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Monitoring of Bridge Structures Equipment

By

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The University of Missouri-Rolla

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RESEARCH EQUIPMENT PROJECTS UTC-RE 128

MONITORING OF BRIDGE STRUCTURES EQUIPMENT

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CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

UNIVERSITY OF MISSOURI – ROLLA

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MONITORING OF BRIDGE STRUCTURES EQUIPMENT

EXECUTIVE SUMMARY

The objectives of the proposed project are: a) the development and construction of a field data acquisition system capable of acquiring all the possible measurands involved in a load test; and, b) acquisition of the tools needed for the installation of the sensors. The proposed project uses the results and experience gained in the prior studies conducted at the University of Missouri – Rolla.

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1. INTRODUCTION

1.1 Background

Field testing is an increasingly important endeavor in the effort to deal with the deteriorating infrastructure, in particular bridges and pavements. There is a need for accurate and inexpensive methods for diagnostics, verification of load distribution and determination of the actual load carrying capacity of existing structures.

Recent studies indicate that 40 percent of the national bridges are deficient. The major factors that have contributed to the present situation are: age, inadequate maintenance, increasing load spectra and environmental contamination. The deficient bridges are posted, repaired or replaced. The disposition of bridges involves clear economical and safety implications. To avoid high costs of replacement or repair, the evaluation must accurately reveal the present load carrying capacity of the structure and predict loads and any further changes in the capacity (deterioration) in the applicable time span.

Load testing can also identify hidden strengths in the structure arising from a variety of sources that may avoid the need to conduct costly and disruptive strengthening works.

Instrumentation used to evaluate the structure is likely to involve a combination of strain, deflection and temperature measuring sensors positioned to suit appraisal of the structure's performance with respect to critical stress and deflection criteria.

1.2 Project Objective

The objectives of the project were:

1. The development and construction of a field data acquisition system capable of acquiring all possible measurands involved in a load test; and,
2. Acquisition of the tools needed for the installation of the sensors.

The proposed project uses the results and experience gained in the prior studies conducted at the University of Missouri – Rolla.

FIELD EQUIPMENT

2.1 Data Acquisition System: Orange Box

The "Orange Box" is a portable data acquisition unit, suitable for use in field testing of structures. It is capable of recording 32 high-level channels of data, 16 strain channels, and 32 thermocouple channels, as well as interfacing a Leica Total Station surveying instrument (See Figure 1).

a) Orange Box b) Leica Total Station Surveying Instrument

Figure 1 – Data Acquisition Systems

The high-level channels may consist of DC LVDT's, string transducers, linear potentiometers, or any other +/- 10 Volt DC signal. The strain channels can be used to monitor and record strain gage signals, load cells, strain-based displacement transducers, or any strain based signal. The 32 thermocouple channels are configured for type T thermocouples.

The unit consists of a shock-mounted transport box, with removable front and rear covers. Removal of the front cover exposes the computer keyboard and LED display, as well as the front panel of the data acquisition equipment. Removal of the back panel exposes the connector bay, where cables from all the transducers terminate.

The data acquisition system is comprised of National Instruments equipment, listed below:

1. A PXI-1010 SCXI combination unit, which houses the industrial-grade 2.2 GHz Pentium 4 computer, floppy drive, and CDR/W module;
2. A PXI-6030E Analog to Digital converter module for doing the A/D conversion in the system;
3. A pair of SCXI-1520 modules to interface strain based sensors;
4. A SCXI-1102B module for multiplexing high-level sensors;
5. A SCXI-1102B module for multiplexing thermocouple sensors;

