ДГКС ASES | E-62
Kongres 2026
Congress 2026

doi: 10.67563/ASESCONF2026009F

Božidar S. Furundžić[1]

STATIC TENSILE FACTORY ACCEPTANCE TESTING OF THE OVM.ST15-47 PARALLEL-STRAND HANGER SYSTEM FOR THE NEW SAVA BRIDGE IN BELGRADE, SERBIA

Summary: This paper presents the full-scale static tensile factory acceptance testing of the OVM.ST15-47 parallel-strand hanger system intended for installation on the New Sava Bridge in Belgrade, Serbia. Each tested hanger assembly consisted of 47 seven-wire prestressing strands, with a nominal tensile strength of 1,860 MPa and a nominal cross-sectional area of 150 mm² per strand, together with the associated anchorage and fork components. Two representative full-scale hanger specimens were subjected to a predefined staged loading procedure, including a 60-minute load-holding period at 0.8 of the guaranteed ultimate tensile strength (GUTS), followed by loading to the governing acceptance force. The required acceptance force was defined as the greater of 95% GUTS and 92% of the calculated actual ultimate tensile strength (AUTS) of the 47-strand bundle. Both specimens exceeded the governing force and minimum elongation requirements. No damage to specimens and no failure of anchorage-system components were observed after the loading procedure. The results demonstrate that both tested hanger assemblies satisfied the specified static tensile acceptance criteria.

Keywords: arch bridge, bridge hanger, parallel-strand system, full-scale testing, factory acceptance testing, static tensile test, anchorage system

FABRIČKO PRIJEMNO ISPITIVANJE STATIČKIM ZATEZANJEM SISTEMA VEŠALJKI OVM.ST15-47 SA PARALELNIM UŽADIMA ZA NOVI SAVSKI MOST U BEOGRADU, SRBIJA

Rezime: U radu je prikazano fabričko prijemno ispitivanje statičkim zatezanjem, u punoj razmeri, sistema vešaljki OVM.ST15-47 sa paralelnim užadima, namenjenog za ugradnju na Novom savskom mostu u Beogradu. Svaki ispitivani sklop vešaljke sastojao se od 47 sedmožičnih užadi za prednaprezanje, nominalne zatezne čvrstoće 1.860 MPa i nominalne površine poprečnog preseka od 150 mm² po užetu, zajedno sa pripadajućim sidrenim sklopovima i viljuškama. Dva reprezentativna uzorka vešaljki podvrgnuta su unapred definisanom postupku stepenastog opterećenja, koji je obuhvatio zadržavanje opterećenja u trajanju od 60 minuta na nivou od 0,8 garantovane granične zatezne čvrstoće (GUTS), nakon čega je opterećenje povećano do merodavne prijemne sile. Zahtevana prijemna sila određena je kao veća od 95% GUTS i 92% proračunske stvarne granične zatezne čvrstoće (AUTS) sklopa od 47 užadi. Oba uzorka zadovoljila su zahtev u pogledu merodavne prijemne sile i minimalnog izduženja. Nakon ispitivanja nisu uočena oštećenja na uzorcima, niti je došlo do otkaza komponenata sidrenog sistema. Rezultati pokazuju da su oba ispitana sklopa vešaljki zadovoljila propisane kriterijume.

Ključne reči: lučni most, vešaljka mosta, sistem sa paralelnim užadima, ispitivanje u punoj razmeri, fabričko prijemno ispitivanje, ispitivanje statičkim zatezanjem, sidreni sistem

[1] CPM Consulting d.o.o, Belgrade, Serbia, bfurundzic@gmail.com

1. INTRODUCTION

Hangers are primary load-transfer elements in tied-arch and through-arch bridges, transferring loads from the bridge deck to the main arch ribs. Owing to their structural function, exposure to repeated traffic and environmental actions, and the sensitivity of their anchorage zones, the mechanical reliability and durability of hanger systems are essential to the safety and serviceability of the complete bridge structure. Previous research has therefore examined the fatigue behaviour of bridge hangers, corrosion-fatigue interaction, anchorage details, inspection requirements, and the long-term reliability and durability of cable-supported systems (Cai et al., 2018; Duan et al., 2024; Teichgraeber, 2025).

Analytical calculations and numerical models are necessary for evaluating the global and local structural response of hanger systems. However, the behaviour of a manufactured hanger assembly also depends on the interaction among the strands, anchorage components, sockets, forks, protective elements, and associated load-transfer details. Consequently, full-scale testing provides an essential means of verifying that the complete manufactured assembly can attain the prescribed acceptance force without premature failure or unacceptable damage. Full-scale acceptance testing is particularly important for systems employing prestressing strands, where the resistance of individual strands must be considered together with the performance of the complete anchorage assembly (International Federation for Structural Concrete [fib], 2019; Post-Tensioning Institute [PTI], 2018).

The New Sava Bridge in Belgrade employs prefabricated multi-strand hangers connecting the bridge deck to the main arch ribs. The selected OVM.ST15-47 parallel-strand hanger system, hereinafter referred to as the OVM hanger system, comprises 47 individually protected high-strength steel strands assembled within a fork-to-fork configuration. Because the structural response of the system depends on the complete load-transfer path, verification based exclusively on the mechanical properties of individual strands would not be sufficient. The factory acceptance programme therefore included static tensile testing of full-scale specimens representative of the manufactured bridge hangers.

The objective of this paper is to present and evaluate the static tensile factory acceptance testing of two full-scale OVM hanger specimens. The investigation links the relevant bridge design requirements, hanger configuration, strand properties, reference tensile forces, test arrangement, metrological traceability, loading procedure, and measured response. Particular attention is given to the relationship among the maximum design hanger force, the governing acceptance force, and the maximum forces achieved during testing.

The paper also distinguishes between the calculated actual ultimate tensile strength of the 47-strand bundle and the force achieved by the complete hanger assembly during the acceptance test. The full-scale specimens were not tested to failure; therefore, the achieved test forces represent demonstrated compliance with the prescribed acceptance criterion rather than the experimentally determined ultimate resistance of the complete hanger system.

During the Engineer’s review of the manufacturer’s technical documentation, it was established that no previous full-scale tensile test was available for the complete fork-to-fork OVM.ST15-47 hanger system. The available records documented individual materials and components but did not demonstrate the behaviour of the complete assembly. The Engineer therefore required static tensile acceptance testing of two representative full-scale specimens as part of the project quality-control programme.

The OVM.ST15-47 hanger assemblies were manufactured by Liuzhou OVM Machinery Co., Ltd. The full-scale testing was arranged by the Contractor, PowerChina International Group Limited, following an instruction issued by the Engineer, the joint venture of Louis Berger Adria and CPM Consulting. The tests were performed by Liuzhou OVM Structure Monitoring Technology Co., Ltd., while Bureau Veritas acted as the independent third-party witnessing body.

