

MONITORING OF TENDON FORCES IN SWEDISH CONTAINMENTS

Energiforsk seminar – 15/3

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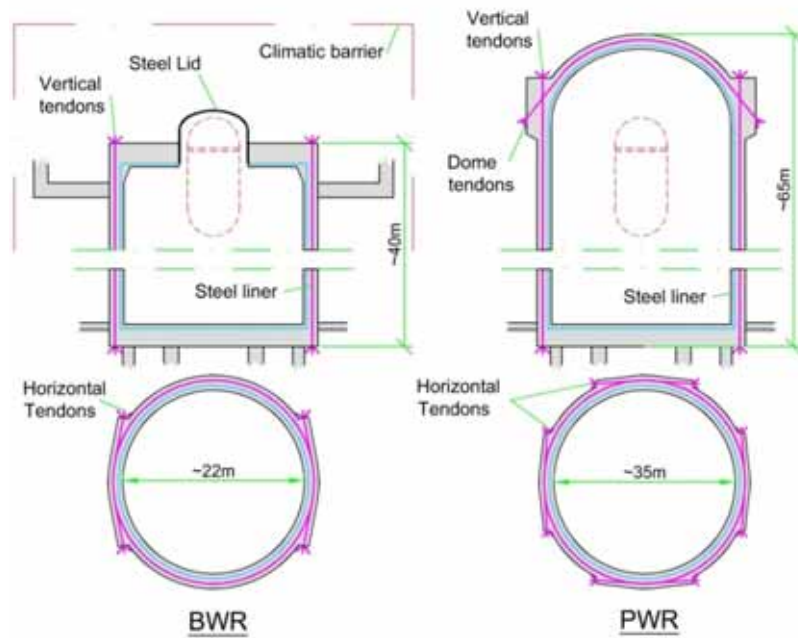


SWEDISH CONTAINMENTS WITH UNBONDED TENDONS

- Forsmark 1-3, Boiling water reactors (BWR)
- Ringhals 2-4, Pressurized water reactors (PWR)



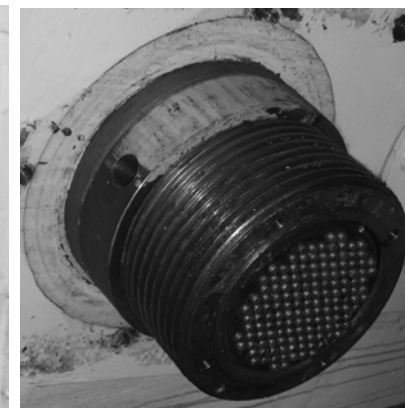
SWEDISH CONTAINMENTS WITH UNBONDED TENDONS



VSL

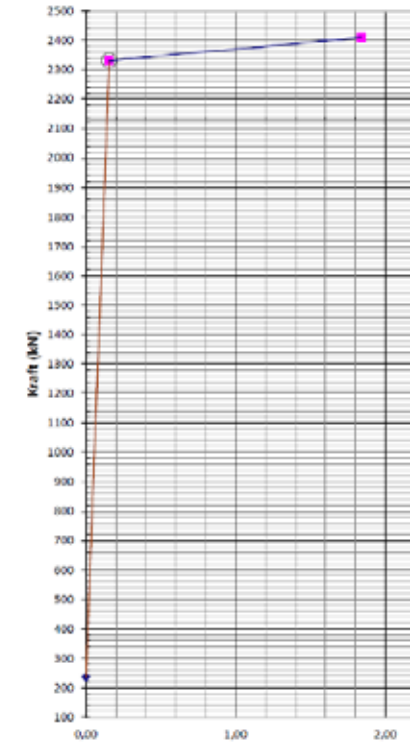
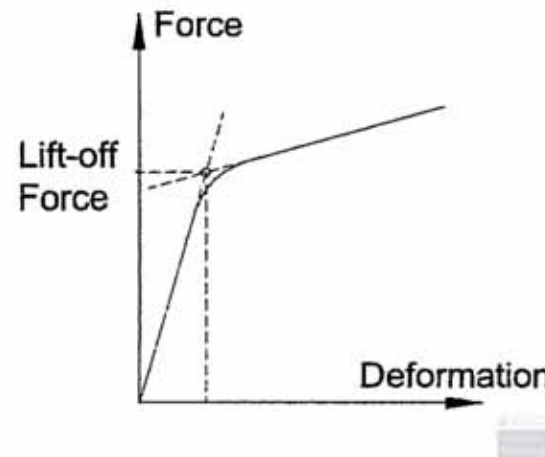


BBRV



MEASUREMENTS OF TENDON FORCES

Tendon forces are measured at regular intervals, every 5th year
Measurements by connecting a hydraulic jack to the anchor head



