Synthesis of Methods for Repair of Bridge Girder

Quarterly Progress Report
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1. PROJECT ABSTRACT

Many bridges in the United States are aging and due for repair or strengthening. Corrosion of prestressed girder ends is a prevalent problem that significantly reduces the flexural and/or shear load bearing capacity of the girders, thus resulting in an overall reduction in the bridge load bearing capacity. Moreover, over-height vehicles continue to collide and impact bridge girders around the country, which compromise the flexural capacity of bridge girders. Several research studies and state DOTs initiatives looked into innovative repair and strengthening methods for girders end zones and/or mid span impacts. The goal of this project is to synthesize the available literature on bridge girders repair methods with focus on prestressed girders and end zones damage. The synthesis will summarize and compare the design and application procedure of different methods to provide a guide or catalog for bridge engineers working on girders end repair.

2. RESEARCH PLAN

2.1. STATEMENT OF PROBLEM

Corrosion is a prevalent problem affecting prestressed and reinforced concrete girder ends and often leads to a significant reduction in the load bearing capacity of the girders. Moreover, over-height vehicles continue to collide and impact bridge girders, which compromise the flexural capacity of bridge girders. Several research studies and state DOTs initiatives looked into innovative repair and strengthening methods for girders. Figure 1 shows a case study from Minnesota (Shield 2018) where a prestressed girder end damage is shown and the procedure for repairing is illustrated as well. In this case, shotcrete was used with additional epoxy-coated reinforcement.

Other methods that use different techniques or different materials such as fiber reinforced polymers (FRP) (Andrawes et al. (2018)) or recently, ultra-high performance concrete (UHPC) are available as well (Zmetra et al. (2017)). Some of the methods were only applied in a laboratory environment to test the method, and others have been well implemented and steered by dedicated design guidelines, which in most cases, cover only one single method of repair. For example, Pantelides et al. (2010) developed methods and design guidelines for repair and retrofit of bridge girders suffering (1) shear strength deficiencies related to end cracking and (2) flexural strength deficiencies related to vehicular collision. Scaled test specimens were fabricated and subjected to cyclic loading in order to instigate damage similar to that caused by end cracking and vehicular collision. Subsequently, the damaged specimens were repaired with external post-tensioned carbon fiber rods and re-tested to failure. In their report, Pantelides et al. (2010) presented the data from the tests and design guidelines for the use of external post-tensioned carbon fiber rods for repair applications. Similar studies and guidelines often focus on only one specific repair approach used in their area. The goal of this project is to synthesize the available literature on bridge girders repair methods used in different states and internationally, and eventually provide a comprehensive guideline for such repair requirements.

Figure 1. Reinforced shotcrete repair of prestressed bridge girder ends in Minnesota (Photos adopted from Shield 2018)

2.2. RESEARCH APPROACH AND OBJECTIVES

As presented above, there are different studies and methods that could be used for girders repair and strengthening. Thus, the goal of this project is to collect all the available information from research studies and DOT practices and synthesize this information for a comprehensive summary of the methods and application procedure and guidelines. The study will focus on prestressed girders and end zones damage repair methods. However, information from other repair applications such as for steel girders (e.g. Zmetra et al. 2017 previously discussed) or repair at locations other than end zones will be collected and summarized if needed to inform and direct the study.

The research team will look into different ways of collecting, organizing, and presenting the state-of-the-art and state-of-practice as related to prestressed girders repair methods. Research experimental and analytical or computational work versus field applications is one approach. Reaching out to different states to collect available designers' memos for repair methods of girder ends or current practices is another approach. For example, repair methods can use conventional concrete, high strength grout, FRP, UHPC, shotcrete, etc. therefore, the different approaches for collecting and organizing the information will ensure that all the available information will be accessed and considered in the synthesis. This study will also consider coordination with ISU, one

of the ABC-UTC partner universities, to include the significant work researchers at ISU have done in this area. Coordination with other partner universities and reaching out for community input for some of the recent work that is still ongoing and has not been yet published will be sought through events such as Research Day hosted by the ABC-UTC or similar avenues.

2.2.1. SUMMARY OF PROJECT ACTIVITIES

The project objective will be achieved through a series of tasks as follows:

- Task 1 – Conduct comprehensive literature search on girders end repair methods
- Task 2 – Categorize all the available information based on material of repair, method of application, etc.
- Task 3 – Reach out to representative state DOTs for feedback on preferred repair methods (if needed, and if we have enough information after completely investigating the literature, we will reach out to AASHTO committee members to make recommendations for bridge girder repair methods)
- Task 4 – Synthesize results from previous tasks in a final report and provide guidelines on selection of best repair method

2.2.2. DETAILED WORK PLAN

A detailed description of the proposed research tasks is presented in this section.

Task 1 – Conduct comprehensive literature search on girders end repair methods:

Comprehensive search was conducted to collect a list of 111 literature on girder repair methods. This was done mainly for reinforced concrete bridges. Additionally, a number of publications on steel and timber bridge girder repair methods were also collected. These were considered to be beneficial in improving the knowledge on RC bridge girder repair applications.

Some other information in the format of articles, reports, presentations, webpages, or videos on girders repair practices used by different state DOTs were also gathered.

Task 2 – Categorize all the available information based on material of repair, method of application, etc:

The literature found in Task one in addition to 170 more literature were looked at carefully for (1) the specific girder deficiency concern(s) they addressed and for (2) the repair material utilized. This information is provided in Appendix 1.

2.3. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

Based on the classification of the literature in Appendix 1, the following outline has been created for the final report of this project:

Abstract

1. Introduction

2. Repair materials

    2.1. Fiber Reinforced Composites

2.1.1. Polymeric composites

2.1.2. Cement based composites

2.1.3. Hybrid fiber reinforced composites CFRP Rod Panel (CRP)

2.2. Steel

2.3. Ultra-high performance fiber reinforced concrete (UHPFRC)

2.4. Ferrocement

2.5. Shotcrete

2.6. Coatings and Sealers

3. Repair process

3.1. Steel and Fiber-Reinforced composite repair methods

3.1.1. Surface preparation

3.1.2. Application of the repair material

3.1.2.1. Externally bonded (EB) technique

3.1.2.2. Near Surface Mounted (NSM) technique

3.1.2.3. Embedded reinforcement

3.1.3. Post-tensioning of the repair material (optional)

3.1.4. Anchorage system

3.2. Ultra-high performance fiber reinforced concrete (UHPFRC)

3.3. Shotcrete

3.4. Strand Splicing

4. Repair applications

4.1. Shear strengthening

4.2. Flexural strengthening

4.3. Serviceability Performance

4.3.1. Fatigue

4.3.2. Corrosion

4.4. Fire performance

5. Recommendations

6. References

The literature in different categories are being studied carefully, and a draft of the report with the above outline is being populated using the obtained information.

At the end of this stage, we expect to gain the understanding required for judging each methodology compared to others and to provide in chapter five of the final report.

2.4. APPLICABILITY OF RESULTS TO PRACTICE

The results from this project are expected to benefit different states DOTs where girders repair and maintenance is a common issue.

3. PROJECT TIMELINE AND PROGRESS

The remaining of the study will be conducted over a period of 3 months following the schedule in Table 1. The milestones are marked on the schedule.

Table 1. Project guideline and progress

Tasks	Year 1			
	Q1	Q2	Q3	Q4
1. Comprehensive literature search	X			
2. Categorizing the information		X		
3. DOT survey (if needed)			X	
4. Final report and guideline				X

Completed work In progress Remaining

Based on presented progress and schedule, the percentage of completion of this project is as follows:

Item	% Completed
Percentage of Completion of this project to Date	60

4. REFERENCES

1. Andrawes, B., I. Shaw, H. Zhao (2018). “Repair & strengthening of distressed/damaged ends of prestressed beams with FRP composites”, Research Report No. FHWA-ICT-18-001.

2. Shield, C. and P. Bergson (2018). "BR27568–Experimental Shear Capacity Comparison Between Repaired and Unrepaired Girder Ends."

