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M. Shinozuka, M.Q. Feng, H. Kim, T. Uzawa and T. Ueda
Department of Civil and Environmental Engineering
University of Southern California
Los Angeles, California 90089-2531

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1 Fred Champion Professor, Department of Civil and Environmental Engineering, University of Southern California; now Distinguished Professor and Chair, Department of Civil Engineering, University of California, Irvine
2 Associate Professor, Department of Civil Engineering, University of California, Irvine
3 Visiting Scholar, Department of Civil and Environmental Engineering, University of Southern California
4 Visiting Researcher, Department of Civil and Environmental Engineering, University of Southern California

MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
University at Buffalo, State University of New York
Red Jacket Quadrangle, Buffalo, NY 14261

# Preface

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) is a national center of excellence in advanced technology applications that is dedicated to the reduction of earthquake losses nationwide. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission is to reduce earthquake losses through research and the application of advanced technologies that improve engineering, pre-earthquake planning and post-earthquake recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

MCEER's research is conducted under the sponsorship of two major federal agencies, the National Science Foundation (NSF) and the Federal Highway Administration (FHWA), and the State of New York. Significant support is also derived from the Federal Emergency Management Agency (FEMA), other state governments, academic institutions, foreign governments and private industry.

The Center's FHWA-sponsored Highway Project develops retrofit and evaluation methodologies for existing bridges and other highway structures (including tunnels, retaining structures, slopes, culverts, and pavements), and improved seismic design criteria and procedures for bridges and other highway structures. Specifically, tasks are being conducted to:

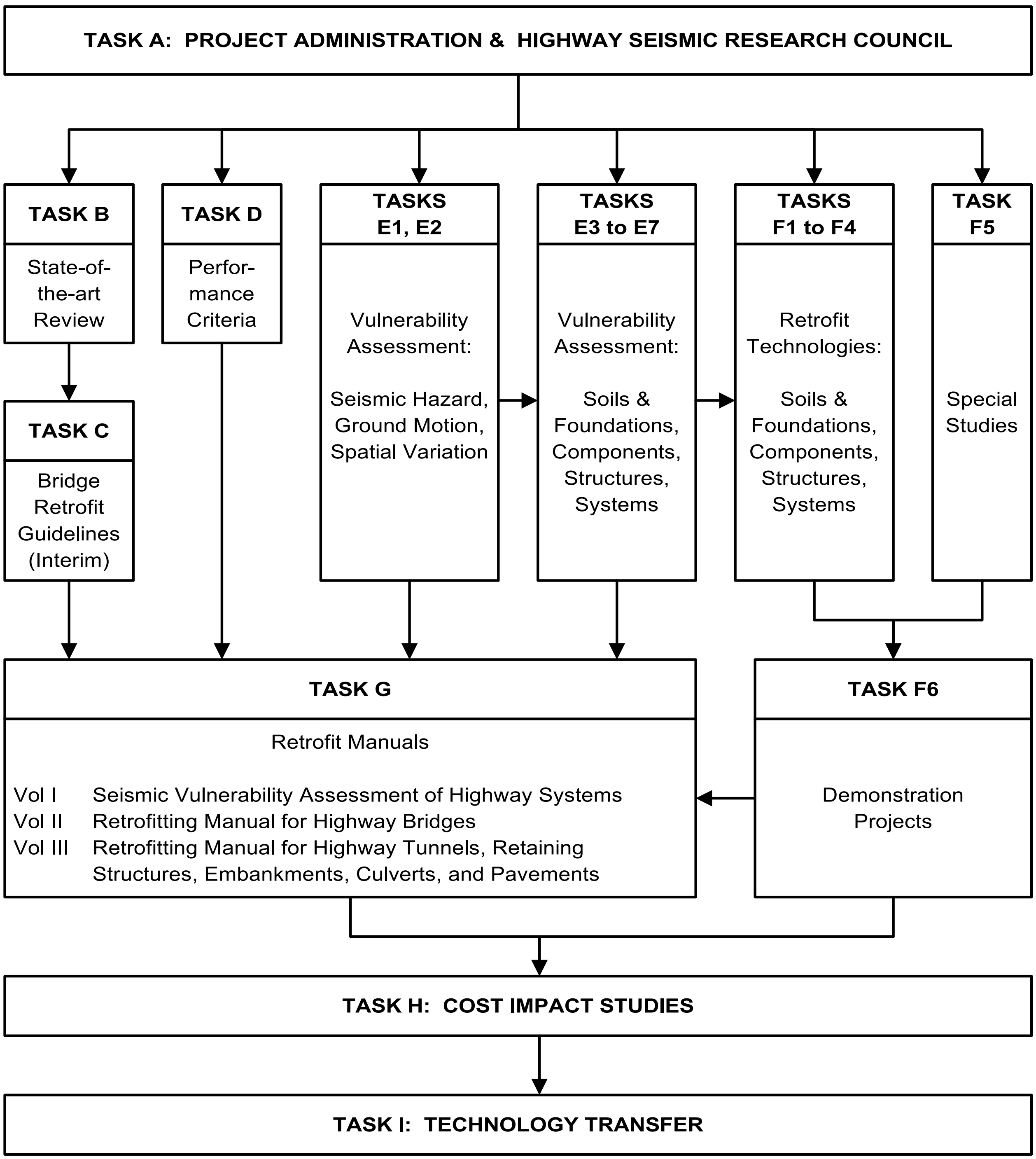
- assess the vulnerability of highway systems, structures and components;
- develop concepts for retrofitting vulnerable highway structures and components;
- develop improved design and analysis methodologies for bridges, tunnels, and retaining structures, which include consideration of soil-structure interaction mechanisms and their influence on structural response;
- review and recommend improved seismic design and performance criteria for new highway systems and structures.

Highway Project research focuses on two distinct areas: the development of improved design criteria and philosophies for new or future highway construction, and the development of improved analysis and retrofitting methodologies for existing highway systems and structures. The research discussed in this report is a result of work conducted under the existing highway structures project, and was performed within Tasks 106-E-7.3.5 and 106-E-7.6, "SRA Validation and Fragility Curves" of that project as shown in the flowchart on the following page.

*This report presents methods of developing bridge fragility curves on the basis of statistical analysis. Two types of curves are developed. Empirical fragility curves use bridge damage data from the past earthquakes, particularly from the 1994 Northridge and 1995 Kobe earthquakes, and analytical fragility curves are constructed for typical bridges in the Memphis, Tennessee area using nonlinear dynamic analysis. The Los Angeles area expressway network is used as an* *example to determine the effectiveness of using these fragility curves to estimate seismic performance. The conceptual and theoretical treatment dealt with in this study may provide a theoretical basis and practical analysis tools for the development of fragility curves and their application in assessing the seismic performance of transportation networks.*

*Furthermore, this report has unique pedagogical and archival features in that it (1) summarizes a number of journal and conference papers published earlier together with other unpublished materials arising from this study in a consistent manner, (2) includes damage data obtained from the 1994 Northridge and 1995 Hanshin-Awaji (Kobe) earthquake shortly after the events, (3) shows how one can simulate a set of simulated damage data by Monte Carlo techniques, (4) provides statistical procedures for hypothesis testing and estimation of confidence interval for the parameters in the fragility model, irrespective of whether data are empirically or analytically developed, and (5) actual process of these testing and estimation is guided step-by-step using the archived damage data.*

**SEISMIC VULNERABILITY OF EXISTING HIGHWAY CONSTRUCTION**
**FHWA Contract DTFH61-92-C-00106**



# ABSTRACT

This report presents methods of bridge fragility curve development on the basis of statistical analysis. Both empirical and analytical fragility curves are considered. The empirical fragility curves are developed utilizing bridge damage data obtained from past earthquakes, particularly the 1994 Northridge and 1995 Hyogo-ken Nanbu (Kobe) earthquake. Analytical fragility curves are constructed for typical bridges in the Memphis, Tennessee area utilizing nonlinear dynamic analysis.

Two-parameter lognormal distribution functions are used to represent the fragility curves. These two-parameters (referred to as fragility parameters) are estimated by two distinct methods. The first method is more traditional and uses the maximum likelihood procedure treating each event of bridge damage as a realization from a Bernoulli experiment. The second method is unique in that it permits simultaneous estimation of the fragility parameters of the family of fragility curves, each representing a particular state of damage, associated with a population of bridges. The method still utilizes the maximum likelihood procedure, however, each event of bridge damage is treated as a realization from a multi-outcome Bernoulli type experiment.

These two methods of parameter estimation are used for each of the populations of bridges inspected for damage after the Northridge and Kobe earthquakes and with numerically simulated damage for the population of typical Memphis area bridges. Corresponding to these two methods of estimation, this report introduces statistical procedures for testing goodness of fit of the fragility curves and of estimating the confidence intervals of the fragility parameters. Some preliminary evaluations are made on the significance of the fragility curves developed as a function of ground intensity measures other than PGA.

Furthermore, applications of fragility curves in the seismic performance estimation of expressway network systems are demonstrated. Exploratory research was performed to compare the empirical and analytical fragility curves developed in the major part of this report with those

constructed utilizing the nonlinear static method currently promoted by the profession in conjunction with performance-based structural design. The conceptual and theoretical treatment discussed herein is believed to provide a theoretical basis and practical analytical tools for the development of fragility curves, and their application in the assessment of seismic performance of expressway network systems.

# ACKNOWLEDGMENT

This study was supported by the Federal Highway Administration under contract DTFH61-92-C-00106 (Tasks 106-E-7.3.5 and 106-E-7.6) through the Multidisciplinary Center for Earthquake Engineering Research (MCEER) in Buffalo, NY. The authors wish to express their sincere gratitude to Dr. Ian Buckle for his support and encouragement and Mr. Ian Friedland for ably managing the project at MCEER.

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# SECTION 1
# INTRODUCTION

Bridges are potentially one of the most seismically vulnerable structures in the highway system. While performing a seismic risk analysis of a highway system, it is imperative to identify seismic vulnerability of bridges associated with various states of damage. The development of vulnerability information in the form of fragility curves is a widely practiced approach when the information is to be developed accounting for a multitude of uncertain sources involved, for example, in estimation of seismic hazard, structural characteristics, soil-structure interaction, and site conditions.

In principle, the development of bridge fragility curves will require synergistic use of the following methods: (1) professional judgement, (2) quasi-static and design code consistent analysis, (3) utilization of damage data associated with past earthquakes, and (4) numerical simulation of bridge seismic response based on structural dynamics.

An exploratory work is carried out in this study to develop fragility curves for comparison purposes on the basis of the nonlinear static method consistent with method (2) in the preceding paragraph. The major effort of this study, however, is placed on the development of empirical and analytical fragility curves as described in methods (3) and (4) above, respectively: the former by utilizing the damage data associated with past earthquakes, and the latter by numerically simulating seismic response with the aid of structural dynamic analysis. At the same time, it introduces statistical procedures appropriate for the development of fragility curves under the assumption that they can be represented by two-parameter lognormal distribution functions with the unknown median and log-standard deviation. These two-parameters are referred to as the fragility parameters in this study. Two different sets of procedures describe how the fragility parameters are estimated, the test of goodness of fit can be performed and confidence intervals of the parameters estimated. The one procedure (Method 1) is used when the fragility curves are independently developed for different states of damage, while the other (Method 2) when they are constructed dependently on each other in such a way that the log-standard deviation is common to all the fragility curves. The empirical fragility curves are developed utilizing bridge damage data obtained from the past earthquakes, particularly the 1994 Northridge and the 1995 Hyogo-ken Nanbu (Kobe) earthquake. Analytical fragility curves are developed for typical bridges in the Memphis, Tennessee area on the basis of a nonlinear dynamic analysis.

Two-parameter lognormal distribution functions were traditionally used for fragility curve construction. This was motivated by its mathematical expedience in approximately relating the actual structural strength capacity with the design strength through an overall factor of safety which can be assumedly factored into a number of multiplicative safety factors, each associated with a specific source of uncertainty. When the lognormal assumption is made for each of these factors, the overall safety factor also distributes lognormally due to the multiplicative reproducibility of the lognormal variables. This indeed was the underpinning assumption that was made in the development of probabilistic risk assessment methodology for nuclear power plants in the 1970's and in the early 1980's (NRC, 1983). Although this assumption is not explicitly used in this report, fragility curves are modeled by lognormal distribution function in this study. Use of the three-parameter lognormal distribution functions for fragility curves is possible with the third parameter estimating the threshold of ground motion intensity below which the structure will never sustain any damage. However, this has never been a popular decision primarily because no one wishes to make such a definite, potentially unconservative assumption.

The study also includes the sections where some preliminary evaluations are made on the significance of the fragility curves developed as a function of ground intensity measures other than PGA, and furthermore, applications of fragility curves in the seismic performance estimation of expressway network systems are demonstrated.

Finally, an exploratory work is performed to compare the analytical fragility curves developed in the major part of this study with those constructed utilizing the nonlinear static method currently promoted by the profession in conjunction with performance-based structural design.

The conceptual and theoretical treatment dealt with in this study is believed to provide a theoretical basis and analytical tools of practical usefulness for the development of fragility curves and their applications in the assessment of seismic performance of expressway network systems.

This study emphasizes statistical analysis of fragility curves and in that sense it is rather unique together with Basoz and Kiremidjian (1998). The reader is referred to the following papers, among many others, for the previous work performed on fragility curves with different emphasis and developed for civil structures; ATC-13 (ATC, 1985), Barron-Corvera (1999), Dutta and Mander (1998), Hwang et al. (1997), Hwang amd Huo (1998), Hwang et al. (1999), Nakamura and Mizutani (1996), Nakamura et al. (1998), Shinozuka et al. (1999), and Singhal and Kiremidjian (1997).

# SECTION 2
# EMPIRICAL FRAGILITY CURVES

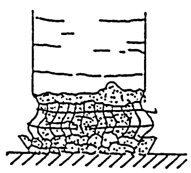
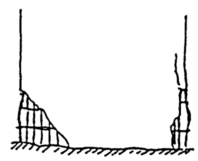
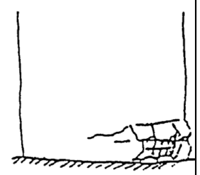
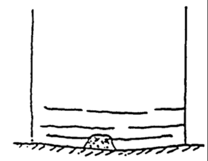
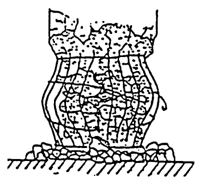
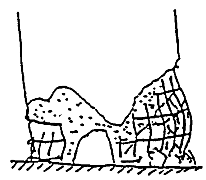
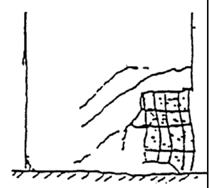
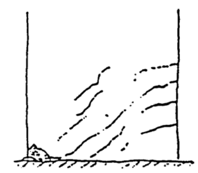
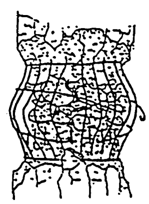
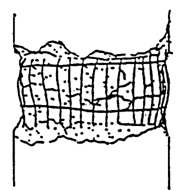
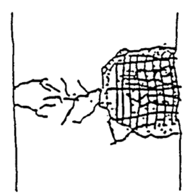
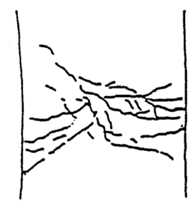
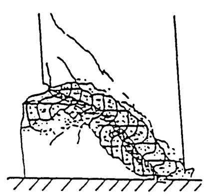
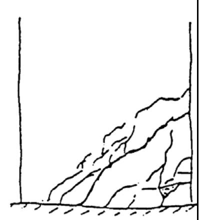
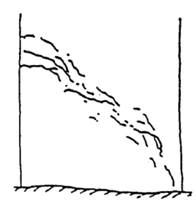
It is assumed that the empirical fragility curves can be expressed in the form of two-parameter lognormal distribution functions, and developed as functions of peak ground acceleration (PGA) representing the intensity of the seismic ground motion. Use of PGA for this purpose is considered reasonable since it is not feasible to evaluate spectral acceleration by identifying significantly participating natural modes of vibration for each of the large number of bridges considered for the analysis here, without having a corresponding reliable ground motion time history. The PGA value at each bridge location is determined by interpolation and extrapolation from the PGA data due to D. Wald of USGS (Wald, 1998).