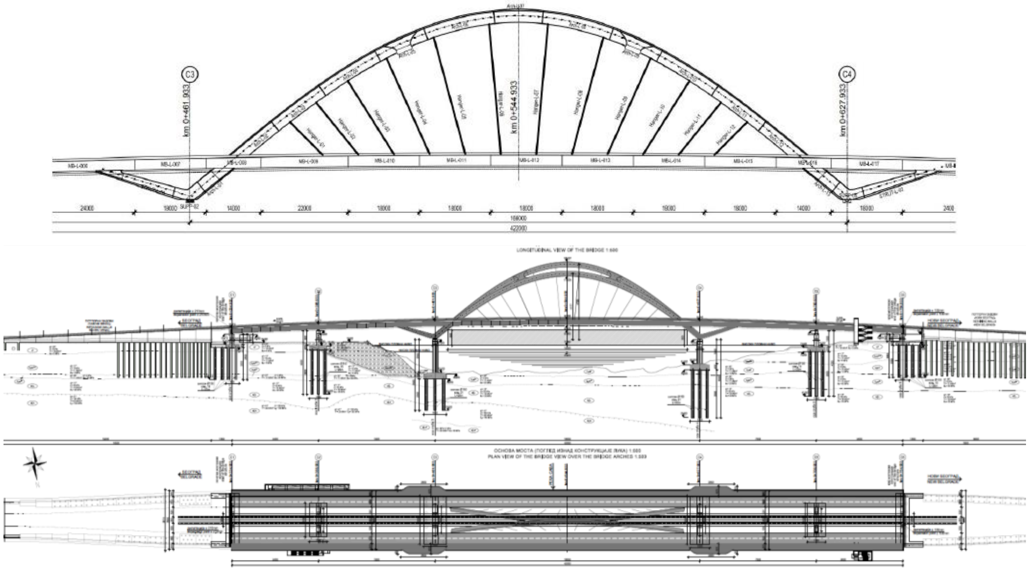

Figure 1: General arrangement of the New Sava Bridge: longitudinal elevation and plan view

2. BRIDGE AND HANGER SYSTEM

This section provides a brief overview of the bridge configuration and the OVM.ST15-47 parallel-strand hanger system investigated in this study.

2.1. BRIDGE CONFIGURATION

The New Sava Bridge in Belgrade is a steel tied-arch bridge with a main span of approximately 166 m and a total structural length of approximately 420 m. Its standard width is approximately 38.1 m, increasing to 42.1 m at the pedestrian viewing platforms. The bridge accommodates four road lanes, a central double-track tram corridor, and pedestrian and bicycle paths on both sides. It is supported by six reinforced-concrete piers, two of which are located in the river, forming two navigation openings of approximately 75 m. The main load-bearing system comprises the steel arch ribs, the tied deck structure, and the hanger system through which the deck loads are transferred to the arches (Millennium Team et al., n.d.).

The hanger arrangement follows the geometry of the main bridge structure. Individual hanger lengths and inclinations vary along the main span according to their positions relative to the arch ribs and the bridge deck. Consequently, each hanger assembly must satisfy specific geometric requirements while maintaining a consistent structural configuration and load-transfer mechanism.

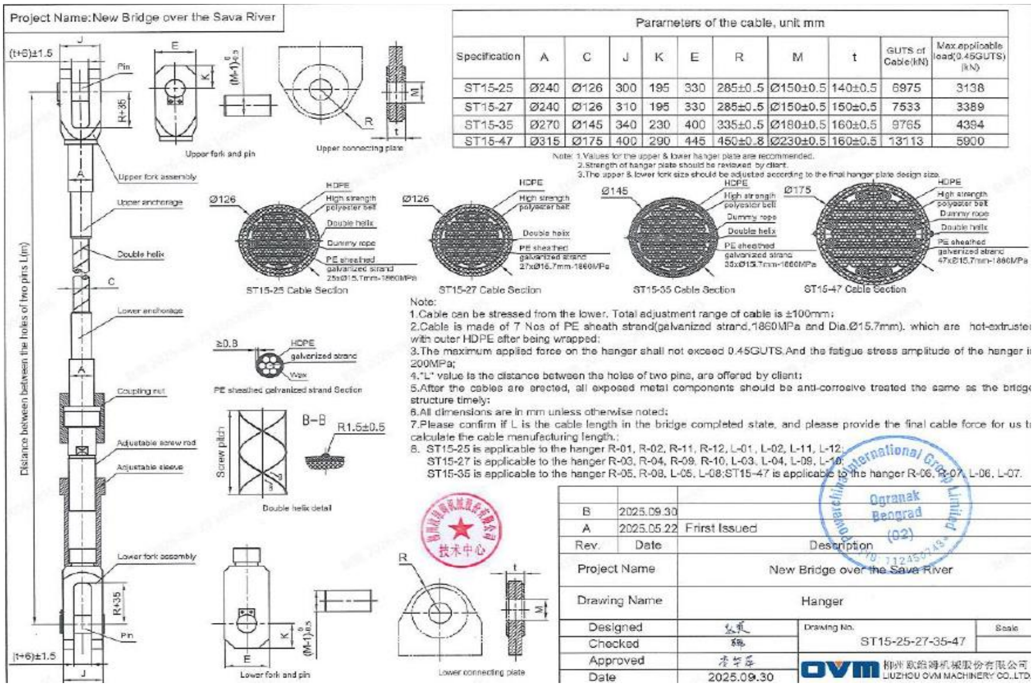

Figure 2: General arrangement and principal components of the OVM.ST15 hanger system

The project execution documentation defines the characteristic coordinates, control points, and system lengths of the hangers. Particular attention was given to hangers R-06, R-07, L-06, and L-07, whose geometric data were used to establish the dimensions of the representative hanger assemblies included in the factory acceptance-testing programme. The designation letters R and L identify the hanger positions on the right and left sides of the bridge, while the numerical suffixes identify their respective positions within the hanger arrangement.

