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Hangar Stressing on the 6th Street Viaduct Replacement, Los Angeles, CA

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ABSTRACT: Spanning across Freeway 101, several rail roads and the LA river, the 6th Street Viaduct replacement project is one of the largest bridge projects in the City of Los Angeles. The original bridge was built in 1932 and became a backdrop to the film industry. The iconic bridge was demolished following the decision to replace it with the existing 6th Street Viaduct due to the structure becoming seismically vulnerable. At 3,060-ft-long and 100-ft-wide, the redevelopment of the new bridge – designed by Michael Maltzan, – includes 10 network arch spans, with a total of 388 hangers supporting the bridge deck. The bridge spans 101 Highway, the Los Angeles River. The hanger installation and stressing for the bridge was a complex procedure that would need careful attention to detail for loading the hangars before removal of formwork and for fine tuning the final load criteria. There were 18 load sequences per arch. The instrumentation and monitoring of the hangars while loading required a novel approach that started two years in advance of the works with development of a bespoke system, calibration and acceptance. During installation and works many lessons were learnt by all parties involved. The close working relationship with a desire to succeed between the site team and designers was as fascinating as the technical brilliance applied by all to deliver this section of the project in a safe manner, within the schedule and to the specification.

KEY WORDS: Bridge; structural monitoring; strain gauges, load verification, dataloggers,hangers

1. Introduction

The 6th Street Viaduct replaced the original, beloved bridge in 1932, which had been deteriorating for decades due to alkali silica reaction. This condition is caused by an aggregate in the concrete that drew in moisture and caused cracks. After repeated attempts to retrofit the old bridge the decision was made that it needed to be replaced. In 2012, after much outreach and consultation with the community, the Los Angeles Bureau of Engineering held an international design competition to select a design for the new viaduct. Michael Maltzan Architects, a local Los Angeles firm, and HNTB, were the winners with the design, called "The Ribbon of Light".

In 2016 the bridge was demolished completely, and construction on the new Sixth Street Viaduct began. Funded by the Federal Highway Transportation Administration, the California Department of Transportation, and the City of Los Angeles, the $588 million Sixth Street Viaduct Replacement Project was led by the Los Angeles Bureau of Engineering under City Engineer Gary Lee Moore in partnership with the LA Bureau of Contract Administration.

The new Sixth Street Viaduct consists of 10 pairs of arches that range in heights from 30 feet to 60 feet tall. Each arch has a 9-degree outward cant, 10-foot width, and requires 260 cubic yards of concrete. Arches had to be poured at a rate of 4 vertical feet per hour for a total of 12-14 hours per arch due to the formwork and intricate support system.

The arches join into a Y-shaped column, and in total, the 23 columns and 2 abutments of the bridge use triple friction pendulum bearings for seismic base isolation. These bearings allow movement up to 30 inches in any lateral direction, not only ensuring earthquake survival, but making the Sixth Street Viaduct one of the largest base-isolated structures in the world. Generally, construction developed from east to west and was led by contractor Skanska-Stacy and Witbeck Inc. Arches were poured without cables in place, then cables 2 ¾in. in diameter were added and tightened to create a network-tied arch structure.

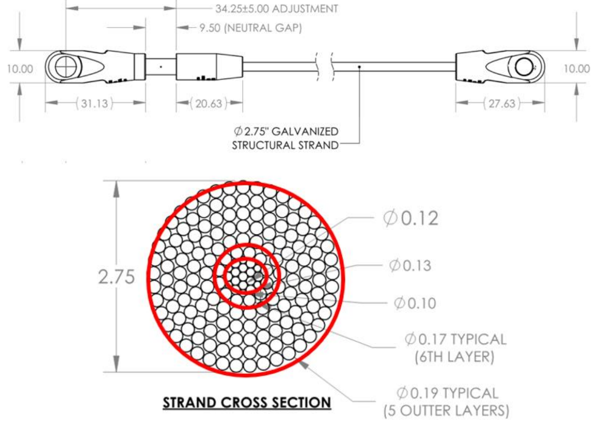

Figure 1. Typical strand construction

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Figure 2. General view of the Sixth Street Viaduct Replacement

2. Development of a Custom Load Verification System.

Following an extensive series of interviews with manufacturers specializing in conventional load verification technologies, the contractor—Stacy Witbeck Skanska Joint Venture (JV)—engaged Geo Instruments to develop a bespoke load verification system tailored to the unique constraints of the Sixth Street Viaduct project. A key requirement was that instrumentation could not be integrated during strand manufacturing due to the complexity of the process. The system needed to be repeatable, allow for self-performed installation by the JV team following training, and support real-time data acquisition both on the bridge deck and remotely for review and approval by the design team based in Canada. Load measurements were required to achieve accuracy within 2 % of the target load for each loading cycle.