For the development of empirical fragility curves, the damage reports are usually utilized to establish the relationship between the ground motion intensity and the damage state of each bridge. This is also the case for the present study. One typical page of the damage report for the Caltrans' bridges under the Northridge event is shown in table 2-1, where the extent of damage is classified in column 5 into the state of no, minor, moderate and major damage in addition to the state of collapse. The report did not provide explicit physical definitions of these damage states (in column 5, a blank space signifies no damage). As far as the Caltrans' bridges are concerned, this inspection report (table 2-1) is used when a damage state is assigned to each bridge in the analysis that follows. In view of the time constraint in which the inspection had to be completed after the earthquake, the classification of each bridge into one of the five damage states, understandably, contains some elements of judgement.

Hanshin Expressway Public Corporation's (HEPC's) report on the damage sustained by RC bridge columns resulting from the Kobe earthquake uses five classes of damage state as shown in figure 2-1 in which the damage states As, A, B, C and D are defined by the corresponding sketches of damage within each of four failure modes. It appears reasonable to consider that these damage states are respectively classified as states of collapse (As), major damage (A), moderate damage (B), minor damage (C) and no damage (D).

**TABLE 2-1 Northridge Earthquake Damage Data**

| BRIDGE NO | YEAR BUILT | LENGTH (ft) | DECK_WD (ft) | DAMAGE STATE | PGA(g) D.Wald | SOIL TYPE | NO. OF SPANS | SKEW (DEG.) | HINGE JOINT | BENT JOINT |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| 53 1782S | 1965 | 66 | 338 | | 0.30 | C | 1 | 36 | 0 | 0 |
| 53 1783 | 1967 | 318 | 547 | MAJ | 0.61 | C | 2 | 40 | 0 | 0 |
| 53 1784 | 1967 | 156 | 1670 | | 0.09 | C | 4 | 4 | 0 | 0 |
| 53 1785 | 1967 | 155 | 1480 | | 0.09 | C | 3 | 7 | 0 | 0 |
| 53 1786 | 1967 | 155 | 1680 | | 0.11 | C | 3 | 4 | 0 | 0 |
| 53 1789 | 1967 | 219 | 1207 | | 0.10 | C | 2 | 5 | 0 | 0 |
| 53 1790 | 1967 | 1511 | 1380 | MIN | 0.29 | C | 14 | 9 | 4 | 0 |
| 53 1790H | 1967 | 2831 | 280 | MOD | 0.29 | C | 27 | 99 | 13 | 0 |
| 53 1792L | 1967 | 146 | 680 | MAJ | 0.64 | C | 1 | 32 | 0 | 0 |
| 53 1792R | 1967 | 146 | 680 | MIN | 0.64 | C | 1 | 32 | 0 | 0 |
| 53 1793 | 1963 | 25 | | | 0.12 | C | 2 | 30 | 0 | 0 |
| 53 1794 | 1966 | 444 | 400 | | 0.10 | C | 5 | 99 | 0 | 0 |
| 53 1795 | 1967 | 19 | | | 0.10 | C | 1 | 20 | 0 | 0 |
| 53 1796 | 1967 | 220 | 395 | MOD | 0.68 | C | 2 | 0 | 0 | 0 |
| 53 1797L | 1967 | 741 | 68 | COL | 0.68 | C | 5 | 67 | 2 | 0 |
| 53 1797R | 1967 | 741 | 68 | COL | 0.68 | C | 5 | 67 | 2 | 0 |
| 53 1806 | 1970 | 218 | 997 | | 0.11 | C | 2 | 5 | 0 | 0 |
| 53 1807 | 1968 | 277 | 340 | MOD | 0.47 | C | 3 | 0 | 0 | 2 |
| 53 1808F | 1965 | 15 | | | 0.23 | C | 1 | 10 | | |
| 53 1809 | 1968 | 222 | 340 | MOD | 0.43 | C | 2 | 7 | 0 | 0 |
| 53 1810L | 1967 | 151 | 680 | | 0.43 | C | 3 | 9 | 0 | 0 |
| 53 1810R | 1967 | 151 | 680 | | 0.43 | C | 3 | 9 | 0 | 0 |
| 53 1811 | 1967 | 537 | | | 0.10 | C | 8 | 0 | 0 | 0 |
| 53 1812 | 1967 | 296 | | | 0.09 | C | 4 | 0 | 0 | 0 |
| 53 1813 | 1967 | 540 | | | 0.09 | C | 8 | 0 | 0 | 0 |
| 53 1815 | 1967 | 246 | 407 | MAJ | 0.59 | C | 2 | 0 | 0 | 0 |
| 53 1817 | 1966 | 63 | 1580 | | 0.15 | C | 1 | 0 | 0 | 0 |
| 53 1818 | 1966 | 92 | 1480 | | 0.15 | C | 1 | 0 | 0 | 0 |
| 53 1819 | 1966 | 83 | 1680 | | 0.15 | C | 1 | 0 | 0 | 0 |
| 53 1838G | 1967 | 944 | 400 | MIN | 0.32 | C | 10 | 30 | 4 | 0 |
| 53 1850 | 1966 | 185 | 877 | | 0.15 | C | 2 | 0 | 0 | 0 |
| 53 1851 | 1967 | 3065 | 1160 | MOD | 0.33 | C | 30 | 40 | | |
| 53 1852F | 1967 | 830 | 340 | MIN | 0.32 | B | 9 | 30 | 3 | 0 |
| 53 1853G | 1967 | 297 | 400 | | 0.33 | B | 3 | 25 | 0 | 0 |
| 53 1854G | 1967 | 1282 | 340 | | 0.33 | B | 13 | 99 | 3 | 0 |
| 53 1855F | 1967 | 656 | 340 | MIN | 0.32 | B | 7 | 99 | 1 | 0 |
| 53 1856 | 1966 | 785 | | MIN | 0.39 | B | 5 | 99 | | |

| Damage State / Damage Mode | As | A | B | C | D |
|---|---|---|---|---|---|
| **1. Bending Damage at ground level**<br><br>**(This mode ultimately produces buckling of rebar, spalling and crushing of core concrete)** | **Damage through entire cross-section**<br> | **Damage mainly at two opposite sides**<br> | **Damage mainly at one side**<br> | **Light cracking and partial spalling**<br> | **No Damage** |
| **2. Combined Bending & Shear Damage at ground level**<br><br>**(Bending and shear cracks progress with more wide-spread spalling than model and hoops detached from anchorage)** | **Internal damage**<br> | **Damage at two sides**<br> | **Damage mainly at one side**<br> | **Light cracking and partial spalling**<br> | **No damage** |
| **3. Combined Bending & Shear Damage at the level of reduction of longitudinal rebar**<br><br>**(Damage and collapse are observed at about the location, typically 4-5m above ground, of reduction of longitudinal rebar accompanying buckling of rebar and detached hoops)** | **Internal damage**<br> | **Internal damage**<br> | **Damage mainly at one side**<br> | **Partial damage**<br> | **No damage** |
| **4. Shear Damage at ground level**<br><br>**(Columns with low aspect ratio sheared at $45^0$ angle)** | **Damage through entire cross-section**<br> | **Damage through column**<br> | **Partial damage**<br> | **Light cracking***<br> | **No Damage** |

* No description provided in the original

**FIGURE 2-1 Description of States of Damage for Hanshin Expressway Corporation's Bridge Columns**

The perishable nature of damage information urgently calls for the establishment of standardized description of seismic damage based on more physical interpretation of what is visual for the post-earthquake damage inspection in the future destructive earthquake. Such description of seismic damage carefully recorded will be of lasting value to the earthquake engineering research community for the development of its capability in systematically estimating the seismic vulnerability of urban built environment. In this respect, classification more rigorously defined on the basis of quantitative analysis of physical damage is highly desirable. This, however, was not pursued in this study for various practical reasons; one dominant reason is the anticipated difficulty in collecting and interpreting detailed damage data that would permit such a quantitative analysis. Obviously, the fragility curves developed in this study on the basis of these damage data are valid for the Caltrans' and HEPC's bridges prior to the their repair and retrofit that took place after the earthquakes. In this context, it is an interesting subject of future study to examine the impact of repair and retrofit from the viewpoint of fragility curve enhancement.

In this study, the parameter estimation, hypotheses testing and confidence interval estimation related to the fragility curves are carried out in two different ways. The first method (Method 1) independently develops a fragility curve for each of a damage state for each sample of bridges with a given set of bridge attributes. A family of four fragility curves can, for example, be developed independently for the damage states respectively identified as "at least minor", "at least moderate", "at least major" and "collapse", making use of the entire sample (of size equal to 1,998) of Caltrans' expressway bridges in Los Angeles County, California subjected to the Northridge earthquake and inspected for damage after the earthquake. This is done by estimating, by the maximum likelihood method, the two fragility parameters of each lognormal distribution function representing a fragility curve for a specific state of damage. These fragility curves are valid under the assumption that the entire sample is statistically homogeneous. The same independent estimation procedure can be applied to samples of bridges more realistically categorized. A sample consisting only of single span bridges out of the entire sample is such a case for which four fragility curves can also be independently developed for all the bridges with a single span. Method 1 also includes the procedure to test the hypothesis that the observed damage data are generated by chance from the corresponding fragility curves thus developed (test of goodness of fit). In addition, Method 1 provides a procedure of estimating statistical confidence intervals of the fragility parameters through a Monte Carlo simulation technique.

It is noted that the bridges in a state of damage as defined above include a sub-set of the bridges in a severer state of damage implying that the fragility curves developed for different states of damage within a sample are not supposed to intersect. Intersection of fragility curves can happen, however, under the assumption that they are all represented by lognormal distribution functions and constructed independently, unless log-standard derivations are identical for all the fragility curves. This observation leads to the following method referred to as Method 2, where the parameters of the lognormal distribution functions representing different states of damage are simultaneously estimated by means of the maximum likelihood method. In this method, the parameters to be estimated are the median of each fragility curve and one value of the log-standard derivation prescribed to be common to all the fragility curves. The hypothesis testing and confidence interval estimation will follow accordingly.

Additional comments are in order with respect to the assumption that all fragility curves are represented by lognormal distributions. As mentioned above, bridges in a severer state of damage constitute a sub-set of those in a state of lesser damage, and fragility curves associated with the severer states must be determined taking into consideration that they are statistically conditional to the fragility curves associated with the lesser states of severity. Hence, as the common sense also dictates, the values of the fragility curve at a specified ground motion intensity such as PGA is always larger for a lesser state of damage than that for a severer state. Although the assumption of lognormal distribution functions with identical log-standard deviation satisfies the requirement just mentioned, this is not sufficient to theoretically justify the use of lognormal distribution functions for fragility curves associated with all states of damage. In this regard, it is possible to develop a conditional fragility curve associated with each state of damage. This is achieved by implementing the following three steps (Mizutani, 1999); first, consider the (unconditional) fragility curve for a state of "at least minor" damage. Second, develop the conditional fragility curve for bridges with a state of damage one rank severer, i.e., "at least moderate" damage. This conditional fragility curve is constructed for the bridges in a state of "at least moderate" damage, considering only those bridges in the "at least minor" state of damage. Finally, the conditional fragility value for the "at least moderate" state of damage is multiplied by the unconditional fragility value for the "at least minor" state of damage at each value of ground motion intensity to obtain the unconditional fragility curve for the "at least moderate" state of damage. Sequentially applied, this three-step process will produce a family of four fragility curves for "at least minor", "at least moderate", "at least major" and "collapse" (in the case of Caltrans' bridges considered in this study) which will not intersect. The fragility curve for "at least minor" state of damage is unconditional to begin with since the state of damage one rank less severe is the state of "at least no" damage which is satisfied by each and every bridge of the entire sample of bridges.

While the three-step process above does produce a family of fragility curves that will not intersect, it cannot always develop lognormal distribution functions for all the damage states either independently or simultaneously. For mathematical expedience and computational ease, this study uses Methods 1 and 2 to develop fragility curves in the form of lognormal distribution function.

## 2.1 Parameter Estimation; Method 1

In Method 1, the parameters of each fragility curve are independently estimated by means of the maximum likelihood procedure as described below. The likelihood function for the present purpose is expressed as

$$L = \prod_{i=1}^{N} \left[F(a_i)\right]^{x_i} \left[1 - F(a_i)\right]^{1-x_i} \tag{2-1}$$

where $F(.)$ represents the fragility curve for a specific state of damage, $a_i$ is the PGA value to which bridge $i$ is subjected, $x_i$ represents realizations of the Bernoulli random variable $X_i$ and $x_i$=1 or 0 depending on whether or not the bridge sustains the state of damage under PGA = $a_i$, and $N$ is the total number of bridges inspected after the earthquake. Under the current lognormal assumption, $F(a)$ takes the following analytical form

$$F(a) = \Phi\left[\frac{\ln\left(\frac{a}{c}\right)}{\zeta}\right] \tag{2-2}$$

in which "$a$" represents PGA and $\Phi[.]$ is the standardized normal distribution function.

The two-parameters $c$ and $\zeta$ in (2-2) are computed as $c_0$ and $\zeta_0$ satisfying the following equations to maximize ln $L$ and hence $L$;

$$\frac{d\ln L}{dc} = \frac{d\ln L}{d\zeta} = 0 \tag{2-3}$$

This computation is performed by implementing a straightforward optimization algorithm.

## 2.2 Parameter Estimation; Method 2

A set of parameters of lognormal distributions representing fragility curves associated with all levels of damage state involved in the sample of bridges under consideration are estimated simultaneously in Method 2. A common log-standard deviation is estimated along with the medians of the lognormal distributions with the aid of the maximum likelihood method. The common log-standard deviation forces the fragility curves not to intersect. The following likelihood formulation is developed for the purpose of Method 2.

Although Method 2 can be used for any number of damage states, it is assumed here for the ease of demonstration of analytical procedure that there are four states of damage including the state of no damage. A family of three (3) fragility curves exist in this case as schematically shown in figure 2-2 where events $E_1$, $E_2$, $E_3$ and $E_4$ respectively indicate the state of no, at least minor, at least moderate and major damage. $P_{ik} = P(a_i, E_k)$ in turn indicates the probability that a bridge $i$ selected randomly from the sample will be in the damage state $E_k$ when subjected to ground motion intensity expressed by PGA = $a_i$. All fragility curves are represented by two-parameter lognormal distribution functions

$$F_j(a_i; c_j, \varsigma_j) = \Phi\left[\frac{\ln(a_i / c_j)}{\varsigma_j}\right] \tag{2-4}$$

where $c_j$ and $\zeta_j$ are the median and log-standard deviation of the fragility curves for the damage state of “at least minor”, “at least moderate” and “major” identified by $j$ = 1, 2 and 3 respectively. From this definition of fragility curves, and under the assumption that the log-standard deviation is equal to $\zeta$ common to all the fragility curves, one obtains:

$$P_{i1} = P(a_i, E_1) = 1 - F_1(a_i; c_1, \zeta) \quad (2\text{-}5)$$

$$P_{i2} = P(a_i, E_2) = F_1(a_i; c_1, \zeta) - F_2(a_i; c_2, \zeta) \quad (2\text{-}6)$$

$$P_{i3} = P(a_i, E_3) = F_2(a_i; c_2, \zeta) - F_2(a_i; c_3, \zeta) \quad (2\text{-}7)$$

$$P_{i4} = P(a_i, E_4) = F_3(a_i; c_3, \zeta) \quad (2\text{-}8)$$

The likelihood function can then be introduced as

$$L(c_1, c_2, c_3, \zeta) = \prod_{i=1}^{n} \prod_{k=1}^{4} P_k(a_i; E_k)^{x_{ik}} \quad (2\text{-}9)$$

where

$$x_{ik} = 1 \quad (2\text{-}10)$$

if the damage state $E_k$ occurs for the $i$-th bridge subjected to $a = a_i$, and

$$x_{ik} = 0 \quad (2\text{-}11)$$

otherwise. The maximum likelihood estimates $c_{0j}$ for $c_j$ and $\zeta_0$ for $\zeta$ are obtained by solving the following equations,

$$\frac{\partial \ln L(c_1, c_2, c_3, \zeta)}{\partial c_j} = \frac{\partial \ln L(c_1, c_2, c_3, \zeta)}{\partial \zeta} = 0 \qquad (j = 1,2,3) \quad (2\text{-}12)$$

by again implementing a straightforward optimization algorithm.

