CRITICAL GAPS IN DURABILITY DATA FOR FRP COMPOSITES IN CIVIL INFRASTRUCTURE

by

Vistasp M. Karbhari
Department of Structural Engineering (MC-0085)
University of California, San Diego
La Jolla, CA 92093
and
Joannie W. Chin
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899 USA
and
David Reynaud
Civil Engineering Research Foundation
1015 15th Street, NW
Suite 600
Washington, DC 20005

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Vistasp M. Karbhari
Department of Structural Engineering (MC-0085)
University of California, San Diego
La Jolla, Ca 92093

Joannie W. Chin
Building Materials Division
National Institute of Standards and Technology
Bldg 226, Room B350
Gaithersburg, MD 20899

David Reynaud
Civil Engineering Research Foundation
1015 15th Street, NW; Suite 600
Washington, DC 20005

ABSTRACT

Although fiber-reinforced polymer (FRP) composites are increasingly being used for the renewal of civil infrastructure, there are still some major questions related to the durability of these materials in a civil engineering environment. This concern is emphasized since the structures of interest are primarily load bearing and are expected to be in service, without substantial inspection or maintenance, for extended time periods (75+ years). This paper presents a synopsis of a gap analysis study undertaken under the aegis of the Civil Engineering Research Foundation (CERF) and the Market Development Alliance (MDA) of the FRP Composites Industry to identify critical gaps in data needed for such applications. The study focuses on the use of FRP in internal reinforcement, external strengthening, seismic retrofit, bridge decks, structural profiles and panels. Environments of interest are moisture/solution, alkalinity, creep/relaxation, fatigue, fire, thermal effects (including freeze-thaw) and UV-exposure.

1. INTRODUCTION

Fiber-reinforced polymer (FRP) composites are increasingly being used in civil infrastructure in applications ranging from reinforcing rods and tendons, wraps for seismic retrofit of columns and externally bonded reinforcement for strengthening of walls, beams, and slabs, composite bridge decks, and even hybrid (FRP composite in combination with conventional materials) and all-composite structural systems. Their use in these applications is predicated on performance attributes linked to their light weight, high stiffness-to-weight and strength-to-weight ratios, ease of installation in the field, potential lower systems level cost, and potentially high overall durability. Since FRP composites are still relatively unknown to the practicing civil engineer and infrastructure systems planner, there are heightened concerns related to the overall durability of these materials, especially as related to their capacity for sustained performance under harsh and changing environmental conditions under load.

Although FRP composites have been successfully used in markets such as corrosion equipment, the automotive, marine and aerospace sectors, there are critical differences in loading, environment and even the types of materials and processes used in these applications as compared to the materials-process-load combinations that are likely to be used in civil infrastructure applications. FRP composites have also been successfully applied in pipelines, underground storage tanks, building facades, and architectural components, and anecdotal evidence provides substantial reason to believe that if appropriately designed and fabricated, these systems can provide longer lifetimes and lower maintenance than equivalent structures fabricated from conventional materials. However, actual data on durability is sparse, not well documented, and in cases where available – not easily accessible to the civil engineer. In addition, there is a wealth of contradictory data published in a variety of venues that tends to confuse the practicing engineer. The reasons for the apparent contradictions on durability are related to reporting of data without sufficient detail of the actual materials used, use of different forms of materials and processing techniques, and even changes in the materials systems with time (especially as related to resin formulations which are specified only by generic names). There is also some evidence of rapid degradation of specific types of FRP composites when exposed to certain environments found in the civil engineering environment.

Acknowledging that if FRP composites are to be widely accepted in the near future by practicing civil engineers, architects, and planners as construction materials at the same level as conventional materials such as timber, steel and concrete, the composites industry has recognized the critical need to address aspects related to long-term durability of these materials. This study is part of an overall attempt by the MDA to provide pertinent information to the end user in a format that is easily accessible and usable. The overall goals of the MDA effort were to (a) identify high priority, near term opportunities for the implementation of FRP composites in civil infrastructure through detailed discussions and prioritization from the end users (civil designers, construction companies and owners of bridges, buildings, and other civil infrastructure facilities), and (b) identify barriers to the penetration of FRP products into the marketplace. One of the specific obstacles identified early in the study was that of durability and a detailed study was put together to focus specifically on this aspect.