Traditional strand loading methods typically employ in-strand tensiometers or vibration-based devices. However, the project's emphasis on repeatability and operational simplicity led to the selection of vibrating wire strain gauges—recognized for their reliability and proven performance in structural load measurement.

Vibrating wire strain gauges operate by tensioning a steel wire between two fixed anchors within a stainless-steel housing. Electromagnetic coils induce oscillation in the wire via a brief voltage or swept frequency excitation. The wire vibrates at its resonant frequency, generating a sinusoidal alternating current. This frequency is captured by a readout unit or data logger equipped with a vibrating wire interface and converted into engineering units of strain. Changes in structural force alter the wire's tension, thereby shifting its resonant frequency. The square of the frequency change is directly proportional to the change in strain.

These gauges are cost-effective, durable, and compact, with the capability to record data at intervals as short as one second. For this application, low-profile vibrating wire strain gauges manufactured by Geosense (UK) were selected. The chosen model had a maximum strain capacity of 3000 µ€ which was deemed suitable for the expected load range.

To ensure consistent and accurate strain measurements, each vibrating wire strain gauge was mounted on a custom-engineered aluminum clamp designed to securely interface with the prestressing strands. The clamp assembly was developed to prevent slippage or misalignment during strand elongation, thereby preserving measurement integrity. A secondary carrier clamp, positioned above the primary clamp, housed the strain gauge and enabled reuse across multiple strands without compromising performance or structural integrity. The prototype assembly was presented to the client for review and approval.

Figure 3. Prototype strain gauge assembly.

3. Load Verification Tests.

An opportunity to conduct a destructive test on a single strand was utilized to validate the design. The initial test setup included two strain gauges mounted on opposite sides (top and bottom) of the test strand. The gauges were configured to record data at five-second intervals. The testing facility prepared and rigged the test frame to simulate loading conditions representative of field operations. in such a way that

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there were not any incremental load stops to verify the load and strain alignment. The test was too fast, and load profiles generated on the test machine did not mimic the anticipated loading sequence anticipated on site. The initial destructive test provided limited insight into the load recording capabilities of the test frame. Unfortunately, the load data output was incompatible with standard data analysis platforms such as Microsoft Excel, which hindered post-processing and review. Following this session, and in consultation with the client, it was agreed to proceed with a single strain gauge per strand for subsequent tests. This decision was based on the observation that strand bending was negligible due to the strand's diameter and length, and that dual-gauge setups would unnecessarily slow down field operations.

The second test session comprised a series of ten proving tests, each requiring the strand to withstand a load of one million pounds prior to failure. Strain gauges were mounted at the mid-span of each strand, and data was recorded at two-second intervals. The resulting strain measurements demonstrated strong consistency and alignment with expected values, thereby validating the reliability of the system and increasing confidence in its field performance.

Despite the successful strain data acquisition, the load recording methodology employed by the testing facility remained a limitation. The format of the load data continued to be incompatible with standard analytical tools, presenting challenges for integration and review by the project team

