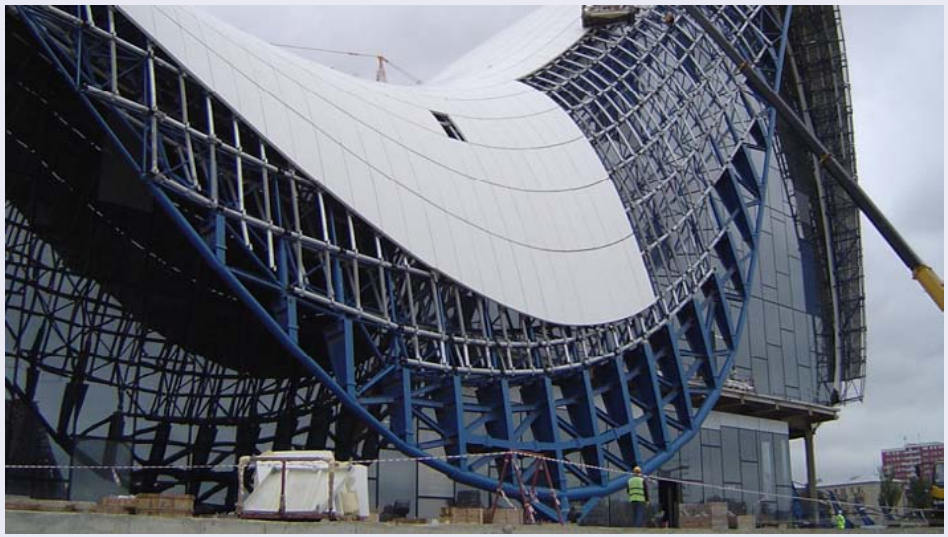

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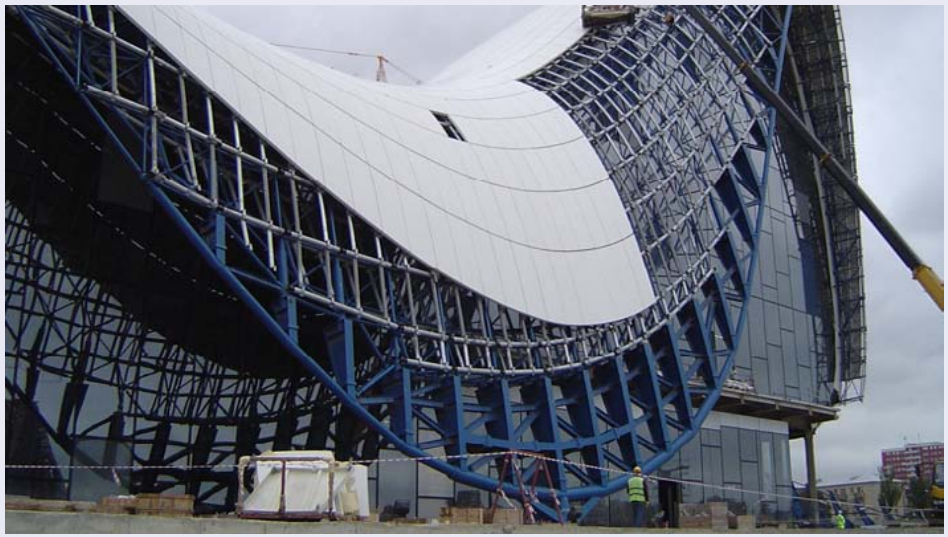

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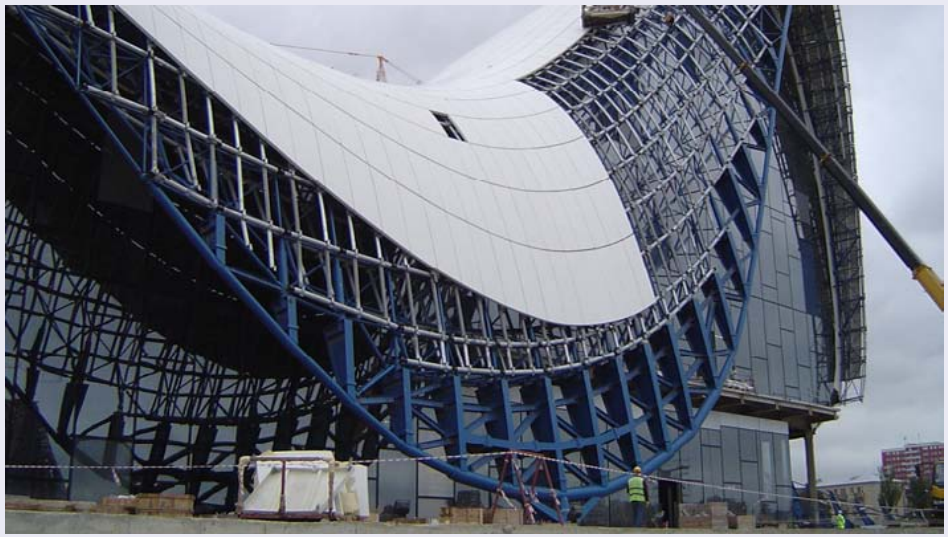

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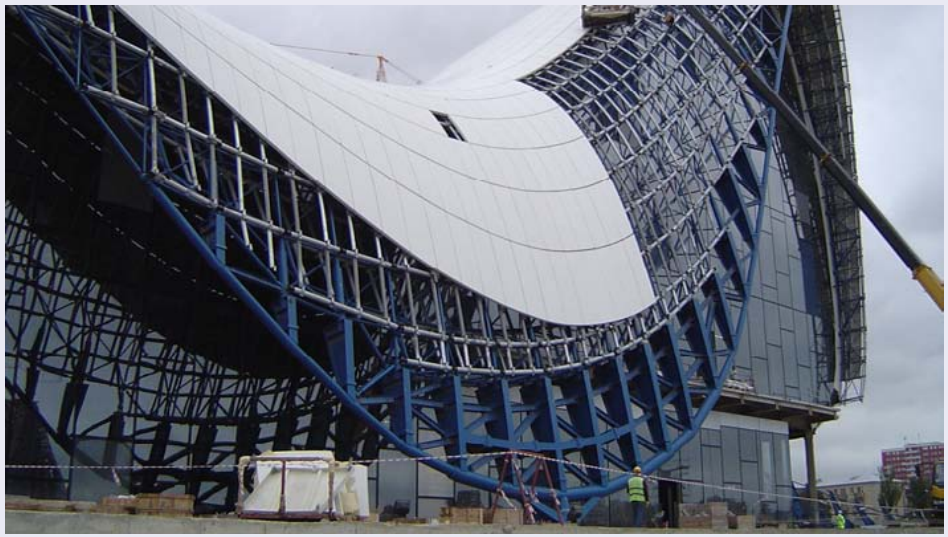

