# EXPERIMENTAL AND IN SITU STUDY OF BRIDGE BEAMS SUPPORTED BY BOTTOM EXTERNAL TENDONS

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## ABSTRACT

*The primary subject of this paper is a 10-span bridge construction built in Slovakia. The superstructure consists of 2 girders in a cross-section with span lengths 29+8×35+29 m and total length 347 m. The pair of external tendons is deviated in the middle of each span through a V-shaped steel saddle. The standard capacity of the external tendons is 19×0.61" and 12×0.61" at abutment spans.*

*The bridge was monitored during the construction period. Some cross-sections over the supporting pillars and in the middle of spans were chosen and equipped with vibrating strain gauges for strain monitoring of the concrete. Elastomagnetic force sensors were installed both on the selected internal tendons and on the most significant external tendons.*

*The test model was constructed according to the cross-section shape of the bridge construction, but considering only a 2-span continuous beam with steel saddles in a longitudinal direction. Results of measurements are compared with each other. Changes of strain in the concrete during the prestressing of each stage, increasing of force in the tendons during prestressing, decreases due to losses and stress range in the external tendons during loading, were monitored, and they were also verified on a non-linear computing model.*

**Keywords:** Monitoring, Assessment, Maintenance, Post-Tensioning

## INTRODUCTION

Viaduct 215-00 (Fig. 1 and Fig. 2) is located on the highway D1 Fričovce – Prešov west (Slovakia) and is designed as continuous post-tensioned slab with 2 beams, supported in the middle of the spans by tendon ties. The span lengths are 29 + 8×35 + 29 m, and the total bridge length 347 m (Fig. 8). A similar bridge construction viaduct Osomort in Girona (Spain) was implemented in the 1990s, and this bridge is considered to be a highly successful technical and architectural construction. Structural systems of bridges with high eccentricity external cables are still very popular in present times. External tendons located under the bridge slab in the form of ties are placed outside the bridge contour because of the higher effectivity of prestressing. These structural systems are classified in the same bridge category as extradosed bridges.

Bridge 215-00 is the first of its type of structural bridge in Slovakia and also from this point of view it was necessary to monitor in detail the stress state and deformation of the bearing structure during the construction period.

Fig. 1 Panoramatic perspective of the whole bridge structure during the construction period

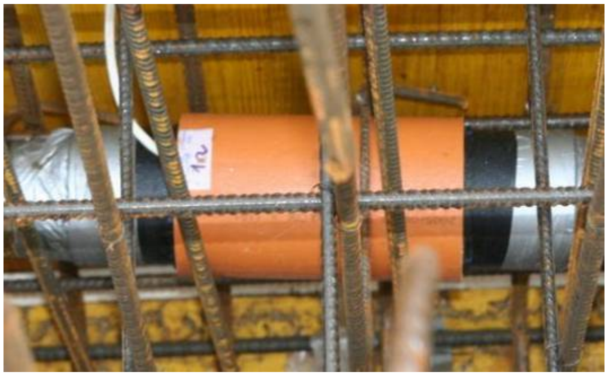
Fig. 2 Part of viaduct 215-00 during the construction period

## DESCRIPTION OF THE BRIDGE MONITORING

### FOCUS OF MONITORING

The bearing structure was built in 5 stages with spans number 5 and number 6 first due to more rapid construction. Each following stage consists of one span from both sides (direction to city Prešov – spans number 1, 2, 3, 4 and direction to city Poprad – spans numbers 7, 8, 9, 10 on other side). Besides the standard test on concrete specimens – cubes, prisms and cylinders, and prestressing steel, the structure stress state of the 2 middle spans number 5 and number 6 within the range was examined:

- stress measurement in bonded tendons with EM (elastic-magnetic) transducers PSS90 (see [1] for more information on EM method),
- stress measurement in the external tendons with EM transducers PSS140,
- stress measurement in the concrete with vibrating wire strain gauges in selected cross sections.