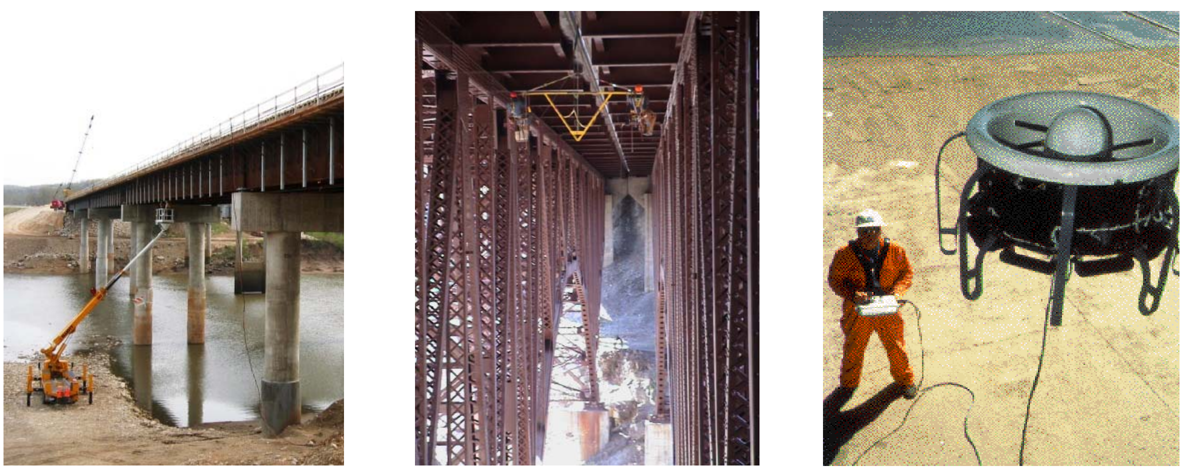
6. I/O devices in order to connect additional peripherals and other data acquisition systems such as a Leica Total Station surveying instrument.

The entire Orange Box data acquisition is controlled by a custom made LabVIEW program, which allows control of data rate, sensor selection and calibration, and display of the data. The integration of data from sensors and the Total Station yields a data acquisition system which provides better answers in the field.

2.2 Modular frame cart for inspection of slab-on-girder bridge superstructure

Accurate routine inspection and monitoring of bridge structures are essential to rate their condition and prioritize maintenance, rehabilitation and emergency repairs. In order to overcome the limitations of traditional inspection methods, such as visual inspection [1], extensive research is being funded to develop cost-effective nondestructive in situ health monitoring techniques [2] for either global or local structural assessment. These methods typically require sensors be placed in contact with the structure, and accessing the desired locations may become of concern due to the complexity, variability and location of bridge superstructures. Nevertheless, accessibility represents a key factor in enabling efficient inspection and/or sensor installation operations, and may indirectly affect the final performance of the monitoring system.

A wide variety of vehicle-mounted working platforms are commonly used for the purpose, as that depicted in Figure 2a. However, alternative and creative solutions may be required to best suit particular needs: for instance, Figure 2b shows the inspection of in-board structural members of two paired steel arch bridges using a custom-made mobile truss cart that was moving on the roadway [3], while a robotic aerial inspection platform prototype, currently under development, is illustrated in Figure 2c [4].



a) Vehicle-mounted platform *b) Mobile truss cart [3]* *c) Aerial platform [4]*

Figure 2 - Examples of accessibility solutions for bridge superstructure inspection

A modular frame cart for inspection of slab-on-girder bridge superstructures is presented herein.

The vehicle was developed to overcome a number of issues posed by field installation of sensors and their circuits along I-girders, to be used for structural health monitoring [5].

The cart was first used on Bridge A6358 [5] (See Figure 2a), sited on the U.S. Rt. 54/Osage River, Miller County, MO. It is a symmetric five-span continuous high performance steel (HPS) bridge with a reinforced concrete deck. The external spans are 45 m and 56 m long, respectively, while the central one has a length of 61 m, resulting in a total bridge length of 263 m. Each internal support consists of reinforced concrete bents on two circular piers having a 2 m diameter. The superstructure consists of five composite, equally spaced, HPS I-girders acting compositely with the 216 mm thick concrete deck.