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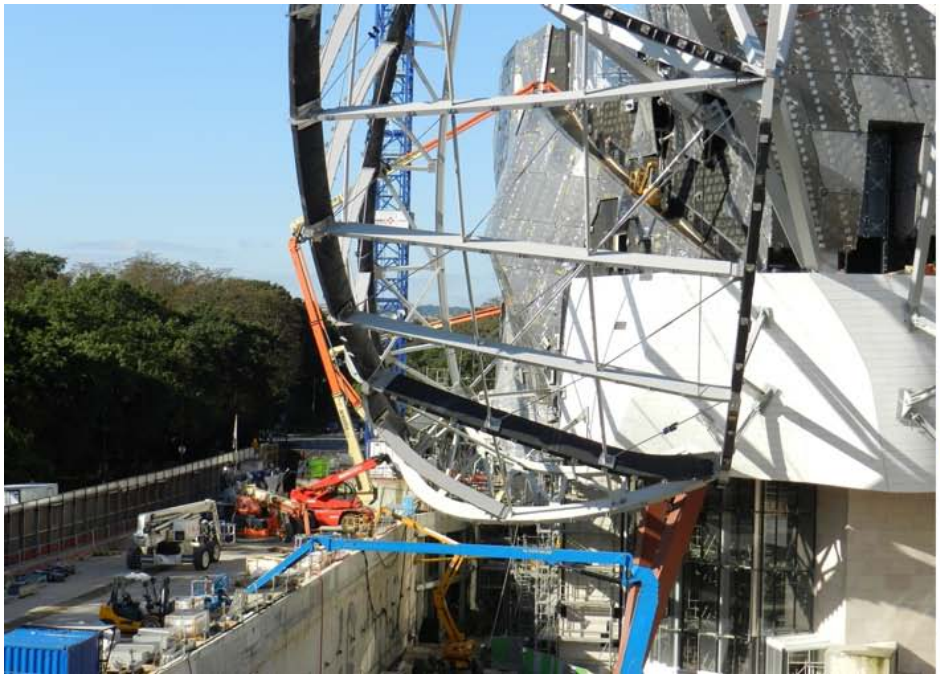
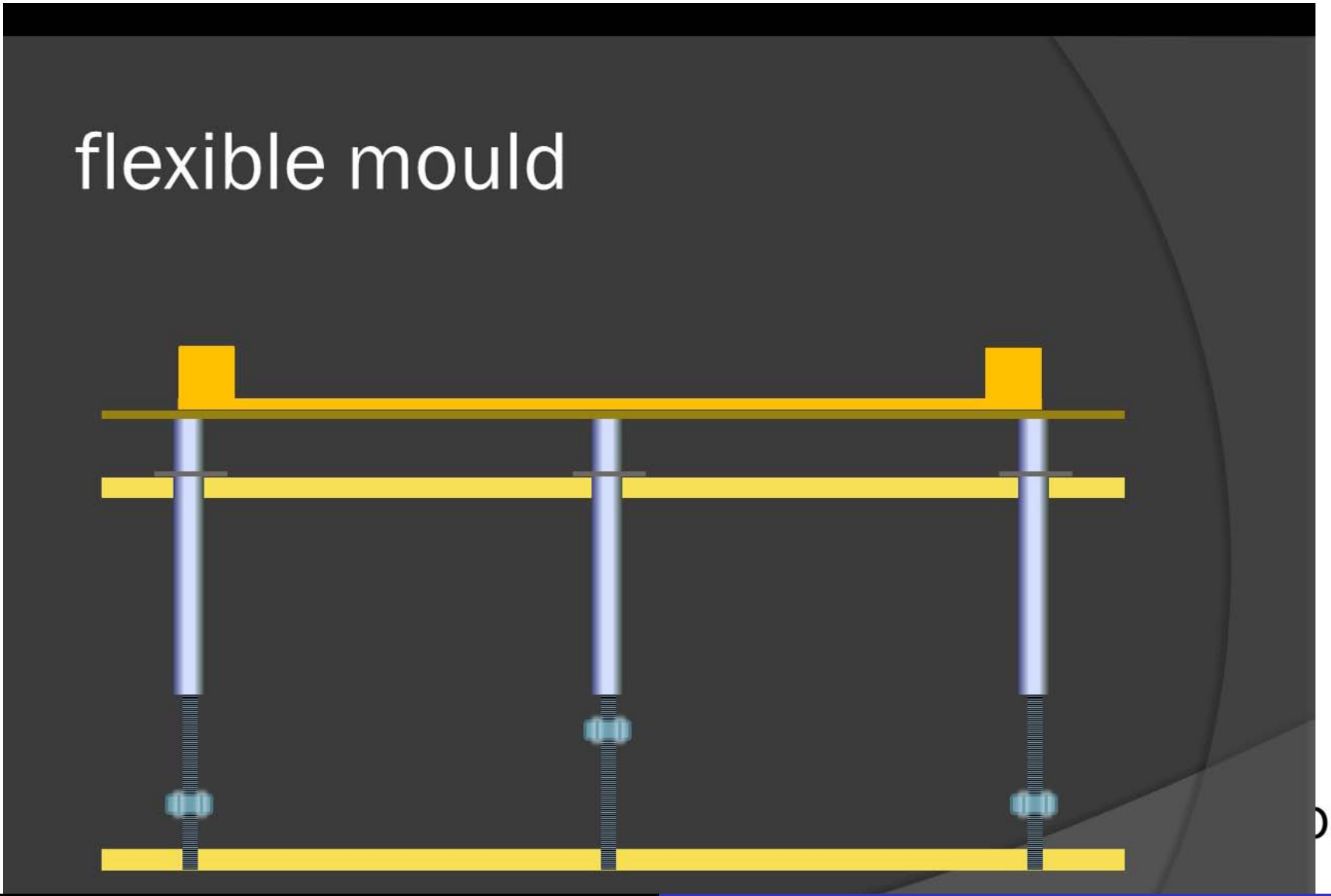
Curved façade cladding



Fondation Louis Vuitton pour la création, Paris
Frank O'Gehry Architects

Principle



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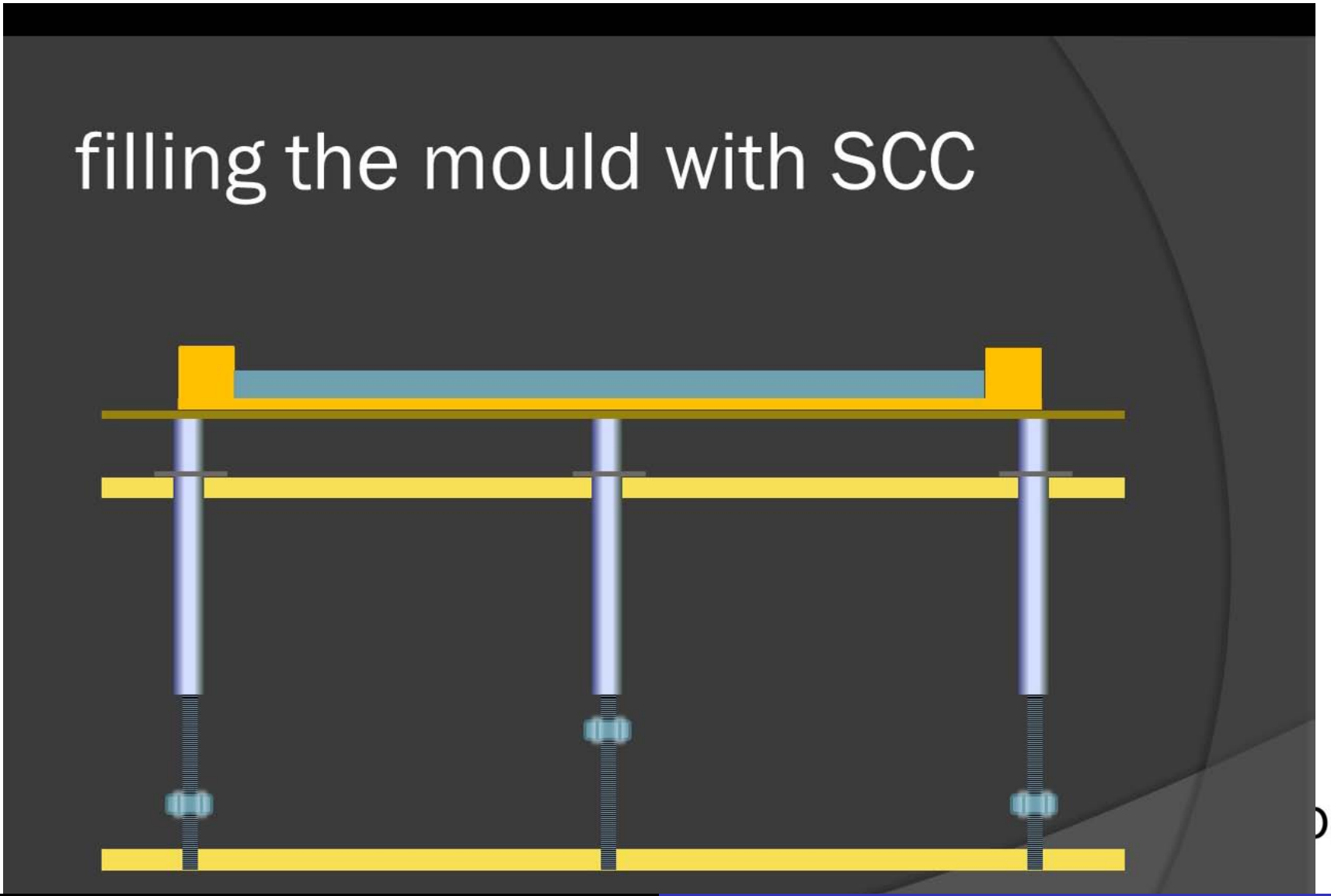