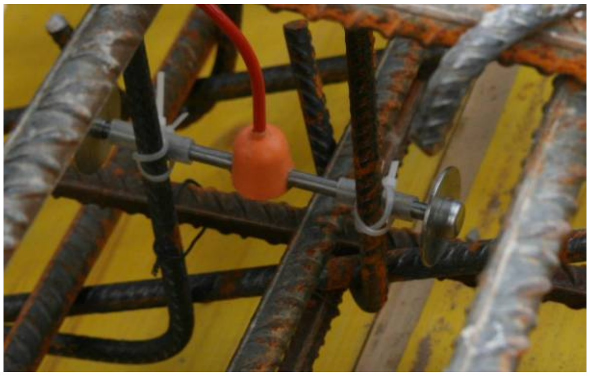


Fig. 3 EM transducer embedded on corrugated steel sheath (left)
Fig. 4 Vibrating wire strain gauge embedded on steel reinforcement (right)

## STRESS MEASUREMENT IN BONDED TENDONS

Measurement of stress in selected bonded 12 - 19 strands tendons was carried out with EM transducers PSS90 (Fig. 3). Globally were embedded 14 pieces of EM transducers PSS 90, of which one as compensatory (Fig. 5).

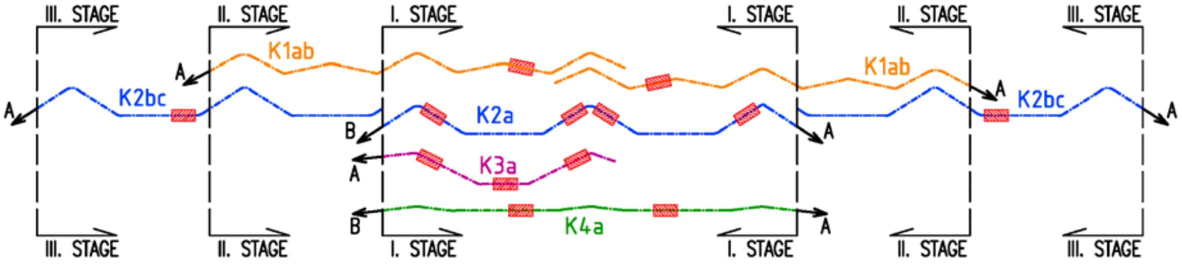


Fig. 5 Layout of tendons geometry and position of transducers on bonded tendons

EM transducers PSS90 for measuring of force (Fig. 3) were embedded on tendons K1ab (12 strands, tendon length 85,3 m), K2a (13 strands, tendon length 84,6 m), K2bc (13 strands, tendon length 72,7 m), K3a (12 strands, tendon length 47,2 m) and K4a (19 strands, tendon length 84,0 m) in such positions for monitoring of initial prestressing force and its transmission over the length of the tendon (Fig. 5).

STRESS MEASUREMENT IN EXTERNAL TENDONS

Measurement of the stress state in 8 pieces of external 19 strand tendons was carried out with EM transducers PSS140. Transducers on tendons VK4 – VK7 (4 middle spans number 4, 5, 6, 7) are embedded on the protective HDPE duct (Fig. 7). The position of the transducers (Fig. 6) makes it possible to monitor prestressing force, along with its losses.

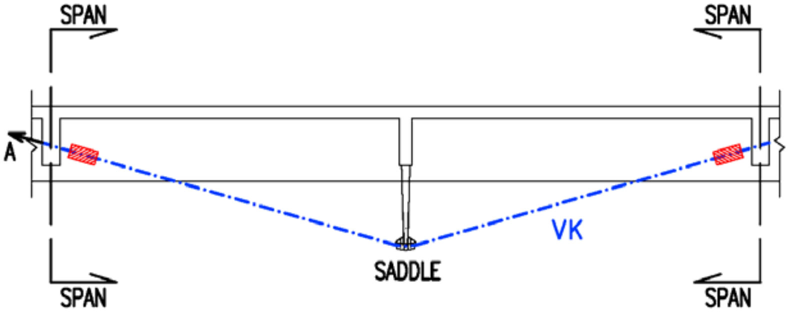


Fig. 6 Layout of external tendons geometry and position of transducers (left)
Fig. 7 EM transducer embedded on protective HDPE duct (right)

