



# Burðargetumat steyptra brúa

Álagsprófun brúar á Steinavötn

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Einar Óskarsson

Ólafur Sveinn Haraldsson

Aron Bjarnason

Atli Geir Ragnarsson, Háskólanum í Reykjavík

Rannsóknaráðstefna Vegagerðarinnar / 1.nóvember 2019

osmos



ETH zürich



## Innihald

- Aðdragandi prófananna
- Af hverju vorum við að þessum prófunum?
- Hvað var gert
- Örstutt farið í niðurstöður



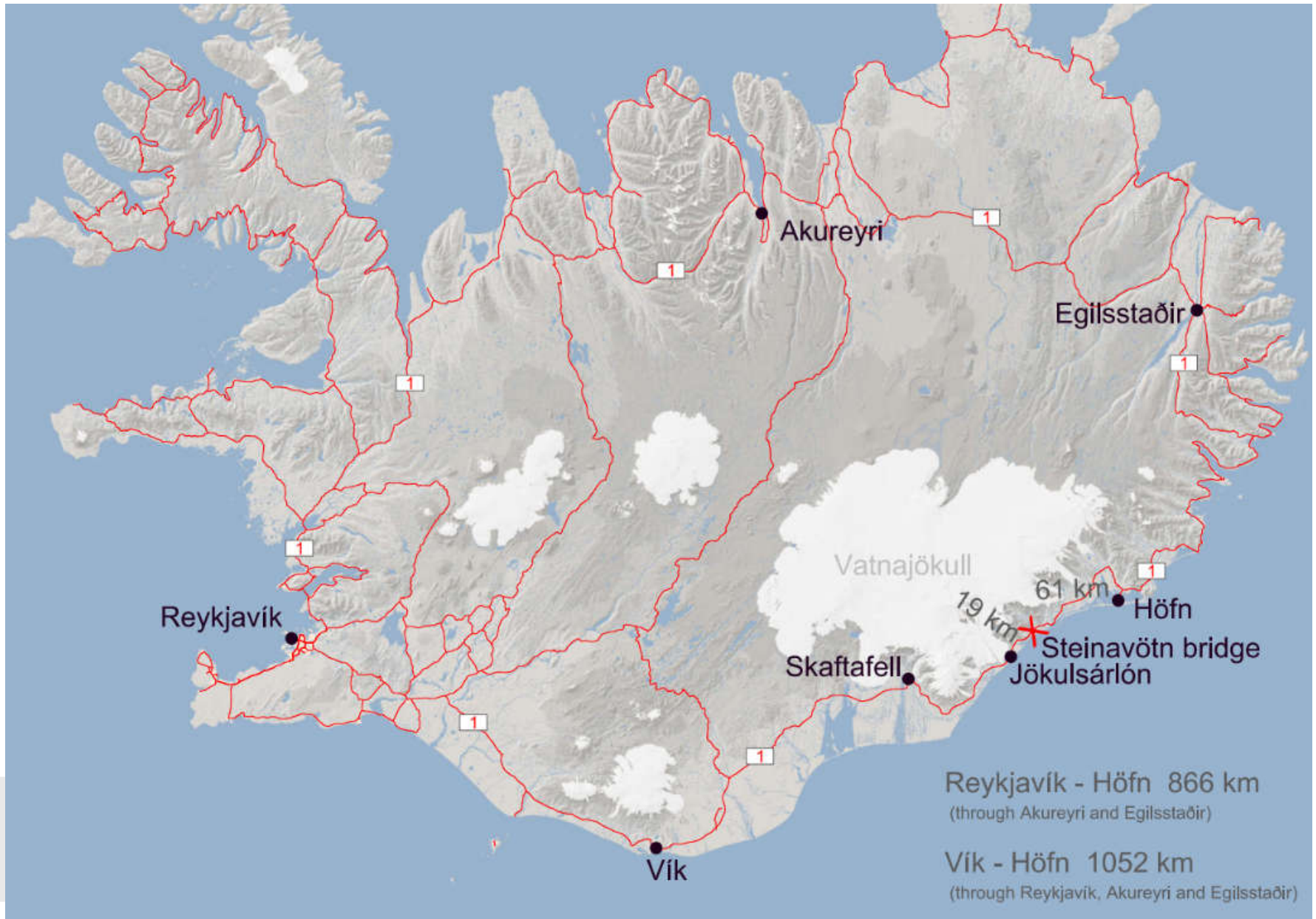
## Þátttakendur

- Einar Óskarsson, Vegagerðin
- Ólafur Sveinn Haraldsson, Vegagerðin
- Aron Bjarnason, Vegagerðin
- Atli Geir Ragnarsson, tæknifræðinemi HR
- Prof.Eleni Chatzi (ETH Zurich)
- Dr. Vasilis Dtertimanis (ETH Zurich)
- Constant Choqueuse (Osmos Monitoring Group)
- Jónas Þór Snæbjörnsson (Háskólinn í Reykjavík)
- Eypór Þórhallsson (Háskólinn í Reykjavík)
- Brúarvinnuflokkur Vegagerðarinnar í Vík

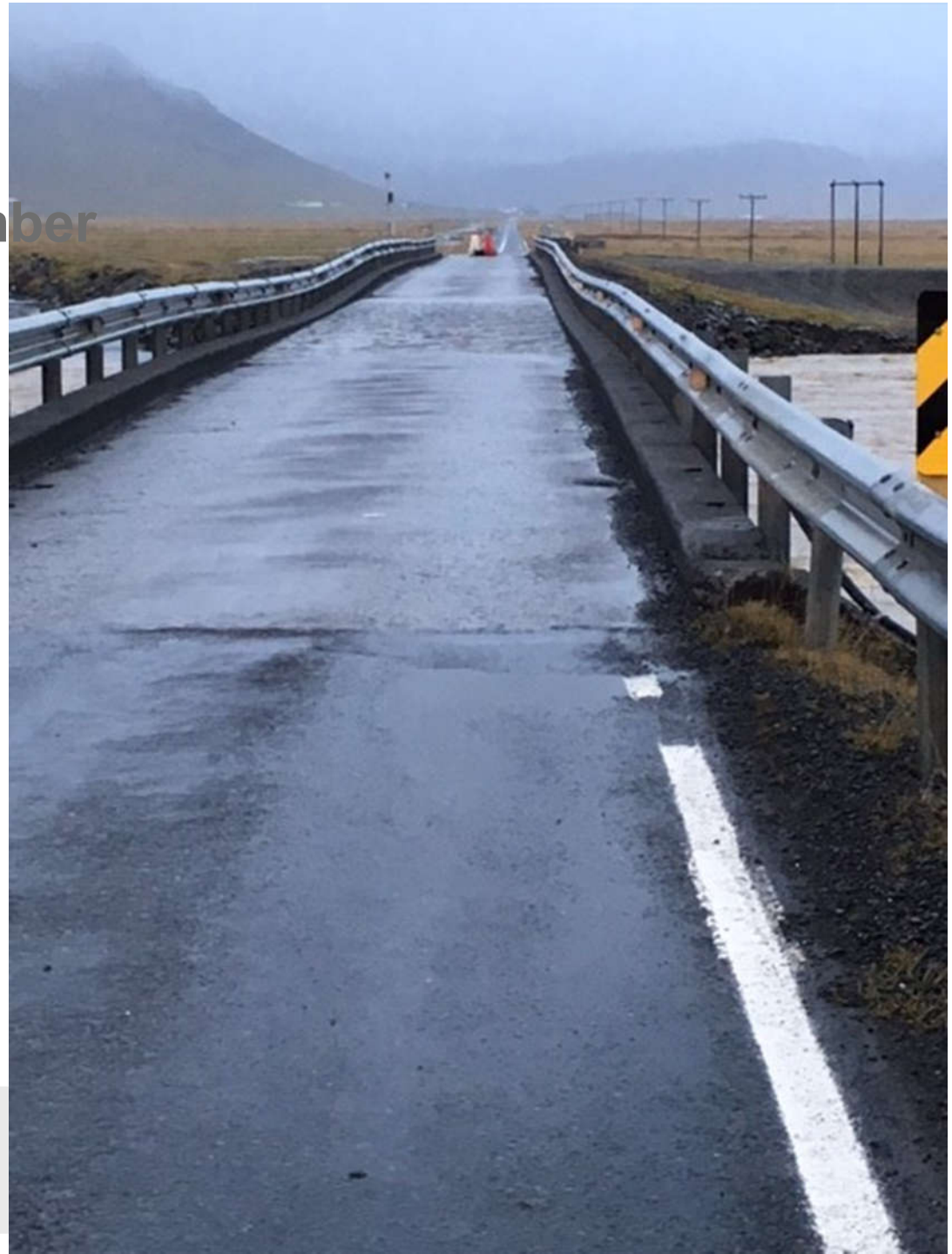
## Brú á Steinavötn

- Miðvikudagur 28.September
  - Miðvikudagskvöld 28.september
  - Fimmtudagur 29. September
  - Föstudagur 30.September
  - Föstudagur 30.sept
  - Föstudagur 30.sept
  - Laugardagur 31.sept  
setja út fyrir bráðabirgðavegi
  - Sunnudagur 1.okt
  - Mánudagur 2. okt
  - Þriðjudagur 3.okt
  - Miðvikudagur 4.okt
- Rigningar á Austurlandi, 50-200 ára flóð  
Hringvegi við Steinavötn lokað, Hringvegur á Mýrum lokast  
Grafið frá stöpli, búið að staðsetja nýja brú  
Undirbúningur framkvæmda  
Tilkynning til sveitarfélags um framkvæmdir  
Hönnun bráðabirgðavegar  
Byrjað á undirstöðum, vatnaveitingar, búið að  
  
Hringvegur um Mýrar opnast  
  
Vatni veitt undir nýja brú  
Frágangur á vegi, opnað á hádegi

# Lokanir á Hringvegi (1)




Atburðarásin 29.september



# Brú á Steinavötn

28.9 kl.12:15



Steinavötn (12:15)  
Stöpull hefur sigið um 20  
cm  
Stöpull virðist vera aðeins  
snúinn.

# Brú á Steinavötn

28.9 kl.13

Steinavötn (13:03)  
Sprungur yfir aðliggjandi  
stöplum. Fjölgaði eftir því  
sem á leið.



# Brú á Steinavötn

28.9 kl.19

Steinavötn (~19:00)  
Stöpullinn virðist hanga laus  
í yfirbyggingunni.



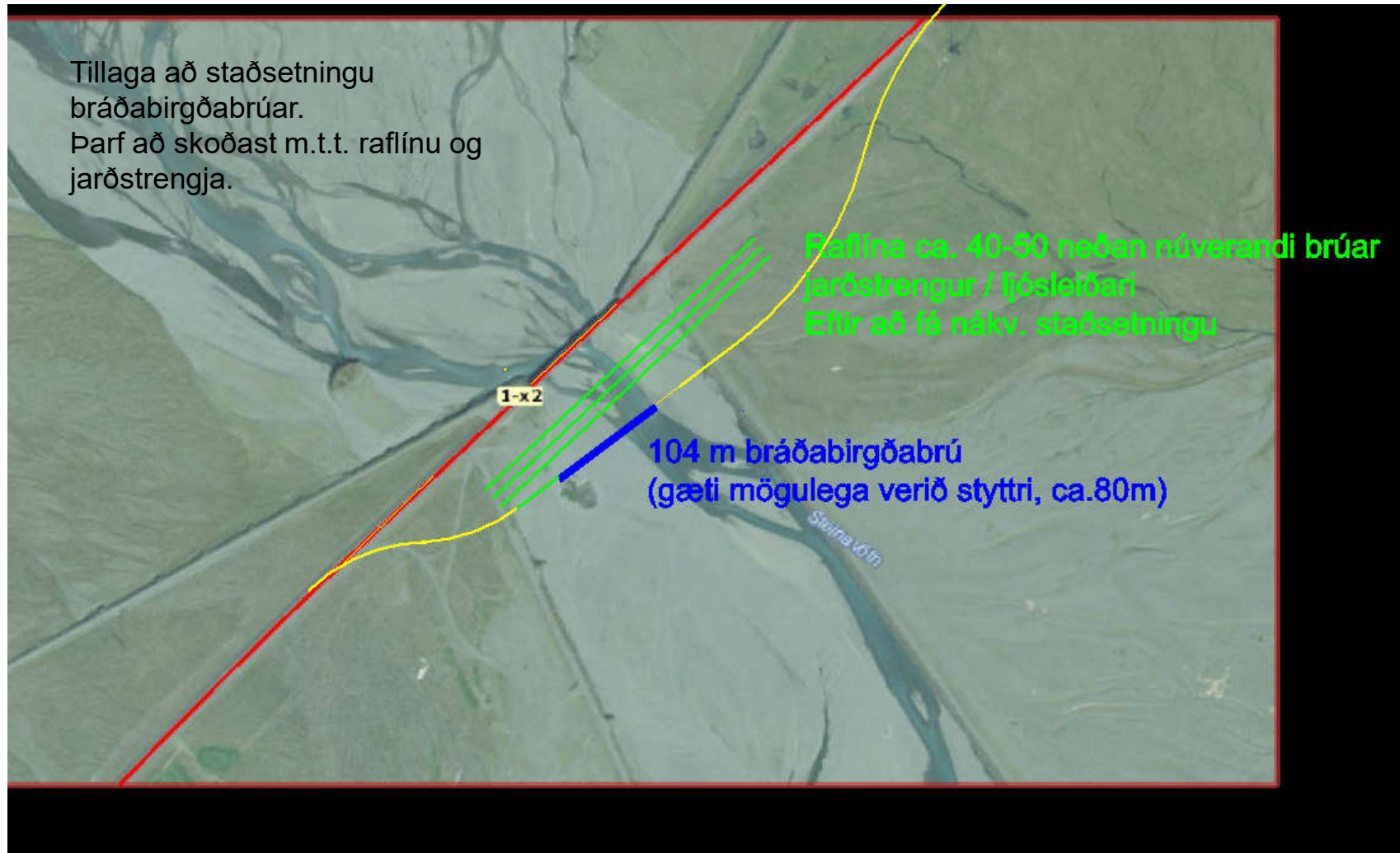
Tillaga að staðsetningu  
bráðabirgðabrúar.  
Þarf að skoðast m.t.t. raflínu og  
jarðstrengja.