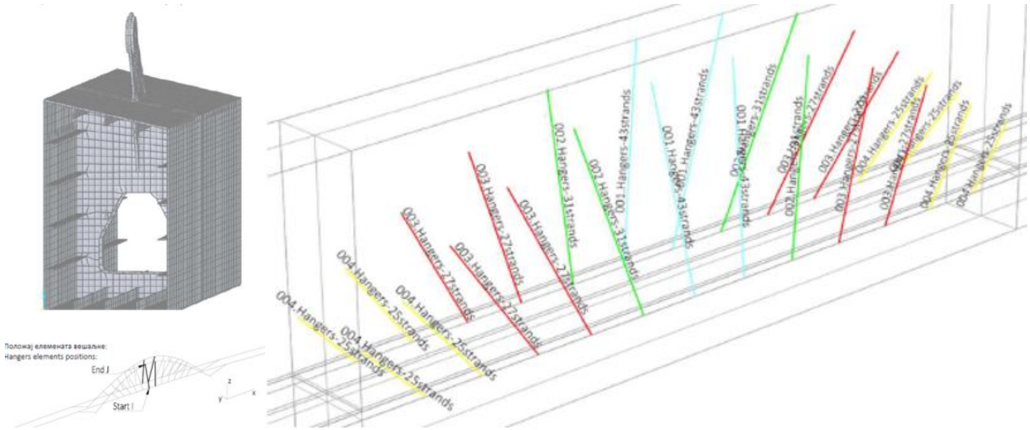

Figure 3: Bottom hanger anchorage and hanger arrangement: three-dimensional model of the bottom anchorage segment (left) and positions of the hanger elements in the bridge model (right)

Table 1: Coordinates and system lengths of hangers R-06, R-07, L-06, and L-07

Hanger	Point	x[mm]	y[mm]	z[mm]	ΔL_1[mm]	ΔL_2[mm]	ΔL_3[mm]
R-06	Start I	205500	−6874	88158	30749	27861	26390
	CP1	205378	−6629	89518			
	CP2	205292	−6458	90470			
	CP3	202963	−1802	116342			
	CP4	202919	−1714	116832			
	End J	202787	−1449	118303			
R-07	Start I	214500	−6874	88158	30749	27861	26390
	CP1	214622	−6629	89518			
	CP2	214708	−6458	90470			
	CP3	217037	−1802	116342			
	CP4	217081	−1714	116832			
	End J	217213	−1449	118303			
L-06	Start I	205500	6874	88158	36574	33682	32211
	CP1	205378	6630	89518			
	CP2	205292	6459	90470			
	CP3	202449	793	122051			
	CP4	202405	705	122542			
	End J	202273	441	124016			
L-07	Start I	214500	6874	88158	36574	33682	32211
	CP1	214622	6630	89518			
	CP2	214708	6459	90470			
	CP3	217551	793	122051			
	CP4	217595	705	122542			
	End J	217727	441	124016			

The complete hanger system includes the parallel-strand bundle, external protective elements, upper and lower anchorage assemblies, and fork-type end connections. The fork connections transfer the hanger force to the corresponding structural attachment points on the arch and deck. Because the individual hanger assemblies differ in length but employ the same principal system components, verification of the complete load-transfer mechanism was performed using representative full-scale test specimens.

2.2. HANGER GEOMETRY AND ANCHORAGE CONFIGURATION

The investigated hanger is a prefabricated parallel-strand assembly with fork-type connections at both ends and the tensioning end located at the bottom. Hanger lengths within the bridge system range from approximately 7.8 m to 32.1 m. Its geometry is defined by the positions of the structural connection points, the hanger axis, the anchorage zones, and the effective length of the strand bundle. The principal dimensional components are denoted as ΔL_1, ΔL_2, and ΔL_3 in the project documentation.

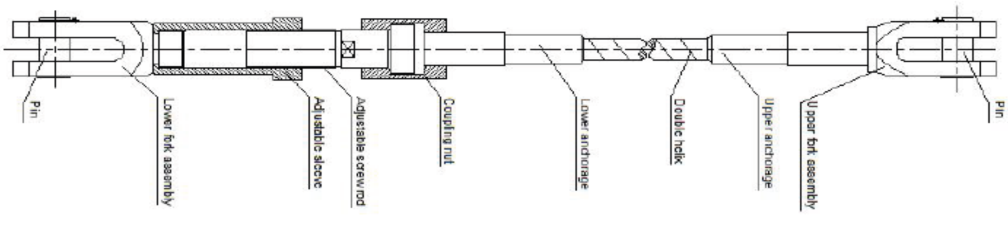

Figure 4: Hanger geometry and definition of the characteristic system lengths ΔL_1, ΔL_2, and ΔL_3

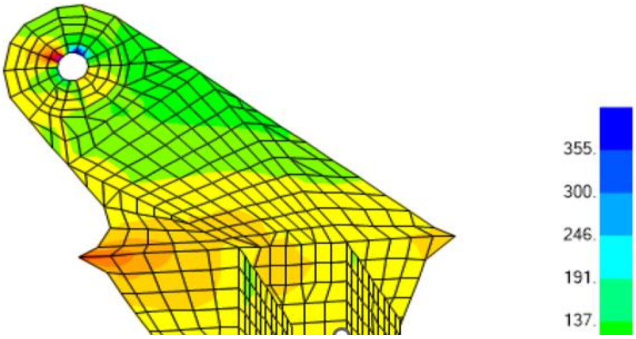

Figure 5: Three-dimensional finite-element model of the fork-type hanger anchorage component

These characteristic dimensions describe the geometric relationship among the structural connection points, fork components, anchorage assemblies, and effective strand length. Their accurate definition is necessary for manufacturing, installation, adjustment, and the correct transfer of tensile force through the complete hanger system. The dimensional configuration also provides the basis for establishing the geometry of the full-scale test specimens.

Each anchorage assembly collects the tensile forces developed in the 47 individual strands and transfers their combined force through the socket and fork connection to the bridge structure. The anchorage and fork components must therefore resist high concentrated forces while maintaining the alignment and integrity of the complete strand bundle. Their structural performance cannot be assessed solely from the tensile properties of the individual strands.

The detailed project design included three-dimensional finite-element modelling of the fork-type anchorage component and its transition zones. The model was used to evaluate the distribution of stresses and identify structurally critical regions within the anchorage assembly. However, numerical modelling represents only one component of the verification process. Full-scale physical testing was required to confirm that the manufactured strand–anchorage–fork assembly could transfer the prescribed tensile force without premature failure or unacceptable damage.

The static tensile acceptance test was therefore conducted on the complete fork-to-fork hanger assembly rather than on isolated anchorage components. This approach enabled direct verification of the entire load-transfer path, including the strand bundle, anchorage zones, sockets, forks, and their mutual interaction under the prescribed loading sequence.

3. TEST SPECIMENS AND MATERIAL BASIS

This section describes the configuration of the tested full-scale hanger specimens and the mechanical properties used to define the reference and acceptance forces.

