SISTEM ZA MONITORING NOVOG ŽELEZNIČKO-DRUMSKOG MOSTA U NOVOM SADU

MONITORING SYSTEM FOR NEW RAIL-ROAD BRIDGE NOVI SAD

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1 UVOD

Projekat "Monitoring sistem i probno opterećenje Železničko-drumskog mosta u Novom Sadu" je konačno prihvaćen u martu 2016. godine od strane izvođača radova (AZVI/Taddei/Horta/Coslada), projektanta (A. Bojović, kompanija "Deling", Beograd) kao sofisticirana, racionalna i modifikovana verzija inicijalnog plana aktivnosti "Oprema za monitoring" i "Probno opterećenje", nakon brojnih priprema, od 2014. godine. Ovaj projekat je realizovan u okviru FTN konzorcijuma čiji su partneri:

- Departman za građevinarstvo i geodeziju, Fakultet tehničkih nauka (FTN), Univerzitet u Novom Sadu (glavni partner konzorcijuma),
- Građevinsko-arhitektonski fakultet Univerziteta u Nišu - Niš (pridruženi partner),
- TRCpro - Petrovaradin (partner za opremu i logistiku),
- GeoGIS Consultants - Beograd (partner za geodetsko merenje),
- Creative Tree i IK Solutions - Novi Sad (partneri za razvoj softvera) i
- Wiss, Janney, Elstner Associates, Inc. - Čikago, SAD (konsalting partner).

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1 INTRODUCTION

Optimized project for "Monitoring Equipment and Test Load of Railway Road Bridge in Novi Sad" was finally accepted in March 2016, both by Contractor (AZVI/Taddei/Horta JV) and Designer (A. Bojović, "Deling" company, Belgrade) as a sophisticated, rational and modified version of initial "Monitoring Equipment" and "Test Load" plan of activities, after many preparations, since 2014. This project is realized by the following FTN Joint venture:

- Department for Civil Engineering and Geodesy, Faculty of Technical Sciences (FTN), University of Novi Sad (main partner of Joint venture),
- Faculty of Civil Engineering and Architecture, University of Niš (consulting partner),
- TRC Pro - Petrovaradin (hardware installation and logistics partner),
- GeoGIS Consultants - Belgrade (geodesy partner in test by load),
- Creative Tree - Novi Sad (software development partner) and
- Wiss, Janney, Elstner Associates, Inc. - Chicago, USA (consulting partner).

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Poštovani su i ispunjeni sledeći dokumenti:

- SRPS U.M1.046 - Tehnička regulativa za ispitivanje mostova probnim opterećenjem [1],
- inicijalni "Metod rada za monitoring" i "Metod rada za probno opterećenje" ([4] i [5]),
- konačni "Metod rada za monitoring i probno opterećenje" [2], i

• zahtevi Investitora, Projektanta, Izvođača radova, Podizvođača radova i Inženjera.

Naše opšte primedbe i preporuke su bile:

- dugotrajni monitoring i ispitivanje probnim opterećenjem treba realizovati u istoj konfiguraciji mernih mesta, senzora i opreme, s izuzetkom nekih zona koje su značajne samo u fazi lansiranja oba lučna mosta,
- isti radni tim treba da bude odgovoran za opremu, monitoring i ispitivanje probnim opterećenjem i
- snabdevanje i ugradnja opreme, instalacija monitoring sistema i ispitivanje probnim opterećenjem bi trebalo organizovati kao zadatak FTN konzorcijuma po sistemu "ključ u ruke", a obezbeđenje teretnih vozila kamiona/vagona/lokomotiva, kao i logistike na gradilištu treba da organizuje AZVI kao Izvođač radova, prema preporukama FTN tima.

2 OPIS KONSTRUKCIJE ŽELEZNIČKO-DRUMSKOG MOSTA U NOVOM SADU

Most se nalazi na lokaciji starog "Žeželjevog mosta, na trasi međunarodne magistralne elektrificirane pruge "Beograd - Budimpešta". Most ima dva koloseka, dve drumske trake i dve pešačko-biciklističke trake, izveden je kao čelična konstrukcija, u skladu sa urbanističkim zahtevima grada Novog Sada.

Ukupna dužina mosta je 474.0m i sastoji se od četiri, u konstrukcijskom smislu, potpuno nezavisne celine sledećih karakteristika:

- raspon 25,3m + 1,7m (prilazna konstrukcija mosta 1-2A na strani Petrovaradina),
- raspon 177,0m (lučna konstrukcija mosta 2-3A na strani Petrovaradina),
- raspon 3,0m (prelazna konstrukcija u zoni centralnog stuba)
- raspon 219,0m + 1,7m (lučna konstrukcija mosta 3B-4 na Novosadskoj strani),
- raspon 46,3m (prilazna konstrukcija mosta 4B-5 na Novosadskoj strani),
- razmak između osa zatega = 23,5m,
- razmak između osa luka 2-3 na vrhu = 12,978m,
- razmak između osa luka 3-4 na vrhu = 10,5m,
- razmak između spoljašnjih ivica maski = 31,4m i
- visine lukova su 34,0m i 42,0m.

Prilazne konstrukcije mosta su sistema proste grede sa sledećim karakteristikama:

- bočne grede: čelične konstrukcije, istog oblika kao zatega susednog lučnog mosta,
- srednja greda: spregnuta konstrukcija čelik-beton,
- kolovozna ploča: armiranobetonska, spregnuta vertikalno sa poprečnim nosačima kolovozne konstrukcije i srednjom gredom, dok je sa bočnim gredama spregnuta horizontalno i
- primenjeni materijali: čelik S355, beton C35/45, armatura B500B (ili C).

Respected and fulfilled documents were:

• SRPS U.M1.046 - Serbian technical regulation for testing of bridges by load [1],

• initial "Method Statement for Monitoring and Test Load" ([4] and [5])

• final "Method Statement for Monitoring and Test Load" [2] and

• requirements of Employer, Designer, Contractor, Subcontractor and Engineer.

Our general remarks and recommendations were:

• Long time monitoring and test by load should be performed by same configuration of measurement points, gauges and equipment, with except of some points which are important only in launch phase of both of arch bridges,

• same working team could be in charge for equipment, monitoring and test by load and

• supply and installation of equipment, building of monitoring system and test by load should be organized as a "turn-key" task by FTN Joint venture and obtaining of loaded trucks/wagons/locomotives as well as construction site logistics should be organized by AZVI as Contractor, according to recommendations from FTN team.

2 BASIC STRUCTURAL DESCRIPTION OF THE RAILWAY ROAD BRIDGE IN NOVI SAD

The bridge is located on the place of the old Žeželj Bridge, on the way of the major international electrified railroad "Belgrade - Budapest". Bridge has two tracks, two road lanes and two foot-cycle paths with steel bridge structure according to the requirements of urban conditions of the city of Novi Sad.

Total length of the bridge is 474.0m and it consists of four, in structural manner, completely independent parts with the following dimensions:

- span 25.3m+1.7m (approach bridge part 1-2A on Petrovaradin side),
- span 177.0m (arch bridge part 2-3A on Petrovaradin side),
- span 3.0m (transition structure on central pier zone)
- span 219.0m+1.7m (arch bridge part 3B-4 on Novi Sad side),
- span 46.3m (approach bridge part 4B-5 on Novi Sad side),
- spacing of the ties axes = 23.5m,
- spacing of the arches axes 2-3 at the top = 12.978m,
- spacing of the arches axes 3-4 at the top = 10.5m,
- spacing between the outer edges of the masks = 31.4m and
- height of arches are 34.0m and 42.0m.