2. SCOPE OF STUDY AND PANEL STRUCTURE

Within the overall objective of studying aspects related to durability of FRP composites for use in a civil engineering environment, the MDA, in conjunction with the Civil Engineering

Research Foundation (CERF), and under funding from the Federal Highway Administration (FHWA) and MDA, is attempting to (a) conduct an overall review of available information to assess the availability of information related to composites durability, (b) identify critical gaps in knowledge, (c) prioritize research needs, and (d) formulate a coherent strategy for addressing these needs. This paper provides an overview of the results obtained through the first phase of study through the use of a focussed research panel.

In order to accomplish this a research panel was set up consisting of 7 subcommittees, each focussed on a specific environmental condition. The environmental conditions were picked based on input from the user/owner community and on the expertise of the co-chairs of the research panel. An overall structure of the panel is shown in Figure 1, and the membership of each of the subcommittees is listed in Table 2. Synergistic effects (i.e. effects resulting from the combination of environmental conditions, both in the absence and presence of load) are known to exacerbate individual effects, and these were to be considered within the overall study as related to the dominant environmental condition, and were hence not considered separately.

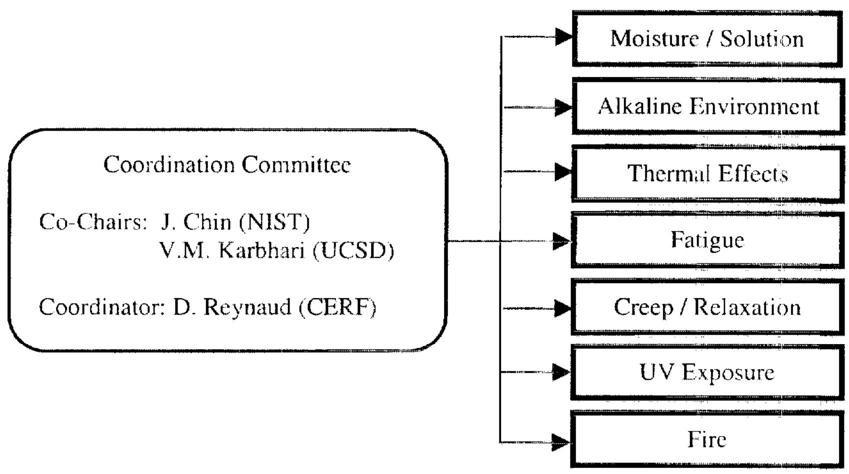

Figure 1: Overall Structure of the Research Panel

In order to provide focus for the overall study it was decided to relate the effects of each environmental condition to specific application areas that had been determined by the user/owner community, through a detailed questionnaire and workshops, to have near-term market potential. These application areas were determined to be (a) FRP composite rebar as an alternative to steel reinforcement in concrete, (b) FRP composite jackets/wraps for seismic retrofit of columns, piers, and walls, (c) External repair and strengthening of beams, slabs, and columns, (d) FRP composite bridge decks, either in conjunction with conventional girders and superstructure, or incorporating the use of FRP composite girders and superstructure (or integral bridge superstructure systems), and (e) FRP composite structural components in the form of wall panels and profiles. It should be noted that although other areas of potential interest including FRP composite cables and tendons, stay-in-place-formwork, and complete building systems were also identified, they were given a low priority in terms of near-term market penetration potential by the user/owner community and were hence not considered further in the study.

Subcommittee Area	Membership
Moisture/Solution	Dr. Donald Hunston (NIST) – Chair Dr. Thomas Juska (Newport News) Prof. Vistasp Karbhari (UCSD) Prof. Roger Morgan (AMEES/MSU) Dr. Carol Williams (US NSWC)
Alkaline Environment	Prof. Brahim Benmokrane (U. of Sherbrooke) – Chair Dr. Salem Faza (Marshall Industries Composites) Prof. Hota GangaRao (WVU) Prof. Vistasp Karbhari (UCSD) Prof. Max Porter (ISU)
Thermal Effects	Dr. Thomas Juska (Newport News) - Chair Prof. Leif Carlsson (FAU) Dr. Piyush Dutta (US Army CRREL) Prof. Jack Weitzman (UT)
Creep/Relaxation	Prof. Roger Morgan (AMEES/MSU) - Chair Dr. Colin Dunn (AMEES/MSU) Mr. Chris Edwards (Dow Chemical Co.)
Fatigue	Prof. Jack Lesko (VPI) - Chair Prof. Charles Bakis (PSU) Dr. Clem Heil (Brandt Goldsworthy & Associates) Prof. Antonio Nanni (UMR) Mr. Steven Phifer (VPI) Prof. Kenneth Reifsnider (VPI)
UV Exposure	Dr. Joannie Chin (NIST) – Chair Dr. Jonathan Martin (NIST) Dr. Tinh Nguyen (NIST)
Fire	Dr. Usman Sorathia (NSWCCD) – Chair Dr. Richard Lyon (FAA) Dr. Tom Ohlemiller (NIST) Prof. Judy Riffle (VPI) Mr. Neil Schultz (VTEC)

