COMPREHENSIVE APPROACH TO SERVICE LIFE DESIGN OF BRIDGES

Atorod Azizinamini

Department of Civil and Environmental Engineering
Florida International University
10555 W. Flagler Street, EC 3677
Miami, FL 33174
Phone: (305) 348-3821
Fax: (305) 348-2802
Email: aazizina@fiu.edu

Submitted for publication to the Transportation Research Record, Journal of the Transportation Research Board

Word Count: 5333 + 7Figures@250 = 7083 words (Limit = 7500 words)

July 8, 2013

Submitted for publication to the Transportation Research Record, Journal of the Transportation Research Board in response to following calls for papers

1. Bridge Performance Forecasting
2. At the Cross Roads: Sustainable Solutions and Concrete Durability
3. Multimodal Loads on Bridges
4. National Bridge Performance Measures and How They are used to Communicate Bridge Needs to others including the Public
ABSTRACT

The design for service life is gaining more importance as limited resources demand enhancing the service life of existing and new bridges. As part of the research project entitled *Bridges for Service Life Beyond 100 Years: Innovative Systems, Subsystems and Components* and supported by *Second Strategic Highway Research Program (SHRP 2) Project R19A*, a systematic and general approach to design of new and existing bridges for service life has been developed that is applicable to any bridge structure. Design for service life must be approached at the design stage and provide the owner with a clear picture of the efforts that will be needed to keep the bridge operational for a specified and intended service life. Design for service life must include, an inspection, maintenance, replacement and retrofit plan where needed. Further, the entire service life design process must be documented and effectively communicated with the owner. In short, in order to keep the bridge operational for a specified number of years as defined by the owner, any surprise element must be eliminated.

The objective of this paper is to provide a brief synopsis of the general philosophy and major steps that could lead to comprehensive design of bridges for service life and to outline the major steps involved in service life design. Interested readers could refer to the major product of the SHRP2 Project R19A, referred to as *Design Guide for Bridges for Service Life*, and hereinafter referred to as the Guide. The Guide is available through TRB at the following site.

http://www.trb.org/Main/Blurbs/168760.aspx

Key words: Design, Bridges, Guide, Service Life, SHRP2, maintenance, operation, retrofit

(68 words in abstract = 248 words

(Limit on abstract = 250 words)
BRIEF BACKGROUND

Ensuring public safety by providing adequate strength for constructed facilities has long been the cornerstone of the framework used by engineers for bridge design.

Significant changes to our contemporary bridge design specifications have also been related mainly to strength issues. The transitions from Allowable Stress Design (ASD) to Load Factor Design (LFD), and more recently to the Load and Resistance Factor Design (LRFD), reflect this line of thinking.

A review of bridges that have lasted more than 100 years provides valuable lessons. These bridges are not particularly innovative in system or materials, but have proven to be:

- Maintainable and well maintained over their 100-year lives, due to extreme importance or high capital replacement cost;
- Resistant to environmental and man-made hazards;
- Adaptable to changes in functional use as well as service limit state demands and/or;
- Originally overdesigned.

Traditional approaches for enhancing the service life of bridges, used in various codes and specifications such as AASHTO specs, Eurocodes, or British Standards, are mainly in indirect forms, specifying the use of certain details or properties such as cover thickness, maximum crack width, concrete compressive strength, etc. Designing bridges for service life, however, is more than just addressing the service life and durability of concrete.

Furthermore, designing for service life for bridges needs to be approached in a systematic, all-inclusive manner, rather than as a series of isolated tasks that address the service life of a particular portion of a bridge independently. The interaction between strategies for enhancing the service life of different bridge elements, components, and subsystems must be given critical consideration. In addition, a maintenance program, retrofit or replacement options, and management plan should all be part of this systematic service life design approach. In summary, at the design stage the design for service life should be approached as a comprehensive plan that provides the owner with a complete picture of what will be necessary for the bridge to achieve its specified service life.

