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TEST ARRANGEMENT FOR MEASUREMENTS OF THE PRETENSION FORCE IN HIGH STRENGTH BOLTS

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INTRODUCTION

Slip resistance connections are commonly used for in-situ assembled joints of structures dominantly loaded by cyclic loading, for example in bridges, telecommunication towers, towers for wind turbines. The level of the pretension force in the bolt and the friction coefficients of the surfaces in a connection influence the strength of the slip resistance connection.

The purpose of this experimental research provided by the Faculty of Civil Engineering, the University of Belgrade, is to quantify losses of the pretension force in high strength bolts (short-term and long-term), which are used in friction connections with zinc silicate primer as corrosion protection. Continuous monitoring of connections with pretension forces, performed over a two-years period, is used to predict minimal value of the pretension force at the end of the life time of a structure. The loss of the pretension force function will be proposed based on the actual experiments and comparison with the available literature.

The experimental investigation of connections using high strength pretension bolts is performed in seven steps:

1. *Measurements of thickness of zinc silicate primer on steel plates,*
2. *Measurements of zinc silicate primer friction coefficient,*
3. *Measurements of high strength bolts strength class,*
4. *Measurements of friction coefficient between nut thread and bolt thread,*
5. *Installation of strain gauges in bolts,*
6. *Calibration of the bolts,*
7. *Assembly of bolts in connections and continuous monitoring of the pretension force.*

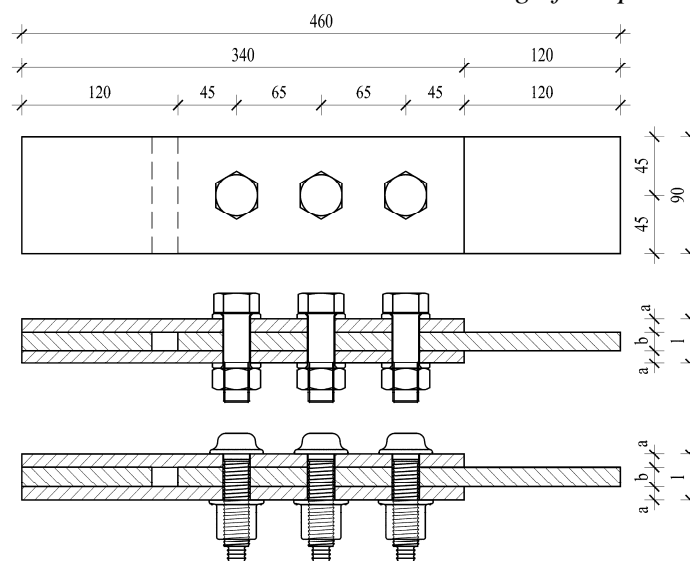


Fig.1. A typical specimen, three high strength bolts (HBT or DIN) in double lap connections

The layout of a typical specimen is shown in (Fig.1). Experimental research is very comprehensive, see the overview of specimens prepared in (Fig.2). Following parameters are studied:

1. type of the bolt – two types of the bolts: Huck BobTail high strength lockbolts [1] and high strength bolts (HV) according to EN 14399-4 standard [2],
2. length of the bolts – three different clamping lengths: 18 mm, 35 mm and 55 mm requiring three different length of the bolts,
3. thickness of primer – two types of steel plates: steel plates blasted until degree of cleanliness Sa 2½ and steel plates blasted and coated with zinc silicate primer Resist 86 [3],
4. type of load acting on specimens – two types of tests: pure relaxation test (only pretension force in the bolts acting on specimens) and dynamic load test (after two months of pure relaxation test specimens are exposed to 2×10^6 cycles of dynamic load defined for Woehler's class less than 112[4]).

All the bolts have the same diameter of 20 mm and all steel plates are grade S355.

