Applicable NDT Methods for Inspection of FRP Reinforced/Strengthened Concrete Elements

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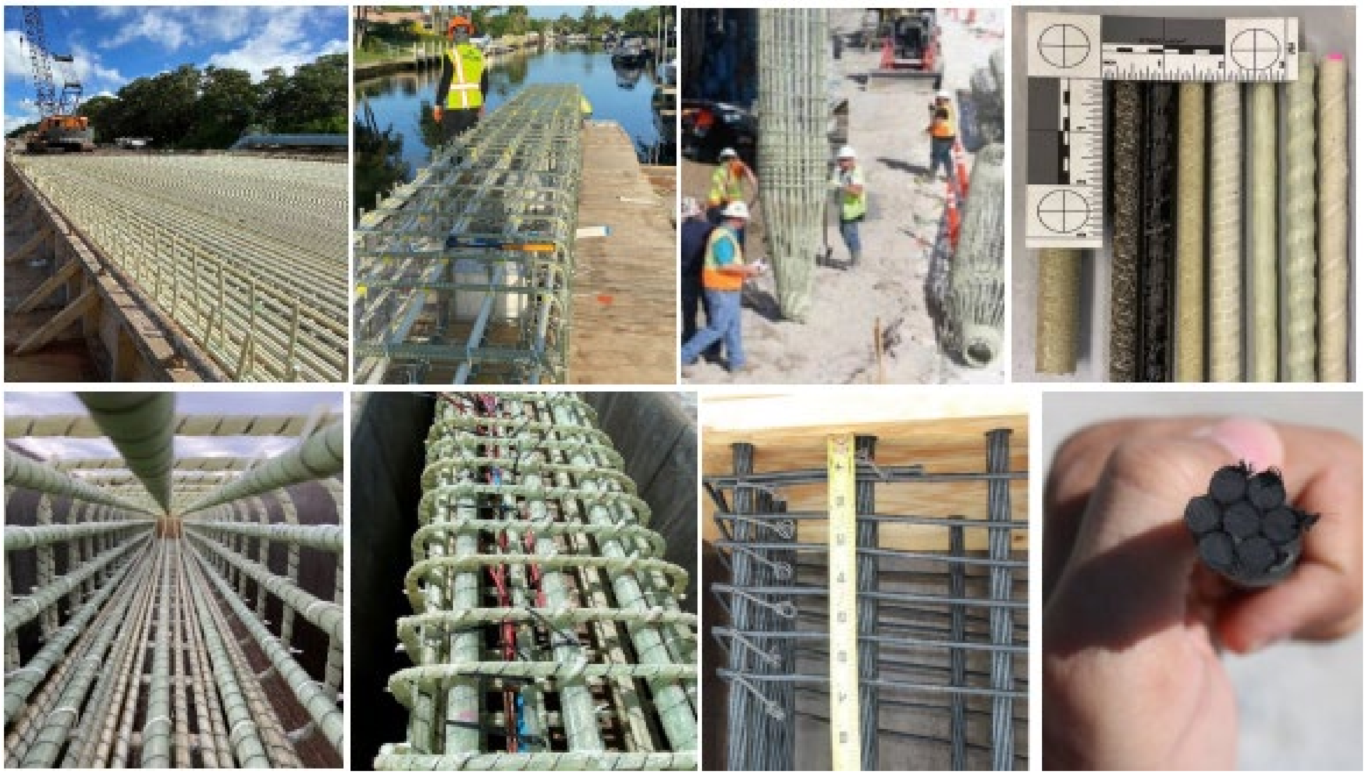
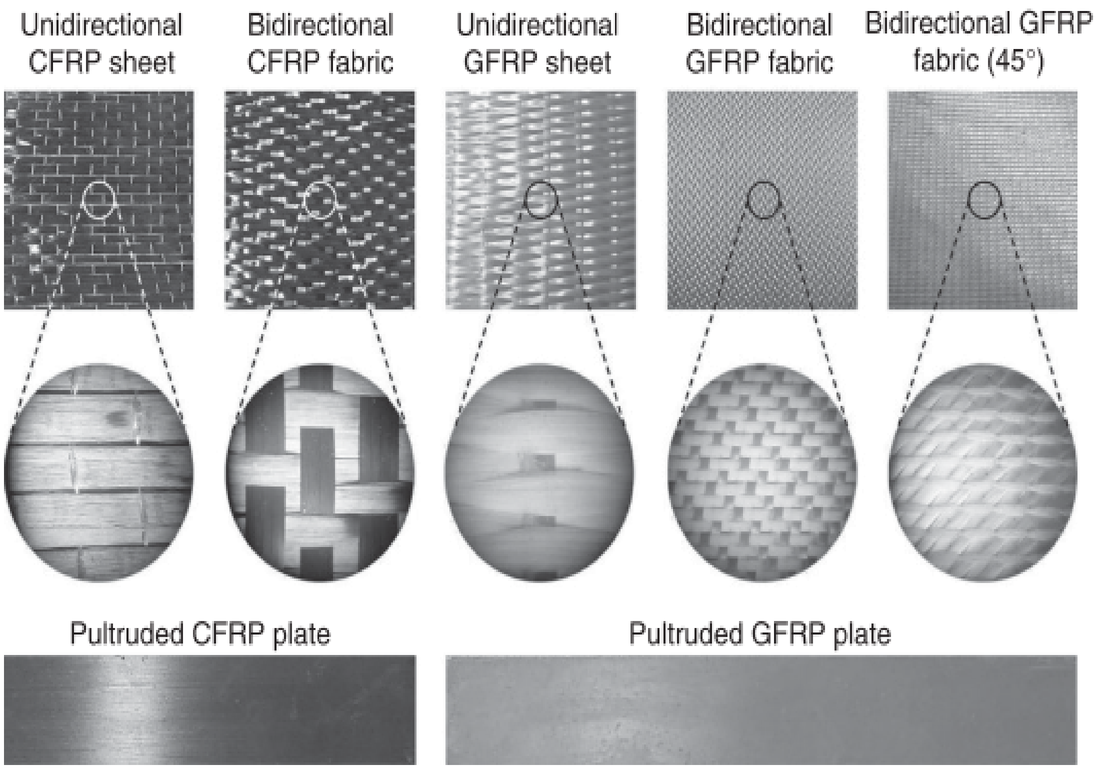
Application – Internal (FRP Reinforced)

- Embedded FRP rebars/strands (GFRP-glass, CFRP-carbon, BFRP-basalt)

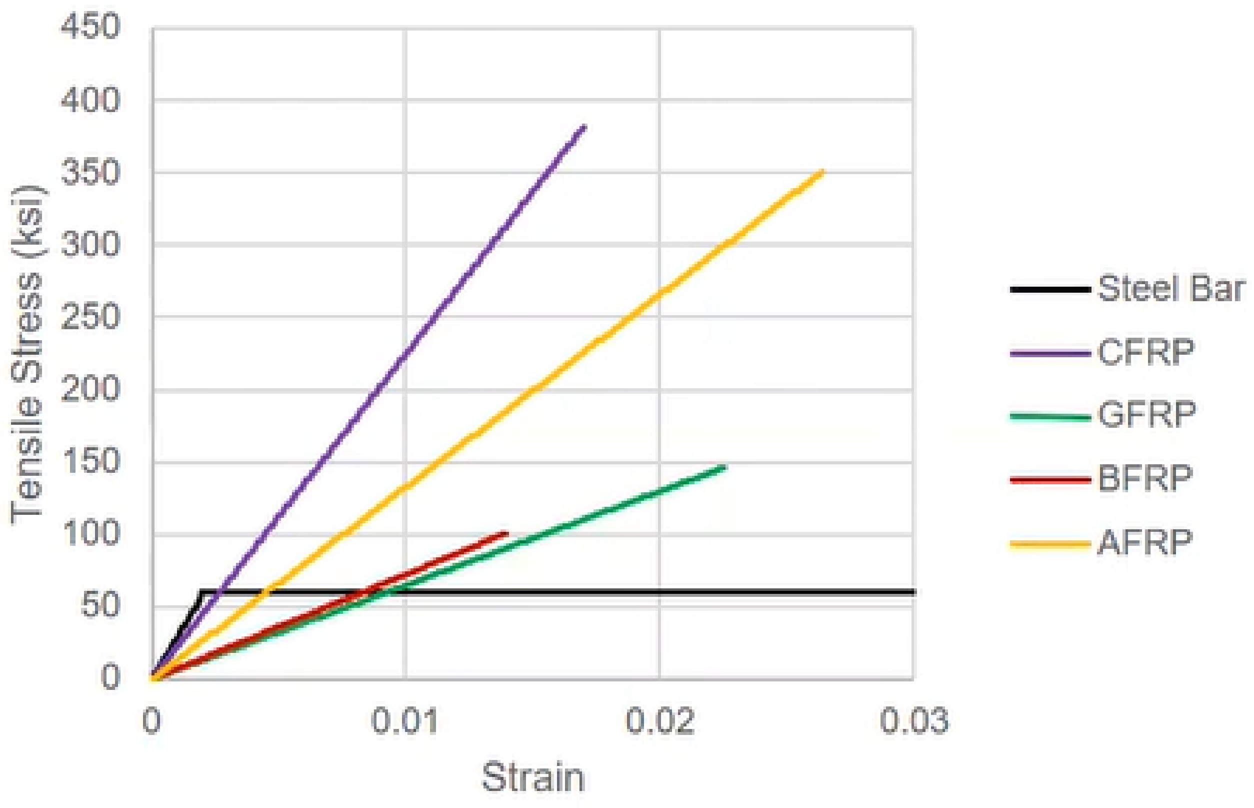


Application – External (FRP Strengthened)