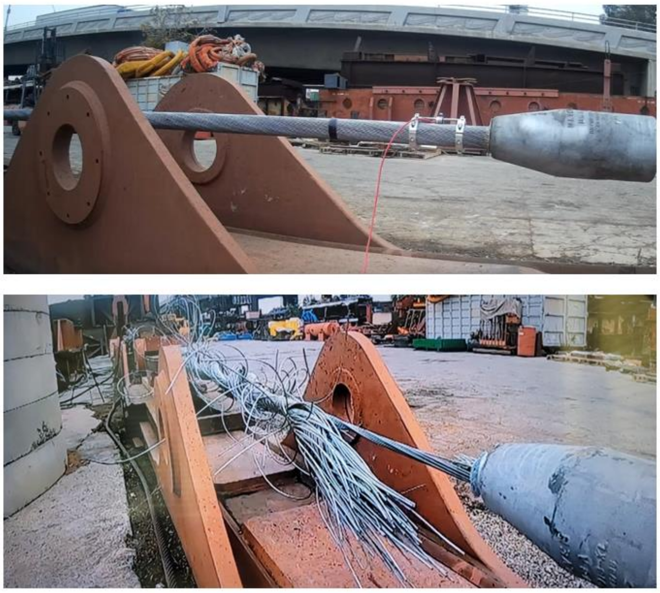

Figure 3.Testing hanger strands to destruction.

The third round of testing was conducted at the strand manufacturer's facility, enabling a more controlled environment and allowing tests to be performed at loading rates that closely matched field conditions. This controlled setup facilitated more accurate correlation between applied load and strain gauge measurements.

Following these tests, the client reviewed the results and verified the accuracy of the instrumentation system. Based on the successful performance and alignment with project requirements, the client approved the methodology and proceeded with the procurement and fabrication of the full instrumentation system.

4. Field Work.

During the planning phase, the decision was made to utilize Campbell Scientific CR6 data loggers, equipped with the necessary number of multiplexers to accommodate strain gauge readings. The CR6 model was selected primarily for its integrated Wi-Fi capability, which enables real-time data visualization, an essential feature for the loading team during operations. Each arch structure required instrumentation of approximately 18 to 22 strands, with the optimal placement for the data loggers initially identified as the base of the arches, housed within secure enclosures.

Figure 4. Strain Gauge assembly and logger setup.

Strain gauge cables were procured based on the measured distances to the midpoints of each strand, with additional length included to ensure connectivity to the central logger. However, due to significant incidents of theft and equipment damage during the early stages of construction, the client mandated the relocation of the logger enclosures to the top of the arches. To accommodate this change in routing and cable length, pigtails with M12 connectors were added to both the loggers and multiplexers. Each pigtail was uniquely numbered to correspond with its respective strand, streamlining the installation process.

Although relocating the data loggers to elevated positions introduced logistical challenges—particularly related to working at height—the use of modular connectors proved to be a significant advantage. These connectors simplified installation and maintenance, especially under constrained site conditions.

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To ensure all stakeholders were aligned with the revised installation procedures and loading protocols, the client organized a pre-installation workshop. This session brought together the site personnel, design team, and representatives from Geo Instruments to review the updated methods, including bracket installation, strain gauge handling, and the specific loading cycles planned for each arch. This collaborative approach helped streamline field operations and ensured consistency across the instrumentation process.

SPAN 12 NORTH																							
	FORCE IN CABLE AT INSTALLATION STAGE [kips]																		FORCE IN CABLE AT FOLLOWING CONSTRUCTION STAGES [kips]				
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	FALSEWORK REMOVAL	ADJACENT SPAN FALSEWORK REMOVAL	BEFORE HANGER FINAL STRESSING	AFTER HANGER FINAL STRESSING	EOC
H01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	219	205	205	217	180	124	142	143
H02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	275	276	282	276	221	183	188
H03	-	-	-	-	-	-	-	-	-	-	-	216	219	211	211	205	199	200	229	178	150	152	155
H04	-	-	-	-	-	-	-	-	-	-	-	-	-	218	218	199	150	151	169	165	148	131	136
H05	-	-	-	-	-	-	-	-	-	198	197	186	190	187	187	188	188	189	218	166	145	147	152
H06	-	-	-	146	165	152	154	165	168	176	177	171	176	119	119	105	85	86	124	126	128	129	135
H07	-	-	-	-	-	-	-	191	185	163	161	163	166	172	172	175	178	179	208	169	151	150	156
H08	-	131	156	101	110	81	73	80	82	85	87	70	77	55	55	49	43	45	110	120	136	135	141
H09	-	-	-	-	195	197	195	150	146	141	138	146	142	149	148	152	154	155	188	163	150	143	149
H10	-	-	-	-	-	89	67	67	65	52	53	36	45	42	43	41	42	44	123	135	152	142	149
H11	179	212	146	160	94	98	103	86	88	93	90	99	80	85	83	86	87	84	110	95	82	135	141
H12	-	-	-	-	-	-	97	77	70	47	48	40	50	54	55	55	57	61	145	158	175	149	156
H13	-	-	180	191	164	175	183	185	188	198	198	205	156	159	156	158	158	147	164	149	112	128	134
H14	-	-	-	-	-	-	-	-	55	43	41	41	46	50	50	51	53	55	148	164	193	149	156
H15	-	-	-	-	-	-	-	-	-	-	-	-	201	204	200	201	202	174	204	190	145	126	131
H16	-	-	-	-	-	-	-	-	-	-	43	45	44	47	45	46	46	44	136	154	213	130	135
H17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	166	216	203	172	174	179
H18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52	52	52	44	94	102	129	134	137
																	Sum	2304	3087	2896	2727	2578	2671

