# Service Life of a Structural Retrofit

## Engineering Judgment is a Key Element When Using FRP Advanced Composite Materials

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Service life is a concept always on the minds of engineers. Unfortunately, with the large majority of structures built post WWII, the engineering community is faced with a nation of structures all coming to the end of their service lives. Fiber Reinforced Polymers (FRP) Systems have been elegantly providing solutions to upgrade and extend the service life of structures for almost twenty years now. With limited financial resources and distressed structural elements, FRPs offer an excellent alternative to costly new structures and more obtrusive traditional repairs. While FRP systems can greatly extend the service life and performance of structures, the service life of the FRP system itself must also be considered.

*Construction photo circa 1950.*

The service life of concrete buildings and bridges can be 50, 100 or even 150 years. Several factors affect the performance of concrete structures and thereby limit their service life. These include, but are not limited to, the type of concrete, construction methods, coatings and environmental factors. However, there is no universal method of determining an exact service life. For example, there are no provisions in ACI 318-05 that require an explicit life-span for a building. Typically, structural durability is accounted for globally with strength reduction factors and load increase factors. The assumption being that this will produce a sufficient margin of safety between demand and capacity to withstand strength degradation over time in order to reach a desired design life (*Figure 1*).

Until model codes can incorporate time-dependent deterioration models, the design of structural durability will largely depend on engineering judgment, as it has in the past. This is further complicated with retrofit designs. Therefore, designers need to educate themselves and be conscientious of the structural elements, parameters and factors that affect an FRP retrofit design.

Over the past twenty years, externally bonded FRP systems have been used to repair and retrofit a variety of structures for a variety of reasons. FRP systems bring great qualities for retrofit designs including non-corrosive properties, lightweight, low-profile, and high strength-to-weight ratios. When properly designed, FRP can add shear strength, ductility, confinement, flexural strength and tensile capacity to exiting walls, beams, slabs and columns

There are numerous factors to consider when designing an FRP system to ensure the retrofit meets or exceeds the intended service life. However, there are two questions any engineer should ask before commencing with an FRP design alternative: 1) is it feasible and, 2) how difficult is obtaining building permits for the specific application and municipality? Feasibility depends on life safety and economics, an FRP solution should not be considered if failure of the FRP system would result in a catastrophic failure of the structure. Economics naturally weighs in on any design alternative, but FRPs are often prematurely eliminated as cost prohibitive before all the factors are considered. For example, the logistical advantages including ease and speed of installation often outweigh the increased price per unit price of FRP. And, with