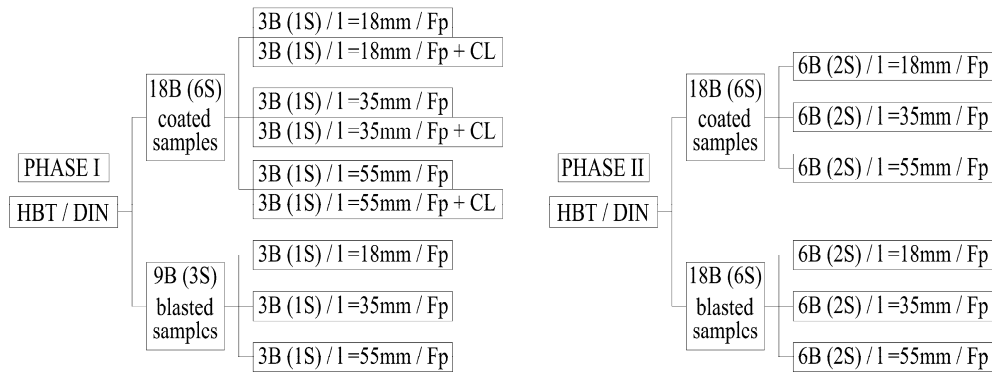


Fig.2. Scope of experiment: B-bolt, S-specimen, l-clamping length, F_p-pretension force, CL-Cyclic load

1 MEASUREMENT OF COATING THICKNESS AND DETERMINATION OF FRICTION COEFFICIENT

One of the main challenges in the application of the friction connections is to provide adequate anti-corrosion protection in the friction areas, and at the same time provide satisfactory friction coefficient. For a long time metallization was the most often used anti-corrosion protection in friction areas. This means the application of certain alloys (usually AlMn5) on the friction areas, which among other things requires both well trained manpower and a lot of time. In recent years the metallization process has increasingly been replaced by the use of zinc silicate coating, whose application is much simpler and faster. In Serbia, zinc silicate coatings were applied for the first time in friction areas during the reconstruction of the "Gazelle" bridge in Belgrade in the period between 2010-2012. For this purpose Jotun's zinc silicate primer Resist 86 was used. The friction coefficient was determined according to EN 1090-2-2008 Annex G [5] and the obtained results were between 0,45 and 0,50 which was enough for friction surface classes A and B. The only unknown parameter was the influence of zinc silicate usage in friction areas on losses of the pretension force in high strength bolts. All of the above results in the usage of Resist 86 for this experimental research.

It is a two-component, quick curing zinc rich ethyl silicate coating. It consists of the liquid component A and dry zinc dust component B mixed in the ratio of 8:2,6. It is very important that the component A has a limited lifetime, which is six months if stored in a dry, dark place at the temperature of 23 °C. Therefore, the usage of Resist 86 must be very carefully planned, regardless of whether it is used in real structures or in experimental research.

During the coating of plates for the main experimental research (measuring of losses of pretension force in high strength bolts), the plates for experimental determination of the friction coefficient were coated as well. This confirms the value of the friction coefficient resulting from the experiments conducted during the reconstruction of the "Gazelle" bridge.

The nominal coating thickness for dry film is 50-90 μm . After applying each layer of primer with a brush, its thickness was measured while a film was wet. After the period of drying, the thickness of the dry film was measured with the Dualscope measuring instruments which are used for measuring coating thickness in laboratory conditions. The coating thickness was measured in eight points on each side of each plate.

Mean value of the measured thickness of primer on specimens from phase I is 390 μm and on specimens from phase II 328 μm . Each presented value is the sum of six thicknesses (two sides of three plates which forms each specimen).

2 INSTALATION OF STRAIN GAUGES IN THE BOLTS

Because of small clamping lengths and not enough space for bonding of strain gauges on the bolt shaft surface, BTM-6C strain gauges are embedded into a hole drilled in the center of the bolt head using A-2 adhesive. These strain gauges may be used only in cases where the loss of cross-sectional area of the bolt, as a result of drilling the holes for the installation of strain gauges, is not greater than 5%. For bolt M20 drilling the $\text{Ø}2$ mm hole represents the loss of an area of exactly 1% and, in this regard, the use of strain gauges BTM-6C is fully justified.

An adhesive (manufacturer mark A-2) which is used for embedding BTM-6C strain gages is a two-component heat curing epoxy adhesive which consists of a drug A (main agent) and a drug B (hardener) in each tube. These components are mixed with each other in the weight ratio of A:B = 1:10 in an amount which is required for the installation of strain gauges.

Prior to installation it is necessary to preheat bolts and adhesive. They should be heated at 50 - 60 $^{\circ}\text{C}$ and kept at that temperature for 30 min. This reduces the viscosity of adhesive (which is necessary for successful instalation of strain gauges), and provides that the viscosity does not increase at the time of adhesive contact with the bolt (the bolt is also warm). In order to achieve this requirement, a laboratory hot plate and two temperature probes were used. One probe was inserted into the hole drilled in the bolt shank, and the other was used to measure the temperature of the hot plate.