3. Pantelides, C., L. Reaveley, C. Burningham. (2010). “Repair pf prestressed concrete girder ends and girder collision repair”, Report No. UT-10.04.

4. Zmetra, K.M., K. McMullen, A. Zaghi, K. Wille. (2017). “Experimental study of UHPC repair for corrosion-damaged steel girder ends”, Journal of Bridge Engineering, 22(8):04017037

APPENDIX 1

No.	Literature title: Concerns	Repair material
1	**REPAIR OF BRIDGE GIRDERS INCLUDES FIRST APPLICATION OF POST TENSIONED CARBON FIBER STRAND:** -	external post tensioned high strength bars, carbon fiber strands
2	**REPAIR OF IMPACT-DAMAGED PRESTRESSED CONCRETE BRIDGE GIRDERS USING CFRP MATERIALS:** **1)** impact damage	CFRP sheets
3	**Behavior of RC box beam strengthened with basalt FRP using end anchorage with grooving:** **1)** sudden and premature failure or debonding due to the lack of end anchorage **2)** stress-strain relationship, ductility, and failure mode of BFRP-strengthened beams near initial flexural cracks	BFRP
4	**Residual strength of CFRP strengthened prestressed concrete bridge girders after hydrocarbon fire exposure:** **1)** fire performance	CFRP

5	**Time-dependent reliability analyses of prestressed concrete girders strengthened with CFRP laminates:** **1)** degradation caused by pitting corrosion	CFRP laminate
6	**Investigations on behaviour of flexural deficient and CFRP strengthened reinforced concrete beams under static and fatigue loading:** **1)** flexural strengthening	CFRP
7	**Post-tension near-surface mounted strengthening system for reinforced concrete beams with changes in concrete condition:** **1)** flexural capacity (due to aging or external environment)	NSM CFRP
8	**Strengthening of reinforced concrete beams by using fiber-reinforced polymer composites: A review:** **1)** flexural strengthening **2)** shear strengthening **3)** torsional strengthening **4)** blast resistance **5)** impact strength **6)** fatigue life **7)** seismic resistance	FRP composites
9	**Performance Evaluation of a Fire Damaged and FRP Laminate Strengthened Reinforced Concrete Bridge:** **1)** long-term performance and structural integrity **2)** lateral flexural load distribution and midspan deflection	CFRP
10	**Experimental testing of older AASHTO Type II bridge girders with corrosion damage at the ends:** **1)** shear strength and durability (due to cracking caused by corrosion) issues of corroded girders	Nothing

11	**Repair & Strengthening of Distressed/Damaged Ends of Prestressed Beams with FRP Composites:** **1)** reduced bond stress-slip properties due to environmental exposure **2)** Shear capacity of end regions	GFRP laminates, CFRP laminates, NSM CFRP bars
12	**Evaluation of Repair Techniques for Impact-Damaged Prestressed Beams:** **1)** over-height vehicle collision	fabric-reinforced cementitious matrix (FRCM)
13	**Strengthening a 20-Year-Old Post-Tensioned Concrete Box Beam with Double-Layer Prestressed Steel Wire Ropes:** **1)** serviceability (crack width, deflection)	double-layer prestressed steel wire ropes (PSWRs)
14	**Affordable Bridge Girder End Repair Method Restores Concrete Beams to Original Strength:** **1)** Deterioration	shotcrete
15	**Field test of an old RC bridge before and after NSM strengthening:** **1)** serviceability (deflection) **2)** load carrying capacity	post tensioned NSM system
16	**Experimental research on flexural behaviors of damaged PRC beams strengthened with NSM CFRP strips:1)** flexural behaviors (load carrying capacity, stiffness, deflection)	NSM CFRP strips
17	**Fatigue behaviour of damaged RC beams strengthened with ultra high performance fibre reinforced concrete:** **1)** fatigue	ultra-high performance fibre-reinforced concrete (UHPFRC)
18	**Carbon fiber–reinforced polymer rod panels for strengthening concrete bridges:** **1)** flexural strengthening **2)** bond characteristics	FRP laminates and fabric and rods

19	**Behavior of reinforced concrete beams strengthened with CFRP rod panels CRP 195:** **1)** flexural strengthening	EB CFRP rod panels
20	**I-10 Girder Repair Using Post-Tensioned Steel Rods and Carbon Fiber Composite Cables (CFCC) :** a) Rate of deterioration: **1)** sudden failure due to breakage of prestressing tendons **2)** gradual deterioration due to transfer of loads to external bars **3)** bending or warping in the week axis due to uneven deterioration b) Corrosion (should be studied in long term)	external post-tensioning using both highstrength steel rods and Carbon Fiber Composite Cables (CFCC)
21	**Experimental and theoretical analysis of severely damaged concrete beams strengthened with CFRP:** **1)** strength, stiffness and ductility	EB CFRP wraps
22	**BR27568 – Experimental Shear Capacity Comparison Between Repaired and Unrepaired Girder Ends:** **1)** debonding and shear strength	specific form of concrete placement called "shotcrete"—a mix of sand, aggregate and cement
23	**Repair of Prestressed Concrete Bridge Beams:** **1)** Honeycomb/Voids and cracks	CFRP
24	**Performance of CFRP-Strengthened Concrete Bridge Girders under Combined Live Load and Hydrocarbon Fire:1)** CFRP debonding **2)** Concrete spalling	CFRP wraping
25	**Repair of Damaged Prestressed Concrete Girders with FRP and FRCM Composites:** Impact damage due to overheight vehicles: **1)** Flexural capacity	CFRP and fabric-reinforced cementitious matrix (FRCM)

26	**Prestress beam end repair: testing and shotcrete performance :** -	shotcrete
27	**Performance of FRCM-Strengthened RC Beams Subject to Fatigue:** **1)** long term performance (flexural fatigue performance)	Fabric-reinforced cementitious matrix (FRCM)
28	**Fatigue Assessment Model of Corroded RC Beams Strengthened with Prestressed CFRP Sheets:** **1)** Fatigue Assessment	Prestressed CFRP Sheets
29	**Arizona DOT uses carbon fiber strips to repair I-17 bridge girders:** **1)** over height collision damage	carbon fiber strips
30	**Finite element model for predicting post delamination behaviour in FRP-retrofitted beams in flexure:** **1)** post delamination behaviour **2)** flexural strengthening **3)** debonding load	FRP
31	**Composite Strengthening of a Bridge:** -	EB or NSM CFRP composites
32	**Assessment of residual strength of concrete girders rehabilitated using NSM CFRP with cementitious adhesive made with graphene oxide after exposure to fatigue loading:** **1)** residual strength **2)** fatigue loading	NSM CFRP
33	**Performance of RC beams rehabilitated with NSM CFRP strips using innovative high-strength self-compacting cementitious adhesive (IHSSC-CA) made with graphene oxide:1)** ductility	NSM CFRP strips

34	**Fatigue performance of near-surface mounted CFRP strips embedded in concrete girders using cementitious adhesive made with graphene oxide:** **1)** fatigue performance	NSM CFRP strips
35	**Post-tension near-surface-mounted strengthening systems of full-scale PSC girders:** **1)** flexural capacity	Post-tensioned NSM CFRP system
36	**Flexural strengthening of reinforced concrete beams with pre-stressed near surface mounted CFRP systems:** **1)** Flexural strengthening	pre-stressed NSM CFRP systems
37	**Repair of damaged end regions of PC beams using externally bonded FRP shear reinforcement:** **1)** shear reinforcement	EB CFRP, EB GRFP
38	**Predicting Flexural Fatigue Performance of RC Beams Strengthened with Externally Bonded FRP due to FRP Debonding:** **1)** Flexural Fatigue Performancedue to debonding **2)** Deflection	EB FRP laminates
39	**Fatigue life-based design of RC beams strengthened with NSM FRP:** **1)** fatigue life	NSM FRP
40	**Experimental and Theoretical Serviceability of Strengthened and Nonstrengthened Unbonded Posttensioned Indeterminate I-Beams:** **1)** serviceability	externally applied unidirectional carbon-fiber-reinforced polymer sheet (CFRP) (ply) at sagging and hogging regions
41	**Experimental Investigation of Reinforced Concrete T-Beams Strengthened in Shear with Externally Bonded CFRP Sheets:** **1)** Shear capacity	externally bonded (EB) U-wrapped CFRP

