Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 999 (1997)

Artikel: Advanced composites for bridge infrastructure rehabilitation and renewal

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DOI: https://doi.org/10.5169/seals-1058

Advanced Composites for Bridge Infrastructure Rehabilitation and Renewal

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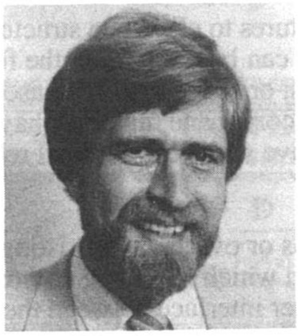

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Summary

Recent developments in new bridge systems using advanced composite (polymer matrix composite) materials and manufacturing technologies have shown that while these new bridge systems are technically feasible, they are not yet economically competitive. However, the combination of these new advanced composite materials with conventional structural materials such as concrete and steel can result in new composite design and construction concepts which are both structurally and economically efficient.

1. Introduction

Deterioration of our aging bridge inventory, wear from service and environmental loads, as well as ever increasing allowable or legal loads require accelerated rehabilitation and renewal programs to maintain even current service levels on our bridge infrastructure network. Demands for longer service life, increased durability and reduced maintenance have prompted a new look at advanced composite materials such as glass, aramid and carbon fibers embedded in a polymer matrix to provide due to their chemical inertness, high mechanical characteristics, and light weight, some of the above performance requirements.

To date advanced composite materials have been used very effectively in the repair and strengthening of existing concrete bridges and in the seismic retrofit of bridge columns, bridge superstructures and shear walls. The main advantages are derived from the light weight of these new materials in the form of easy handling during installation at insignificant increases in weight and structural dimensions. The strengthening applications to date consist either of epoxy bonding of cured pultruded laminates [1] or of wet lay-up fabrics onto the concrete substrate [2], creating a new composite structure.

Attempts to manufacture complete advanced composite replacement members or complete bridge systems [2, 6] have shown that all-advanced composite structural systems are certainly feasible with current materials and manufacturing technologies, but while technically sound and structurally reliable these new members or systems have, economically, a difficult time to compete with conventional construction costs on a first cost basis as long as no provisions are made for increased durability and reduced maintenance and with it for overall reduced life cycle costs. In comparison with conventional structural materials, advanced composites have high material to labor cost ratios which, even with significant efforts in manufacturing automation, can only be reduced final costs nominally.

Recent developments have focused on new hybrid systems which combine the advanced composite materials with conventional construction materials such as the concrete filled carbon shell system (CSS) and conceptual design and optimization studies have shown that even on a first cost basis these new bridge systems can be cost competitive with conventional bridge construction. The developments and application of advanced composites in new composite construction applications in bridge infrastructure retrofit and renewal are discussed in the following.

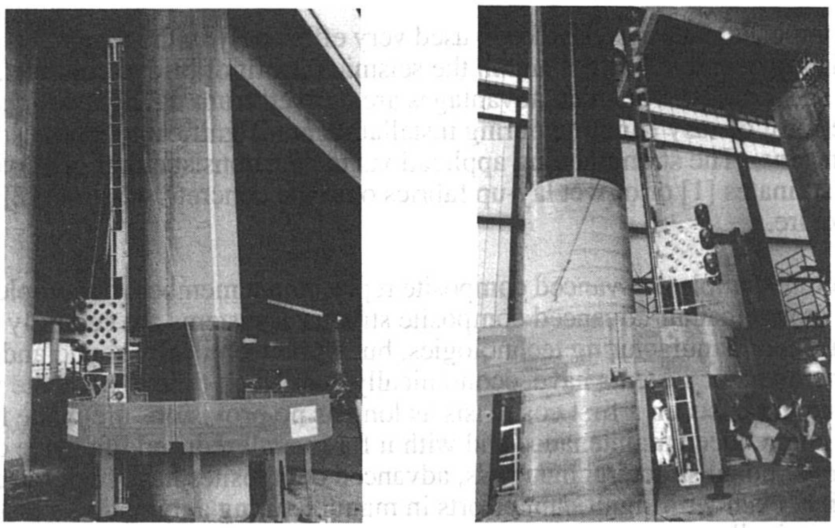
2. Advanced Composites for Bridge Rehabilitation

The rehabilitation of existing bridge structures to eliminate structural deficiencies and to provide extended and increased service capacities can be required in the form of repair of damaged regions, strengthening of substandard components, or retrofit for increased seismic response capacities. In all three areas of rehabilitation, advanced composite materials have been shown to be structurally efficient, easy to install and cost competitive with conventional rehabilitation concepts and procedures, [1, 2].