IN-SERVICE INSPECTIONS - RINGHALS

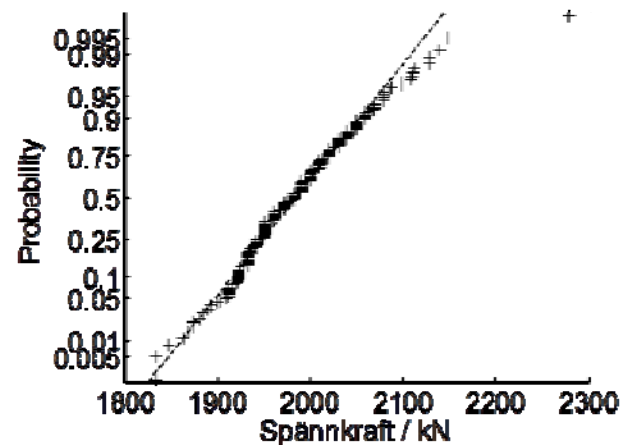
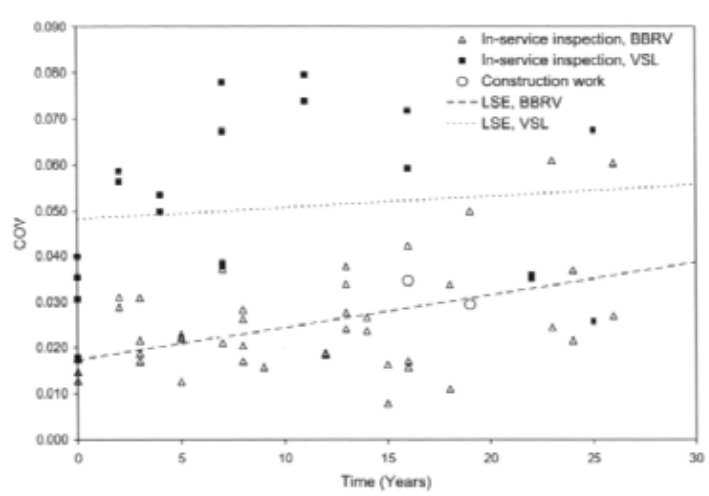
Inspections according to American guidelines, Regulatory Guide 1.35

- 4 % of the tendons in each group are tested (minimum 4)
- No abnormal degradation only 2 % may be tested (minimum 3)
- Performed every 5th year
- Detensioning of tendons
- Inspection of grease

IN-SERVICE INSPECTIONS (ISI) - FORSMARK

Modified version of Regulatory Guide:

- Variation in tendon forces increase with time
- Tendon forces are normally distributed
- Number of tested tendons based on statistical evaluation of measured forces



INSTRUMENTATION OF TENDONS

- Load cells
- Strain gauges on strands or on the anchor head

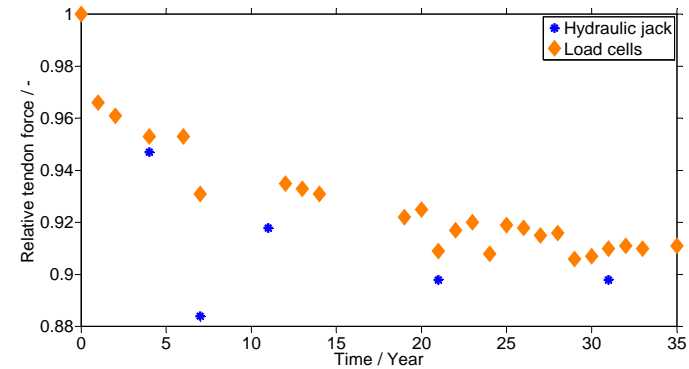
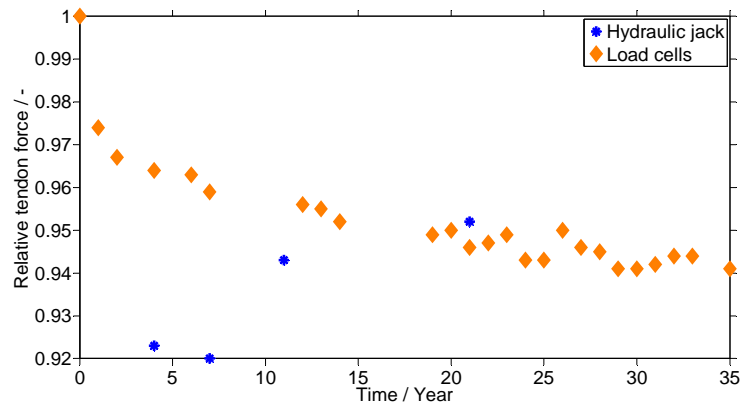
Advantages compared to ISI