STRESS MEASUREMENT IN CONCRETE

Stress measurement in fibers of concrete was carried out in selected cross sections with vibrating wire strain gauges. Strain gauges with thermometers (ST) are embedded in 5 cross sections (Fig. 8) in each beam at the bottom (bottom fiber) and at the top (upper fiber) for estimate of stress behaviour over the depth of the girder (Fig. 8).

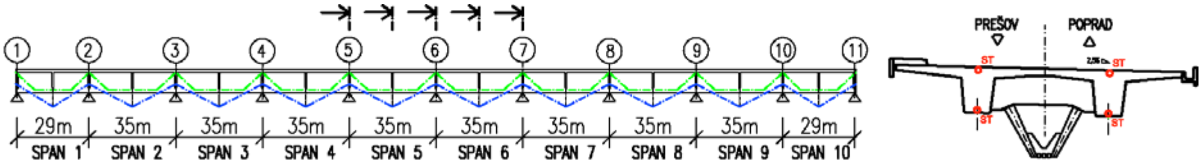


Fig. 8 Layout of selected cross sections with embedded strain gauges

## EVALUATION OF MONITORING

During the construction period 4 building stages were examined in detail, 3 of them during prestressing of bridge beams (Fig. 5). The last stage of monitoring represented measuring of stress changes during the prestressing of external tendons in the spans number 4, 5, 6, and 7. Within the scope of monitoring a total of 23 measurings of stress in concrete fibers and forces in prestressing tendons were carried out, including continuous measuring during its post-tensioning. Before putting the bridge into service 3 stages of measuring were carried out as part of the loading test – before, during and after the loading test. Due to the large scope of monitoring only selected and interesting results are presented.

## FORCE MEASUREMENT IN BONDED TENDONS

Tendon K2a with 3 EM transducers was prestressed on 17.11.2008 in the first building stage. At first the tendon was prestressed with the full amount of designed force from side „A“ (Fig. 5), and then from side „B“. Transfer of force over the tendon length (in position of EM transducers) and estimation of losses due to friction are illustrated in Fig. 9.

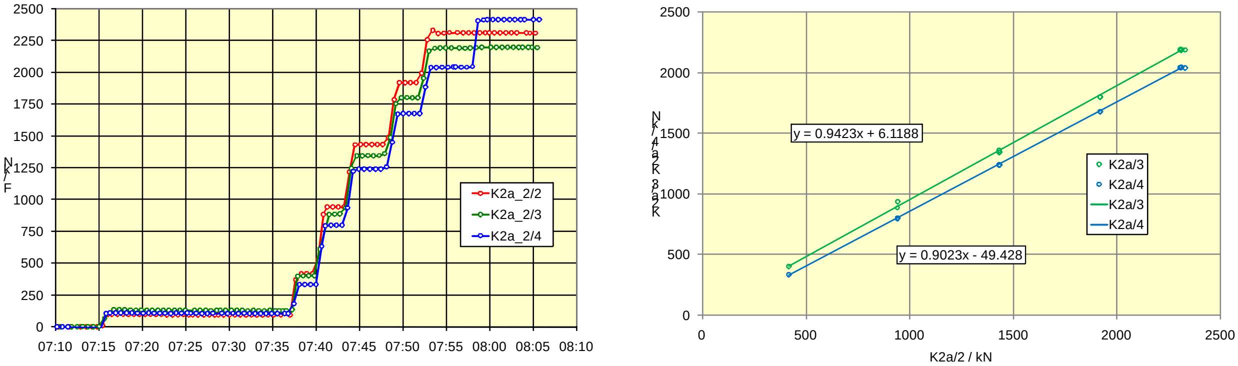


Fig. 9 Transfer of force in tendon K2a and estimation of losses due to friction

Measurement of the force in bonded tendons was also carried out after 3 time periods. In these time stages were registered time-dependent losses of prestress (Fig. 10) in the range 1,1 – 3,9%. Creep and shrinkage of concrete are closely associated with relative humidity. The temperature of the concrete was measured with vibrating wire strain gauges (Fig. 10).

