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QUALITY CONTROL OF PRESTRESSED CONCRETE SLEEPERS DURING MANUFACTURING PROCESS

Hakan Guler, Mehmet Secil Uzuner
hguler@sakarya.edu.tr, secil.uzuner@betra.com.tr

University of Sakarya, Civil Engineering Department, Esentepe/Sakarya
Sleeper Company, Pamukova/Sakarya
TURKEY

Abstract*: There is an increasing demand for railway projects on the world. This demand also increases the demand for railway infrastructure and superstructure components which are ballast, rails, sleepers and fastening systems. In ballasted tracks the rails rest on the sleepers and together form the superstructure. Generally timber, concrete and steel sleepers are used on rail tracks. The concrete sleepers are an important element of superstructure having specific advantages which are heavy weight, long service life, great freedom of design and relatively simple to manufacture. The prestressed concrete sleepers were begun to produce and use widely with the emerging concrete technology. The prestressed concrete sleepers provide higher speeds and greater axle loads on the railway tracks. Consequently defined quality control studies must be performed during manufacturing process of the concrete sleepers to obtain the desired performance from the concrete sleepers. It is possible to realize analyses using the measured data and the measurement systems analysis during the quality control studies. In this study, Gage R&R or GRR method was used for the prestressed concrete sleepers to measure the amount of variability induced in measurements by the measurement system itself, and compares it to the total variability observed to determine the viability of the measurement system.*

Key words: *Prestressed concrete sleepers, Measurement systems analysis, Repeatability, Reproducibility.*

INTRODUCTION

The conventional railways mostly consist of rails and sleepers supported by a ballast layer. The ballast layer lies on a subballast layer that forms the transition between ballast layer and formation layer. The rails are connected to the sleepers by fastenings. The major advantages of a ballasted railway track are low construction costs, proven technology, simple replacement of track components, simple correction of track geometry, easy adjustments of track curves and alignments, good drainage, good elasticity and good damping of noise. Axle loads, speeds also service life, maintenance, local conditions and availability of basic materials are major factors to define the type of railway track structure. Consequently the choice of a track system is a technical and economic problem which has to be answered according to each individual case [1].

The functions and requirements of sleepers are: to provide a support for rails and fastenings, to transfer rail forces to the ballast bed, to preserve track gauge and rail inclination, to provide adequate electrical insulation between both rails, and to be resistant to mechanical influences and weathering over a long time period. Specific advantages of concrete sleepers are: heavy weight, long service life, great freedom of design, and they are relatively simple to manufacture. There are two basic types of concrete sleepers. The twin-block sleeper, which consists of two blocks of reinforced concrete connected by a coupling rod or pipe, and the monoblock sleeper, which is based on the shape of a beam and has roughly the same dimensions as a timber sleeper [2].

PRESTRESSED CONCRETE SLEEPERS

Reinforced concrete elements are recently the most commonly used structural material because the tensile strength of concrete is small and the steel bars are embedded in the concrete element to carry all internal tensile forces caused internal or external effects. The tensile forces can be caused by imposed loads or deformations, or by external effects such as temperature changes or shrinkage. The external loads cause tension in the bottom side which may lead to cracking. The reinforced concrete elements are usually cracked under daily service loads. On a cracked crosssection, the applied moment is resisted by compression in the concrete above the crack and tension in the bonded reinforcing steel [3].

Prestressed concrete is a kind of reinforced concrete. An initial compressive load is applied on a structure to reduce or eliminate the internal tensile forces and in that way control or eliminate the cracking in the reinforced concrete element. The initial compressive load is imposed and sustained by highly tensioned steel reinforcement reacting on the concrete. Consequently the prestressed section is considerably stiffer than the equivalent reinforced section. Prestressing may also impose internal forces which are of opposite sign to the external loads and may therefore significantly reduce or even eliminate deflection [3]. The main advantages of prestressing are [4]:

- Reduce deflections of reinforced concrete elements which are under service loads
- Fatigue resistance is considerably raised.
- Segmental forms of construction can be applied.
- Very high strength steel may be used to form the tendons.
- Sections of reinforced concrete element are smaller due mainly to the capacity to reduce deflection.