- Original post-tensioning forces are known
- Continuous monitoring of prestress losses
- Degradations or failures of tendons can be detected early



INSTRUMENTATION OF TENDONS – FORSMARK 1

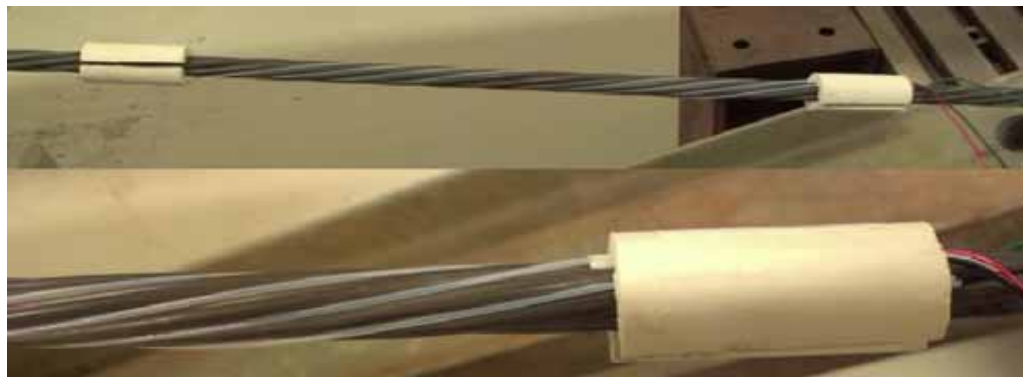
- Load cells on horizontal and vertical tendons
- Monitoring of tendon forces
- Similar results as the ISIs



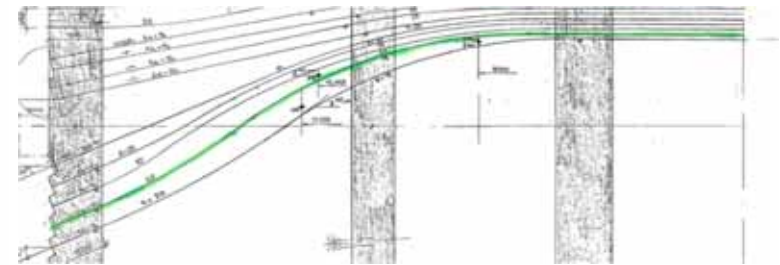
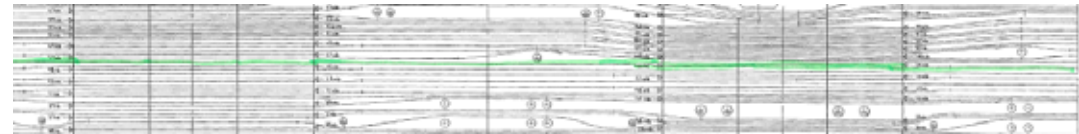
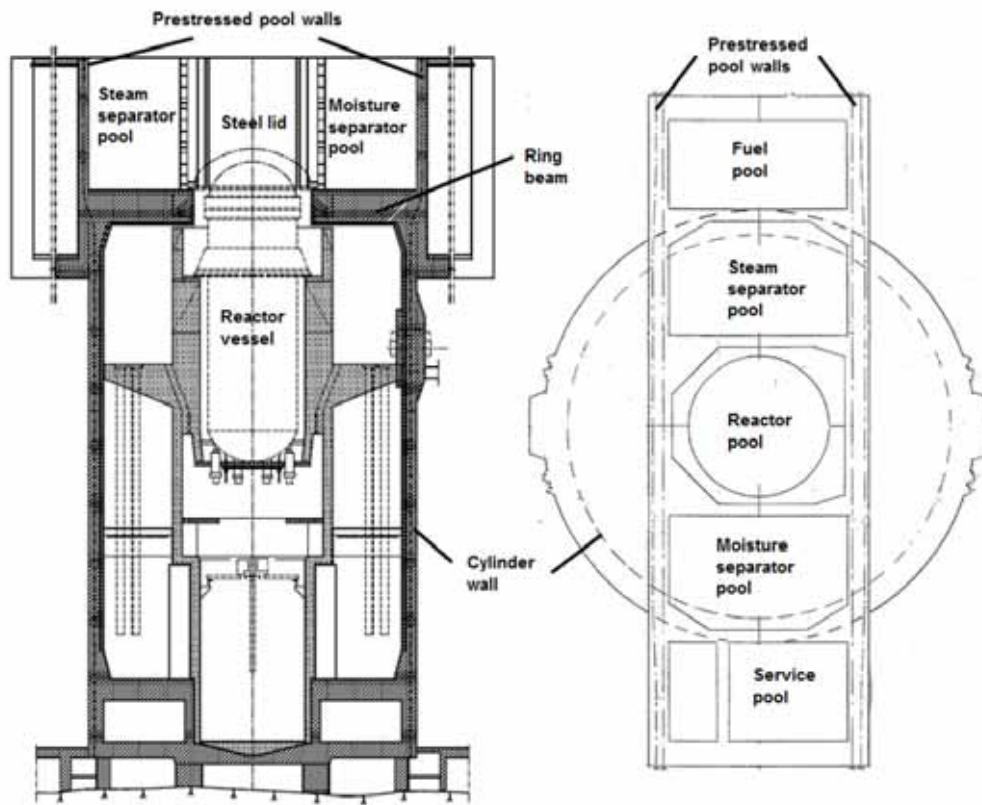
INSTRUMENTATION OF TENDONS – FORSMARK 2