42	**Fabric Reinforced Cementitious Matrix (FRCM) Composites as a Repair System for Transportation Infrastructure:** **1)** impact damge	FABRIC REINFORCED CEMENTITIOUS MATRIX (FRCM) COMPOSITES
43	**Fatigue Behavior of Large-Scale Reinforced Concrete Beams Strengthened in Flexure with Fiber-Reinforced Polymer Laminates:1)** Fatigue bahvior **2)** Flexural strengthening	CFRP laminates (EB or NSM)
44	**Analysis of the fatigue behavior of reinforced concrete beams strengthened in flexure with fiber reinforced polymer laminates:** **1)** flexural fatigue behavior	FRP laminates
45	**Structural performance of impact damaged and repaired concrete bridge girder using GFRP rebars:** Impact damage of overheight vehicles: **1)** Flexural capacity **2)** Girder stiffness, strains, and stresses **3)** Durability (resistance to corrosion)	GFRP bars
46	**Shear strengthening of reinforced concrete beams using externallybonded aluminum alloy plates: An experimental study:** **1)** Shear strengthening	EB aluminum alloy plates
47	**Cost-Effective and Rapid Concrete Repair Techniques:** Review, summary, survey	Review, summary, survey
48	**Finite element parametric study of reinforced concrete beams shear-strengthened with embedded FRP bars:** **1)** shear strengthening	embedded FRP bars
49	**Prestressed CFRP Strips for Concrete Bridge Girder Retrofitting: Application and Static Loading Test:** **1)** Flexural strengthening **2)** load carrying capacity	(CFRP) strips with a gradient anchorage

50	**Effect of the thickness of concrete cover on the fatigue bond strength of GFRP wrapped and non-wrapped reinforced concrete beams containing a lap splice:** **1)** fatigue bond strength	GFRP wrap
51	**Fatigue Behavior of Reinforced Concrete Beams Strengthened with Externally Bonded Prestressed CFRP Sheets:** **1)** fatigue behavior	posttensioned prestressed CFRP sheets
52	**Experimental performance of RC beams strengthened with FRP materials under monotonic and fatigue loads:1)** fatigue resistance	(EBR) polymeric plates and near-surface mounted (NSM) CFRP bars
53	**Time-dependent reliability of strengthened PSC box-girder bridge using phased and incremental static analyses:** **1)** reliability (Excessive long-term deflection and unexpected cracks) **2)** restore bearing capacity	FRP and external post-tensioning
54	**Reinforced Concrete Beams with and without FRP Web Reinforcement under Pure Torsion:** **1)** torsional resistance **2)** torsional cracking	Sand-coated glass-FRP (GFRP) and carbon-FRP (CFRP) bars and stirrups
55	**Flexural behavior of preloaded reinforced concrete beams strengthened by prestressed CFRP laminates:** **1)** Flexural strength and stiffness	pre-tensioned (prestressed) CFRP laminates
56	**Evaluation and Repair of Existing Bridges in Extreme Environments:** **1)** corrosion **2)** shear capacity	pre-stressed CFRP
57	**Experimental study of flexural fatigue performance of reinforced concrete beams strengthened with prestressed CFRP plates:** **1)** flexural fatigue performance	prestressed CFRP plates

58	**Structural Testing and Dissection of Carbon Fiber-Reinforced Polymer-Repaired Bridge Girders Taken Out of Service:** **1)** Durability and corrosion protection (brackish water environment and chloride contamination) **2)** Ultimate strength and CFRP/concrete bond	CFRP wraps
59	**Research progress on the flexural behaviour of externally bonded RC beams:** **1)** flexural strengthening, stiffness, ductility	Review (FRP)
60	**Shear strengthening of full-scale RC T-beams using textile-reinforced mortar and textile-based anchors:** **1)** Shear capacity **2)** End anchorage system	textile-reinforced mortar (TRM) jackets and textile-based anchors
61	**Extending the Fatigue Life of Reinforced Concrete T-Beams Strengthened in Shear with Externally Bonded FRP: Upgrading versus Repairing:1)** Fatigue performance of EB-CFRP beams strengthened in shear	externally bonded CFRP (EB-CFRP) sheets
62	https://www.youtube.com/watch?v=Ommd8_JOEV0&list=PL5JY3er6Wwbj6eMw7TWUK7l6XBkZRPyPe : -	CFRP sheets
63	**Behavior of reinforced concrete box beam with initial cracks repaired with basalt fiber-reinforced polymer sheet:** **1)** beams with initial flexural cracks **2)** stiffness and load carrying capacity	BFRP sheets
64	**Strengthening of Concrete Structures Using FRP Composites:** -	FRP
65	**Structural evaluation of reinforced concrete beams strengthened with innovative bolted/bonded advanced frp composites sandwich panels:** **1)** service and ultimate flexural behavior	bolted/bonded advanced frp composites sandwich panels

66	**FRCM and FRP composites for the repair of damaged PC girders:** **1)** durability	FRP and Fabric-reinforced-cementitious-matrix (FRCM)
67	**Ultimate Unbonded Tendon Stress in CFRP Strengthened Post-Tensioned Indeterminate I-Beams Cast with HSCs:** **1)** tendon stress	EB CFRP sheets
68	**Effect of FRP Wrapping on Fatigue Bond Behavior of Spliced Concrete Beams:** **1)** fatigue bond strength	FRP Wrapping
69	**Fatigue Bond Characteristics and Degradation of Near-Surface Mounted CFRP Rods and Strips in Concrete:** **1)** Fatigue Bond Characteristics	NSM CFRP rods and strips
70	**Nonlinear finite element modelling and parametric study of CFRP shear-strengthened prestressed concrete girders:** **1)** shear strengthening	EB CFRP
71	**Analytical Modeling of the Repair Impact-Damaged Prestressed Concrete Bridge Girders:**-	strand splices, fiber reinforcedpolymer (FRP) overlays, and fabric reinforced cementitious matrix (FRCM) overlays.
72	**Laboratory Investigation of Concrete Beam-End Treatments:** **1)** corrosion	Sikagard 62 (a high-build, protective, solvent-free, epoxy coating) concrete coatings
73	**Predicting Fatigue Service Life Extension of RC Bridges with Externally Bonded CFRP Repairs:** **1)** fatigue service life	EB CFRP

74	**Bond and flexural behavior of concrete elements strengthened with NSM CFRP laminate strips under fatigue loading:** **1)** long term performance under fatigue loading **2)** bond and flexural behavior	NSM CFRP laminate strips
75	**Fatigue Flexural Behaviour of Reinforced Concrete Beams with Non-Prestressed and Prestressed Basalt Fiber Reinforced Polymer Bars:** **1)** Fatigue Flexural Behaviour	Non-Prestressed and Prestressed BFRP
76	**Strengthening of RC beams using prestressed fiber reinforced polymers – A review:** **1)** flexural strength, fatigue life and the serviceability (review)	prestressed FRP
77	**Fatigue behavior of RC T-beams strengthened in shear with EB CFRP L-shaped laminates:** **1)** Fatigue behavior	EB CFRP L-shaped laminates
78	**REPAIR OF IMPACT-DAMAGED PRESTRESSED BRIDGE GIRDERS WITH STRAND SPLICES AND FABRIC REINFORCED CEMENTITIOUS MATRIX SYSTEMS:** **1)** impact damage	STRAND SPLICES AND FABRIC REINFORCED CEMENTITIOUS MATRIX SYSTEMS
79	**Fatigue performance of corroded reinforced concrete beams strengthened with CFRP sheets:** **1)** flexural fatigue performance	CFRP sheets
80	**Repairing/Strengthening of Bridges with Post-tensioned FRP Materials and Performance Evaluation:1)** flexural strengthening	prestressed CFRP laminates
81	**Effect of Corrosion Damage on Service Response of Bridge Girders Strengthened with Posttensioned NSM CFRP Strips:** **1)** service response (corrosion)	NSM CFRP strips