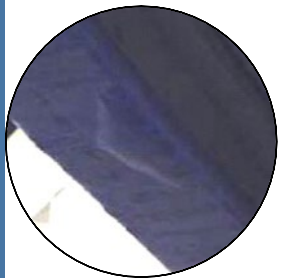


Advantages

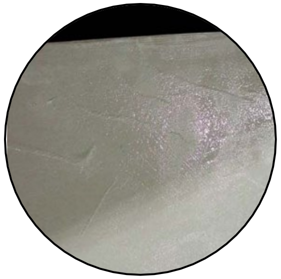
- Corrosion resistance
- Higher strength
- Lighter weight



Defects in External Application

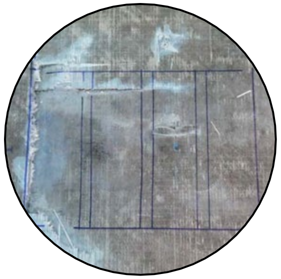


Blisters



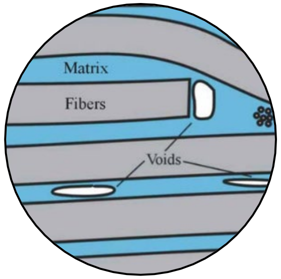
Wrinkling

Scratches

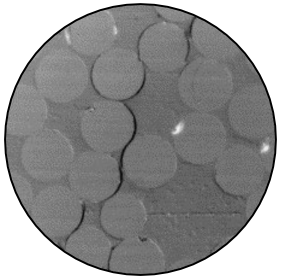


Discoloration

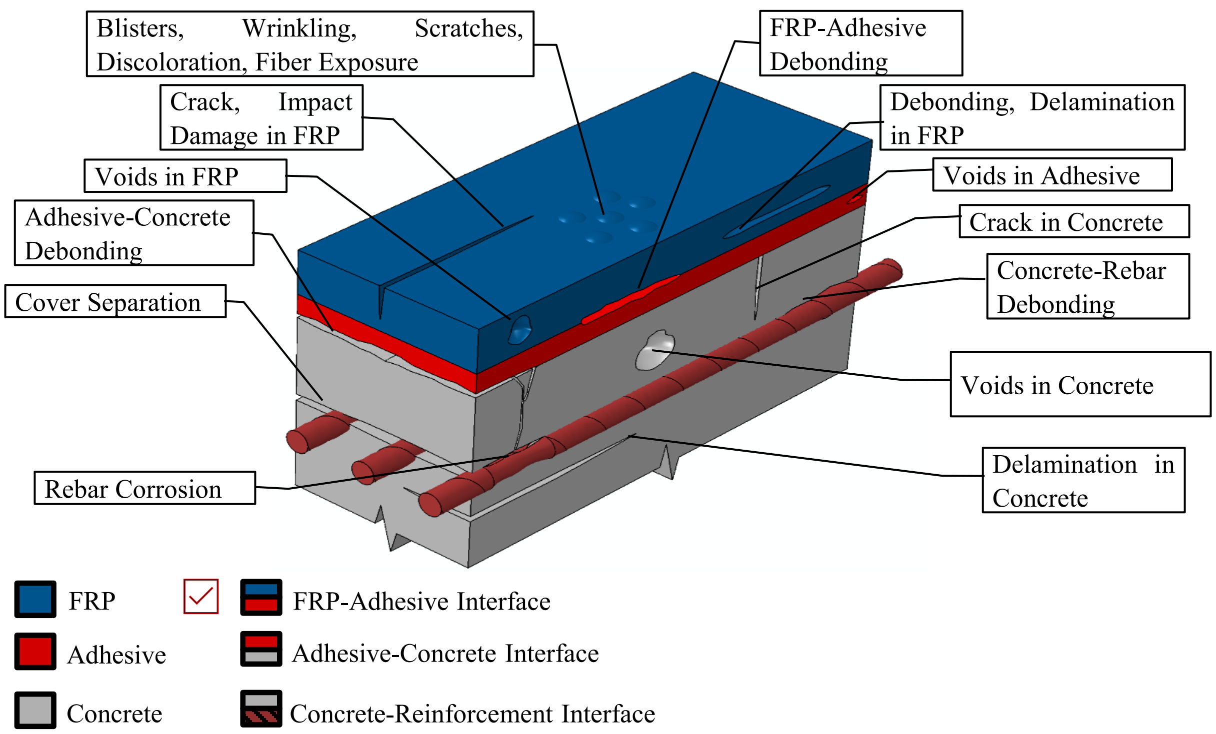
Fiber Exposure

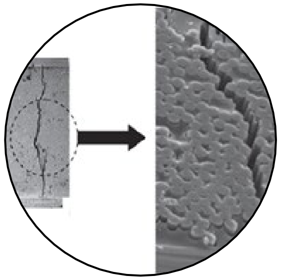


Voids

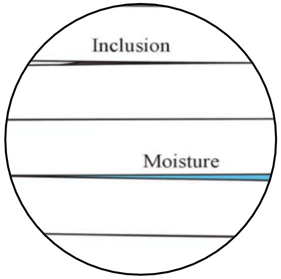


Debonding

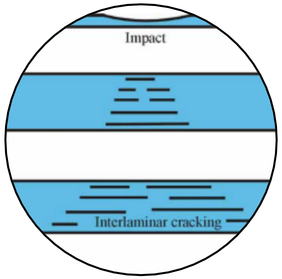




Cracks

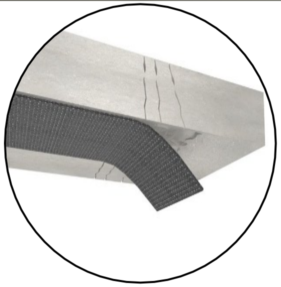


Delamination

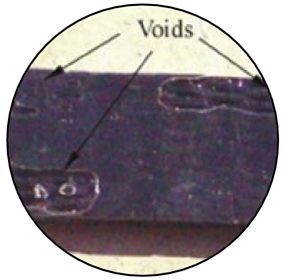


Impact Damage

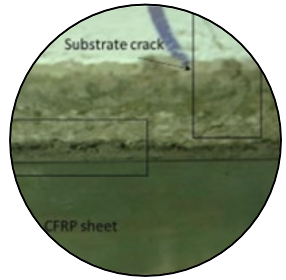
Defects in External Application



Debonding