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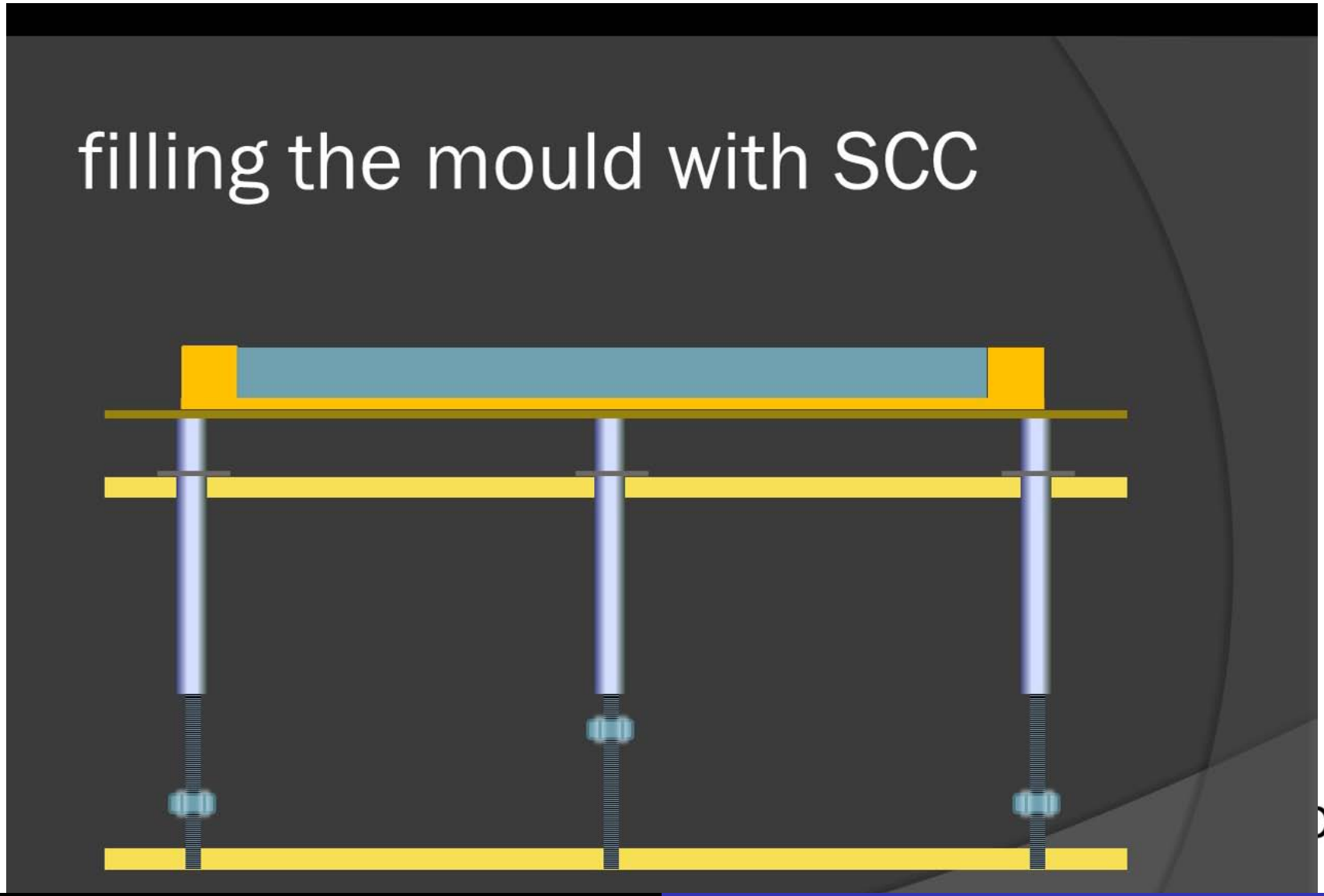

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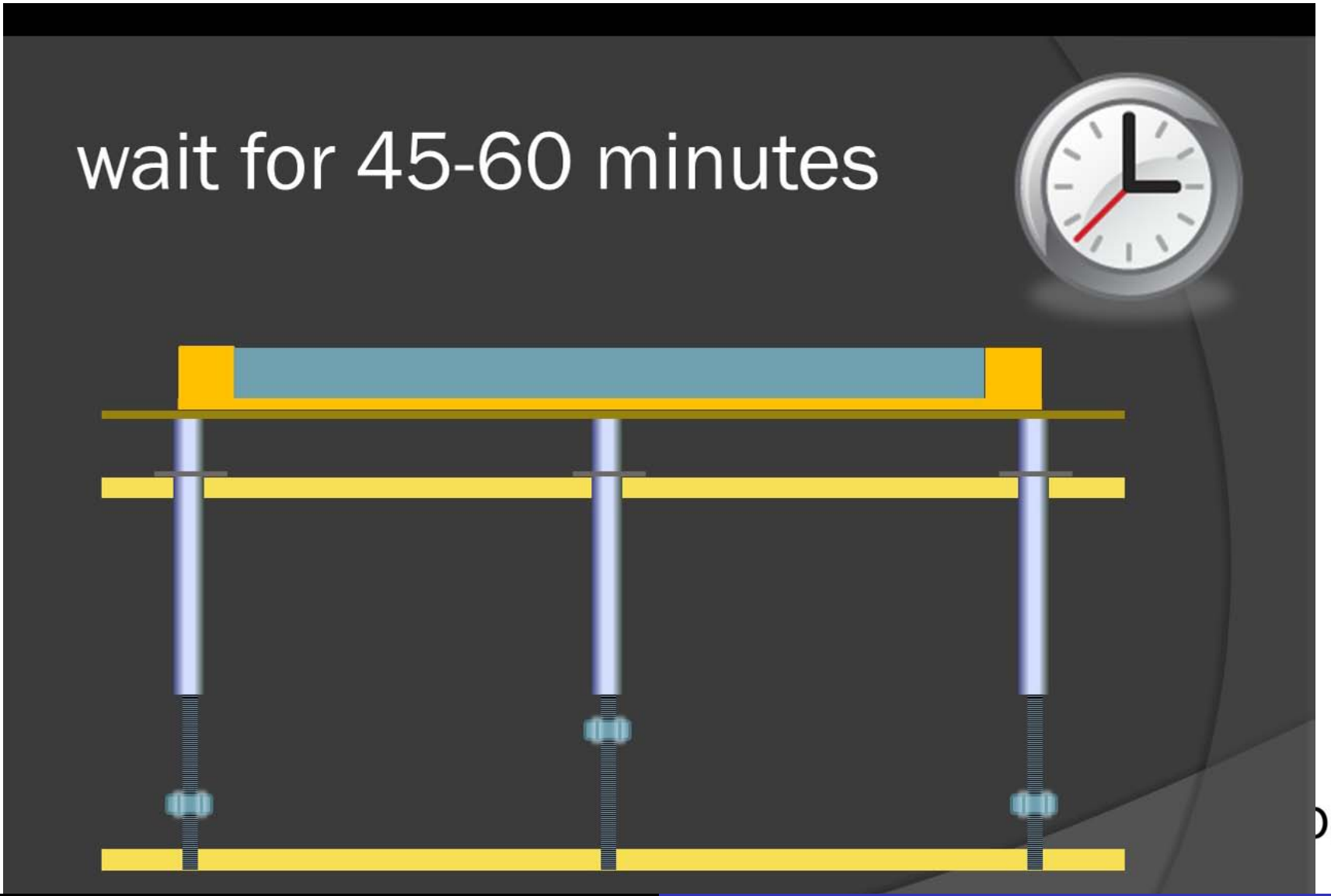