Raflína ca. 40-50 neðan núverandi brúar  
jarðstrengur / ljósleiðari  
Eftir að fá nákv. staðsetningu

1-x2

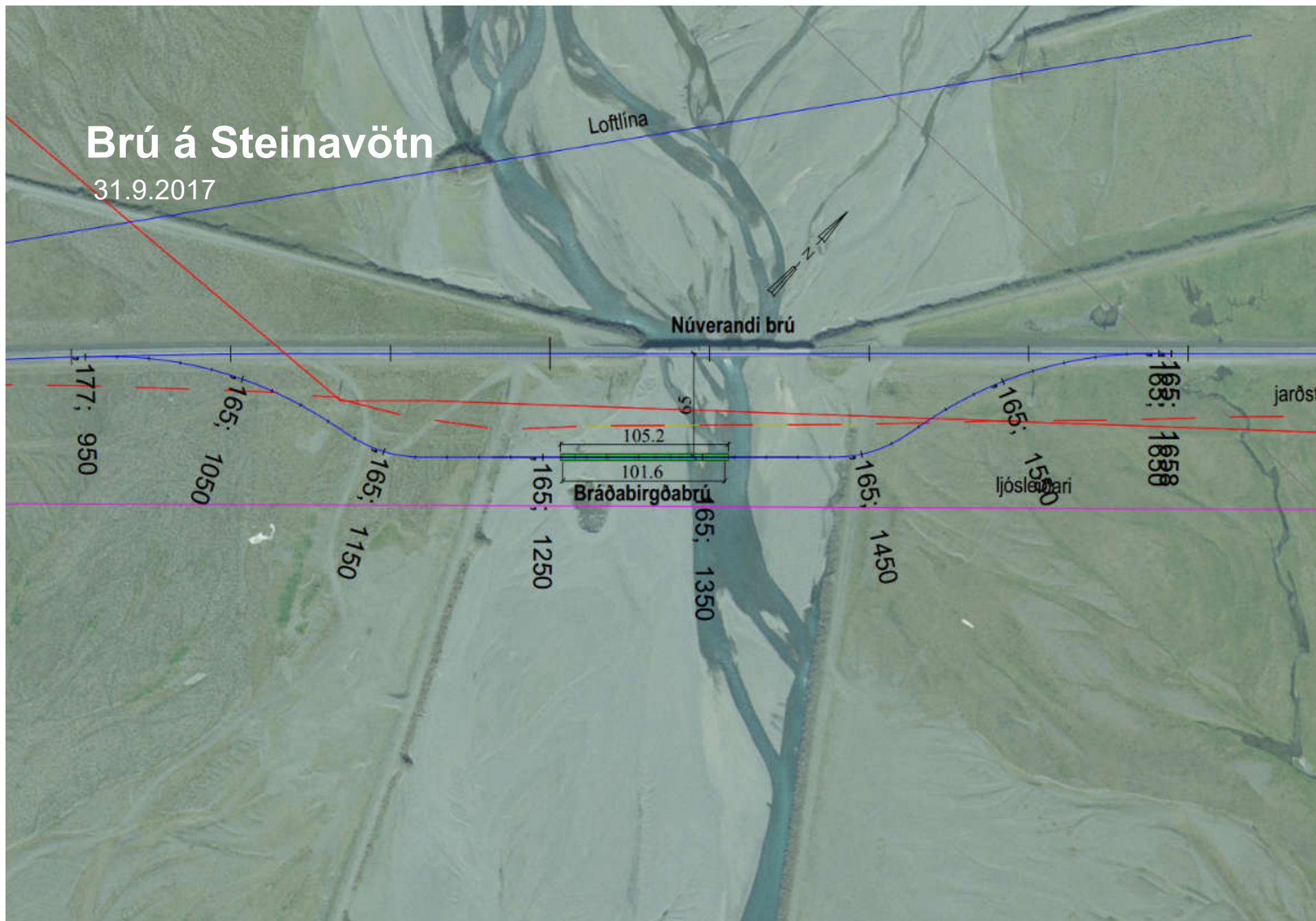
104 m bráðabirgðabrú  
(gæti mögulega verið styttri, ca.80m)

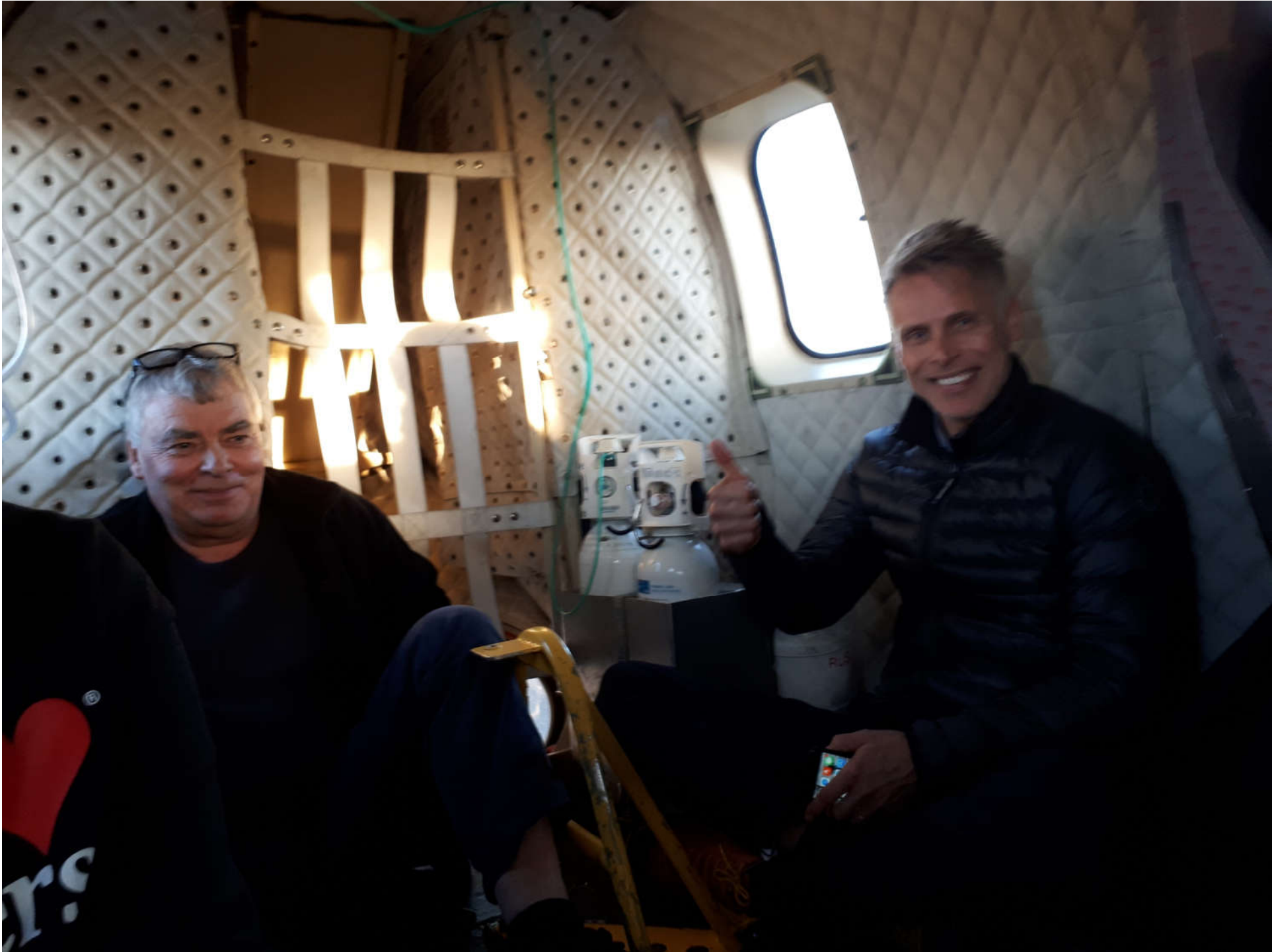
Steina 107m



# Brú á Steinavötn

31.9.2017







Mynd: Hreggviður Simonarson - Landhelgisgæslan

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# Flóð á Austurlandi

Föstudagur 30.sept 2017 – Ráðherrar og vegamálastjóri á staðinn



Jón Gunnarsson, Hreinn Haraldsson og Bjarni Benediktsson ræða við viðbragðsaðila á Hornafjarðarflugvelli.

# Flóð á Austurlandi

Föstudagur 30.sept 2017 – Ráðherrar og vegamálastjóri á staðinn



Jón Gunnarsson samgönguráðherra og Hreinn Haraldsson vegamálastjóri á Hornarfjarðarflugvelli í morgun. [mbl.is/Sigurður Bogi](http://mbl.is/SigurðurBogi)