Table 1: Subcommittee Structure and Membership

3. DEFINITION OF DURABILITY

It should be noted that although the term durability is widely used, its meaning and implications are often ambiguous. Often it is erroneously taken to refer only to the effect of natural or solution based weathering/degradation of a composite, whereas in reality this is only a small aspect of the overall phenomenon. FRP composites (and their constituents) can be affected by a variety of factors (including those related to the natural and surrounding environment), and the actual effect of each of these factors, or combinations thereof, can be substantially effected by the presence or absence of defects or other damage to the composite (or constituents thereof). A variety of different constituent materials are commercially available and the appropriate combination of these constituents allows for the development of a FRP composite system that provides the performance attributes for its intended use. In order to ensure that the term and its implications were completely understood for the purpose of the study, the durability of a material or structure was defined as its ability to resist cracking, oxidation, chemical degradation, delamination, wear, and/or the effects of foreign object damage for a specified period of time, under the appropriate load conditions, under specified environmental conditions. This concept is realized in design through the application of sound design principles and the principles of damage tolerance whereby levels of performance are guaranteed through relationships between performance levels and damage/degradation accrued over specified periods of time. In this sense, damage tolerance is defined as the ability of a material or structure to resist failure and continue performing at prescribed levels of performance in the presence of flaws, cracks or other forms of damage/degradation for a specified period of time under specified environmental conditions. The overall concept is shown schematically in Figure 2. The use of this concept allows for the design of a structure using performance values that change with time based on external influences as long as the values do not fall below prescribed minimum levels, thereby accommodating limited degradation that is likely to take place with any material system due to mechanical, physical, or chemical factors.

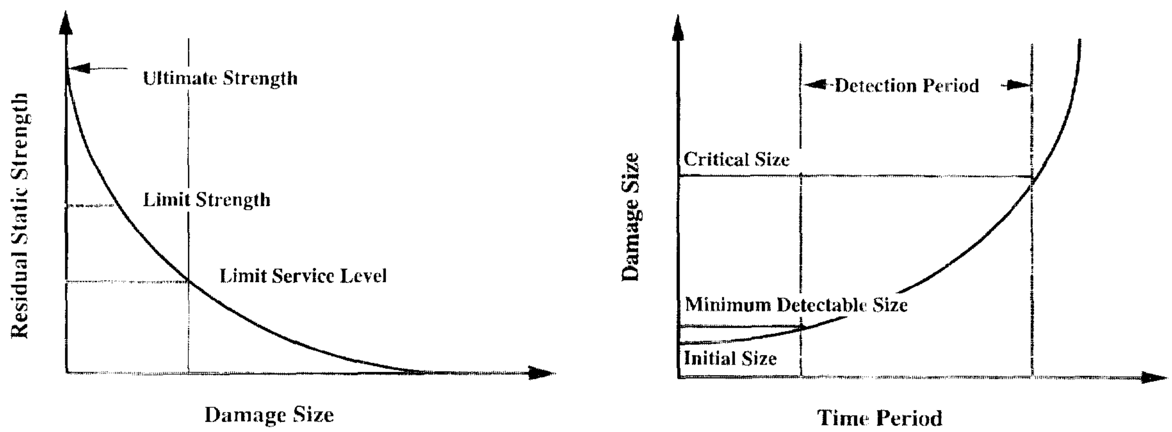

Figure 2: Schematic Showing Application of Concepts of Durability and Damage Tolerance to Design

4. METHODOLOGY USED IN GAP ANALYSIS

In order to assist in the completion of gap analysis it was decided to evaluate each application area for the effects of environmental exposure on the basis of two separate criteria, (a) importance of data, and (b) availability of data, the ranking of which would then be combined to provide an overall prioritization. The methodology for ranking used a scale of 1-5 as listed below. The use of the opposing scales for the two items ensures that when added the highest priority would be for items that have a high level of importance/need and are not widely available. This would ensure that data for items that are either (a) not important or merely of academic interest, and/or (b) already widely available, do not become priorities.