The addition of advanced composite strips or overlays to existing bridge decks, girders, or columns results in a new composite action which to a large extent depends, in terms of performance characteristics, on the polymer interface between the two materials, on the mechanical characteristics of the substrate, i.e. the surface of the existing material, and on the environmental and time-dependent compatibility of the two materials in terms of chemical interaction, differences in thermal coefficients, and differences in time-dependent effects. The currently practiced "art" of rehabilitation with these new materials needs to be developed into a "science" with established design criteria and guidelines, validated application and quality assurance procedures, and a properly designed and implemented instrumentation and monitoring program to provide the to date uncertain long-term performance and durability characteristics.

At the University of California, San Diego (UCSD) comprehensive research efforts since 1993 [2, 3] into the use of advanced composite rehabilitation concepts for existing structural concrete systems have resulted in (1) strengthening concepts for bridge decks and superstructures with carbon fabric overlays for increased load capacities, (2) strengthening and retrofitting of pier walls with carbon overlays for increased lateral in-plane and out of plane force and deformation capacities, and (3) seismic retrofit concepts for columns through advanced composite jacketing for increased structural ductility.

For example both full scale laboratory validation tests and field applications for Caltrans (California Department of Transportation) on the I-10 Santa Monica Viaduct in Los Angeles, California, have been successfully completed, see Fig. 1, demonstrating not only the technical soundness of the new composite structure under extreme loading conditions but also the economical competitiveness with conventional (steel or concrete jacketing) retrofit procedures.



a) Field Application *b) Full Scale Laboratory Testing*

Fig. 1 Seismic Retrofit Application and Validation of a Continuous Carbon Fiber Jacketing System for Two Column Bent on the Santa Monica Viaduct

For the advanced composite retrofit of structural concrete columns, comprehensive design guidelines for (1) shear strengthening, (2) flexural plastic hinge confinement and column bar buckling restraints, and (3) reinforcement lap splice debonding have been developed [3], as summarized in Table 1, which shows the controlling proportionality relationships based on column dimension D in the loading direction and the mechanical characteristics of the advanced composite jacket system in the form of f_{ju} ultimate jacket capacity, ε_{ju} ultimate jacket strain and E_j jacket modulus in the hoop direction.

Table 1 Summary of Advanced Composite Jacket Thickness Relationships for Seismic Retrofit

Response Limit State	Shear Strength Enhancement	Plastic Hinge Confinement	Lap Splice Clamping
Composite Jacket Thickness t_j	$t_j \sim \frac{1}{D \cdot E_j} \cdot C_v$	$t_j \sim \frac{D}{f_{uj}\varepsilon_{uj}} \cdot C_c$	$t_j \sim \frac{D}{E_j} \cdot C_\ell$

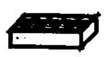
In Table 1, C_v, C_c and C_ℓ are design values based on relationships developed in [3, 4] for the specific column geometry and seismic demand.

3. Bridge Deck Replacement

Compelling arguments can be made for modular bridge deck replacement systems which are (1) quick and easy to install to minimize traffic interruptions, (2) lighter than conventional concrete decks to provide increased traffic load capacities and/or reduced seismic mass, and provide (3) increased durability, reduced maintenance and longer life cycles.

In a joint research program between DARPA (Defense Advanced Projects Research Agency) and FHWA (Federal Highway administration) modular advanced composites replacement bridge decks with different cores and geometries were developed and tested at UCSD, see test matrix in Table 2.