82	**Synthesis of DOT Use of Beam End Protection for Extending the Life of Bridges:** Synthesis study	beam end coatings and treatments
83	**Torsional Analysis of Multicell Concrete Box Girders Strengthened withCFRPUsing aModifiedSoftened TrussModel:** **1)** Torsional capacity	CFRP
84	**Performance of Concrete Beams Reinforced with Basalt FRP for Flexure and Shear:** **1)** shear and flexural strengthening	Basalt FRP (BFRP)
85	**Flexural Strengthening of RC Beams with an Externally Bonded Fabric-Reinforced Cementitious Matrix:** **1)** flexural strengthening	Externally Bonded Fabric-Reinforced Cementitious Matrix
86	**Modeling of the Flexural Fatigue Capacity of RC Beams Strengthened with FRP Sheets Based on Finite-Element Simulation:** **1)** Flexural Fatigue Capacity	FRP sheets
87	**Strengthening of shear critical RC beams with various FRP systems:** **1)** shear strengthening	CFRP, GFRP, and FRCM (fiber reinforced cementitious matrix) wraps
88	**Shear behavior of basalt fiber reinforced polymer (FRP) and hybrid FRP rods as shear resistance members:** **1)** shear strengthening	(FRP) and hybrid FRP rods
89	**Repair of Prestressed-Concrete Girders Combining Internal Strand Splicing and Externally Bonded CFRP Techniques:** Impact-damaged prestressed-concrete I-girders: **1)** Flexural capacity **2)** CFRP debonding **3)** Restore prestressing force **4)** increase residual capacity of the girder	hybrid strand-splice and EB-CFRP repair

90	**CFRP Shear Strengthening of Reinforced-Concrete T-Beams with Corroded Shear Links:1)** Shear Strengthening	(CFRP) sheets or embedded CFRP rods
91	**Design and Construction Guidelines for Strengthening Bridges using Fiber Reinforced Polymers (FRP):** -	EB FRP
92	**New Anchorage Technique for FRP Shear-Strengthened RC T-Beams Using CFRP Rope:** **1)** Shear-Strengthening	CFRP Rope
93	**Probabilistic Analysis of High Strength Concrete Girders Strengthened with CFRP:** -	CFRP
94	**Behavior of Laterally Damaged Prestressed Concrete Bridge Girders Repaired with CFRP Laminates Under Static and Fatigue Loading:** **1)** over-height vehicles collision	CFRP laminates
95	**Time-variant flexuralreliability of RC beams with externally bonded CFRP under combined fatigue-corrosion actions:** **1)** flexural reliability (corrosion, fatigue, aging) **2)** combined fatigue-corrosion actions	CFRPlaminates
96	**Fatigue behavior of RC T-beams strengthened in shear with CFRP sheets:** **1)** fatigue performance	CFRP sheets
97	**Repair using steel fiber reinforced polymer on US150 bridges:** **1)** durability (cracking and corrosion)	steel fiber reinforced polymer sheets (SFRP)

98	**Repair of I-65 Expressway Bridges Using Carbon Fiber Reinforced Polymer (CFRP) Composites:** **1)** Excessive translations in both vertical and horizontal directions	CFRP wraps
99	**Analytical fatigue prediction model of RC beams strengthened in flexure using prestressed FRP reinforcement:1)** flexural strengthening **2)** fatigue loading	prestressed FRP reinforcement
100	**Performance Evaluation of RC Beams Strengthened with an Externally Bonded FRP System under Simulated Vehicle Loads:** Transient vehicle loads present during the installation and curing: **1)** Bond performance between CFRP and concrete **2)** load-carrying capacity and ductility	CFRP sheets
101	**Self-Stressed Steel Fiber Reinforced Concrete as Negative Moment Connection for Strengthening of Multi-span Simply-Supported Girder Bridges:** **1)** cracking **2)** load-carrying capacity **3)** serviceability	Self-Stressed Steel Fiber Reinforced Concrete
102	**PRECRACKED RC T-BEAMS REPAIRED IN SHEAR WITH PRESTRESSED CFRP STRAPS:** **1)** shear strengthening	PRESTRESSED CFRP STRAPS
103	**Experimental Study on Full-Scale Pretensioned Bridge Girder Damaged by Vehicle Impact and Repaired with Fiber-Reinforced Polymer Technology:** **1)** Vehicle Impact damage (shear strengthening needed)	CFRP sheets
104	**Cohesive Model-Based Approach for Fatigue Life Prediction of Reinforced-Concrete Structures Strengthened with NSM FRP:** **1)** Fatigue Life	NSM FRP

105	**Research progress on the fatigue performance of RC beams strengthened in flexure using Fiber Reinforced Polymers:** **1)** flexural strengthening **2)** fatigue performance	(FRP) reinforcement
106	**Parametric Effects on Evaluation of an Impact-Damaged Prestressed Concrete Bridge Girder Repaired by Externally Bonded Carbon-Fiber-Reinforced Polymer Sheets:** **1)** impact damage	EB CFRP sheets
107	**Behavior of RC T-Beams Strengthened in Shear with CFRP under Cyclic Loading:1)** Shear strength under cyclic loading (fatiqgue life) **2)** CFRP debonding	EB-CFRP strips
108	**Novel cement-based composites for the strengthening and repair of concrete structures: General visions:** **1)** Ultimate load carrying capacity **2)** Shear load carrying capacity **3)** High deformability	high-performance fibre-reinforced cement based composites (HPFRCCs): textile-reinforced concrete (TRC) and strainhardening cement-based composites (SHCCs)
109	**Post-Damage Repair of Prestressed Concrete Girders:** **1)** Flexural and shear strength recovery **2)** Stiffness recovery	CFRP, GFRP, NSM metal rods
110	**UPDATED RESEARCH FOR COLLISION DAMAGE AND REPAIR OF PRESTRESSED CONCRETE BEAMS:** **1)** overheight vehicle collision	(FRP) based repair techniques
111	**Precracked reinforced concrete T-beams repaired in shear with bonded carbon fiber-reinforced polymer sheets:** **1)** shear strengthening	CFRP sheets

112	**ON THE REPAIR OF IMPACT-DAMAGED PRESTRESSED CONCRETE BRIDGE GIRDERS:** **1)** over-height vehicle impact	strand splices and applications of fiber reinforced polymers (FRP)
113	**The repair of damaged bridge girders with carbon-fiber reinforced polymer "CFRP" laminates:** Girders laterally damaged by overheight vehicle collisions: **1)** Restore flexural capacity (ultimate strength and displacement) under static and fatigue loading	CFRP laminates
114	**The Repair of Laterally Damaged Concrete Bridge Girders Using Carbon Fiber Reinforcing Polymers (CFRP):** **1)** Debonding problem **2)** Load carrying capacity **3)** Deflection	CFRP laminates
115	**Repair and Strengthening of Reinforced Concrete Beams:** Summary	Summary
116	**Structural behaviour of RC beams externally strengthened with FRP sheets under fatigue and monotonic loading:1)** fatigue and post-fatigue static behaviour	EB FRP sheets
117	**Shear-Strengthening of Reinforced & Prestressed Concrete Beams Using FRP: Part II – Experimental Investigation:** **1)** shear strengthening	CFRP strips
118	**Comparative durability analysis of CFRP-strengthened RC highway bridges:** **1)** durability (growth of live load, corrosion, aging)	CFRP laminates
119	**NSM shear strengthening technique with CFRP laminates applied in high-strength concrete beams with or without pre-cracking:** **1)** shear strengthening	NSM CFRP