After installation of strain gauges the bolts were lifted in upright position for 12 h, so the adhesive can cure at room temperature. Adhesive A-2 does not cure fully in room temepature so the final stage is curing at 140 $^{\circ}\text{C}$ for 3 hours. It is very important to increase the temperature gradually after placing the bolts in the laboratory oven, from room temepature to 140 $^{\circ}\text{C}$. Quick temeparure elevation may cause air bubbles or cracks in adhesive.

After cooling of the bolts, installed strain gauges were connected to the measuring equipment to determine their accuracy. Bolts containing strain gauges that do not generate the specified resistance of 120 Ω should not be used because the damage of the strain gauge.

3 CALIBRATION OF THE HIGH STRENGTH BOLTS

For the calibration of the bolts and the measurement of pretension force two acquisition systems were used. Calibration, as well as monitoring of pretension forces in each bolt, during the first two months after implantation, was carried out with HBM MGC plus acquisition system (*Fig. 3b*). After two months, the measurement was continued with Data Tacker DT85G Series 3 GeoLogger which will be used until the end of the experimental research. Both acquisition systems have two resistors with known resistance R_1 and R_3 and need two more resistors to form full Wheatstone bridge. One of them is strain gauge in the bolt R_2 and the other is strain gauge for temepature compensation R_4 as it is shown in *Fig. 3a*.

The procedure of strain gauges calibration is one of the most important parts of the bolt preparation and of the hole experimental research. In fact, it would not be able to implement the experimental research without determination of the response of each strain gage embedded in the bolt. In addition, the calibration is used to check the accuracy of the strain gauges. Calibration of 126 bolts was performed in two phases, at the Laboratory for experimental strength of the Military Technical

institute in Belgrade. For this purpose, testing machine „Schenck Trebel“ with capacity 400 kN, was used.

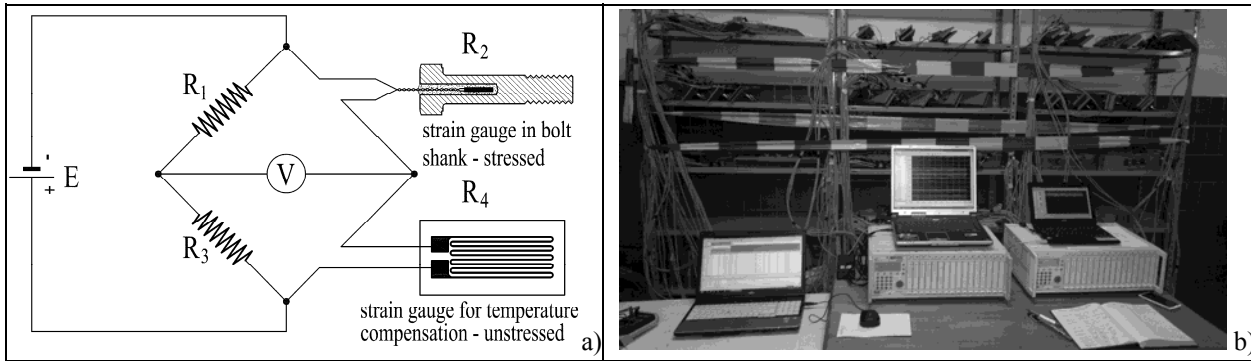


Fig.3. a) Quarter-bridge strain gauge circuit with temperature compensation; b) Acquisition systems

Special calibration tools were designed and made so that bolts can be properly fixed in the testing machine and exposed to calibration load spectra. Each type of the bolt (HBT and HV) has its own tool with the matching thread (Fig.4b). The length of the tool thread is equal to the length of the nut thread. Also, for each type and length of the bolt, the distance between calibration tools is defined in a way to ensure that the stress in the bolts during calibration fully responds to the stress after installation of the bolts in the specimen.