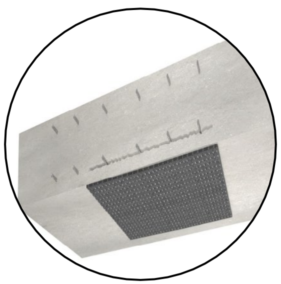
Voids



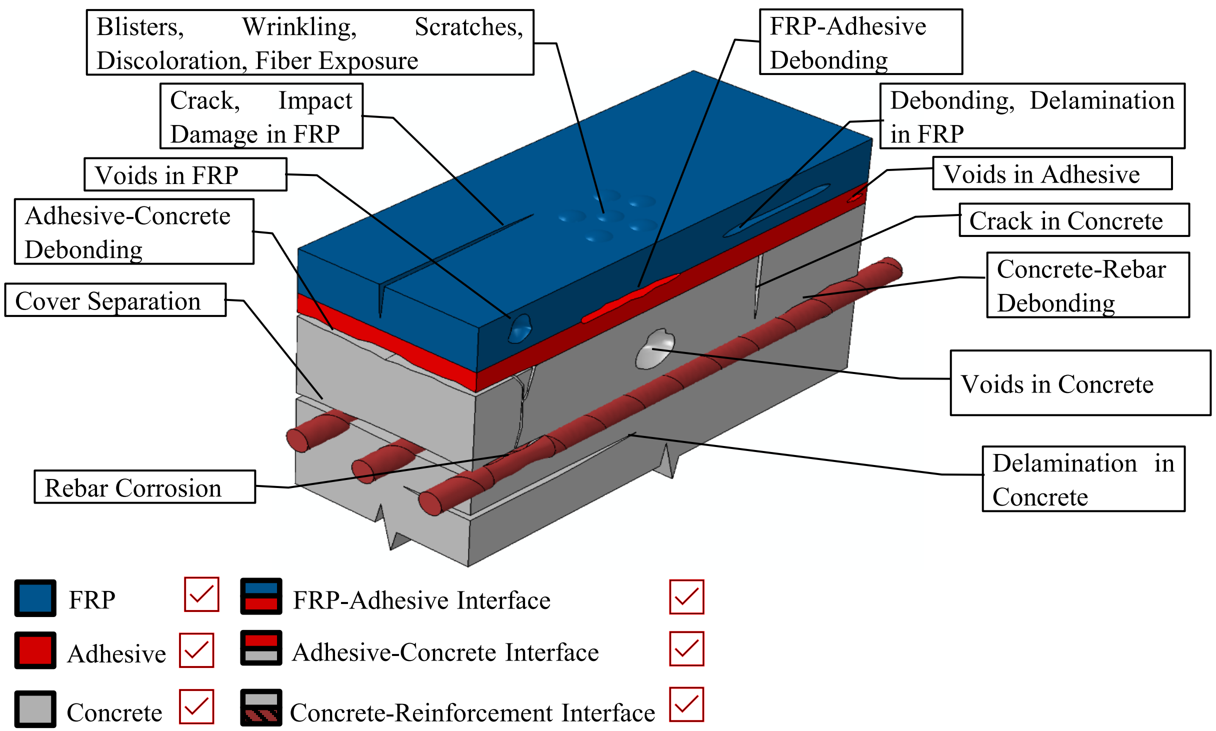
Substrate Crack

Concrete Voids

Concrete Delam.

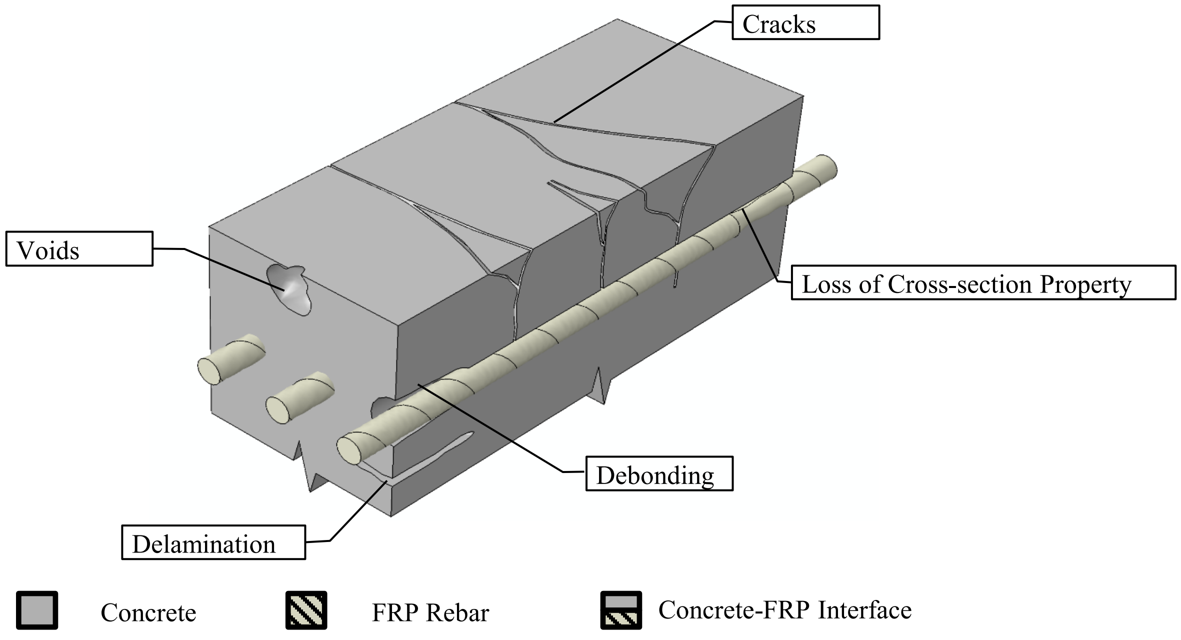


Cover Separation



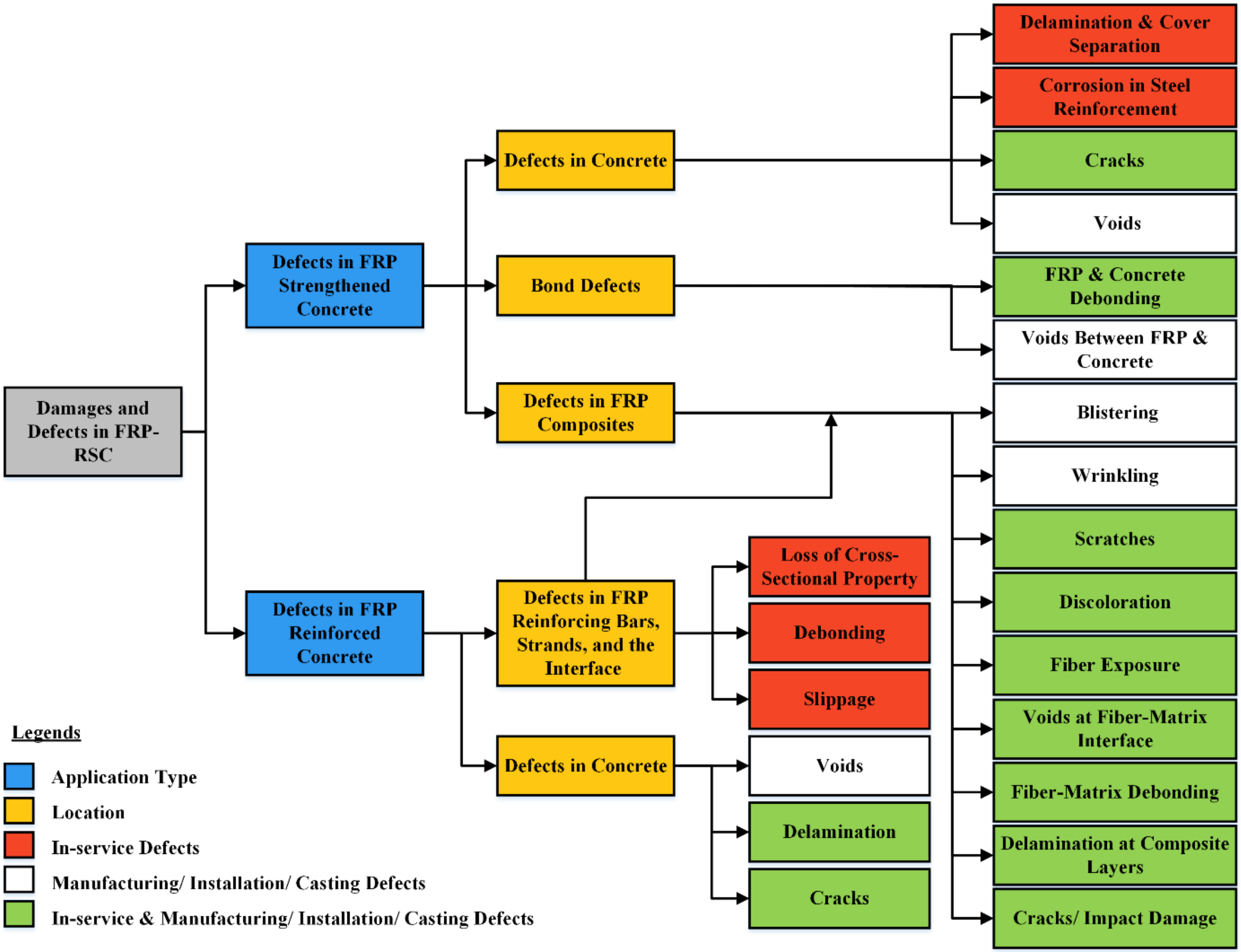
Steel Corrosion

Potential Defects in Internal Application



Defect Categories	Defect Locations	Defects
Defects in FRP Composites (Defects in FRP Reinforcing Bars)	FRP Reinforcement	Loss of Cross-sectional Property (Other Potential Defects: Blisters, Wrinkling, Scratches, Discoloration, Fiber Exposure, Voids in FRP, Debonding/ Delamination in FRP, Crack in FRP)
Defects at the Interface	Concrete-FRP Reinforcement Interface	Debonding (Other Potential Defects: Slippage)
Defects in Concrete	Concrete	Voids Delamination Cracks