Approach bridges are simply supported beam systems with following girders and characteristics:

- side girders: steel structure, same shape as tie adjacent tied-arch bridges,
- middle girder: composite structure steel /concrete,
- deck plate: reinforced concrete, part of composite cross-beams and middle girder for vertical actions: coupled with side girders for horizontal actions and
- structural materials are steel S355, concrete

Prelazna konstrukcija je sistema roštilja gde su podužni i poprečni nosači spregnuti sa AB pločom. Lučni mostovi su slobodno oslonjeni prostorni lukovi sa zategom i sa sledećim karakteristikama i segmentima:

- lukovi, poprečne grede za vezu lukova, zatege (čelična konstrukcija),
- vešaljke (kablovi sa paralelnim strukovima),
- poprečne grede (čelična konstrukcija),
- betonska kolovozna ploča (armiranobetonska spregnuta sa poprečnim nosačima) i
- primenjeni materijali: čelik S355 i S460, beton C35/45 i C40/50, kablovi $f_y=1860\text{MPa}$, armatura B500B (ili C).

Svi čelični delovi konstrukcije su zavareni u radionici, spojevi su zavareni na licu mesta, AB ploča je betonirana na licu mesta. Svi zahtevi pravilnika za projektovanje koji se odnose na trajnost, granična stanja nosivosti (GSN), granična stanja upotrebljivosti (GSU) i aeroelastičnu stabilnost su zadovoljeni.

3 MONITORING PARAMETARA KONSTRUKCIJE MOSTA

Monitoring obuhvata niz aktivnosti osmatranja, prikupljanja podataka, transfer, analizu i prezentaciju podataka dobijenih dugotrajnim merenjem tokom eksploatacije mosta. Cilj monitoringa je formiranje baze podataka za praćenje ponašanja konstrukcije mosta čime se izbegava potencijalna degradacija konstrukcijskih performansi mosta (nosivost, krutost, upotrebljivost i trajnost).

Monitoring mosta uključuje sledeće aktivnosti:

- monitoring utezanja vešaljki,
- monitoring lansiranja lučnih mostova,
- monitoring lansiranja i nanošenja stalnog opterećenja na prilazne rampe i uklanjanje privremenih oslonaca prilaznih rampi,
- monitoring nanošenja stalnog opterećenja na lučne mostove,
- monitoring izgrađenog mosta u testu probnog opterećenja i
- monitoring izgrađenog mosta tokom eksploatacije (tj. dugotrajni monitoring).

4 SPECIFIKACIJE PROCEDURE I OPREME ZA MERENJE

Naš optimizovani Projekat obuhvata sledeću konfiguraciju posmatranih zona/preseka mosta:

- Z-pomeranja: 12 zona u polju i 8 oslonačkih zona,
- X-pomeranja: 4 oslonačke zone,
- Nagibi: 12 zona u polju i 9 oslonačkih zona,
- Naponi: 4 zona u polju, 8 oslonačkih zona i 2 zone za vreme navlačenja mosta,
- sile u 80 vešaljki,
- ubrzanja, frekvencije i parametri prigušenja: 12 zona u polju i 9 oslonačkih zona i
- temperatura u konstrukciji mosta: 12 zona u polju i 9 oslonačkih zona.

C35/45 and reinforcement B500B (or C).

Transition structure is the system of cross and connection beams with RC deck plate.

Arch bridges are simply supported arch-tie space structural systems with the following parts and characteristics:

- arches, transversal arch connecting beams, ties (steel structures),
- hangers (cables with parallel strands),
- cross beams (steel structure) and
- concrete deck plate (reinforced concrete coupled with cross beams).
- structural materials: steel S355 and S460, concrete C35/45 and C40/50, cables $f_y=1860\text{MPa}$ and reinforcement B500B (or C).

All steel structural parts are welded at workshop, connection joints are welded at site, and RC deck plate are concreted at site. All design code requirements related to durability, ultimate limit states (ULS), serviceability limit states (SLS) and aero elastic stability, are satisfied.

3 MONITORING OF BRIDGE STRUCTURAL PARAMETERS

Monitoring was performed through the set of activities that include observation, acquisition, transfer, analysis and presentation of data obtained by long time measurement during bridge exploitation. Monitoring target was database formation for observing bridge structure behaviour due to avoid potential deterioration of bridge structural performance (bearing capacity, stiffness, serviceability and durability).

Bridge monitoring comprehends the following:

- monitoring during tensioning of hangers,
- monitoring during launching of arch bridges,
- monitoring during installation of permanent load on approach bridges and releasing of approach bridges from temporary supports,
- monitoring during installation of permanent load on arch bridges,
- monitoring of completed bridge during test by load and
- monitoring of completed bridge during exploitation (i.e. long time monitoring).

4 SPECIFICATION OF MEASUREMENT PROCEDURES AND EQUIPMENT

Our optimized project comprehends the following configuration of observed zones/sections of the bridge:

- Z-deflections: 12 mid span zones and 8 support zones,
- X-deflections: 4 support zones,
- Inclinations: 12 midspan zones and 9 support zones,
- Stresses: 4 midspan zones, 8 support zones and 2 zones during launching
- forces in 80 hangers,
- acceleration, frequency and damping parameters: 12 midspan zones and 9 support zones and
- temperature in bridge structure: 12 midspan zones and 9 support zones.

Oprema za monitoring, softver i vozila za ispitivanje probnim opterećenjem su:

- 328 mernih traka u 14 preseka (za napone u konstrukciji),
- 80 merača sile (isporučenih od strane proizvođača vešaljki, za sile u vešaljkama)
- 12 deflektometara u 4 preseka pokretnih oslonaca (za horizontalna pomeranja),
- 32 dvoosna inklinometra (za merenje promene vertikalnog nagiba i indirektno registrovanje vertikalnih pomeranja) sa ugrađenim troosnim akcelometrom i senzorom za merenje temperature u 20 preseka konstrukcije i u jednom preseku zone centralnog stuba (za merenje ubrzanja u svim pravcima i merenje temperature u konstrukciji)
- meteorološka stanica za merenje temperature i vlažnosti vazduha i brzine vetra,
- 28 akvizicionih i kontrolnih uređaja (14 zona),
- 2 PC sistema (van mosta),
- Ethernet (1.2km) i signal kablovi (8.6km),
- Originalno razvijeni i fabrički softver za upravljanje mernim podacima i
- 38 kamiona (235kN), 32 E/4 (720kN) vagona, 10 E/2 (360kN) vagona i 3 lokomotive (1009kN svaka) u 28 šema opterećenja: 24 statičke i 4 dinamičke.

Sva pomenuta oprema je obaveza FTN osim merača sile u vešaljkama (obaveza dobavljača vešaljki - VSL) i vozila za test probnim opterećenjem (obaveza AZVI kao izvođača radova).

