CRITICAL GAPS IN DURABILITY DATA FOR FRP COMPOSITES IN CIVIL INFRASTRUCTURE

by

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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.

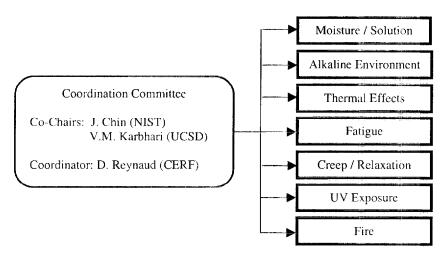


Figure 1: Overall Structure of the Research Panel

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.

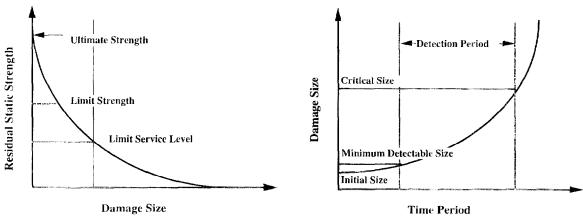


Figure 2: Schematic Showing Application of Concepts of Durability and Damage Tolerance to Design

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	1	ontinuo nmersio		F	Humidit	У	Сус	clic Eff	ects
	U	25%	L	U	25%	L	U	25%	L
		THE MANAGEMENT			TITOWN COMMENT				
C-PE	3	5	5	5	5	5	5	5	5
C-VE	5	5	5	5	5	5	5	5	5
С-Е	3	3	5	3	5	5	5	5	5
G-PE	1	3	*	3	5	3	5	5	*
G-VE	1	5	*	ı	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		nuous osure		nittent osure		rgistic ects
Managarahan ay ang 50 magana ay ang 50 magana an	A	В	A	B B	A	B B
Int. Reinforcement	Hart State of the		Annouse, nyamini Sant Militar at M	ACCUSED NAME OF THE OWNER, OWNER, OWNER,	MINE MANAGEMENT	
Rebar	5		3		5	
Ext. Reinforcement	HI JOX HIMANIA AND AND AND AND AND AND AND AND AND AN	Actor Columnia and a manta	ANNUMBER OF STREET, CHARLES OF COLUMNS	COOR HERESTER THE STATE STREET, STATE STREET, STATE STREET, STATE STREET, STATE STREET, STATE STREET, STATE ST	THE PERSONNEL CONTRACTOR OF TH	A CONTRACTOR OF THE PARTY OF TH
Beams	5	5	5	3	5	5
Slabs	5	5	5	5	5	5
Columns	5	5	5	5	5	5
Seismic Retrofit			- And the second	ACCUMULATIVE NATIONAL PROPERTY OF	PRODUCTION CONTRACTOR	debin e en
Columns, piers	5	3	1	3	3	3
Walls	5	3	3	5	5	5
Deck Systems				A. COLLING MANAGEMENT NAME OF PARTIES.	RETTO CO-COLUMBA,	State i markini sie ilintico cu
Conventional beams/girders	5	3	3	3	5	3
Integral/composite	5	5	3	5	5	5
beams/girders						
Structural Elements					action and a contract of the c	Elemento i con introduzioni della contra
Wall panels, profiles	3		3		3	The said of the state of the said of the s

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

Application Area		inuous osure		nittent osure	Syner Effe	
	A	В	A	В	A	В
Int. Reinforcement	na - IIII o III o II	at oddin ze di s operanom z mon-	4) 11000 11 110000 11000 11000 11000 110000 11000 11000 11000 11000 11000 11000 11000 11000 11000 11000 11	de la companya de la	The same of the sa	American Section Control
Rebar	1		3		3	Maria di Santa di San
Ext. Reinforcement		A PERSON CAMERA STATE MATERIAL		Солотипання на начина на година се се постава на година на година на година на година на година на година на г Солотипа	A A-THAIRMAN MAN IN MOVEMENT AND	minta recordidana da munera
Beams	5	5	5	5	5	5
Slabs	5	5	5	5	5	5
Columns	5	5	5	5	5	5
Seismic Retrofit					Subministration of the second of	den a selection and a
Columns, piers	3	5	5	3	5	5
Walls	3	5	5	3	5	5
Deck Systems				THE RESIDENCE OF THE PARTY OF T	Militia William III.	
Conventional beams/girders	5	5	3	3	5	5
Integral/composite	5	5	3	3	5	5
beams/girders						
Structural Elements					White the second	
Wall panels, profiles	3		3		5	The college of the co