3.1. HANGER SYSTEM CONFIGURATION

Two representative full-scale OVM.ST15-47 hanger specimens, designated SY-1-1 and SY-1-2, were prepared for static tensile factory acceptance testing. The specimens represented hangers L-06 and L-07, selected because they were subjected to the highest design working forces within the investigated hanger group. Each specimen reproduced the ST15-47SAVA.0 anchorage configuration, providing a conservative basis for the full-scale acceptance assessment. Each specimen comprised 47 parallel seven-wire prestressing strands, the corresponding upper and lower anchorage assemblies, and fork-type end connections. The specimens reproduced the principal configuration and load-transfer details of the hanger system intended for installation on the New Sava Bridge (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b).

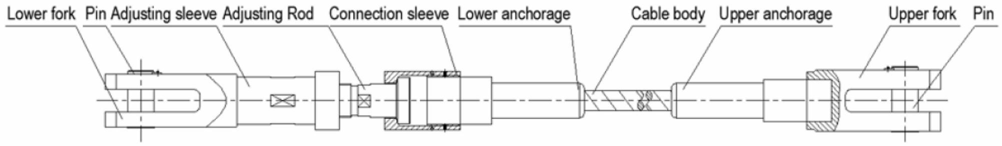

Figure 6: General arrangement and principal components of the fork-to-fork OVM.ST15-47 hanger assembly

The strand arrangement and anchorage components were representative of the manufactured bridge hangers. The complete specimens were tested in a fork-to-fork configuration so that the applied tensile force passed through the entire structural assembly. This arrangement enabled simultaneous verification of the strand bundle, anchorage zones, sockets, forks, and their mutual interaction under the prescribed tensile loading.

Each hanger specimen incorporated 47 individually protected seven-wire strands. The strands were arranged in parallel and anchored as a single structural bundle. The nominal strand designation was 1 × 7–15.7–1860, indicating a seven-wire strand with a nominal diameter of 15.7 mm and a nominal tensile strength of 1,860 MPa. The corresponding hanger-system designation was OVM.ST15-47, where the numerical suffix identifies the 47-strand configuration.

The free length between the sockets was required to be at least 3,500 mm to permit representative deformation of the strand bundle and reliable evaluation of elongation during testing. The measured free lengths were 4,593 mm for Specimen SY-1-1 and 4,600 mm for Specimen SY-1-2. Both specimens therefore satisfied the minimum geometric requirement defined in the approved test documentation (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b, 2026c).

Before testing, the specimens were checked for conformity with the approved configuration. The inspection included verification of the specimen identification, number and arrangement of strands, anchorage and fork components, free length, exposed assembly details, and general condition of the complete hanger system.

3.2. STRAND PROPERTIES AND REFERENCE FORCES

Each full-scale hanger specimen comprised 47 seven-wire prestressing strands, each with a nominal diameter of 15.7 mm, a nominal tensile strength of 1,860 MPa, and a nominal metallic cross-sectional area of 150 mm². The strands were specified in accordance with the applicable project requirements and the relevant provisions governing prestressing steel strands (European Committee for Standardization, n.d.).

The nominal breaking force of a single strand, F_{pk}, was calculated as follows:

$$F_{pk} = f_{pk} \times A_p = 1{,}860 \text{ MPa} \times 150 \text{ mm}^2 = 279{,}000 \text{ N} = 279 \text{ kN} \quad (1)$$

where f_{pk} is the nominal tensile strength and A_p is the nominal metallic cross-sectional area of one strand.

For the complete 47-strand bundle, the guaranteed ultimate tensile strength (GUTS) was calculated from the nominal breaking force of one strand:

$$\text{GUTS} = [n]_{pk} = 47 \times 279 = 13{,}113 \text{ kN} \quad (2)$$

In addition to verification of the nominal material properties, three representative strand specimens were subjected to individual tensile tests. Their measured ultimate tensile forces were 290.5, 290.6, and 290.5 kN. The average measured ultimate tensile force of one strand was therefore:

$$F_{(u,\,avg)} = (290.5 + 290.6 + 290.5)/3 = 290.53 \text{ kN} \approx 290.5 \text{ kN} \quad (3)$$

For consistency with the value adopted in the approved test report, the average force was taken as 290.5 kN. The calculated actual ultimate tensile strength of the complete 47-strand bundle (AUTS) was consequently determined as:

$$AUTS = [nF]_{(u,\ avg)} = 47 \times 290.5 = 13{,}653.5\ kN \quad (4)$$

In this paper, AUTS denotes a calculated reference value obtained by multiplying the average measured ultimate tensile force of the three individual strand specimens by the total number of strands in the hanger. It does not represent the experimentally determined failure resistance of the complete hanger assembly, because the full-scale hanger specimens were not loaded to failure.

The approved acceptance procedure specified two reference force levels:

$$F_{(ref,1)} = 0.95 \times GUTS = 0.95 \times 13{,}113 = 12{,}457.35\ kN \quad (5)$$

$$F_{(ref,2)} = 0.92 \times AUTS = 0.92 \times 13{,}653.5 = 12{,}561.22\ kN \quad (6)$$

The governing acceptance force was defined as the greater of these two values. Accordingly, the criterion based on 92% of AUTS governed the full-scale static tensile test, resulting in a required acceptance force of 12,561.22 kN (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b, 2026c).

Table 2: Mechanical properties of the strands and reference tensile forces for the 47-strand hanger system

Parameter	*Monostrand*	*Cable (47 strands)*
Nominal breaking force, GUTS (kN)	*279*	*13,113*
Actual breaking force, AUTS (kN)	*290.5*	*13,653.50*
95% GUTS (kN)	*265.05*	*12,457.35*
92% AUTS (kN) — governing criterion	*267.3*	*12,561.22*
Cross-sectional area (mm²)	*150*	*7,050*

4. TEST SETUP, EQUIPMENT AND METROLOGICAL TRACEABILITY

This section describes the full-scale test arrangement, the loading and measuring equipment, and the metrological traceability of the instruments used during testing.

4.1. TEST ARRANGEMENT

The static tensile tests were conducted using a full-scale hanger assembly installed horizontally in a purpose-built, self-reacting test frame. The test frame was designed to resist the applied tensile force without transferring significant external reactions to the surrounding structure. One end of the hanger specimen was connected to the fixed reaction assembly, while the opposite end was connected to the hydraulic loading system.