Prestressing is generally applied to a concrete member by highly tensioned steel reinforcement (wire, strand, or bar) reacting on the concrete. The high strength prestressing steel is most often tensioned using hydraulic jacks. The tensioning operation may occur before or after the concrete is cast and, accordingly, prestressed members are classified as either pretensioned or post-tensioned [3].

The European Standart which is prEN 13230 defines technical criteria and control procedures which have to be satisfied by the constituent materials and the finished concrete sleepers and bearers, i.e.: precast concrete sleepers, bearers for switches and crossings, and special elements for railway tracks. EN 13230 covers the general requirements for concrete sleepers and bearers and is used in conjunction with five parts [5].

GENERAL REQUIREMENTS OF CONCRETE SLEEPERS AND BEARERS

According EN 13230, each concrete sleeper and bearer must have the following permanent markings which are: year of manufacture, mould identification, identification mark of the production plant. In addition, the date of manufacture or batch number shall be marked on each concrete sleeper and bearer. The purchaser may require additional information to be marked on the concrete sleepers and bearers. After production process, the sleepers have to be checked whether they have the following requirements [5]:

- The top surface and sides of the concrete element shall have a uniform appearance. A random scattering of air holes shall be permitted on any surface.
- For sleepers intended for ballasted tracks, the bottom surface shall be rough and uniform.
- For sleepers on non-ballasted tracks, particular requirements for the bottom surface may be requested.
- Particular attention should be given to the rail seat area which shall be free of any individual large void.

Remedial work on a concrete element after demoulding which does not affect the mechanical performance of the product may only be carried out if detailed procedures have been included within the description of the manufacturing process [6].

Track signaling systems and electric traction systems require a minimum electrical resistance from one rail to the other. The sleepers must have the required electrical resistance [6].

Before starting production, the supplier must complete a production file for manufacturing data which must be submitted in confidence to the purchaser and shall include the following [6]:

- Water/cement ratio and tolerance;
- Weight of each concrete component plus tolerance;
- Grading curves for each concrete aggregate plus tolerance;
- Properties of the concrete after 7 days and after 28 days;
- Maximum relaxation for prestressing tendons after 1 000 hours;
- Description of the prestressing system including prestressing force and tolerance on each tendon;
- Methods of concrete vibration;
- Curing time and temperature cycle;
- Minimum concrete compressive strength before releasing prestressing tendons ;
- Method used for releasing prestressing force;
- Stacking rules after manufacturing.

The maximum tolerances specified in Table 1 apply to ballasted track and can be varied by the purchaser in the case of special requirements such as dedicated concrete elements for ballastless track or use of a sleeper laying machine, etc. [6].

The position of the centroid of the prestressing tendons must be within ± 3 mm from the design position relative to the rail seat. The individual prestressing tendons must be within ± 6 mm from the design position relative to the rail seat. The total prestressing force must be applied within ± 5 % of the specified force. Procedures must be defined in the quality plan of the supplier [6].

Table 1. Maximum tolerances

Dimensions	Description	Tolerances
L	Overall length of the concrete element.	± 10 mm
b_1, b_2	Top and bottom width of the concrete element.	± 5
H_P	Depth at any position along the total length of the prestressed concrete element	(+5 / -3) mm
L_1	Distance between the rail fastening gauge points.	(+2 / -1) mm
L_2	Position of the rail fastening gauge point with regard to the end of the concrete element.	± 8
L_3	Total length of reinforced concrete block.	± 8
I	Inclination of the rail seat.	$\pm 0.25^{o}$
F	Plainness of each rail seat area with regard to 2 points 150 mm apart	1 mm
T	Relative twist between rail seats	0.7 mm
M	Mass of the sleeper	± 5%

Figure 1 shows the dimensional checking points of main line sleepers.