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

Application Area	Conti Expe	nuous osure		nittent osure	Syner Effe	gistic ects
	Α	В	A	В	A	В
Int. Reinforcement			30 - 1, 2 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1		henne jaljulishin in remane eramentera.	TOTAL STATE OF THE
Rebar	6		6		8	- 1 1845 PRO 800-194()-1
Ext. Reinforcement			Action of the Party of the Part			and the contract of the contra
Beams	10	10	10	8	10	10
Slabs	10	10	10	10	10	10
Columns	10	10	10	10	10	10
Seismic Retrofit			indentaria (m. 1901). A la	B	n viz rediktriklade i rumannessenen en t	NAMES OF THE PARTY
Columns, piers	8	8	6	6	8	8
Walls	8	10	6	8	10	10
Deck Systems			HANNELS WASHINGTON TO THE STREET		The second secon	AND THE RESERVE AND THE PERSON NAMED IN
Conventional beams/girders	10	8	6	6	10	8
Integral/composite	10	10	6	8	10	10
beams/girders						
Structural Elements				Transition of the second of th	Minimum (Mini) — (1862/1107/2016)	the state of the s
Wall panels, profiles	6	A Section of the last of the l	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	conditi	er Dry ions and ress	Under Wet Conditions and no Stress Under Wet Conditions and stress		conditi stress Tempera	er Wet ons and and/or ature (Hot nate)		
	A	В	A	В	A	В	A	В
Int. Reinforcement	1 1 1 2 2 2 3 1 3 2 2		Marian Maria Maria Maria	Premium minimum mannerite (2000	T with displaying the second substitution of		пости основна см . очерр	
Rebar	3	3	3	3	5	5	5	5
Ext. Reinforcement		· · · · · · · · · · · · · · · · · · ·	and the second s	THE STATE OF THE S	Action different monormus	A I CONTRACTOR OF THE PROPERTY		
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				1)		THE PERSON NAMED IN COLUMN TWO IS NOT	id antico essentiamente proceso e espe	al a contrata a more (1)
Columns, piers	3	3	3	3	5	5	5	5
Walls	3	3	3	3	5	5	5	5
Deck Systems							ий с иму-соверующий совети по	denouvelle Determination
Conventional	3	3	3	3	5	5	5	5
beams/girders			the second control of the second second					
Integral/composite	3	3	3	3	5	5	5	5
beams/girders	Olot acilitana a canada a canada							
Structural Elements	this child solution are some tables		and the second of the second o	4-16-2		particular and the second		
Wall panels,	3	3	3	3	5	5	5	5
profiles		The second second second						

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

Application Area	conditi	er Dry ons and ess	conditio	er Wet ns and no ress	conditi	r Wet ons and ess	conditi stress Tempera	er Wet ons and and/or ature (Hot nate)	
	A	В	A	В	A	В	A	В	
Int. Reinforcement			· · · · · · · · · · · · · · · · · · ·		CONTRACTOR OF THE PARTY OF THE		n HEda		
Rebar	5	5	3	3	5	5	5	. 5	
Ext. Reinforcement							-4-10-1		
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								minimization and an arrangement of the second	
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	conditi	er Dry ons and ress	• 1		conditi	r Wet ons and ess	Under Wet conditions and stress and/or Temperature (Hot climate)		
	A	В	A	В	A	В	A	В	
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.