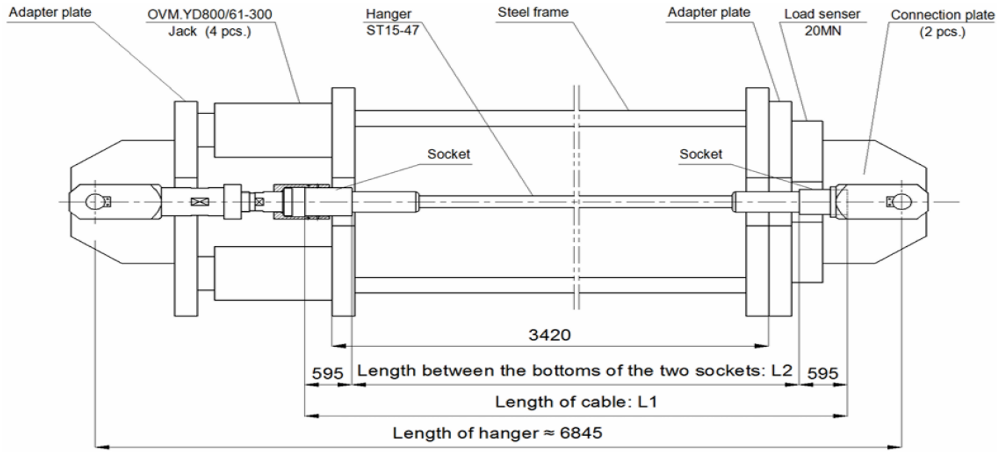

Figure 7: General arrangement and principal dimensions of the full-scale static tensile test assembly

The loading system comprised four hydraulic jacks, each with a nominal capacity of 8 MN. The jacks introduced the tensile force along the longitudinal axis of the hanger specimen through the stressing-end assembly. The arrangement was configured to maintain the alignment of the complete specimen and to reproduce the principal force-transfer mechanism of the fork-to-fork hanger system.

The complete test assembly included the full-scale hanger specimen, fixed-end anchorage, stressing-end anchorage, fork components, reaction structure, hydraulic jacks, load-measurement devices, and displacement-measurement equipment. The specimen was positioned so that the tensile force passed through the complete strand–anchorage–fork load path, corresponding to the structural mechanism used in the bridge application.

Before the application of load, the identification and general condition of each specimen were verified. The pre-test inspection included the strand bundle, exposed strand sections, anchorage assemblies, sockets, fork connections, protective components, and accessible load-transfer details. The measured free length between the sockets was also recorded and compared with the minimum required value. The position and alignment of the specimen were checked before testing. Particular attention was given to the alignment of the hanger axis with the hydraulic loading system because unintended eccentricity could introduce secondary bending effects and affect the measured response. After the alignment and instrumentation checks had been completed, the test assembly was approved for the prescribed staged loading procedure (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b, 2026c).

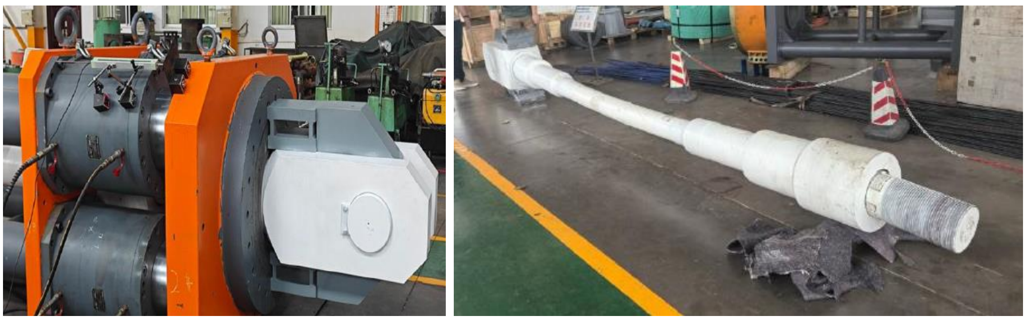

Figure 8. Pre-test inspection of the hanger specimen: anchorage assembly (left) and stressing-end components (right)

Figure 9: Full-scale static tensile test arrangement: fixed-end anchorage (left) and longitudinal view of the assembled hanger specimen (right)

4.2. MEASURING EQUIPMENT AND CALIBRATION

The applied tensile force was monitored using calibrated LC-3/20 MN dynamometers connected to digital force indicators. The dynamometers had a nominal measuring capacity of 20 MN and were covered by calibration certificates LSfm2025-02593 and LSfm2025-02914 issued by the National Institute of Metrology, China (2025). The reported relative measurement uncertainty was 0.3%, providing an appropriate level of accuracy for verifying attainment of the governing acceptance force.

The hydraulic loading equipment was checked and calibrated before testing. The hydraulic jacks were calibrated on May 20, 2026, before the full-scale tests conducted on May 22 and June 11, 2026. The calibration and verification records formed part of the documentation reviewed by the author of this article before the commencement of testing.

Dimensional measurements were performed using verified steel rulers and steel tape measures. The corresponding verification records included certificates CCL25090072 and CCC25050110. The WAW-600 universal testing machine used for testing the individual strand specimens was covered by verification certificate LLC26040033. The machine was verified on April 8, 2026, as a Class 1 testing machine, with the verification remaining valid until April 7, 2027 (Liuzhou Institute of Metrology and Measurement Technology, 2025–2026).

The verification of the strand-testing machine was particularly important because the average measured ultimate force of the three individual strand specimens was used to calculate AUTS and, consequently, the governing full-scale acceptance force. The metrological chain therefore connected the individual strand-test results, the calculated reference force, and the applied force measured during the full-scale hanger tests.

Figure 10: Digital force indicators used for monitoring the applied tensile load

Displacement measurements were recorded at the prescribed loading stages. The reported jack-piston displacement represents the response of the complete test arrangement, including deformation of the hanger assembly, seating and adjustment within the anchorage system, and deformation of the loading and reaction components. It should therefore be distinguished from the directly measured elongation of the free strand length.

The available calibration and verification documentation provided traceability for the principal force and dimensional measurements used in the acceptance assessment. This traceability was essential because the difference between the prescribed acceptance force and the maximum force achieved during testing was relatively small. Compliance could therefore be evaluated only using appropriately calibrated and documented measuring equipment.

4.3. THIRD-PARTY WITNESSING

The full-scale factory acceptance tests were witnessed by Bureau Veritas, Industry & Facilities Division, acting as an independent third-party inspection body. The inspection activities included verification of the test-specimen identification, review of the applicable test documentation, examination of the test arrangement and measuring equipment, observation of the loading procedure, and confirmation of the reported test results.

The third-party witnessing also covered the conformity of the testing activities with the approved procedure and the availability of the relevant calibration and verification records. The observations and results were documented in Third-Party Inspection Report No. INS/SR/SHOP-26/057-02, Revision 00 (Bureau Veritas, Industry & Facilities Division, 2026).

Independent witnessing did not replace the technical evaluation of the test results but provided additional documentary assurance that the prescribed testing procedure was followed and that the reported results corresponded to the observed full-scale tests.