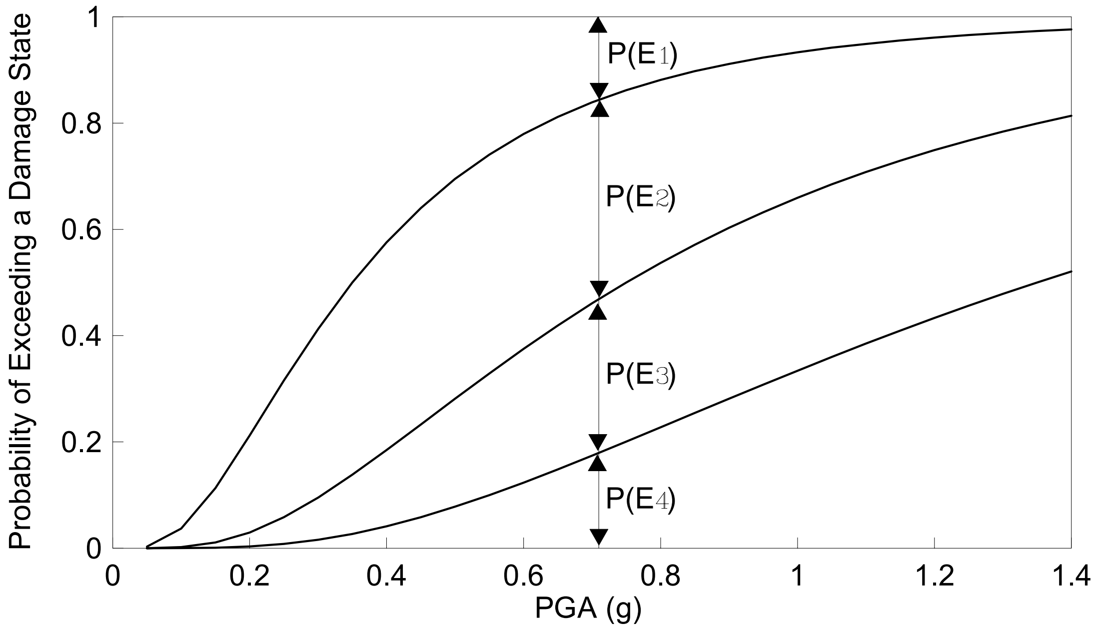



**FIGURE 2-2 Schematics of Fragility Curves**

## 2.3 Fragility curves for Caltrans' and HEPC's bridges

Four fragility curves for Caltrans' bridges associated with the four states of damages are plotted in figures 2-3 and 2-4, upon estimating the parameters involved by Methods 1 and 2 respectively (with their respective median and log-standard deviation values also indicated). These fragility curves are constructed on the damage data summarized in the format of table 2-2 which, for computational convenience, is transformed from that of table 2-1 which is developed in principle by overlaying the Caltrans' bridge map (figure 2-5) on the Northridge earthquake PGA contour map due to D. Wald (figure 2-6). In table 2-2, bridges are renumbered in the ascending order with respect to PGA. The entry of 1 in each of the columns (4)~(7) indicates that the bridge is at least in the state of damage designated by the column, while the entry of 0 shows that the bridge does not suffer from the state of damage designated or severer. Figures 2-7~2-10 show separately the four fragility curves developed for Caltrans' bridges obtained by Method 1 (figure 2-3) together with the damage data further transformed from table 2-2 just to demonstrate the statistical variation of the data relative to the estimated fragility curve. The black diamonds in figures 2-7~2-10 indicate these damage data developed in such a way that the entire sample of 1998 bridges are sub-divided into 44 groups of 44 bridges (starting from bridges 1~44, bridges 45~88, and so on) with the last group having 62 bridges. The number of the bridges that sustained the state of damage under consideration in a group is divided by the total number of bridges in the group (which is 44 except for the last group) and this ratio is used as a realization of fragility value at the PGA value representative of the group obtained by averaging the smallest and the largest PGA value assigned to the bridges in the group. Whether the fit of the fragility curves to the input data can be judged acceptable in statistical sense is the subject of study in a later section of this report (Section 5.1 and 5.2). Figures 2-11~2-14 show the statistical variation of the same input data relative to the estimated fragility curves obtained by Method 2 (figure 2-4) with each curve plotted separately (though estimated together). The fragility curves identified by "minor" in figures 2-7 and 2-11 are associated with the state of "at least minor damage". Similar meaning applies to other three fragility curves identified by "moderate", "major" and "collapse", unless specified otherwise. The difference between figures 2-3 and 2-4 is relatively insignificant, although Method 2 produced larger probabilities of minor damage and smaller probabilities of major damage than Method 1 throughout the range of PGA examined.

Fragility curves are also constructed (Nakamura et al., 1998) on the basis of a sample of 770 single-support reinforced concrete columns along two stretches of the viaduct, one in the HEPC's Kobe Route and the other in the Ikeda Route with total length of approximately 40 km. Table 2-3 represents the input damage data reformatted from the damage report by HEPC's engineers after the 1995 Kobe earthquake. These bridge columns are of similar geometry and similarly reinforced as shown in figure 2-15 which is drawn for a typical column (#Kou-P362). In this respect, the 770 columns under consideration here constitute a much more homogeneous statistical sample than the Caltrans' bridges considered earlier. The PGA value at each column location under the Kobe earthquake is estimated by Nakamura et al (1998) on the basis of the work by Nakamura et al (1996).

Integrating the damage state information with that of the PGA, and making use of the maximum likelihood method involving (2-1)~(2-3), three (3) sets of $c_0$ and $\zeta_0$ are obtained independently by Method 1 and corresponding three fragility curves for the states of at least minor, at least moderate and at least major damage are constructed as shown in figure 2-16 together with values of the median $c_0$ and log-standard deviation $\zeta_0$. As in the case of Caltrans' bridges, the curve with "minor" designation represents, at each PGA value "$a$", the probability that "at least minor" state of damage will be sustained by a bridge (arbitrarily chosen from the sample of bridges) when it is subjected to PGA "*a*". The same meaning applies to other curves with their respective damage state designations. On the other hand, using (2-4), (2-9) and (2-12) in exactly the same way as in the case of the Caltrans' bridges, Method 2 estimates the fragility parameter values simultaneously. A family of three fragility curves for the four states of damage are constructed and plotted in figure 2-17 together with three respective estimates of median ($c_0$ written for $c_{j0}$) and log-standard deviation ($\zeta_0$). To show the statistical variation of the HEPC's damage data with respect to the estimated fragility curves, figures 2-18~2-20 and figures 2-21~2-23 are drawn respectively for the individual fragility curves estimated by Methods 1 and 2. For this purpose, similarly to figures 2-7~2-14, the input damage data are reformatted from table 2-3 so that the bridge columns are grouped into 14 groups of 55 columns (column 1~55, 56~110, and so on) each with a representative PGA obtained by averaging the largest and smallest PGA values within the group.