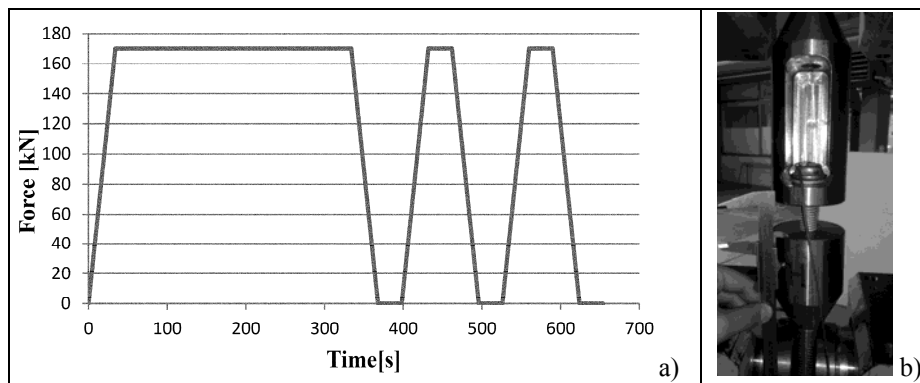


Fig.4. a) Calibration load spectra [6]; b) Calibration tools

Each bolt was calibrated with the same load spectra shown on Fig.4a. Load is always rising in the controlled rate of 5 kN/s until a certain force is reached. Next 300 seconds have been kept on constant value of the load so we can check if the bolt and strain gauge perform linearly and if the strain gauge is inserted in the bolt shank properly. After keeping the load constant for five minutes, unloading starts until the zero load level is reached again. Then the loading-unloading process is repeated twice, with the stop at the peak load level for 30 seconds. From the achieved data the ratio between the applied load and strains in the bolts is calculated with the method of least squares. If it shows a completely linear behaviour all the way to the maximum load during all load cycles, the bolt is approved for testing.

4 DYNAMIC LOAD

From the point of the load, two types of tests were performed in phase I of the experimental research: pure relaxation test (specimens exposed only to the pretension force in high strength bolts) and pure relaxation test in combination with external loading. In the second case, specimens were in pure relaxation test during the first two months after installation of the bolts and after that they were exposed to cyclic load in an axial tension force acting on specimens with frequency of 10 Hz. In phase II only pure relaxation tests were performed.

Six specimens (eighteen bolts) were exposed to cyclic load. These tests were performed in Experimental strength laboratory of the Military technical institute in Belgrade using MTS testing

machine with a capacity of ± 500 kN. Each specimen was exposed to 2×10^6 cycles of load and unload while the pretension force in the bolts was continuously measured with sampling rate 1 Hz. Dynamic load is applied in a series of 10^5 cycles with a 700 seconds brake after each series (Fig. 5). Brakes are necessary for the stabilization of the specimen and the pretension force in the bolts so they can be measured.

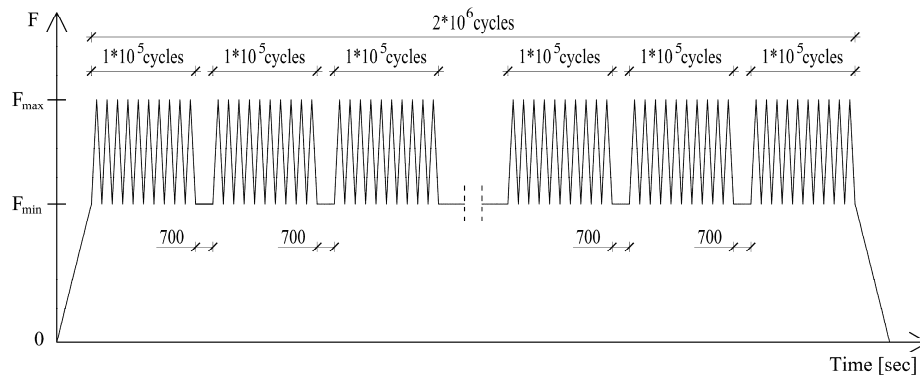


Fig. 5. Dynamic load spectrum

The cyclic load spectrum is defined by frequency of load and minimum and maximum force value acting on specimen during one cycle. The initial assumption in determining the scope of the dynamic forces acting on the specimen is the desire to simulate operational loads of the structure that was designed in a way that during its lifetime the slip of friction connection should never occur. According to Eurocode [4] double covered symmetrical joints with preloaded high strength bolts are in detail category 112, so for them $\Delta\sigma_c = 112$ MPa, calculated on the gross cross section. This means that double covered symmetrical joints with preloaded high strength bolts, as the specimens in this experimental research, will fracture after 2×10^6 cycles of load which causes stress change in the gross cross section of the specimen $\Delta\sigma_c = 112$ MPa.