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# Flóð á Austurlandi

Föstudagskvöld 30.9, Ingunn mætt á staðinn



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FRAMSÝNI





# Brú á Steinavötn

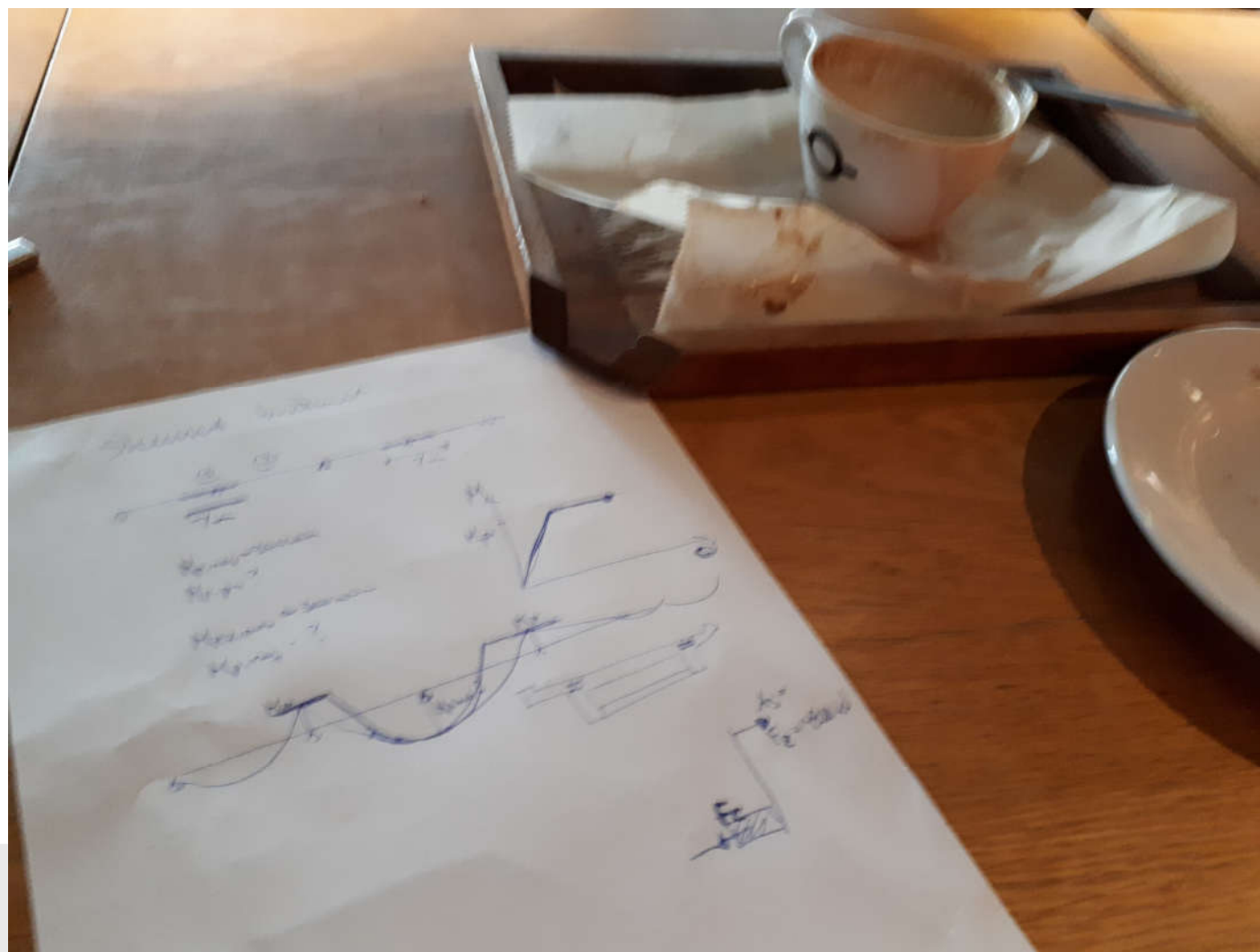
1.10.2017





# Flóð á Austurlandi

Sunnudagur 2.10



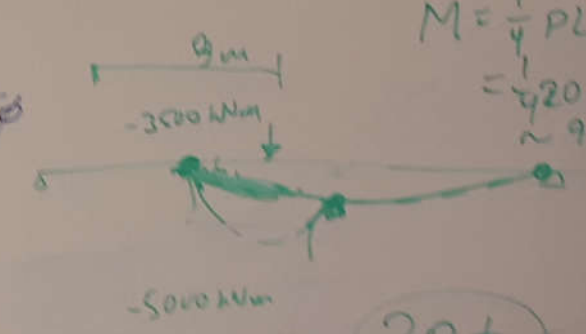
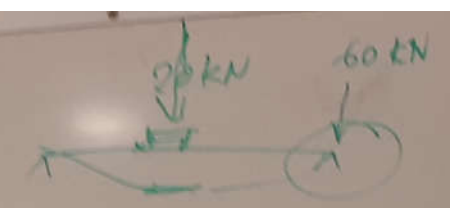
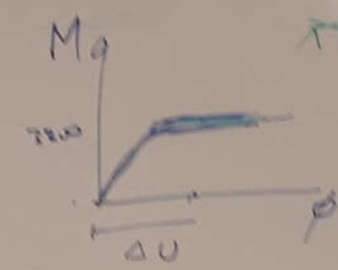
VEGAGERÐIN

þollið 3300



í renpu!  
lættar st

1100 kNm  
250 kNm



$$M = \frac{1}{4} PL$$
$$= \frac{1}{4} 20 \cdot 18$$
$$\sim 90 \text{ kNm}$$

-5000 kNm

20t



~ 800 kNm  
5000 kNm



20 cm 10000 kNm

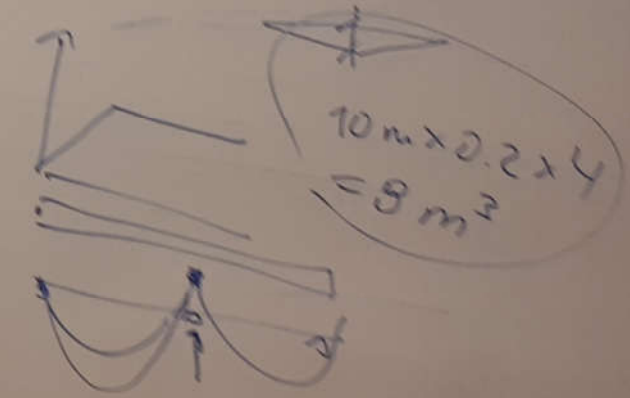
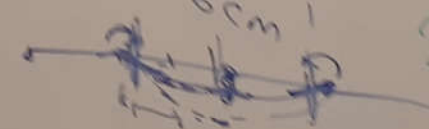


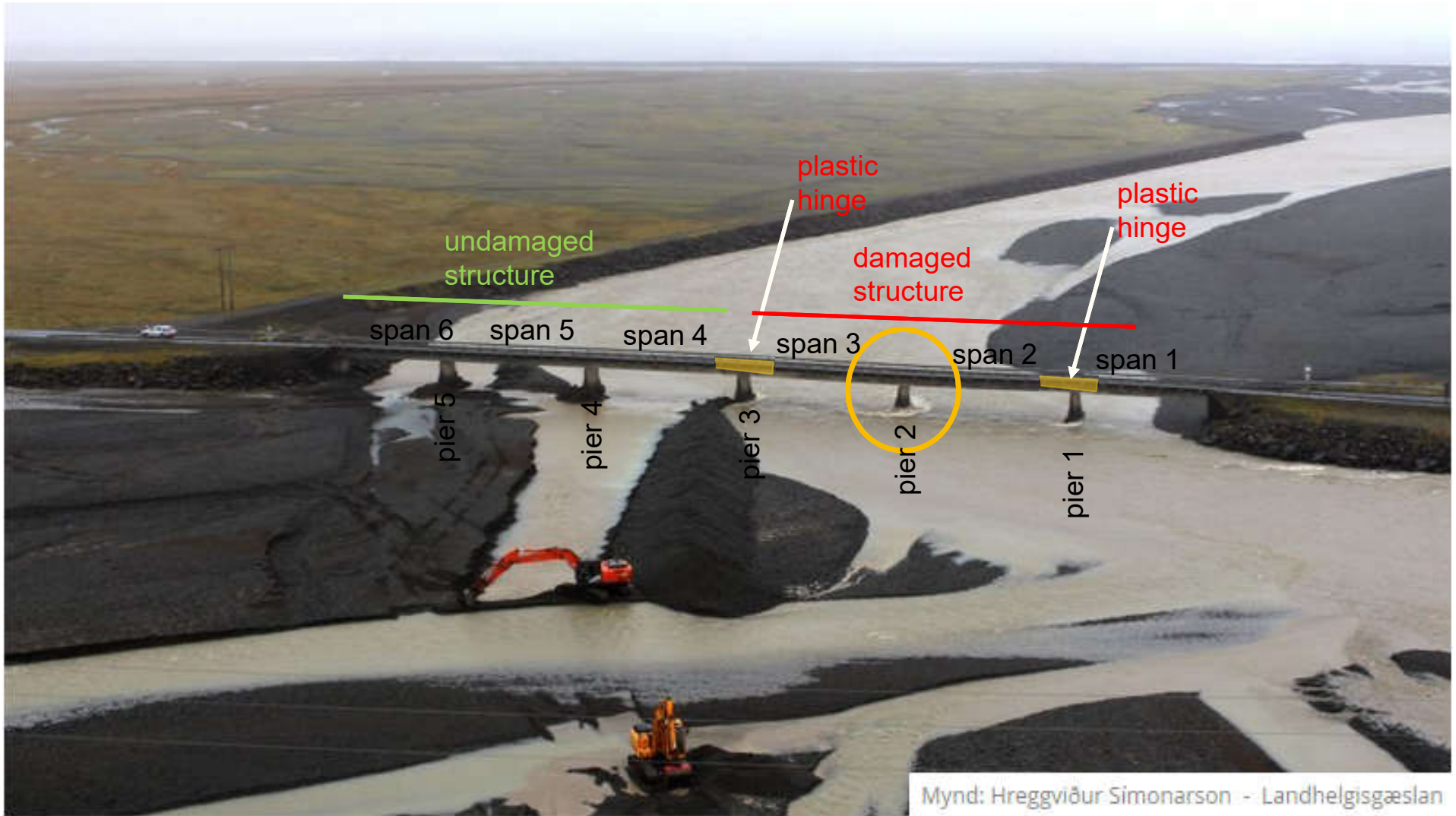
300 kN

EI

6cm

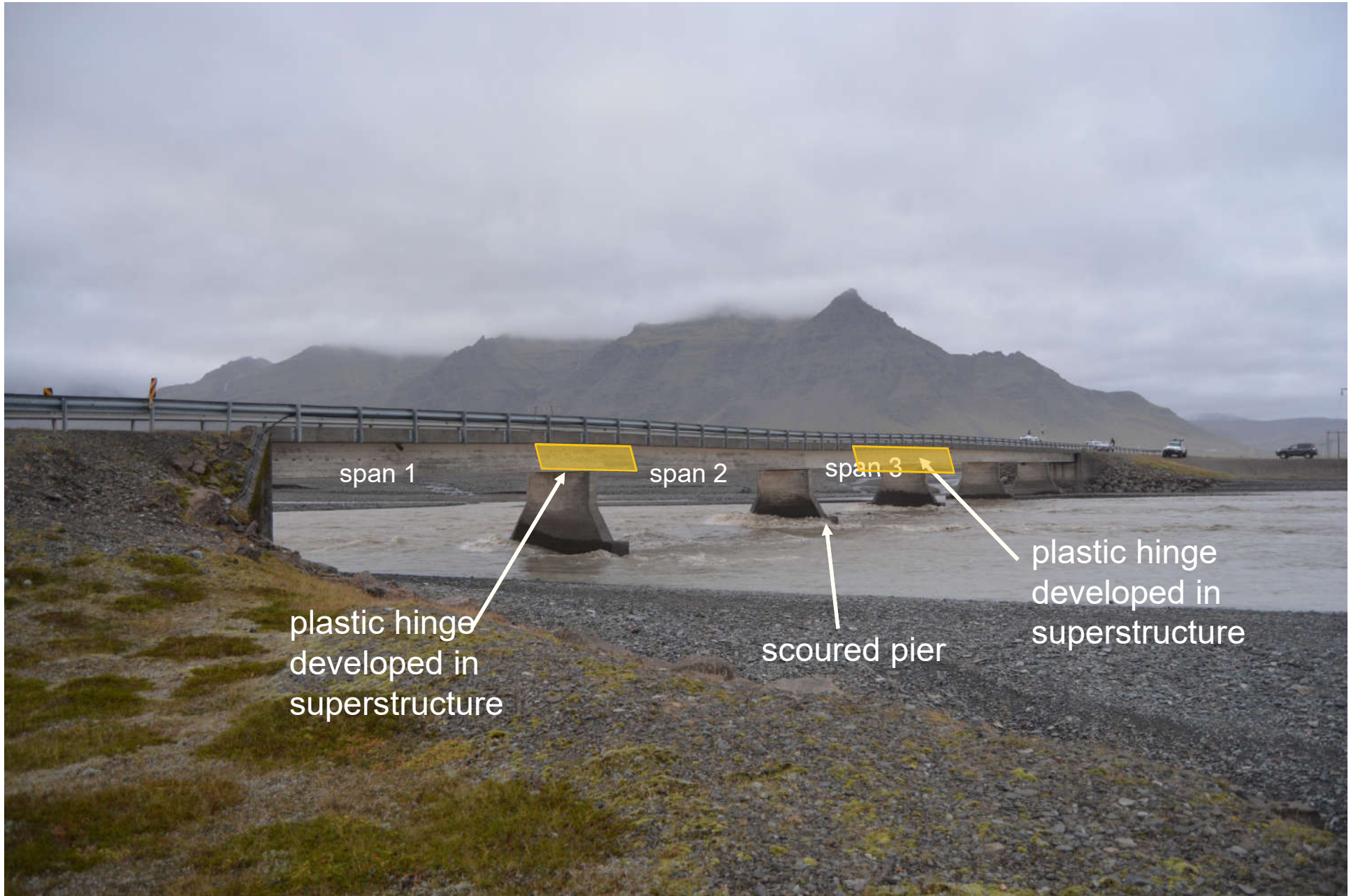
20cm





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span 1

span 2

span 3

plastic hinge developed in superstructure

scoured pier

plastic hinge developed in superstructure

## Verkefnahópurinn

- Vegagerðin
- ETH Zurich
- Háskólinn í Reykjavík
- Osmos Monitoring Group



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# Hvað var verið að mæla?

Titringsmælingar

Streitumælingar  
(optical fiber)

Færslumælingar





# Titringsmælingar





# Færslumælingar



# Dýnamísk próf



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# Streitumælingar



CO 9, CO 10 & CO 11



CO12, CO 13 & Temp 1



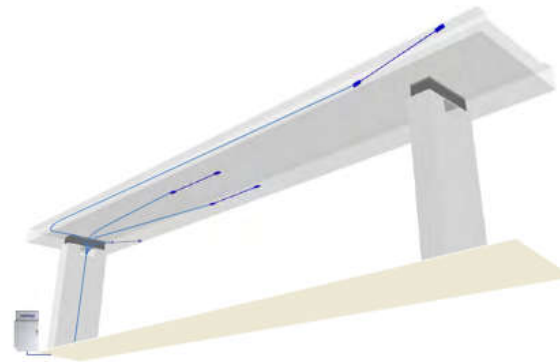
CO 14, CO 15 & CO 16



Station 2



# Streitumælingar



OSMOS real-time Continuous Monitoring of bridges via OSMOS optical fiber sensors provides a constant and accurate tracking of structural performance and integrity by timely detecting deformations and stresses in critical zones of the bridge.