5. TEST PROCEDURE AND ACCEPTANCE CRITERIA

The tests were conducted in accordance with the approved project-specific test plan and factory acceptance documentation (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b, 2026c). Specimen SY-1-1 was tested on May 22, 2026, and Specimen SY-1-2 on June 11, 2026. Before loading, the specimen identification, geometry, strand bundle, anchorage assemblies, fork connections, measuring devices, and hydraulic system were inspected.

The loading sequence was defined as a fraction of GUTS. After establishing the reference condition at 0.1 GUTS, the load was increased through 0.2, 0.4, 0.6, and 0.8 GUTS. The corresponding forces were 1,311.3, 2,622.6, 5,245.2, 7,867.8, and 10,490.4 kN. Force and jack-piston displacement were recorded at the prescribed stages. At 0.8 GUTS, the load was maintained for 60 minutes, after which loading continued to the governing acceptance force.

The required force was defined as the greater of 95% GUTS and 92% AUTS:

$$0.95 \text{ GUTS} = 12{,}457.35 \text{ kN} \tag{7}$$

$$0.92 \text{ AUTS} = 12{,}561.22 \text{ kN} \tag{8}$$

Consequently, 92% AUTS governed and the required acceptance force was 12,561.22 kN. The specimens also had to achieve a total elongation of at least 1.5% and show no failure of the strand bundle, sockets, forks, or other anchorage-system components.

Total elongation was evaluated from the measured displacement between the 0.1 GUTS reference point and the maximum test force, corrected for the calculated elastic elongation between zero load and 0.1 GUTS:

$$\varepsilon_{Tu} = \frac{\Delta L_{0.1-\max} + \Delta L_{0-0.1}}{L_1(0.1) - \Delta L_{0-0.1}} \tag{9}$$

where:

$$\Delta L_{0-0.1} = \frac{F_{0.1} L_1(0)}{AE} \tag{10}$$

The total metallic strand area was A = 7,050 mm^2, and the nominal modulus of elasticity was E = 195 GPa. This correction distinguishes the evaluated specimen elongation from the jack-piston displacement of the complete test arrangement.

The tests were intended to verify attainment of the prescribed acceptance level rather than determine the failure resistance of the full-scale hanger assemblies.

Table 3: Loading protocol and measurement stages applied to both hanger specimens

Load stage	Force (kN)	Remark
0 (point)	0	Reference geometry measured
0.1 GUTS	1,311.3	Point for elongation, length re-measured
0.2 GUTS	2,622.6	Piston displacement recorded
0.4 GUTS	5,245.2	Piston displacement recorded
0.6 GUTS	7,867.8	Piston displacement recorded
0.8 GUTS, held 60 min	10,490.4	Load hold; displacement before/after
Loading to maximum	≥ 12,561.2 required	≥ 92% AUTS or 95% GUTS, whichever greater

6. TEST RESULTS

This section presents the measured maximum tensile forces, total elongations, load–displacement response, and post-test condition of the two full-scale hanger specimens.

6.1. MAXIMUM TENSILE FORCES AND ELONGATIONS

Both full-scale hanger specimens reached and exceeded the governing acceptance force of 12,561.22 kN. Specimen SY-1-1 reached a maximum test force of 12,575.7 kN, whereas Specimen SY-1-2 reached 12,614.4 kN (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b).

The achieved forces, expressed as percentages of the calculated AUTS, were 12,575.7/13,653.5 × 100 = 92.1% for Specimen SY-1-1, and 12,614.4/13,653.5 × 100 = 92.4% for Specimen SY-1-2.

The margins by which the specimens exceeded the governing acceptance force were 12,575.7 - 12,561.22 = 14.48 kN and 12,614.4 - 12,561.22 = 53.18 kN, respectively. Although these margins were relatively small, both measured forces exceeded the prescribed requirement. This assessment was supported by the documented calibration and measurement traceability of the force-measurement system.

The measured total elongation was 2.7% for Specimen SY-1-1 and 2.1% for Specimen SY-1-2. Both values exceeded the specified minimum elongation of 1.5%. The corresponding margins above the minimum requirement were therefore 1.2 and 0.6 percentage points, respectively.

The results demonstrate that both complete strand–anchorage–fork assemblies attained the required force and elongation levels. No premature failure of the strand bundle, sockets, forks, or other anchorage-system components was observed during the prescribed loading procedure.

The reported maximum test forces represent the highest forces attained during the approved acceptance tests. Because the full-scale specimens were not loaded to structural failure, these values should not be interpreted as the ultimate tensile resistance of the complete hanger assemblies.

Table 4: Summary of acceptance criteria and static tensile test results for both hanger specimens

Quantity	Requirement	Specimen 1	Specimen 2
Free length between sockets, L2 (mm)	≥ 3,500	4,593	4,600
Maximum tensile force (kN)	≥ 12,561.22	12,575.7	12,614.4
Ratio to AUTS (%)	≥ 92.0	92.1	92.4
Total elongation εTu (%)	≥ 1.5	2.7	2.1
Damage to specimen	—	No damage	No damage
Anchorage system after test	No failure	Normal	Normal

6.2. LOAD-DISPLACEMENT RESPONSE

Jack-piston displacement increased progressively with the applied tensile force in both specimens. Relative to the displacement reading established at the 0.1 GUTS reference load, the maximum recorded jack-piston displacements were 119.97 mm for Specimen SY-1-1 and 90.98 mm for Specimen SY-1-2.

At the beginning of the 60-minute holding period at 0.8 GUTS, the recorded jack-piston displacement for Specimen SY-1-1 was 57.43 mm. At the end of the holding period, it was 60.23 mm. The additional displacement recorded during the hold was therefore 60.23 – 57.43 = 2.80 mm. For Specimen SY-1-2, the corresponding displacement increased from 41.13 to 42.97 mm, giving an additional displacement of 42.97 – 41.13 = 1.84 mm.

Both specimens remained stable during the prescribed holding period and subsequently reached the governing acceptance force. No sudden increase in displacement or visible loss of integrity was reported during the loading sequence (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b).

The different displacement histories of the two specimens should be interpreted in the context of the complete test arrangement. Jack-piston displacement incorporates several components of the system response, including elastic deformation of the hanger assembly, initial seating of the strand bundle, adjustment within the anchorage components, deformation of the loading equipment, and possible tolerances within the reaction frame.

Consequently, jack-piston displacement should not be regarded as identical to the elongation or strain of the free strand length. The directly evaluated total elongations of 2.7% and 2.1% were used for the elongation acceptance assessment, whereas jack-piston displacement provided supporting information on the overall response and stability of the full-scale test arrangement.