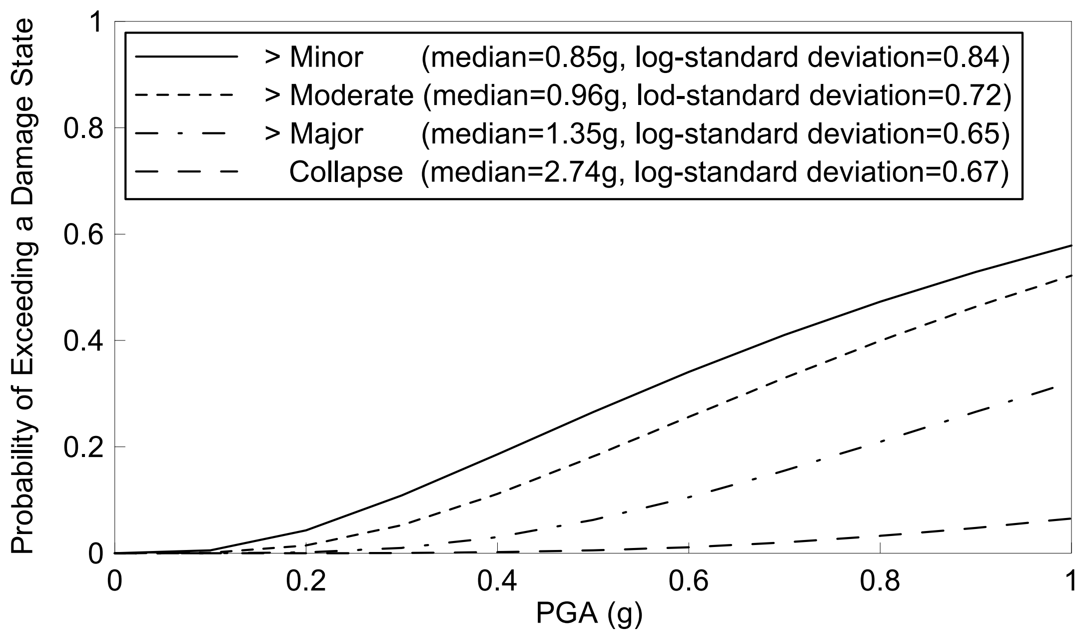



**FIGURE 2-3 Fragility Curves for Caltrans' Bridges (Method 1)**

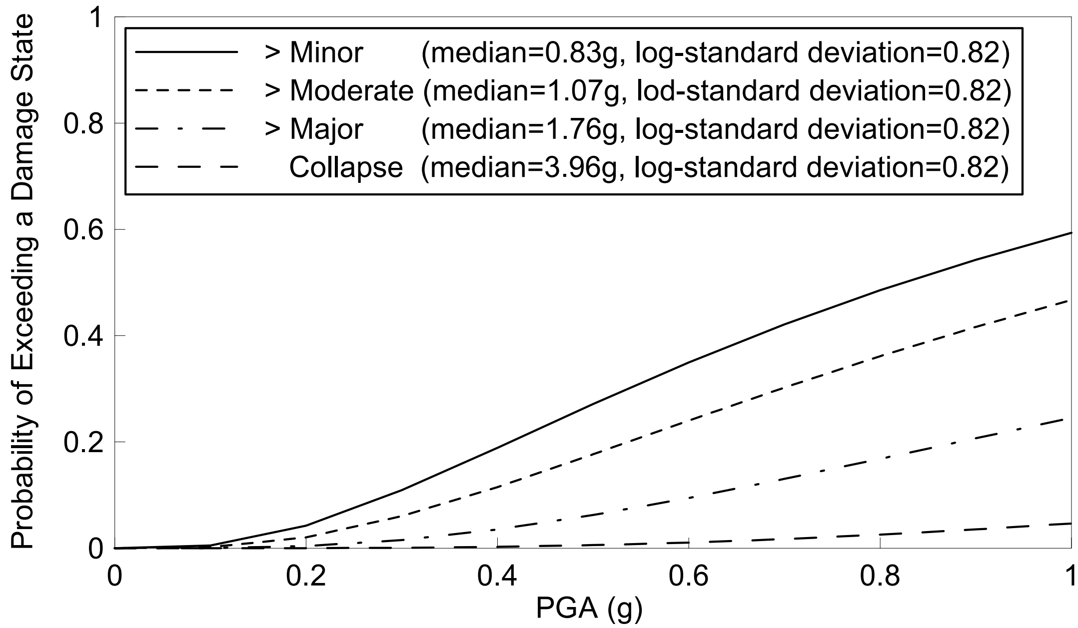



**FIGURE 2-4 Fragility Curves for Caltrans' Bridges (Method 2)**

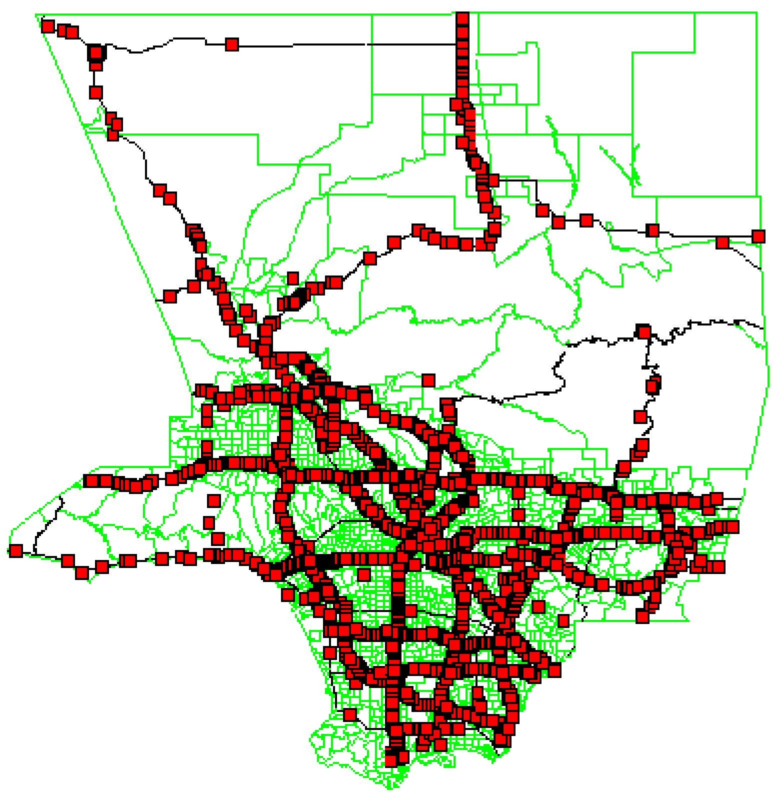


**FIGURE 2-5 Caltrans' Express Bridge Map in Los Angeles County**

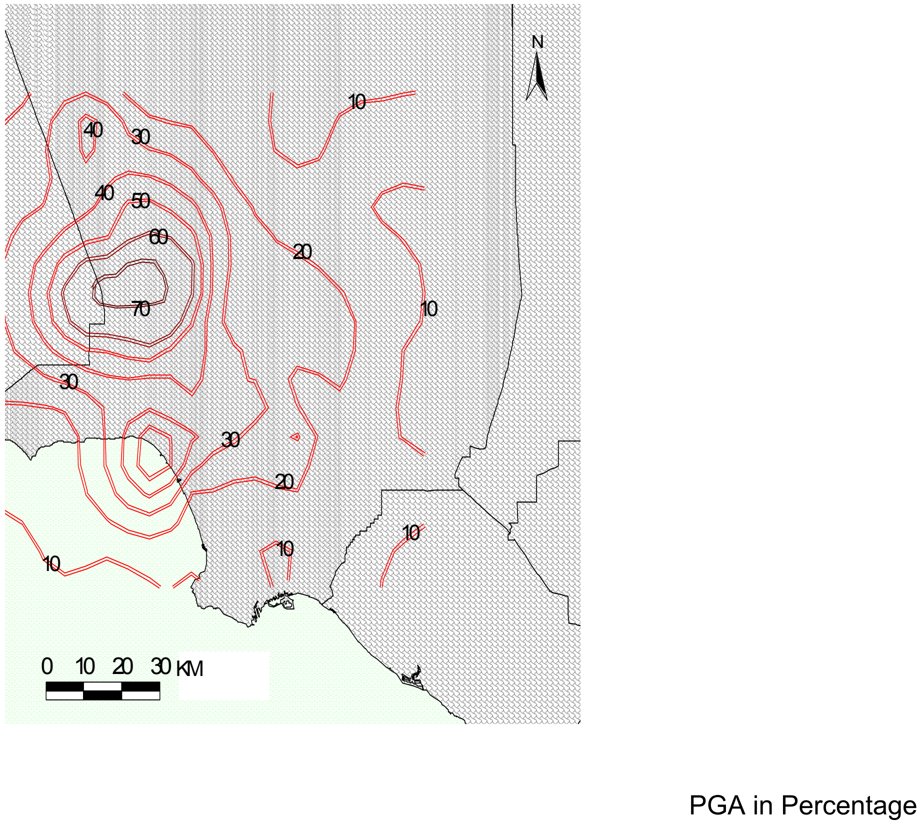



**FIGURE 2-6 PGA Contour Map (1994 Northridge Earthquake; D. Wald)**

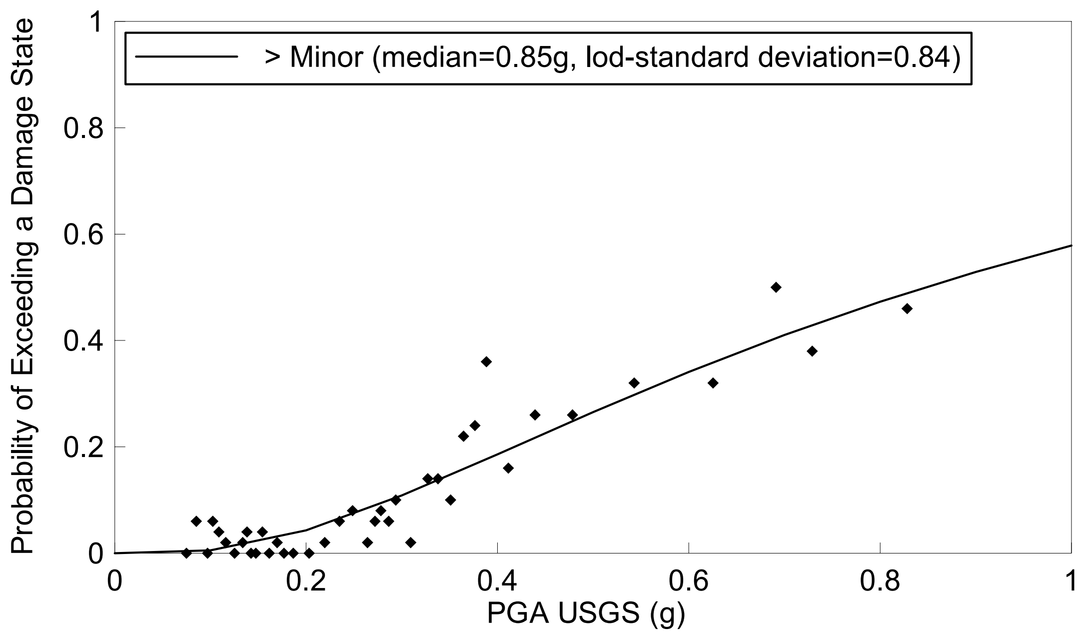



**FIGURE 2-7 Fragility Curve for Caltrans' Bridges**

**with at least Minor Damage and Input Damage Data (Method 1)**

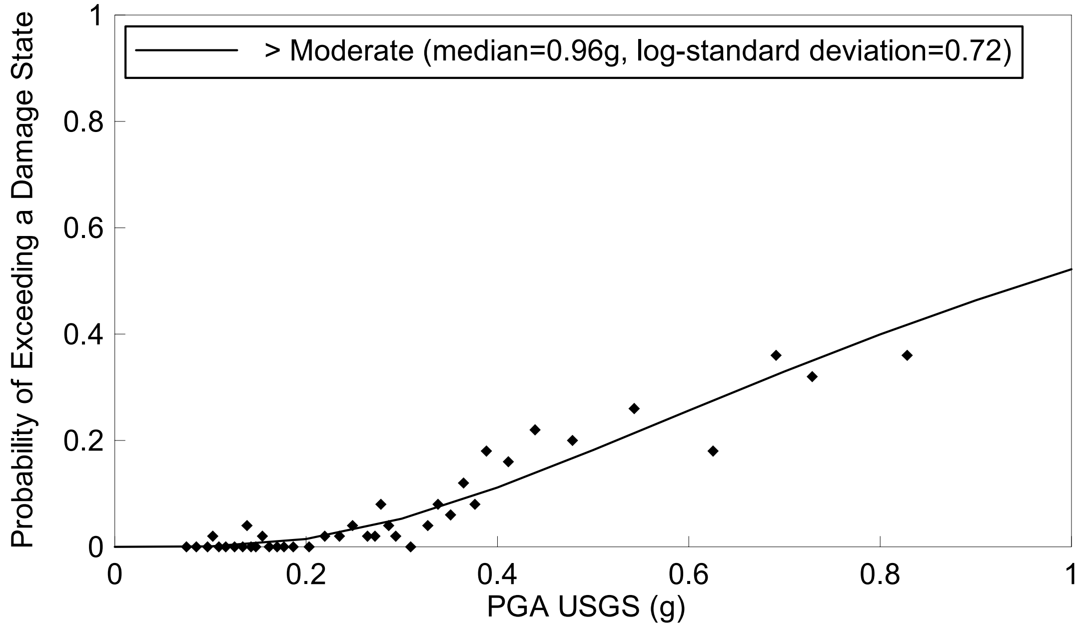



**FIGURE 2-8 Fragility Curve for Caltrans' Bridges**

**with at least Moderate Damage and Input Damage Data (Method 1)**

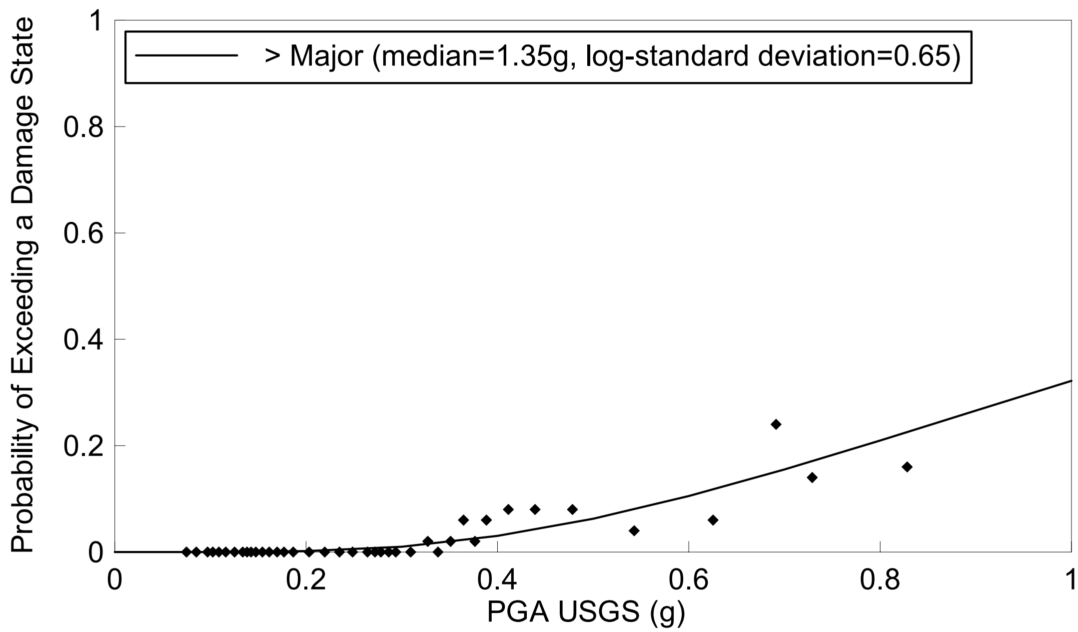



**FIGURE 2-9 Fragility Curve for Caltrans' Bridges**

**with at least Major Damage and Input Damage Data (Method 1)**

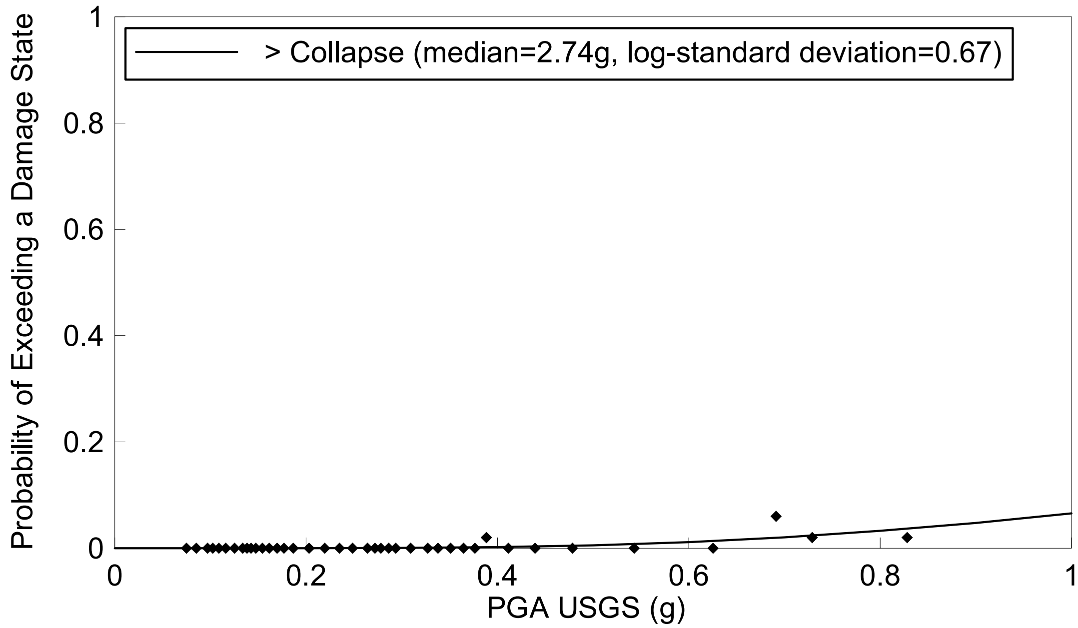