SECURED  
CLOUD



NOTIFY

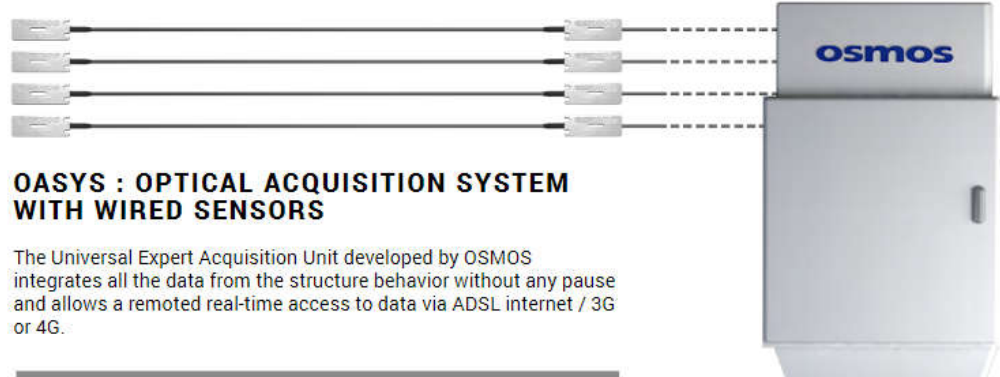


ALERT

ANALOG  
SENSORS  
READY

REAL TIME  
DATA

SYNCHRONIZED  
INFORMATION



## OASYS : OPTICAL ACQUISITION SYSTEM WITH WIRED SENSORS

The Universal Expert Acquisition Unit developed by OSMOS integrates all the data from the structure behavior without any pause and allows a remoted real-time access to data via ADSL internet / 3G or 4G.

- Multi-channel simultaneous detection

# Slökun







# Efnisgæðin







**Að líkja eftir skemmdum**

# Að líkja eftir skemmdum

















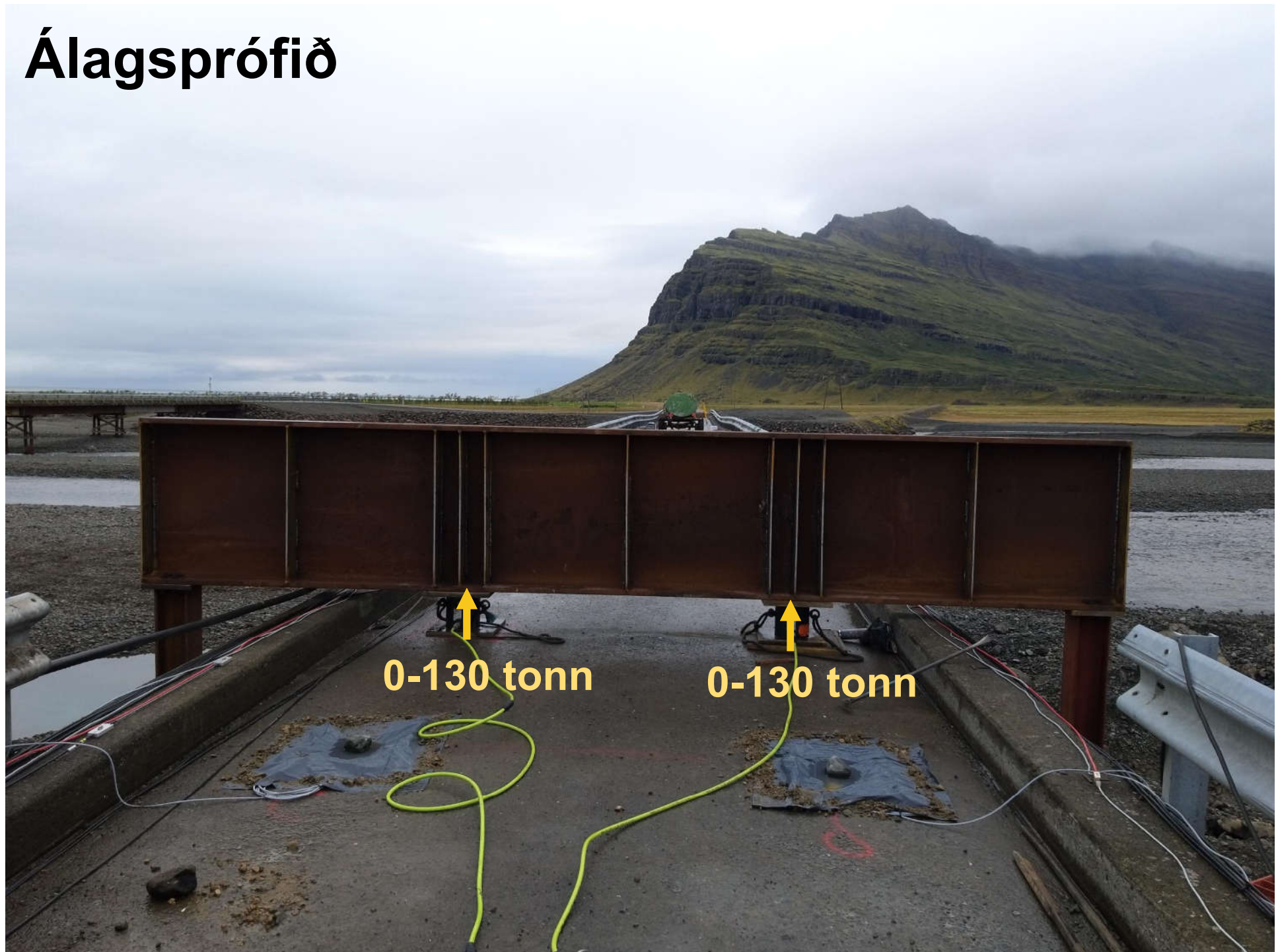




# Álagsprófið



# Álagsprófið



# Álagsprófið













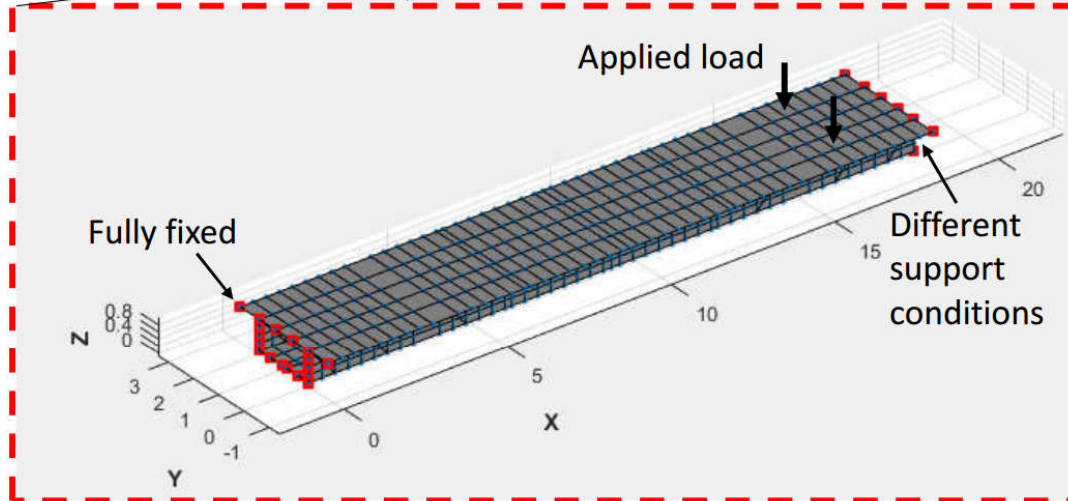
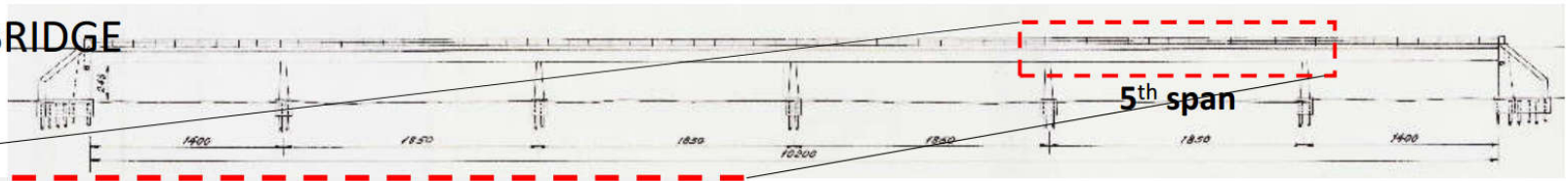
Titringsmælingar

Streitumælingar  
(optical fiber)

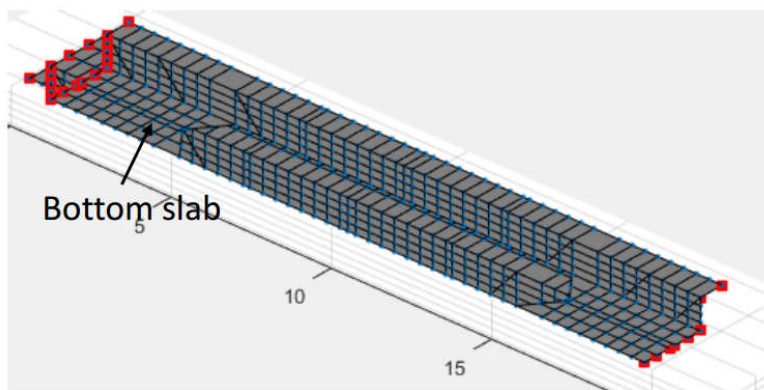
Færslumælingar

# Ólínulegt FE-líkan (ETH Zürich)

STEINAVÖTN BRIDGE  
NLFEM Model



- The 5<sup>th</sup> span of the bridge was modeled using nonlinear shell elements.
- Two concentrated loads corresponding to the jacks were defined at 2.1m from the pier.
- Permanent loads were neglected.
- The left side is always fully fixed; the right side assumes different support conditions (see next slide).
- Contribution of diagonal reinforcement and bottom slab was taken into account
- Presence of transverse diaphragms and other secondary elements was neglected



## Material properties

Concrete

**Compressive strength:  $f_c = 30\text{MPa}$**

**Tangent Modulus:  $E_c = 27000\text{MPa}$**

**Peak strain:  $\epsilon_o = 0.003$**

**Tensile strength:  $f_{ct} = 2\text{MPa}$**

Steel

**Yield strength  $f_{sy} = 300\text{MPa}$**

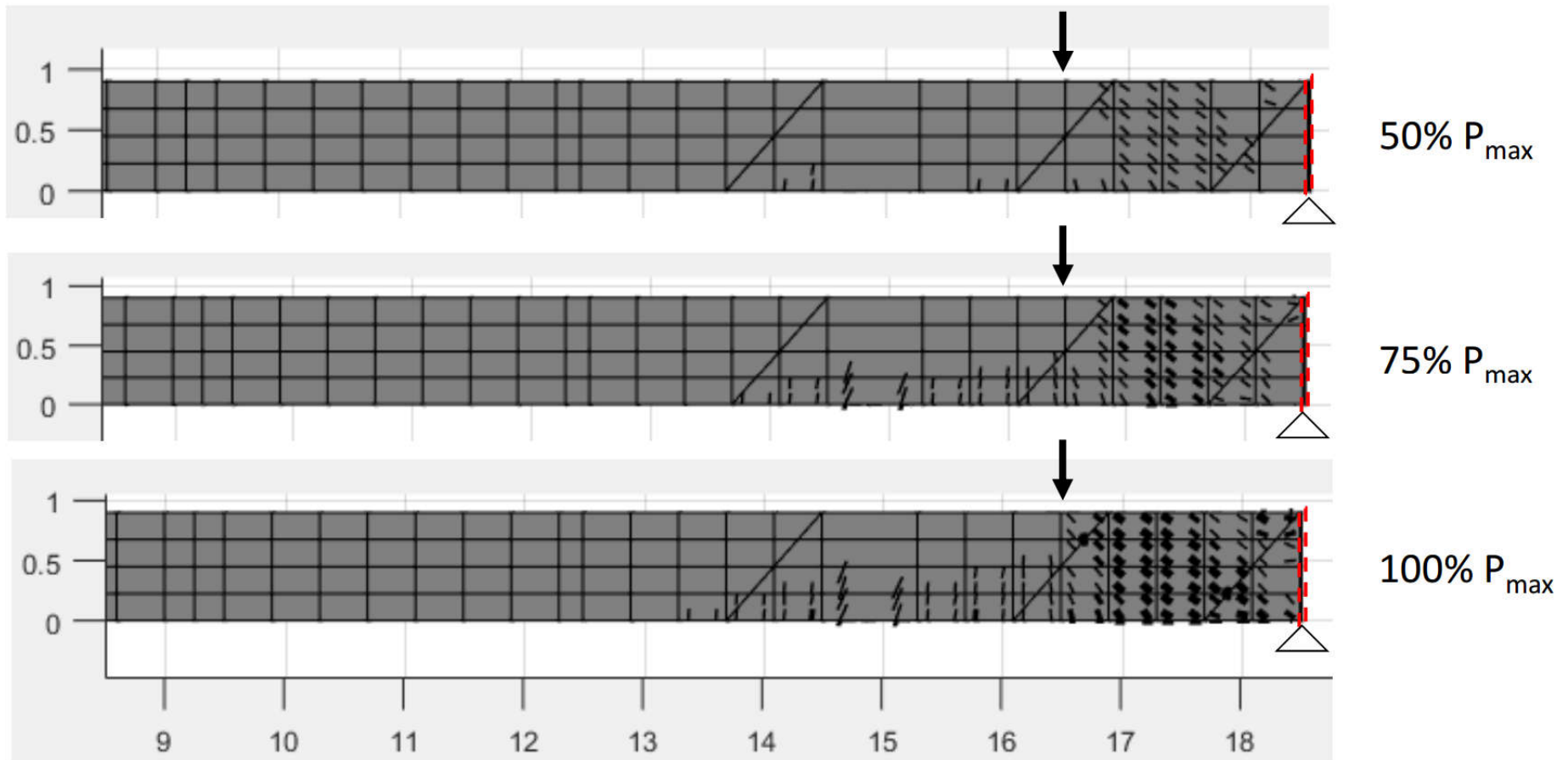
**Young Modulus  $E_s = 200000\text{MPa}$**