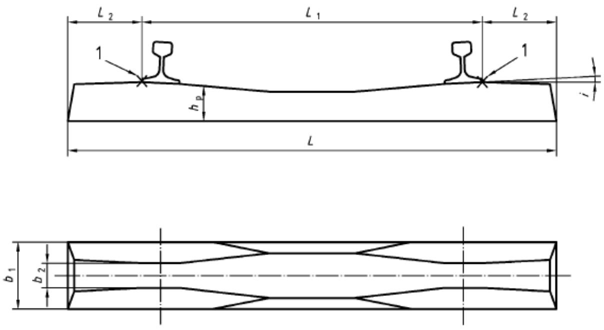

Figure 1. Prestressed mono block main line sleeper

PRODUCT STRENGTH TESTS

There are two kind of produc tests which are design approval test and rutine test for acceptance of concrete sleepers and bearers. Design approval test: a test on a concrete sleeper or bearer or part of a concrete sleeper or bearer to demonstrate compliance with the design. It is carried out on a 4 to 6 weeks-old concrete sleeper or bearer. Routine test: a product test as a part of the manufacturing quality control process [5].

Bending tests are defined for each concrete sleeper and bearer. The routine test procedures are carried out on concrete sleepers and bearers selected at random from the manufacturing production line. No additional preparation to normal production is allowed. Routine tests are usually assessed on a defined statistical basis [6].

The tests carried out for the sleepers and bearers are three kinds which are static bending test: a static load condition to confirm the behaviour of a concrete sleeper or bearer. Dynamic bending test: a dynamic load condition which applies a pulsating and increasing load to the concrete sleeper or bearer in order to simulate the situation in the track of impact loads. Only required for design approval tests. Fatigue bending test: a dynamic condition to simulate the loads applied to the concrete sleeper or bearer by traffic. An optional design approval test carried out at the request of the purchaser [6].

The sleepers are tested and mechanical parameters are evaluated. First crack which one of important mecanical parameter: a crack which originates in the tensile face of the concrete sleeper and bearer extending to a minimum depth of 15 mm on one side or other of the concrete sleeper and bearer and which increases in depth with further application of load [6].

The strength test are applied to the sleepers at the rail seat section and at the center section dividing two types which are positive and negative center tests. The arrangement for the rail seat positive load test and the negative centre load test are shown in Figure 2 and 3. The load F_r and F_{cn} are applied perpendicularly to the base of the sleeper. The end of the sleeper opposite to the end being tested must be unsupported for the rail seat test. In Figure 2, definition of the numbers: 1 Rigid support, 2 Articulated support, 3 Resilient pad, 4 Prestressed monobloc sleeper, 5 Standard rail pad as defined by the purchaser, 6 Tapered packing , 7 Lateral stop [6].

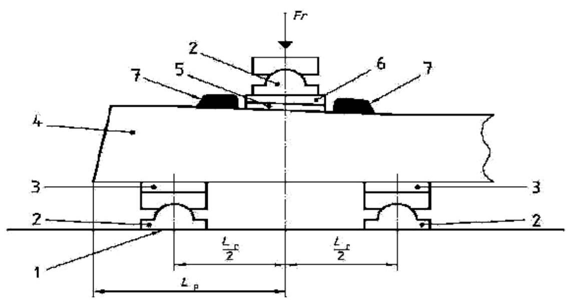

Figure 3. Test arrangement at the rail seat section for the positive load test

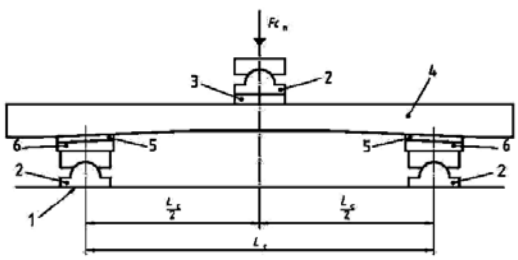

Figure 4. Test arrangement at the centre section for the negative load test

Product inspection must be carried out on all sleepers required for design approval tests including dimensions and tolerances. The relation between the design distance between the centre line of the rail seat to the edge of the sleeper at the bottom (Lp) and the design distance between the articulated support centre lines for the test arrangement at the rail seat section (Lr) is given in Table 2 [6].