Table 2 Advanced Composite Replacement Bridge Deck Test Matrix

Configuration								
Manufacturer	Dupont	Dupont	Dupont	Dupont	Lockheed-Martin	Lockheed-Martin	Core-Kraft	Northrop-Grumman
Core / L x W	Balsa	Foam Filled Boxes	Foam Filled Truss	Foam Filled Hat	Pultruded Profiles with Face Sheets	Trapezoidal Profiles with Face Sheets	Corrugated Core with Face Sheets	Egg Crate Core
Sub-Component Shear 1m x 0.6m	●	●	●		●			
Sub-Component Flexure 2.4m x 0.6m			●		●		●	
Full Size Double Bending 4.3m x 0.6m		●	●	●	●			●
Prototype Panel 4.6m x 2.3m			●	●		●		

Note: Panel Depth D = 230 mm for all Test Specimens

The large and full scale tests to date have shown that advanced composite replacement bridge decks can be manufactured at prototype scale and (1) exhibit a design stiffness between the cracked and uncracked stiffness of a reinforced concrete deck panel, (2) have strengths which exceed those of an equivalent reinforced concrete panel by factors of 4 and more, (3) weigh 1/5 or less of the weight of a concrete panel with the same depth, and (4) costs approximately 3 to 4 times the initial cost of a cast-in-place concrete deck. However, no design optimization has been performed on these panels since the primary objective to date was the manufacturability of full scale bridge deck sections based on different structural cores and manufacturing procedures. Wear and durability tests of advanced composite replacement deck panels are currently in progress in a roadway test section exposed to regular traffic at UCSD.

4. New Bridge Systems

Research and developments to date on the use of advanced composites in civil engineering construction have shown that cost competitiveness with conventional structural materials and construction concepts is difficult to achieve with all-advanced composite structural systems due to the high materials cost contribution. However, developments of new structural concept and systems which combine the superior mechanical and chemical characteristics of strength in tension in the direction of the composite fibers with dominant characteristics of conventional materials such as compression in concrete to form a new type of composite structural system with great technical and economic potential.

One such concept is that of a carbon or carbon/glass hybrid shell system for bridge columns, wherein the use of prefabricated (filament wound) advanced composite tubes serve the dual purpose of formwork for the concrete and reinforcement, see Fig. 2. The composite tubes feature a ribbed inner surface for mechanical interlock with the infill concrete.