Ranking for Importance of Data
5: Critical, cannot go forward without it
3: Important to have
1: Good to have, but not essential

Ranking for Availability of Data
1: Widely available and validated
3: Sparse and/or questionable
5: Not available

In addition, effects on structural components and/or systems were considered in terms of effects on the composite itself (A), effects on the interface (or adhesive between the concrete and the FRP composite) (B), and effects on the substrate itself (C). In the case of UV exposure effects were differentiated between those at the structural and aesthetic degradation levels, whereas in the case of fire, effects were differentiated between external and confined applications.

5. SUMMARY OF GAP ANALYSIS

The following provides a basic summary of the gap analysis for each of the environments following the methodology of ranking defined in the previous section.

5.1 Moisture/Solution: Table 2 presents the perceived availability of data on the basis of material system under consideration. In this table, effects are differentiated between unloaded specimens, U, specimens under sustained loading at levels below 25% of ultimate, 25%, and specimens under sustained loading at levels above 40% of ultimate, L. Categories marked by an asterisk, *, relate to materials systems-loading combinations that are not recommended without further testing.

Material System	Continuous Immersion			Humidity			Cyclic Effects		
	U	25%	L	U	25%	L	U	25%	L
C-PE	3	5	5	5	5	5	5	5	5
C-VE	5	5	5	5	5	5	5	5	5
C-E	3	3	5	3	5	5	5	5	5
G-PE	1	3	*	3	5	3	5	5	*
G-VE	1	5	*	1	5	5	5	5	5
G-E	3	5	*	3	5	3	3	5	5
A-PE	5	5	*	5	5	3	5	5	*
A-VE	5	5	*	5	5	5	5	5	*
A-E	1	5	*	3	5	3	1	5	*

Table 2: Data Availability on Moisture/Solution Effects by Material System
(C: Carbon fiber, G: E-glass fiber, A: Aramid fiber, PE: Polyester resin, VE: Vinylester resin, E: Epoxy)

Results of the gap analysis for importance of data, availability of data, and overall prioritization are reported in Tables 3, 4 & 5, respectively. In all these the category marked A represents effects on the composite itself, whereas the category marked B represents effects at the interface/bond/adhesive level.

Application Area	Continuous Exposure		Intermittent Exposure		Synergistic Effects	
	A	B	A	B	A	B
Int. Reinforcement						
Rebar	5		3		5	
Ext. Reinforcement						
Beams	5	5	5	3	5	5
Slabs	5	5	5	5	5	5
Columns	5	5	5	5	5	5
Seismic Retrofit						
Columns, piers	5	3	1	3	3	3
Walls	5	3	3	5	5	5
Deck Systems						
Conventional beams/girders	5	3	3	3	5	3
Integral/composite beams/girders	5	5	3	5	5	5
Structural Elements						
Wall panels, profiles	3		3		3	

Table 3: Ranking of Importance of Data for Moisture/Solution Effects

Application Area	Continuous Exposure		Intermittent Exposure		Synergistic Effects	
	A	B	A	B	A	B
Int. Reinforcement						
Rebar	1		3		3	
Ext. Reinforcement						
Beams	5	5	5	5	5	5
Slabs	5	5	5	5	5	5
Columns	5	5	5	5	5	5
Seismic Retrofit						
Columns, piers	3	5	5	3	5	5
Walls	3	5	5	3	5	5
Deck Systems						
Conventional beams/girders	5	5	3	3	5	5
Integral/composite beams/girders	5	5	3	3	5	5
Structural Elements						
Wall panels, profiles	3		3		5	