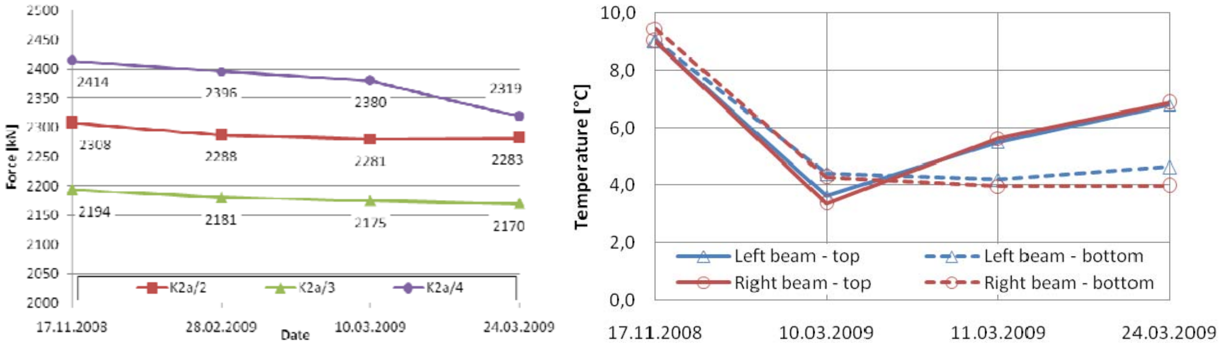


Fig. 10 Change of force in time and temperature of construction

## COMPARISON OF MEASUREMENT AND THEORY

A comparison of theoretical and measured values of force in tendon K2a over its length is illustrated in Fig. 11. For better results of monitoring a number of EM transducers were used on one tendon, located in specified positions. The theoretical transmission of force is computed using recommended values 0,19 of $\mu$ for strands (coefficient of friction between the tendon and its duct) and 0,005 $m^{-1}$ of $k$ (unintentional angular displacement for internal tendons). However, for the verification of the real values of prestressing losses in tensioning, it is recommended to measure the transmission of force over the tendon length. Measurement proved that real values of losses are lower, approximately 0,15 of $\mu$ and 0,003 $m^{-1}$ of $k$.

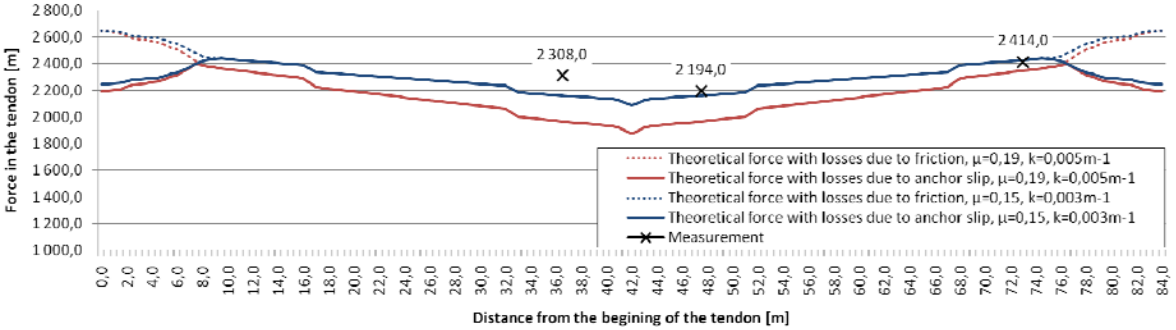


Fig. 11 Transmission of force in tendon K2a and comparison with theoretical values

## FORCE MEASUREMENT IN EXTERNAL TENDONS

External tendons (Fig. 12) have a simple geometry in the form of a “V“ and they are assembled from Monostrands, which are pulled to the HDPE duct with an outer diameter of 140 mm (Fig. 12). The position of end anchoring and the direction of the tendon in the cross beam do not allow the use of a 19-strand stressing jack. That is why a single stressing jack was used for the external tendons. After the completion of tendon prestressing, the HDPE duct was filled with grouting.