	El							Freeze / Freeze-Thaw Conditions				ons
Application Area	Prolo	nged	The	rmal	The	rmal	Prolo	onged	The	rmal	The	rmal
	Expo	sure	Сус	ling	Grac	lients	Expo	osure	Сус	ling	Grac	lients
	Α	В	A	В	Α	В	Α	В	Α	В	Α	В
Internal Reinforceme	ent								D-1 11 12 13 14 15 15 15 15 15 15 15	and the second second	Stamment Lindbien.	Tracurinic asis is a
Rebar	3	3	3	3	1	1	1	3	1	3	3	5
External Reinforceme	ent								ge-i-media-maria-	(Adjust		
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									bre i mianumatica se	here a min manna	pronesi-are dome nti	T-Transmitted
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		-							er: (a: Hans Lutterichau	National Property	निवस्ता स्थानितः । सिवस्तारका । द	Talifornia (Carantella Carantella
Conventional	3	3	3	3	1	1	1	3	1	3	3	5
beams/girders												
Integral girders	3	3	3	3	1	ı	1	3	1	3	3	5
Structural Elements	tructural Elements										to the second of	30.00
Panels, profiles	3	3	3	3	1	1	1	3	1	3	3	5

Table 9: Ranking of Importance of Data for Thermal Effects

	El	evated	Tempe	rature (Conditio	ns	Free	eze / Fr	eeze-T	haw C	v Conditions		
Application Area	Expo at Ele	onged osure evated mp.		rmal cling		rmal lients	1						
	Α	В	Α	В	A	В	A	В	A	В	Α	В	
Internal Reinforceme	ent											All Maria	
Rebar	3	3	3	3	5	5	1	3	1	3	3	5	
External Reinforcem	ent												
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											A. (Page - 17)		
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	3	3	3	3	5	5	ı	3	1	3	3	5	
beams/girders		-			Storme Libra abouton					Canadi and to			
Integral girders	3	3	3	3	5	5	1	3	1	3	3	5	
Structural Elements	planta de la la la constitución de						and the second of the second of the second	PERSONAL PROPERTY.	pou seuceum				
Panels, profiles	3	3	3	3	5	5	1	3	1	3	3	5	