Table 4: Ranking of Availability of Data for Moisture/Solution Effects

Application Area	Continuous Exposure		Intermittent Exposure		Synergistic Effects	
	A	B	A	B	A	B
Int. Reinforcement						
Rebar	6		6		8	
Ext. Reinforcement						
Beams	10	10	10	8	10	10
Slabs	10	10	10	10	10	10
Columns	10	10	10	10	10	10
Seismic Retrofit						
Columns, piers	8	8	6	6	8	8
Walls	8	10	6	8	10	10
Deck Systems						
Conventional beams/girders	10	8	6	6	10	8
Integral/composite beams/girders	10	10	6	8	10	10
Structural Elements						
Wall panels, profiles	6		6		8	

Table 5: Overall Ranking of Gaps for Moisture/Solution Effects

5.2: Alkaline Environment: This environment is considered separately from that of general moisture/solution since it is primarily associated with concrete which has a high pore water pH and contains specific salts from the cementitious mix. The results of the gap analysis for importance of data, availability of data and overall priority are reported in Tables 6, 7 & 8, respectively.

Application Area	Under Dry conditions and stress		Under Wet conditions and no stress		Under Wet conditions and stress		Under Wet conditions and stress and/or Temperature (Hot climate)	
	A	B	A	B	A	B	A	B
Int. Reinforcement								
Rebar	3	3	3	3	5	5	5	5
Ext. Reinforcement								
Beams	3	3	3	3	5	5	5	5
Slabs	3	3	3	3	5	5	5	5
Columns	3	3	3	3	5	5	5	5
Seismic Retrofit								
Columns, piers	3	3	3	3	5	5	5	5
Walls	3	3	3	3	5	5	5	5
Deck Systems								
Conventional beams/girders	3	3	3	3	5	5	5	5
Integral/composite beams/girders	3	3	3	3	5	5	5	5
Structural Elements								
Wall panels, profiles	3	3	3	3	5	5	5	5

Table 6: Ranking of Availability of Data for Alkaline Exposure Effects

Application Area	Under Dry conditions and stress		Under Wet conditions and no stress		Under Wet conditions and stress		Under Wet conditions and stress and/or Temperature (Hot climate)	
	A	B	A	B	A	B	A	B
Int. Reinforcement								
Rebar	5	5	3	3	5	5	5	5
Ext. Reinforcement								
Beams	5	5	3	3	5	5	5	5
Slabs	5	5	3	3	5	5	5	5
Columns	5	5	3	3	5	5	5	5
Seismic Retrofit								
Columns, piers	5	5	3	3	5	5	5	5
Walls	5	5	3	3	5	5	5	5
Deck Systems								
Conventional beams/girders	5	5	3	3	5	5	5	5
Integral/composite beams/girders	5	5	3	3	5	5	5	5
Structural Elements								
Wall panels, profiles	5	5	3	3	5	5	5	5

Table 7: Ranking of Importance of Data for Alkaline Exposure Effects

Application Area	Under Dry conditions and stress		Under Wet conditions and no stress		Under Wet conditions and stress		Under Wet conditions and stress and/or Temperature (Hot climate)	
	A	B	A	B	A	B	A	B
Int. Reinforcement								
Rebar	8	8	6	6	10	10	10	10
Ext. Reinforcement								
Beams	8	8	6	6	10	10	10	10
Slabs	8	8	6	6	10	10	10	10
Columns	8	8	6	6	10	10	10	10
Seismic Retrofit								
Columns, piers	8	8	6	6	10	10	10	10
Walls	8	8	6	6	10	10	10	10
Deck Systems								
Conventional beams/girders	8	8	6	6	10	10	10	10
Integral/composite beams/girders	8	8	6	6	10	10	10	10
Structural Elements								
Wall panels, profiles	8	8	6	6	10	10	10	10

Table 8: Overall Ranking of Gaps for Alkaline Exposure Effects

5.3 Thermal Effects: Effects under this area are considered under two separate categories namely, (a) elevated temperature conditions, pertaining to temperatures above the cure temperature, and (b) freeze and freeze-thaw conditions, since their effects on performance and degradation are significantly different. The results of the gap analysis for importance of data, availability of data and overall priority are reported in Tables 9, 10 & 11, respectively.