Table 2. Value of Lr in relation to Lp

L_p (m)	L_r (m)
$L_p < 0.349$	0.3
$0.350 \le L_p < 0.399$	0.4
$0.400 \le L_p < 0.499$	0.5
$L_p \ge 0.450$	0.6

The test loads are calculated by using the design moments according to the customer demand. The design moments are calculated by using the axial loads and the speeds on the track. The following equations represent the calculation of the initial reference test loads applied to the rail seat and the center part of the sleepers [6]:

$$F_{ro} = \frac{4M_{dr}}{L_r - 0.1} \quad (1)$$

$$F_{co} = \frac{4M_{dc}}{L_c - 0.1} \quad (2)$$

$$F_{con} = \frac{4M_{dcn}}{L_c - 0.1} \quad (3)$$

- F_{r0} = Initial reference test load for the rail seat section, in kN
- F_{c0} = Positive initial reference test load at the centre section of the sleeper, in kN
- F_{c0n} = Negative initial reference test load at the centre section of the sleeper, in kN
- M_{dr} = Positive bending moment at the rail seat, kNm
- M_{dc} = Positive bending moment at the centre part, kNm
- M_{dcn} = Negative bending moment at the centre part, kNm

The static test procedure at the rail seat section for the design approval test and the routine test are shown in Figure 5 and 6 for the rail seat section as an example. The dynamic and fatique tests were not studied in this study. The dashed lines in the figure represents required part of test and the continous line in the figure represents the optional part of test. The symbols in the figure are [6]:

- F_{rr} = Test load which produces first crack formation at the bottom of the rail seat section, in kN
- $F_{r0.05}$ = Test load for which a crack width of 0,05 mm at the bottom of the rail seat section persists after removal of the load, in kN
- F_{rB} = Test load at the rail seat section which cannot be increased, in kN

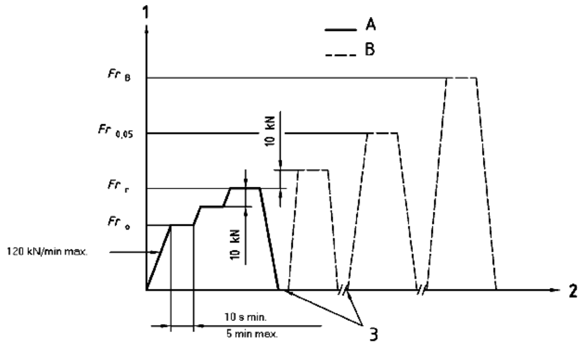

Figure 5. Static test procedure at the rail section for positive design approval test

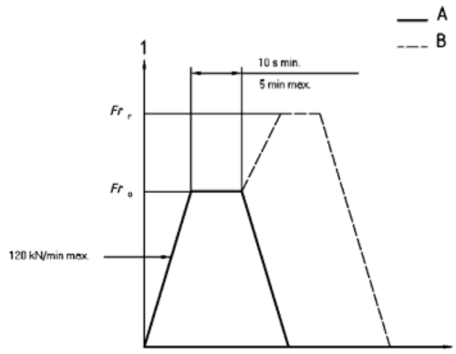

Figure 6. Static test procedure at the rail section for positive routine test

QUALITY CONTROL OF PRESTRESSED CONCRETE SLEEPERS

Quality management implementation is one of the most difficult tasks for the companies and it is still very difficult to implement a quality system. One of the major components of quality improvement measurement systems is the statistical process control. Nowadays many manufacturing companies use statistical process control to make certain and get better the quality of the products. The statistical process control is comprehensively based on the measurements and test data as the key inputs to the statistical process control system. The goal of testing and measuring is to provide results that are both accurate and precise. A variance or a standard deviation is commonly used to quantify these results [7]. Measurement systems analyses were developed to determine whether the measured data reliable or not. Generally measuring system errors are considered into five groups [8]:

- Bias: The difference between the observed average of measurements.
- Repeatability: The random variation resulting from successive trials under defined conditions of measurement.
- Reproducibility: The variation in the average of measurements caused by a normal condition of change in the measurement process.
- Stability: Refers to both statistical stability of a measurement process and measurement stability over time.
- Linearity: The difference in bias errors over the expected operating range of the measurement system.