Table 10: Ranking of Availability of Data for Thermal Effects

	El	evated	Tempe	rature (Conditio	ns	Free	eze / Fr	eeze-T	haw C	Conditi	ons
Application Area	Expo at Ele	onged osure vated np.				Thermal Gradients		Prolonged Exposure		Thermal Cycling		rmal lients
	A	В	A	В	A	В	A	В	Α	В	Α	В
Internal Reinforceme	nt.								- I man worth (TOTAL TOTAL MARKET		5
Rebar	6	6	6	6	6	6	2	6	2	6	6	10
External Reinforcem	ent								Eller (special control of the control	water that distance		
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				1 I www.ii - a.			- Commission of the Commission	TO THE PERSON NAMED IN COLUMN TO THE	en e sem appropriate	enemin T. Un. commit-	manera, a manara ang	
Conventional	6	6	6	6	6	6	2	6	2	6	6	10
beams/girders												
Integral girders	6	6	6	6	6	6	2	6	2	6	6	10
Structural Elements	Structural Elements									put manage		·
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	Impo	rtance of	Data	Avail	lability o	f Data		Overall	
	Α	В	C	Α	В	C	Α	В	С
Internal Reinforcem	ent					and continue to the desire		The second secon	not resident titly first still
Rebar	5			3			8		
External Reinforcen	ient					and the second s		was and a second state of	
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								annual a community	
Columns, piers	3	3		3	3		6	6	
Walls	3	3		3	3		6	6	**************************************
Deck Systems									
Conventional	5	5	5	3	3	3	8	8	8
beams/girders		-		an - company to the section of the s		· · · · · · · · · · · · · · · · · · ·			NAME AND PROPERTY OF THE PARTY AND ADDRESS.
Integral girders	5	5	5	3	3	3	8	8	8
Structural Elements		W. Company of Strategy	An experience of the second se						Andrews and the second
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		ustain Stress oadir	8		Pure Fatigue Loading		Fatigue And Temp.			Fatigue & Moisture / Salt			Fatigue & Creep		
	Α	В	C	Α	В	C	A	В	C	A	В	С	Α	В	С
Internal Reinforcement					**************************************	4		, and the second	Ammonton 2, 22.	- Contraction	Selective and the	Финанически (26)	иливорирусскі	inina manana ang i	пинитист н
Rebar	4	4	2	4	4	2	5	5	1	5	5	1	5	5	1
External Reinforceme	ent			ĺ	- Anniellen arter	1) 51 - 11 - 12 - 12 - 12 - 12 - 12 - 12 -	Career Landson Strategy	faller traverspan	Marie Programmy Services as	9	Perior Constitution of the	A-w	Minimum manager	TO ARREST COMPANY	Acception - 21
Beams	3	3	1	4	4	3	5	5	1	5	5	1	5	5	1
Slabs	3	3	ı	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						n de Renamen kv	broginskiństo	eministration of	THE REPORT OF THE PROPERTY.	Chimeles and a	hes	To Hill Virgin Tilling	эпинко-чиность	transacti (High calls)	A. minera mana
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		mengarankana			Min-commission	Indexeduador-	- Anna Anna Anna Anna Anna Anna Anna Ann	an a ii Assi minasa	Augustu suncenar	THE STATE OF THE PARTY	AND THE PERSON NAMED IN COLUMN	enite instrument	orlando sintines es	comit a distant.	
Conventional beams/girders	4	4	1	5	5	1	5	5	1	5	5]	5	5	1
Integral/composite beams/girders	4	5	1	4	5	I	5	5	1	5	5	1	5	5	1
Structural Elements		and the second s		Taranti I maniferia de la companio			A STATE OF STREET OF STREET STREET, STREET STREET, STR			The state of our supplies of the control of the con					
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	В	C	Α	В	C	Α	В	C	A	В	C	Α	В	С
Internal Reinforcemer	11	19.0	*******		Aurani amuu	Access Collections (in announce	chour againse	AFIRA PIPE	March College Street	nesaniteRedi*(ees	TOTAL PROPERTY.	I I HOUSE IN COLUMN	Acceptance of the second
Rebar	2	4	2	3	4	2	5	5	1	3	5	1	5	5	1
External Reinforceme	ent					Memospiphica.	THE STREET, SHIPPING AND ADDRESS OF THE PARTY OF THE PART	Service construction		THE RESERVE OF THE PERSON NAMED IN		k unit tan			deneme te receive
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		gen 3, -0.13 tal 16t.			BENEVOUS PRINCIPALIST	Property and the state of the s	l	CO CERT CONTRACTOR	Oran David Hill		1		ecterose compos	A DECEMBER OF THE	f miss man read
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					pitti - marit - pietiti - re		2 esseni-incominis	де пто пти на прида	dia di Ingeria (a Leber)	MANUSTRUM - TANK	Australia de la constitución de	Andrew Control	THURSHIM OF	THE PERSON NAMED IN COLUMN	farenter au
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	I
Structural Elements			,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,								e e e e e e e e e e e e e e e e e e e		THE PERSON NAMED IN	Amidanis Inara (40	
Wall panels, profiles	2	4	3	3	4	3	5	5	1	5	5	j	5	5	1