Often in recent times, efforts to address the durability and service life of concrete are miscommunicated as efforts to design for service life for bridges. While concrete is used in many parts of many bridges, development of a service life plan for an entire bridge system is well beyond a plan for the design of simply the concrete elements used in a particular bridge structure. For example, notable efforts to develop a scientific approach for service life and durability of concrete elements (covering buildings, bridges, and tunnels) were carried out as a series of studies between 1996 and 1999 in Europe for the fédération international du béton (The International Federation for Structural Concrete or fib). A product of those efforts was the publication of fib Bulletin 34, Model Code for Service Life Design, (TTD 2006). Bulletin 34, however, only concentrated on addressing concrete service life and durability. Further, caution must be exercised when applying the recommendations of this publication to concrete placed in a horizontal configuration, such as a bridge deck. While Bulletin 34 has many useful
recommendations for designing concrete elements for service life and durability, the application of its recommendations to bridge components, such as bridge decks, is questionable—in particular, the use of various solutions to Fick’s second law to predict the rate of chloride ingress through deck concrete. Most of the available commercial programs for service life design also concentrate on addressing the durability of concrete elements of the bridge and use the fundamental concepts stated in Bulletin 34.

One of the missing elements for designing bridges for service life is the framework that would approach the problem in a systematic manner and provide a complete solution in a format that could ensure long-lasting bridges. Individual solutions to issues that historically have reduced service life, maintenance plans, retrofit or replacement plans, bridge management, and life cycle cost analysis are all just components of this systematic framework and not the framework itself. The steps within this framework should start at the design stage and should provide the owner with complete information for ensuring the serviceability of the bridge for a specified target service life. It is important for the plan to be transparent and to identify the challenges for the period of specified service life at the design stage, so the owner will encounter no surprises.

ELEMENTS OF FRAMEWORK FOR DESIGN OF BRIDGES FOR SERVICE LIFE

Before defining the steps within the framework for design of bridges for service life, several necessary definitions and elements will be described. More detailed description is provided in the Guide.

Bridge Service Life Related Terminology and Relationships

Following are some of the definitions that are related to service life design. These definitions are compatible with AASHTO LRFD Bridge Design Specifications (2010), hereinafter referred to as LRFD Specifications. The service life design and subsystem are the two definitions that are introduced by SHRP 2 Project R19A.

Service Life

The time duration during which the bridge element, component, subsystem, or system provides the desired level of performance or functionality, with any required level of repair and/or maintenance.

Target Design Service Life

The time duration during which the bridge element, component, subsystem, and system is expected to provide the desired function with a specified level of maintenance established at the design or retrofit stage.

Design Life

The period of time on which the statistical derivation of transient loads is based: 75 years for the current version of AASHTO LRFD Bridge Design Specifications (2012), hereafter referred to as LRFD Specifications.
Bridge Element

Individual bridge members such as a girder, floor beam, stringer, cap, bearing, expansion joint, railing, etc. Combined, these elements form subsystems and components, which then constitute a bridge system.

Bridge Component

A combination of bridge elements forming one of the three major portions of a bridge that makes up the entire structure. The three major components of a bridge system are substructure, superstructure, and deck.

Bridge Subsystem

A combination of two or more bridge elements acting together to serve a common structural purpose, for example composite girder, which could consist of girder, reinforcement, and concrete.

Bridge System

The three major components of the bridge—deck, substructure, and superstructure—combined to form a complete bridge.

In addition to the terminology defined above, several relationships also exist between service life and design life of various bridge component, element, subsystem and system that are defined in the Guide.

Factors Affecting the Service Life

The factors affecting service life are identified using a fault tree approach, which provides a systematic method of identifying factors in various categories and successive subcategories. The Guide provides fault trees applicable for most common types of elements, components, or subsystems used in practice. In the case of major and complex bridges, designers should develop customized fault trees, reflecting the specifics associated with location and traffic conditions.

Following is brief description of what fault tree is, how it is constructed, and how it works.

The fault tree is used to systematically identify the factors that can affect service life of a particular bridge element, component, or subsystem. A customized fault tree can be developed using data and experiences collected from, and available from local agencies.