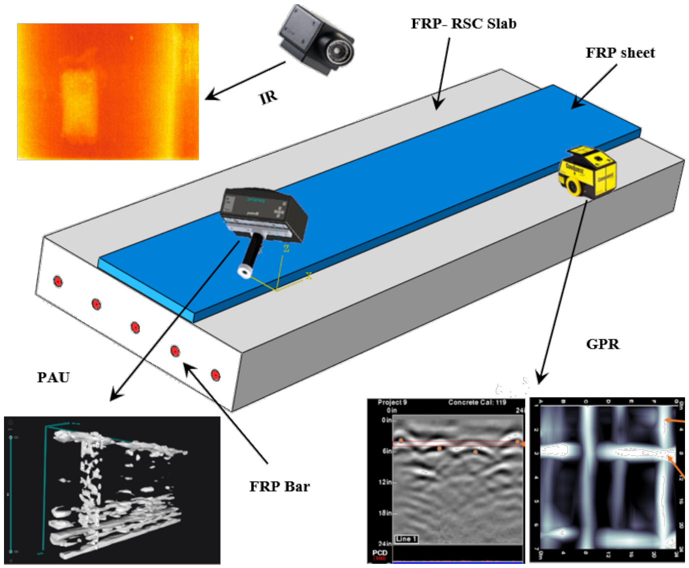
Defects in FRP-RSC Elements



Need of NDTs for FRP Inspection

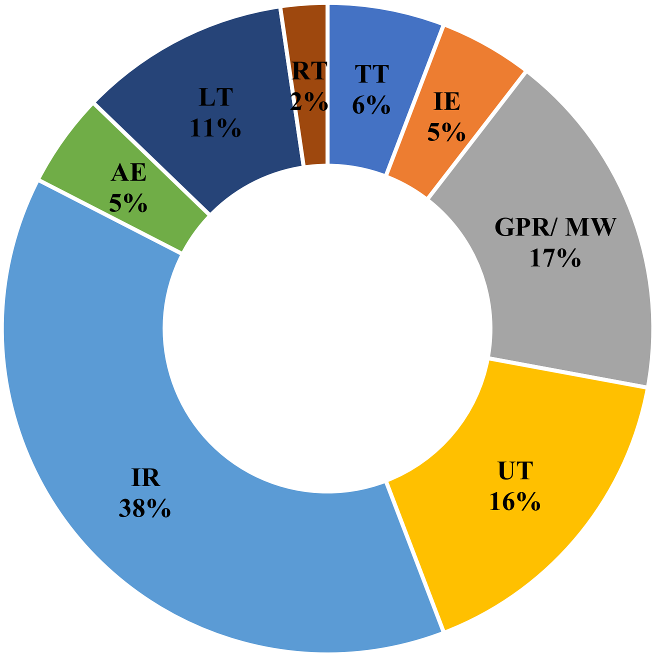
- Lack of guidelines and specifications on the inspection of FRP application
- The failure of structures reinforced with FRP rebars are not as ductile as conventional constructions and hence it is vital to detect signs of potential failure as early as possible.
- Concrete structures strengthened with externally bonded FRP composites are covered and cannot be inspected as readily.

Selection of NDTs

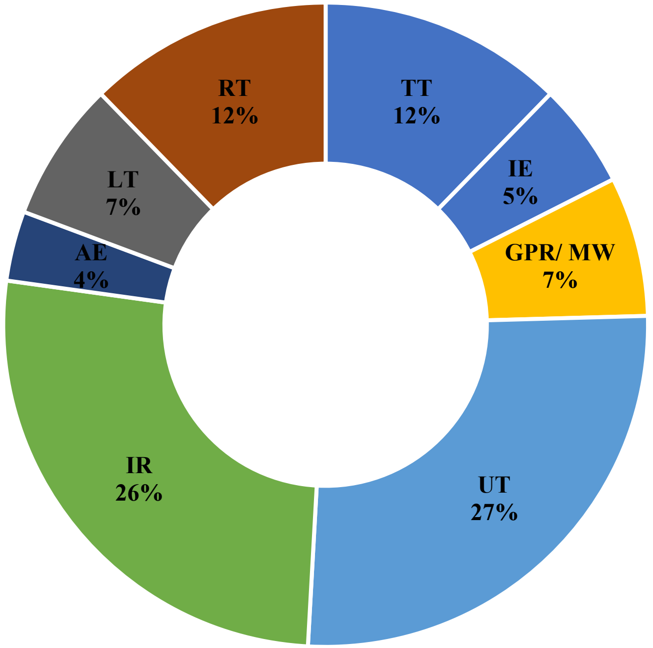


NDT and other inspection methods to be considered for use in FRP-RSC	
NDT Methods including Visual	**Global Structural Response Testing**
Visual inspection (VT) Visual inspection under loading Visually aided inspection (use of borescopes) Tap testing (TT) Impact Echo Testing (IE) Microwave Testing (MW) Ground Penetrating Radar (GPR) Sonic Pulse Velocity Testing (SPV) Ultrasonic Testing (UT) Phased Array Ultrasonic Testing (PAU) Infrared Thermography Testing (IR) Acoustic Emission Testing (AE) Impulse Response Testing (IRT) Laser Testing Method (LT) Radiographic Testing (RT) Sampling- cores, coupons, etc. (semi-destructive)	Modal testing Load testing and response measurement Application of damage detection methods Model updating, Precursor Trans., etc. Application of Machine Learning (ML) and Artificial Intelligence (AI) **New Trends and Complementary Methods** Automated inspection vehicles Airborne inspection **Other NDT with less relevance** Magnetic Flux Leakage Testing (MFL) Chemical and electrical testing (CET) Dye penetrant testing (DPT) Eddy current testing (ECT) Magnetic particle testing