The gage repeatability and reproducibility (R&R) study, also called the gauge capability study, is usually employed to provide quantitative information about the performance of a measurement process. A reproducibility condition occurs when the standardized measuring procedure is carried out on identical test material but under different conditions such as operators, apparatus, laboratories and times. With standardized test methods, the standard deviations obtained under ‘repeatability conditions’ and ‘reproducibility conditions’ can be distinguished easily. The total gauge variability is defined as the sum of the repeatability variability and the reproducibility variability (Eq. 4) (Figure 7) [8].

$$\sigma^2_{\mathrm{GRR}} = \sigma^2_{\mathrm{reproducibility}} + \sigma^2_{\mathrm{repeatability}} \tag{4}$$

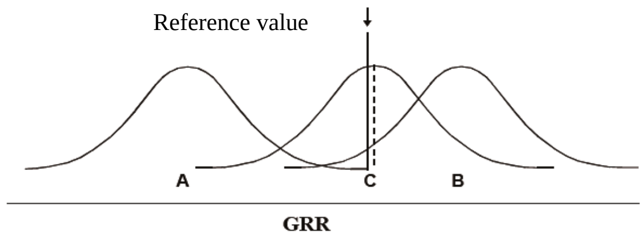

Figure 7. Gauge capability

In an R&R study, the prestressed concrete sleepers produced at Betra Sleeper Factory in Sakarya were discussed with gage repeatability and reproducibility (R&R) study. Nearly all requirements mentioned in EN 13230 were analyzed. The results were given in Table 3 and the method was summarized and demonstrated in Table 4 and 5. Table 4 and 5 represent an example of the conicity measurement results at the rail seat section. There surveyors measured ten prestressed concrete samples two times separately according to EN 13230. The averages and the ranges were calculated in Table 4 and then the measurement system and the surveyors were discussed (Table 5). The measurements and the results were discussed according to percentage of repeatability and reproducibility (R&R) values [9].

- If %R&R < %10 "The measurement system is acceptable"
- If %R&R < %30 "The measurement system is conditionally acceptable"
- If %R&R > %30 "The measurement system is suitable"
- If %EV > %AV "The problem is with the measurement system"
- If %EV < %AV "The problem is with the surveyors"

At the rail seat section area, the results for conicity were find as: %R&R = %27.1, %EV = %25.5, %AV = %9.2. The result for the conicity was found as "The measurement system is acceptable" (Table 5).

If the result was unacceptable, the measuring system might be checked and calibrated again. In case of any improvement on results then a new measuring system must be used for the test. If the problem was with the surveyors, the surveyors might be checked while they were testing the products. If required, the surveyors must be trained.

Table 3. Gauge R&R results for prestressed concrete sleepers

No	Definition	Gauge R&R Result
1.	Overall length of the concrete element.	acceptable
2.	Top and bottom width of the concrete element.	acceptable
3.	Depth at any position along the total length	acceptable
4.	Distance between the rail fastening gauge points.	conditionally acceptable
5.	Position of the rail fastening gauge point	acceptable
6.	Total length of reinforced concrete block.	acceptable
7.	Inclination of the rail seat.	conditionally acceptable
8.	Plainness of each rail seat area	acceptable
9.	Relative twist between rail seats	conditionally acceptable
10.	Mass of the sleeper	acceptable
11.	Design approval test	acceptable
12.	Rutin test	acceptable
13.	Wire coordinates	acceptable

CONCLUSION

The adequate requirements must be taken during the manufacturing process to get the desired performance from the prestressed concrete sleepers. It is wise to check the sleepers not only after the production phase also during the all manufacturing processes to increase the quality. The followings given below must be considered for a high quality sleeper production system:

- Producing the sleepers according to the standards helps an economical production.
- It is possible to increase quality of the sleepers by analyzing the measured data on the sleepers during the manufacturing processes.
- The statistical techniques must be used for a high quality management system.
- The relevant methods analyzing the all parameters affecting the quality must be chosen to evaluate the produced sleeper.