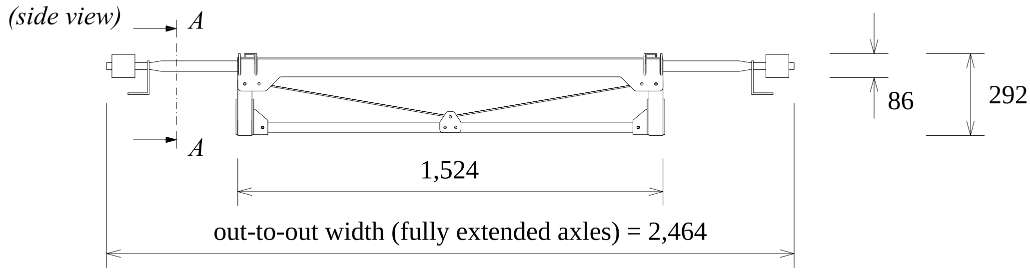
A circuit made of bare fibers and sensing fibers embedded in a custom-made GFRP tape had to be installed on the web of four girders at different depths, along two continuous spans. This required the personnel to access the desired locations along the steel girders and complete the operations with a two-week timeline. The fact that the bridge spans over the Osage River for 174 m, together with the high variability of the water level, precluded the use of a vehicle-mounted platform. This solution was adopted to mount a total of 22 reflecting prisms for automated total station deflection measurements on the first and part of the second span, in less than one working day (figure 1a). Since the concrete deck had not been cast yet, a similar approach using a platform connected with a crane to a vehicle that moved along the roadway was not practical.

The solution proposed consists of a cart able to move along the whole bridge, rolling over the bottom flanges of two parallel girders. The vehicle was developed with the following goals:

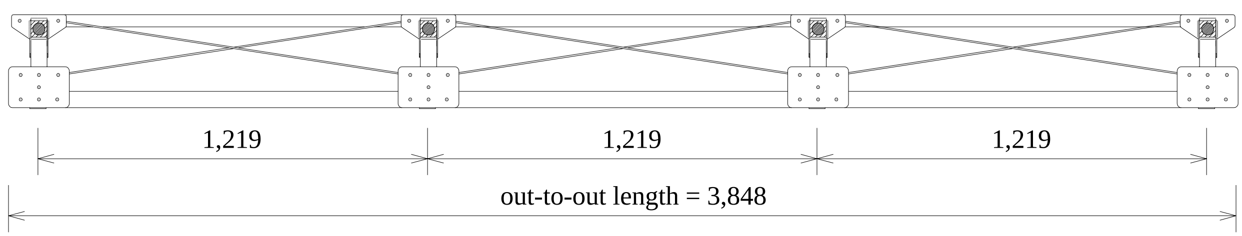
1. The cart needed to safely carry a crew of at least two members and all the material and equipment needed to complete the installation operations, providing a sufficiently large working surface;
2. To move along the full bridge length, proper solutions had to be devised to rapidly by-pass a large number of transverse stiffeners, either stand alone or in combination with cross frames, as shown in the framing plan in figure 2, and the bolted joints, while additional geometrical restrictions were enforced at the bent locations;
3. The vehicle had to be easily conducted due to the presence of personnel that needed to focus on the sensor installation work;
4. The cart had to be as lightweight as possible, for ease in transportation and to allow switching from a girder pair to another without the need of additional operators other than the crew;
5. providing full demountability had practical importance to ensure effective inspection of the device and economical replacement of its components;
6. A modular design of the cart, with the possibility to add/subtract units as needed, was a plus to improve the flexibility in its utilization.

2.2.1 Design and construction

The frame configuration illustrated in Figure 3 and Figure 4 was selected to meet the aforementioned requirements. The cart was designed and constructed in a collaborative effort between the University of Missouri-Rolla and the Rolla Technical Institute. Due consideration was given to ease and rapidity in construction, using commercially and readily available components and limiting the machining operations. The allowable stress design was used, with a factor of safety of 3 with respect to the yield strength, and 4 with respect to the ultimate strength, depending on the properties guaranteed by the supplier. A minimum span/deflection ratio of 250 and 100 was imposed for the frame structural members under flexure and for the flooring system, respectively, being the latter suggested by the manufacturer [6].