Cilj praćenja različitih mehaničkih i fizičkih veličina može se opisati u sledećem:

- naponi, izračunati iz registrovanih dilatacija, ukazuju na nosivost celokupne konstrukcije (sve merne trake će biti uparene sa "kompenzacionim mernim trakama" za poništavanje uticaja temperature u tačkama registrovanja dilatacija),
- sile u vešaljkama treba da budu osnova za proveru pravilne funkcije vešaljki u takvom tipu konstrukcijskog sistema i promene sila tokom eksploatacije (relaksacija i slični problemi mogu biti otkriveni smanjenjem sile u vešaljkama),
- horizontalna pomeranja u oslonačkim zonama će biti mera uzdužnih deformacija konstrukcijskih delova (pre od promene temperature) i funkcionisanja pokretnih elemenata oslonca,
- nagibi preseka konstrukcije će ukazati na kapacitet krutosti u smislu strukturalne upotrebljivosti u kontaktnim zonama između četiri glavna dela mosta,
- vertikalna pomeranja će se izračunati iz "5 nagiba u liniji" (jedna linija za oba prilazna mosta i dve linije za oba lučna mosta), dobijajući "polinom petog stepena pomeranja" od "polinoma četvrtog stepena nagiba", što je pristupačan postupak u potpunosti prema zahtevima praćenja u realnom vremenu i potrebne tačnosti (greška je manja od rezolucije merenja mernih traka i mnogo preciznija od GPS procedura),
- vibracije i ubrzanja u sva tri pravca će se koristiti za procenu dinamičkih faktora, svojstvenih frekvencija i vrednosti prigušenja, što su parametri za proveru globalnog ponašanja konstrukcijskog sistema mosta u kratkom i dužem vremenskom periodu,
- temperature u konstrukciji će se posmatrati zbog poznavanja temperaturnih gradijenata koji će pomoći da se objasne različiti fenomeni ponašanja u potpunosti i

Monitoring equipment, software and test by load vehicles are:

- 328 strain gauges in 14 sections (for structural stresses),
- 80 force gauges (for forces in hangers, delivered by "VSL" company)
- 12 deflection gauges in 4 movable support sections (for horizontal deflections),
- 32 bi-axial inclinometers (for vertical inclinations and vertical deflections in indirect manner) with embedded tri-axial accelerometers and temperature gauges in 20 structural sections and in one section of central pier zone (for accelerations and structural temperature),
- air temperature, humidity and windspeed gauges and devices for recognition of traffic circumstances,
- 28 Acquisition and Control devices (14 zones),
- 2 PC systems (out of bridge),
- Ethernet (1.2km) and signal cables (8.6km),
- custom and OEM software for management of measurement data and
- 38 trucks (235kN), 32 E/4 (720kN) wagons, 10 E/2 (360kN) wagons and 3 locomotives (1009kN each) in 28 load schemes: 24 static and 4 dynamic.

All mentioned equipment is duty of FTN except force gauges in hangers (obligation of supplier of hangers - "VSL") and loaded vehicles for Test Load (obligation of AZVI as Contactor).

The aim of observation of various mechanical and physical quantities could be described in the following:

- stresses, calculated from registered strains, indicate a bearing capacity state of the whole structure (all strain gauges are coupled by "compensation strain gauges" for annul influence of temperature in strain registering points),
- forces in hangers should be base for check of proper function of hangers in such type of structural system and changes of forces during exploitation (relaxation and similar problems may be diagnosed by decreasing forces in hangers),
- horizontal deflections in support zones are indicators of longitudinal deformations of structural parts (mainly from temperature changes) and function of movable supports,
- inclinations of structural sections indicate stiffness capacity in the sense of structural serviceability in contact zones between four main bridges parts,
- vertical deflections are calculated from "5 inclinations-in-line" (one line for both approach bridges and two lines for both arch bridges), obtaining the "5th degree deflection polynomial" from "4th degree inclination polynomial", what is fully affordable procedure according to the requirements of the real time monitoring and needed accuracy (errors scale is less than measurement resolution of gauges and much precise than GPS based procedures),
- vibration and acceleration in all three directions are used for estimation of dynamic factors, natural frequencies and damping values what are parameters for checking global bridge structures systems work during the short time and long time periods,
- by the knowledge of structural temperatures it is possible to obtain temperature gradients for right explanation of some structural behaviour phenomenon and

- parametri sredine (meteorološki podaci) zajedno sa uslovima saobraćaja će se koristiti za dobijanje potpunog pregleda mogućih uzroka potencijalnih problema koji su relevantni za eksploataciju mosta.

- meteorological data together with traffic flow circumstances will be used for obtaining full view on possible causes for all issues relevant for bridge exploitation.

5 OPŠTE SPECIFIKACIJE MERENJA

Svi predloženi merači, uređaji i oprema imaju merne performanse na višem nivou od realno potrebnih konstrukcijskih i inženjerskih zahteva ovog monitoringa i isporučeni su od istaknutih proizvođača sa referencama za srodne građevinske konstrukcije.

FTN tim je u potpunosti sposoban za odgovarajući rad sa "Opremom za monitoring" i "Probnim opterećenjem" i profesionalno korišćenje svih predviđenih merača, uređaja i opreme, što se potvrđuje brojem i vrstom njihovih referenci, naučnim i inženjerskim iskustvom.

Sistem za merenje za sve mostovske konstrukcije se sastoji od tri podsistema:

- podsistem merača (merne trake, merači sile, inklinometri, akcelometri, termometri i deflektometri), koji je dat u Tabeli 1,
- podsistem za akviziciju podataka (digitalnih višekanalni mernih pojačala sa fabrički ugrađenim softverom i namenskim računarskim sistemima sa softverom za prikupljanje podataka) i
- podsistem za procesiranje podataka (mrežno orijentisan višenamenski računarski sistem za prikupljanje, prenošenje i obradu podataka stečenih iz prethodno spomenutog podsistema sa originalnim "user friendly" orijentisanim softverom za proračun i prikazivanje podataka).

5 GENERAL MEASUREMENT SPECIFICATIONS

All proposed gauges, devices and equipment are with measurement performances on higher level than real needed structural and engineering issues of this monitoring case and from eminent manufacturers which have references for related civil engineering structures.

FTN team is completely capable for competent work on "Monitoring Equipment" and "Test Load" tasks and professional use of all proposed gauges, devices and equipment what are verified by quantity and kind of their references, scientific and engineering experience.

Measurement system for all bridges consists of three subsystem parts:

- subsystem of gauges (strain gauges, force gauges, inclinometers, accelerometers, thermometers and deflectometers), what is given in Table 1,
- subsystem of data acquisition devices (digital multichannel measuring amplifiers with factory embedded software and dedicated computer systems with software for data acquisition) and
- subsystem for data processing (multipurpose computer system for collection, transfer and processing of data acquired from previously mentioned subsystem with custom developed user friendly software for data presentation).

Tabela 1: Sumarni raspored mernih mesta
Table 1: Summary configuration of strain gauges

Deo mosta <i>Part of bridge</i>	Merne trake na čeliku <i>Strain gauges on steel</i>	Merne trake na čeliku (rozete) <i>Strain gauges on steel (rosettes)</i>	Merne trake na betonu <i>Strain gauges (concrete)</i>	Merne trake na armaturi <i>Strain gauges (RF bars)</i>	Senzori sila u vešaljkama <i>Force gauges (hangers)</i>	Inklinometri (akcelometri + termometri) <i>Inclinometers (accelerometers + thermometers)</i>	Horizontalni deflektometri <i>Horizontal deflectometers</i>
1-2A	17	42	3	2	-	5	3
2-3A	91	-	3	6	36	11	3
3B-4	91	-	3	6	44	11	3
4B-5	17	42	3	2	-	5	3
Ukupno	328				80	32	12

Neophodno je naglasiti da svi uređaji podsistema za akviziciju podataka i podsistema za obradu podataka imaju veću tačnost merenja i obrade od svih korištenih merača i senzora zbog digitalne rezolucije koja pokriva interval izmerenih i registrovanih vrednosti više nego dovoljno dobro u odnosu na stvarne inženjerske potrebe u ovom slučaju.

It is necessary to emphasize that all the devices of data acquisition subsystem and data processing subsystem have greater measurement and processing accuracy than all used gauges and sensors, because of digital resolution which covers interval of measured and registered values more than sufficient in relation to the real engineering need in such case.

5.1 Oprema za registrovanje normalnih i smičućih napona

FTN projekat obuhvata 328 mernih traka na sledeći način:

5.1 Equipment for Registering axial and shear stresses

FTN project undertakes 328 items of strain gauges in the following manner:

- prilazni most 1-2A: 64 senzora (17+42+3+2, čelik + rozete + beton + arm. šipke),
- lučni most 2-3A: 100 senzora (91+3+6, čelik + beton + arm. šipke),
- lučni most 3B-4: 100 senzora (91+3+6, čelik + beton + arm. šipke) i
- prilazni most 4B-5: 64 senzora (17+42+3+2, čelik + rozete + beton + arm. šipke).