SPAN 12 SOUTH																							
	FORCE IN CABLE AT INSTALLATION STAGE [kips]																		FORCE IN CABLE AT FOLLOWING CONSTRUCTION STAGES [kips]				
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	FALSEWORK REMOVAL	ADJACENT SPAN FALSEWORK REMOVAL	BEFORE HANGER FINAL STRESSING	AFTER HANGER FINAL STRESSING	EOC
H01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	225	212	212	220	185	130	145	146
H02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	229	229	234	231	185	168	173
H03	-	-	-	-	-	-	-	-	-	-	-	275	278	269	270	262	256	256	274	226	194	165	169
H04	-	-	-	-	-	-	-	-	-	-	-	-	-	172	172	151	108	109	127	127	123	122	127
H05	-	-	-	-	-	-	-	-	-	275	275	255	258	253	253	253	252	252	264	215	182	164	169
H06	-	-	-	99	123	107	109	125	127	136	138	124	128	79	80	66	49	50	88	93	105	128	134
H07	-	-	-	-	-	-	-	259	253	222	220	220	223	225	225	229	230	231	242	206	177	159	165
H08	-	120	144	107	118	83	74	84	86	89	91	70	77	60	60	54	50	52	115	127	146	134	140
H09	-	-	-	-	243	245	243	183	180	172	169	179	175	180	180	183	185	185	204	183	169	151	157
H10	-	-	-	-	-	107	81	81	80	61	63	42	51	49	51	49	50	53	133	145	158	145	152
H11	175	205	141	150	69	74	80	59	60	67	65	75	55	59	57	59	60	56	77	66	63	135	141
H12	-	-	-	-	-	-	119	94	87	56	56	48	58	62	63	64	65	69	158	170	182	156	164
H13	-	-	175	183	149	162	172	175	178	191	191	199	148	150	145	147	147	134	147	135	106	125	130
H14	-	-	-	-	-	-	-	-	54	39	37	38	42	46	46	47	48	51	152	168	194	160	167
H15	-	-	-	-	-	-	-	-	-	-	-	-	205	206	200	201	202	168	193	180	132	119	124
H16	-	-	-	-	-	-	-	-	-	-	38	40	39	41	39	39	40	37	139	159	219	145	150
H17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	194	238	223	179	172	176
H18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73	73	73	62	119	127	154	143	146
																	Sum	2401	3126	2965	2798	2636	2729

Figure 5. Typical Load sequence of strands per arch.

The pre-installation workshops proved instrumental in resolving potential installation issues and allowed the team to simulate and troubleshoot scenarios that could arise during field operations. As is common with large-scale infrastructure projects, the introduction of a novel instrumentation method attracted attention from a wide range of stakeholders. In anticipation of this, the first week of loading operations was dedicated to comprehensive onsite training. This included verification of installation procedures, validation of data flow, and execution of trial runs to ensure system readiness.