a) Front view



b) Side view (A-A)

Figure 3 - Dimensions of cart framework (not to scale, in mm)

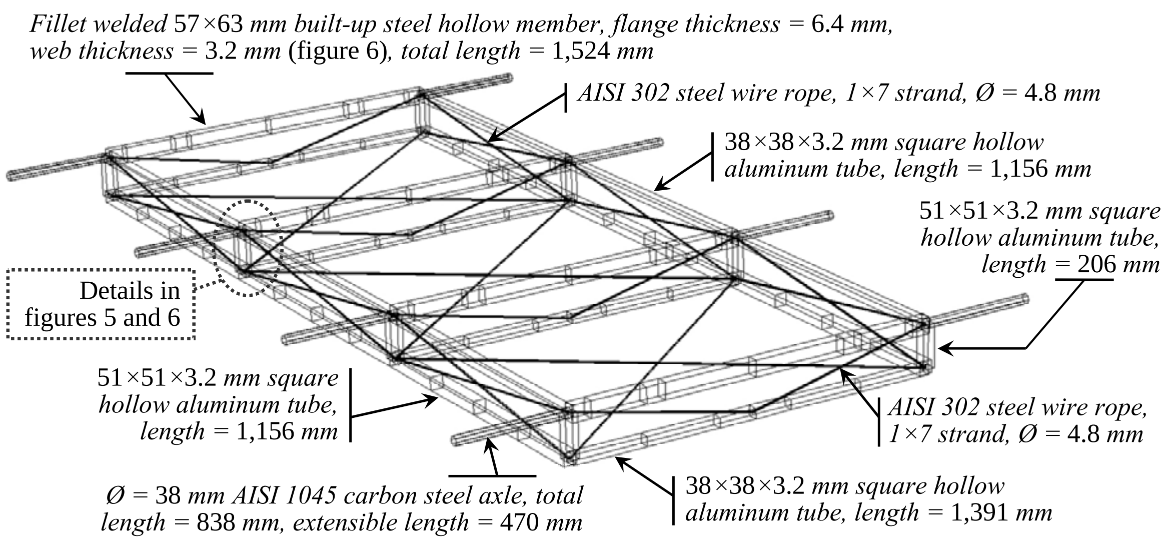


Figure 4 - Outline wireframe of modular cart structure (aluminum: IADS 6061-T6 alloy; steel: AISI 1018 low-carbon alloy, unless specified).

2.2.2 Geometry

The cart frame is composed by three box-shaped 1,463 m wide and 1,219 m long (center-to-center) demountable modules, for a total working surface of 5.3 m^2. The overall dimensions are provided in Figure 3. The maximum height of the frame is 292 mm, of which only 86 mm laid above the bottom of the wheels. The out-to-out width with fully extended axles is 2,464 mm, and the possibility of adjusting the extension length by means of electrical actuators, as described later on, allows for utilization on other bridges.

The selected geometry was conceived to maximize the available space, since two to three crew-members were to stay on board for several hours, while meeting strict dimensional limitations. These were controlled by the position of the lower transverse member of the cross frames, that allowed a net clearance of 102 mm above the girders bottom flange bearing the vehicle, and the clear space between the flanges, ranging between 2,083 mm and 2,235 mm. Additional geometrical restrictions were dictated by the width of the bevel sole steel plates over the elastomeric pads and by the concrete surface at the bent locations, which allowed a total horizontal and vertical net clearance of 1,727 mm and 302 mm, respectively.