The fault tree starts with the identification of major factors that can reduce service life of a particular bridge element, component, or subsystem. Each major factor can then be broken down into more detailed subcomponents, each capable of reducing the service life. The fault tree continues branching until each branch ends with factors at the lowest or base levels of influence. The factors with subcomponents are placed inside rectangles, and the identified lowest or base factors are placed inside circles. Figure 1, for example, shows a portion of the fault tree used in the Guide for cast-in-place bridge deck.
FIGURE 1 Starting point for fault tree for a bridge deck.

In Figure 1 Error! Reference source not found., either of two main factors is shown to be capable of contributing to reduced service life of a bridge deck: obsolescence or deficiency. The elliptical symbol just above these two factors is referred to as an “or gate,” which signifies that either one of the factors below it could result in reduced service life. The fault tree shown in Error! Reference source not found. continues to list the major categories of factors that could result in reduced service life of bridge deck, those related to induced loads, natural or man-made hazards, and production/operation defects.

Figure 2, shows the continuation of the fault tree for breakdown of factors related to load-induced factors for bridge deck.
In Figure 2, the factors related to load-induced are subcategorized into traffic-induced loads or loads induced by system-dependent loads factors, such as restraints provided by shear studs, etc. As shown in Figure 2, two factors are further broken down into subcomponents, each capable of reducing the service life of bridge deck. The factors inside the circles are the basic factors without any further subcomponent. They represent the end of that branch of the fault tree and require the development of individual strategies for mitigation. For most commonly used bridge element, component or subsystems, the Guide provides various strategies capable of mitigating the factors identified in the circles within each fault tree.

**Quantifying Service Life of Bridge Element, Component, Subsystem, and System**

One of the important steps in developing a systematic and comprehensive service life design plan for bridges is the capability to predict the expected service life of various bridge elements, components, and subsystems, which in turn will dictate the service life of the bridge system. The service life prediction capability is important for developing maintenance, retrofit, and replacement plans, which are an integral part of service life design process.

Bridge elements, components, subsystems, and systems are subject to the effects of traffic and the environment. These external sources of deterioration act through various mechanisms to cause actual deterioration of bridge elements and eventually failure. The mechanisms of deterioration are the physical laws that govern such deterioration. Deterioration rates can be described using mathematical expressions or empirical/semiempirical models, which are developed using data collected by field monitoring of bridges, laboratory generated data, expert opinions, or combination of available data. Service life is also affected by risk to damage
from either traffic or extreme environmental occurrences. The acceptability of this damage is evaluated based on risk. Service life can be extended by minimizing risk or designing for appropriate levels of extreme occurrences.

Enhanced service life for bridge elements, components, subsystems, and systems can be achieved through:

- Use of durable materials,
- Use of either passive or active protection systems,
- Optimum selection of details,
- Optimum maintenance and repair,
- Reduced service level,
- Increased factor of safety or reduction in stress levels, and
- Isolation from risk damage.

To estimate the service life of bridge elements, components, or subsystems quantitatively, the following information is needed:

- Source of deterioration,
- Deterioration mechanism,
- Deterioration models, and
- Failure modes.

The following sections provide information on each of these items.

Source of Deterioration

Traffic related or environmental effects form the basic external cause of deterioration. For example, deicing compounds, an external source of deterioration, can result in corrosion of reinforcement in bridge elements.

Deterioration Mechanism

Deterioration is governed by a process called the deterioration mechanism. For example, sliding surfaces in bearings experience deterioration through horizontal movement and friction between sliding materials, created by truck passages or temperature fluctuations. The horizontal movement and friction in this instance is the deterioration mechanism. In the case of concrete elements, ingress of chloride through concrete causes initiation of corrosion in unprotected steel reinforcement. In this instance, the ingress of chloride is the deterioration mechanism.

Deterioration Models

Deterioration models are used to describe the rate of deterioration. They describe the relationship between the condition of the bridge (or its element) and its time of use, and show how the bridge deteriorates over time. It assumes that no replacements or major repairs are made,
but it usually implies that scheduled maintenance actions are performed as planned. The basic model applies either to a bridge system as a whole, or to any of its subsystems, components, or elements.

In practice, the development of realistic behavioral deterioration models is a data-intensive process complicated by lack of knowledge of the underlying physical and chemical processes fostering deterioration, as well as by the data availability. At the present time the available deterioration models, which are based on long-term data collection, are very limited. Further, as time passes, the quality of the bridge design and construction improves. As a result, application of data collected from existing bridges to predict performance of future bridges should be practiced with caution.