Application Area	Elevated Temperature Conditions						Freeze / Freeze-Thaw Conditions					
	Prolonged Exposure		Thermal Cycling		Thermal Gradients		Prolonged Exposure		Thermal Cycling		Thermal Gradients	
	A	B	A	B	A	B	A	B	A	B	A	B
Internal Reinforcement												
Rebar	3	3	3	3	1	1	1	3	1	3	3	5
External Reinforcement												
Beams	3	3	3	3	1	1	1	3	1	3	3	5
Slabs	3	3	3	3	1	1	1	3	1	3	3	5
Columns	3	3	3	3	1	1	1	3	1	3	3	5
Seismic Retrofit												
Columns, piers	3	3	3	3	1	1	1	1	1	1	1	5
Walls	3	3	3	3	1	1	1	3	1	3	3	5
Deck Systems												
Conventional beams/girders	3	3	3	3	1	1	1	3	1	3	3	5
Integral girders	3	3	3	3	1	1	1	3	1	3	3	5
Structural Elements												
Panels, profiles	3	3	3	3	1	1	1	3	1	3	3	5

Table 9: Ranking of Importance of Data for Thermal Effects

Application Area	Elevated Temperature Conditions						Freeze / Freeze-Thaw Conditions					
	Prolonged Exposure at Elevated Temp.		Thermal Cycling		Thermal Gradients		Prolonged Exposure		Thermal Cycling		Thermal Gradients	
	A	B	A	B	A	B	A	B	A	B	A	B
Internal Reinforcement												
Rebar	3	3	3	3	5	5	1	3	1	3	3	5
External Reinforcement												
Beams	3	3	3	3	5	5	1	3	1	3	3	5
Slabs	3	3	3	3	5	5	1	3	1	3	3	5
Columns	3	3	3	3	5	5	1	3	1	3	3	5
Seismic Retrofit												
Columns, piers	3	3	3	3	5	5	1	3	1	3	3	5
Walls	3	3	3	3	5	5	1	3	1	3	3	5
Deck Systems												
Conventional beams/girders	3	3	3	3	5	5	1	3	1	3	3	5
Integral girders	3	3	3	3	5	5	1	3	1	3	3	5
Structural Elements												
Panels, profiles	3	3	3	3	5	5	1	3	1	3	3	5

Table 10: Ranking of Availability of Data for Thermal Effects

Application Area	Elevated Temperature Conditions						Freeze / Freeze-Thaw Conditions					
	Prolonged Exposure at Elevated Temp.		Thermal Cycling		Thermal Gradients		Prolonged Exposure		Thermal Cycling		Thermal Gradients	
	A	B	A	B	A	B	A	B	A	B	A	B
Internal Reinforcement												
Rebar	6	6	6	6	6	6	2	6	2	6	6	10
External Reinforcement												
Beams	6	6	6	6	6	6	2	6	2	6	6	10
Slabs	6	6	6	6	6	6	2	6	2	6	6	10
Columns	6	6	6	6	6	6	2	6	2	6	6	10
Seismic Retrofit												
Columns, piers	6	6	6	6	6	6	2	4	2	4	4	8
Walls	6	6	6	6	6	6	2	6	2	6	6	10
Deck Systems												
Conventional beams/girders	6	6	6	6	6	6	2	6	2	6	6	10
Integral girders	6	6	6	6	6	6	2	6	2	6	6	10
Structural Elements												
Panels, profiles	6	6	6	6	6	6	2	6	2	6	6	10

Table 11: Overall Ranking of Gaps for Thermal Effects

5.4 Creep and Relaxation: This is an important condition for consideration since in general very little work has been done to date on effects on incompletely cured systems, such as would be seen in systems cured under ambient conditions. The results of the gap analysis for importance of data, availability of data and overall priority are reported in Table 12.

Application Area	Importance of Data			Availability of Data			Overall		
	A	B	C	A	B	C	A	B	C
Internal Reinforcement									
Rebar	5			3			8		
External Reinforcement									
Beams	5	5	3	3	3	3	8	8	6
Slabs	5	5	3	3	3	3	8	8	6
Columns	5	5		3	3		8	8	
Seismic Retrofit									
Columns, piers	3	3		3	3		6	6	
Walls	3	3		3	3		6	6	
Deck Systems									
Conventional beams/girders	5	5	5	3	3	3	8	8	8
Integral girders	5	5	5	3	3	3	8	8	8
Structural Elements									
Panels, profiles	3	3		3	3		6	6	

Table 12: Gap Analysis for Creep and Relaxation Effects

5.5 Fatigue Effects: The results of the gap analysis for importance of data, availability of data and overall priority are reported in Tables 13, 14 & 15, respectively.