2.2.3 Materials

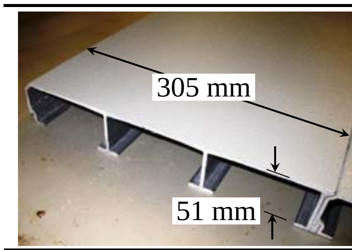
A summary of the structural members making up the body of the vehicle is shown in Figure 4. Extensive use of A6061-T6 aluminum profiles was made to build the framework, in order to minimize the overall weight while providing sufficient strength, stiffness and fatigue resistance. Typical material properties are reported in Table 1. Due to weldability characteristics and to contain the maximum deflection, AISI 1018 low-carbon steel (nominal tensile and yield strength σ_u=634 MPa and σ_y=386 MPa, respectively) was utilized for the four transversal members containing the axles, built-up from 3.2 mm and 6.4 mm thick plates that were cut to measure and welded together. The axles were realized by machining commercially available Ø 38 mm AISI 1045 carbon steel rods (nominal yield strength σ_y=531 MPa). AISI 302 stainless steel wire rope with guaranteed breaking strength of 20.9 kN was used for all the diagonal ties.

Table 1 - Typical properties of IADS 6061-T6 aluminum alloy

Density	2,700 kg/m^3
Tensile strength, ultimate	310 MPa
Tensile strength, yield	275 MPa
Elongation at break	12-17% in 5 cm
Modulus of elasticity	69 GPa
Poisson’s ratio	0.33
Fatigue strength @ $N = 5{\cdot}10^8$	95 MPa
Fracture toughness	29 MPa $m^{1/2}$

Structural FRP pultruded panels made of glass fibers and mat, and polyester resin matrix, with a weight of 12.7 kg/m^2, were utilized as the flooring system. Single 1,524×305×51 mm planks with gritted surface were cut to measure and interlocked to form the working platforms. The load - deflection properties for the span used are reported in Table 2 [6], along with a picture of the plank assembly. The total weight of the cart was limited to 192 kg, 57% of which given by the transversal steel members and axles and 28% by the GFRP platform.

Table 2 - GFRP Safplank® load - deflection data (span s = 1,524 mm) [6]



Uniform load (N/m^2)	2,394	4,788	9,576	14,364
Deflection (mm)	3.6	7.1	14.3	> s/100
Concentrated load (N/m)	730	1,460	2,920	4,380
Deflection (mm)	1.1	2.3	4.6	6.9

2.2.4 Detailing

All structural members were pin-connected with each other using Ø 9.5 mm high strength steel fasteners, thus allowing for full demountability of the framework, providing a 3 mm spacing between each other to obtain actual hinges. Wood blocks were inserted as cores in the aluminum profiles at the fastener locations. In order to prevent loosening and backing-off in the connections during the field operations, self-locking fasteners were utilized. Figure 5 shows the detail of the mechanical joint assembly between the lateral members supporting the GFRP platform, the bottom transverse profiles, and the vertical ties connecting the working plane to the top transverse support steel members.

These welded built-up components, detailed in Figure 6, contain two independent, 832 mm long Ø 38 mm steel axles. Each of them passes through two 51×51×76 mm steel blocks, spaced at 210 mm, which hold the axles in place and aligned. In order to accommodate an anti-overturn 6.4 mm thick steel plate equipped with a PTFE guide damper, and a 82.5×82.5 mm polyurethane lift truck wheel with steel core and precision ball bearing, the diameter of the axles was reduced from 38 mm to 25 mm at the outer end, for a length of 159 mm, with a 38 mm taper. Each wheel was secured by means of a Ø 4.8 mm ring-grip steel pin.

A total of eight aluminum electric actuators were connected to Ø 9.5 mm threaded rods welded onto the anti-overturn steel plates. By drilling with a 6.4 mm hex key shaft at the free end of the actuators, the axles were allowed to slide back and forth, extending for a maximum of 470 mm on each side of the vehicle. This system enables the cart to move with four to six wheels out of eight, by retracting the wheels from the supporting flanges to by-pass the vertical stiffeners, cross frames and diaphragms at the bent locations, as shown in Figure 6c. Properly connected ties composed of a steel wire rope, thimbles and clips, and a forged eye-and-eye turnbuckle withstand the tension reactions needed at the unsupported nodes of the frame structure. The system also provides the ability to adjust the position of the wheels when by-passing the bolted joint plates, since less than 30 mm of net space was available between the bolt nut and the edge of the flange.