Deterioration models can be based on some level of understanding of the mechanism governing the deterioration and the capability to express the process using a mathematical expression. An example is deterioration of concrete elements because of chloride induced corrosion of reinforcement. The assumption is that ingress of chloride through the concrete element is governed by Fick’s second law, which assumes a homogeneous material.

In the case of chloride and carbonation induced corrosion, there is some level of agreement within the scientific community as to the existence of deterioration models. However, for other deterioration modes such as sulfate attack, alkali-silica reactivity (ASR), and freeze/thaw or wear and abrasion, there is a lack of adequate models.

There are different approaches to solving Fick’s second law. A finite difference approach, or the use of error functions, is reported in published literatures. Equation 1 is an error function solution of Fick’s second law, capable of predicting the chloride concentration level at various depths within the concrete element.

\[
C_{\text{crit}} = C(x=a,t) = C_0 + (C_{S,\Delta x} - C_0) \left[ 1 - \text{erf} \left( \frac{a - \Delta x}{2 \sqrt{D_{\text{app,C}} \cdot t}} \right) \right]
\]

EQ 1

Where:

- \(C_{\text{crit}}\): critical chloride content [wt.-%/c]
- \(C(x,t)\): content of chlorides in the concrete at a depth \(x\) (structure surface: \(x=0\) m) and at time \(t\) [wt.-%/c]
- \(C_0\): initial chloride content of the concrete [wt.-%/c]
- \(C_{S,\Delta x}\): chloride content at a depth \(\Delta x\) and a certain point of time \(t\) [wt.\(x\)]
- \(x\): depth with a corresponding content of chlorides \(C(x,t)\) [mm]
- \(a\): concrete cover [mm]
- \(\Delta x\): depth of the convection zone (concrete layer, up to which the process of chloride penetration differs from Fick’s 2nd law of diffusion) [mm]
- \(D_{\text{app,C}}\): apparent coefficient of chloride diffusion through concrete [mm-2/years]
- \(t\): time [years]
- \(\text{erf}\): error function
Equation 1 should be used in conjunction with probabilistic approaches to account for variability of several parameters, such as apparent coefficient of diffusion, chloride concentration, and critical chloride level to start corrosion. Furthermore, the diffusivity of concrete through different layers of concrete element is not uniform. Equation 1 predicts the chloride content in the structure at a given depth (x) and time (t). This number is given by the left-hand side of the equation, C(x,t).

The C(x,t) obtained from Equation 1 is then compared to the critical chloride content, C_{crit}, which is the value determined to be the point at which corrosion starts. When the chloride level at a given depth, x, of the structure is reached, the critical value, the corrosion is assumed to initiate. The service life of concrete element can then be assumed to consist of the time period to initiate corrosion plus the time period for propagation of the corrosion to the point that will limit the functionality of concrete element. This process is depicted in Figure 3.

![Figure 3: Relationship between damage and service life. (Source COWI, Denmark)](image)

The Guide provides additional deterioration models, such as models to predict the reduction in thickness of sliding surfaces used in various bearing devices.

**Failure Modes**

Sources of deterioration (such as deicing compounds), acting through deterioration mechanisms (such as ingress of chloride through concrete cover), and described by deterioration models (such as solution to Fick’s second law) result in failure modes (corrosion of reinforcement, causing corrosion induced cracking and loss of strength). The final failure could consist of several stages, such as start and propagation phases.

**Service Life Estimation**

SHRP 2 Project R19A introduces two general philosophies to estimate the service life of bridge elements, components, and subsystems. The end result of quantifying the service life of bridge elements, components, or subsystems is to establish the t_{se}, the service life of bridge elements, components, or subsystems, in years and compare it to specified service life of the bridge system to determine the need for retrofit or replacement strategies if needed.

Two general design approaches for service life are:

- Finite Service Life Approach, and
- Target Service Life Approach.
When the design service life, $t_s$, of the bridge element, component, or subsystem, established through one of the two design approaches for service life philosophies is less than the specified design life of the bridge system, $t_D$, the bridge element, component, or subsystem under consideration could be replaced to achieve the specified design life of the bridge system.