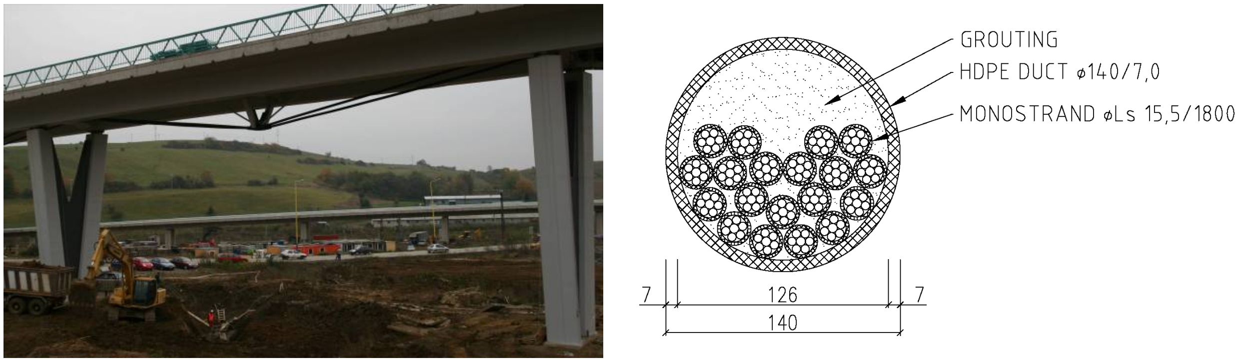


Fig. 12 External tendons on the bridge and layout of Monostrands in tendon

One of the tasks of the monitoring was to ensure sufficient force transmission from one end of the tendon to the other, besides other tasks. Following the results of this measurement, stressing of external tendon from the second side was omitted. Results of force measurement on the tendon VK6P are illustrated in Fig. 13.

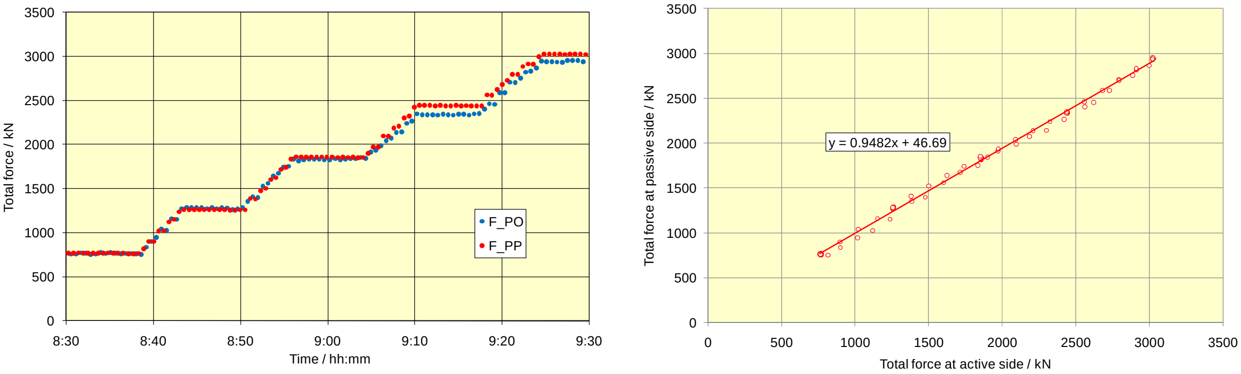


Fig. 13 Transmission of force at the beginning and at the end of tendon VK6P and estimation of losses due to friction