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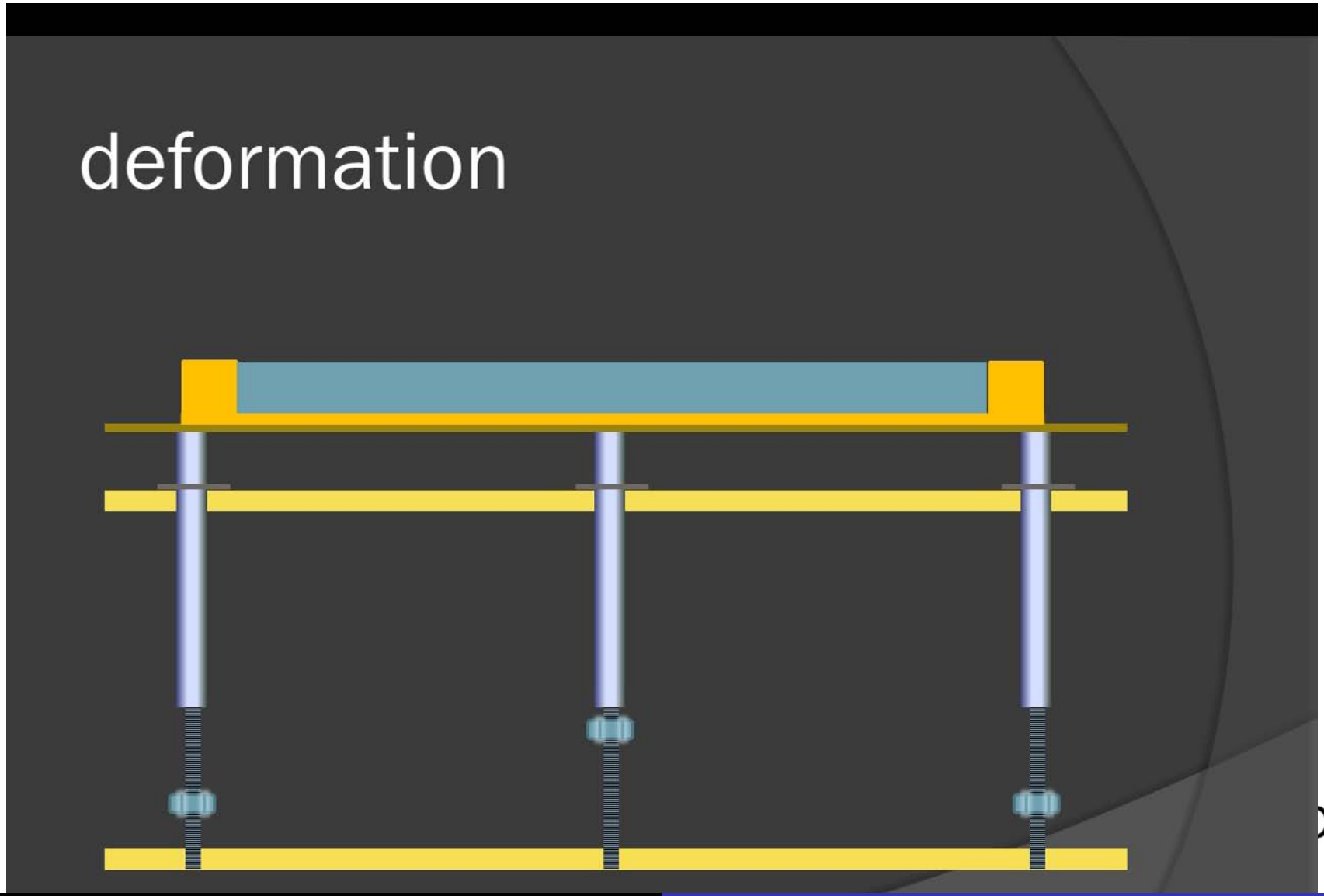

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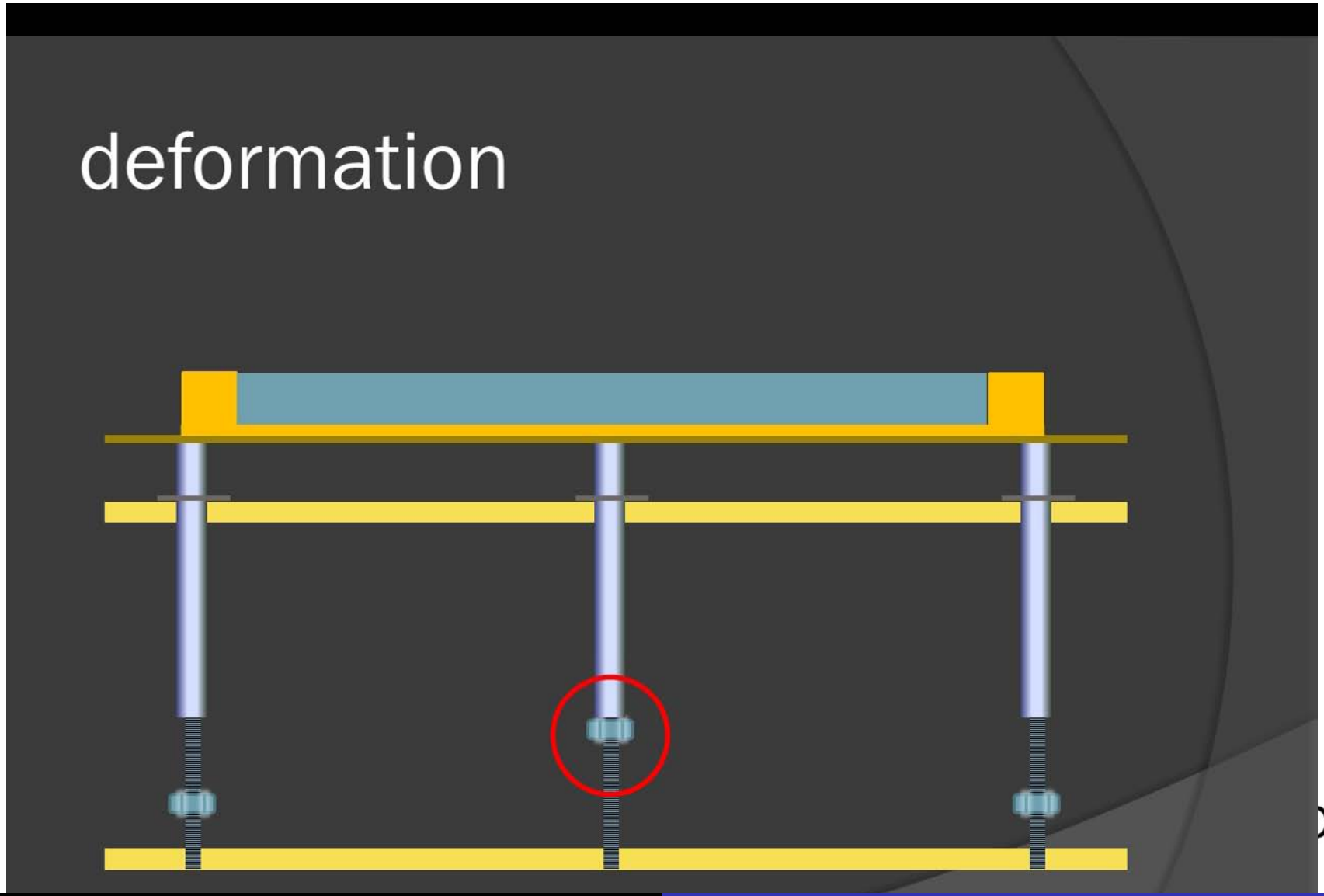