The major difference between the two approaches for service life design is the existence of well-accepted deterioration models, which is needed before using the finite service life approach.

**Finite Service Life Approach**

Bridge elements, components, and subsystems designed using the finite service life approach, should have service life that is greater than or equal to specified bridge system service life. Otherwise, the bridge element, component, or subsystem under consideration must be retrofitted or replaced to allow the bridge to continue providing its intended function until reaching the specified bridge system service life. In the finite service life approach, the service life of the bridge components, elements, or subsystems is estimated using well-accepted deterioration models. The existence of deterioration models is therefore essential for use of the finite service life approach.

The deterioration models are generally developed using one of the following approaches:

- Mathematical models which describe the deterioration rate. These models could be approximate or based on laws of physics. The solution to Fick’s second law as described earlier is an example.

- Empirical or semiempirical models developed using data collected from laboratory or field performance of bridges. Fatigue models used in the *LRFD Specifications* is an example of empirical deterioration model.

- Empirical models based on expert opinions or experiences. Examples include various models used in Pontis™.

**Target Service Life Approach**

In many instances the deterioration models are not available or their applicability is questionable. In these situations, available alternatives are 1) use of high performing material that does not deteriorate, such as use of stainless steel, an approach is generally referred to as the avoidance of deterioration method within European practice, or 2) use material that based on experience, or based on expert opinion, could provide a specified or a target service life. If the estimated service life of the bridge element, component, or subsystem is less than the specified service life of the bridge, retrofit or replacement strategies must be specified, allowing the bridge system to continue providing its intended function.

The major difference between finite service life and target service life design approaches is that in finite service life design approach, the condition of the bridge element, component, and subsystem can be traced over time using deterioration models, whereas in target service life design approach, only the total expected service life is estimated. The specified target service life...
of bridge element, component, or subsystem is mainly established based on experience or expert
opinion, and could vary significantly from assumed values. Nevertheless, specifying a target
service life for a given bridge element, component, or subsystem allows the bridge owner to plan
and anticipate necessary maintenance actions and places demands on the designer to incorporate
necessary design features where needed. For example, the service life of PTFE sliding surfaces
in bearing devices could be assumed to be about ten years (target service life of 10 years). The
designer must then incorporate necessary mechanisms to lift the bridge and replace the sliding
surfaces, preferably while maintaining traffic. On the other hand, the bridge owner must plan and
anticipate the replacement of sliding surfaces every 10 years.

FRAMEWORK TO DESIGN FOR SERVICE LIFE

While the framework to design for service life developed by SHRP 2 Project R19A is
universal and applicable to any bridge, the choices of solutions to mitigate factors that
historically have resulted in lowering the service life of bridges are bridge, location, and traffic
specific. For instance, solutions that could lead to mitigate a service life factor of cast-in-place
bridge deck in a warm climate could be different than solutions to mitigate the same factor if the
bridge was located in cold climate, where deicing salts are used. As a result, the approach for
design for service life promoted by SHRP 2 Project R19A is to equip the designer with
knowledge of factors affecting the service life of bridge parts, to provide an array of solutions
capable of mitigating them, and to let the designer make the final selection. Further, not all
bridges need to last 100 years and service life design options with lower initial costs could be
sufficient, as design for service life does not necessarily have to be associated with higher initial
costs.

The first step in the design for service life is to comprehend the body of knowledge
related to bridge durability under different exposure conditions and constraints, and to establish
an array of options capable of enhancing service life. This objective is achieved by including
eleven chapters in the Guide, each devoted to different bridge element, component, subsystem or
system. Some of the chapters in the Guide also include innovative solutions to details that have
historically resulted in lowering the service life of bridges.

For signature and long-span bridges, designers could identify the factors that affect the
service life and develop project-specific solutions. In these unique cases, the solutions can be
based on data collected by local Departments of Transportation, or agencies responsible for
maintaining the bridge.

Flowcharts shown in Figures 4 through 6 are used to demonstrate the general steps within
the framework for design for service life. Blocks within each flowchart are numbered. The
following sections briefly describe each step.