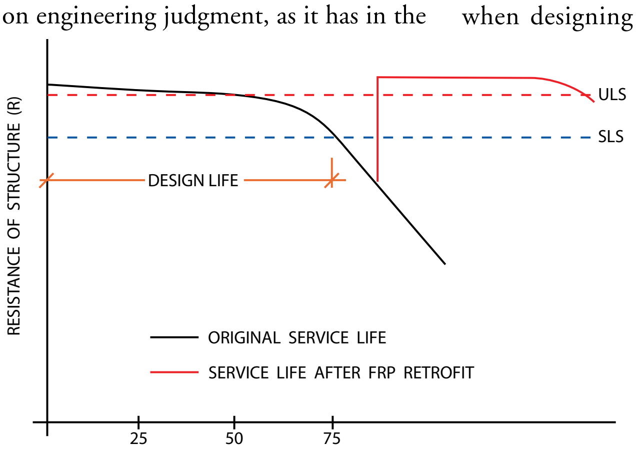


*Figure 1: Resistance of Structure vs. Age of Structure.*

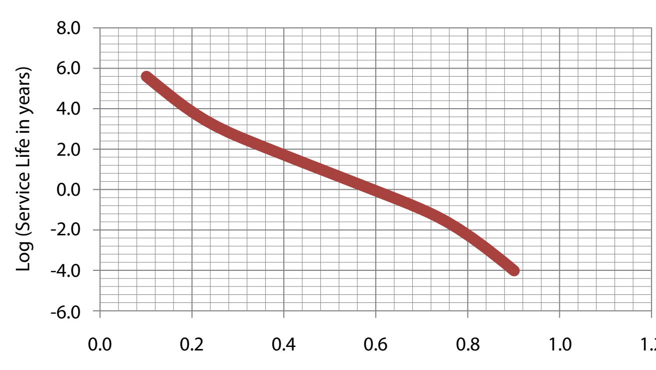


*Figure 2: Log Service Life vs. Design Strain/Tensile Breakage Strain.*

owners becoming sophisticated with their capital investments, the "first costs" versus the "life-time costs" of an FRP system often well outweigh a cheaper traditional solution that will require regular maintenance over the life of the repair.

Now, assuming the project is feasible and the application is within the current industry practice to pull a permit, what are some of the many factors that impact the service life of an FRP system? Is the FRP supporting sustained loads or intermittent live loads, what are the environmental exposure conditions, what is the application for shear, flexure, etc., will coatings be applied? Below, each one of these topics has been elaborated to help engineers with the engineering judgment required when designing FRP retrofits and their relative service lives.

*Figure 3: Large Retail Space.*

*Figure 4: Pre-stressed Concrete Cylinder Pipe.*

## Sustained versus Intermittent Loads

FRP may be designed as a passive structural member or an active structural member. Passive structural strengthening includes, for example, seismic and blast mitigation retrofits. In these types of applications, the FRP will see no loads for the majority (perhaps all) of its lifetime. Only in the event of an earthquake or blast will it have load. Active structural strengthening will see loading on a regular basis. This includes retrofitting bridges and buildings to increase their load carrying capacity, such as heavier vehicles on a bridge or the change of use in a building. Some of these applications will be for intermittent loads such as vehicular traffic or for long term sustained loads, such as high density files placed on top of a slab retrofitted with FRP. The different types of fibers behave differently under these types of loading conditions. Glass fibers are the most susceptible to creep rupture, and carbon fibers are the least affected. ACI 440.2R-08 addresses this issue by placing limits on the ultimate allowable stress that can be used in design. This is done to ensure a safe long term application under sustained stress. The viscolestic nature of the polymer matrix under sustained loads needs to be properly addressed. Short term experimental tests, that have traditionally been used in the aerospace industry, can be used to quickly evaluate the creep behavior of the system.

One example is the Reiner-Weissenberg criterion. This demonstrates that higher sustained stresses leading to associated strains closer to the composites ultimate strain significantly reduce the service life. This is illustrated in the log graph in *Figure 2* and *Table 1*.

## Environmental Conditions

Environmental conditions play an important role in the service life of an FRP. Temperature,