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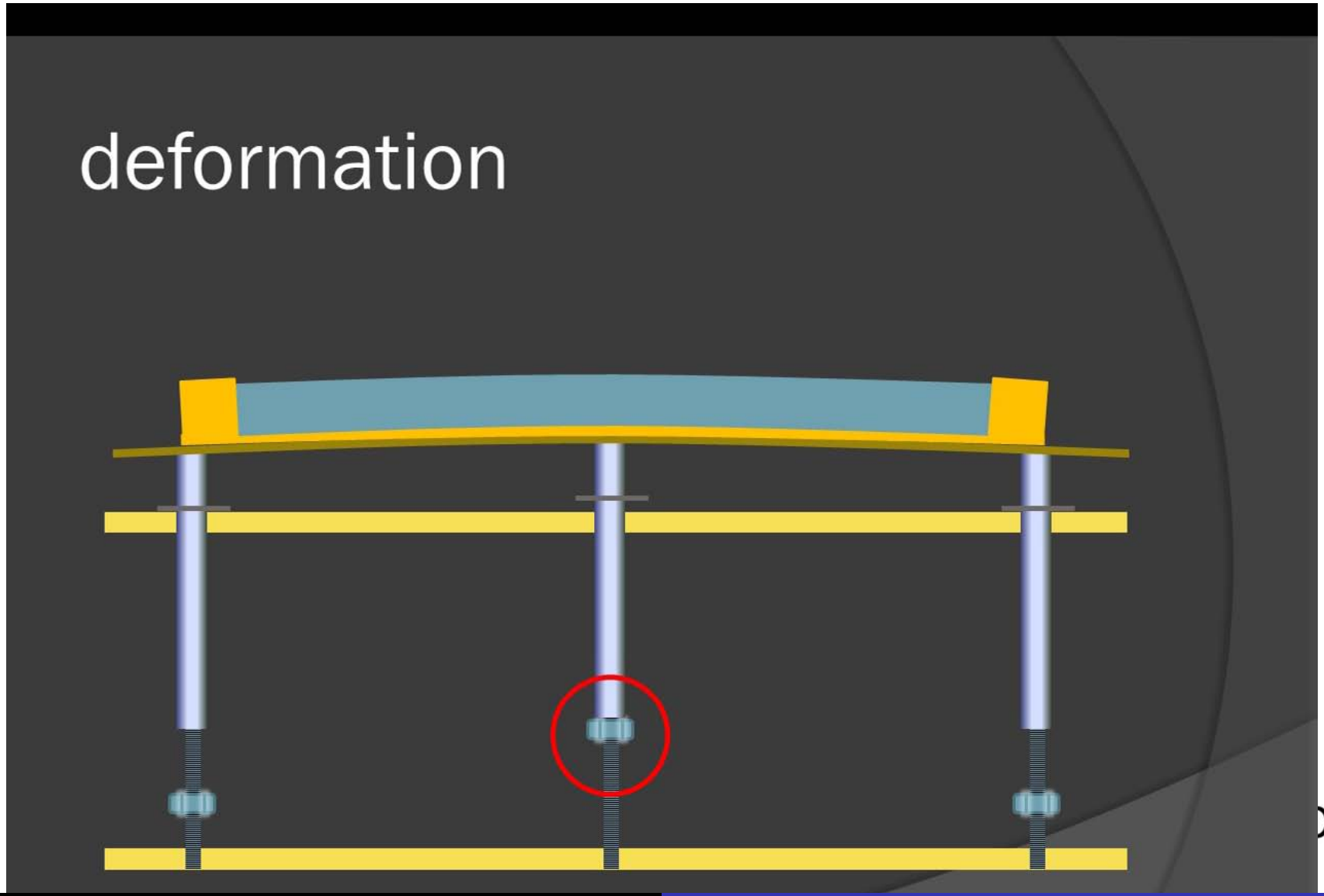

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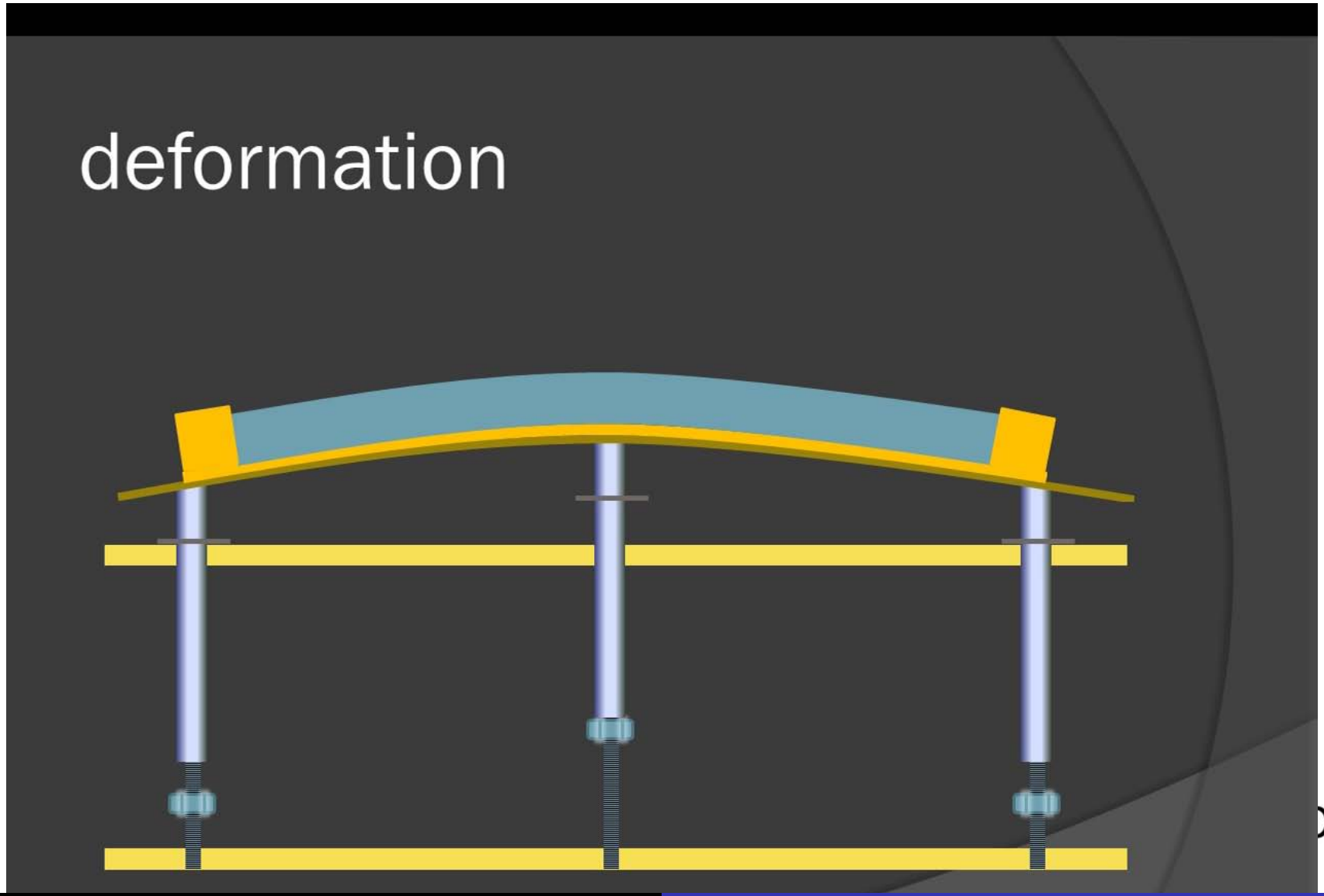