**Strain hardening:  $b = 0.005$**

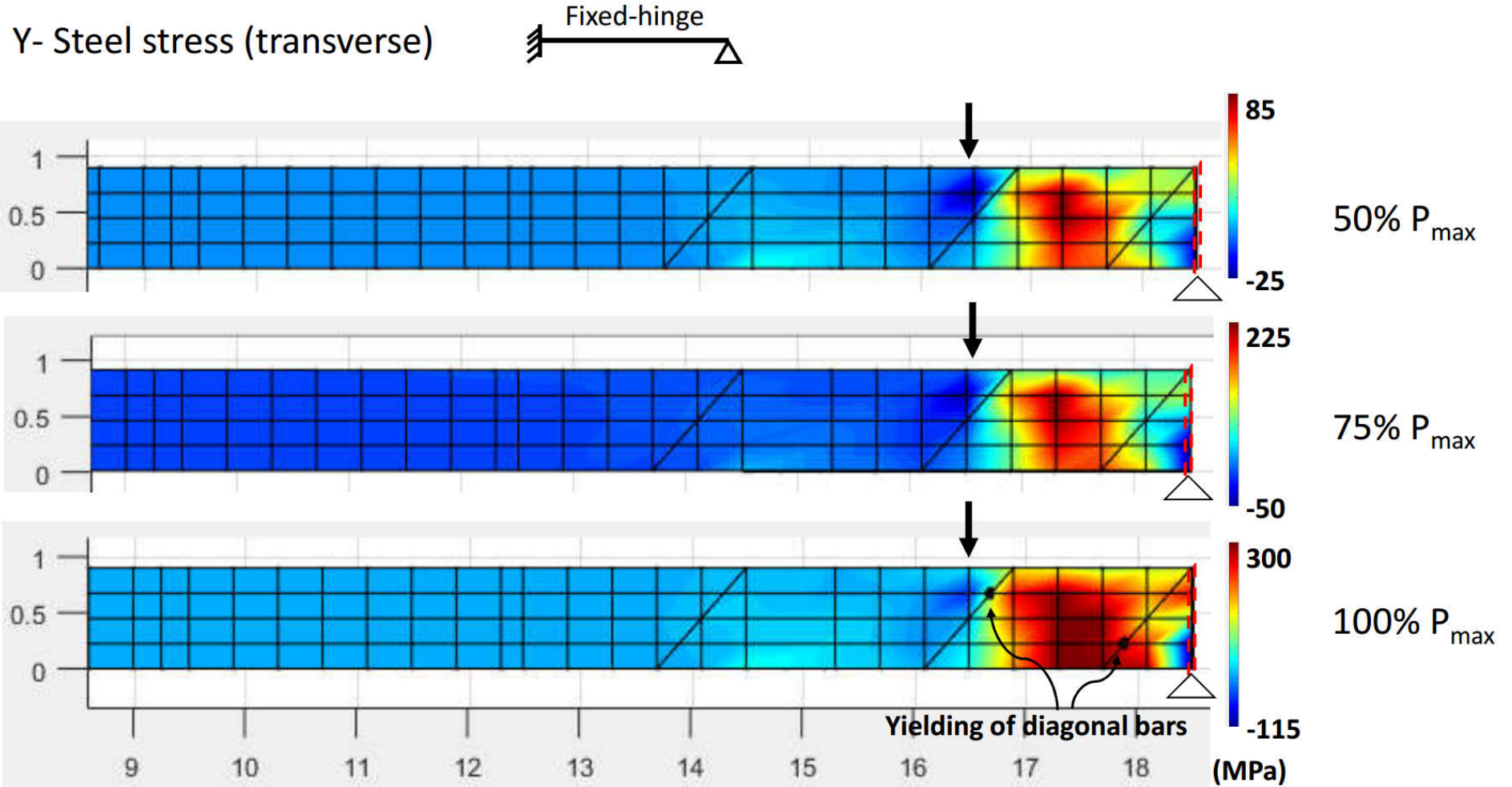
**Fracture strain:  $\epsilon_u = 10\%$**

# Áætluð sprungumyndun (ETH Zürich)

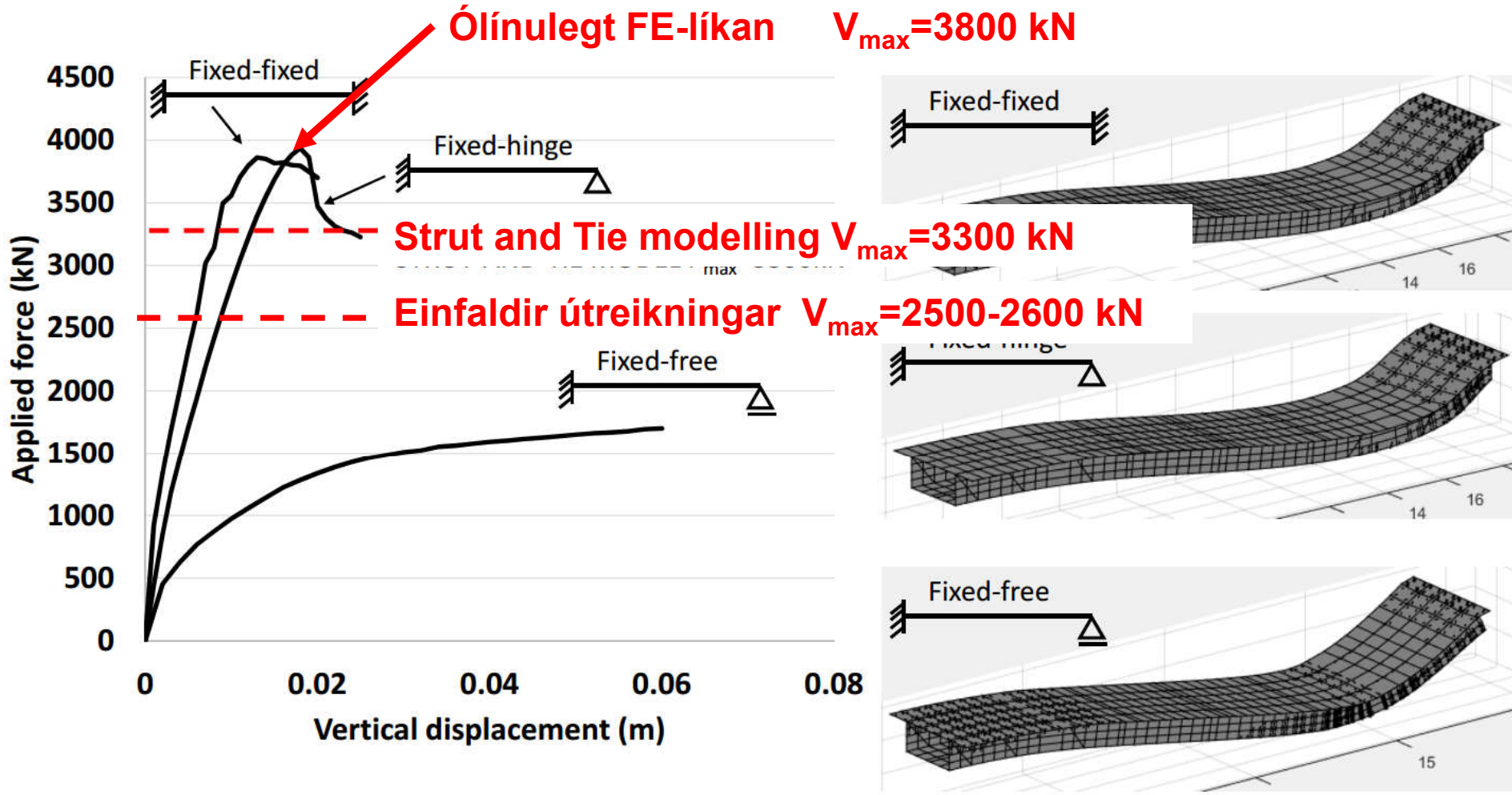
CRACK PATTERNS 



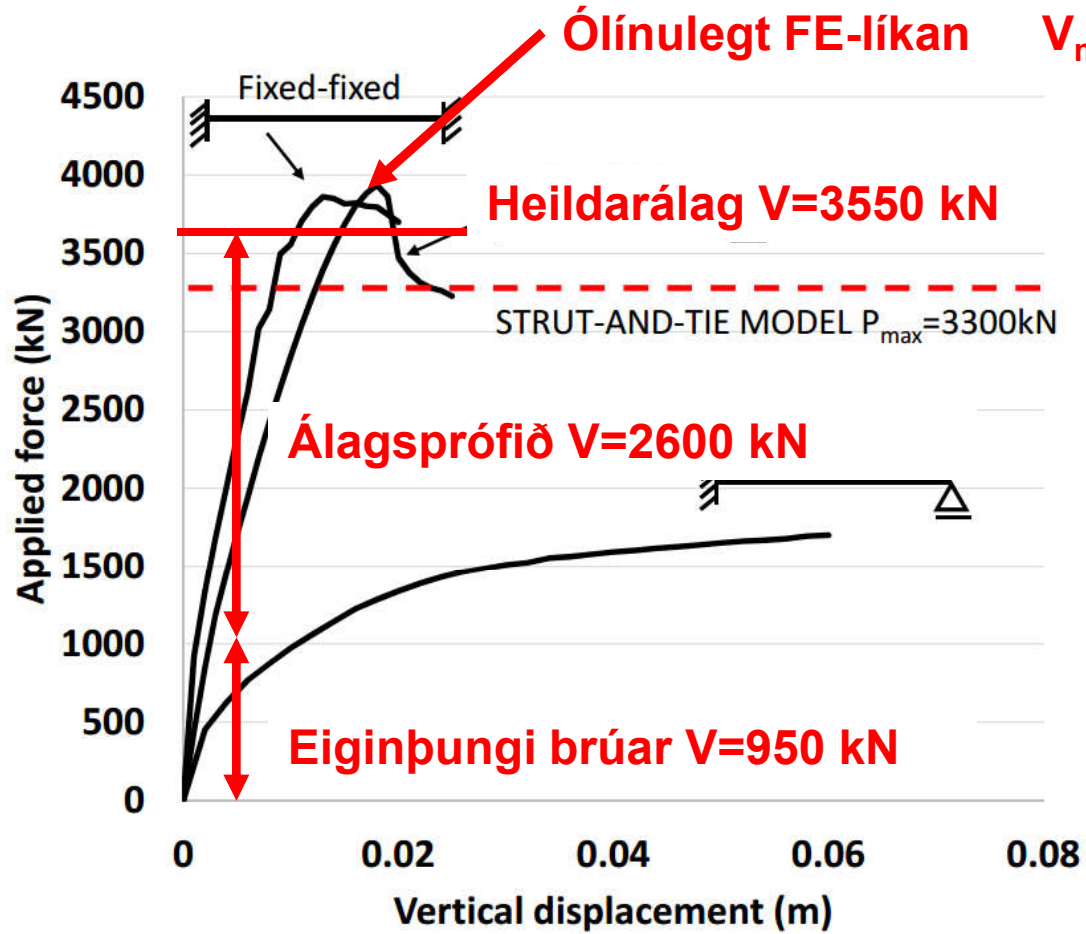
# Áætluð sprungumyndun (ETH Zürich)