Sve merne trake isporučuje kompanija "Hottinger-Baldwin Messtechnik" (HBM, Nemačka) na tri sledeća tipa:

- merne trake za čelik (jednoosna konfiguracija): LY11-6/120,
- merne trake za beton: LY41-50/120 (pre-wired verzija od LY11) i
- merne trake za šipke armature: LY11-6/120.

Svaka pojedinačna merna traka će biti spojena sa odgovarajućom "kompenzacionom mernom trakom" za kompenzaciju uticaja temperature u tački za registraciju, povezivanjem pomoću 5-žičnih kablova i podešavanjem mernih pojačala u podešavanjima "polovina mosta". Deklarisana tačnost merenja sa pomenutim tipovima mernih traka je 1µm/m.

5.2 Oprema za registrovanje vertikalnih pomeranja

Za posmatranje vertikalnih pomeranja, monitoring sistem koristi 30 dvoosnih inklinometara sa ugrađenim troosnim akcelorometarima i senzorima za merenje temperature u sledećem rasporedu

- prilazni most 1-2A: 5 komada (u osi centralnog sanduka),
- lučni most 2-3A: 10 komada (5 komada u osama svake zatege),
- lučni most 3B-4: 10 komada (5 komada u osama svake zatege),
- prilazni most 4B-5: 5 komada (u osi centralnog sanduka).

Svi inklinometri je isporučila kompanija "Sensr" (SAD), a tip "CX1 Structural Response Monitor" se koristi za sve mostove. Veza između CX1 i namenskog računarskog podsistema je zasnovana na Ethernet/IP.

Kao što je pomenuto, vertikalna Z-pomeranja se izračunavaju iz nagiba. Ovo je jedini mogući način za tačno dobijanje Z-pomeranja u "realnom vremenu" i standardna procedura za monitoring ovakvog tipa konstrukcije.

Zbog toga što se svaki CX1 sastoji ne samo od inklinometra, već i od senzora za merenje temperature, moguće je postići vrlo dobre rezultate temperaturne kompenzacije za dugotrajno praćenje. Tačnost CX1 je $\pm 0.0001^\circ$, što drži apsolutnu grešku u granicama od $\pm 0.19\text{mm}$ za ugib većeg Lučnog mosta 3B-4.

Dodatni razvoj u poređenju sa drugim slučajevima monitoringa je uvođenje 5 inklinometara i liniji što obezbeđuje tačnost potrebnog inženjerskog nivoa. Za upoređenje, najbolji komercijalno dostupni GPS sistemi imaju apsolutnu grešku od 3.5mm i 15mm za statička i dinamička merenja Z-pomeranja, što je potpuno neodgovarajuće za potrebe monitoringa ovog mosta.

- approach bridge 1-2A: 64 gauges (17+42+3+2, steel+rosettes + concrete + bars),
- arch bridge 2-3A: 100 gauges (91+3+6, steel+concretes +bars),
- arch bridge 3B-4: 100 gauges (91+3+6, steel+concretes +bars) and
- approach bridge 4B-5: 64 gauges (17+42+3+2, steel+rosettes +concrete + bars).

All strain gauges are delivered from "Hottinger-Baldwin Messtechnik" (HBM, Germany) company in three following types:

- strain gauges for steel (single or rosette configuration): LY11-6/120,
- strain gauges for concrete: LY41-50/120 and
- strain gauges for reinforcement bars: LY11-6/120.

Each single strain gauge is coupled with "compensation strain gauge" to eliminate the influence of temperature in measurement point, with connection by 5-wire cables and adjustment of measurement amplifiers in "half bridge" settings. Declared accuracy of measurement with mentioned types of strain gauges is 1µm/m.

5.2 Equipment for Observation of vertical deflections

For observation of vertical deflection our project acclaims use of 30 bi-axial inclinometers with embedded tri-axial accelerometers and temperature gauges in the following arrangement:

- Approach bridge 1-2A: 5 items (in one central box axis),
- Arch bridge 2-3A: 10 items (5 items in axes per each tie),
- Arch bridge 3B-4: 10 items (5 items in axes per each tie),
- Approach bridge 4B-5: 5 items (in one central box axis).

All inclinometers are delivered from "Sensr" company (USA) and type "CX1 Structural Response Monitor" are used for all bridges. Connection between CX1 and dedicated computer subsystem is based on Ethernet/IP.

It is already mentioned that vertical Z-deflections are calculated from inclinations. This is the only possible way for "real time" and accurate observation of Z-deflection and standard procedure for monitoring of this kind of structures.

It is possible to achieve very good results in temperature compensation for long time monitoring since each CX1 consists of both inclinometer and temperature gauge as well. Accuracy of CX1 is $\pm 0.0001^\circ$, what makes the absolute error of approximately 0.19mm for observation of larger arch bridge.

Additional development in comparison of other monitoring cases is introduction of 5 inclinometers in line what increase needed accuracy to reasonable engineering level. As comparison example, the best commercially available GPS based systems have absolute accuracy between 3.5mm and 15mm for static and dynamic measurements of Z-deflections, what is completely inappropriate for our needs.

5.3 Oprema za merenje ugla rotacije

Za merenje ugla rotacije Monitoring sistem obuhvata pomenuti "CX1 Structural Response Monitor" koji u osnovi sadrži dvoosni inklinometar. Koristi se sledeći raspored inklinometara:

- prilazni most 1-2A: 5 komada (u osi centralnog sanduka),
- lučni most 2-3A: 11 komada (5 komada u osama svake zatege, jedan u zoni centralnog stuba),
- lučni most 3B-4: 11 komada (5 komada u osama svake zatege, jedan u zoni centralnog stuba),
- prilazni most 4B-5: 5 items (in one central box axis).

Svi komentari, objašnjenja i detalji dati u prethodnom poglavlju važe i u ovom slučaju merenja.

5.4 Oprema za merenje horizontalnih pomeranja

Za posmatranje horizontalnih X-pomeranja u zonama pokretnih oslonaca, FTN projekat predviđa 12 induktivnih deflektometara u sledećem rasporedu

- prilazni most 1-2A (zona "1"): 3 komada,
- lučni most 2-3A (zona "2"): 3 komada,
- lučni most 3B-4 (zona "4"): 3 komada i
- prilazni most 4B-5 (zona "5a"): 3 komada.

Svi deflektometri su od "Hottinger-Baldwin Messtechnik" (HBM) i koriste se tipovi WA500 (za lučne mostove) i WA200 (za prilazne mostove). WA500/WA200 će biti povezani pomoću 5-žičnih kablova sa mernim pojačalima. Tačnost merenja je 0.01mm.

5.5 Oprema za merenje ubrzanja konstrukcije

Za merenje ubrzanja tačke konstrukcijskog sistema, Monitoring sistem koristi pomenuti "CKS1 Structural Response Monitor" koji se sastoji od jednog triosnog akcelometra. Sledeći je raspored akcelometara:

- prilazni most 1-2A: 5 komada (u osi centralnog sanduka),
- lučni most 2-3A: 11 komada (5 komada u osama svake zatege,
- jedan u zoni centralnog stuba),
- lučni most 3B-4: 11 komada (5 komada u osama svake zatege,
- jedan u zoni centralnog stuba),
- prilazni most 4B-5: 5 komada (u osi centralnog sanduka).