In this study, gauge repeatability and reproducibility method was chosen to evaluate the measuring system, the product and the appraisers. The adequacy of a gauge capability study is critical to studying the statistical-control characteristics of the prestressed concrete sleepers. The findings were found to be useful to check parameters affecting the prestressed concrete sleepers and the required precautions were taken on the base of the results.

Table 4. Gage repeatability and reproducibility data collection sheet

Appraiser/Trial		Part										Avarage
		1	2	3	4	5	6	7	8	9	10	
1. A	**1**	2.890	2.910	2.930	2.950	2.820	3.050	3.030	3.100	3.070	2.750	2.950
2.	**2**	2.870	2.910	2.900	2.950	2.750	3.010	3.050	3.150	3.110	2.860	2.956
3.	**3**											
4.	**Avar.**	2.88	2.91	2.92	2.95	2.79	3.03	3.04	3.13	3.09	2.81	$\overline{X}_a = 2.953$
5.	**Range**	0.02	0.00	0.03	0.00	0.07	0.04	0.02	0.05	0.04	0.11	$\overline{R}_a = 0.038$
6. B	**1**	2.900	2.910	2.950	2.990	2.810	3.040	3.050	3.150	3.110	2.900	2.981
7.	**2**	2.890	2.960	2.930	3.000	2.830	3.000	3.010	3.090	3.090	2.880	2.968
8.	**3**											
9.	**Avar.**	2.90	2.94	2.94	3.00	2.82	3.02	3.03	3.12	3.10	2.89	$\overline{X}_b = 2.975$
10.	**Range**	0.01	0.05	0.02	0.01	0.02	0.04	0.04	0.06	0.02	0.02	$\overline{R}_b = 0.029$
11. C	**1**	2.880	2.940	2.940	2.970	2.810	3.080	3.070	3.100	3.080	2.860	2.973
12.	**2**	2.890	2.940	2.920	2.960	2.780	3.000	3.030	3.120	3.090	2.870	2.960
13.	**3**											
14.	**Avar.**	2.885	2.940	2.930	2.965	2.795	3.040	3.050	3.110	3.085	2.865	$\overline{X}_c = 2.967$
15.	**Range**	0.010	0.000	0.020	0.010	0.030	0.080	0.040	0.020	0.010	0.010	$\overline{R}_c = 0.023$
16. Part Avara. $\overline{X}_p$		2.887	2.928	2.928	2.970	2.800	3.030	3.040	3.118	3.092	2.853	$\overline{\overline{X}} = 2.965$ $R_p = 0.318$
17.	$(\overline{R}_a + \overline{R}_b + \overline{R}_c)/$ Number of Appraisers=											$\overline{\overline{R}} = 0.030$
18.	$(Max\overline{X} - Min\overline{X}) =$											$\overline{X}_{Diff} = 0.0215$
19.	$\overline{\overline{R}} x D_4 =$											UKL$_R$=0.098
20.	$\overline{\overline{R}} x D_3 =$											AKL$_R$=0

D_4 = 3.27 for 2 trials and 2.58 for 3 trials. *UCL_R* represents the limit of individual *R*'s. Circle those that are beyond this limit. Identify the cause and correct. Repeat these readings using the same appraiser and unit as originally used or discard values and re-average and recompute *R* and the limiting value from the remaining observations.