Selection of NDTs

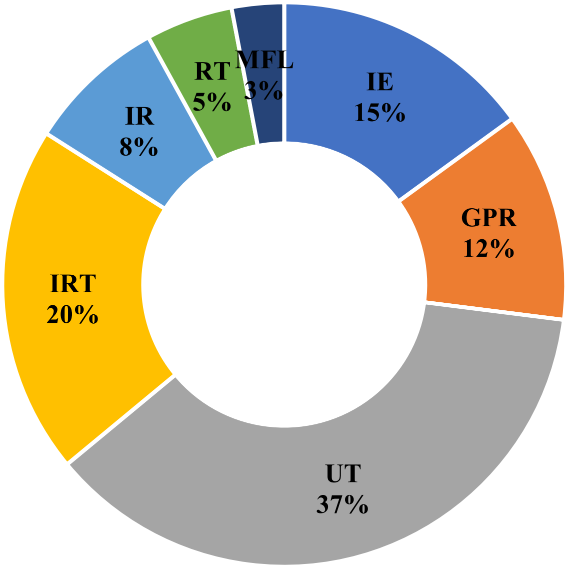


NDT applicable for bond defects

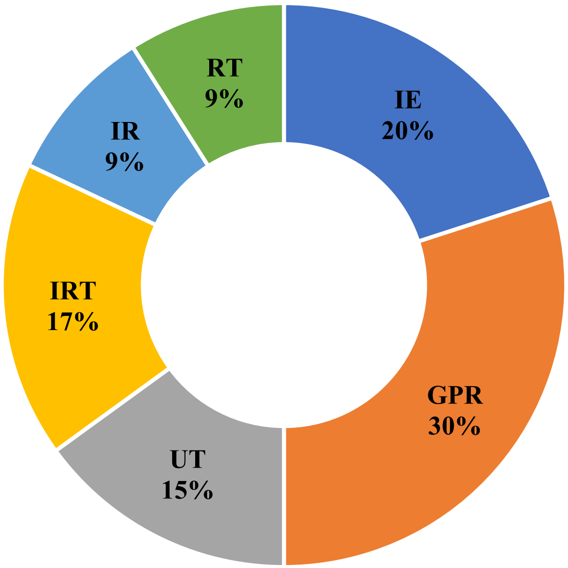


NDT applicable for defects within FRP composite layer

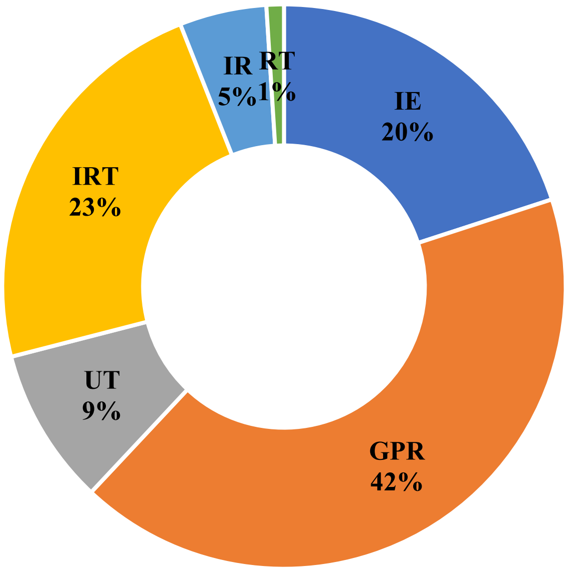
Selection of NDTs



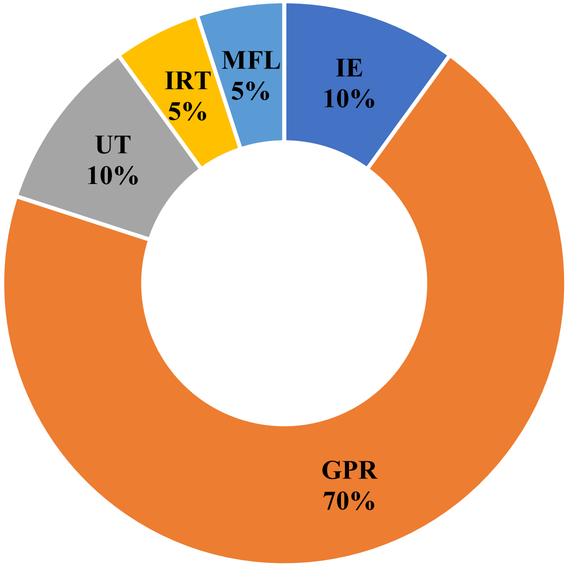
For cracks in concrete



For voids in concrete

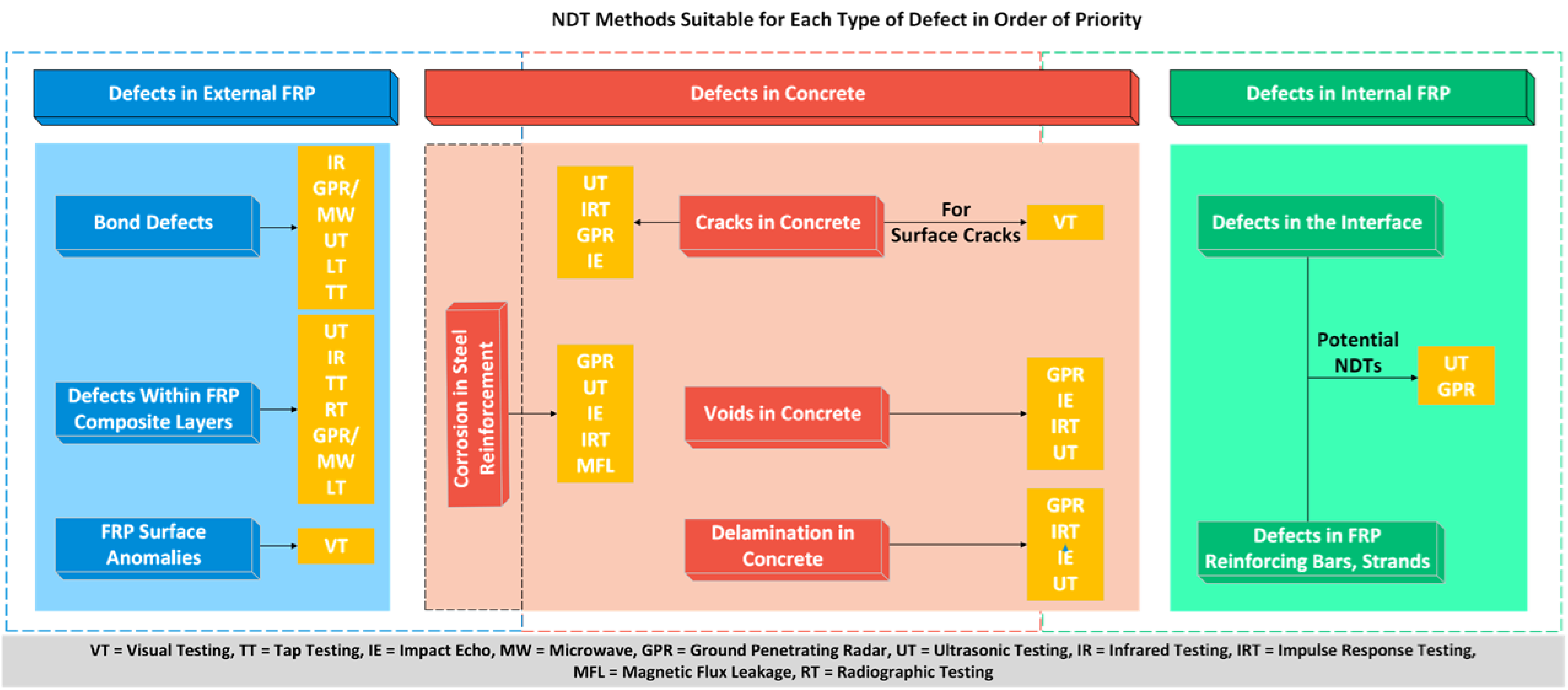


For delamination in concrete



For corrosion in steel reinforcement

Selection of NDTs

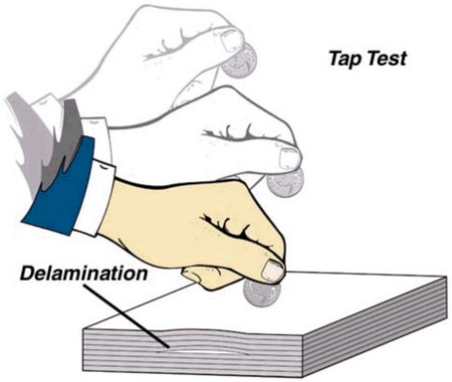


Promising NDT methods selected for inspecting FRP-RSC elements

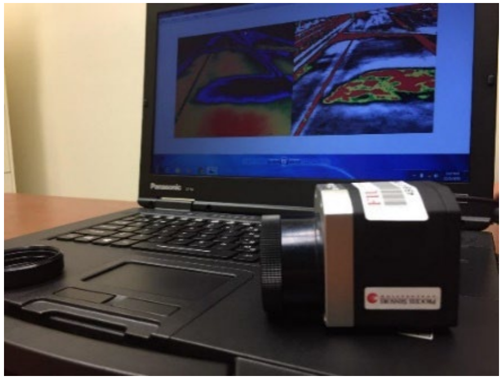
Internal Application

Ground Penetrating Radar (GPR)

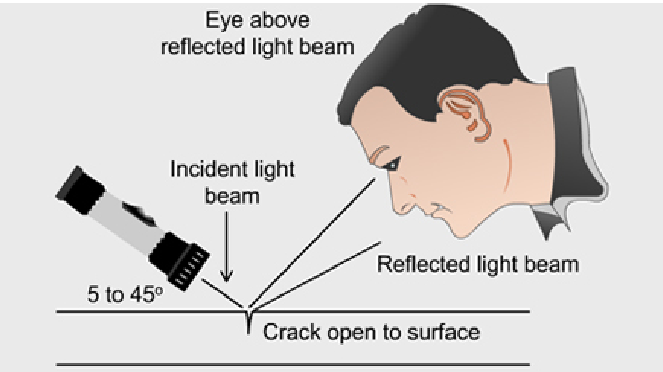
Phased Array Ultrasonic (PAU)