Before the beginning of testing with cycling load, the pretension force was calculated for each bolt in the specimen. This was possible thanks to continuous measurement of strain gauge dilatation in all bolts and the fact that each bolt has its calibration curve.

5 CONCLUSIONS

Continuous monitoring of the pretension force in the high strength bolts is a very complex process. In order to conduct this kind of research, substantial financial resources, laboratory resources, sophisticated measuring equipment and very precise planning are required. Researchers must be especially careful when it comes to shelf life of the adhesive and zinc silicate coatings. The adhesive has a shelf life of 3 months while the liquid component of Resist 86 coating has a shelf life of 6 months, which requires very precise planning of the dynamics of the experiment.

The presented experimental study started in May 2013. with the installation of the phase I specimens, after 18 months of preparing and planning each part of the experiment. Specimens of the phase II were installed in January 2014. At present, phase I of the specimens monitoring has continuously been carried out for 9 months, and the first detailed analysis and presentation of results will ensue after 12 months.

In Table 2 short-term losses (12 h after installation) of pretension force in phase I bolts is shown. Presented losses are calculated in regard to **maximum** reached value during the installation!

Table 2. Average short-term losses of pretension force [%]

| Bolt type | Blasted specimens | | | Coated specimens | | |
|-----------|----------------------|------|------|----------------------|------|------|
| | Clamping length [mm] | | | Clamping length [mm] | | |
| | 18 | 35 | 55 | 18 | 35 | 55 |
| HBT | 46,3 | 26,3 | 24,4 | 46,9 | 30,2 | 24,3 |
| DIN | 10,1 | 9,8 | 7,8 | 14,0 | 12,1 | 11,6 |

Huck bolts were installed using hydraulic installation tool, as shown in [1]. Calibrated manual torque wrench was used to install high strength bolts according to [2], since this is most frequently used method in Serbia. Value of k-factor [7] was pre-determined experimentally. For this research, the tightening torque $1,0M_{r,i}$ was applied in one step.

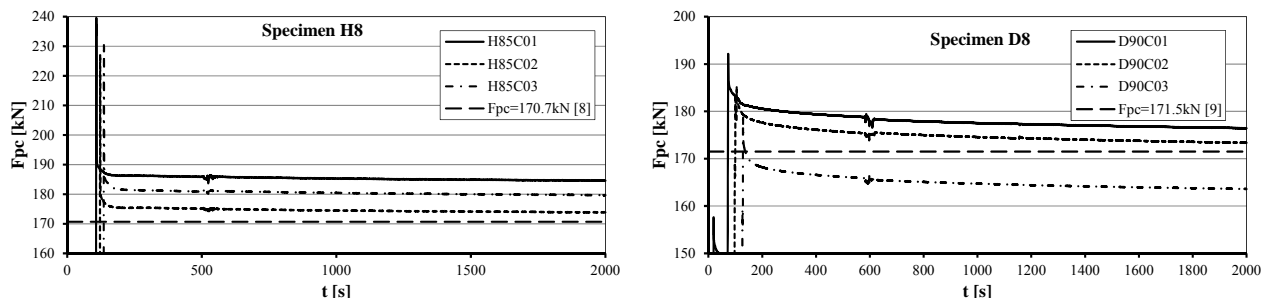


Fig. 6. Initial losses of pretension force

For better understanding of values in *Table 2*, initial losses (in first 30 minutes after bolt installation) of pretension force in six bolts was shown in *Fig. 6*. All bolts are with clamping length 55 mm, installed in specimens with anti corrosion protection. Huck bolts have significant loss of pretension force which occur in installation process. However, for bolt length over 70 mm, design value of pretension force is achieved.

ACKNOWLEDGMENTS

The authors are grateful to the companies and individuals that financially and with the necessary material, supported this research: „Alcoa Fastening Systems“ (Telford, England), „Amiga“ (Kraljevo, Serbia), „Armont SP“ (Belgrade, Serbia), „Bata-Mat“ (Belgrade, Serbia), „Euris“ (Belgrade, Serbia), „INM“ (Arije, Serbia), „Johannes Steiner GmbH & Co.“ (Weningen, Germany), „Jotun“ (Norway), „Lim inženjering“ (Belgrade, Serbia), „Mašinoprojekt Kopriv“ (Belgrade, Serbia), „Modipack“ (Požega, Serbia), „Mostogradnja“ (Belgrade, Serbia), „NB Celik“ (Batajnica, Serbia), „PERI oplata“ (Šimanovci, Serbia) „RT Trans“ (Belgrade, Serbia) and „Xella Serbia“ (Vreoci, Serbia).