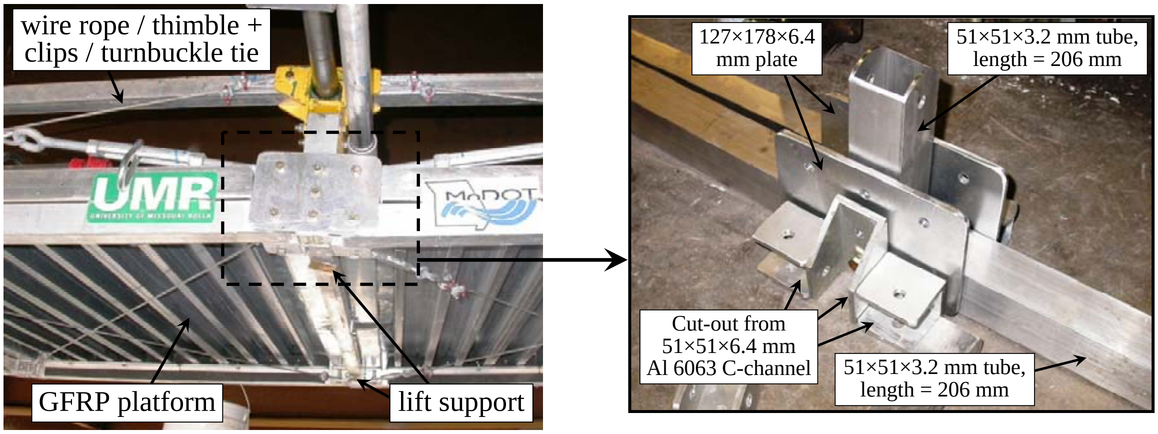
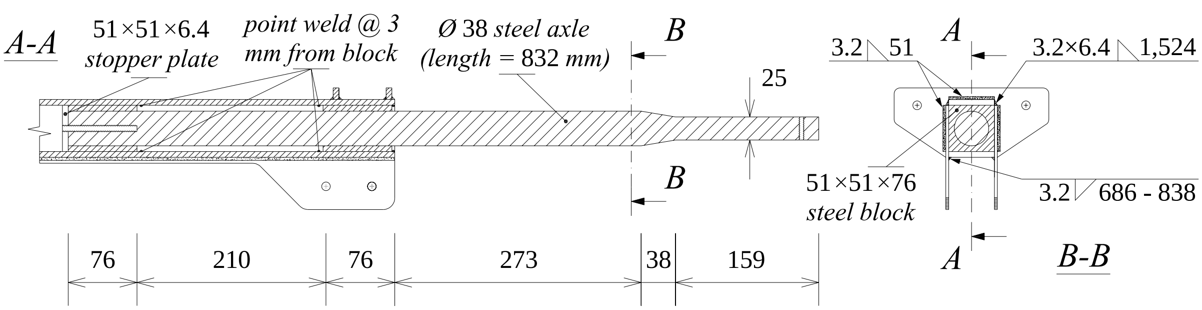
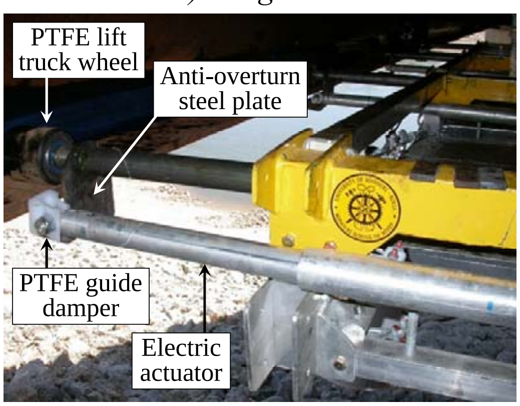