Energiforsk project during 2014

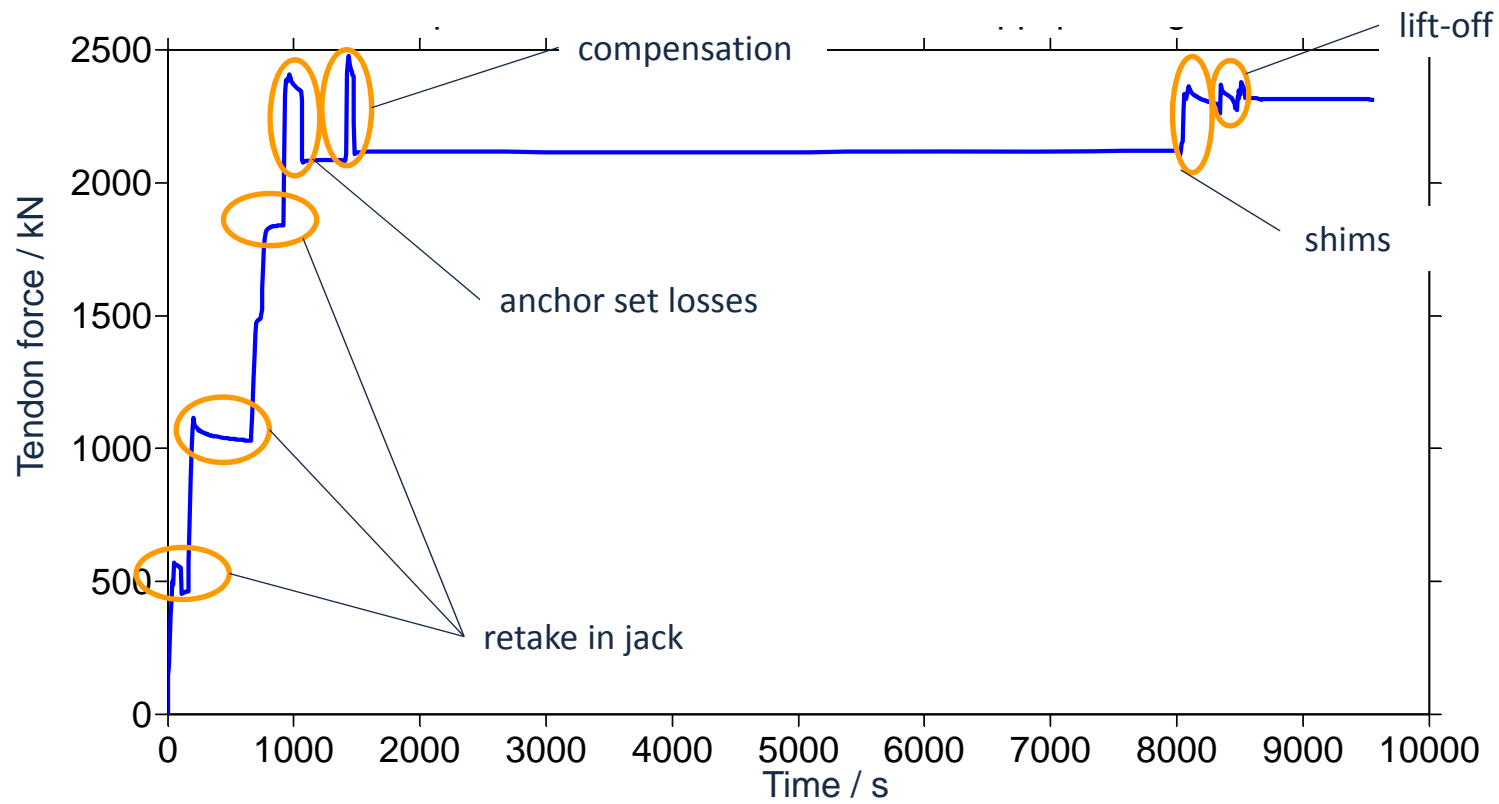
- During ISI 2014 3 tendons were de-tensioned and replaced
- Vertical and horizontal tendons (cylinder wall), horizontal tendon (pool wall)
- The new tendons were instrumented with load cells and strain gauges