Application Area	Sustained Stress Loading			Pure Fatigue Loading			Fatigue And Temp.			Fatigue & Moisture / Salt			Fatigue & Creep		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement															
Rebar	4	4	2	4	4	2	5	5	1	5	5	1	5	5	1
External Reinforcement															
Beams	3	3	1	4	4	3	5	5	1	5	5	1	5	5	1
Slabs	3	3	1	4	4	3	5	5	1	5	5	1	5	5	1
Columns	4	4	1	4	4	1	5	5	1	5	5	1	5	5	1
Seismic Retrofit															
Columns, piers	3	5	3	4	4	3	3	5	1	3	5	1	3	5	1
Shear Walls	3	5	3	3	4	2	3	5	1	3	5	1	3	5	1
Deck Systems															
Conventional beams/girders	4	4	1	5	5	1	5	5	1	5	5	1	5	5	1
Integral/composite beams/girders	4	5	1	4	5	1	5	5	1	5	5	1	5	5	1
Structural Elements															
Wall panels, profiles	3	5	2	5	5	2	5	5	1	5	5	1	5	5	1

Table 13: Ranking of Importance of Data for Fatigue Effects

Application Area	Sustained Stress Loading			Pure Fatigue Loading			Fatigue And Temp.			Fatigue & Moisture / Salt			Fatigue & Creep		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement															
Rebar	2	4	2	3	4	2	5	5	1	3	5	1	5	5	1
External Reinforcement															
Beams	2	4	2	2	5	3	5	5	1	5	5	1	5	5	1
Slabs	2	4	2	1	5	3	5	5	1	5	5	1	5	5	1
Columns	3	5	3	3	5	3	5	5	1	5	5	1	5	5	1
Seismic Retrofit															
Columns, piers	3	4	2	3	4	1	5	5	1	5	5	1	5	5	1
Shear Walls	3	4	2	2	4	2	5	5	1	5	5	1	5	5	1
Deck Systems															
Conventional beams/girders	2	5		2	4		5	5	1	5	5	1	5	5	1
Integral/composite beams/girders	2	4		2	4		5	5	1	5	5	1	5	5	1
Structural Elements															
Wall panels, profiles	2	4	3	3	4	3	5	5	1	5	5	1	5	5	1

Table 14: Ranking of Availability of Data for Fatigue Effects

Application Area	Sustained Stress Loading			Pure Fatigue Loading			Fatigue And Temp.			Fatigue & Moisture / Salt			Fatigue & Creep		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement															
Rebar	6	8	4	7	8	4	10	10	2	8	10	2	10	10	2
External Reinforcement															
Beams	5	7	3	6	9	6	10	10	2	10	10	2	10	10	2
Slabs	5	7	3	5	9	6	10	10	2	10	10	2	10	10	2
Columns	7	9	4	7	9	4	10	10	2	10	10	2	10	10	2
Seismic Retrofit															
Columns, piers	6	9	5	7	8	4	8	10	2	8	10	2	8	10	2
Shear Walls	6	9	5	5	8	4	8	10	2	8	10	2	8	10	2
Deck Systems															
Conventional beams/girders	6	9		9	9		10	10	2	10	10	2	10	10	2
Integral/composite beams/girders	6	9		6	9		10	10	2	10	10	2	10	10	2
Structural Elements															
Wall panels, profiles	5	9	5	8	9	5	10	10	2	10	10	2	10	10	2

Table 15: Overall Priority of Data for Fatigue Effects

5.6 Effects of Fire: Fire is an important consideration and data needs to be evaluated based on the location of the structure or component. The results of the gap analysis for importance of data, availability of data and overall priority are reported in Tables 16, 17 & 18, respectively. In each data is evaluated in terms two conditions represented as application of material in external conditions / application of material in confined conditions.