Tap Testing



Infrared Thermal Imaging



Visual Inspection

Promising NDT methods selected for inspecting FRP-RSC elements

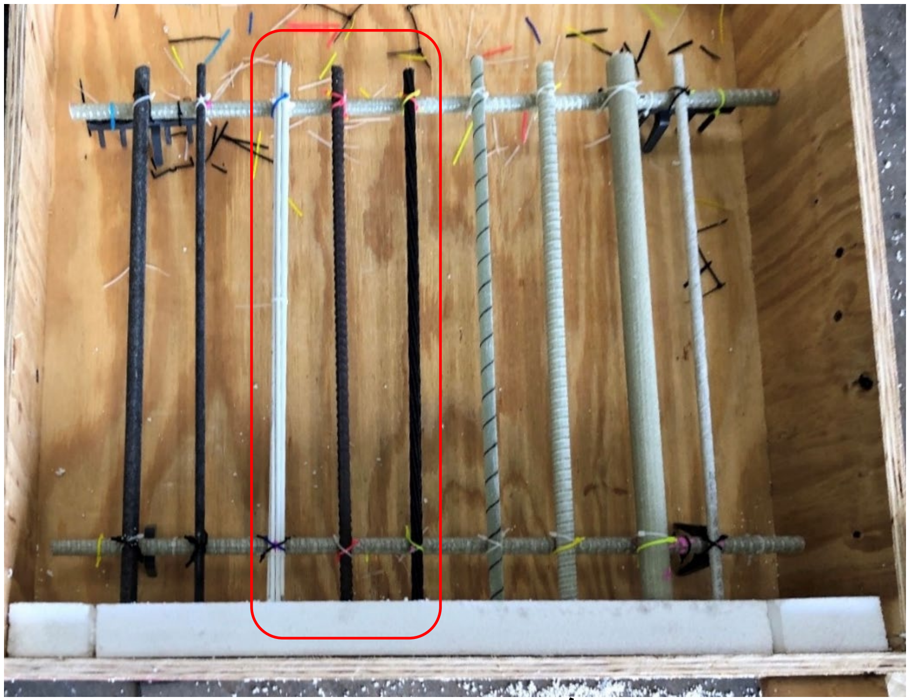
Conquest 100
(1 GHz)

Proceq GP8000
(4 GHz)

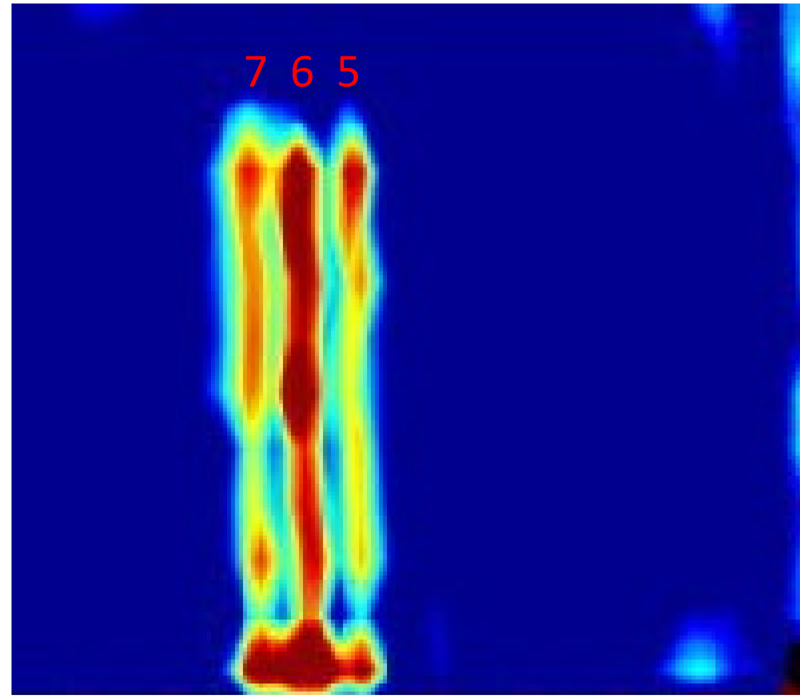
Pundit live
array pro

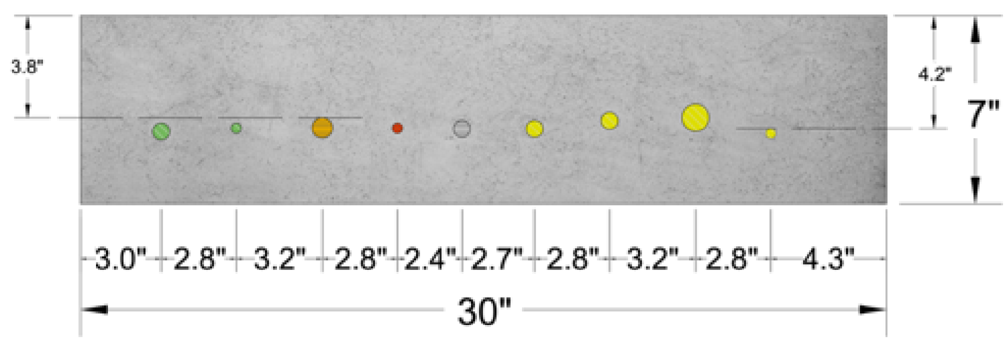
A1040 MIRA 3D

Slab with different FRP bars

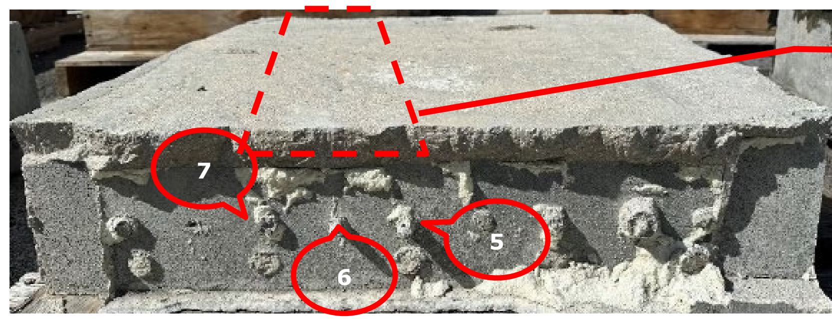


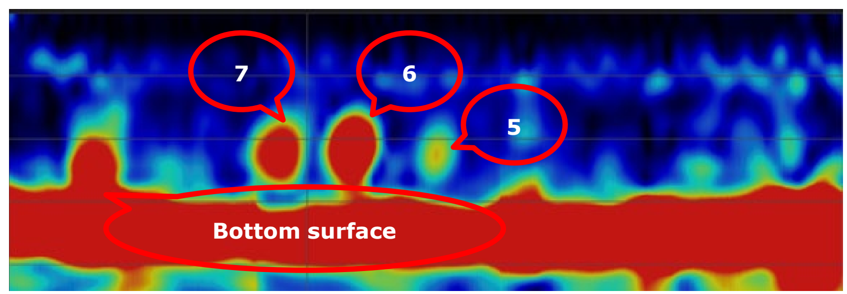
#5 BFRP bar
#3 BFRP bar
#6 GFRP strand
#3 steel bar
#5 CFRP strand
#5 GFRP bar
#5 GFRP bar
#8 GFRP bar
#3 GFRP bar