120	**Strength And Durability Of Near-Surface Mounted CFRP Bars For Shear Strengthening Reinforced Concrete Bridge Girders:** **1)** shear strengthening	NSM CFRP
121	**Shear-strengthening of reinforced & prestressed concrete beams using FRP: Part I — Review of previous research:** **1)** Shear strengthening	FRP
122	https://www.youtube.com/watch?v=NSbpl9f0lO8: 1) shear and flexural strengthening	precured rigid fiber resin laminate strips and then carbon wrap flexible fabric
123	**Fatigue behavior of RC beams strengthened with prestressed NSM CFRP rods:** **1)** fatigue performance	prestressed NSM CFRP rods
124	**Coatings and Treatments for Beam Ends:** **1)** service life and durability	review, survey
125	**Behavior of prestressed concrete I-girders strengthened in shear with externally bonded fiber-reinforced-polymer sheets:** **1)** shear strengthening **2)** ultimate bearing capacity	CFRP sheets
126	**A new ductility model of reinforced concrete beams strengthened using Fiber Reinforced Polymer reinforcement:** **1)** ductility	FRP reinforcement
127	**Behavior of Various Anchorage Systems Used for Shear Strengthening of Concrete Structures with Externally Bonded FRP Sheets:1)** anchorage systems **2)** debonding failure **3)** shear strengthening	EB CFRP
128	**Phased Nonlinear Finite-Element Analysis of Precracked RC T-Beams Repaired in Shear with CFRP Sheets:** **1)** shear strengthening	CFRP sheets

129	**Fatigue of reinforced concrete beams strengthened with externally post-tensioned CFRP tendons:** **1)** fatigue performance	externally post-tensioned CFRP tendons
130	**Nonlinear finite element modeling of RC beams strengthened with NSM FRP rods:** **1)** flexural strengthening	NSM FRP rods
131	**Limits of Application of Externally Bonded CFRP Repairs for Impact-Damaged Prestressed Concrete Girders:** **1)** impact damage	EB CFRP
132	**Proposed evaluation and repair procedures for precast, prestressed concrete girders with end-zone cracking:** **1)** end zone cracks	epoxy injection
133	**GUIDE TO RECOMMENDED PRACTICE FOR THE REPAIR OF IMPACT-DAMAGED PRESTRESSED CONCRETE BRIDGE GIRDERS:** **1)** vehicular impact damage	EB CFRP, post tensioned steel hybrid with strand splice
134	**Reliability Assessment of FRP-Strengthened Concrete Bridge Girders in Shear:** **1)** shear strengthening	FRP
135	**Behavior of full-scale RC T-beams strengthened in shear with externally bonded FRP sheets:** **1)** Shear strengthening	EB-FRP
136	**Shear strengthening of RC T-beams with externally side bonded GFRP sheet:** **1)** shear strengthening	epoxy bonded glass fiber fabric
137	**Shear Strengthening of RC Beams with Externally Bonded FRP Composites: Effect of Strip-Width-to-Strip-Spacing Ratio:1)** shear strengthening	EB-FRP strips and sheets
138	**Carbon fiber shear retrofit of forty-two-year-old AASHTO I-shaped girders:** **1)** shear retrofit	CFRP

139	**Fatigue performance of reinforced concrete beams strengthened with CFRP sheets:** **1)** Fatigue performance	CFRP sheets
140	**Fatigue performance of reinforced concrete beams with externally bonded CFRP reinforcement:** **1)** Fatigue performance	EB CFRP
141	**Three-Dimensional Nonlinear Finite-Element Analysis of Prestressed Concrete Beams Strengthened in Shear with FRP Composites:** **1)** shear strengthening	FRP
142	**Fatigue performance of reinforced concrete beams with externally bonded CFRP reinforcement:** **1)** flexural fatigue performance	EB CFRP fabrics
143	**Flexural strengthening of reinforced concrete beams using prestressed, near-surfacemounted CFRP bars:** **1)** Flexural strengthening	NSM CFRP bars
144	**Texas' Use of CFRP to Repair Concrete Bridges:** **1)** mpact-damage **2)** flexural strengthening **3)** shear strengthening **4)** ductility	EB CFRP
145	**Seismic Rehabilitation of RC Bridges by Using FRP and SRP: Case Study of a Bridge in the South of Italy:** **1)** load carrying capacity	FRP and Steel Reinforced Polymer spikes (SRP)
146	**CFRP Repair of Corroded Girder: Four Years of Service:** **1)** corrosion	CFRP

147	**REPAIR OF CRACKED PRESTRESSED CONCRETE GIRDERS, I-565, HUNTSVILLE, ALABAMA:1)** Shear and flexural strength **2)** performance under daily truck loads and temperature variations	FRP
148	**Design for FRP Systems for Strengthening Concrete Girders in Shear:** **1)** shear strengthening	FRP
149	**Comprehensive Study on Using Externally Bonded FRP Composites for the Rehabilitation of Reinforced Concrete T-Beam Bridges:** **1)** long-term performance under static and fatigue loads	EB FRP Composites
150	**Performance of RC Beams Strengthened Using Prestressed NSM-CFRP Strips Subjected to Fatigue Loading:** **1)** fatigue loading	Prestressed NSM-CFRP Strips
151	**Bond analysis of corroded reinforced concrete beams under monotonic and fatigue loads:** **1)** fatigue bond behaviour	CFRP
152	**Fatigue of Concrete Beams Strengthened with Glass-Fiber Composite under Flexure:** **1)** fatigue performance	GFRP
153	**District 3-0 Investigation of Fiber Wrap Technology for Bridge Repair and Rehabilitation (Phase III):** -	-
154	**Effect of Concrete Substrate Repair Methods for Beams Aged by Accelerated Corrosion and Strengthened with CFRP:** Concrete substrate repair: **1)** long-term performance and durability **2)** flexural strengthening	EB-CFRP, polymer crack-injection and replacement of concrete cover with polymer-modified concrete (PMC) containing corrosion inhibitor

155	https://www.youtube.com/watch?v=rV2n9u4QeKw: -	FRP strips
156	**Prestressed CFRP for Strengthening of Reinforced Concrete Structures: Recent Developments at Empa, Switzerland:1)** flexural and shear strengthening	Prestressed CFRP strips
157	**Fatigue Performance of RC Beams Strengthened in Shear with CFRP Fabrics:** **1)** shear strengthening **2)** fatigue performance	EB CFRP
158	**Fatigue Flexural Behavior of Corroded Reinforced Concrete Beams Repaired with CFRP Sheets:** **1)** Fatigue Flexural Behavior	CFRP Sheets
159	**Rehabilitation of Reinforced Concrete T-beam Structures using Externally Bonded FRP Composites:** **1)** long-term performance under static and fatigue loads	externally bonded FRP composites
160	**REPAIR OF PRESTRESSED CONCRETE GIRDER ENDS AND GIRDER COLLISION REPAIR:** **1)** shear strength deficiencies related to end cracking **2)** flexural strength deficiencies related to vehicular collision	external post-tensioned carbon fiber rods
161	**FRP REPAIR OF CORROSION-DAMAGED CONCRETE BEAMS – WATERLOO EXPERIENCE:** **1)** Durability (corrosion cracking)	FRP
162	**Strengthening and repair of RC beams with fiber reinforced concrete:** **1)** mid-span displacement (serviceability) **2)** Ultimate load-bearing capacity	FRP jacket or High Performance Fiber Reinforced Concrete (HPFRC)

163	**FRP Strengthening of Full-Scale PC Girders:** **1)** overheight vehicles or construction equipment impact	EB CFRP laminates
164	**Retrofitting Precast Bridge Beams with Carbon Fiber-Reinforced Polymer Strips for Shear Capacity:** **1)** Shear capacity **2)** Ductility	CFRP strips
165	**Strengthening RC Beams in Flexure Using New Hybrid FRP Sheet/Ductile Anchor System:1)** Ductility **2)** Flexural capacity	Hybrid FRP sheet/ductile anchor system
166	**Repair Method for Prestressed Girder Bridges:** **1)** flexural strength **2)** Ductility	(CFRP) strips, CFRP fabric, near-surface mounted (NSM) CFRP, prestressed CFRP, post-tensioned CFRP, strand splicing and external steel post-tensioning
167	**Numerical Analysis of Continuous Beams Prestressed with External Tendons:** **1)** rotation capacity of plastic hinges	prestressed with bonded or external tendons
168	**Strengthening of prestressed concrete girders with composites: Installation, design and inspection:** **1)** load carrying capacity **2)** Serviceability	(FRP) or steel reinforced polymer (SRP)
169	**Effective methods of using CFRP bars in shear strengthening of concrete girders:** **1)** shear strengthening **2)** delamination, debonding or fracture of FRP	NSM CFRP bars
170	**Fatigue Behavior of RC Beams Strengthened with NSM CFRP Rods:** **1)** fatigue behavior	NSM CFRP Rods