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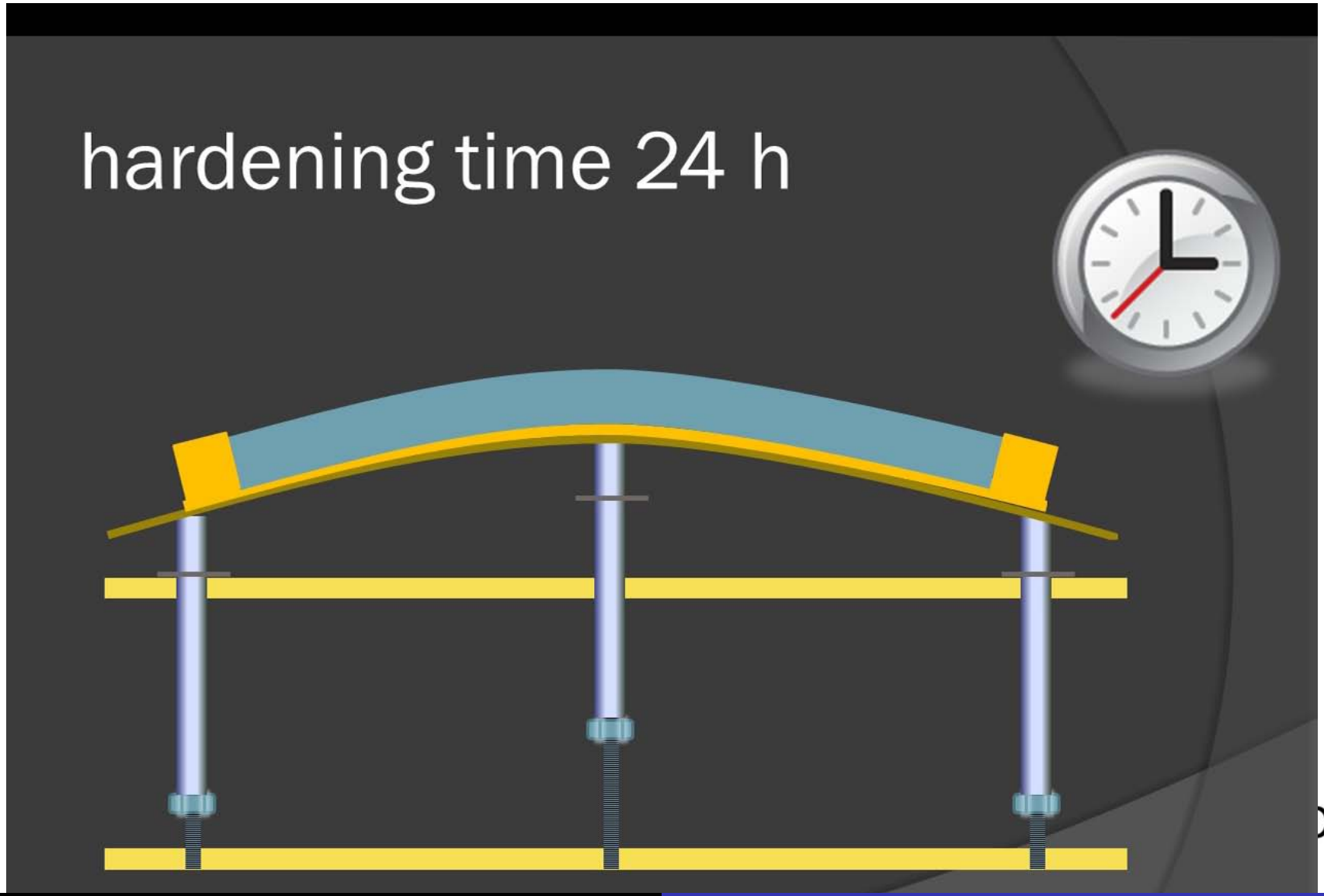

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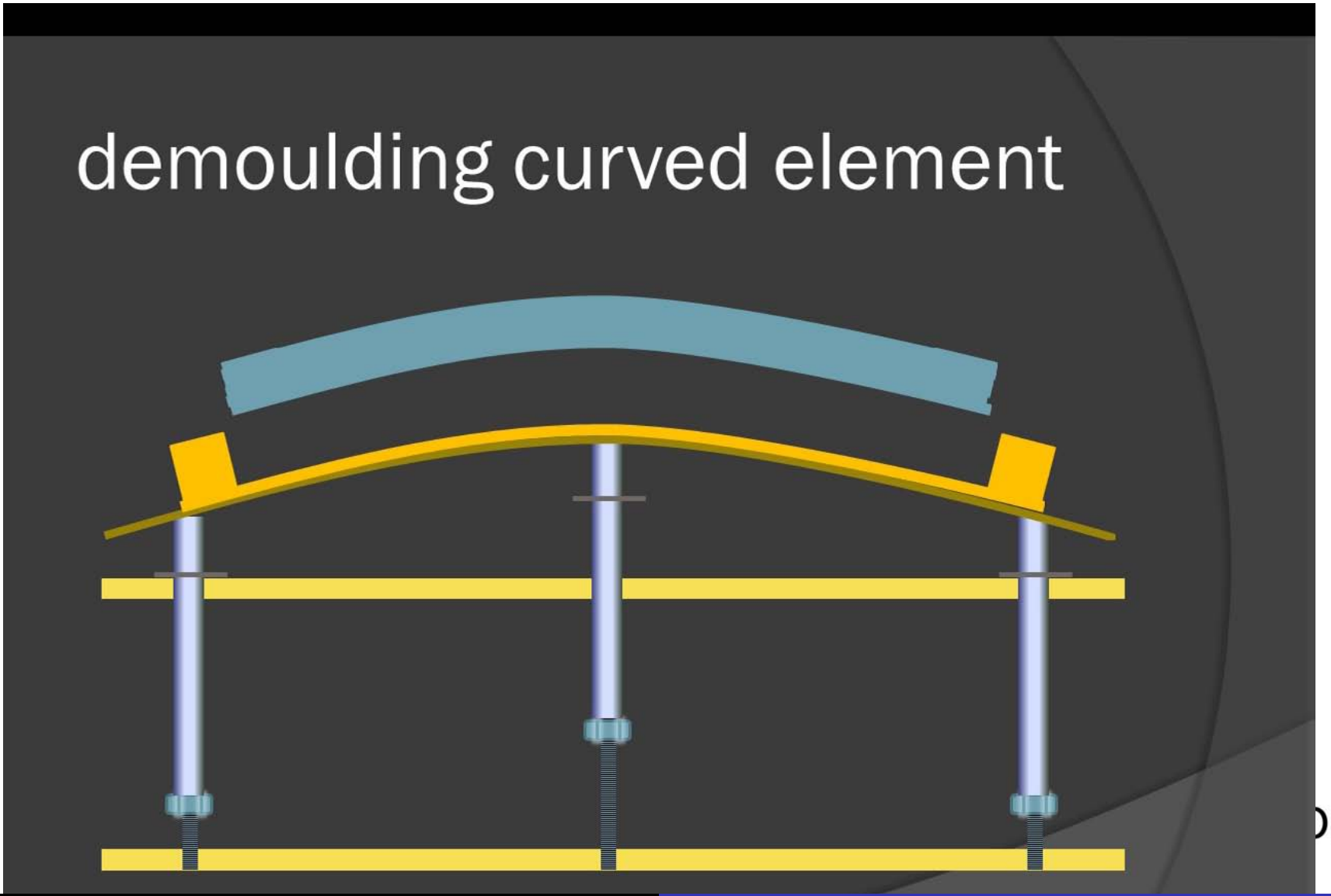
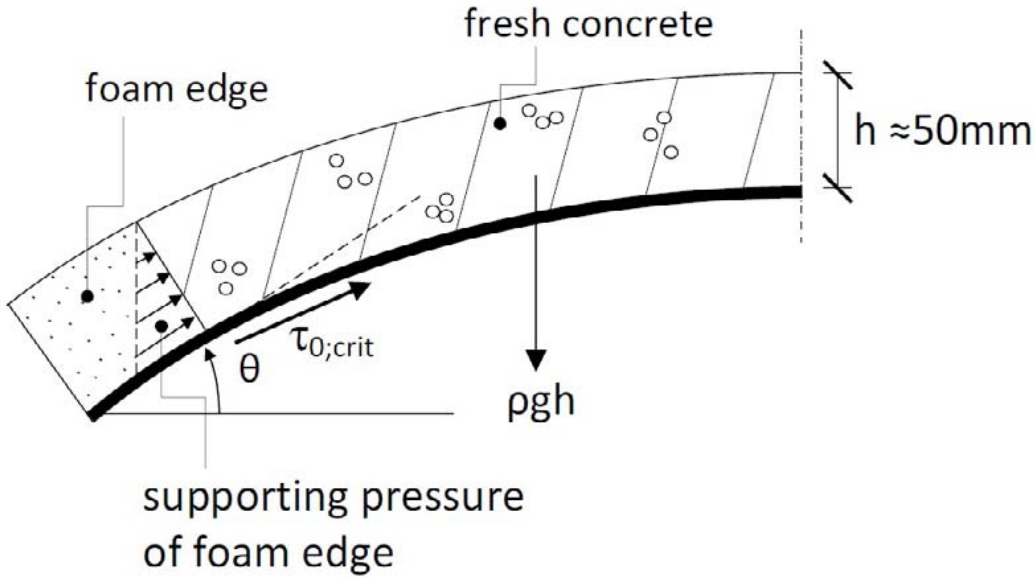


Slope

Open mould -> slope

- Gravity makes concrete flow down
- Yield strength keeps concrete in place
- Edge of mould keeps concrete in place



Curvature

Bending -> Curvature

- By deforming a strain is initiated
- Yield strength might lead to cracks
- Relation between R and h?