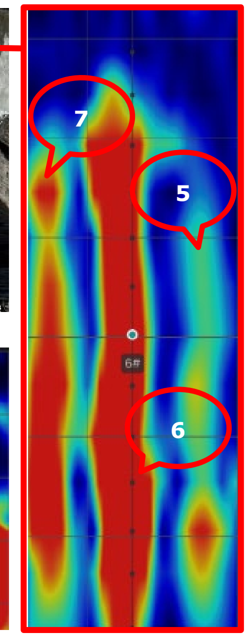




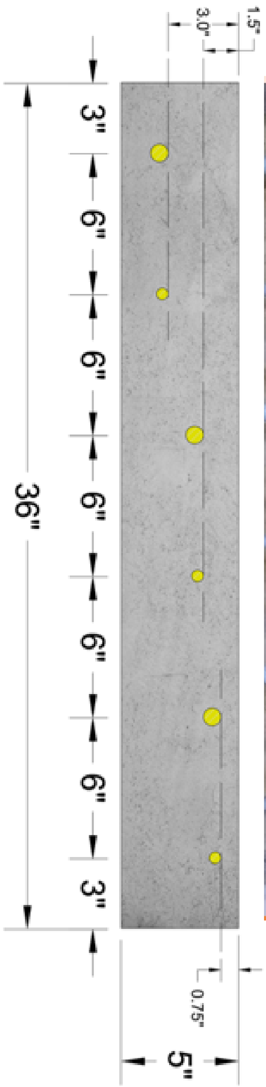
Slab with different FRP bars

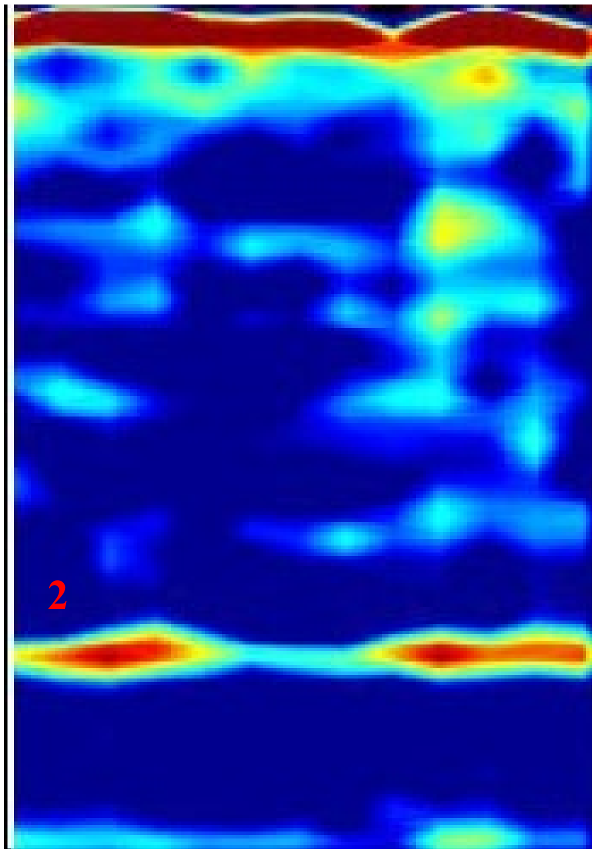


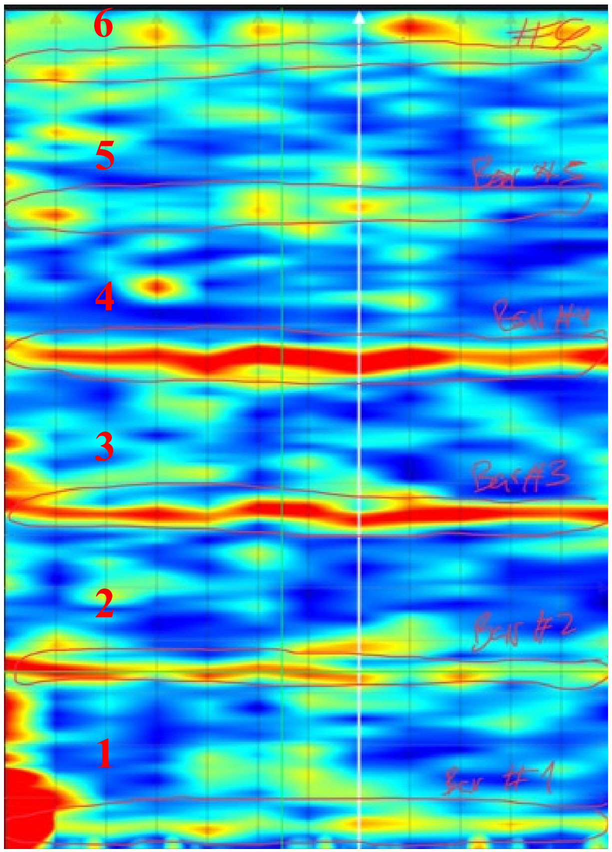




Slab with GFRP bars



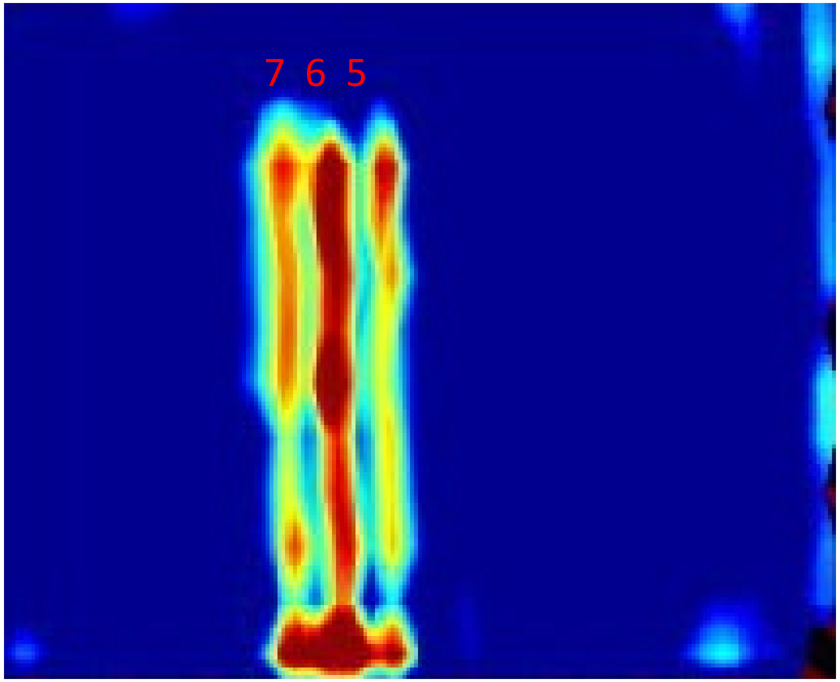




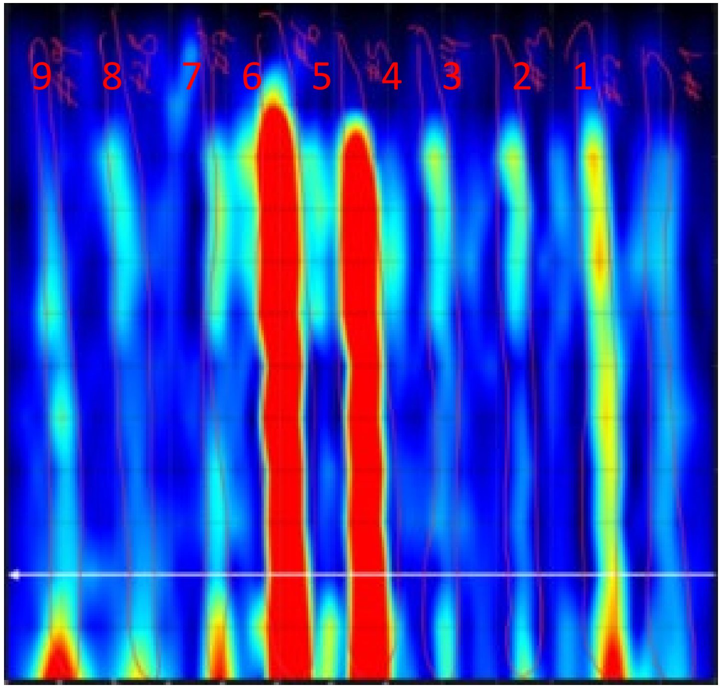
1 GHz

4 GHz

Slab with different FRP bars

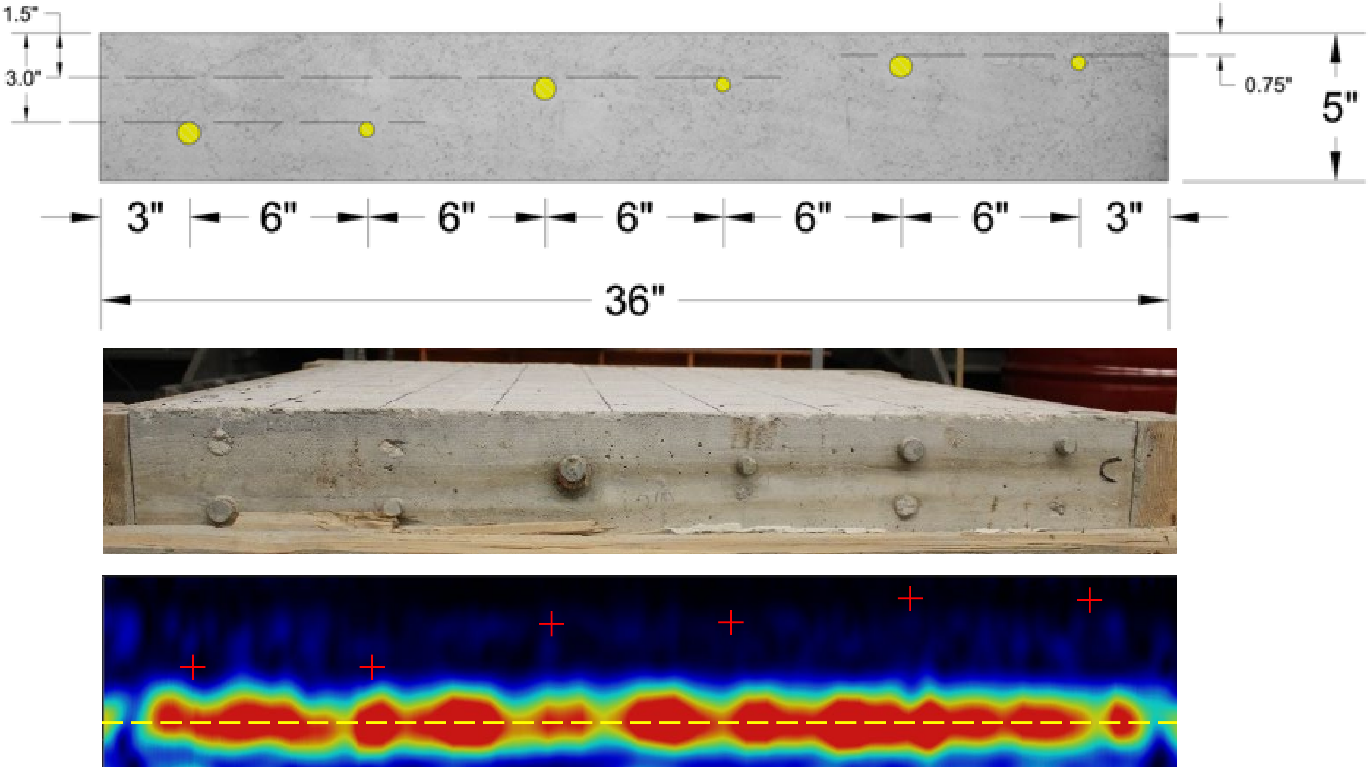


1 GHz



4 GHz

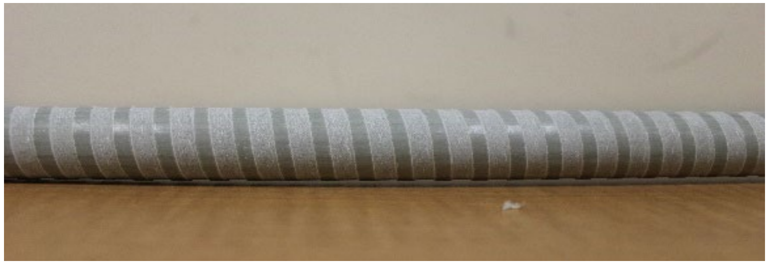
Slab with GFRP bars



Summary of Preliminary Test Results (GPR/PAU)

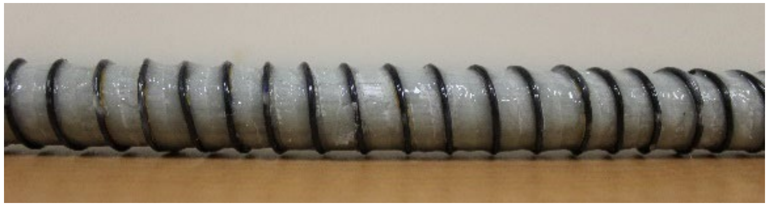
- The detection of FRP bars improves with the increase in the frequency of GPR devices.
- However, higher frequency GPR devices still can not detect bars that are deeper and smaller in size.
- PAU can detect FRP strands but not GFRP and BFRP bars
- Further research on improving the detectability of FRP bars needs to be carried out

Methods for Improving the Detectability of Embedded FRP



GFRP Bar

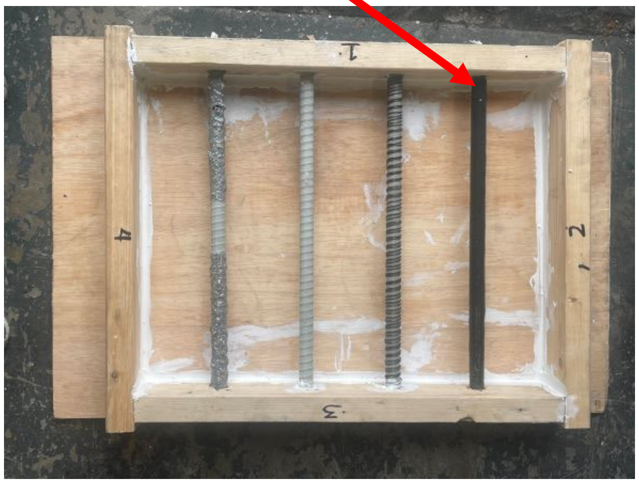
Modification (i)
FRP Bar with Iron Particle Coating

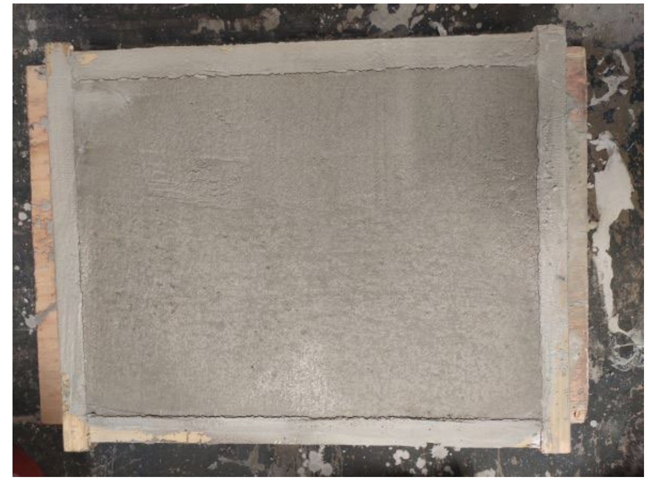


Modification (ii)
FRP Bar with Iron Wire Winding

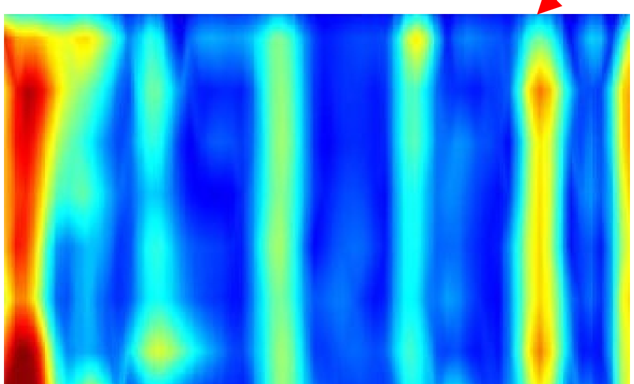
Methods for Improving the Detectability of Embedded FRP

Iron-particle-coated bar

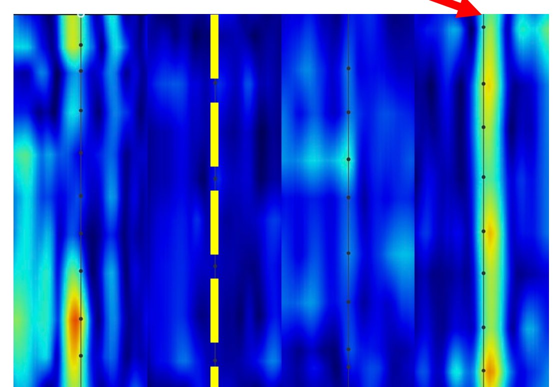




High-detectability for iron-coated bar



GPR test results



PAU test results

Advantages

- Easy to implement as the modifications can be incorporated in the manufacturing process adding virtually no extra operation or machinery