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KEYWORDS: Zinc silicate primer, friction area, high strength bolts, strain gauge, calibration.

ABSTRACT

Slip resistance connections are commonly used for in-situ assembled joints of structures dominantly loaded by cyclic loading, for example in bridges, telecommunication towers, towers for wind turbines. The level of the pretension force in the bolt and the friction coefficients of the surfaces in a connection influence the strength of the slip resistance connection.

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All specimens consist of three steel plates and three bolts. Plates are in double covered and symmetrical position, with bolts in one row. Experimental research is very comprehensive, see the overview of specimens prepared in (Fig.1). Following parameters are studied:

1. *type of the bolt – two types of the bolts: Huck BobTail high strength lockbolts [1] and high strength bolts (HV) according to EN 14399-4 standard [2],*
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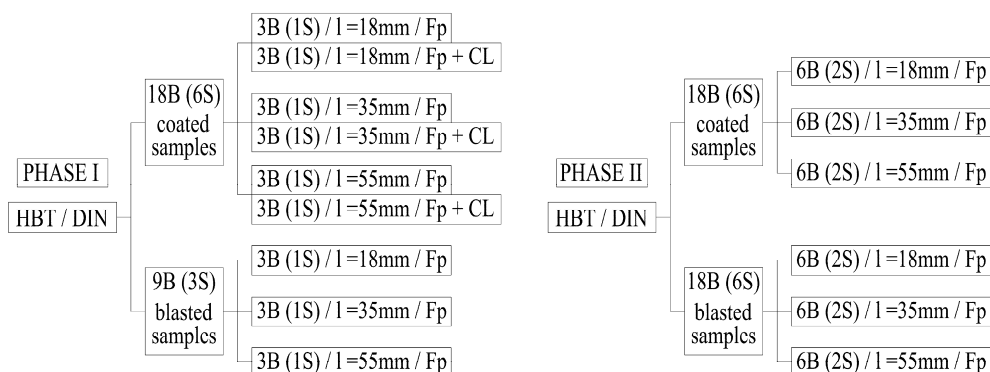


Fig.1. Scope of experiment: B-bolt, S-specimen, l-clamping length, F_p-pretension force, CL-Cyclic load

All the bolts have the same diameter of 20 mm and all steel plates are grade S355.

CONCLUSIONS

The presented experimental study started in May 2013 with the installation of the phase I specimens. Specimens of the phase II were installed in January 2014. At present, phase I of the specimens monitoring has continuously been carried out for 9 months, and the first detailed analysis and presentation of results will ensue after 12 months.

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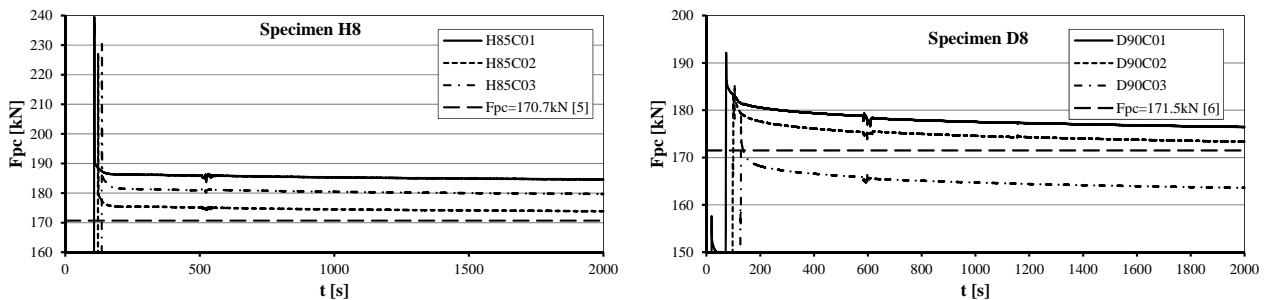


Fig. 3. Initial losses of pretension force

For better understanding of values in *Table 2*, initial losses (in first 30 minutes after bolt installation) of pretension force in six bolts was shown in *Fig. 3*. All bolts are with clamping length 55 mm, installed in specimens with anti corrosion protection. Huck bolts have significant loss of pretension force which occur in installation process. However, for bolt length over 70 mm, design value of pretension force is achieved.

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