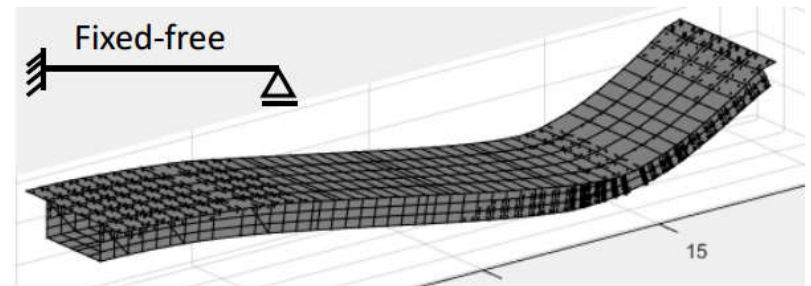
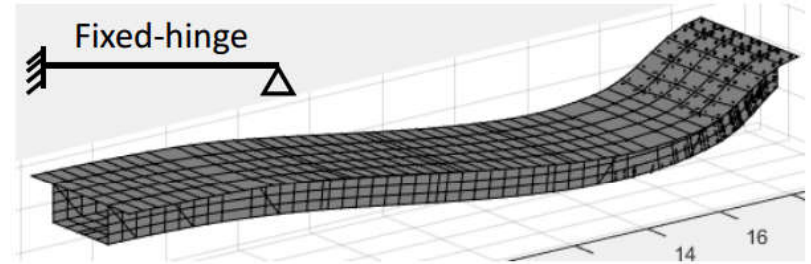
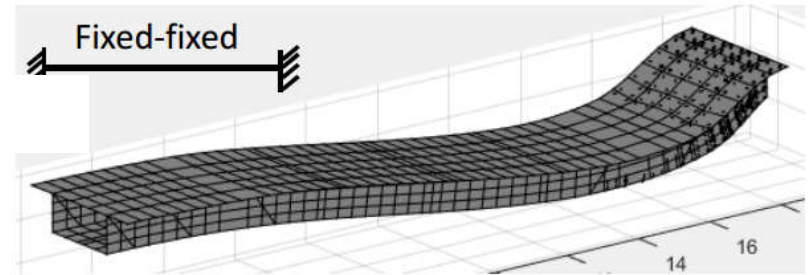
# Samanburður álagsprófs við fræðin



# Samanburður álagsprófs við fræðin



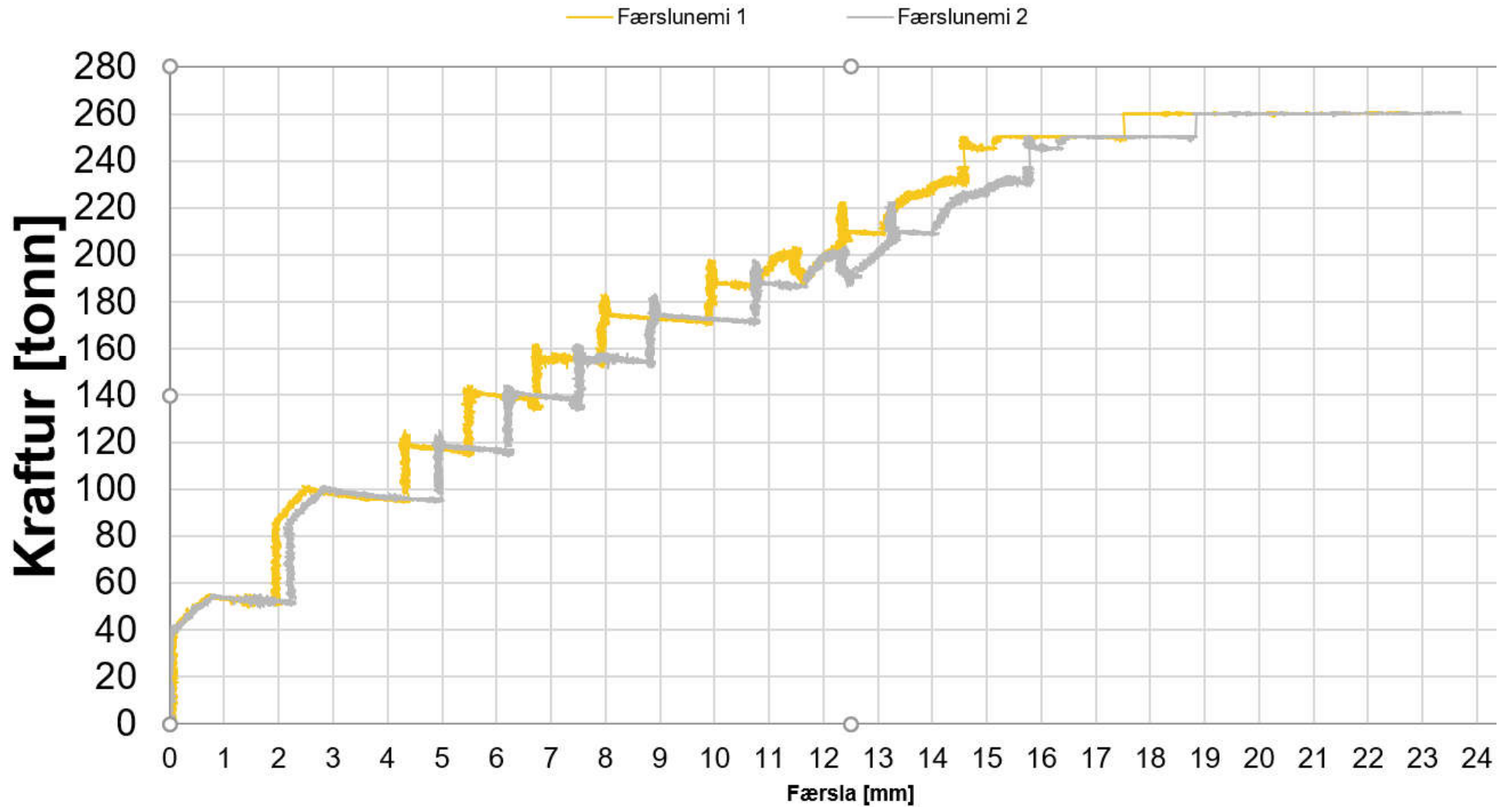
$V_{max}=3800$  kN





# Færsla á miðju hafi við álagspróf

## Kraftur tjakka og færsla á miðju hafi



# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 0 kN**  
**V<sub>samt</sub> = 950 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 1200 kN**  
**V<sub>samt</sub> = 2150 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 1400 kN**  
**V<sub>samt</sub> = 2350 kN**



Úrvinnsla: Atli Geir Ragnarsson



# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 1600 kN**  
**V<sub>samt</sub> = 2550 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 1800 kN**  
**V<sub>samt</sub> = 2750 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

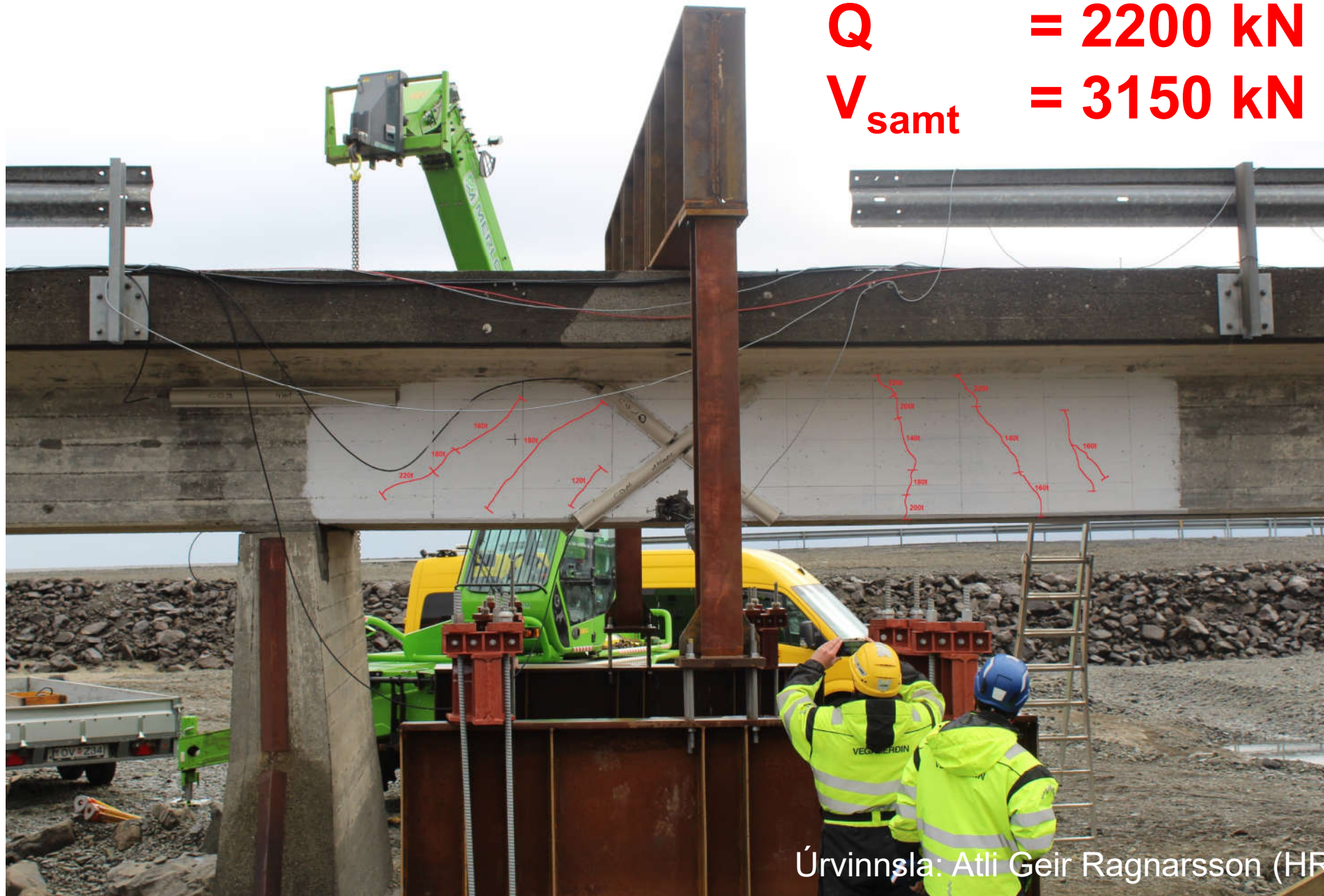
**G = 950 kN**  
**Q = 2000 kN**  
**V<sub>samt</sub> = 2950 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2200 kN**  
**V<sub>samt</sub> = 3150 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)



# Álagsprófið - Þróun á sprungum

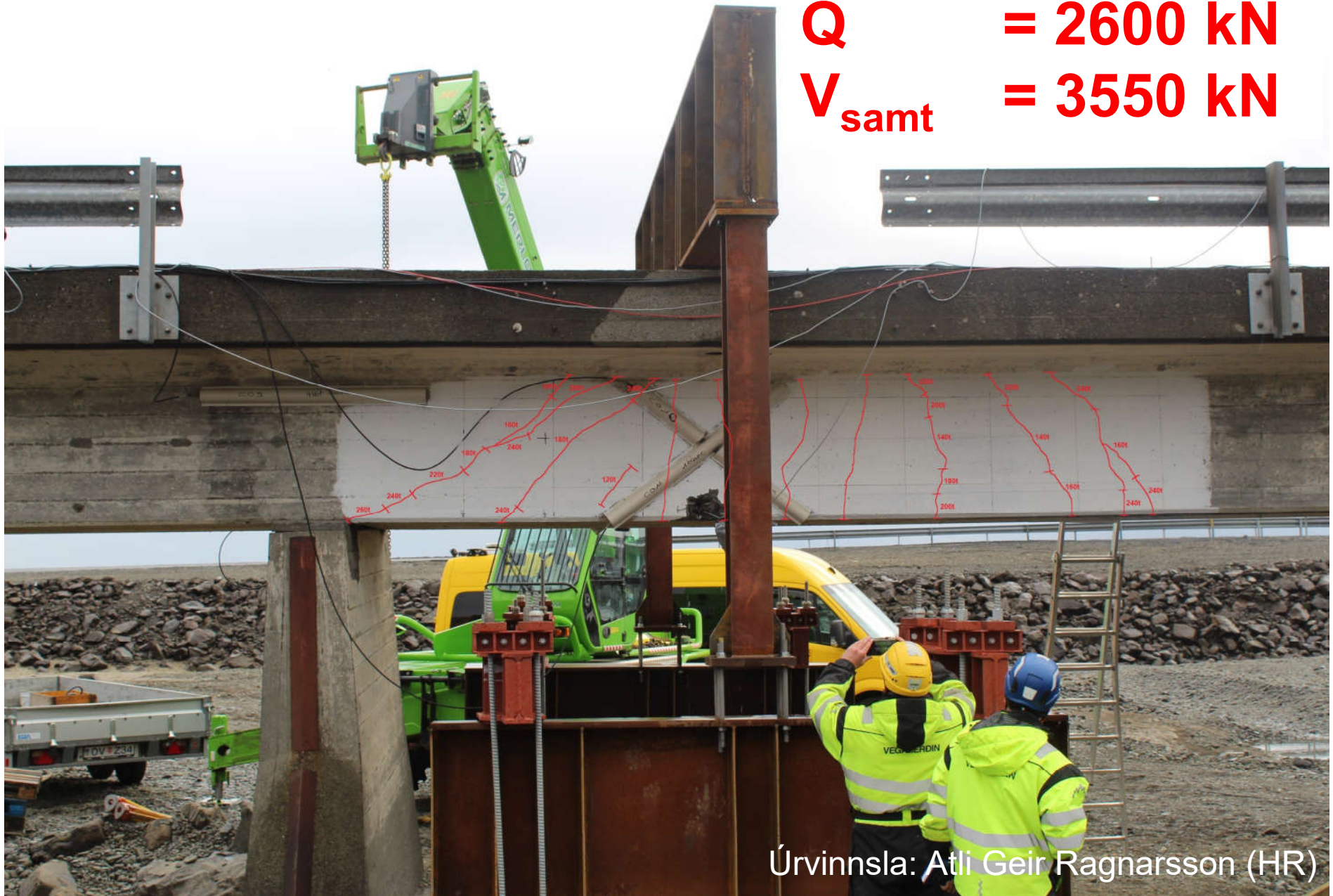
**G = 950 kN**  
**Q = 2400 kN**  
**V<sub>samt</sub> = 3350 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

## Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



Urvinnsla: Atli Geir Ragnarsson (HR)

## Álagsprófið - Þróun á sprungum

**G** = 950 kN  
**Q** = 2600 kN  
**V<sub>samt</sub>** = 3550 kN



Úrvinnsla: Atli Geir Ragnarsson (HR)

# Álagsprófið - Þróun á sprungum

**G**

**= 950 kN**

**Q**

**= 2600 kN**

**V<sub>samt</sub>**

**= 3550 kN**



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Úrvinnsla: Atli Geir Ragnarsson (HR)



# Álagsprófið - Þróun á sprungum

**G = 950 kN**  
**Q = 2600 kN**  
**V<sub>samt</sub> = 3550 kN**



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Úrvinnsla: Atli Geir Ragnarsson (HR)

## Álagsprófið - Þróun á sprungum

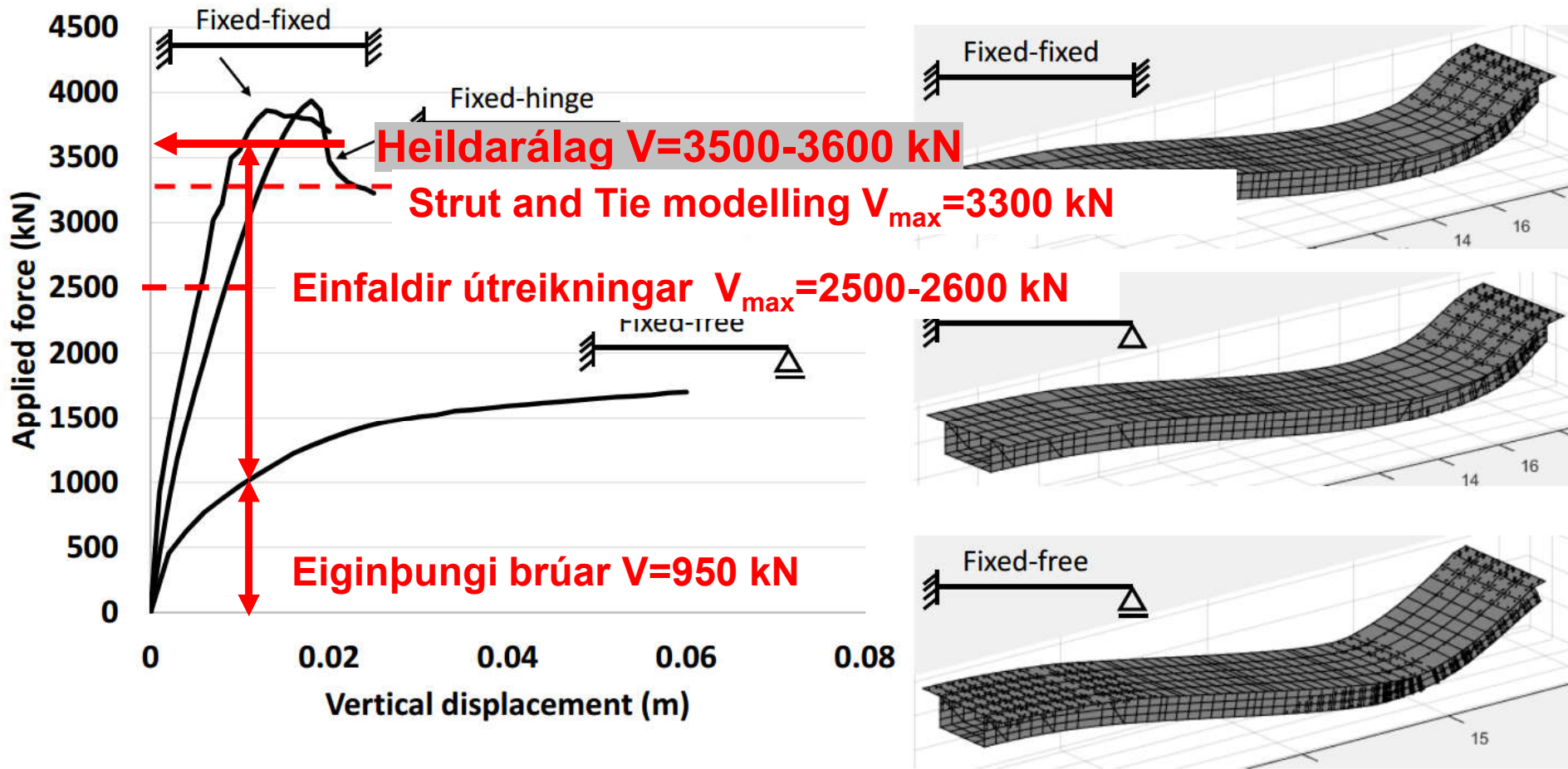
$$\begin{aligned} G &= 950 \text{ kN} \\ Q &= 2600 \text{ kN} \\ V_{\text{samt}} &= 3550 \text{ kN} \end{aligned}$$



Úrvinnsla: Atli Geir Ragnarsson

# Samanburður álagsprófs við fræðin

## Fyrstu niðurstöður



# Eigintíðnir

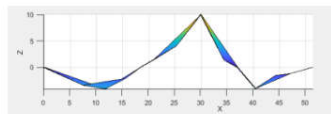
1st

2nd

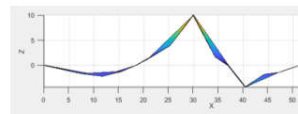
3rd

4th

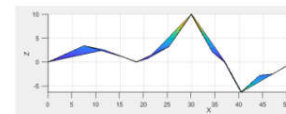
MACEC



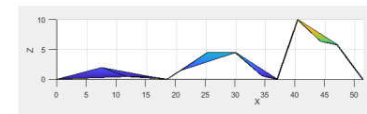
5.5 Hz



6.4 Hz



7.8 Hz



11.7 Hz

SAP2000



5.1 Hz



6.9 Hz



8.5 Hz



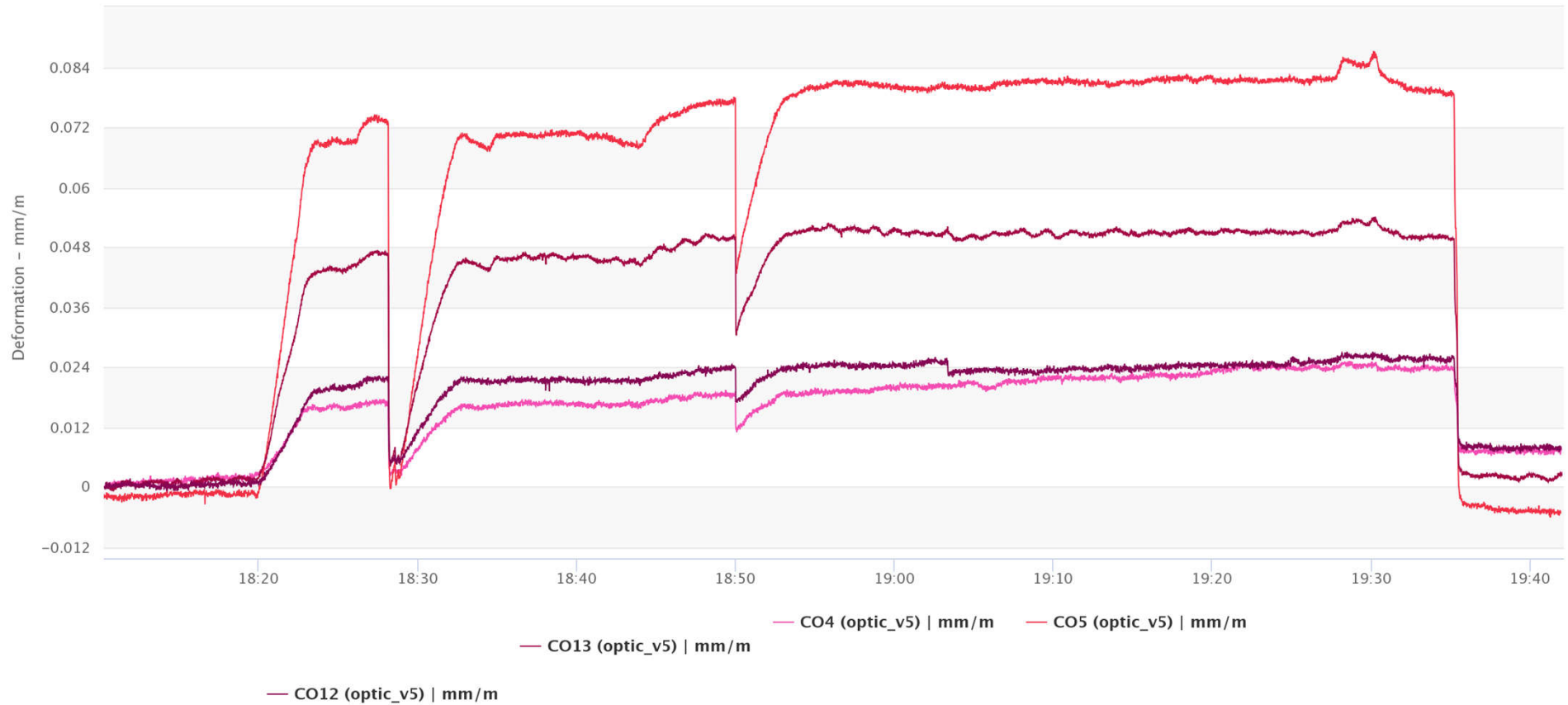
13.1 Hz

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# Streitumælingar – mid span loaded span 5.sept (120t)