Application Area	Flame Spread			Fire Endurance			Smoke and Toxicity			Heat Release		
	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement												
Rebar				3	3							
External Reinforcement												
Beams	3/5	3/3		5/5	5/5	1/1	1/5	1/3		3/5	3/3	
Slabs	3/5	3/3		5/5	5/5	1/1	1/5	1/3		3/5	3/3	
Columns	3/5	3/3		5/5	5/5	1/1	1/5	1/3		3/5	3/3	
Seismic Retrofit												
Columns, piers	3/5	3/3		5/5	5/5	1/1	1/5	1/3		3/5	3/3	
Shear Walls	3/5	3/3		5/5	5/5	1/1	1/5	1/3		3/5	3/3	
Deck Systems												
Conventional beams/girders	3/5	1/1		5/5	5/5	1/1	1/5	1/3		3/5	3/3	1/1
Integral/composite beams/girders	3/5	3/3		5/5	5/5		1/5	1/3		1/5	1/5	
Structural Elements												
Wall panels, profiles	3/5	3/3		5/5	5/5		1/5	1/3		1/5	1/5	

Table 16: Ranking of Importance of Data for Effects of Fire

Application Area	Flame Spread			Fire Endurance			Smoke and Toxicity			Heat Release		
	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement												
Rebar	5	5	5	5	5	5	5	5	5	5	5	5
External Reinforcement												
Beams	5	5	5	5	5	5	5	5	5	5	5	5
Slabs	5	5	5	5	5	5	5	5	5	5	5	5
Columns	5	5	5	5	5	5	5	5	5	5	5	5
Seismic Retrofit												
Columns, piers	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5
Shear Walls	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5	3/5
Deck Systems												
Conventional beams/girders	3	3	3	3	3	3	3	3	3	3	3	3
Integral/composite beams/girders	5	5		5	5		5	5		5	5	
Structural Elements												
Wall panels, profiles	3	3	3	3	3	3	3	3	3	3	3	3

Table 17: Ranking of Availability of Data for Effects of Fire

Application Area	Flame Spread			Fire Endurance			Smoke and Toxicity			Heat Release		
	A	B	C	A	B	C	A	B	C	A	B	C
Internal Reinforcement												
Rebar	5	5	5	8	8	5	5	5	5	5	5	5
External Reinforcement												
Beams	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Slabs	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Columns	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Seismic Retrofit												
Columns, piers	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Shear Walls	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Deck Systems												
Conventional beams/girders	6/8	4/4		8/8	6/6	4/4	4/8	4/6		6/8	6/6	
Integral/composite beams/girders	8/10	8/8		10/10	10/10		6/10	6/8		6/10	6/10	4/4
Structural Elements												
Wall panels, profiles	6/8	6/8		8/8	8/8		4/8	4/6		4/8	4/8	

Table 18: Ranking of Priority of Data Gaps for Effects of Fire

5.7 UV Effects: In considering the effects of UV exposure, it was noted that these effects would only be of importance in cases where the FRP composite was exposed directly to UV rays. In many cases, the FRP composite is likely to be on the underside of bridges or slabs, or inside buildings. The results of the gap analysis for importance of data, availability of data and overall priority are reported in Table 19.

Application Area	Importance of Data		Availability of Data		Overall	
	Structural Concerns	Aesthetic Concerns	Structural Concerns	Aesthetic Concerns	Structural Concerns	Aesthetic Concerns
Internal Reinforcement						
Rebar						
External Reinforcement						
Beams, Slabs						
Columns	5	1	5	1	10	2
Seismic Retrofit						
Columns, piers	5	1	5	1	10	2
Walls	5	1	5	1	10	2
Deck Systems						
Conventional beams/girders	3	1	5	1	8	2
Integral/composite beams/girders	3	1	5	1	8	2
Structural Elements						
Panels, profiles*	5	1	5	1	10	2

* If used in exterior applications

Table 19: Gap Analysis for Effects of UV Exposure

6. SUMMARY AND CONCLUSIONS

Although there are significant gaps in durability data that need to be addressed, it must be emphasized that a number of these gaps exist not because the data itself does not exist, but rather because the data is not accessible. A large amount of data has been generated by industry through R&D projects, by government laboratories, particularly Department of Defense related laboratories. In a number of cases this data is considered sensitive, confidential or proprietary and hence has not been made publicly available, whereas in other cases data generated in the past could conceivably have been misplaced or archived and forgotten following changes in research personnel. The panel recommends that a 3-pronged approach be taken in furthering this effort, through (1) establishment of a computer based data base for validated data, (2) focussed research to address prioritized needs identified by the gap analysis, and (3) establishment of an evaluation panel to assess effects on projects already completed in order to document field performance.

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8. DISCLAIMER

The opinions expressed in this paper are a result of panel deliberations among the members of the research panel. They do not necessarily reflect the views of the Federal Highway Administration or the National Institute of Standards and Technology.