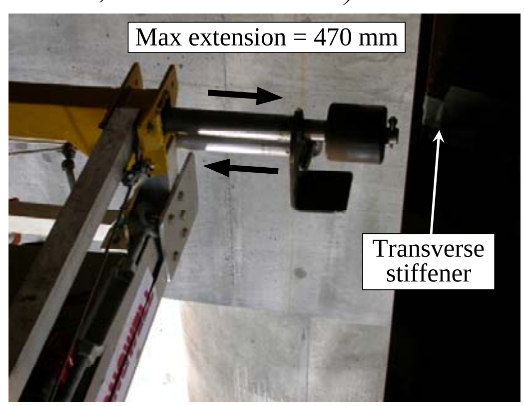
Figure 5 - Detail of bottom bolted connection assembly (material Al 6061-T6, unless specified).



a) Longitudinal sectional view (not to scale, dimensions in mm)



b) Close-up



c) Obstacle by-passing

Figure 6 - Fillet welded built-up steel support member and axles assembly

In order to facilitate uplifting of the retracted axles to re-position the wheels over the flanges at the bents, two lift supports were mounted in the bottom transverse profiles. They consist of Ø 13 mm steel hex bolts with threaded length of 102 mm, which pass through a filleted 31×31×51 mm aluminum block inserted into the hollow tube, and with a 38×38×3.2 mm square plate welded at the outer end (Figure 5): using a ratchet wrench, it was possible to rapidly lift the cart bearing on the concrete surface. When outside the bent locations, this was done using a system of chains secured either at the cross braces or at the stiffener/top flange web gaps, together with a falling chain hooked to the transverse built-up member. Further development of the concept cart should provide the ability to by-pass obstacles independently of anchorage areas. A viable option may be devising a portable frame to be connected to the supported transverse members, and equipped with a web-strap puller/hoist hooked to the unsupported member with retracted axles to be lifted.

Double-L built-up aluminum profiles, placed between the GFRP planks and the longitudinal support tubes, were used to prevent horizontal movement of the working platform, interposing adhesive backed rubber layers to reduce vibrations and improve the comfort.

2.3 Fiber Optics Equipment

Advances in the production of optical fibers made possible the recent development of innovative sensing systems for the health monitoring of civil structures. The main reasons for this development are the reduced weight and dimensions of fiber optic sensors, the strong immunity to electromagnetic interference, the improved environmental resistance and the scale flexibility for small-gauge and long-gauge measurements. These systems can provide high-resolution and measurement capabilities that are not feasible with conventional technologies. In addition, they can be manufactured at a low cost and they offer a number of key advantages, including the ability to multiplex an appreciable number of sensors along a single fiber and interrogate such systems over large distances. For these reasons, it is evident that fiber optic sensors will change the instrumentation industry in the same way fiber optics has revolutionized communications.

The equipment for the installation of the fiber optics on Bridge structures will comprise:

1. Fujikura FSH 20CSII Splicer;
2. Alcoa Fujikura Cleaver;
3. Other Accessories (Fiber Optic Thermal Stripper, Fiber Optics Blades, Spicer Electrodes)

2.4 Other Tools for Bridge Testing

In order to execute the sensors installation and the load testing more efficient a series of tools are necessary. The list in the following is based on tools that have been checked out for field projects in the last year:

1. Secured storage containers to be permanently mounted to the truck;
2. Safety equipment. This includes equipment common to road work, as well as that necessary for all work done inside and outside of the lab;
3. Ladders and walk boards;
4. Tools include those appropriate for measurement and marking of bridge decks, power generation, wood, concrete and steel manipulation;
5. Installation of a permanently mounted inverter with a back-up battery supply as well as a committed and secured 5K generator already owned by UMR.

2. CONCLUSIONS

The proposed equipment enhanced the research capabilities at UMR. In particular makes possible:

a) To acquire various measurands of interest in a load test (i.e. strains, displacements, forces and temperatures), and

b) To install the corresponding sensors.

Faculty and students in the UMR departments of Civil Engineering, Mechanical and Aerospace Engineering, Electrical and Computer Engineering, and Metallurgical Engineering will use the equipment for field testing. The equipment is located at the Engineering Research Laboratory at UMR and it will be used in transportation as well as other research projects conducted by UMR personnel.

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