171	**Fatigue Performance of CFRP Strengthened RC Beams under Environmental Conditioning and Sustained Load:** **1)** fatigue performance	CFRP
172	**Flexural Strengthening of Real-Scale RC and PRC Beams with End-Anchored Pretensioned FRP Laminates:** **1)** Flexural Strengthening	Pretensioned FRP Laminates
173	**STRUCTURAL REPAIR OF PRESTRESSED CONCRETE BRIDGE GIRDERS:** **1)** flexural strengthening	(CFRP) strips, CFRP fabric, (NSM) CFRP, prestressed CFRP, post-tensioned CFRP, strand splicing and external steel post-tensioning
174	**ENVIRONMENTAL DURABILITY OF REINFORCED CONCRETE DECK GIRDERS STRENGTHENED FOR SHEAR WITH SURFACE-BONDED CARBON FIBER-REINFORCED POLYMER :1)** shear strengthening **2)** durability **3)** fatigue	CFRP
175	**Shear Repair Methods for Conventionally Reinforced Concrete Girders and Bent Caps:** **1)** shear repair	epoxy crack injection, internal steel bars, external steel bars, surface bonded CFRP, and near-surface mount CFRP
176	**Shear Repair Methods for Conventionally Reinforced Concrete Girders and Bent Caps:** **1)** shear strengthening **2)** aesthetics **3)** durability	epoxy crack injection, internal steel bars, external steel bars, surface bonded CFRP, and near-surface mount CFRP

177	**Shear Strengthening of RC T-Beams Using Mechanically Anchored Unbonded Dry Carbon Fiber Sheets:** **1)** shear strengthening	Mechanically Anchored Unbonded Dry Carbon Fiber Sheets
178	**Fatigue Behavior of RC Beams Strengthened with NSM CFRP Rods:** **1)** fatigue life	NSM CFRP Rods
179	**Repair of Bridge Girder Damaged by Impact Loads with Prestressed CFRP Sheets:** damaged by frequent impact loads of heavy trucks: **1)** flexural behavior **2)** serviceability	prestressed CFRP sheets
180	**Live Load Distributions on an Impact-Damaged Prestressed Concrete Girder Bridge Repaired Using Prestressed CFRP Sheets:** **1)** impact damage	CFRP sheets
181	**Effects of Gradually Anchored Prestressed CFRP Strips Bonded on Prestressed Concrete Beams:** **1)** flexural post-strengthening	CFRP strips
182	**Fracture Evaluation of GFRP–Concrete Interfaces for Freeze–Thaw and Wet-Dry Cycling:** **1)** durability	EB GFRP fabrics
183	**Experimental Study of Intermediate Crack Debonding in Fiber-Reinforced Polymer Strengthened Beams:1)** Intermediate Crack Debonding	FRP
184	**Strengthening reinforced concrete bridges in New Mexico using fiber reinforced polymers : a compendium of four reports:** **1)** shear and flexural strengthening	CFRP
185	**Ductility and Cracking Behavior of Prestressed Concrete Beams Strengthened with Prestressed CFRP Sheets:** **1)** flexural strengthening	CFRP sheets

186	**Structural Performance of RC Beams Poststrengthened with Carbon, Aramid, and Glass FRP Systems:** **review:** **1)** load carrying capacity	Poststrengthened with Carbon, Aramid, and Glass FRP Systems
187	**Flexural Strengthening of RC Beams with Prestressed CFRP Sheets: Development of Nonmetallic Anchor Systems:** -	prestressed CFRP sheets
188	**Fatigue of Diagonally Cracked RC Girders Repaired with CFRP:** **1)** anticipated life of FRP repairs for shear strengthening of bridge members under repeated service loads (fatigue life)	EB-CFRP laminates
189	**Fatigue Behavior of Externally Strengthened Concrete Beams with Fiber-Reinforced Polymers: State of the Art:** **1)** Fatigue life as a function of the applied load range, bond behavior of externally bonded FRP, damage accumulation, crack propagation, size effects, residual strength, and failure modes	FRP
190	**Sources of End Zone Cracking of Pretensioned Concrete Girders:** **1)** crack types and repair methods	-
191	**FRP Composites for Reinforced and Prestressed Concrete Structures:** **1)** Shear strengthening **2)** Flexural strengthening	FRP
192	**Evaluating Fiber Reinforced Polymer Repair Method for Cracked Prestressed Concrete Bridge Members Subjected to Repeated Loadings Phase 2:1)** fatigue performance **2)** Flexural strengthening	CFRP wraps
193	**40-Year-old full-scale concrete bridge girder strengthened with prestressed CFRP plates anchored using gradient method:** **1)** flexural strengthening	prestressed CFRP plates

194	**Response of CFRP-strengthened beams under fatigue with different load amplitudes:** **1)** fatigue performance	CFRP
195	**Flexural behavior of aged prestressed concrete girders strengthened with various FRP systems:** **1)** flexural behavior	CFRP
196	**Monotonic and Fatigue Flexural Behaviour of RC Beams Strengthened with Prestressed NSM CFRP Rods:** **1)** monotonic and fatigue flexural strength	non-prestressed and prestressed NSM CFRP Rods
197	**Torsional Capacity of CFRP Strengthened Reinforced Concrete Beams:** **1)** torsional strengthening	FRP
198	**FRP Composites for Retrofitting of Existing Civil Structures in Europe: State-of-the-Art Review:** Review	FRP
199	**Experimental study of FRP-strengthened RC bridge girders subjected to fatigue loading:** **1)** service load-carrying capacity **2)** Debonding **3)** Fatigue resistance	CFRP and GFRP saturated in an epoxy resin matrix
200	**ANALYTICAL MODELING OF FLEXURAL DEBONDING IN CFRP STRENGTHENED REINFORCED OR PRESTRESSED CONCRETE BEAMS:** **1)** FLEXURAL DEBONDING	CFRP
201	**Long-Term Durability of State Street Bridge on Interstate 80:1)** Durability (environmental comditions)	CFRP
202	**Flexural Fatigue Behavior of Reinforced Concrete Beams Strengthened with FRP Fabric and Precured Laminate Systems:** **1)** flexural strengthening	CFRP

203	**Analysis and Design Procedure for FRP-Strengthened Prestressed Concrete T-Girders Considering Strength and Fatigue:** **1)** flexural strengthening **2)** fatigue **3)** serviceability	CFRP
204	**Shear repair of P/C box beams using carbon fiber reinforced polymer (CFRP) fabric:** **1)** shear strengthening	EB-CFRP fabric
205	**Nonlinear Finite Element Analysis of a FRP-Strengthened Reinforced Concrete Bridge:** **1)** Girder capacity **2)** Failure mode	FRP
206	**Concrete Beams Strengthened with Prestressed Near Surface Mounted CFRP:** **1)** ultimate load capacity **2)** midspan deflection	prestressed NSM CFRP
207	**Flexural behavior of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix:** **1)** flexural strengthening	CFRP sheets bonded with an inorganic matrix
208	**Behavior of Prestressed Concrete Strengthened with Various CFRP Systems Subjected to Fatigue Loading:** **1)** fatigue behavior	CFRP
209	**Capabilities of Diagonally-Cracked Girders Repaired with CFRP :** **1)** shear strengthening	CFRP
210	**Full-Scale Experimental Investigation of Repair of Reinforced Concrete Interstate Bridge Using CFRP Materials:** **1)** fatigue **2)** debonding **3)** ductility	CFRP systems
211	**Cyclic Behavior of RC Beams Strengthened with Carbon Fiber Sheets Bonded by Inorganic Matrix:1)** fatigue performance	carbon fiber sheets bondedby an inorganic matrix