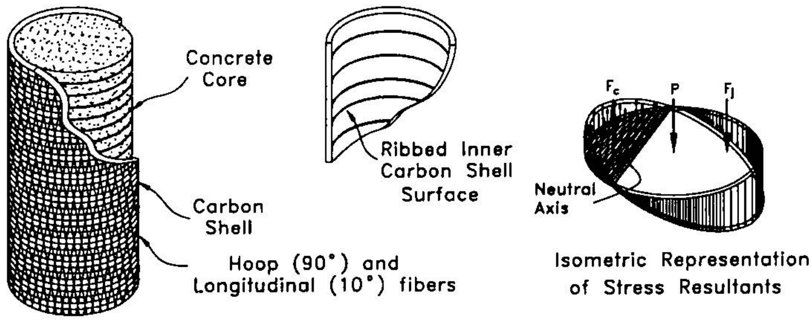
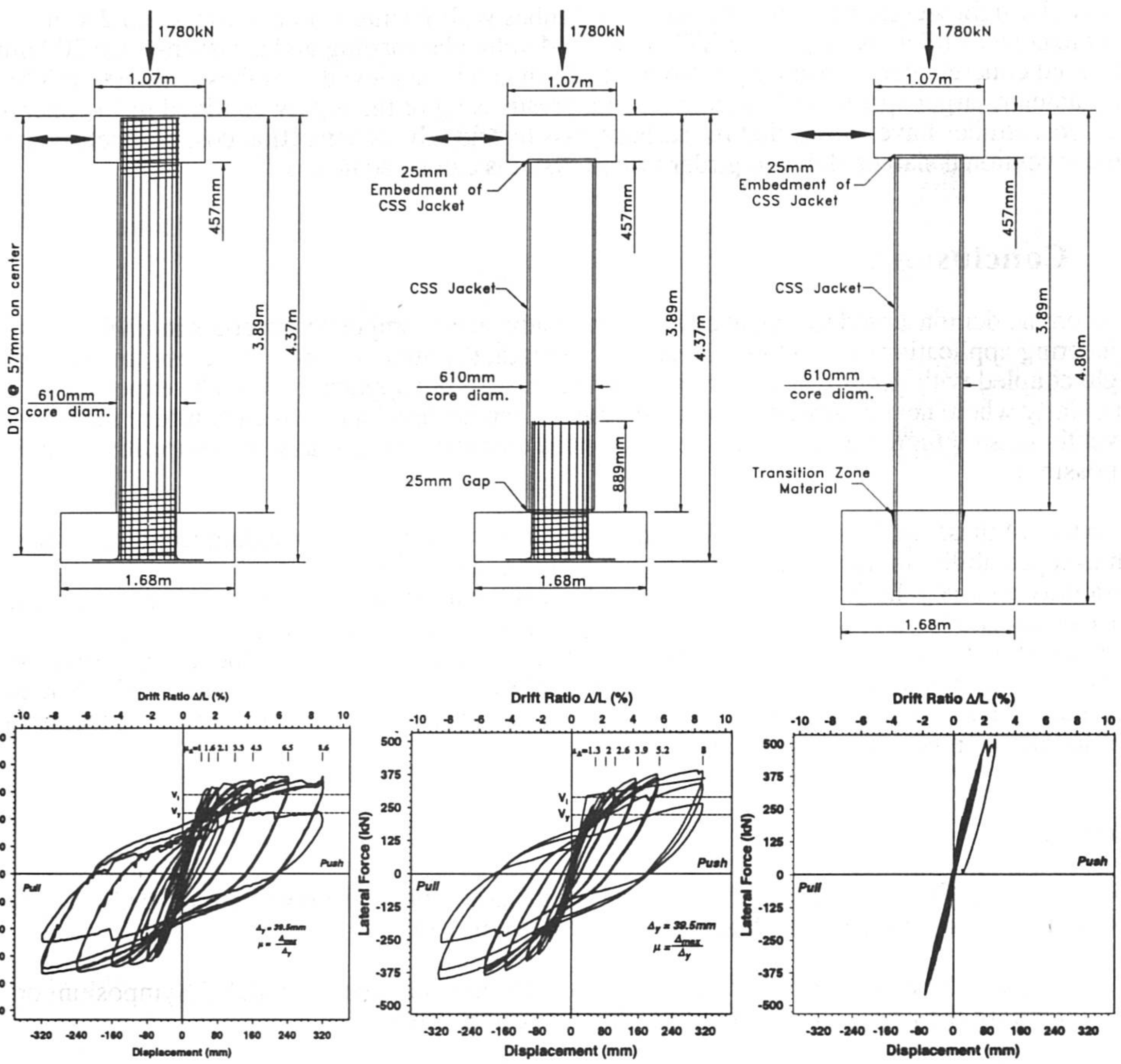


Fig. 2 Concrete Filled Composite Shell Concept

The concrete filled composite shell system replaces conventional reinforcing steel and formwork while providing better confinement to the concrete core, increased durability and greatly enhanced ease of handling and erection speeds. Initial tests on the system comprised of concrete filled carbon shell cantilever columns, see Fig. 3, showed that design objectives of ductile response or elastic strength can be achieved and compared favorably with the corresponding reinforced concrete columns response.

The observed excellent structural response of the concrete filled carbon shell columns [5] allows the development of complete composite bridge systems where concrete filled composite tubes are employed as girders, beams and pylons as outlined in Fig. 4 on the conceptual design of a new composite cable stayed bridge [6].