Figure 6. View of typical strand hanging operation

During installation, each strand was secured to the top of the arch using custom holders, aligned with corresponding lower brackets, pinned, and subsequently tensioned. The strain gauge was connected to the strand and set to 1000 Hz manually using a GK404 VW readout to accommodate the expected loading tension. The strain gauges were factory calibrated in bulk to avoid any errors in this process. Given the length of the strands (up to 40 feet) significant initial curvature was observed prior to loading which forced a revision of the strain gauge loading sequence to avoid strain gauge bending. A bedding-in phase was necessary to allow the strand to settle and align properly before the verification load was applied. A proving load of 10 tons was established as a baseline across the project to confirm system integrity. Operational loads for individual strands varied between 48 and 100 tons, depending on their location and structural role within the arch system. The contractor's jacking system consisted of a custom hydraulic setup featuring a yoke-style configuration designed to sit directly over each strand. This system included integrated load readouts and was operated via a tablet interface that displayed calculated load values derived from strain measurements at 30-second intervals.

Figure 7. Contractors strand loading system

Typical strain gauge readings, acquired through up to eight Campbell Scientific CR6 Wi-Fi data loggers with two number 32 channel multiplexers each, installed on the arches were recorded at one-second intervals per gauge and converted to load. During each loading sequence, the supervising engineer plotted the strain gauge load data against the hydraulic jacking system's load readings. These plots were reviewed and verified in real time by the City Engineer. Each strand's loading cycle was individually signed checked and signed off to ensure compliance with the performance criteria.

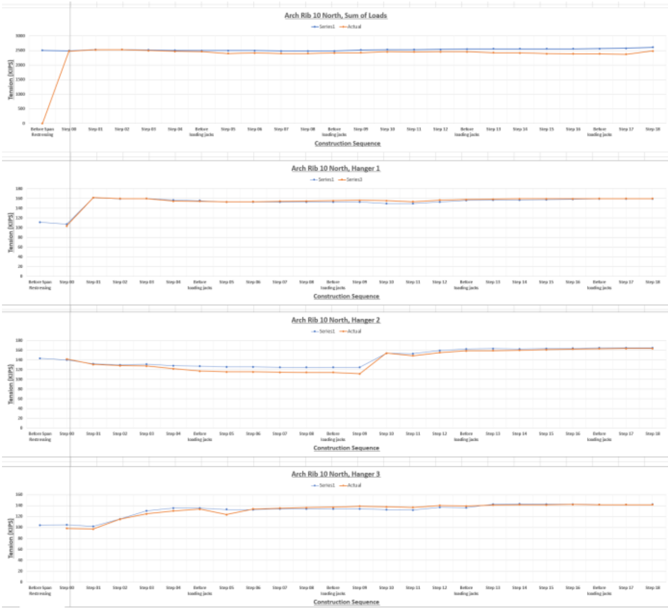

Figure 8. Hangar required load with applied load site plots

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The data from the strain gauges was sent via modem and Wi-Fi to the Geo Instruments servers and in-house visualization software – Quickview.

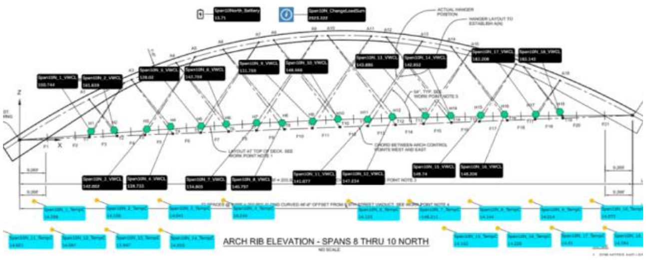

Figure 9.QuickView visualization platform

This software portal allowed the designers and contractors not on the bridge to view the loading sequence, one minute behind the actual site work. The data points on the site view showed digits, load and temperature for each strain gauge as well as the accumulative total load of the arch. Data was viewed and downloaded by consultant Ramboll for design verification and quality control reporting.

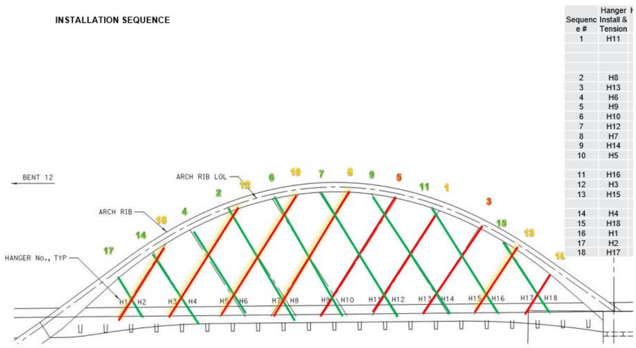

Figure 10. Sequence of strand installation.