Tačnost CX1 ugrađenog akcelometra je u rasponu od 1.0mm/s^2 (sa rezolucijom od 0.1mm/s^2 , što čini ovaj uređaj potpuno pogodnim za merenje svih komponenti konstrukcijskog ubrzanja, posebno u slučaju tzv. "ambijentalnih" vibracija, koje su osnova za procenu svojstvenih frekvencija i konstrukcijskih parametara prigušenja). Predviđeni broj akcelometara daje mogućnost "mapiranja promene dinamičkih parametara" kroz vreme praćenja, što će biti izvor za procenu promene krutosti i konstrukcijskih parametara upotrebljivosti.

5.3 Equipment for Measurement of angle rotations

The abovementioned "CX1 Structural Response Monitor" which basically consists of bi-axial inclinometer was adopted for measuring angle rotation. The following pattern of 32 items of inclinometers is used:

- Approach bridge 1-2A: 5 items (in one central box axis),
- Arch bridge 2-3A: 11 items (5 items in axes of each tie, one in central pier zone),
- Arch bridge 3B-4: 11 items (5 items in axes of each tie, one in central pier zone),
- Approach bridge 4B-5: 5 items (in one central box axis).

All comments, explanations and details given in previous chapter are valid in this case of measurement.

5.4 Equipment for Measuring horizontal deflections

For observation of horizontal X-deflection in zones of movable supports FTN project assumes 12 inductive deflectometers in the following arrangement:

- Approach bridge 1-2A (zone "1"): 3 items,
- Arch bridge 2-3A (zone "2"): 3 items,
- Arch bridge 3B-4 (zone "4"): 3 items and
- Approach bridge 4B-5 (zone "5a"): 3 items.

All deflectometers are from "HBM" company: type WA500 for arch bridges and type WA200 for approach bridges. WA500/WA200 are connected by 5-wire cables with measurement amplifiers. Measurement accuracy of these gauges is 0.01mm.

5.5 Equipment for Measuring structural accelerations

The abovementioned "CX1 Structural Response Monitor" which consists one tri-axial accelerometer was used for measuring accelerations of structural point. The following pattern of 32 items of such embedded accelerometers is used:

- Approach bridge 1-2A: 5 items (in one central box axis),
- Arch bridge 2-3A: 11 items (5 items in axes of each tie, one in central pier zone),
- Arch bridge 3B-4: 11 items (5 items in axes of each tie, one in central pier zone),
- Approach bridge 4B-5: 5 items (in one central box axis).

Accuracy of CX1 embedded accelerometer is in range of 1.0mm/s^2 (with resolution of 0.1mm/s^2 , which makes this device completely suitable for measurement of all components of structural acceleration, especially in the case of so-called "ambient" vibration, which are the bases for estimation of natural frequencies and structural damping parameters. This number of accelerometers provides the possibility for defining the "map of change of dynamic parameters" through the time of monitoring, which will be the source of estimation of change of stiffness and structural serviceability parameters.

5.6 Oprema za merenje temperature konstrukcije

Za merenje temperature u tačkama konstrukcije monitoring sistem predviđa isti "CX1 Structural Response Monitor" koji sadrži jedan termometar u sledećem rasporedu:

- prilazni most 1-2A: 5 komada (u osi centralnog sanduka),
- lučni most 2-3A: 11 komada (5 komada u osama svake zatege,
- jedan u zoni centralnog stuba),
- lučni most 3B-4: 11 komada (5 komada u osama svake zatege,
- jedan u zoni centralnog stuba),
- prilazni most 4B-5: 5 komada (u osi centralnog sanduka).

Tačnost CX1 ugrađenog termometra je 1°C (sa rezolucijom od 0.1°C, što čini ovaj uređaj potpuno pogodnim za merenje temperature u konstrukciji). Predviđeni broj ugrađenih termometara daje mogućnost za "mapiranje temperature u konstrukciji", što će biti osnova za analizu i procenu promene ponašanja konstrukcije.

5.7 Oprema za merenje sila u vešaljima

Oprema za merenje sila u vešaljima je obaveza dobavljača vešaljki (VSL), a FTN preuzima obavezu da uključi VSL monitoring podsistem sa monitoring sistemom celog mosta.

5.8 Registrovanje vremenskih uslova

Ovi tipovi i brend opreme će biti kompatibilni sa zvaničnim zahtevima Republičkog hidrometeorološkog zavoda Srbije (RHMS) zbog mogućeg sukoba interesa i zakonskih propisa u ovoj oblasti. Zbog toga će informacije o konačnom izboru opreme podsistema za registraciju vremenskih uslova biti predstavljene nakon konačnog dogovora između Investora (Železnice Srbije) i RHMS.

Ova okolnost je uobičajena za svaku zgradu ili konstrukciju koja je vlasništvo države, imovina državnog preduzeća ili javne službe.

5.9 Snimanje toka saobraćaja

Snimanje toka saobraćaja vrši se sinhronizovanim radom podsistema kamera za snimanje i podsistema za akviziciju podataka nekom vrstom "značajnog okidača" koji se dobija kao prekoračenje prethodno definisanih izmerenih vrednosti iz podsistema određenog broja senzora.

U svakodnevnom "normalnim" i "neincidentnim" okolnostima saobraćaja snimanje saobraćajnog toka će se vršiti uz pomoć podsistema kamera za snimanje koji snima delove konstrukcije mosta i koloseke i drumske trake u vremenskim intervalima koji predstavljaju kompromis između potrebe za ispravnim pregledom saobraćaja i racionalne upotrebe memorije. Jedna slika u sekundi (1FPS) je u tom smislu optimalna brzina snimanja za dobijanje dovoljne količine informacija o položaju vozila ako voze na maksimalnoj granici brzine u

5.6 Equipment for Measuring structure temperature

Measurement of temperatures is predicted by the same "CX1 Structural Response Monitor" which consists of one thermometer. The following pattern of 32 items of such embedded thermometers is used:

- Approach bridge 1-2A: 5 items (in one central box axis),
- Arch bridge 2-3A: 11 items (5 items in axes of each tie, one in central pier zone),
- Arch bridge 3B-4: 11 items (5 items in axes of each tie, one in central pier zone),
- Approach bridge 4B-5: 5 items (in one central box axis).

Accuracy of CX1 embedded thermometer is in range of 1°C (with resolution of 0.1°C, what make this device completely suitable for measurement of structural temperature. Predicted number of embedded thermometers gives opportunity to obtain the "map of structural temperatures" through time of monitoring, which will be the basis for analyzing and estimating the change of structural behaviour.

5.7 Equipment for Measuring forces in hangers

Equipment for measuring forces in hangers is obligation of supplier of hangers ("VSL") and FTN takes the responsibility to harmonize "VSL" monitoring subsystem with the whole monitoring system of the bridge.

5.8 Registering of weather conditions

This type and brand of equipment will comply with official requirements of Republic Hydrometeorological Service of Serbia (RHMS of Serbia) because of possible conflict of interest and law regulations in this area. Thus, information about the final choice of weather conditions registering equipment subsystem will be presented after the final agreement between Investor (Railways of Serbia) and RHMS of Serbia.

This circumstance is usual for any building or structure which is the property of state, property of state company or public service.

5.9 Recording traffic flow

Recording traffic flow will be performed through synchronized work of camera recording subsystem and dedicated data acquisition subsystem by some kind of "significant trigger" obtained as exceed of previously defined measured values from number of sensors and gauges subsystem.