212	**Repair and Strengthening of Highway Bridges with FRP:** **1)** flexural strengthening	CFRP
213	**VALUE ENGINEERING AND COST EFFECTIVENESS OF VARIOUS FIBER REINFORCED POLYMER (FRP) REPAIR SYSTEMS :** **1)** impact damaged **2)** fatigue loading	FRP
214	**Experimental study and analysis of RC beams strengthened with CFRP laminates under sustaining load:** **1)** flexural strengthening	CFRP laminates
215	**Behavior of Reinforced Concrete T-Beams Strengthened in Shear with Carbon Fiber-Reinforced Polymer— An Experimental Study:** **1)** shear strengthening	CFRP
216	**REPAIR OF IMPACT-DAMAGED PRESTRESSED CONCRETE BRIDGE GIRDERS USING CARBON FIBER REINFORCED POLYMER (CFRP) MATERIALS:** Over-height vehicles impact damage: **1)** Flexural strengthening and **2)** Shear strengthening	CFRP sheets
217	**Repair of Bridge Girders with Composites: Experimental and Analytical Validation:** **1)** Flexural capacity **2)** deflections **3)** failure modes	EB-CFRP
218	**Fatigue Tests of Reinforced Concrete Beams Strengthened Using Carbon Fiber-Reinforced Polymer Composites:** **1)** fatigue behavior	EB-CFRP
219	**Fatigue Behavior of Prestressed Concrete Bridge Girders Strengthened with Various CFRP Systems:** **1)** fatigue performance **2)** ultimate capacity	CFRP

220	**Comparison of Three Flexural Retrofit Systems under Monotonic and Fatigue Loads:1)** Flexural Retrofit **2)** Fastener development	CAA, NSM, and PAF FRP retrofit systems
221	**Concrete Beams Exposed to Live Loading during Carbon Fiber Reinforced Polymer Strengthening:** **1)** Live Loading during strengthening	CFRP laminates, NSM reinforcement
222	**Strength-Fatigue Behavior of Fiber Reinforced PolymerStrengthened Prestressed Concrete T-Beams:** **1)** fatigue performance	CFRP
223	**Fatigue Behavior of Reinforced Concrete Beams Strengthened with Different FRP Laminate Configurations:** **1)** fatigue behavior	FRP laminates
224	**Flexural Fatigue Behavior of Reinforced Concrete Beams Strengthened with FRP Fabric and Precured Laminate Systems:** **1)** flexural strengthening	CFRP fabrics, FRP precured laminates
225	**REPAIR OF THE UPHAPEE CREEK BRIDGE WITH FRP LAMINATES:** **1)** flexural capacity	EB FRP strips
226	**Postrepair Fatigue Performance of FRP-Repaired Corroded RC Beams: Experimental and Analytical Investigation:** **1)** Postrepair Fatigue Performance	FRP sheets
227	**Control of Corrosion-Induced Damage in Reinforced Concrete Beams Using Carbon Fiber-Reinforced Polymer Laminates:** **1)** Corrosion resistance (uniform corrosion and shear-span corrosion)	CFRP laminates
228	**Rehabilitation techniques for concrete bridges:** Synthesis study: **1)** corrosion damage at beam ends	sealers, epoxy coatings, patching, polymer (resin) coatings and fiber-reinforced polymer (FRP) wraps.

229	**Evaluating FRP repair method for cracked prestressed concrete bridge members subjected to repeated loadings phase 1:** **1)** shear and flexural strengthening	CFRP sheets
230	**STATIC AND FATIGUE PERFORMANCE OF 40 YEAR OLD PRESTRESSED CONCRETE GIRDERS STRENGTHENED WITH VARIOUS CFRP SYSTEMS:1)** static and fatigue behavior	CFRP
231	**JOINT KDOT-MODOT: EVALUATION OF FRP REPAIR METHOD FOR CRACKED PC BRIDGE MEMBERS :** **1)** Shear strength for under-reinforced bridge girders **2)** Flexural strengthening	CFRP
232	**Fatigue Behavior of Reinforced Concrete Beams Strengthened with Carbon Fiber Reinforced Plastic Laminates:** **1)** flexural fatigue behavior	CFRP laminates
233	**Evaluation of Prestressed Concrete Girders Strengthened with Carbon Fiber Reinforced Polymer Sheets:** **1)** shear and flexural strengthening	CFRP sheets
234	**Potential Retrofit Methods for Concrete Channel Beam Bridges Using Glass Fiber Reinforced Polymer:** **1)** Flexural capacity	GFRP fabric wrap and GFRP spray
235	**Effective Structural Concrete Repair:** **1)** over-height vehicle impacts **2)** deterioration	patching and CFRP
236	**Strengthening of an Impact-Damaged PC Girder:** Impact-Damaged girders: **1)** Flexural capacity	CFRP
237	**Shear Strengthening of a PC Bridge Girder with NSM CFRP Rectangular Bars:** **1)** Shear strengthening **2)** Flexural strengthening	NSM CFRP Rectangular Bars and externally bonded pre-cured CFRP laminates

238	**Flexural Retrofitting of Concrete Bridge Beams Using CFRP Fabrics:** **1)** Flexural strengthening **2)** Debonding failure (end debond and mid-span debond)	CFRP fabrics
239	**Fatigue Behavior of Carbon Fiber Reinforced Polymer-Strengthened Reinforced Concrete Bridge Girders:** **1)** flexural fatigue performance	one-dimensional FRP composite
240	**MICROWAVE NDE OF RC BEAMS STRENGTHENED WITH CFRP LAMINATES CONTAINING SURFACE DEFECTS AND TESTED UNDER CYCLIC LOADING:1)** Flexural and shear strengthening **2)** Delamination	EB CFRP laminates
241	**Overheight Vehicle Collisions with Highway Bridges:** **1)** Overheight Vehicle Collisions	survey
242	**Experimental investigation into flexural retrofitting of reinforced concrete bridge beams using FRP composites:** **1)** flexural retrofitting **2)** End cover separation and shear crack debond	FRP composites
243	**Bond Mechanism of NSM FRP Bars for Flexural Strengthening of Concrete Structures:** **1)** Flexural Strengthening **2)** Bond Mechanism	NSM FRP Bars
244	**Near-Surface-Mounted Fiber-Reinforced Polymer Reinforcements for Flexural Strengthening of Concrete Structures:** **1)** Flexural Strengthening	NSM FRP
245	**EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF REPAIRED AND STRENGTHENED REINFORCED CONCRETE STRUCTURAL ELEMENTS UTILIZING CFRP:** **1)** Shear and flexural strength **2)** slip failure	CFRP sheets

246	**Repair of Damaged Prestressed Concrete Bridges Using CFRP:** **1)** impact damage	CFRP
247	**Investigation of Bond in Concrete Structures Strengthened with Near Surface Mounted Carbon Fiber Reinforced Polymer Strips:** **1)** bond mechanism	NSM CFRP strips
248	**Rapid strengthening of reinforced concrete bridges:** **1)** Ultimate load bearing capacity	FRP strips (Mechanically Fastened (MF) Fiber-Reinforced Polymer (MF-FRP) method)
249	**Effectiveness of FRP for Strengthening Concrete Bridges:1)** flexural strengthening	NSM FRP bars and strips, EB FRP sheets and strips
250	**Flexural Reliability of Reinforced Concrete Bridge Girders Strengthened with Carbon Fiber-Reinforced Polymer Laminates:** **1)** flexural strengthening	CFRP laminates
251	**Performance of Reinforced Concrete T-Girders Strengthened in Shear with Carbon Fiber-Reinforced Polymer Fabric:** **1)** shear strengthening	epoxy-bonded bidirectional CFRP fabric
252	**Strengthening Highway Bridges with CFRP Composites:** **1)** load carryig capacity	CFRP Composites
253	**Strengthening of casilina bridge with carbon bre reinforced polymer sheets:** **1)** flexural strengthening	CFRP sheets