Table 5: Jack-piston displacements recorded at the prescribed load stages

Load stage	Specimen 1 – displacement (mm)	Specimen 2 – displacement (mm)
0.1 GUTS (point)	0	0
0.2 GUTS	5.43	5.82
0.4 GUTS	16.59	16.73
0.6 GUTS	29.49	28.11
0.8 GUTS (start of hold)	57.43	41.13
0.8 GUTS (end of 60-min hold)	60.23	42.97
Maximum force	119.97	90.98

6.3. POST-TEST CONDITION OF SPECIMENS & ANCHORAGE COMPONENTS

Following completion of the prescribed loading procedure and unloading, both full-scale hanger specimens were visually inspected. The inspection covered the exposed strand bundle, anchorage zones, sockets, forks, and other accessible structural components of the hanger assembly.

No damage was identified in either full-scale specimen, and no failure occurred in any component of the anchorage system. The sockets and fork-type connections remained intact, and no visible evidence of unacceptable deformation, cracking, fracture, strand slippage, or loss of anchorage integrity was reported (Liuzhou OVM Structure Monitoring Technology Co., Ltd., 2026b; Bureau Veritas, Industry & Facilities Division, 2026).

The absence of observed damage after unloading confirmed that the required tensile force had been transferred through the complete strand–anchorage–fork load path without visible impairment of the tested assemblies. This post-test condition formed an integral part of the acceptance assessment, together with attainment of the governing force and minimum elongation requirements.

The individual strand specimens used to determine the average actual ultimate tensile force were tested separately to rupture. These tests produced characteristic wire fractures and provided the experimental material basis for calculating AUTS. The fractured individual strand shown in Figure 11 should therefore be distinguished from the two full-scale hanger specimens, neither of which was tested to failure.

Figure 11: Individual strand specimen after tensile testing, showing characteristic wire fractures

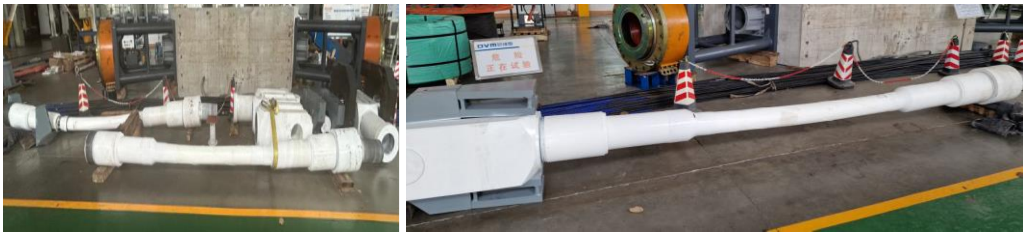

Figure 12: Post-test inspection of the hanger specimens and anchorage assemblies

Table 6: Measured strand tensile strength and calculated acceptance forces for the OVM.ST15-47 hanger system

<table>
<tr><td>Sample name</td><td>ST15-47 hanger system</td><td>Type/Model</td><td colspan="5">Strand: 47×15.7-1860MPa
Hanger: ST15-47SAVA.0</td></tr>
<tr><td rowspan="5">Basic Parameters of the Sample</td><td colspan="7">Type of mono strand: 1×7-15.7-1860</td></tr>
<tr><td>Measured ultimate tensile force</td><td>1#</td><td>290.5kN</td><td>2#</td><td>290.6kN</td><td>3#</td><td>290.5kN</td></tr>
<tr><td>Average ultimate tensile force</td><td colspan="2">290.5 kN</td><td colspan="3">numbers of strands</td><td>47</td></tr>
<tr><td>Nominal Breaking Force (GUTS)</td><td colspan="2">13113 kN</td><td>0.95 GUTS</td><td colspan="3">12457.35 kN</td></tr>
<tr><td>Actual Breaking Force (AUTS)</td><td colspan="2">13653.5 kN</td><td>0.92 AUTS</td><td colspan="3">12561.22 kN</td></tr>
</table>

Table 7: Acceptance criteria and test results for the two hanger specimens

Testing items	*Specification requirements*	*Actual values*	
		-1st (SY-1-1)	*-2nd (SY-1-2)*
Length of hanger L(mm)	≥3500	4593	4600
Max tensile force of hanger (kN)	≥12561.22	12575.7	12614.4
Total elongation ε_{tu}	≥1.5%	2.7%	2.1%
The location of damage to the specimen	/	*No damage*	*No damage*
Inspection of assemblies after testing	/	*Normal*	*Normal*
Remarks	*No failure occurs in any components of the anchorage system.*		

7. DISCUSSION

The results are interpreted through three distinct force levels: the maximum design hanger force, the governing factory-acceptance force, and the maximum force achieved during each test. The maximum design force for the investigated hanger was 7,729 kN, whereas the governing acceptance force was 12,561.22 kN. The two specimens reached 12,575.7 and 12,614.4 kN, respectively. Thus, the governing acceptance force and both achieved test forces were approximately 1.63 times the maximum design force.

This ratio provides a transparent measure of test severity but should not be interpreted as a conventional global safety factor. Design action, material resistance, acceptance force, and achieved test force belong to different verification levels and may incorporate different characteristic values, partial factors, and acceptance provisions.

The difference between the maximum forces achieved by the specimens was 38.7 kN, corresponding to approximately 0.31% of their mean maximum force. This close agreement indicates consistent attainment of the prescribed acceptance level by the two assemblies. However, two tests do not provide a statistical evaluation of production variability or ultimate hanger resistance, particularly because neither specimen was loaded to failure.

The specimens exhibited different jack-piston displacement histories and total elongations while satisfying the same acceptance requirements. Such differences may arise from strand-bundle seating, anchorage adjustment, assembly tolerances, specimen geometry, and deformation of the loading and reaction system. Jack-piston displacement therefore describes the response of the complete test arrangement and should not be equated directly with free-strand strain.

During the 60-minute hold at 0.8 GUTS, the additional recorded displacements were 2.80 and 1.84 mm. Both specimens remained stable and subsequently reached the governing acceptance force. Following unloading, no visible wire breaks, socket damage, fork damage, strand slippage, or anchorage-component failure was reported. The results therefore verify the integrity of the complete strand-anchorage-fork load path at the prescribed acceptance level.

Full-scale testing complements, rather than replaces, project calculations, numerical modelling, material certification, and individual strand tests. The numerical model identifies the expected stress distribution and critical anchorage regions, whereas physical testing verifies the manufactured assembly under controlled loading. This combined approach is consistent with the general principles applied to the acceptance of cable systems using prestressing steels (International Federation for Structural Concrete [fib], 2019; Post-Tensioning Institute [PTI], 2018).

The investigation was limited to the static tensile testing of two representative specimens. It does not independently establish fatigue resistance, corrosion durability, or long-term in-service performance. These aspects require the applicable design checks, material-protection requirements, production controls, inspection procedures, and maintenance programme (Cai et al., 2018; Duan et al., 2024; Teichgraeber, 2025).