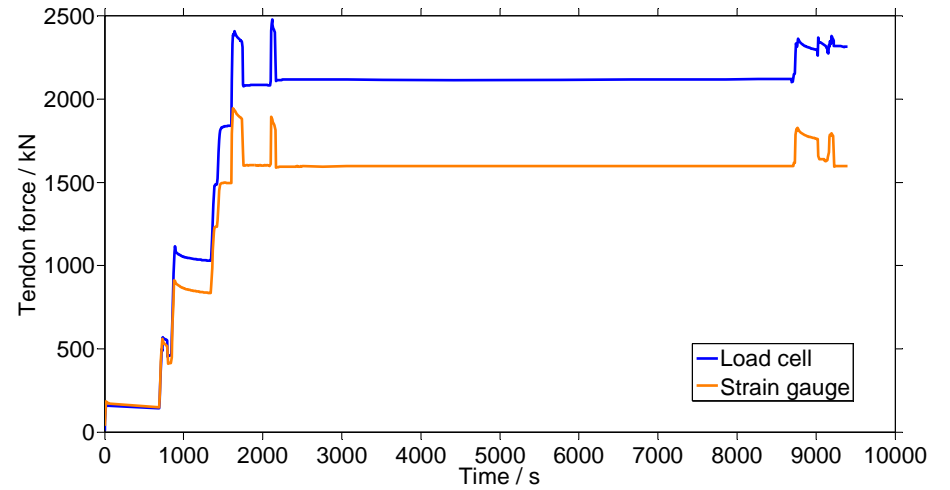
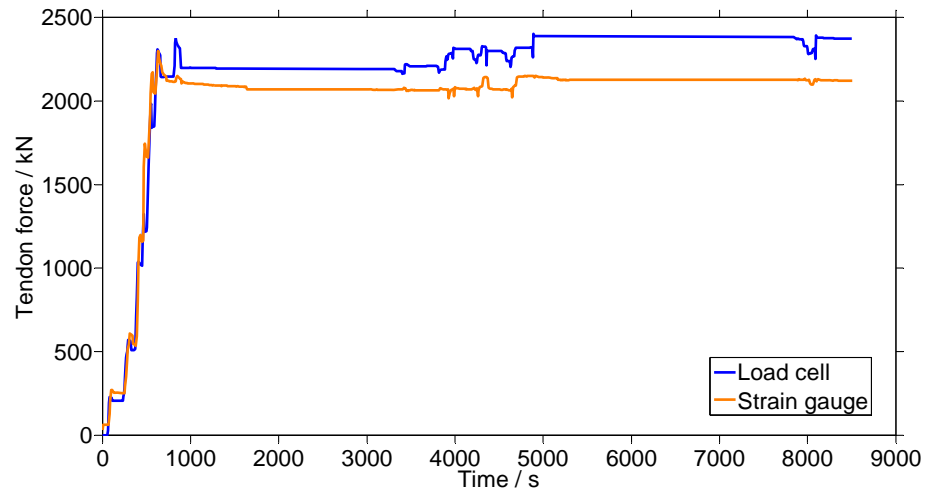
FORSMARK 2



MEASUREMENTS DURING TENSIONING



MEASUREMENTS DURING TENSIONING



ANCHOR SET LOSSES

Tendon	Loss / kN	Loss / %
Vertical, cylinder wall	165	7.1
Horizontal, cylinder wall 1	396	20.4
Horizontal, cylinder wall 2	396	19.0
Horizontal, pool wall 1	330	13.7
Horizontal, pool wall 2	351	15.3