Table 14: Ranking of Availability of Data for Fatigue Effects

Application Area		istain Stress oadir	3		Pure Fatigue Loading		4	Fatigue And Temp.			Fatigue & Moisture / Salt			Fatigue & Creep		
() () () () () () () () () ()	A	В	C	Α	В	C	A	В	С	Α	В	C	Α	В	C	
Internal Reinforcemen	Internal Reinforcement		SHIP OF THE REAL PROPERTY.										National Community of the Community of the Computer of the Com			
Rebar	6	8	4	7	8	4	10	10	2	8	10	2	10	10	2	
External Reinforceme	nt															
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										htter minskilmerne						
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	Fire Endurance			Smoke and Toxicity			Heat Release		
	Α	В	С	Α	В	C	Α	В	C	Α	В	C
Internal Reinforcement											house come the fit control	duran anna an
Rebar				3	3			10			Charles Heart Course Course	
External Reinforceme	ent		initial and a									
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		AII PIRANGE PARAGETO	The second second									
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	TO SECUL CALLES	3/5	3/3	DUDS-CORE TOWN
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	Fla	me Spi	read	Fire	Endur	ance	l	noke a		He	Heat Release		
Euchina	Α	В	C	Α	В	C	A	В	C	Α	В	C	
Internal Reinforcemer				***************************************		Company of the second	AN HOUSE HOUSE, MAN	Marketine and State	liter Den regoringe	EN RRESEMBLISHING			
Rebar	5	5	5	5	5	5	5	5	5	5	5	5	
External Reinforceme	ent			W-14-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1		**************************************	TO DESCRIPTION AND ADDRESS.		Manager :		and commercial supple	oe ii o oo mulling aan	
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	***************************************	talental care					- X-10-11-11-11-11-11-11-11-11-11-11-11-11-	and the second s	an manifest representation		MARKON E. III.		
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					A ALAMANA AT THE	Corectlin divining 1994	HIHOMOTE	RI FININGS OF STREET	TO GREEN STREET	- Carrier Contract Co	ALICE STATES OF THE STATES	- insimulari	
Conventional beams/girders	3	3	3	3	3	3	3	3	3	3	3	3	
Integral/composite beams/girders	5	5	The state of the s	5	5		5	5		5	5	at the makes to make	
Structural Elements		The formal of the first		The state of the s	menenne di didicini	***************************************	All the second management of	resolumos munera	Street,	Southern Selection And second	SHORTONOS POR DESIG	discrimentament	
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	Flan	ne Spre	ead	Fire	Enduran		oke ar		Heat Release			
	Α	В	C	Α	В	С	Α	В	C	A	В	С
Internal Reinforcemer		MINISTER PROPERTY OF THE PROPE	CHILITERE W. I. I. CANA		ALCONOMIC STATES OF THE STATES	of	CHINESON INTERNATIONAL PROPERTY.	STREET,	enostraner a			
Rebar	5	5	5	8	8	5	5	5	5	5	5	5
External Reinforceme	ent		-		Sellji kaldardar perem atra	AND PROPERTY OF STREET		байнын аң ба лы жара	de innissement de la militario	Hermanninnelidellenen	Annual de la Carte de Carte	THT MANNE CA
Beams	8/10	8/8		10/10	10/10	6/6	6/10	6/8	PIPE MARKET	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					innis innumerite dilimitaria	and the same of the		al souther Constitution		THE RESERVE OF THE PERSON NAMED IN COLUMN TWO IN COLUMN TW	antenna umaaraara	hittacalamate: - taraya
Columns, piers	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	and a second second
Shear Walls	8/10	8/8		10/10	10/10	6/6	6/10	6/8		8/10	8/8	
Deck Systems							A CONTRACTOR OF STREET	HARLEST STREET	is resource enemy	Mesen cici a acente es	THE COMMENT OF THE PROPERTY OF	had stoppe :
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			***************************************	A COMPANY OF THE PARTY OF THE P	minimum maska ilia masma	and the second section.		Trace squirement state	R - 111 Handa - Alabah	and the second house	Anthomas and a summer	
Wall panels, profiles	6/8	6/8		8/8	8/8	PIOT AND MARKATER PROPERTY.	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	Importanc	ce of Data	Availabili	ty of Data	Ove	erall
	Structural	Aesthetic	Structural	Aesthetic	Structural	Aesthetic
	Concerns	Concerns	Concerns	Concerns	Concerns	Concerns
Internal Reinforceme	nt		-			
Rebar			eminimies, institution, institution			
External Reinforceme	nt		AND THE PROPERTY OF THE PROPER	том о д населения в под	THE RESERVE OF THE PARTY OF THE	zama diliba si Firome unbersimanna
Beams, Slabs					31/20	
Columns	5	1	5	ı	10	2
Seismic Retrofit						
Columns, piers	5	1	5	1	10	2
Walls	5	1	5	1	10	2
Deck Systems						THE RESIDENCE OF THE PARTY OF T
Conventional	3	1	5	1	8	2
beams/girders			!			
Integral/composite	3	Ī	5	1	8	2
beams/girders						
Structural Elements						NAMES OF THE OWNER OF THE OWNER, WHEN THE OWNER,
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.