**FIGURE 2-10 Fragility Curve for Caltrans' Bridges with Collapse Damage and Input Damage Data (Method 1)**

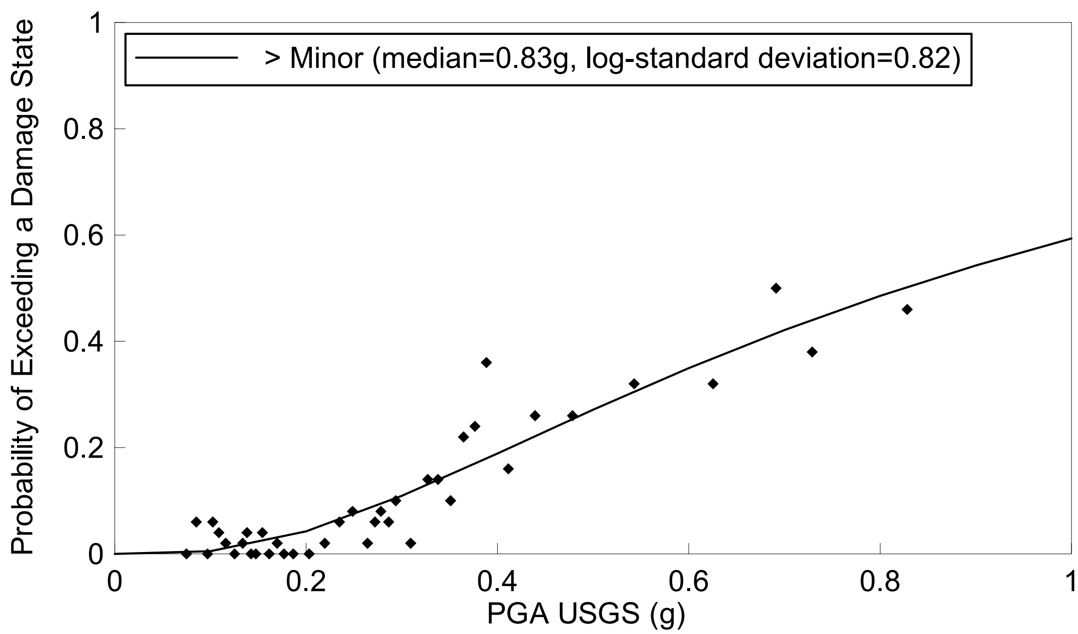



**FIGURE 2-11 Fragility Curve for Caltrans' Bridges with at least Minor Damage and Input Damage Data (Method 2)**

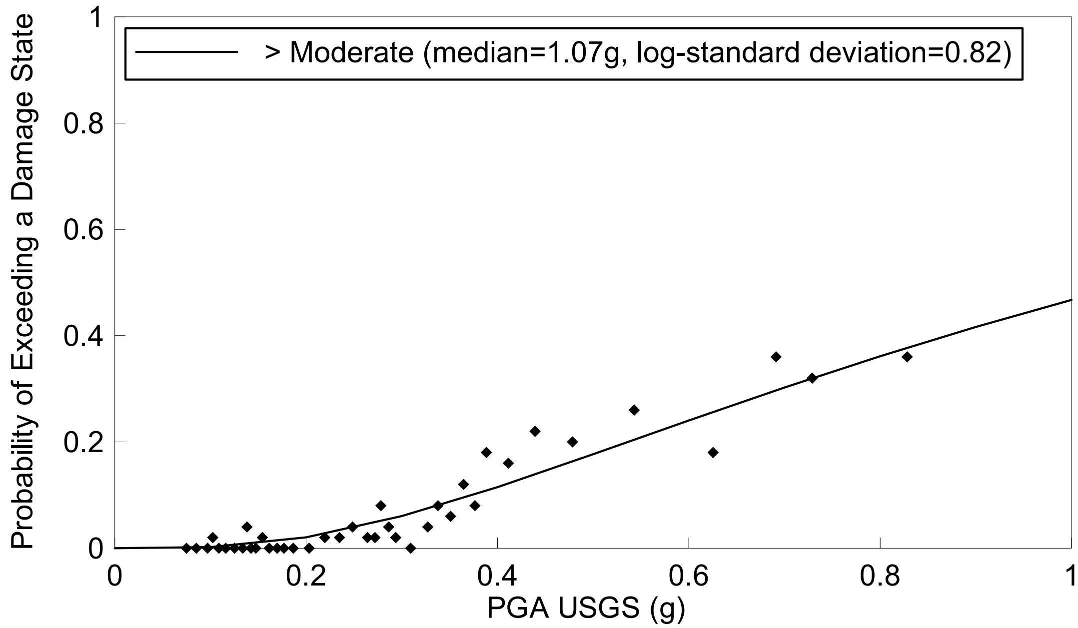



**FIGURE 2-12 Fragility Curve for Caltrans' Bridges with at least Moderate Damage and Input Damage Data (Method 2)**

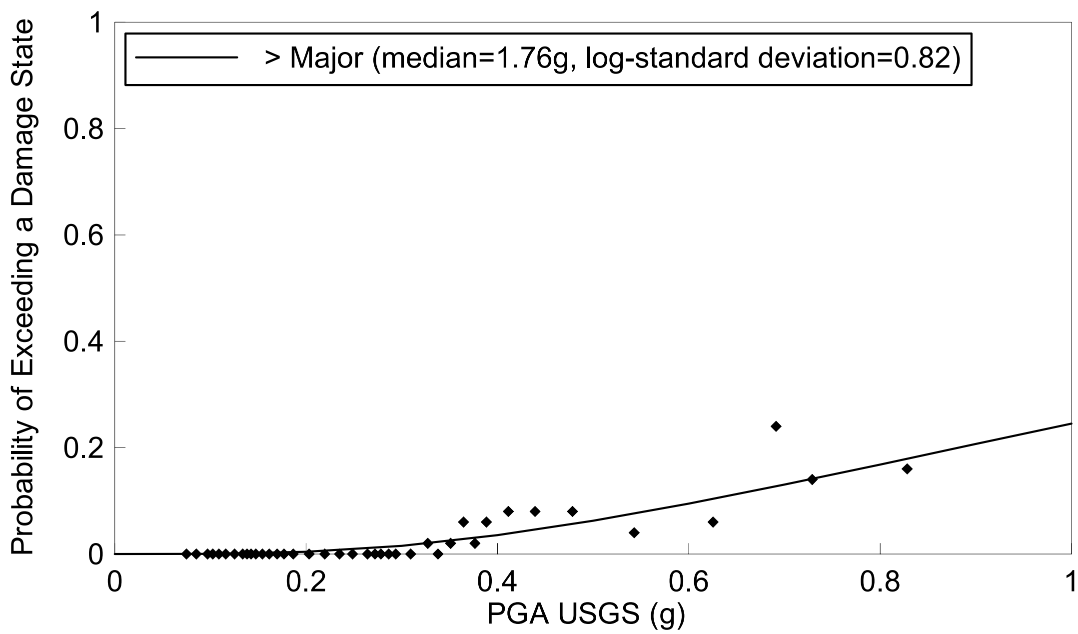



**FIGURE 2-13 Fragility Curve for Caltrans' Bridges with at least Major Damage and Input Damage Data (Method 2)**

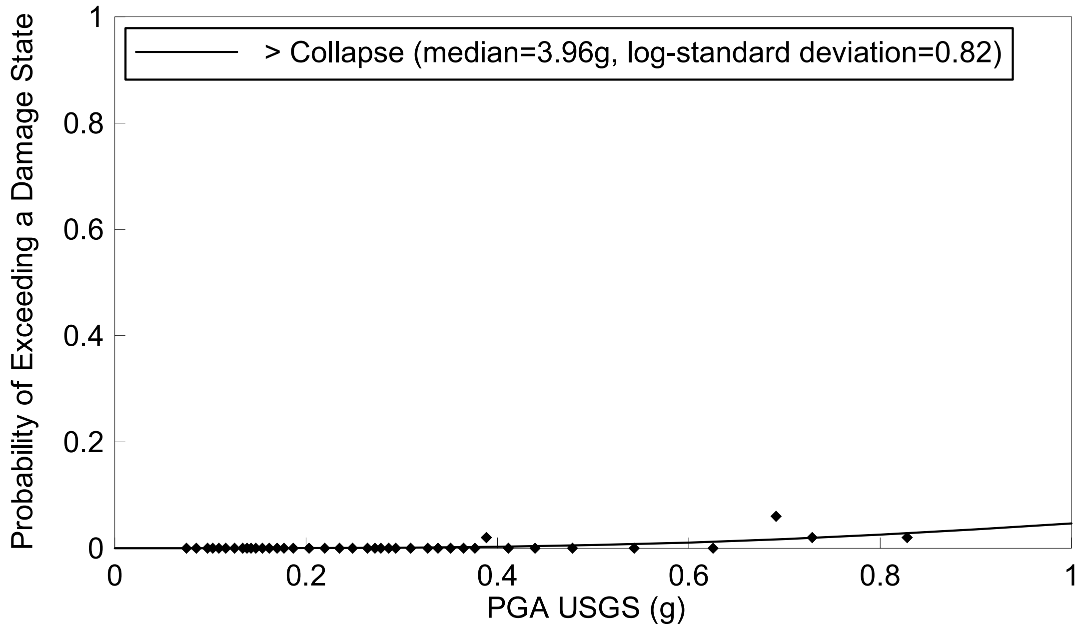



**FIGURE 2-14 Fragility Curve for Caltrans' Bridges with Collapse Damage and Input Damage Data (Method 2)**

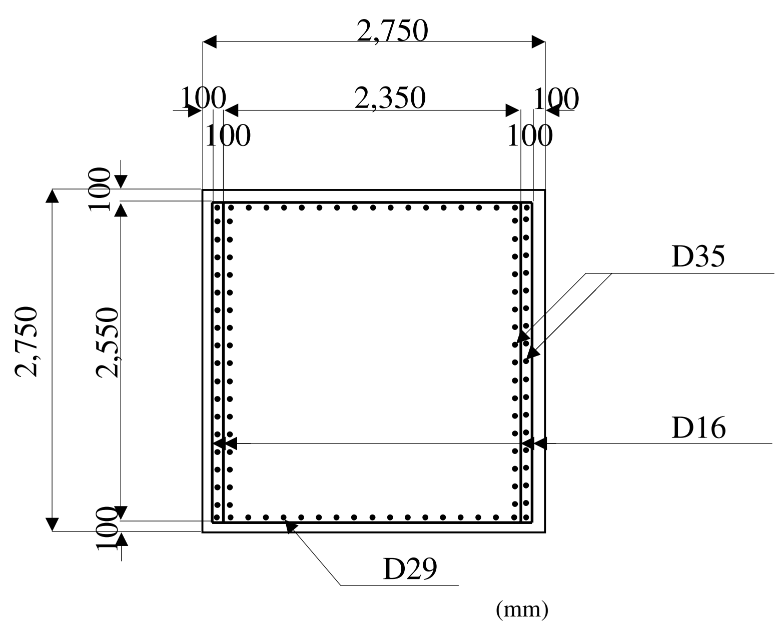



**FIGURE 2-15 A Typical Cross-Section of HEPC's Bridge Columns**

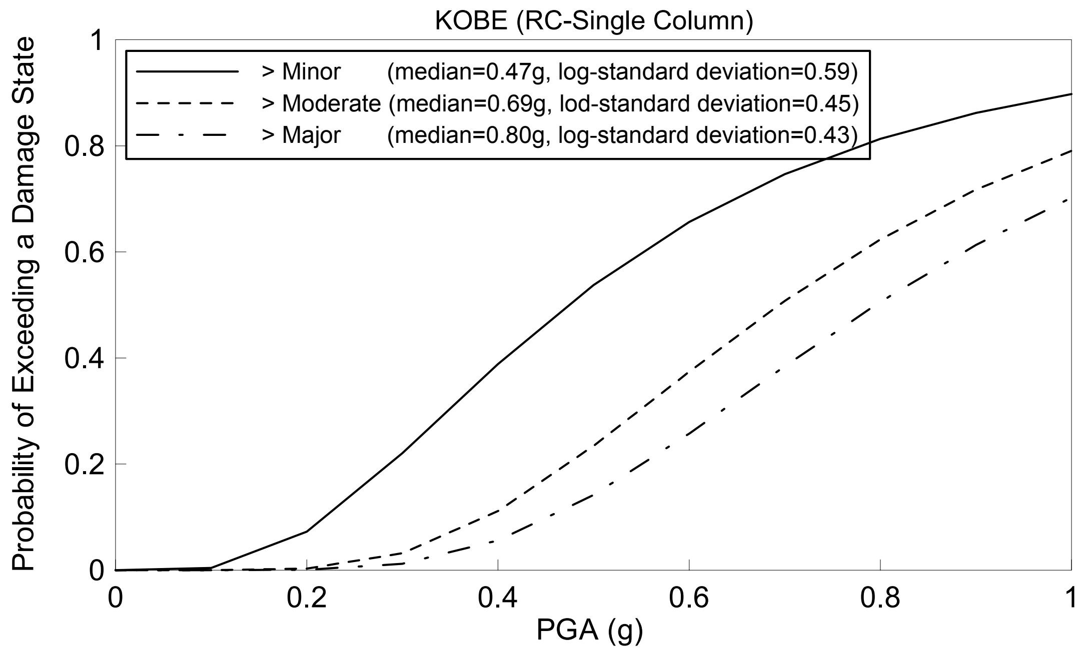