Leading up to a complete advanced composite cable stayed bridge, as shown in Fig. 4, simple and continuous modular concrete filled composite girder bridge systems are currently under development in a joint research effort with Caltrans and the Federal Highway Administration.



a) Conventional RC Column *b) Ductile Design Concept* *c) Strength Design Concept*

Fig. 3 Concrete Filled Shell Column Tests

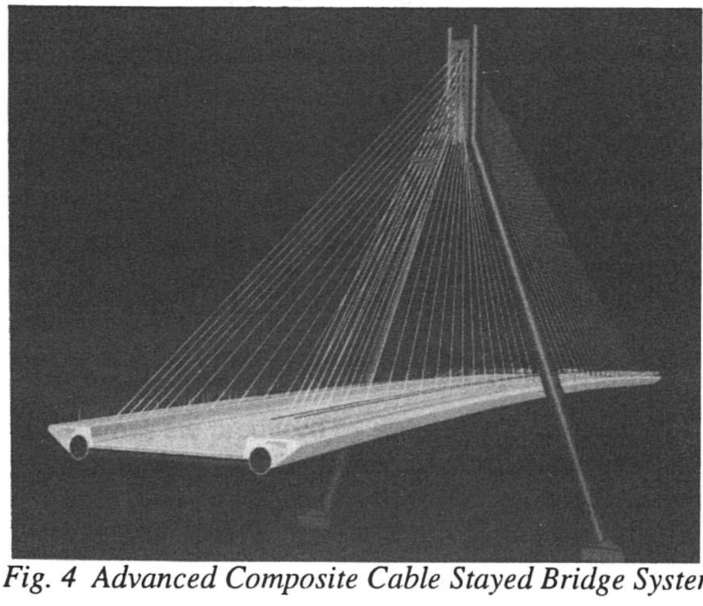


Fig. 4 Advanced Composite Cable Stayed Bridge System

For circular light weight concrete grouted hybrid tubes with 10 mm wall thickness and 2.4 m center to center girder spacing, AASHTO HS-20/44 vehicular loading and a cast-in-place 200 mm reinforced concrete deck, span ranges from 8 to 25 m can be achieved for tubes with 300 to 800 mm diameter, larger spans can be achieved with prestressing of the highly confined infill concrete. Initial cost studies have shown that for carbon/glass hybrid tube construction cost-competitiveness with conventional slab or slab and girder bridge systems can be achieved.

5. Conclusions

Based on the demonstrated technical advantages of advanced composite materials in civil engineering applications of (1) high directional strength, (2) high chemical inertness, and (3) light weight coupled with simplified construction, expanding future applications can be expected. Particularly where new composite structural systems can be developed which combine inexpensive conventional structural materials with new advanced composite materials cost competitive solutions are possible.

The extent of these applications will depend on (1) the resolution of outstanding technical issues such as repeatability in large component manufacturing, durability in the civil environment, reparability and recyclibility, (2) the extent to which automation in the manufacturing process can reduce costs, and (3) the availability of validated codes, standards and design guidelines. However, already the worldwide applications to date in bridge repair, strengthening and seismic retrofit, have shown that advanced composites provide viable alternatives for bridge infrastructure rehabilitation and extensions to new composite structural systems for complete bridge replacement or infrastructure renewal are imminent.

References

[1] Meier, U., "Strengthening of Structures Using Carbon Fiber/Epoxy Composites," Construction and Building Materials, Vol. 9, No. 6, 1995.

[2] Seible, F., "Structural Rehabilitation with Advanced Composites," IABSE Symposium on Extending the Lifespan of Structures, San Francisco, 1995.

[3] Seible, F., Priestley, M.J.N., and Innamorato, D., "Earthquake Retrofit of Bridge Columns with Continuous Carbon Fiber Jackets - Volume II, Design Guidelines" Advanced Composite Technology Transfer Report No. ACTT-95/08, August 1995, 96 pp.

[4] Priestley, M.J.N., Seible, F., and Calvi, G.M., "Seismic Design and Retrofit of Bridges," John Wiley & Sons, 1996, 686 pp.

[5] Seible, F., "Design of Structures with Advanced Composites for the 21st Century," IASS Symposium on Conceptual Design, Stuttgart, October 1996.

[6] Seible, F., Hegemier, G., Karbhari, V., Mertz, D., and Sauvageut, G., "Design Study of an All Advanced Composite Cable Stayed Bridge — I-5/Gilman Bridge in San Diego, Vol. III-Design Criteria," Advanced Composite Technology Transfer Report No. ACTT-96/05, May 1996