Step 1. The design for service life starts by first considering all project demands set by
the owner, including the service life requirements, as stated in Figure 4.

Step 2. In considering the project requirements, all feasible and preliminary bridge
alternatives that could satisfy the project demands are selected. For example, one might want to
consider steel, concrete, and segmental bridge alternates for a particular bridge. The development
of the potential bridge systems is carried out in a conventional manner, meeting all the provisions
of the LRFD Specifications. It is good practice to consider potential service life problems, even
at this stage of the design process. Chapter 2 of the *Guide* provides descriptions of most commonly used bridge systems and the advantages and disadvantages of each with respect to service life.

Steps 3 and 4. The next steps in the process consist of evaluating each bridge system alternate one at a time and considering service life issues related to each element, component, and subsystem of that bridge system. For example, assume that one of the bridge systems to be considered for a particular project is a steel bridge alternate. The designer will first develop the preliminary bridge configurations using the conventional approaches that meet all LRFD Specifications. Then, using procedures depicted in blocks 4a, 4b, 4c, each element, component, or subsystem of the steel bridge alternate will be checked against the service life requirements using the fault tree approach, described earlier. These evaluation requirements may lead to changes in the details of the element, component, or subsystem under consideration. For example, the preliminary deck configuration may indicate that use of 8-in. thick concrete is sufficient from a strength standpoint. Going through the fault tree corresponding to bridge deck the designer may change the deck thickness to 9 in. to address potential overloads, or wear and abrasion.
FIGURE 4 General flowchart demonstrating the Guide’s approach for service life design.

Steps 5 through 8. At the end of Step 4, and after going through appropriate fault trees for various bridge elements, components, and subsystems, the designer will have developed a bridge system that meets both strength and service life requirements, as illustrated by Step 5 in Figure 5.
To some extent, changes to configurations of various bridge elements, components, and subsystems are carried out separately. Therefore, there is a need to make sure that these changes are compatible and not contradictory or overly conservative. Steps 6 and 7 in Figure 5 depict this process. For example, in the steel bridge example discussed previously, service life requirements may dictate the use of a jointless, integral abutment system and require metalizing the end of the girder. The designer may then want to consider not metalizing the end of the girder, since leaking joints would be eliminated. Finally, for the selected bridge system alternate under consideration a final configuration is developed, Step 8, that meets both strength and service life requirements.

**FIGURE 5 General flowchart demonstrating the Guide’s approach for service life design.**

Steps 9 through 12. The next step in the process is to evaluate the service life of the various bridge elements, components, and subsystems of the bridge alternate under consideration and compare it to the owner-specified target service design life of the bridge system. For example, the owner may require that the bridge provide 100 years of service life, whereas the life of a particular bridge element, such as the sliding surface for a bearing, may be limited to 20 years.
years. There would therefore be a need to think ahead and accommodate replacement of the sliding surfaces. Regardless, there will be a need for a systematic maintenance plan that could require the designer to identify “hot areas” requiring more detailed inspection and maintenance. Blocks 9a through 9d depict the development of a maintenance plan and/or rehabilitation and replacement plan for the bridge system alternate under consideration. The result of this process, as illustrated in Step 10, is a bridge system alternate that meets both strength and service life requirements with an associated maintenance and/or rehabilitation or replacement plan for the bridge. The next step, as illustrated in Step 10, is to carry out life cycle cost analysis considering the final configuration of the selected bridge alternate and maintenance plan. The same steps are repeated for all bridge alternate systems as shown by Step 11. After comparing all alternates, the designer can then make a recommendation as to which alternate should be used, allowing the owner to make the final selection.

FIGURE 6 General flowchart demonstrating the Guide’s approach for service life design.
In instances where specified by the owner and for major and complex bridges, the final step in the design for service life process is the development of a bridge Owner’s Manual, which summarizes the processes used for design for service life and provides complete descriptions of outcomes and recommendations. The intention is to equip the owner with the necessary knowledge to keep the bridge operational for the specified service life period. The bridge Owner’s Manual should be provided to the owner at the time of opening the bridge to traffic, following an independent review process.