**FIGURE 2-16 Fragility Curves for HEPC's Bridge Columns (Method 1)**

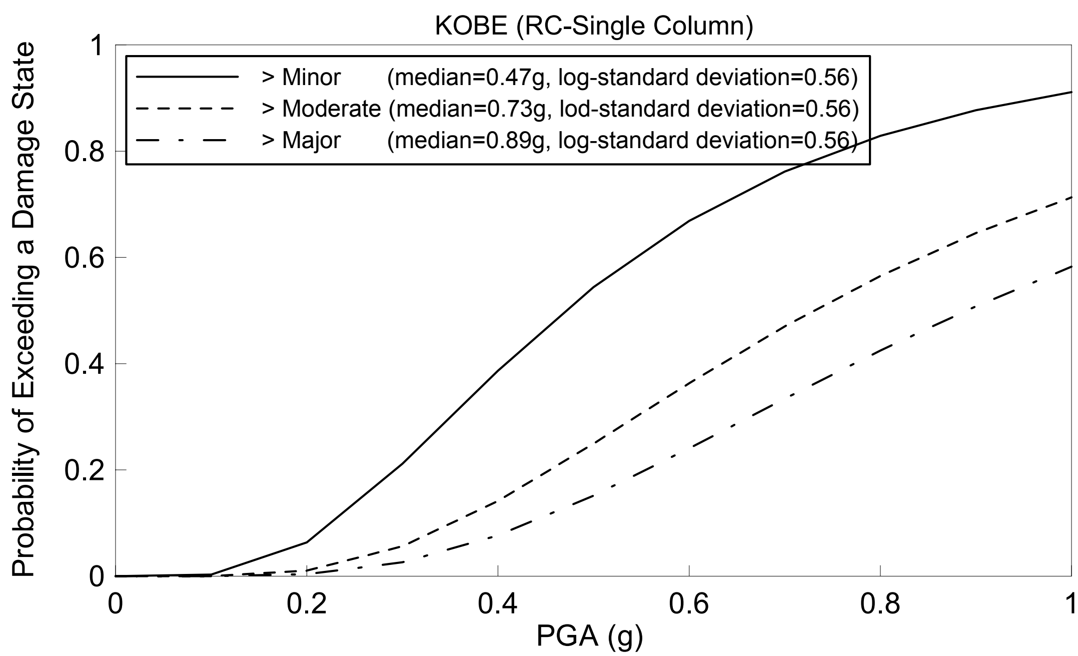



**FIGURE 2-17 Fragility Curves for HEPC's Bridge Columns (Method 2)**

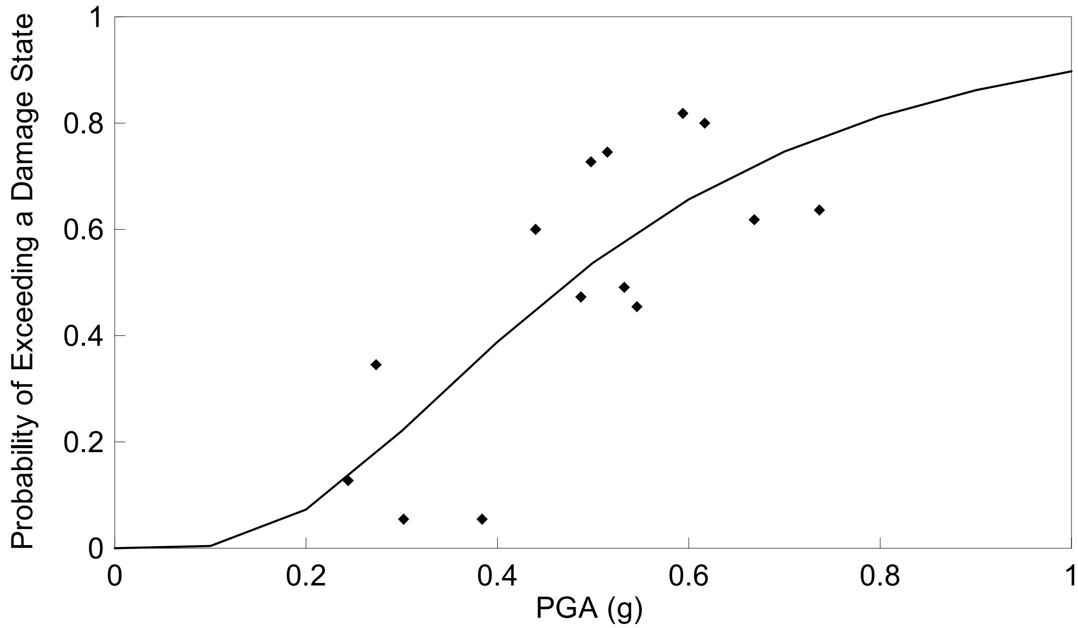



**FIGURE 2-18 Fragility Curve for HEPC's Bridge Columns with at least Minor Damage and Input Damage Data (Method 1)**

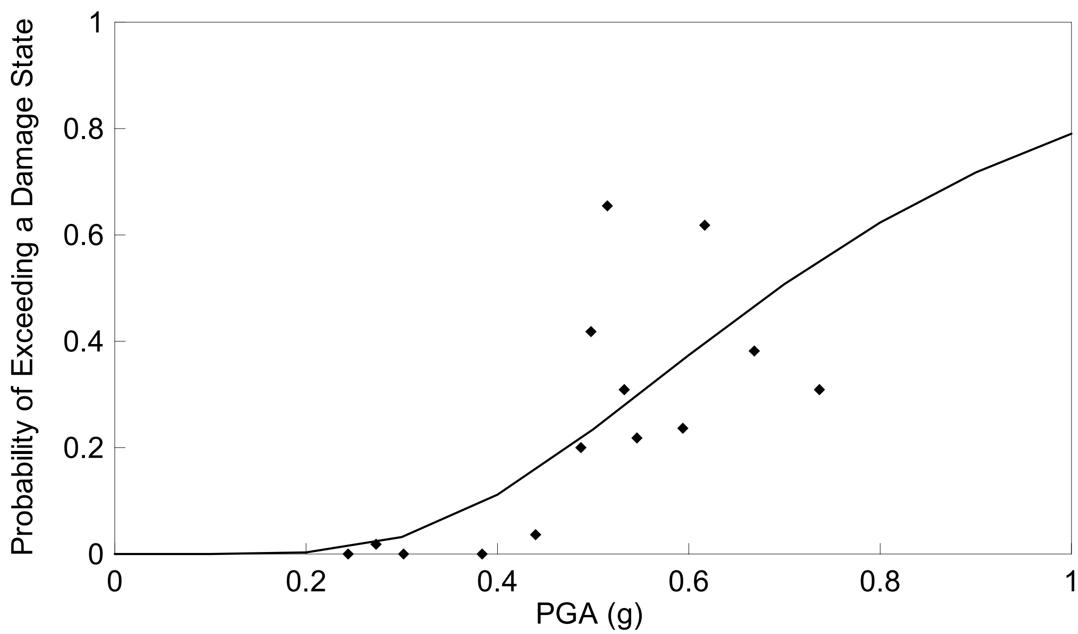



**FIGURE 2-19 Fragility Curve for HEPC's Bridge Columns with at least Moderate Damage and Input Damage Data (Method 1)**

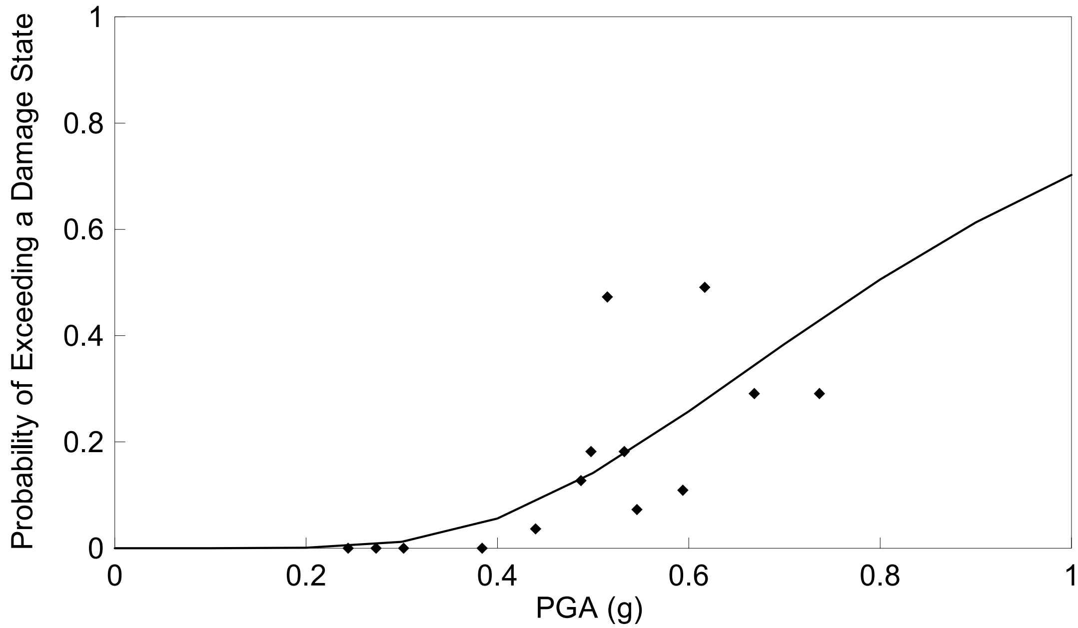



**FIGURE 2-20 Fragility Curve for HEPC's Bridge Columns with Major Damage and Input Damage Data (Method 1)**

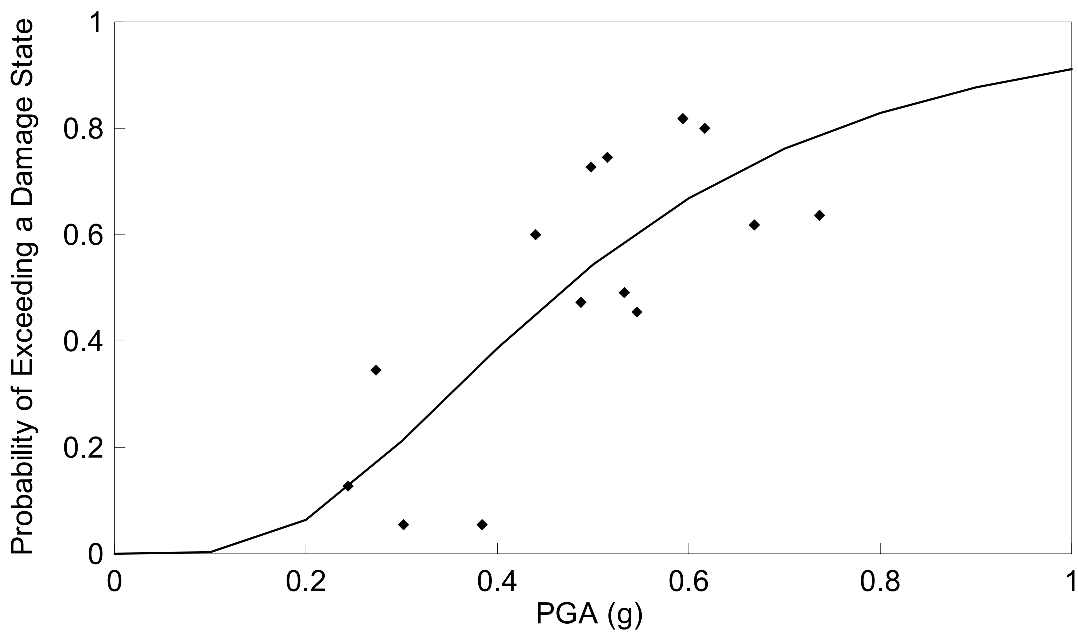



**FIGURE 2-21 Fragility Curve for HEPC's Bridge Columns with at least Minor Damage and Input Damage Data (Method 2)**

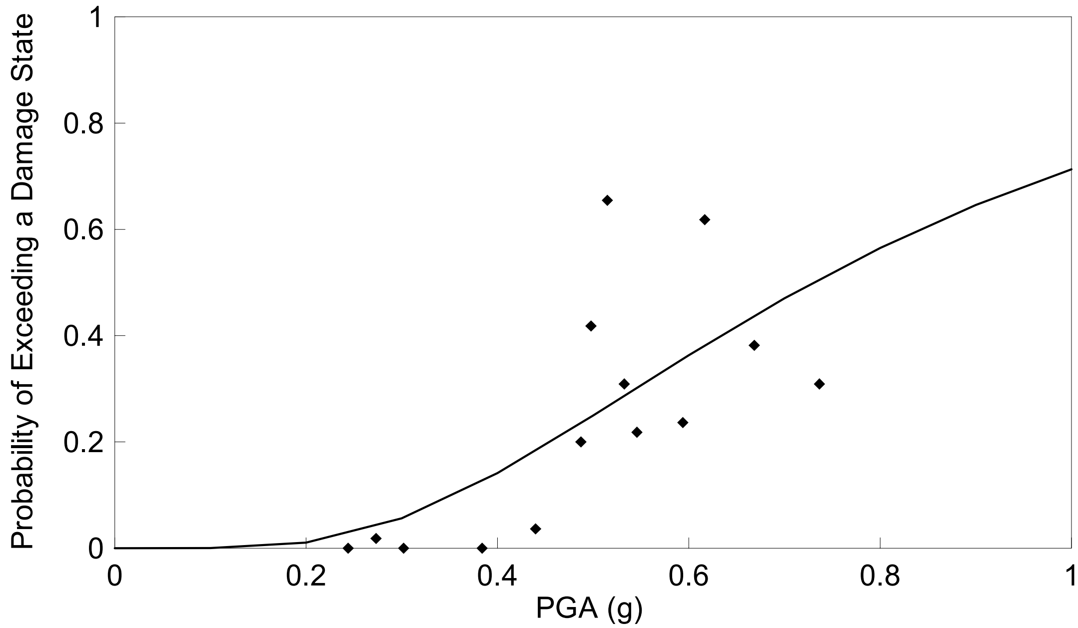



**FIGURE 2-22  Fragility Curve for HEPC's Bridge Columns with at least Moderate Damage and Input Damage Data (Method 2)**