COMPENSATION FOR ANCHOR SET LOSSES

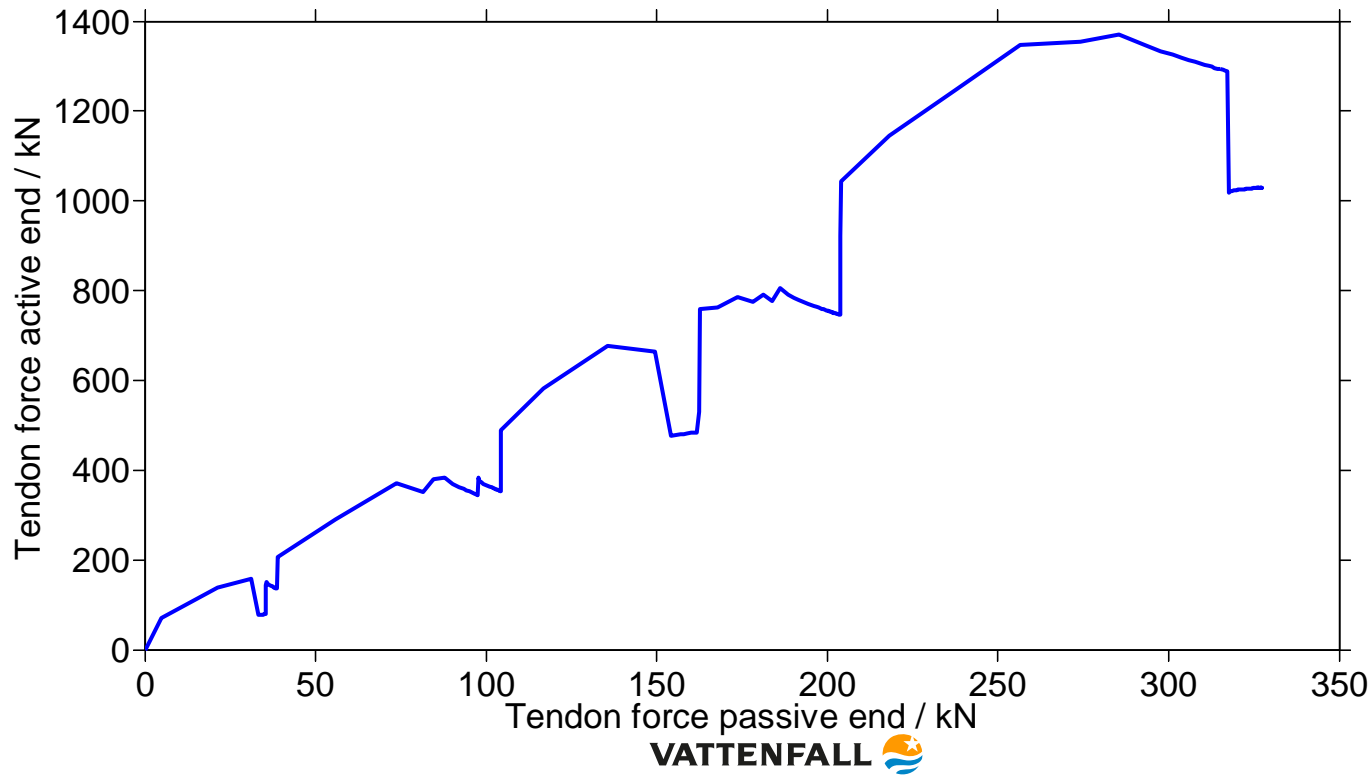
Tendon	Increase / kN	Increase / %	Effect / kN	Effect / %
Vertical, cylinder wall	232	10.8	54	2.5
Horizontal, cylinder wall 1	477	30.5	88	5.7
Horizontal, cylinder wall 2	436	25.8	80	4.7
Horizontal, pool wall 1	429	18.1	67	3.5
Horizontal, pool wall 2	402	19.3	32	1.5

ACCURACY OF HYDRAULIC JACK MEASUREMENTS

Tendon	Hydraulic jack / kN	Load cell / %	Difference / %
Vertical, cylinder wall	2357	2374	-0,7
Horizontal, cylinder wall 1	2078	1968	5,6
Horizontal, cylinder wall 2	2086	1991	4,8
Horizontal, pool wall 1	2347	2267	3,5
Horizontal, pool wall 2	2327	2202	5,7