254	**An experimental study on the flexural behavior of RC beams with cementitious repair materials:** **1)** Flexural strengthening in the tension zone (bending capacity) **2)** deflection **3)** ductility index **4)** failure mode **5)** crack developement	Polymer Cementitious Mortar and Cement Mortar
255	**Static Behavior of 40 Year-Old Prestressed Concrete Bridge Girders Strengthened with Various FRP Systems:** **1)** ultimate strength	CFRP
256	**Upgrading Torsional Resistance of Reinforced Concrete Beams Using Fiber-Reinforced Polymer:** **1)** torsional strengthening	FRP fabric
257	**STRENGTH AND DUCTILITY OF RC BEAMS REPAIRED WITH BONDED CFRP LAMINATES:** **1)** strength and ductility	EB-CFRP laminate
258	**FATIGUE BEHAVIOR OF RC BEAMS STRENGTHENED WITH GFRP SHEETS:** **1)** fatigue performance	GFRP sheets
259	**RESPONSE OF RC BEAMS STRENGTHENED WITH CFRP LAMINATES AND SUBJECTED TO A HIGH RATE OF LOADING:1)** high rate loading	CFRP LAMINATES
260	**Static and Fatigue Analyses of RC Beams Strengthened with CFRP Laminates:** **1)** Short term behavior (flexural capacity) **2)** Fatigue response	CFRP laminates
261	**CONCRETE BEAMS STRENGTHENED WITH EXTERNALLY BONDED FRP PLATES:** -	EB-FRP plates
262	**STRENGTHENING OF IMPACT-DAMAGED BRIDGE GIRDER USING FRP LAMINATES:** **1)** over height impact damage (flexural capacity)	CFRP laminates

263	**Repair and Strengthening of Impacted PC Girders on Bridge A4845 Jackson County, Missouri:** **1)** long-term bond durability	externally bonded FRP reinforcement
264	**SIGNIFICANCE OF MIDSPAN DEBONDING FAILURE IN FRP-PLATED CONCRETE BEAMS:** **1)** flexural strengthening	adhesively-bonded FRP plates
265	**External steel plate systems for the shear strengthening of reinforced concrete beams:** **1)** shear strengthening	attaching steel plates
266	**Strengthening of an Impacted PC Girder on Bridge A10062, St Louis County, MO:** **1)** flexural strengthening	EB-FRP reinforcement
267	**Flexural Strengthening of Reinforced Concrete Beams by Mechanically Attaching Fiber-Reinforced Polymer Strips:** **1)** flexural strengthening	FRP strips
268	**Performance of CFRP Strengthened Reinforced Concrete (RC) Beams in the presence of delaminations and Lap Splices under Fatigue Loading:** **1)** load carrying capacity **2)** Serviceability **3)** fatigue	EB CFRP sheets
269	**Prestressed fibre-reinforced polymer laminates for strengthening structures:** **1)** serviceability (deflections, crack width) **2)** ultimate capacity **3)** shear capacity	EB FRP laminates
270	**Flexural Strengthening with Carbon Fiber-Reinforced Polymer Composites of Preloaded Full-Scale Girders:1)** Flexural Strengthening	epoxy-bonded CFRP laminates
271	**Application of FRP laminates for strengthening of a reinforced-concrete T-beam bridge structure:** **1)** Integrity of the steel reinforcing	bonding FRP laminates

272	**CFRP-STRENGTHENED AND CORRODED RC BEAMS UNDER MONOTONIC AND FATIGUE LOADS:** **1)** corrosion **2)** flexural strengthening	CFRP sheets
273	**Shear behavior of reinforced concrete T-beams with externally bonded fiber-reinforced polymer sheets:** **1)** shear strengthening	EB (uniaxial glass/uniaxial carbon/triaxial glass) FRP
274	**Prestressed FRP sheets for poststrengthening reinforced concrete beams:** **1)** external poststrengthening	CFRP SHEETS (prestressed and nonprestressed)
275	**Repair and Strengthening of Concrete Structures Through Application of Corrective Posttensioning Forces with Shape Memory Alloys:** **1)** shear strength at longitudinal bar **cutoff locations**	SMA
276	**FIELD PERFORMANCE OF FRP BRIDGE REPAIRS:** **1)** Reinforcing bar stresses **2)** vertical midspan deflections	EB-FRP
277	**Behavior of full-scale reinforced concrete beams retrofitted for shear and ¯exural with FRP laminates:** **1)** shear and flexural strengthening	FRP laminates
278	**The use of externally bonded CFRP sheets for shear strengthening of I-shape prestressed concrete bridge girders:** **1)** shear strengthening	CFRP sheets
279	**Composite Materials in Bridge Repair:** **1)** bending and shear strengthening	CFRP strips and sheets, pre-stressed CFRP strips, CFRP cables, non-laminated CFRP straps
280	**Prestressed Concrete Beam End Repair :1)** shear strengthening	patch concrete

281	**IMPACT LOADING OF CONCRETE BEAMS EXTERNALLY STRENGTHENED WITH CFRP LAMINATES:** **1)** flexural strengthening	EB CFRP laminates
282	**Fatigue performance of concrete beams strengthened with CFRP plates:** **1)** fatigue performance	CFRP
283	**Repair and strengthening of reinforced concrete beams using CFRP laminates:** **1)** bending and shear behavior **2)** durability	CFRP
284	**Shear Strengthening of AASHTO Bridge Girders Using Carbon Fiber Reinforced Polymer Sheets:** **1)** shear strengthening	CFRP sheets
285	**An experimental study of the failure modes of reinforced concrete beams strengthened with prestressed carbon composite plates:** -	EB CFRP plates (with and without prestress)
286	**The strengthening and deformation behaviour of reinforced concrete beams upgraded using prestressed composite plates:** **1)** ultimate capacity **2)** deformation	prestressed EB CFRP plates
287	**Rehabilitation of a Reinforced Concrete Bridge Using FRP Laminates:** **1)** loss of load capacity	CFRP and GFRP and AFRP (aramid) laminates
288	**SHEAR AND FLEXURAL STRENGTHENING OF RIC BEAMS WITH CARBON FIBER SHEETS:** **1)** flexural and shear strengthening	thin CFRP sheets
289	**Strengthening of Concrete Members with Advanced Composite Materials:** **1)** ultimate resistance	extemal post-tensioning using CFRP cables, bonding composite straps on the tension side of the members

290	**Repair of impact damaged prestressed bridge girder using a variety of materials and placement methods:** **1)** impact damage	a variety of materials!!
291	**Fatigue Behavior of Reinforced Concrete Beams Strengthened with Different FRP Laminate Configurations:1)** fatigue behavior	FRP laminates
292	**Strengthening of concrete beams using fiber-reinforced platics:** **1)** increase in rigidity and strength **2)** Corrosion and mechanical behavior	externally bonded fiber reinforced plastic
293	**CURRENT PRACTICE IN THE REPAIR OF PRESTRESSED BRIDGE GIRDERS:** **1)** impact damage	synthesis study
294	**Strengthening of reinforced concrete beams with composite materials: theoretical study:** **1)** flexural strengthening	composite thin plates
295	**Concrete bridge protection, repair, and rehabilitation relative to reinforcement corrosion: A methods application manual:** **1)** chloride-induced corrosion of the reinforcing steel (for increasing service life) **2)** concrete removal methods	patching with po:rtland cement concrete, polymer concrete, and high-early-strength hydraulic cement concretes and Shotcreting methods
296	**Reusability and impact damage repair of twenty-year-old AASHTO type III girders:** **1)** impact damage	internal strand splice steel, high strength rods, hairpin epoxy, patch concrete
297	**RC Beams Strengthened with GFRP Plates. I: Experimental Study:** **1)** Flexural strength	GFRP plates

298	**The Cause of Cracking in Post-Tensioned Concrete Box Girder Bridges and Retrofit Procedures:** **1)** cracking in post tensioned girders (shear and flexural cracking)	epoxy or mortar injection