In everyday "normal" and "no accidental" traffic circumstances recording of traffic flow will be carried out by camera recording subsystem which records bridge structural parts and rail and road tracks in the timing which is a compromise between a need for correct traffic observation and rational memory usage. One picture frame in second (1FPS) is in that sense optimal recording speed for obtaining enough amount of information about position of vehicles if they drive on maximum city speed limit (50km/h or 13.9m/s). Only last

uslovima gradske vožnje (50km/h ili 13,9m/s). Samo poslednjih 60min saobraćaja biće zabeleženo u povećanoj rezoluciji vremena (24FPS) za moguće "događaje od većeg značaja". Ako se to ne pojavi, prethodna istorija će se snimiti u 1FPS vremenskoj rezoluciji.

U slučaju "događaja od većeg značaja", što bi moglo da predstavlja neku pobudu registrovanih vrednosti napona i/ili izmerenih vrednosti ugiba i/ili ugla rotacije, ova pojava će biti pokretač za snimanje u povećanoj vremenskoj rezoluciji. Kasnija analiza sinhronizovanog snimanja i serija podataka izmerenih vrednosti može biti osnova za zaključke o uzrocima mogućeg konstrukcijskog problema.

Važno je naglasiti da tipovi i marke opreme moraju biti u skladu sa zvaničnim zahtevima Ministarstva unutrašnjih poslova Republike Srbije (MUP Srbije) zbog mogućeg sukoba interesa i zakonskih propisa u ovoj oblasti. Zbog toga će informacije o konačnom izboru podсистема opreme za snimanje biti predstavljene nakon konačnog dogovora između Investora (Železnice Srbije) i MUP-a Srbije. Ovo je uobičajen pristup za konstrukcije koje su vlasništvo države.

6 SPECIFIKACIJE SISTEMA ZA OBRADU PODATAKA

Sistem za obradu podataka je organizovan u dva podсистема:

- podсистem za akviziciju podataka (digitalnih višekanalnih mernih pojačala sa fabrički ugrađenim softverom i namenskim računarskim sistemima sa softverom za prikupljanje podataka) i
- podсистem za procesiranje podataka (mrežno orijentisan višenamenski računarski sistem za prikupljanje, prenošenje i obradu podataka stečenih iz prethodno spomenutog podсистема sa prilagođenim "user friendly" softverom za proračun i prikazivanje podataka)

Neophodno je naglasiti da tim zadužen za sistem za obradu podataka ima adekvatne kompetencije u oblasti projektovanja mostova, ispitivanju konstrukcija i informacionim tehnologijama. Ovo je očigledno zbog potrebe za prezentacijom, analizom i tumačenjem velike količine podataka, kao i mogućim servisiranjem, popravkom i daljim razvojem sistema.

6.1 Akvizicija, transfer, skladištenje i upravljanje podacima

Prikupljanje podataka se realizuje mrežom HBM univerzalnih industrijskih mernih pojačala tipa PMX koji se nalaze u odgovarajućoj konfiguraciji i sa frekvencijama snimanja u zavisnosti od prirode odgovora konstrukcije. "Standardni" svakodnevni odgovor biće zabeležen frekvencijom "jednom u svakih 5s" i sa "posebnim" snimanjem slučaja "jednom u sekundi", što je dovoljno za naknadnu analizu. Odluka o prelazu sa "standardnog" na "poseban" način snimanja biće zasnovana na funkciji okidača. Okidači će biti veće od uobičajenih vrednosti nekih relevantnih parametara. Tipično ubrzanja i/ili naponi će biti okidači, ali bi izbor bilo koje izmerene veličine kao okidača trebao biti moguć.

Vremensko sinhronizovanje merenja i/ili prikupljanje podataka vršiće se mrežnim upravljanjem

60min of traffic will be recorded in increased time resolution (24FPS) for the possible "event of greater attention". If it fails, the previous history will be recorded in 1FPS time resolution.

In the case of "event of greater attention" which could be some excitation of registered values of stress and/or measured values of deflection and/or angle rotation these phenomenon will be a trigger for recording in increased time resolution. Later analysis of synchronized recording and data series of measured values can be the basis for conclusions on the cause of structural issue.

It is important to emphasize that types and brands of equipment should comply with official requirements of Ministry of Internal Affairs Republic of Serbia (MUP of Serbia) because of possible conflict of interest and law regulations in this area. Thus, information about final choice of recording equipment subsystem will be presented after final agreement between Investor (Railways of Serbia) and MUP of Serbia. This is usual approach for buildings which are the property of state.

6 SPECIFICATION OF DATA PROCESSING SYSTEM

Data processing system is organized into two subsystems:

- subsystem of data acquisition devices (digital multichannel measuring amplifiers with factory embedded software and dedicated computer systems with software for data acquisition) and
- subsystem for data processing (multipurpose computer system for collection, transfer and processing of data acquired from previously mentioned subsystem with custom developed user friendly software for data presentation).

It is necessary to emphasize that the team in charge of data processing system has adequate expert knowledge and skills on bridge design, testing structures and computer technologies. This is obvious because of the need for competent presentation, analysis and interpretation of large amounts of data as well as potential servicing, repair and further development of the system.

6.1 Data acquisition, transfer, storage and management

Data acquisition is realized by HBM universal measurement amplifiers located in appropriate configuration and with recording frequencies depending on the nature of structural response. "Standard" everyday response will be recorded by frequency of "one in every 5s" and with "special" case recording of "one in second", sufficient for subsequent analysis. Decision to switch from "standard" to "special" mode of recording shall be based on trigger functionality. Triggers will be larger than usual values of some relevant parameters. Typically accelerations and/or stresses can be triggers, but choice of any measured quantity as trigger should be possible.

Time synchronization of measurement and/or data collection will be performed by network operation of components of this subsystem, which is a standard

komponentama ovog podsistema, što je standardna opcija u specijalizovanom softveru dopunjenom od strane HBM univerzalne jedinice mernog pojačala (HBM). Slično tome, kompanija Sensr isporučuje sopstveni softver za prikupljanje podataka za upravljanje vezom između CX1 inklinometara i računara.

Od pojačala za akviziciju, podaci će biti preneti preko Ethernet/IP konekcija. U nekim slučajevima i na nekoj lokaciji ova veza će biti bežična.

Podaci, dobijeni na prethodno opisan način, biće sačuvani na uređajima za skladištenje na namenskim računarskim jedinicama sa tzv. "mirrored" i "striped" konfiguracijom što predstavlja prvi nivo zaštite podataka.

Sledeća faza obrade podataka će istovremeno predstavljati drugi nivo zaštite podataka.

6.2 Prezentacija, analiza i interpretacija podataka

Iz ranije opisanog namenskog računarskog sistema (namenjenog za skladištenje podataka) podaci će biti prebačeni u završnu fazu - višenamenski personalni računarski sistem namenjen prezentaciji, analizi i interpretaciji podataka prikupljenih iz mernih mesta. Ovaj računarski sistem će zabeležiti podatke u drugoj tzv. "mirrored" i "striped" konfiguraciji skladištenja, koji služi kao drugi nivo zaštite podataka.

Ovaj sistem automatski generiše dokument izveštaja sa rezimeom rezultata, sa različitim opcijama za alarm i obaveštavanje o hitnim slučajevima, kao i vremensku sinhronizaciju snimljenih putnih i šinskih vozila pomoću sistema kamere.

Izmereni podaci će biti predstavljeni na numerički i grafički način koji su kompatibilni sa široko korišćenim softverom - internet pretraživačima.

Internet pretraživač ima za cilj prikazivanje svih relevantnih podataka sa mogućnostima potrebnog proračuna i obrade u tzv. pozadinskom okruženju koje je transparentno i otvoreno za posvećenog korisnika i sa ograničenim pristupom običnog korisnika.

U ovom slučaju neophodne nadgledane vrednosti i podaci će biti dostupni svim zaduženim osobama u svakom trenutku (24/7) na bilo kojoj lokaciji sa Internet konekcijom i bilo kom sistemskom softverskom okruženju. Jedini neophodan preduslov za korišćenje podataka dobijenih od strane našeg sistema jeste prosečno tehničko obrazovanje u građevinarstvu.