steinavotn : 2019-09-05 18:10:13.000Z - 2019-09-05 19:42:06.000Z

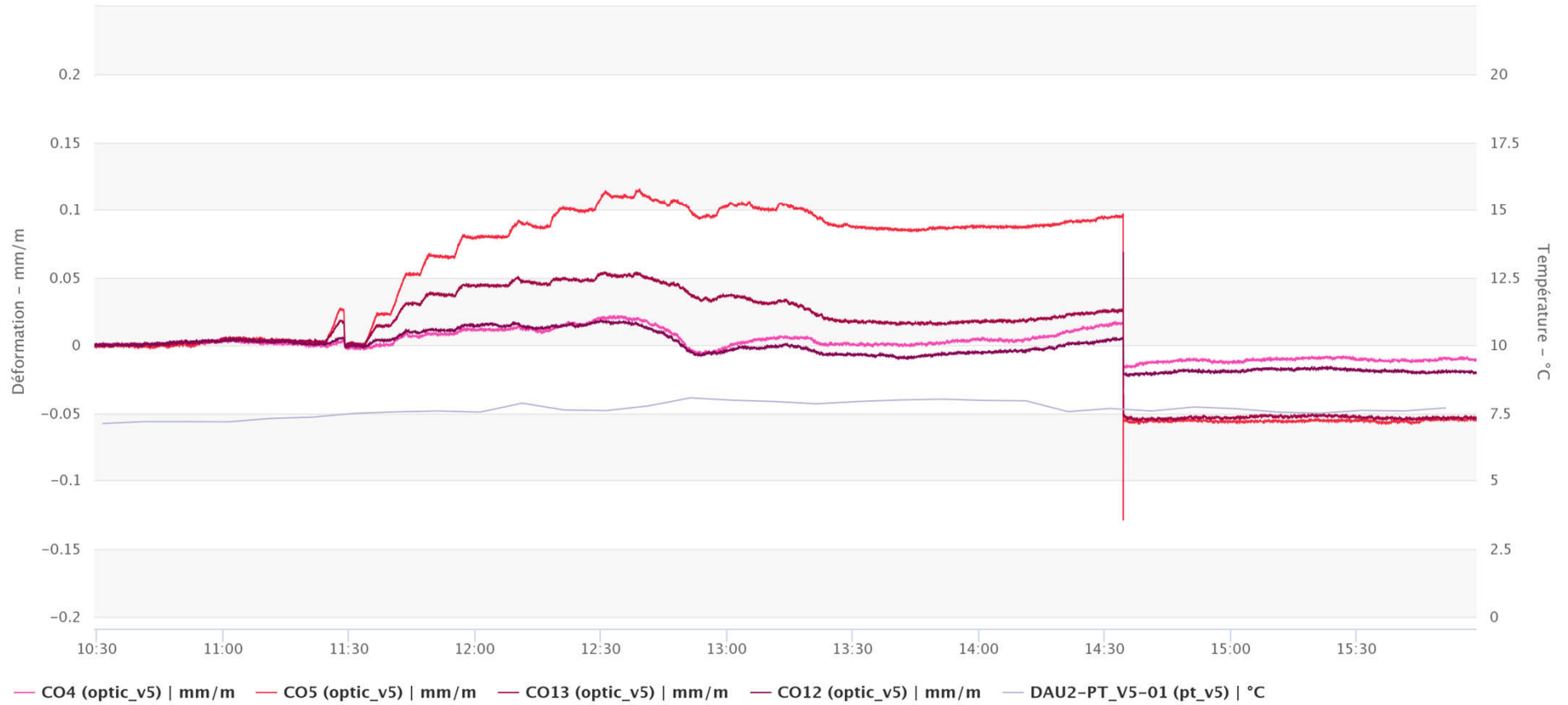


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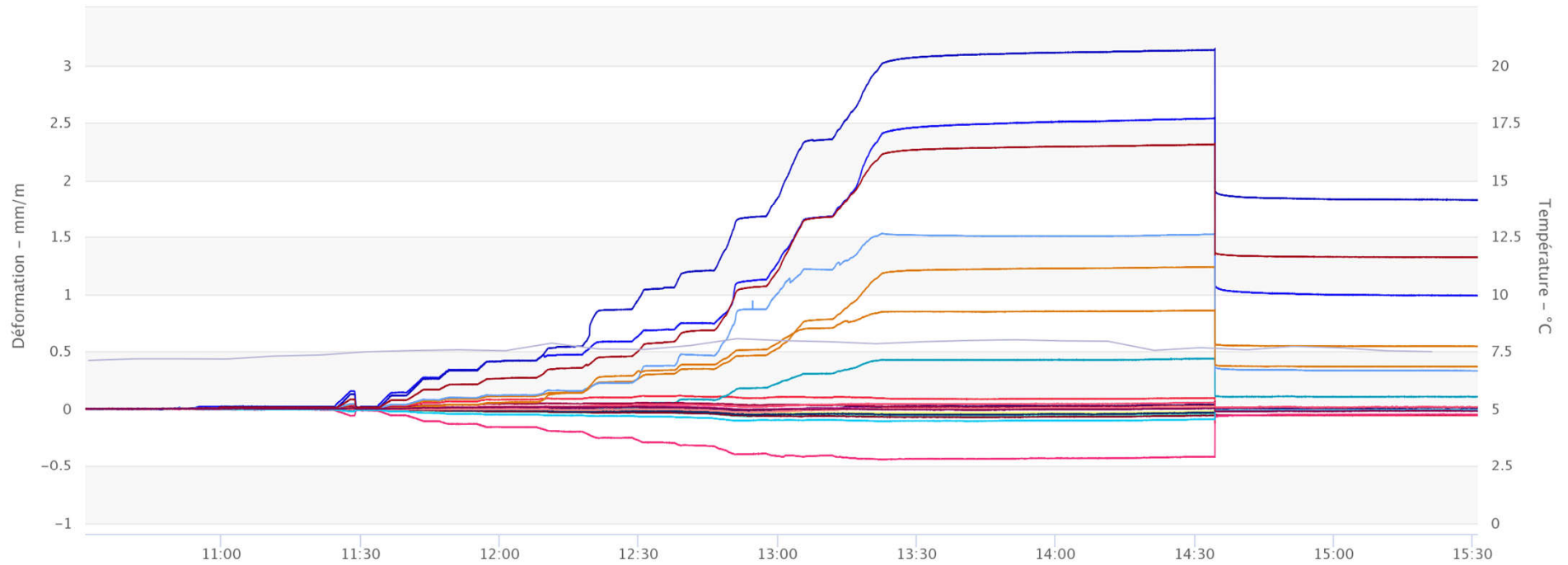
# Streitumælingar – mid span loaded span 17.sept (260t)

steinavotn : 2019-09-17 10:29:14.000Z - 2019-09-17 15:58:20.000Z



# Streitumælingar – allar 17.sept (260t)

steinavotn : 2019-09-17 10:30:30.000Z - 2019-09-17 15:30:54.000Z



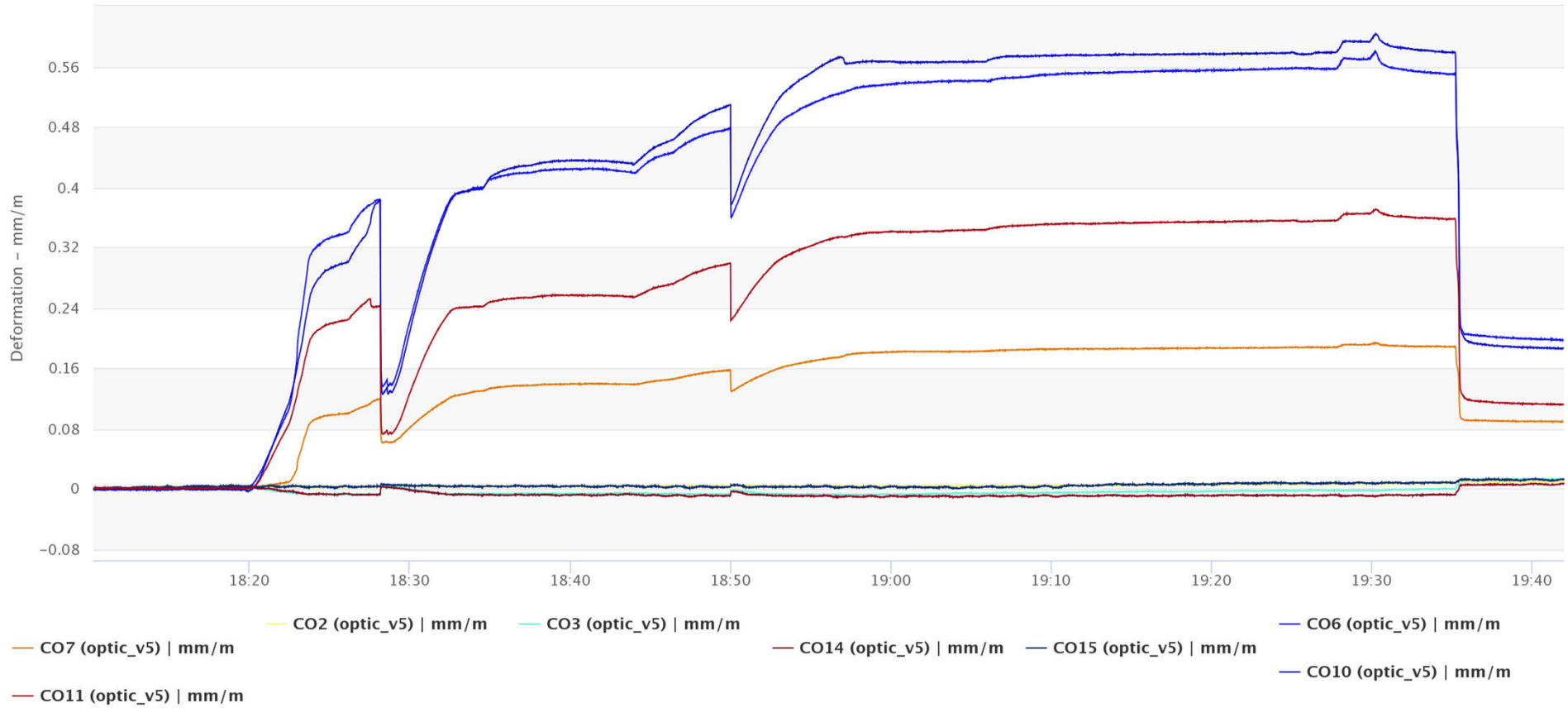
- CO1 (optic\_v5) | mm/m
- CO2 (optic\_v5) | mm/m
- CO3 (optic\_v5) | mm/m
- CO4 (optic\_v5) | mm/m
- CO5 (optic\_v5) | mm/m
- CO6 (optic\_v5) | mm/m
- CO7 (optic\_v5) | mm/m
- CO8 (optic\_v5) | mm/m
- CO13 (optic\_v5) | mm/m
- CO14 (optic\_v5) | mm/m
- CO15 (optic\_v5) | mm/m
- CO16 (optic\_v5) | mm/m
- CO17 (optic\_v5) | mm/m
- CO18 (optic\_v5) | mm/m
- CO19 (optic\_v5) | mm/m
- CO20 (optic\_v5) | mm/m
- CO9 (optic\_v5) | mm/m
- CO10 (optic\_v5) | mm/m
- CO11 (optic\_v5) | mm/m
- CO12 (optic\_v5) | mm/m
- DAU2-PT\_V5-01 (pt\_v5) | °C

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# Streitumælingar – shear evaluation 5.sept (120t)

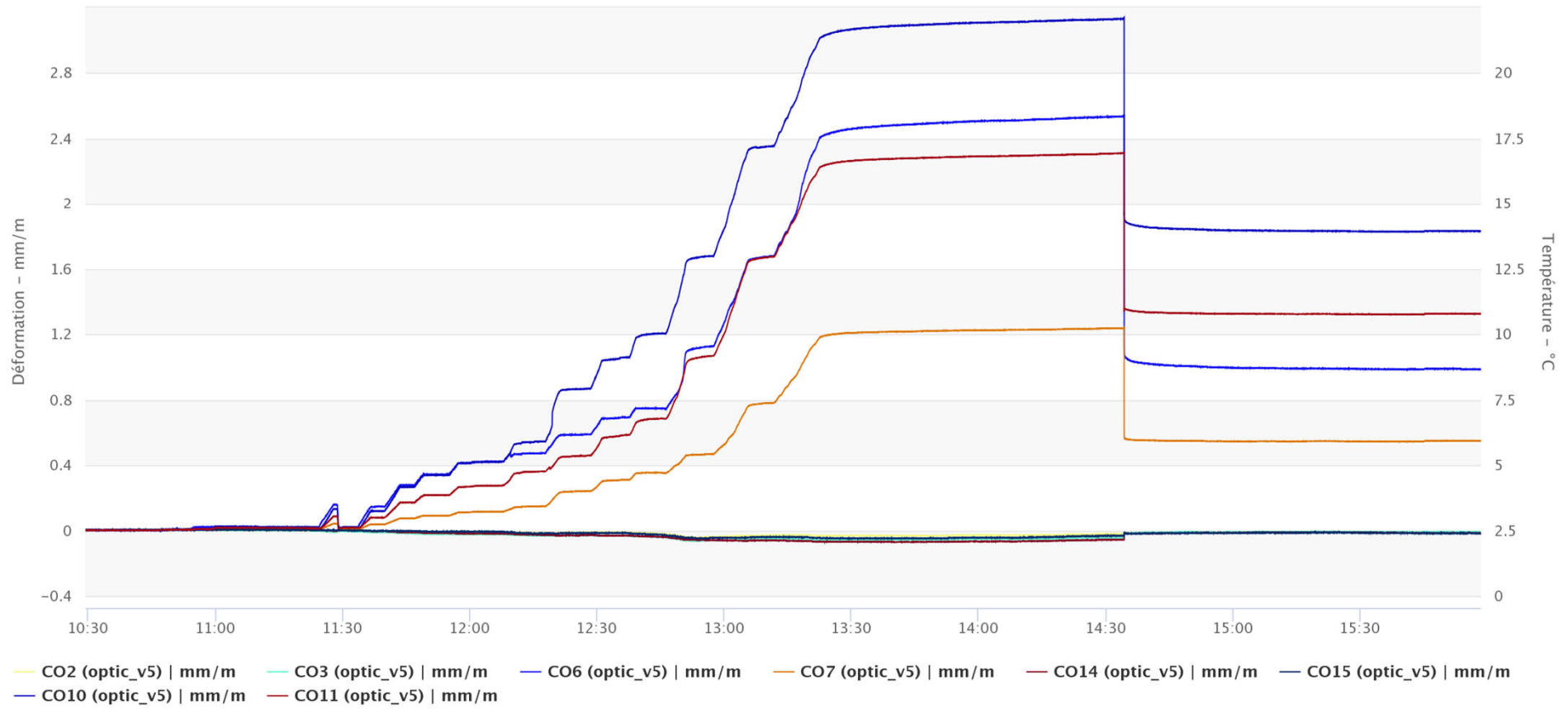
steinavotn : 2019-09-05 18:10:11.000Z - 2019-09-05 19:41:54.000Z





# Streitumælingar – shear evaluation 17.sept (260t)

steinavotn : 2019-09-17 10:29:14.000Z - 2019-09-17 15:58:20.000Z



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## Hvaða upplýsingar liggja þá fyrir



- Athugun á eigintíðnum ETHZ og HR
- Færslumælingar HR
- Optískar streitumælingar Osmos
- Sprunguvíddir og útbreiðsla HR / Vegagerðin

## Hvað er eftir að gera?



- Efnisprófanir, steypa og járnending
- Úrvinnsla mælinga og túlkun