EM transducers were located at the beginning and at the end of the tendon. Post-tensioning was carried out with a single stressing jack in 2 working stages. In the first stage each strand from the total 19 strands was prestressed and anchored with an initial stress of 100 bar, and the bundle of strands was straightened. Thereafter with one lift of the stressing jack without intermediate anchoring the final tendon stress was achieved. During the second lift elongation of the strand to the prestressing protocol at stress values 200 – 300 – 365 bar was registered.

By this means prestressing of the 8 external tendons was measured. The final graph of the dependency between the force on the active side and that on the passive side of the tendon is shown in the Fig. 13. Prestressing losses are in the range 4 – 5% of the overall force. This is a very low value. From practice it is known that stressing of the strands from the second side can have a more unfavourable than positive effect. Furthermore in the stressing of strands from the second side there can occur anchor of wedges at the same position and that is undesirable for unbonded tendons. For the stated reasons given it was decided not to stress the strands from the second side.

## STRESS MEASUREMENT IN CONCRETE

Stress measurement in the concrete was carried out with vibrating wire strain gauges. For computation of stress values from measured strains, the modulus of elasticity from concrete specimens – cubes, prisms and cylinders (strength class for concrete C35/45) from each building stage was evaluated. The modulus of elasticity was controlled by 3 independent laboratories – in situ, supervisor and technical institute, separately for specimens from concrete casting of beams and concrete casting of the bridge slab. For theoretical analysis of the first building stage values 33 GPa for beams and 32 GPa for the bridge slab were then used. The age of the specimens represents the time from concrete casting till prestressing of the tendons. In Fig. 14 are shown comparisons of the stress variation between theoretical computing and measurement for 3 building stages (prestressing of bonded tendons in stage 1 – E1, stage 2 in the direction to city Prešov – E2-PO and stage 2 in the direction to city Poprad – E2-PP). The only difference is in the stress variation for stage 1 – E1, when the whole bearing structure was still bedded in the formwork and values achieved different results compared to the exact computational model with defined supports (pillars and formwork).

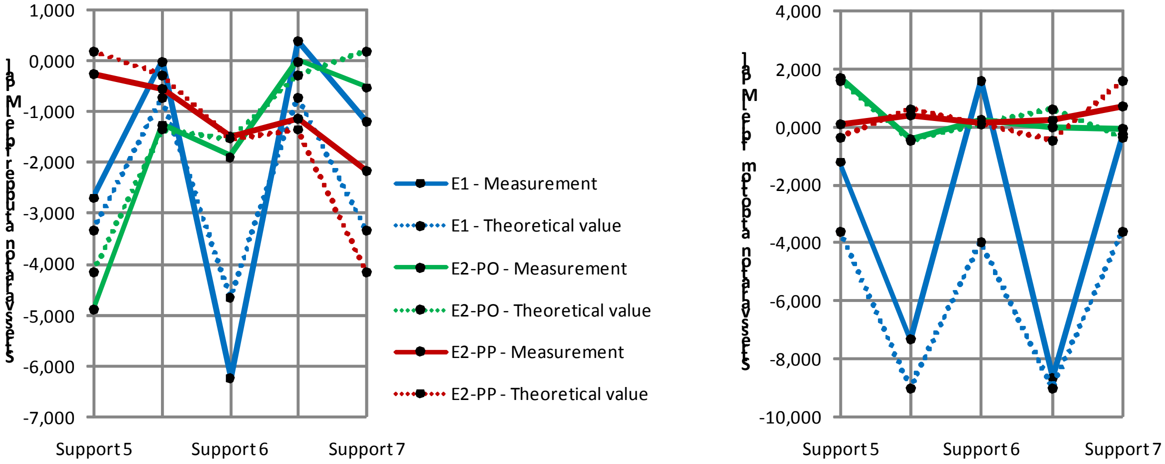


Fig. 14 Stress variation in stages of bonded tendons prestressing

In Fig. 15 are shown comparisons of the stress variation between theoretical computing and measurement for prestressing of external tendons VK5 in span 5 and VK6 in span 6. The results show nearly equivalent values.