Table 5. Gage repeatability and reproducibility report

Gauge analysis				% Total Variation (TV)	
Repeatability – Equipment Variation (EV)					
$EV = \overline{\overline{R}} x K_1$				**%EV=100(EV/TV)**	
$\overline{\overline{R}} =$	0.030	**Trials**	**K1**		
K1=	4.56	2	4.56		
EV=	**0.137**	3	3.05	**%**	**25.5**

Reproducibility – Appraiser Variation (AV)					
$AV = \sqrt{\overline{X}_{Diff} x K_2 - (EV^2 / nxr)}$				**%AV=100(AV/TV)**	
K2=	2.7				
		Appraisers	2	3	
AV=	**0.049**	**K2**	3.65	2.7	**%** **9.2**

Repeatability & Reproducibility (GRR)					
$R \& P = \sqrt{EV^2 + AV^2} =$				**%R&R=100(R&R/TV)**	
		Parts	**K3**	**Measuring system is acceptable**	
		2	3.65		
R&R=	**0.15**	3	2.7	**%**	**27.1**
Part Variation (PV)		4	2.3		
$PV = R_P x K_3$		5	2.08	**%PV=100(PV/TV)**	
		6	1.93		
		7	1.82		
K3=	1.62	8	1.74		
		9	1.67		
PV=	**0.516**	10	1.62	**%**	**96.2**

Total Variation (TV)			
$TV = \sqrt{R \& R^2 + PV^2}$		**ndc=1.41(PV/R&R)**	
TV=	**0.536**		**5.0**

REFERENCES:

[1] Sadeghi, J. M. and Babaee, A. (2006). Structural optimization of B70 railway prestressed concrete sleepers, Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 30, No. B4.

[2] Esveld, C. (2001). Modern Railway Track, MRT Press, Zaltbomme, The Netherlands.

[3] Gilbert, R.I. and Mickleborough N.C. (1990). Design of Prestressed Concrete, Spon Press, Sydney, Australia, pp 4-30.

[4] Threlfall, A., J. (2002). An Introduction to Prestressed Concrete, British Cement Association, Berkshire, UK, pp 2-20.

[5] EN 13230-1 (2002). Railway applications - Track - Concrete sleepers and bearers - Part 1: General requirements.

[6] EN 13230-2 (2002). Railway applications - Track - Concrete sleepers and bearers - Part 2: Prestressed monoblock sleepers.

[7] Wang, F.,K, Eldon, Y., L. (2003). Confidence intervals in repeatability and reproducibility using the Bootstrap method, Total Quality Management, Vol. 14, No. 3, pp. 341-354.

[8] Duncan, A. J. (1986). Quality Control and Industrial Statistics, 5th ed., Richard D. Irwin, Inc., Homewood, Illinois.

[9] Burdick, R. K., and Larsen, G. (1997). Confidence Intervals on Measures of Variability in R&R Studies, Journal of Quality Technology, Vol. 29, No. 3, pp. 261-273.

КАЧЕСТВЕН КОНТРОЛ НА ПРЕДВАРИТЕЛНО НАПРЕГНАТИ БЕТОНОВИ ТРАВЕРСИ ПО ВРЕМЕ НА ПРОИЗВОДСТВЕНИЯ ПРОЦЕС

Хакан Гюлер, Мехмет Узунер

hguler@sakarya.edu.tr, *secil.uzuner@betra.com.tr*

Университет Сакария, Компания за траверси Бетра, Памукова/Сакария

ТУРЦИЯ

Ключови думи: *предварително напрегнати бетонови траверси, анализ на измерителните системи, повторяемост, възпроизводимост.*

Резюме*: Все повече се увеличава търсенето на железопътни проекти по света. Това търсене също така увеличава търсенето на железопътна инфраструктура и компоненти за горно строене, които са баласт, релси, траверси и системи за свързване. При баластовия път релсите се опират на траверси и заедно образуват горното строене. Като цяло за релсови пътища се използват траверси от дърво, бетон и стомана. Бетоновите траверси са важен елемент на горното строене и имат специфични предимства, които са тежест, дълъг експлоатационен живот, голяма свобода на проектирането и сравнително лесно производство. Производството и широкото използване на предварително напрегнатите бетонови траверси започва с възникването на бетоновите технологии. Предварително напрегнатите бетонови траверси осигуряват по-високи скорости и по-голямо осово натоварване на железопътните линии. Следователно изследванията за определяне на контрол на качеството трябва да се извършват по време на процеса на производство на бетонови траверси за постигане на желаните резултати.*