Za osnovnu upotrebu predloženog sistema (prikaz dijagrama podataka, istorije ponašanja mosta, kretanja mogućeg budućeg odgovora mosta, itd.) dovoljan je skroman nivo znanja upotrebe računara. Naše dosadašnje iskustvo je dovoljan dokaz da je ovaj sistem optimalan u smislu korisničkih zahteva.

7 KONFIGURACIJA UREĐAJA ZA MONITORING

Sledeća poglavlja se bave važnim detaljima o konfiguraciji i lokaciji svih merača i senzora za posmatranje konstrukcijske faze mosta tokom probnog opterećenja i eksploatacije (dugotrajno nadgledanje). Ukupan broj mernih senzora je dat u prethodnim poglavljima za sve delove mosta.

option in specialized software supplemented by HBM universal measurement amplifier units (HBM Cotman and HBM Quantum Assistant). Similarly, "Sensr" company delivers its own data acquisition software for management of connection between CX1 inclinometers and computers.

Data will be transferred by Ethernet/IP connections from acquisition amplifier devices. In some cases in bridge inner this connection will be wireless.

Data, acquired as described previously, will be saved in memory storage devices in dedicated computer units with so-called "mirrored" and "striped" disc configuration which represents the first level of data protection.

Next stage in data processing will, at the same time, represent the second level of data protection.

6.2 Presentation, analysis and interpretation of data

From previously described dedicated computer system (dedicated to data storage) data will be transferred to the final stage - multipurpose personal computer system intended for presentation, analysis and interpretation of data collected from measurement points. This computer system records data in another "mirrored" and "striped" storage configuration, serving as a second level of data protection.

This system is capable to generate a report document i.e. summary of results, with various options for alarm and emergency notification as well as time synchronization of recorded road and rail vehicles by camera system.

Measured data will be presented in numerical and graphical manner compatible with widely used web browser software.

Browser is aimed for presentation of all relevant data with abilities of necessary calculation and processing in so-called background environment which is transparent and open for dedicated user and with limited approach of common user.

In this case necessary monitored values and data will be available to all "in charge" personnel at all times (24/7) in any location with Internet connectivity and on any system software environment. The only necessary qualification for use of data obtained by our system is an advanced civil engineering technical education.

For basic use of proposed system (view of data diagrams, history of bridge behaviour, trends of possible future bridge response, triggered points, etc.) the modest skill level of computer use is sufficient. Our previous experience is sufficient proof that this system is optimal in the sense of user-friendly requirements.

7 CONFIGURATION OF MONITORING ITEMS

The following chapters deal with important details on configuration and location of all gauges and sensors for the observation of structural stage of bridge during Test Load and exploitation (long time monitoring). Summary number of measuring gauges and sensors items were given in previous chapters for all bridge parts.

7.1 Monitoring mosta 1-2A

Prilazni most 1-2A (Petrovaradinska strana) će se posmatrati u tri zone/preseka:

- blizu zone oslonca na Petrovaradinskoj strani,
- zona sredine raspona (≈12.00m od oslonačke zone)
- blizu zone sledećeg oslonca.

Konfiguracija mernih tačaka za obe oslonačke zone je ista i razlikuje se u odnosu na zonu sredine raspona. Slike 1-4 prikazuju ove konfiguracije.

7.1 Monitoring of the bridge 1-2A

Approach bridge 1-2A is observed in three zones/sections:

- near to support zone on Petrovaradin side,
- mid span zone (≈12.00m from support section) and
- near to next support zone.

Configuration of measurement points for both of support zones is the same and it is different in comparison with mid span zone. Figures 1-4 show these configurations.

Slika 1. Prilazni most 1-2A - konfiguracija zona posmatranja u osnovi
Figure 1. Approach bridge 1-2A - layout of observation zones

Slika 2. Prilazni most 1-2A – oslonačka zona 1 - konfiguracija mernih mesta
Figure 2. Approach Bridge 1-2A - support zone 1 - configuration of measurement points

Slika 3. Prilazni most 1-2A – srednja zona - konfiguracija mernih mesta
Figure 3. Approach Bridge 1-2A - mid span zone - configuration of measurement points

Slika 4. Prilazni most 1-2A – oslončačka zona 2A - konfiguracija mernih mesta
Figure 4. Approach Bridge 1-2A - support zone 2A - configuration of measurement points

7.2 Monitoring mosta 2-3A (180m, "mali" luk)

Lučni most 2-3A će se posmatrati u četiri zone/preseka:

- blizu zone oslonca na stubu na petrovaradinskoj strani,
- zona privremenog stuba za vreme lansiranja (≈68.50m od oslonca),
- zona sredine raspona (≈88.50m od oslončačke zone),
- blizu zone oslonca na centralnom stubu.

Konfiguracija mernih tačaka za obe oslončačke zone je ista i razlikuje se u odnosu na zonu sredine raspona i zonu privremenog stuba. Slike 5-9 prikazuju ove konfiguracije.

7.2 Monitoring of the bridge 2-3A (180m, "small" arch)

Arch bridge 2-3A is observed in four zones/sections:

- near to support zone on pier in Petrovaradin side,
- zone of temporary column for launching (≈68.50m from support),
- mid span zone (≈88.50m from support zone),
- near to support zone on area of central pier.

Configuration of measurement points for both support zones is the same and it is different in comparison with mid span zone and zone of temporary column. Figures 5-9 show these configurations.

Slika 5. Lučni most 2-3A - konfiguracija zona posmatranja
Figure 5. Arch bridge 2-3A - layout of observation zones

Slika 6. Lučni most 2-3A – oslonačka zona 2 - konfiguracija mernih mesta
Figure 6. Arch Bridge 2-3A - support zone 2 - configuration of measurement points

Slika 7. Lučni most 2-3A – zona privremenog oslonca – merna mesta
Figure 7. Arch Bridge 2-3A - temporary column zone - measurement points

Slika 8. Lučni most 2-3A – srednja zona - konfiguracija mernih mesta
Figure 8. Arch Bridge 2-3A - mid span zone - configuration of measurement points

Slika 9. Lučni most 2-3A – oslonачka zona 3A - konfiguracija mernih mesta
Figure 9. Arch Bridge 2-3A - support zone 3A - configuration of measurement points

7.3 Monitoring mosta 3B-4 (220m, "veliki" luk)

Lučni most 3B-4 će se posmatrati u četiri zone/preseka:

- blizu zone oslonca na centralnom stubu,
- zona privremenog stuba za vreme lansiranja (≈35.0m od zone oslonca na centralnom stubu),
- zona sredine raspona (≈110.0m od oslonачke zone),
- blizu zone oslonca na novosadskoj strani.

Konfiguracija mernih tačaka za obe oslonачke zone je ista i razlikuje se u odnosu na zonu sredine raspona i zonu privremenog stuba. Slike 10-14 prikazuju ove konfiguracije.

7.3 Monitoring the bridge 3B-4 (220m, "big" arch)

Arch bridge 3B-4 is observed in four zones/sections:

- near to central pier support zone,
- zone of temporary column for launching (≈35.0m from central pier support zone),
- mid span zone (≈110.0m from support zone),
- near to support zone on Novi Sad side.

Configuration of measurement points for both support zones is the same and it is different in comparison with mid span zone and zone of temporary column. Figures 10-14 show these configurations.