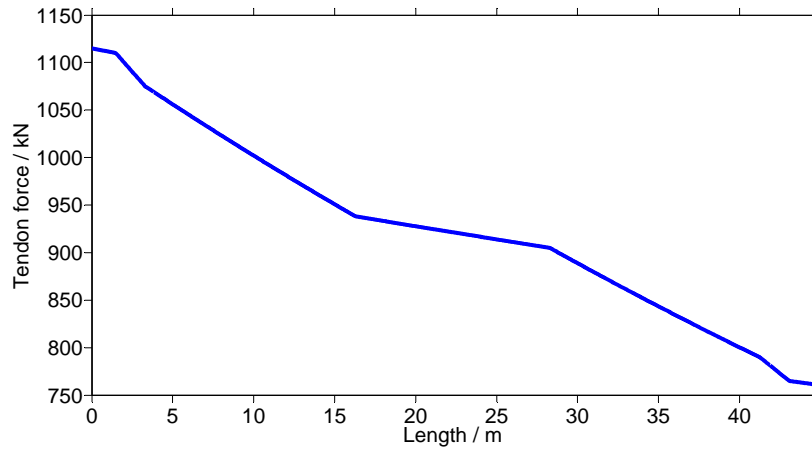
FRICTION LOSSES

Post-tensioning was initially performed from one end

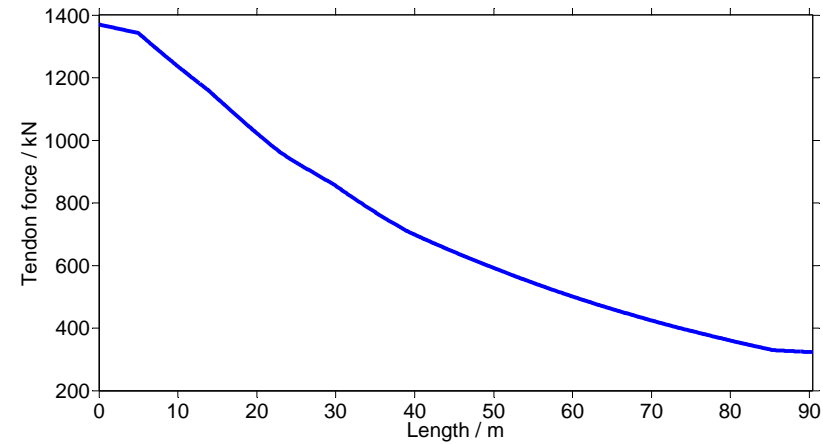


FRICION LOSSES – TENDON FORCE VARIATIONS

Horizontal tendon in pool wall



Horizontal tendon in cylinder wall

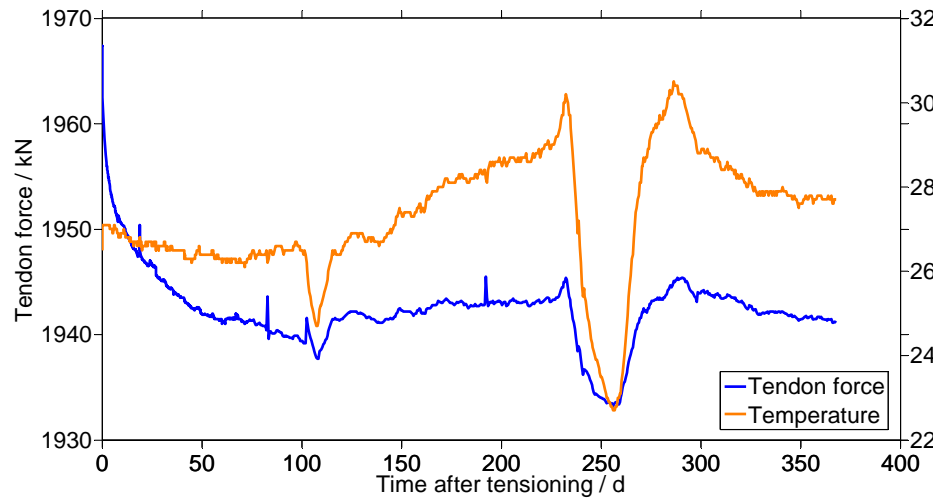


Tendon	k / %	μ / -
Horizontal, cylinder wall	0.15	0.35
Horizonmtal, pool wall	0.15	0.15