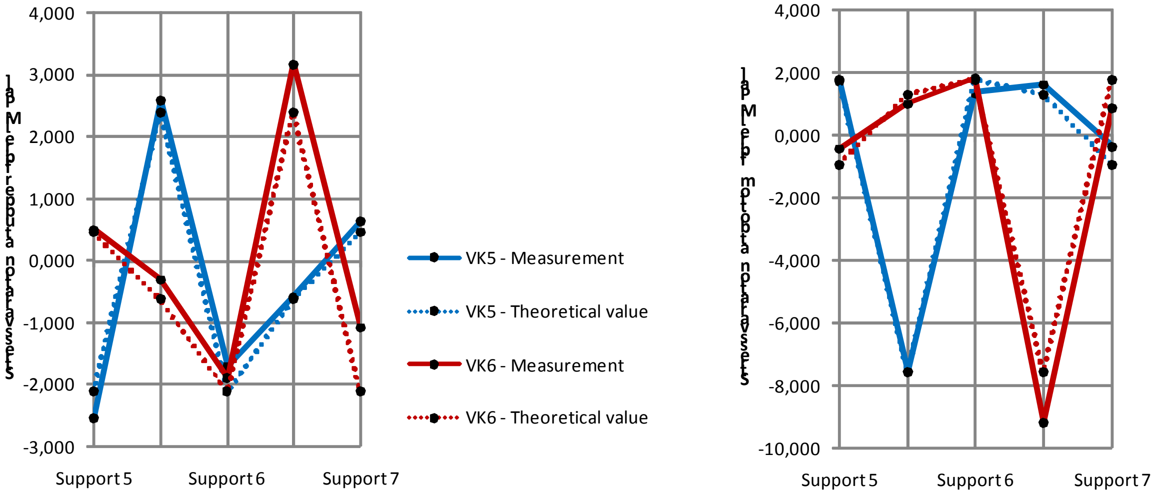


Fig. 15 Stress variation in stages of external tendons prestressing

## CONCLUSIONS

Measured strand elongations of 19-strand tendons K4, which were prestressed in the first stage E1 with a single stressing jack, show an acceptable variance compared to theoretical values (permitted variance for one strand is ±10%, the range of measured values is -2,8% through +6,4%, average variance is +2,4%).

Measured values of force in tendon K2a, K3a and K4a over their length are higher in comparison to theoretical assumptions. The theoretical transmission of force is computed using recommended values 0,19 of $\mu$ for strands and 0,005 $m^{-1}$ of $k$. However for the verification of the real values of prestressing losses in tensioning it is recommended to measure the transmission of force over the tendon length. Measurement proved that real values of losses are lower, approximately 0,15 of $\mu$ and 0,003 $m^{-1}$ of $k$, and force in the tendons is higher than can be computed according to relevant design codes.

Measured losses of prestressing force in the bonded tendons K2a, K3a and K4a during the time period show values -1,1% through -3,9% (tendon K2a); -1,5% through -2,1% (K3a); -1,8% through -1,9% (K4a), which represent time-dependent losses of prestress.

Monitoring of prestressing losses due to friction in external tendons shows that the maximum value of losses due to friction is not more than 5% on the passive side of the tendons. For this reason it was decided not to stress strands from the second side.

Measured stress variations in the concrete for the first building stage (E1), when the whole bearing structure was still bedded in the formwork show different results compared to the exact computational model with defined supports (pillars and formwork).

Measured stress variations in concrete after the prestressing of the second building stage from both sides (E2-PO, E2-PP) and prestressing of external tendons VK5 and VK6 in the 2 middle spans correspond to theoretical assumption.

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