Slika 10. Lučni most 3-B4 - konfiguracija zona posmatranja
Figure 10. Arch bridge 3-B4 - layout configuration of observation zones

Slika 11. Lučni most 3-B4 – oslonaka zona 3 - konfiguracija mernih mesta
Figure 11. Arch Bridge 3-B4 - support zone 3 - configuration of measurement points

Slika 12. Lučni most 3-B4 – zona srednjeg oslonca – merna mesta
Figure 12. Arch Bridge 3-B4 - temporary column zone - measurement points

Slika 13. Lučni most 3-B4 – srednja zona - konfiguracija mernih mesta
Figure 13. Arch Bridge 3-B4 - midspan zone - configuration of measurement points

Slika 14. Lučni most 3-B4 – oslonačka zona B4 - konfiguracija mernih mesta
Figure 14. Arch Bridge 3-B4 - support zone B4 - configuration of measurement points

7.4 Monitoring mosta 4B-5

Prilazni most 4B-5 će se posmatrati u tri zone/preseka:

- blizu zone oslonca na novosadskoj strani,
- zona sredine raspona ($\approx 23.50\text{m}$ od oslonačke zone),
- blizu zone sledećeg oslonca.

Konfiguracija mernih tačaka za obe oslonačke zone je ista i razlikuje se u odnosu na zonu sredine raspona. Slike 15-18 prikazuju ove konfiguracije. Slika 19 daje sumarni prikaz mernih zona duž mosta.

7.4 Monitoring of the bridge 4B-5

Approach bridge 4B-5 is observed in three zones/sections:

- near to support zone on Novi Sad side,
- mid span zone ($\approx 23.50\text{m}$ from support section) and
- near to next support zone.

Configuration of measurement points for both support zones is the same and it is different in comparison with mid span zone. Figures 15-18 show these configurations. Figure 19 shows summary of measurement zones along the bridge.

Slika 15. Prilazni most 4B-5 - konfiguracija zona posmatranja u osnovi
Figure 15. Approach bridge 4B-5 - layout configuration of observation zones

Slika 16. Prilazni most 4B-5 – oslonačka zona 4 - konfiguracija mernih mesta
Figure 16. Approach Bridge 4B-5 - support zone 4 - configuration of measurement points

Slika 17. Prilazni most 4B-5 – srednja zona - konfiguracija mernih mesta
Figure 17. Approach Bridge 4B-5 - mid span zone - configuration of measurement points

Slika 18. Prilazni most 4B-5 – oslonačka zona 5A - konfiguracija mernih mesta
Figure 18. Approach Bridge 4B-5 - support zone 5A - configuration of measurement points

Slika 19. Rezime konfiguracija mernih zona duž mosta
Figure 19. Summary configuration of measurement zones along the bridge

Slika 20 prikazuje neke delove opreme monitoring sistema mosta (merne trake u konfiguraciji rozete, dvoosni inklinometri sa ugrađenim aksijalnim akcelometrom i termometrom, induktivni deflektometar, kutija sa mernim višekanalnim uređajem, jednostruka merna traka sa kompenzacionom mernom trakom).

Fig. 20 shows some parts of equipment of monitoring system of the bridge (strain gauges in rosette configuration, two-axis inclinometers with embedded --axial accelerometer and thermometer, inductive deflectometer, box with measuring multichannel device, single strain gauge in single configuration with compensational strain gauge).

Slika 20. Neki uređaji i senzori korišćeni u monitoring sistemu
Figure 20. Some devices and gauges used in monitoring system

Slika 21 ilustruje radne ekrane originalno razvijenog softvera za praćenje ponašanja mosta usled saobraćajnih dejstava i ispitivanja probnim opterećenjem.

Fig. 21. illustrates working screens of originally developed software for monitoring behaviour of the bridge under traffic actions and test by load.

Slika 21. Ekran rada softvera korišćenog za prikupljanje i prezentaciju podataka monitoring sistema
Figure 21. Some working screens of software used for acquisition and presentation of data from monitoring system

Više detalja je objašnjeno u opširnoj tehničkoj dokumentaciji mosta, posebno u [3].

Much more details are explained in comprehensive technical documentation of bridge, especially in [3].

8 ZAKLJUČCI

U poređenju sa drugim sistemima slične vrste i namene, Monitoring sistem Železničko-drumskog mosta u Novom Sadu jedan je od najvećih naučno-inženjerskih poduhvata Departmana za građevinarstvo i geodeziju Fakulteta tehničkih nauka sa mnogim inovativnim aspektima u oblasti konstrukcijskog monitoringa. Naponi naših partnera u konzorcijumu, "TRC Pro" za hardver i "Creative Tree" za softver, doprineli su da je ranije

8 CONCLUSIONS

In comparison with other systems with similar kind and purpose Monitoring system of Railway Road Bridge in Novi Sad is one of the largest scientific-engineering enterprise of Department of Civil Engineering and Geodesy of Faculty of Technical Sciences with many innovative aspects in structural monitoring field. Efforts of our joint venture partners, "TRC Pro" for hardware and "Creative Tree" for software, contributed that

pomenuto postalo stvarnost. Očigledno je da ovakav složeni sistem praćenja zahteva ekspertski nivo multidisciplinarnog znanja za izradu i pravilnu upotrebu i istovremeno pruža velike mogućnosti za dobijanje vrednih podataka za naučne, konstruktorske i obrazovne svrhe.

9 LITERATURA REFERENCES

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previously mentioned becomes reality. It is obvious that such complex monitoring system needs expert level of multidisciplinary knowledge for building and proper use and in the same time provides large opportunity for obtaining valuable data for scientific, structural engineering and educational purposes.

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REZIME

SISTEM ZA MONITORING NOVOG ŽELEZNIČKO-DRUMSKOG MOSTA U NOVOM SADU

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Ovo je prikaz monitoring sistema za "Železničko-drumski most Novi Sad" koji je sagrađen na mestu čuvenog "Žeželjevog" mosta srušenog 1999. Monitoring sistem je mrežno orijentisani računarski sistem za akviziciju podataka sa ciljem praćenja parametara koji su od značaja za procenu konstrukcijskih performansi mosta. Sistem se sastoji od hardverskog dela (merni uređaji, prateća oprema, kablovi) nabavljenog iz više izvora i softverskog dela originalno razvijenog za potrebe monitoringa probnog opterećenja i eksploatacije mosta. Prema trenutno raspoloživim informacijama ovaj monitoring sistem je jedan od najvećih ove vrste, s obzirom na broj i vrstu mernih mesta, količinu obrađenih i prikazanih podataka, kompleksnost strukture i topologije, kao i na osnovu specijalizovanog softverskog okruženja. Glavni učesnici u razvoju ovog sistema su Departman za građevinarstvo i geodeziju, Fakulteta tehničkih nauka iz Novog Sada, firma "TRC Pro" iz Petrovaradina i softverska firma "Creative Tree" iz Novog Sada.

Ključne reči: Monitoring sistem mosta, akvizicija podataka, probno opterećenje

SUMMARY

MONITORING SYSTEM FOR NEW RAIL-ROAD BRIDGE NOVI SAD

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This is a review of the Monitoring System for "Rail Road Bridge Novi Sad" constructed on the place of famous "Žeželj" bridge, which is demolished in 1999. Monitoring system is a network based computer system for data acquisition with a goal of real-time observing of parameters, which are important for assessment of structural performances of the bridge. The system consists hardware parts (devices, equipment, cables) which delivered by various company sources and software part, which is originally developed and customized for purpose of test by load and exploitation of the bridge. In accordance to currently available information this monitoring system is one of the largest system of this type considering the number and kind of measuring points, quantity of processed and presented data, complexity and topology of its structure, as well as dedicated software environment. Department for Civil Engineering and Geodesy of Faculty of Technical Sciences in Novi Sad, company "TRC Pro" from Petrovaradin and software company "Creative Tree" from Novi Sad are main participants in development of this system.

Key words: Bridge monitoring system, data acquisition, test by load