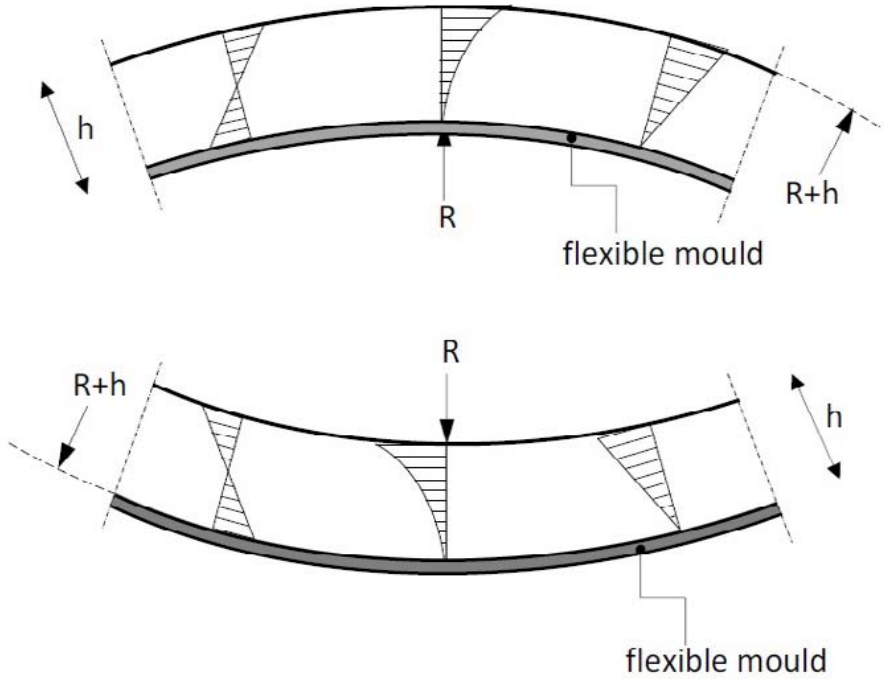


Table with needed yield strength

Table 2. Critical yield strength $\tau_{0;crit}$ necessary for casting under slope θ, depending on mould radius, element length (horizontal) and height (for a circular shape $\tau_{0;crit} = \rho\, g\, h\, L / 2R$)

Element length	**Element height**	**curvature R=1.5 m**		**curvature R=2.5 m**		**curvature R=5.0 m**	
L [m]	h [m]	slope θ [°]	$\tau_{0;crit}$ [Pa]	slope θ [°]	$\tau_{0;crit}$ [Pa]	slope θ [°]	$\tau_{0;crit}$ [Pa]
0.80	0.025	15.5	157	9.2	94	4.6	47
0.80	**0.050**	**15.5**	**314**	9.2	188	4.6	94
0.80	0.100	15.5	628	9.2	377	4.6	188
2.00	0.025	41.8	329	23.6	235	11.5	118
2.00	0.050	41.8	785	23.6	471	11.5	235
2.00	0.100	41.8	1570	23.6	942	11.5	471

Using thixotropy

Thixotropic mixtures were used:

- two mixtures
  - mixture 1 (coarse): all aggregates < 8 mm
  - mixture 2 (fine): al aggregates < 1 mm
- use of sufficient amount of fines
  - cement CEM I 52,5 R
  - Fly ash
  - Omya Betoflow D
- superplasticizer Chryso Premia 196
- quick structural build-up in first hour after mixing

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Test Setup - four identical moulds

Timber frame with silicone moulds

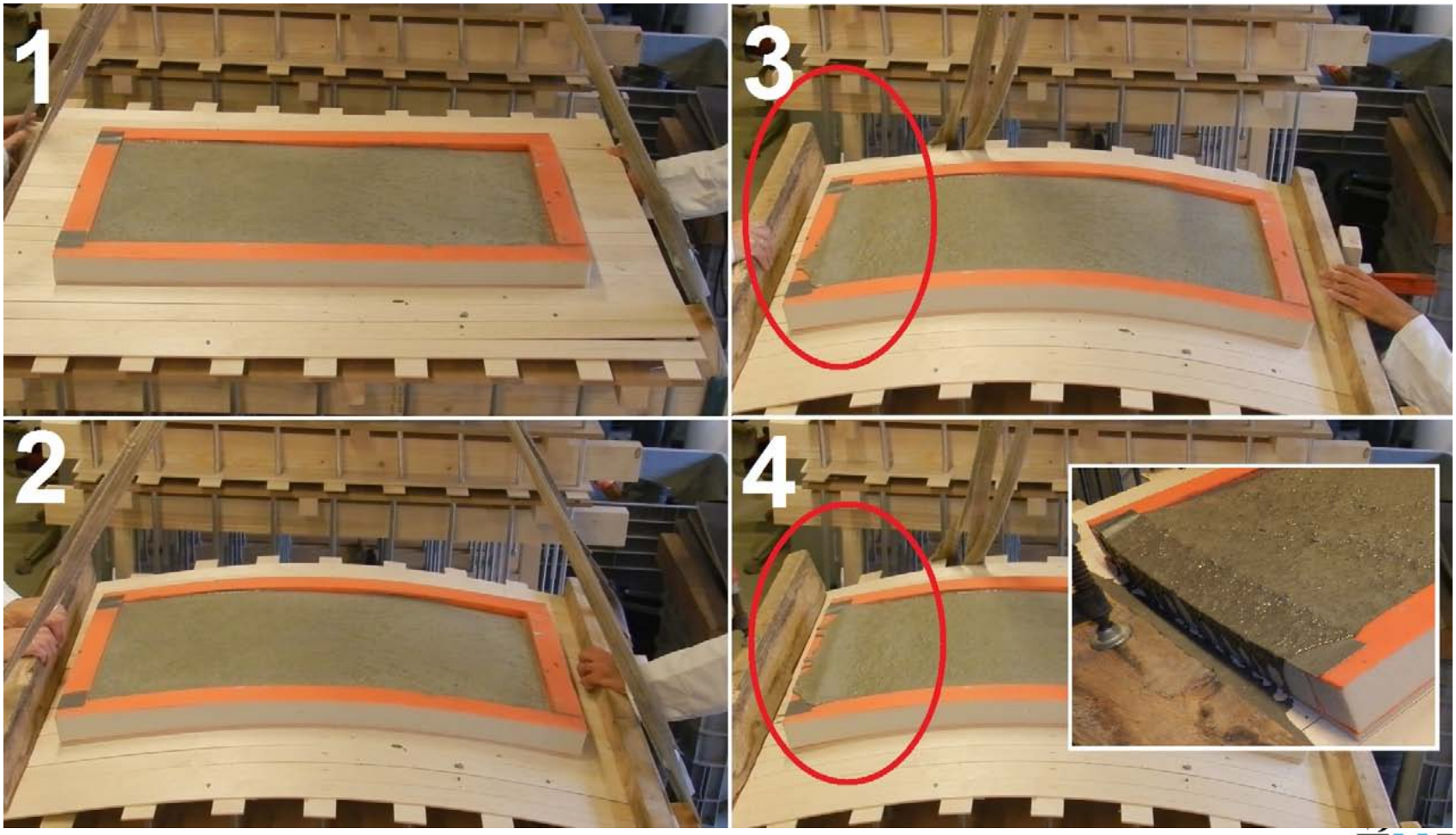
- Simple grid of metal pins
- Manual adjustment of height
- Double layer of timber strips
- Silicone rubber moulds