*Table 1.*

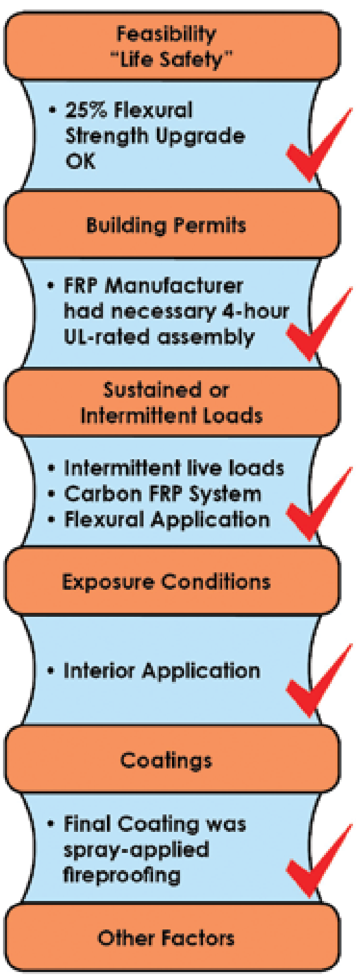

*Figure 5: Parking Garage (rare inclined cracks).*

*Figure 6: Parking Garage (rare inclined cracks).*

freeze-thaw, UV radiation and humidity can all affect the performance of both the resin and fibers. To address this issue, design guidelines use a reduction factor based on both environment and fiber type. ACI 440.2R-08 has reduction factors listed in Table 9.1 of that standard; those factors range from 0.95 for carbon FRPs with interior exposure to 0.50 for glass FRPs used in an aggressive environment. These reduction factors are used for both the ultimate tensile strength and ultimate strain. It is not applied to the modulus, which is typically unaffected by the environment. In the final design equations, it is the modulus that is used along with the calculated design strain. So the reduction factors ensure a factor of safety by providing upper bounds on the strain and stress. This ensures the long term performance of the FRP, and indirectly the service life.

## Coatings

Coatings can provide significant protection to the FRP, and increase the performance and service life. Due to the variety of coatings available for the different FRP systems, the design should ensure that any coating that is used has been tested with the FRP System. This will ensure that the coating will stay well adhered and provide protection from the environment. It should also be noted that the FRP itself provides environmental protection to the reinforced concrete member to which it is bonded. There have been several studies demonstrating that the use of FRP can reduce rates of corrosion and extend the service life of a structure.

It is also important to consider coatings and how they relate to loading type. FRP installations that are designed to carry long-term sustained load must consider if a fire rating is required. Other installations designed as passive members might require a flame and smoke spread rating. It is important to check the local requirements and properly coat the FRP if required.

## Examples from the Field

Now, having taken a cursory review of the multiple factors involved with a FRP retrofit service life, we can walk through a few examples. One of the most common applications for FRP retrofit is the strengthening for increased super imposed live loads. The project shown in *Figure 3 (page 23)* was a large retail store where the occupant wanted to increase the flexural strength of its slabs to accommodate more merchandise storage. In brief, the flexural strength increase was 25%; therefore, it was structurally feasible. The FRP manufacturer had a 4-hour UL rated fire protection system that could be used to pull a permit in San Diego, and the FRP design strain was only slightly reduced since the material was a primary carbon FRP, non-sustained load, interior application. The final coating was spray applied fire proofing; no other factors were considered. Qualitatively, this retrofit is expected to last as long as, or longer than, the traditional materials used in the original construction.

Another project included the strengthening of pre-stressed concrete cylinder pipe for internal and external loads (*Figure 4, page 23*). The pipe section had been inspected and found to have lost 30% of its pre-stressing wire from corrosion. The FRP retrofit was therefore feasible, and appropriate municipality approvals were available for the FRP system. The FRP was not the primary reinforcement but would be in sustained stress; a final coating was applied to aid in the long-term protection of the FRP system. Extra conservatism was added into the design strain of the FRP composite, given the relative importance of the water supply line.

The last project illustrates a construction anomally with an uncertain cause. Several, if not the majority, of the the prestressed double-tees making up the parking garage shown in *Figures 5* and *6* had rare inclined cracks that started approximately five feet from the supports and inclined in the opposite direction when compared to textbook shear cracks. A consensus could not be reached of the cause, so it was decided that proof testing would be completed to establish the existing capacity. FRP composite was used to make the difference between demand and capacity. Since there was some uncertainty of the existing double-tees capacity, the FRP was considered primary reinforcement and would require a fire protection system. The design service life of the project will be conservative considering the interior application, final coating, and low stress that the FRP composite was designed for.

## Conclusions

Service life of structures has a long way to go before it is treated as scientifically as the rest of the structure by the engineering profession. The very use of FRP systems to retrofit structures and extend their service lives inherently complicates the process. Thus, it will continue to depend on engineering judgment to tabulate and assess all of the parameters and factors that contribute to a structurally durable FRP retrofit. The sustained stress should not exceed set limits to avoid creep rupture, coatings should be considered in order to protect against UV degradation, exposure to fire must be considered, and so on. With so many parameters influencing FRP service life, engineers should be careful to choose a system that has been validated by both structural and environmental durability testing. However, when properly designed, an FRP retrofit can add significant service life to a structure and be one of the best design alternatives to our aging infrastructure.▪

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