Table 8: Main design parameters and reference forces of the OVM.ST15-47 hanger system

MAIN data for cables	
Number of strands	*47*
Nominal strand tensile strength (MPa)	*1,860*
Nominal cross-sectional area of one strand (mm²)	*150*
Nominal ultimate load of one strand (kN)	*279*
Nominal Section Area of Strands (mm²)	*7,050*
Ultimate load — 100% GUTS (kN)	*13,113*
Service load capacity — 45% GUTS (kN)	*5,901*
Maximum force in the hanger (kN)	*7,729*

Table 9. Comparison of the maximum design force, required acceptance force, and achieved test forces

Parameter	*Force (kN)*	*Ratio to maximum design force*
Maximum design hanger force	*7,729.00*	*1*
Required test force—92% AUTS	*12,561.22*	*1.63*
Maximum force—Specimen 1	*12,575.70*	*1.63*
Maximum force—Specimen 2	*12,614.40*	*1.63*

8. CONCLUSIONS

Based on the full-scale static tensile factory acceptance testing of the OVM.ST15-47 hanger system, the following conclusions were drawn.

Two representative full-scale specimens, corresponding to hangers L-06 and L-07 and reproducing the ST15-47SAVA.0 anchorage configuration, were tested in accordance with the approved project-specific procedure. The nominal guaranteed ultimate tensile strength (GUTS) of the 47-strand bundle was 13,113 kN. Based on the results of three individual strand tests, the calculated actual ultimate tensile strength (AUTS) was 13,653.5 kN. Consequently, the governing acceptance force was 12,561.22 kN, corresponding to 92% AUTS.

Specimens SY-1-1 and SY-1-2 reached maximum tensile forces of 12,575.7 and 12,614.4 kN, respectively. Both values exceeded the governing acceptance requirement, while the difference between them was only 0.31% of the mean achieved force, indicating a consistent response of the two tested assemblies.

The measured total elongations were 2.7% for Specimen SY-1-1 and 2.1% for Specimen SY-1-2, both exceeding the specified minimum value of 1.5%. Furthermore, both specimens remained stable during the prescribed 60-minute load-holding period at 0.8 GUTS.

Post-test inspection identified no damage to either full-scale specimen and no failure of the strand bundles, sockets, forks, or other anchorage-system components. The governing acceptance force and the maximum forces achieved during testing were approximately 1.63 times the maximum design hanger force of 7,729 kN. This comparison demonstrates the severity of the factory acceptance test but should not be interpreted as a conventional global safety factor.

The results confirm that both tested OVM.ST15-47 hanger assemblies satisfied the specified static tensile acceptance requirements for their intended application on the New Sava Bridge. Because the specimens were not tested to failure, the achieved forces demonstrate acceptance-level compliance rather than the ultimate resistance of the complete hanger system. Fatigue performance, corrosion durability, and long-term structural behaviour remain outside the scope of this investigation.

Overall, the full-scale testing provided direct experimental verification of the acceptance-level tensile performance, deformation response, and integrity of the complete hanger assemblies under the prescribed static tensile loading procedure. By combining bridge design data, strand properties, calibrated measurements, a controlled loading procedure, and post-test inspection, the investigation provides a complete and traceable basis for accepting the tested OVM.ST15-47 system for installation on the New Sava Bridge, subject to compliance with the remaining project requirements concerning manufacturing, installation, fatigue resistance, corrosion protection, inspection, and long-term maintenance. More broadly, the study demonstrates the importance of project-specific full-scale testing for complex bridge hanger systems whose structural performance cannot be fully assessed through individual material tests or numerical analysis alone. The presented methodology and results may therefore serve as a useful reference for the acceptance testing and quality control of comparable parallel-strand hanger systems used in arch bridges.

REFERENCES

[1] Bureau Veritas, Industry & Facilities Division. (2026, June). Third-party inspection report No. INS/SR/SHOP-26/057-02 (Rev. 00) [Inspection report].

[2] Cai, S., Chen, W., & Xu, J. (2018). Full-scale fatigue tests on a novel box-shaped steel rod of a spatial arch bridge for fatigue assessment. Advances in Structural Engineering, 21(5), 694–706. https://doi.org/10.1177/1369433217726897

[3] Duan, Y. F., Wu, S. K., Zhang, H. M., Zhang, R., Yun, C. B., Cheng, J. J. R., & Wang, S. M. (2024). Development of corrosion-fatigue analysis method of cable hangers in tied-arch bridges considering train-bridge interaction. Engineering Structures, 315, Article 118484. https://doi.org/10.1016/j.engstruct.2024.118484

[4] European Committee for Standardization. (2005). Prestressing steels—Part 3: Strand (prEN 10138-3:2005) [Draft European Standard].

[5] International Federation for Structural Concrete. (2019). Acceptance of stay cable systems using prestressing steels (fib Bulletin No. 89, Recommendation). https://doi.org/10.35789/fib.BULL.0089

[6] Liuzhou Institute of Metrology and Measurement Technology. (2025–2026). Verification certificates CCL25090072, CCC25050110, and LLC26040033 [Verification certificates for the steel ruler, steel tape measure, and WAW-600 universal testing machine].

[7] Liuzhou OVM Structure Monitoring Technology Co., Ltd. (2026a). Document list for witnessing the tensile test of the New Sava Bridge hangers [Project document register].

[8] Liuzhou OVM Structure Monitoring Technology Co., Ltd. (2026b, June 25). Static tensile test for the OVM.ST15-47 hanger cable, New Sava Bridge, Serbia (Test Report No. A20260536) [Technical test report witnessed by Bureau Veritas].

[9] Liuzhou OVM Structure Monitoring Technology Co., Ltd. (2026c, January 4). Static tensile test plan of the OVM.ST15-47 hanger cable for the New Sava Bridge, Serbia [Technical test plan].

[10] Millennium Team, Mostogradnja ING, Faculty of Technical Sciences, University of Novi Sad, & IO Design Enterprise. (n.d.). New Sava Bridge: Main bridge structure, superstructure, left (larger) arch, arch hangers Nos. 06 and 07 (Detailed design documentation, Structure Book 2/1.1) [Design drawings].

[11] National Institute of Metrology, China. (2025). Calibration certificates LSfm2025-02593 and LSfm2025-02914 for LC-3/20 MN dynamometers [Calibration certificates].

[12] Post-Tensioning Institute. (2018). Recommendations for stay cable design, testing, and installation (PTI DC45.1-18, 7th ed.).

[13] Teichgraeber, M. (2025). Reliability and durability assessment of bridge stay cables. Archives of Civil and Mechanical Engineering, 25, Article 29. https://doi.org/10.1007/s43452-024-01086-2