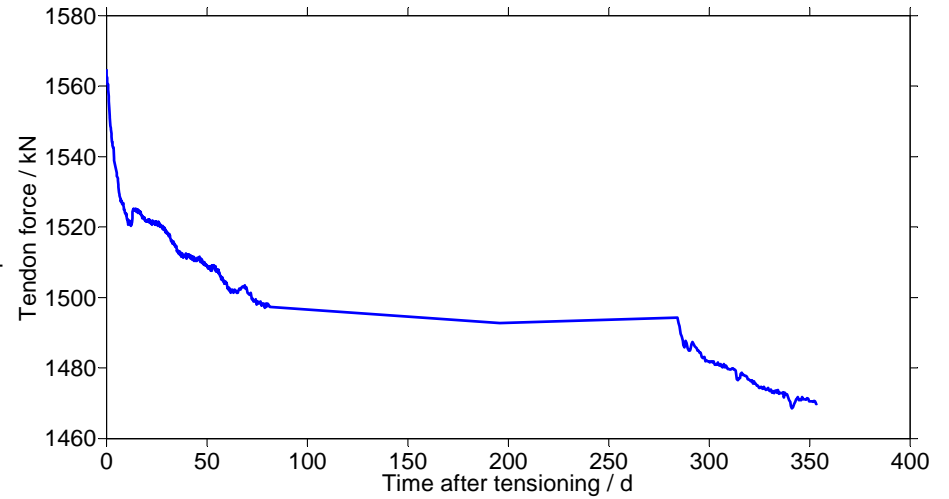
LONG-TERM MEASUREMENTS

Horizontal tendon, pool wall

Load cell

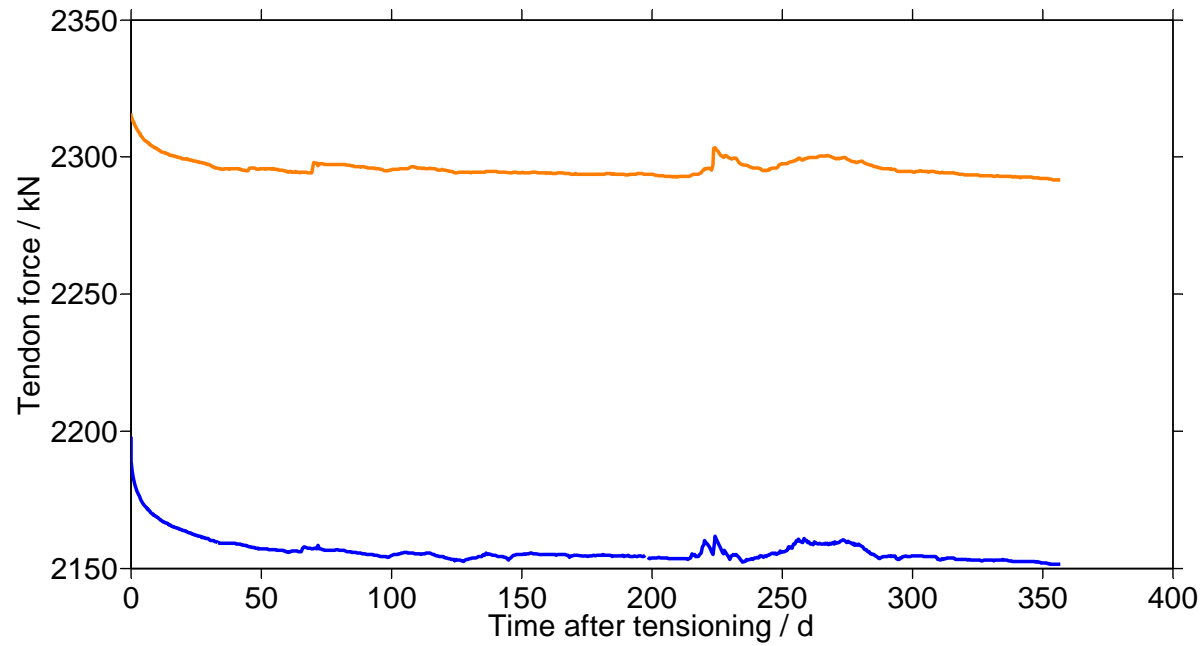


Strain gauge

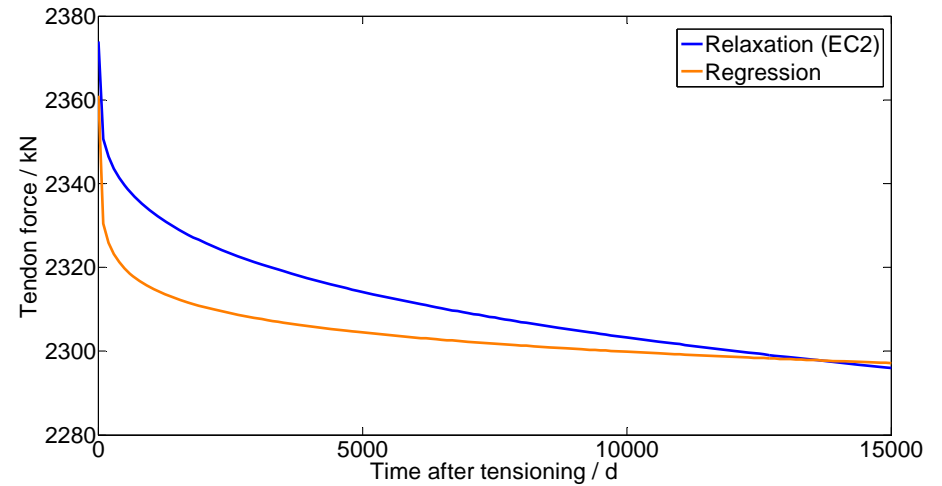


LONG-TERM MEASUREMENTS

Horizontal tendon, cylinder wall



PRESTRESS LOSSES



Tendon	Time / d	Prestress loss / kN	Prestress loss / %	Relaxation (EC2) / %
Vertical, cylinder wall	398	52	2.2	1.4
Horizontal, cylinder wall 1	368	26	1.3	0.6
Horizontal, cylinder wall 2	368	25	1.2	0.6
Horizontal, pool wall 1	357	47	2.1	0.9
Horizontal, pool wall 2	357	24	1.0	1.2

THANK YOU FOR YOUR ATTENTION!