The entire process used for design for service life should be well documented and include assumptions, limitations, and any other information of which the owner should be aware, including complete information with respect to “hot spots” within various bridge elements, components, or subsystems that will require closer inspection, maintenance, retrofit, or replacement. The Owner’s Manual should include a complete management plan with respect to service life, including information on timely maintenance actions, and identify replacement items and methodologies for replacement with information on the required level of traffic interruption, if any. In the case of major and complex bridges, an instrumentation and monitoring plan could be incorporated to assist in determination of service life and implementation of an effective management plan. Additional information to be included in the Owner’s Manual after construction should include the actual material properties of critical bridge elements versus the assumed values used in the design process. Such information is important for future bridge rating.

The bridge Owner’s Manual is analogous to the design calculations that are customarily provided to the bridge owner, except that the Owner’s Manual contains much more detailed information.

Work is underway by this author to develop the next generation of provisions for design of bridges for service life. This effort involves incorporating the Performance Based Service Life Design of Bridges (PBSLDB), into the framework described earlier. Owners have different levels of expectations and needs with respect to length of time that bridge should be in service and level of interruptions that could be accommodated while conducting maintenance actions. These different requirements can best be accommodated within the PBSLD framework.

PBSLDB provides the owners with options, each associated with different initial and long-term costs. The concept of PBSLDB can be explained using an analogy to performance based design of bridges in seismic regions in which, for a given ground motion, design could be fine-tuned to produce different levels of performances during seismic events. The concept is explained using the Figure 7.
In Figure 7, a push over analysis is carried out and different displacement levels of the pier, along with associated damage levels, are indicated. This figure qualitatively indicates the repair level after the earthquake, the associated casualty level, and the period of time during which the bridge will be out of service. Each displacement level will require different levels of design and initial cost. In the case of earthquake design, similar plots could be created for different levels of ground motions.

In service life design, different service life design levels will produce different levels of down times and costs associated with maintenance. Further, different traffic levels can produce different performance levels. The PBSLDB can accommodate the needs and requirements of various owners and make the service life design very appealing to accept and routine step in design. One level of PBSLD is to ignore service life design.

Acknowledgement

This work was sponsored by Transportation Research Board of the National Academy of Sciences, and was conducted as part of the Second Strategic Highway Research Program (SHRP 2, Project R19A). The Project was managed by Program Officers Dr. Monica Starnes (Dec 2007 through Jan 2011), Mark Bush (Jan 2011 through Nov 2011) and Jerry DiMaggio (Dec 2011 onward). The Project Principal Investigator for SHRP 2 Project R19A was Dr. Atorod Azizinamini, Chairperson, Civil and Environmental Engineering Department at Florida International University. The Project was led by an executive committee consisting of author, Mr., Edward H. Power of HDR Engineering, Mr. Glenn F. Myers of Atkins North America and Dr. Celik Ozylidirim of Virginia Center for Transportation Innovation and Research. Other project investigators included Eric S. Kline of KTA, Inc., David W. Whitmore of Vector
Corrosion, Dennis R. Mertz of University of Delaware and Don White of Georgia Institute of Technology. Several graduate students assisted in conduct of the project, which included, Dr. Nima Ala, Dr. Saeed Doust, Dr. Marcelo Da Silva, and Dr. Ardalan Sherafati. Dr. Aaron Yakel and Dr. Kromel Hanna, were the research associates assisting the project.

Several consultants and industry representatives provided input in research and development of various parts of the project. In particular, following individuals are acknowledged. Mr. Martin Burke, private consultant, Dr. Reid W. Castrodale of Carolina Stalite Company, Dr. David Darwin of University of Kansas, Mr. Simon Greensted of Sterling Lloyd, Mr. Mark Kaczinski of D. S. Brown Company, Dr. Ralph Oesterle of CTL Group, Dr. Duncan Paterson of HDR Engineering, Inc., Dr. Charles Roeder of University of Washington, and Mr. Ronald J. Watson of R.J. Watson, Inc. Project team worked closely with AASHTO T-9 technical committee under leadership of Mr. Bruce Johnson.

Opinions and conclusions presented are those of author and do not necessarily represent the viewpoints of sponsor.

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