- Requires no modifications to the NDT devices readily available for customary reinforced concrete
- Requires no special training for the inspectors
- Durable and corrosion resistance
- Cost-effective since the cost of particles are marginal and likely could be salvaged from steel or other manufacturing
- Eliminates the uncertainty and limitations in the use of FRP

Conclusion

- External application (FRP strengthened concrete):
  - IR, GPR, and UT can detect bond defects
  - UT, IR, and TT can detect damages within FRP composites
  - VT can detect FRP surface anomalies
- Internal application (FRP reinforced concrete):
  - GPR can detect FRP strands and shallower/larger GFRP bars but can not detect deeper or smaller bars and damages in them
  - UT can detect FRP strands but not GFRP and BFRP bars
- Steel reinforced concrete strengthened by FRP:
  - GPR, UT, and IE can detect corrosion
  - GPR, IE, IRT, and UT can detect damages in concrete (voids, cracks, delam., etc.)

Note: GPR = Ground Penetrating Radar, UT = Ultrasonic Testing, IR = Infrared Testing, TT = Tap Testing, VT = Visual Testing, IE = Impact Echo, IRT = Impulse Response Testing

Conclusion

- Modifications improve detectability
  - Metallic coating on FRP bar greatly improved their detectability.
  - However, for the method of metal wire winding, more experiments need to be conducted.

References

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Thank You