Temperature Effects and Adaptive Stressing Strategy

Temperature played a significant role in data interpretation and reduction throughout the project. Fortunately, the early phases of construction coincided with an unusually overcast period in Los Angeles, resulting in minimal temperature variation during the typical eight-hour workday. To further mitigate thermal effects, each strain gauge was wrapped in a heat-shielding material. While clamp-on heat shields were initially considered, they proved impractical for field use due to their bulk and handling complexity. Although the City of Los Angeles initially considered retaining the strain gauges for long-term monitoring post-commissioning, this plan was ultimately removed from the project scope during execution.

In the final three months of arch construction, weather conditions shifted unexpectedly, with unseasonably high temperatures becoming a concern. The combination of intense solar radiation, the elevated position of the arches, the increased number of arches complete and the thermal mass of the concrete structure caused the bridge to act as a heat sink. This thermal buildup peaked during the same hours scheduled for hanger stressing, raising concerns about data reliability and structural behavior under elevated temperatures.

Rather than attributing delays or complications to any single party, the site team collaborated closely with the designers to analyze the data and identify the root cause of the discrepancies. With eight arches remaining to be instrumented, the team reviewed the sun trajectory and its impact on different arch segments. It became evident that larger arches and their associated strands were heating more rapidly and retaining heat longer than smaller ones, skewing strain readings throughout the day.

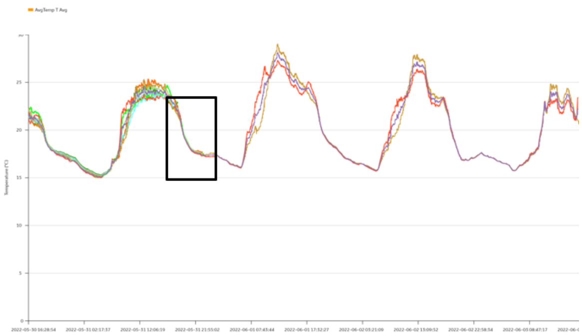

Figure 11. Temperature of strands on arch

To address this, the stressing schedule was revised. Work shifts were rescheduled to occur between midnight and 5:00 a.m., when ambient temperatures were more stable and thermal effects on the instrumentation were minimized. This proactive adjustment allowed the team to complete the stressing operations on schedule and within specification.

5. Conclusion.

All projects provide great feedback what went well and what could be improved on, it’s how instrumentation and structural health monitoring evolves. In hindsight, the initial testing of the strain gauges should have been run under temperature variations, but as discussed, the testing locations were not suitably equipped up for long testing load cycles. The very fast load cycles in the testing locations and the ability to capture data in format that was compatible with instrumentation loggers turned out to be an issue. Such is the rarity of these large-scale tests; it would require some investment from all parties to get suitable outputs.

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Figure 12. View of one completed arch.

The success of the Sixth Street Viaduct instrumentation program was driven by collaborative efforts, continuous feedback, and iterative improvement cycles among all stakeholders on site. The designer's clear articulation of data requirements, particularly the need for rapid and reliable access, guided the development of a robust instrumentation system, including the selection of strain gauges, bracket assemblies, and data loggers.

The site team played a critical role in refining installation procedures. Their feedback on bracket mounting techniques, bolt torque specifications, pre-connection verification methods, and data visualization strategies on the bridge deck significantly enhanced the practicality and reliability of the system.

Credit is due to the Los Angeles Bureau of Engineering for its foresight in supporting this novel testing approach. During early project meetings, concerns were raised regarding the lack of precedent for using this technique on large-scale strand bridges. Nevertheless, the Bureau's commitment to innovation enabled the development of a comprehensive and technically sound solution that instilled confidence across the project team.

The Sixth Street Viaduct replacement officially opened in June 2023, on schedule. It has since become an iconic structure within Los Angeles, earning multiple international awards for its design and construction excellence.

Acknowledgments.

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