Rheology

Slump (flow) tests

BML Viscometer

Deformation after casting



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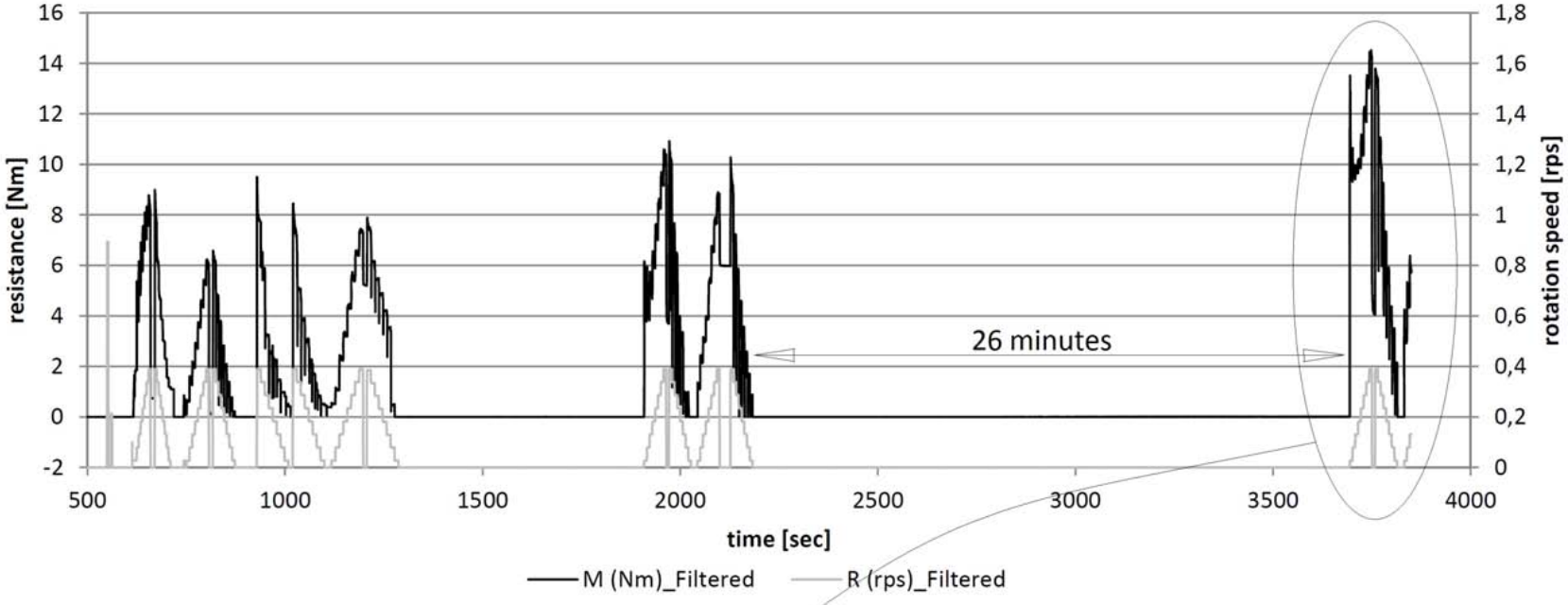
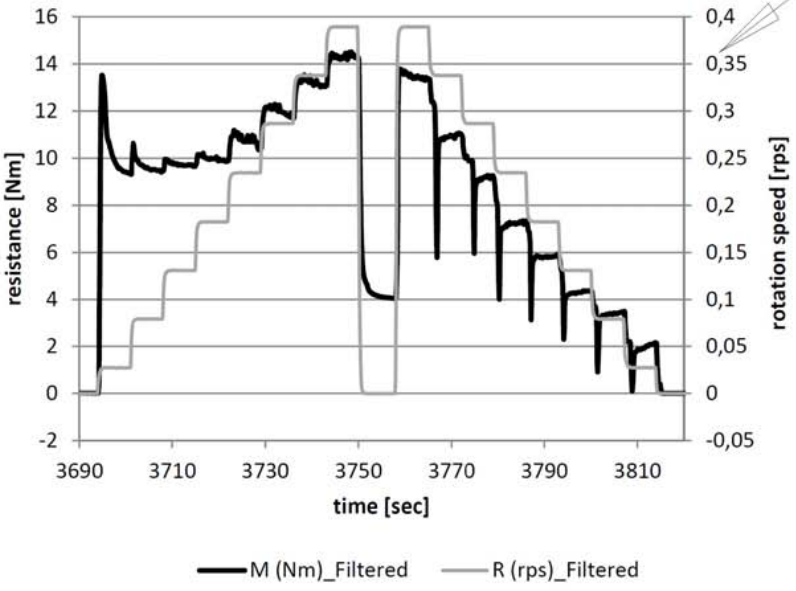
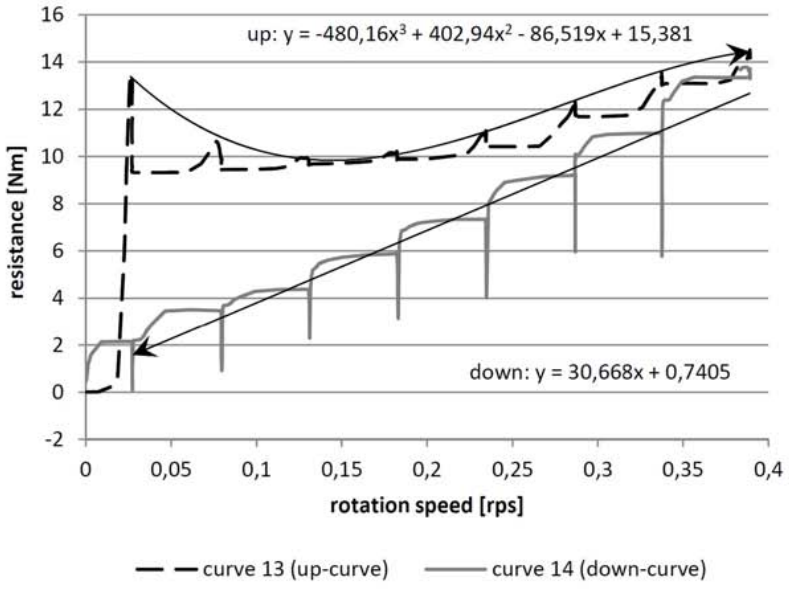
Deformation after casting

Rheology - Slump tests

Rheology - BML Viscometer







Cast elements

Good quality

Combined elements

Cut slices

Conclusions

1. deforming an open mould is possible
   - concrete does not flow out
   - no cracking due to deformation
2. curvature with R=1.5 m is possible
3. deformation 30-60 minutes after mixing
4. use thixotropic mixture
   - quick rise of yield strength
   - still plastic enough to prevent cracking

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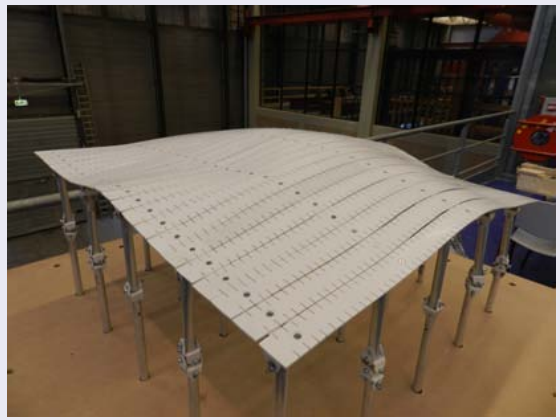
Future research

reinforcement

beauty

shape control



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- lab technicians

conovation

Thank you for your attention!

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