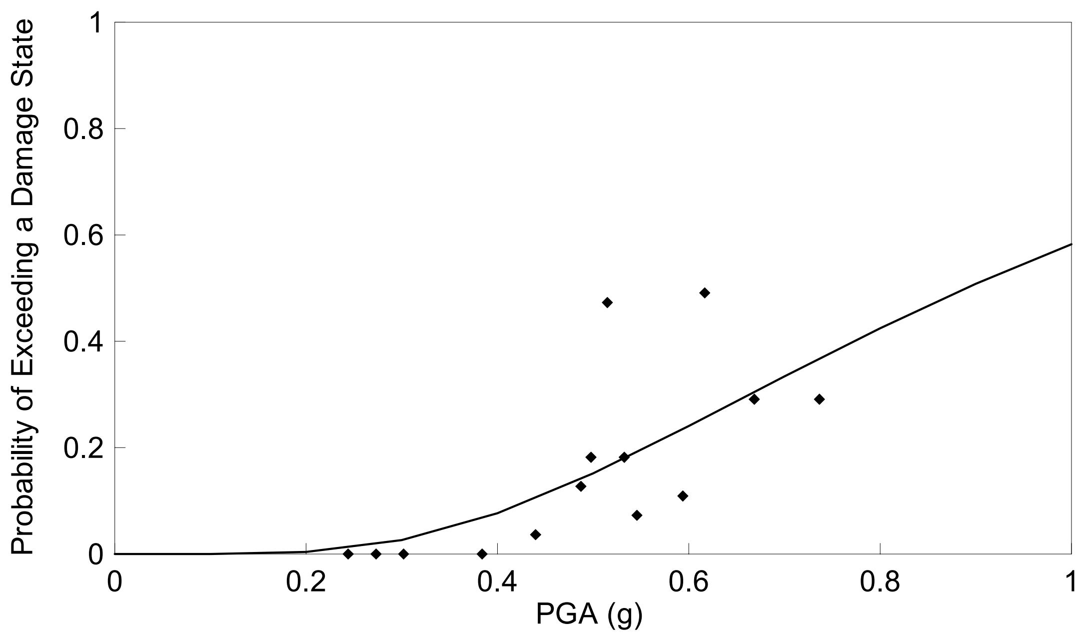



**FIGURE 2-23  Fragility Curve for HEPC's Bridge Columns with Major Damage and Input Damage Data (Method 2)**

**TABLE 2-2 Damage Data for Caltrans' Bridge**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1 | 0.069 | 1 | 0 | 0 | 0 | 0 | 51 | 0.078 | 1 | 0 | 0 | 0 | 0 |
| 2 | 0.072 | 1 | 0 | 0 | 0 | 0 | 52 | 0.078 | 1 | 0 | 0 | 0 | 0 |
| 3 | 0.072 | 1 | 0 | 0 | 0 | 0 | 53 | 0.079 | 1 | 0 | 0 | 0 | 0 |
| 4 | 0.072 | 1 | 0 | 0 | 0 | 0 | 54 | 0.079 | 1 | 0 | 0 | 0 | 0 |
| 5 | 0.072 | 1 | 0 | 0 | 0 | 0 | 55 | 0.079 | 1 | 0 | 0 | 0 | 0 |
| 6 | 0.072 | 1 | 0 | 0 | 0 | 0 | 56 | 0.079 | 1 | 0 | 0 | 0 | 0 |
| 7 | 0.072 | 1 | 0 | 0 | 0 | 0 | 57 | 0.079 | 1 | 0 | 0 | 0 | 0 |
| 8 | 0.072 | 1 | 0 | 0 | 0 | 0 | 58 | 0.080 | 1 | 0 | 0 | 0 | 0 |
| 9 | 0.073 | 1 | 0 | 0 | 0 | 0 | 59 | 0.080 | 1 | 0 | 0 | 0 | 0 |
| 10 | 0.073 | 1 | 0 | 0 | 0 | 0 | 60 | 0.080 | 1 | 0 | 0 | 0 | 0 |
| 11 | 0.073 | 1 | 0 | 0 | 0 | 0 | 61 | 0.080 | 1 | 0 | 0 | 0 | 0 |
| 12 | 0.074 | 1 | 0 | 0 | 0 | 0 | 62 | 0.080 | 1 | 1 | 0 | 0 | 0 |
| 13 | 0.074 | 1 | 0 | 0 | 0 | 0 | 63 | 0.080 | 1 | 1 | 0 | 0 | 0 |
| 14 | 0.074 | 1 | 0 | 0 | 0 | 0 | 64 | 0.080 | 1 | 0 | 0 | 0 | 0 |
| 15 | 0.074 | 1 | 0 | 0 | 0 | 0 | 65 | 0.081 | 1 | 0 | 0 | 0 | 0 |
| 16 | 0.075 | 1 | 0 | 0 | 0 | 0 | 66 | 0.081 | 1 | 0 | 0 | 0 | 0 |
| 17 | 0.075 | 1 | 0 | 0 | 0 | 0 | 67 | 0.081 | 1 | 0 | 0 | 0 | 0 |
| 18 | 0.075 | 1 | 0 | 0 | 0 | 0 | 68 | 0.081 | 1 | 0 | 0 | 0 | 0 |
| 19 | 0.075 | 1 | 0 | 0 | 0 | 0 | 69 | 0.082 | 1 | 0 | 0 | 0 | 0 |
| 20 | 0.075 | 1 | 0 | 0 | 0 | 0 | 70 | 0.082 | 1 | 0 | 0 | 0 | 0 |
| 21 | 0.075 | 1 | 0 | 0 | 0 | 0 | 71 | 0.083 | 1 | 0 | 0 | 0 | 0 |
| 22 | 0.075 | 1 | 0 | 0 | 0 | 0 | 72 | 0.083 | 1 | 0 | 0 | 0 | 0 |
| 23 | 0.075 | 1 | 0 | 0 | 0 | 0 | 73 | 0.083 | 1 | 0 | 0 | 0 | 0 |
| 24 | 0.075 | 1 | 0 | 0 | 0 | 0 | 74 | 0.085 | 1 | 0 | 0 | 0 | 0 |
| 25 | 0.075 | 1 | 0 | 0 | 0 | 0 | 75 | 0.085 | 1 | 0 | 0 | 0 | 0 |
| 26 | 0.075 | 1 | 0 | 0 | 0 | 0 | 76 | 0.085 | 1 | 0 | 0 | 0 | 0 |
| 27 | 0.075 | 1 | 0 | 0 | 0 | 0 | 77 | 0.086 | 1 | 0 | 0 | 0 | 0 |
| 28 | 0.075 | 1 | 0 | 0 | 0 | 0 | 78 | 0.087 | 1 | 0 | 0 | 0 | 0 |
| 29 | 0.075 | 1 | 0 | 0 | 0 | 0 | 79 | 0.087 | 1 | 0 | 0 | 0 | 0 |
| 30 | 0.075 | 1 | 0 | 0 | 0 | 0 | 80 | 0.088 | 1 | 0 | 0 | 0 | 0 |
| 31 | 0.076 | 1 | 0 | 0 | 0 | 0 | 81 | 0.090 | 1 | 0 | 0 | 0 | 0 |
| 32 | 0.076 | 1 | 0 | 0 | 0 | 0 | 82 | 0.090 | 1 | 0 | 0 | 0 | 0 |
| 33 | 0.076 | 1 | 0 | 0 | 0 | 0 | 83 | 0.090 | 1 | 0 | 0 | 0 | 0 |
| 34 | 0.076 | 1 | 0 | 0 | 0 | 0 | 84 | 0.090 | 1 | 0 | 0 | 0 | 0 |
| 35 | 0.076 | 1 | 0 | 0 | 0 | 0 | 85 | 0.090 | 1 | 0 | 0 | 0 | 0 |
| 36 | 0.076 | 1 | 0 | 0 | 0 | 0 | 86 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 37 | 0.076 | 1 | 0 | 0 | 0 | 0 | 87 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 38 | 0.076 | 1 | 0 | 0 | 0 | 0 | 88 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 39 | 0.076 | 1 | 0 | 0 | 0 | 0 | 89 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 40 | 0.077 | 1 | 0 | 0 | 0 | 0 | 90 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 41 | 0.077 | 1 | 0 | 0 | 0 | 0 | 91 | 0.091 | 1 | 0 | 0 | 0 | 0 |
| 42 | 0.077 | 1 | 0 | 0 | 0 | 0 | 92 | 0.092 | 1 | 0 | 0 | 0 | 0 |
| 43 | 0.077 | 1 | 0 | 0 | 0 | 0 | 93 | 0.092 | 1 | 0 | 0 | 0 | 0 |
| 44 | 0.077 | 1 | 0 | 0 | 0 | 0 | 94 | 0.092 | 1 | 0 | 0 | 0 | 0 |
| 45 | 0.077 | 1 | 0 | 0 | 0 | 0 | 95 | 0.092 | 1 | 0 | 0 | 0 | 0 |
| 46 | 0.077 | 1 | 0 | 0 | 0 | 0 | 96 | 0.092 | 1 | 0 | 0 | 0 | 0 |
| 47 | 0.078 | 1 | 0 | 0 | 0 | 0 | 97 | 0.093 | 1 | 0 | 0 | 0 | 0 |
| 48 | 0.078 | 1 | 0 | 0 | 0 | 0 | 98 | 0.093 | 1 | 0 | 0 | 0 | 0 |
| 49 | 0.078 | 1 | 0 | 0 | 0 | 0 | 99 | 0.093 | 1 | 0 | 0 | 0 | 0 |
| 50 | 0.078 | 1 | 0 | 0 | 0 | 0 | 100 | 0.094 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 101 | 0.094 | 1 | 0 | 0 | 0 | 0 | 151 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 102 | 0.094 | 1 | 0 | 0 | 0 | 0 | 152 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 103 | 0.094 | 1 | 0 | 0 | 0 | 0 | 153 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 104 | 0.094 | 1 | 0 | 0 | 0 | 0 | 154 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 105 | 0.095 | 1 | 0 | 0 | 0 | 0 | 155 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 106 | 0.095 | 1 | 0 | 0 | 0 | 0 | 156 | 0.100 | 1 | 0 | 0 | 0 | 0 |
| 107 | 0.095 | 1 | 0 | 0 | 0 | 0 | 157 | 0.101 | 1 | 0 | 0 | 0 | 0 |
| 108 | 0.095 | 1 | 0 | 0 | 0 | 0 | 158 | 0.101 | 1 | 0 | 0 | 0 | 0 |
| 109 | 0.095 | 1 | 0 | 0 | 0 | 0 | 159 | 0.101 | 1 | 0 | 0 | 0 | 0 |
| 110 | 0.095 | 1 | 0 | 0 | 0 | 0 | 160 | 0.101 | 1 | 0 | 0 | 0 | 0 |
| 111 | 0.096 | 1 | 0 | 0 | 0 | 0 | 161 | 0.101 | 1 | 0 | 0 | 0 | 0 |
| 112 | 0.096 | 1 | 0 | 0 | 0 | 0 | 162 | 0.102 | 1 | 0 | 0 | 0 | 0 |
| 113 | 0.096 | 1 | 0 | 0 | 0 | 0 | 163 | 0.102 | 1 | 0 | 0 | 0 | 0 |
| 114 | 0.096 | 1 | 0 | 0 | 0 | 0 | 164 | 0.102 | 1 | 0 | 0 | 0 | 0 |
| 115 | 0.096 | 1 | 0 | 0 | 0 | 0 | 165 | 0.102 | 1 | 0 | 0 | 0 | 0 |
| 116 | 0.096 | 1 | 0 | 0 | 0 | 0 | 166 | 0.102 | 1 | 0 | 0 | 0 | 0 |
| 117 | 0.096 | 1 | 0 | 0 | 0 | 0 | 167 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 118 | 0.096 | 1 | 0 | 0 | 0 | 0 | 168 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 119 | 0.097 | 1 | 0 | 0 | 0 | 0 | 169 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 120 | 0.097 | 1 | 0 | 0 | 0 | 0 | 170 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 121 | 0.097 | 1 | 0 | 0 | 0 | 0 | 171 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 122 | 0.097 | 1 | 0 | 0 | 0 | 0 | 172 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 123 | 0.097 | 1 | 0 | 0 | 0 | 0 | 173 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 124 | 0.097 | 1 | 0 | 0 | 0 | 0 | 174 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 125 | 0.097 | 1 | 0 | 0 | 0 | 0 | 175 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 126 | 0.097 | 1 | 0 | 0 | 0 | 0 | 176 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 127 | 0.098 | 1 | 0 | 0 | 0 | 0 | 177 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 128 | 0.098 | 1 | 0 | 0 | 0 | 0 | 178 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 129 | 0.098 | 1 | 0 | 0 | 0 | 0 | 179 | 0.103 | 1 | 1 | 0 | 0 | 0 |
| 130 | 0.098 | 1 | 0 | 0 | 0 | 0 | 180 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 131 | 0.098 | 1 | 0 | 0 | 0 | 0 | 181 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 132 | 0.098 | 1 | 0 | 0 | 0 | 0 | 182 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 133 | 0.098 | 1 | 0 | 0 | 0 | 0 | 183 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 134 | 0.098 | 1 | 0 | 0 | 0 | 0 | 184 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 135 | 0.098 | 1 | 0 | 0 | 0 | 0 | 185 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 136 | 0.098 | 1 | 0 | 0 | 0 | 0 | 186 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 137 | 0.099 | 1 | 0 | 0 | 0 | 0 | 187 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 138 | 0.099 | 1 | 0 | 0 | 0 | 0 | 188 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 139 | 0.099 | 1 | 0 | 0 | 0 | 0 | 189 | 0.103 | 1 | 0 | 0 | 0 | 0 |
| 140 | 0.099 | 1 | 0 | 0 | 0 | 0 | 190 | 0.104 | 1 | 1 | 0 | 0 | 0 |
| 141 | 0.099 | 1 | 0 | 0 | 0 | 0 | 191 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 142 | 0.099 | 1 | 0 | 0 | 0 | 0 | 192 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 143 | 0.099 | 1 | 0 | 0 | 0 | 0 | 193 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 144 | 0.099 | 1 | 0 | 0 | 0 | 0 | 194 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 145 | 0.099 | 1 | 0 | 0 | 0 | 0 | 195 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 146 | 0.100 | 1 | 0 | 0 | 0 | 0 | 196 | 0.104 | 1 | 0 | 0 | 0 | 0 |
| 147 | 0.100 | 1 | 0 | 0 | 0 | 0 | 197 | 0.105 | 1 | 0 | 0 | 0 | 0 |
| 148 | 0.100 | 1 | 0 | 0 | 0 | 0 | 198 | 0.105 | 1 | 0 | 0 | 0 | 0 |
| 149 | 0.100 | 1 | 0 | 0 | 0 | 0 | 199 | 0.105 | 1 | 0 | 0 | 0 | 0 |
| 150 | 0.100 | 1 | 0 | 0 | 0 | 0 | 200 | 0.105 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 201 | 0.105 | 1 | 0 | 0 | 0 | 0 | 251 | 0.113 | 1 | 0 | 0 | 0 | 0 |
| 202 | 0.105 | 1 | 0 | 0 | 0 | 0 | 252 | 0.113 | 1 | 0 | 0 | 0 | 0 |
| 203 | 0.105 | 1 | 0 | 0 | 0 | 0 | 253 | 0.113 | 1 | 0 | 0 | 0 | 0 |
| 204 | 0.105 | 1 | 0 | 0 | 0 | 0 | 254 | 0.114 | 1 | 0 | 0 | 0 | 0 |
| 205 | 0.105 | 1 | 0 | 0 | 0 | 0 | 255 | 0.114 | 1 | 0 | 0 | 0 | 0 |
| 206 | 0.106 | 1 | 0 | 0 | 0 | 0 | 256 | 0.114 | 1 | 0 | 0 | 0 | 0 |
| 207 | 0.107 | 1 | 0 | 0 | 0 | 0 | 257 | 0.114 | 1 | 0 | 0 | 0 | 0 |
| 208 | 0.107 | 1 | 1 | 0 | 0 | 0 | 258 | 0.114 | 1 | 0 | 0 | 0 | 0 |
| 209 | 0.107 | 1 | 0 | 0 | 0 | 0 | 259 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 210 | 0.107 | 1 | 0 | 0 | 0 | 0 | 260 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 211 | 0.107 | 1 | 0 | 0 | 0 | 0 | 261 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 212 | 0.107 | 1 | 0 | 0 | 0 | 0 | 262 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 213 | 0.107 | 1 | 0 | 0 | 0 | 0 | 263 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 214 | 0.107 | 1 | 0 | 0 | 0 | 0 | 264 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 215 | 0.108 | 1 | 0 | 0 | 0 | 0 | 265 | 0.115 | 1 | 0 | 0 | 0 | 0 |
| 216 | 0.108 | 1 | 0 | 0 | 0 | 0 | 266 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 217 | 0.108 | 1 | 0 | 0 | 0 | 0 | 267 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 218 | 0.109 | 1 | 0 | 0 | 0 | 0 | 268 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 219 | 0.109 | 1 | 0 | 0 | 0 | 0 | 269 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 220 | 0.109 | 1 | 0 | 0 | 0 | 0 | 270 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 221 | 0.109 | 1 | 0 | 0 | 0 | 0 | 271 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 222 | 0.109 | 1 | 0 | 0 | 0 | 0 | 272 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 223 | 0.110 | 1 | 0 | 0 | 0 | 0 | 273 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 224 | 0.110 | 1 | 0 | 0 | 0 | 0 | 274 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 225 | 0.110 | 1 | 0 | 0 | 0 | 0 | 275 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 226 | 0.110 | 1 | 0 | 0 | 0 | 0 | 276 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 227 | 0.110 | 1 | 0 | 0 | 0 | 0 | 277 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 228 | 0.110 | 1 | 0 | 0 | 0 | 0 | 278 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 229 | 0.110 | 1 | 0 | 0 | 0 | 0 | 279 | 0.116 | 1 | 0 | 0 | 0 | 0 |
| 230 | 0.110 | 1 | 0 | 0 | 0 | 0 | 280 | 0.117 | 1 | 0 | 0 | 0 | 0 |
| 231 | 0.110 | 1 | 0 | 0 | 0 | 0 | 281 | 0.117 | 1 | 0 | 0 | 0 | 0 |
| 232 | 0.111 | 1 | 0 | 0 | 0 | 0 | 282 | 0.117 | 1 | 0 | 0 | 0 | 0 |
| 233 | 0.111 | 1 | 0 | 0 | 0 | 0 | 283 | 0.117 | 1 | 0 | 0 | 0 | 0 |
| 234 | 0.111 | 1 | 0 | 0 | 0 | 0 | 284 | 0.117 | 1 | 0 | 0 | 0 | 0 |
| 235 | 0.111 | 1 | 0 | 0 | 0 | 0 | 285 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 236 | 0.111 | 1 | 1 | 0 | 0 | 0 | 286 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 237 | 0.111 | 1 | 0 | 0 | 0 | 0 | 287 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 238 | 0.111 | 1 | 0 | 0 | 0 | 0 | 288 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 239 | 0.111 | 1 | 0 | 0 | 0 | 0 | 289 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 240 | 0.111 | 1 | 0 | 0 | 0 | 0 | 290 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 241 | 0.111 | 1 | 0 | 0 | 0 | 0 | 291 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 242 | 0.112 | 1 | 0 | 0 | 0 | 0 | 292 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 243 | 0.112 | 1 | 0 | 0 | 0 | 0 | 293 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 244 | 0.112 | 1 | 0 | 0 | 0 | 0 | 294 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 245 | 0.112 | 1 | 0 | 0 | 0 | 0 | 295 | 0.118 | 1 | 0 | 0 | 0 | 0 |
| 246 | 0.112 | 1 | 0 | 0 | 0 | 0 | 296 | 0.119 | 1 | 0 | 0 | 0 | 0 |
| 247 | 0.112 | 1 | 0 | 0 | 0 | 0 | 297 | 0.120 | 1 | 0 | 0 | 0 | 0 |
| 248 | 0.113 | 1 | 1 | 0 | 0 | 0 | 298 | 0.120 | 1 | 0 | 0 | 0 | 0 |
| 249 | 0.113 | 1 | 0 | 0 | 0 | 0 | 299 | 0.120 | 1 | 0 | 0 | 0 | 0 |
| 250 | 0.113 | 1 | 0 | 0 | 0 | 0 | 300 | 0.120 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 301 | 0.121 | 1 | 0 | 0 | 0 | 0 | 351 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 302 | 0.121 | 1 | 0 | 0 | 0 | 0 | 352 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 303 | 0.121 | 1 | 0 | 0 | 0 | 0 | 353 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 304 | 0.121 | 1 | 0 | 0 | 0 | 0 | 354 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 305 | 0.121 | 1 | 0 | 0 | 0 | 0 | 355 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 306 | 0.122 | 1 | 0 | 0 | 0 | 0 | 356 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 307 | 0.122 | 1 | 0 | 0 | 0 | 0 | 357 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 308 | 0.122 | 1 | 0 | 0 | 0 | 0 | 358 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 309 | 0.122 | 1 | 0 | 0 | 0 | 0 | 359 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 310 | 0.123 | 1 | 0 | 0 | 0 | 0 | 360 | 0.131 | 1 | 1 | 0 | 0 | 0 |
| 311 | 0.123 | 1 | 0 | 0 | 0 | 0 | 361 | 0.131 | 1 | 0 | 0 | 0 | 0 |
| 312 | 0.124 | 1 | 0 | 0 | 0 | 0 | 362 | 0.132 | 1 | 0 | 0 | 0 | 0 |
| 313 | 0.124 | 1 | 0 | 0 | 0 | 0 | 363 | 0.132 | 1 | 0 | 0 | 0 | 0 |
| 314 | 0.124 | 1 | 0 | 0 | 0 | 0 | 364 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 315 | 0.124 | 1 | 0 | 0 | 0 | 0 | 365 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 316 | 0.124 | 1 | 0 | 0 | 0 | 0 | 366 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 317 | 0.125 | 1 | 0 | 0 | 0 | 0 | 367 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 318 | 0.125 | 1 | 0 | 0 | 0 | 0 | 368 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 319 | 0.125 | 1 | 0 | 0 | 0 | 0 | 369 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 320 | 0.125 | 1 | 0 | 0 | 0 | 0 | 370 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 321 | 0.125 | 1 | 0 | 0 | 0 | 0 | 371 | 0.133 | 1 | 0 | 0 | 0 | 0 |
| 322 | 0.126 | 1 | 0 | 0 | 0 | 0 | 372 | 0.134 | 1 | 0 | 0 | 0 | 0 |
| 323 | 0.126 | 1 | 0 | 0 | 0 | 0 | 373 | 0.134 | 1 | 0 | 0 | 0 | 0 |
| 324 | 0.126 | 1 | 0 | 0 | 0 | 0 | 374 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 325 | 0.126 | 1 | 0 | 0 | 0 | 0 | 375 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 326 | 0.126 | 1 | 0 | 0 | 0 | 0 | 376 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 327 | 0.126 | 1 | 0 | 0 | 0 | 0 | 377 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 328 | 0.126 | 1 | 0 | 0 | 0 | 0 | 378 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 329 | 0.126 | 1 | 0 | 0 | 0 | 0 | 379 | 0.135 | 1 | 0 | 0 | 0 | 0 |
| 330 | 0.126 | 1 | 0 | 0 | 0 | 0 | 380 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 331 | 0.126 | 1 | 0 | 0 | 0 | 0 | 381 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 332 | 0.126 | 1 | 0 | 0 | 0 | 0 | 382 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 333 | 0.127 | 1 | 0 | 0 | 0 | 0 | 383 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 334 | 0.127 | 1 | 0 | 0 | 0 | 0 | 384 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 335 | 0.128 | 1 | 0 | 0 | 0 | 0 | 385 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 336 | 0.128 | 1 | 0 | 0 | 0 | 0 | 386 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 337 | 0.128 | 1 | 0 | 0 | 0 | 0 | 387 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 338 | 0.128 | 1 | 0 | 0 | 0 | 0 | 388 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 339 | 0.129 | 1 | 0 | 0 | 0 | 0 | 389 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 340 | 0.129 | 1 | 0 | 0 | 0 | 0 | 390 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 341 | 0.129 | 1 | 0 | 0 | 0 | 0 | 391 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 342 | 0.129 | 1 | 0 | 0 | 0 | 0 | 392 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 343 | 0.129 | 1 | 0 | 0 | 0 | 0 | 393 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 344 | 0.129 | 1 | 0 | 0 | 0 | 0 | 394 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 345 | 0.129 | 1 | 0 | 0 | 0 | 0 | 395 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 346 | 0.129 | 1 | 0 | 0 | 0 | 0 | 396 | 0.136 | 1 | 0 | 0 | 0 | 0 |
| 347 | 0.129 | 1 | 0 | 0 | 0 | 0 | 397 | 0.137 | 1 | 0 | 0 | 0 | 0 |
| 348 | 0.130 | 1 | 0 | 0 | 0 | 0 | 398 | 0.137 | 1 | 0 | 0 | 0 | 0 |
| 349 | 0.130 | 1 | 0 | 0 | 0 | 0 | 399 | 0.137 | 1 | 0 | 0 | 0 | 0 |
| 350 | 0.130 | 1 | 0 | 0 | 0 | 0 | 400 | 0.137 | 1 | 0 | 0 | 0 | 0 |

**TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)**

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 401 | 0.137 | 1 | 0 | 0 | 0 | 0 | 451 | 0.140 | 1 | 0 | 0 | 0 | 0 |
| 402 | 0.137 | 1 | 0 | 0 | 0 | 0 | 452 | 0.140 | 1 | 0 | 0 | 0 | 0 |
| 403 | 0.137 | 1 | 0 | 0 | 0 | 0 | 453 | 0.140 | 1 | 0 | 0 | 0 | 0 |
| 404 | 0.137 | 1 | 0 | 0 | 0 | 0 | 454 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 405 | 0.137 | 1 | 0 | 0 | 0 | 0 | 455 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 406 | 0.137 | 1 | 0 | 0 | 0 | 0 | 456 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 407 | 0.137 | 1 | 0 | 0 | 0 | 0 | 457 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 408 | 0.137 | 1 | 0 | 0 | 0 | 0 | 458 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 409 | 0.137 | 1 | 0 | 0 | 0 | 0 | 459 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 410 | 0.137 | 1 | 0 | 0 | 0 | 0 | 460 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 411 | 0.137 | 1 | 0 | 0 | 0 | 0 | 461 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 412 | 0.137 | 1 | 0 | 0 | 0 | 0 | 462 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 413 | 0.137 | 1 | 0 | 0 | 0 | 0 | 463 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 414 | 0.137 | 1 | 0 | 0 | 0 | 0 | 464 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 415 | 0.138 | 1 | 1 | 1 | 0 | 0 | 465 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 416 | 0.138 | 1 | 1 | 1 | 0 | 0 | 466 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 417 | 0.138 | 1 | 0 | 0 | 0 | 0 | 467 | 0.141 | 1 | 0 | 0 | 0 | 0 |
| 418 | 0.138 | 1 | 0 | 0 | 0 | 0 | 468 | 0.142 | 1 | 0 | 0 | 0 | 0 |
| 419 | 0.138 | 1 | 0 | 0 | 0 | 0 | 469 | 0.142 | 1 | 0 | 0 | 0 | 0 |
| 420 | 0.138 | 1 | 0 | 0 | 0 | 0 | 470 | 0.142 | 1 | 0 | 0 | 0 | 0 |
| 421 | 0.138 | 1 | 0 | 0 | 0 | 0 | 471 | 0.142 | 1 | 0 | 0 | 0 | 0 |
| 422 | 0.138 | 1 | 0 | 0 | 0 | 0 | 472 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 423 | 0.138 | 1 | 0 | 0 | 0 | 0 | 473 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 424 | 0.138 | 1 | 0 | 0 | 0 | 0 | 474 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 425 | 0.138 | 1 | 0 | 0 | 0 | 0 | 475 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 426 | 0.138 | 1 | 0 | 0 | 0 | 0 | 476 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 427 | 0.138 | 1 | 0 | 0 | 0 | 0 | 477 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 428 | 0.138 | 1 | 0 | 0 | 0 | 0 | 478 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 429 | 0.138 | 1 | 0 | 0 | 0 | 0 | 479 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 430 | 0.138 | 1 | 0 | 0 | 0 | 0 | 480 | 0.143 | 1 | 0 | 0 | 0 | 0 |
| 431 | 0.138 | 1 | 0 | 0 | 0 | 0 | 481 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 432 | 0.139 | 1 | 0 | 0 | 0 | 0 | 482 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 433 | 0.139 | 1 | 0 | 0 | 0 | 0 | 483 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 434 | 0.139 | 1 | 0 | 0 | 0 | 0 | 484 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 435 | 0.139 | 1 | 0 | 0 | 0 | 0 | 485 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 436 | 0.139 | 1 | 0 | 0 | 0 | 0 | 486 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 437 | 0.139 | 1 | 0 | 0 | 0 | 0 | 487 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 438 | 0.140 | 1 | 0 | 0 | 0 | 0 | 488 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 439 | 0.140 | 1 | 0 | 0 | 0 | 0 | 489 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 440 | 0.140 | 1 | 0 | 0 | 0 | 0 | 490 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 441 | 0.140 | 1 | 0 | 0 | 0 | 0 | 491 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 442 | 0.140 | 1 | 0 | 0 | 0 | 0 | 492 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 443 | 0.140 | 1 | 0 | 0 | 0 | 0 | 493 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 444 | 0.140 | 1 | 0 | 0 | 0 | 0 | 494 | 0.144 | 1 | 0 | 0 | 0 | 0 |
| 445 | 0.140 | 1 | 0 | 0 | 0 | 0 | 495 | 0.145 | 1 | 0 | 0 | 0 | 0 |
| 446 | 0.140 | 1 | 0 | 0 | 0 | 0 | 496 | 0.145 | 1 | 0 | 0 | 0 | 0 |
| 447 | 0.140 | 1 | 0 | 0 | 0 | 0 | 497 | 0.145 | 1 | 0 | 0 | 0 | 0 |
| 448 | 0.140 | 1 | 0 | 0 | 0 | 0 | 498 | 0.145 | 1 | 0 | 0 | 0 | 0 |
| 449 | 0.140 | 1 | 0 | 0 | 0 | 0 | 499 | 0.145 | 1 | 0 | 0 | 0 | 0 |
| 450 | 0.140 | 1 | 0 | 0 | 0 | 0 | 500 | 0.145 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 501 | 0.145 | 1 | 0 | 0 | 0 | 0 | 551 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 502 | 0.145 | 1 | 0 | 0 | 0 | 0 | 552 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 503 | 0.145 | 1 | 0 | 0 | 0 | 0 | 553 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 504 | 0.145 | 1 | 0 | 0 | 0 | 0 | 554 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 505 | 0.145 | 1 | 0 | 0 | 0 | 0 | 555 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 506 | 0.145 | 1 | 0 | 0 | 0 | 0 | 556 | 0.151 | 1 | 0 | 0 | 0 | 0 |
| 507 | 0.146 | 1 | 0 | 0 | 0 | 0 | 557 | 0.152 | 1 | 0 | 0 | 0 | 0 |
| 508 | 0.146 | 1 | 0 | 0 | 0 | 0 | 558 | 0.152 | 1 | 0 | 0 | 0 | 0 |
| 509 | 0.146 | 1 | 0 | 0 | 0 | 0 | 559 | 0.152 | 1 | 0 | 0 | 0 | 0 |
| 510 | 0.147 | 1 | 0 | 0 | 0 | 0 | 560 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 511 | 0.147 | 1 | 0 | 0 | 0 | 0 | 561 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 512 | 0.147 | 1 | 0 | 0 | 0 | 0 | 562 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 513 | 0.147 | 1 | 0 | 0 | 0 | 0 | 563 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 514 | 0.147 | 1 | 0 | 0 | 0 | 0 | 564 | 0.153 | 1 | 1 | 1 | 0 | 0 |
| 515 | 0.147 | 1 | 0 | 0 | 0 | 0 | 565 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 516 | 0.147 | 1 | 0 | 0 | 0 | 0 | 566 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 517 | 0.147 | 1 | 0 | 0 | 0 | 0 | 567 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 518 | 0.147 | 1 | 0 | 0 | 0 | 0 | 568 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 519 | 0.147 | 1 | 0 | 0 | 0 | 0 | 569 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 520 | 0.147 | 1 | 0 | 0 | 0 | 0 | 570 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 521 | 0.147 | 1 | 0 | 0 | 0 | 0 | 571 | 0.153 | 1 | 0 | 0 | 0 | 0 |
| 522 | 0.147 | 1 | 0 | 0 | 0 | 0 | 572 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 523 | 0.147 | 1 | 0 | 0 | 0 | 0 | 573 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 524 | 0.147 | 1 | 0 | 0 | 0 | 0 | 574 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 525 | 0.148 | 1 | 0 | 0 | 0 | 0 | 575 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 526 | 0.148 | 1 | 0 | 0 | 0 | 0 | 576 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 527 | 0.148 | 1 | 0 | 0 | 0 | 0 | 577 | 0.154 | 1 | 0 | 0 | 0 | 0 |
| 528 | 0.148 | 1 | 0 | 0 | 0 | 0 | 578 | 0.155 | 1 | 0 | 0 | 0 | 0 |
| 529 | 0.148 | 1 | 0 | 0 | 0 | 0 | 579 | 0.155 | 1 | 0 | 0 | 0 | 0 |
| 530 | 0.148 | 1 | 0 | 0 | 0 | 0 | 580 | 0.155 | 1 | 0 | 0 | 0 | 0 |
| 531 | 0.148 | 1 | 0 | 0 | 0 | 0 | 581 | 0.155 | 1 | 0 | 0 | 0 | 0 |
| 532 | 0.149 | 1 | 0 | 0 | 0 | 0 | 582 | 0.156 | 1 | 0 | 0 | 0 | 0 |
| 533 | 0.149 | 1 | 0 | 0 | 0 | 0 | 583 | 0.156 | 1 | 0 | 0 | 0 | 0 |
| 534 | 0.149 | 1 | 0 | 0 | 0 | 0 | 584 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 535 | 0.149 | 1 | 0 | 0 | 0 | 0 | 585 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 536 | 0.149 | 1 | 0 | 0 | 0 | 0 | 586 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 537 | 0.149 | 1 | 0 | 0 | 0 | 0 | 587 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 538 | 0.149 | 1 | 0 | 0 | 0 | 0 | 588 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 539 | 0.149 | 1 | 0 | 0 | 0 | 0 | 589 | 0.157 | 1 | 1 | 0 | 0 | 0 |
| 540 | 0.149 | 1 | 0 | 0 | 0 | 0 | 590 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 541 | 0.150 | 1 | 0 | 0 | 0 | 0 | 591 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 542 | 0.150 | 1 | 0 | 0 | 0 | 0 | 592 | 0.157 | 1 | 0 | 0 | 0 | 0 |
| 543 | 0.150 | 1 | 0 | 0 | 0 | 0 | 593 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 544 | 0.150 | 1 | 0 | 0 | 0 | 0 | 594 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 545 | 0.150 | 1 | 0 | 0 | 0 | 0 | 595 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 546 | 0.150 | 1 | 0 | 0 | 0 | 0 | 596 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 547 | 0.150 | 1 | 0 | 0 | 0 | 0 | 597 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 548 | 0.150 | 1 | 0 | 0 | 0 | 0 | 598 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 549 | 0.150 | 1 | 0 | 0 | 0 | 0 | 599 | 0.158 | 1 | 0 | 0 | 0 | 0 |
| 550 | 0.150 | 1 | 0 | 0 | 0 | 0 | 600 | 0.158 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 601 | 0.159 | 1 | 0 | 0 | 0 | 601 | 651 | 0.166 | 1 | 0 | 0 | 0 | 0 |
| 602 | 0.159 | 1 | 0 | 0 | 0 | 602 | 652 | 0.166 | 1 | 0 | 0 | 0 | 0 |
| 603 | 0.159 | 1 | 0 | 0 | 0 | 603 | 653 | 0.166 | 1 | 0 | 0 | 0 | 0 |
| 604 | 0.159 | 1 | 0 | 0 | 0 | 604 | 654 | 0.166 | 1 | 0 | 0 | 0 | 0 |
| 605 | 0.159 | 1 | 0 | 0 | 0 | 605 | 655 | 0.166 | 1 | 0 | 0 | 0 | 0 |
| 606 | 0.159 | 1 | 0 | 0 | 0 | 606 | 656 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 607 | 0.159 | 1 | 0 | 0 | 0 | 607 | 657 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 608 | 0.159 | 1 | 0 | 0 | 0 | 608 | 658 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 609 | 0.159 | 1 | 0 | 0 | 0 | 609 | 659 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 610 | 0.159 | 1 | 0 | 0 | 0 | 610 | 660 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 611 | 0.159 | 1 | 0 | 0 | 0 | 611 | 661 | 0.167 | 1 | 0 | 0 | 0 | 0 |
| 612 | 0.159 | 1 | 0 | 0 | 0 | 612 | 662 | 0.168 | 1 | 0 | 0 | 0 | 0 |
| 613 | 0.159 | 1 | 0 | 0 | 0 | 613 | 663 | 0.169 | 1 | 0 | 0 | 0 | 0 |
| 614 | 0.159 | 1 | 0 | 0 | 0 | 614 | 664 | 0.169 | 1 | 0 | 0 | 0 | 0 |
| 615 | 0.160 | 1 | 0 | 0 | 0 | 615 | 665 | 0.169 | 1 | 0 | 0 | 0 | 0 |
| 616 | 0.160 | 1 | 0 | 0 | 0 | 616 | 666 | 0.169 | 1 | 0 | 0 | 0 | 0 |
| 617 | 0.160 | 1 | 0 | 0 | 0 | 617 | 667 | 0.169 | 1 | 0 | 0 | 0 | 0 |
| 618 | 0.161 | 1 | 0 | 0 | 0 | 618 | 668 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 619 | 0.161 | 1 | 0 | 0 | 0 | 619 | 669 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 620 | 0.161 | 1 | 0 | 0 | 0 | 620 | 670 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 621 | 0.161 | 1 | 0 | 0 | 0 | 621 | 671 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 622 | 0.161 | 1 | 0 | 0 | 0 | 622 | 672 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 623 | 0.161 | 1 | 0 | 0 | 0 | 623 | 673 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 624 | 0.162 | 1 | 0 | 0 | 0 | 624 | 674 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 625 | 0.162 | 1 | 0 | 0 | 0 | 625 | 675 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 626 | 0.162 | 1 | 0 | 0 | 0 | 626 | 676 | 0.170 | 1 | 1 | 0 | 0 | 0 |
| 627 | 0.162 | 1 | 0 | 0 | 0 | 627 | 677 | 0.170 | 1 | 0 | 0 | 0 | 0 |
| 628 | 0.162 | 1 | 0 | 0 | 0 | 628 | 678 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 629 | 0.162 | 1 | 0 | 0 | 0 | 629 | 679 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 630 | 0.162 | 1 | 0 | 0 | 0 | 630 | 680 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 631 | 0.163 | 1 | 0 | 0 | 0 | 631 | 681 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 632 | 0.163 | 1 | 0 | 0 | 0 | 632 | 682 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 633 | 0.163 | 1 | 0 | 0 | 0 | 633 | 683 | 0.171 | 1 | 0 | 0 | 0 | 0 |
| 634 | 0.163 | 1 | 0 | 0 | 0 | 634 | 684 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 635 | 0.163 | 1 | 0 | 0 | 0 | 635 | 685 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 636 | 0.164 | 1 | 0 | 0 | 0 | 636 | 686 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 637 | 0.164 | 1 | 0 | 0 | 0 | 637 | 687 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 638 | 0.164 | 1 | 0 | 0 | 0 | 638 | 688 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 639 | 0.164 | 1 | 0 | 0 | 0 | 639 | 689 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 640 | 0.164 | 1 | 0 | 0 | 0 | 640 | 690 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 641 | 0.165 | 1 | 0 | 0 | 0 | 641 | 691 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 642 | 0.165 | 1 | 0 | 0 | 0 | 642 | 692 | 0.172 | 1 | 0 | 0 | 0 | 0 |
| 643 | 0.165 | 1 | 0 | 0 | 0 | 643 | 693 | 0.173 | 1 | 0 | 0 | 0 | 0 |
| 644 | 0.165 | 1 | 0 | 0 | 0 | 644 | 694 | 0.173 | 1 | 0 | 0 | 0 | 0 |
| 645 | 0.165 | 1 | 0 | 0 | 0 | 645 | 695 | 0.173 | 1 | 0 | 0 | 0 | 0 |
| 646 | 0.165 | 1 | 0 | 0 | 0 | 646 | 696 | 0.173 | 1 | 0 | 0 | 0 | 0 |
| 647 | 0.165 | 1 | 0 | 0 | 0 | 647 | 697 | 0.173 | 1 | 0 | 0 | 0 | 0 |
| 648 | 0.165 | 1 | 0 | 0 | 0 | 648 | 698 | 0.174 | 1 | 0 | 0 | 0 | 0 |
| 649 | 0.165 | 1 | 0 | 0 | 0 | 649 | 699 | 0.174 | 1 | 0 | 0 | 0 | 0 |
| 650 | 0.166 | 1 | 0 | 0 | 0 | 650 | 700 | 0.174 | 1 | 0 | 0 | 0 | 0 |

**TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)**

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 701 | 0.174 | 1 | 0 | 0 | 0 | 0 | 751 | 0.182 | 1 | 0 | 0 | 0 | 0 |
| 702 | 0.174 | 1 | 0 | 0 | 0 | 0 | 752 | 0.182 | 1 | 0 | 0 | 0 | 0 |
| 703 | 0.174 | 1 | 0 | 0 | 0 | 0 | 753 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 704 | 0.175 | 1 | 0 | 0 | 0 | 0 | 754 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 705 | 0.175 | 1 | 0 | 0 | 0 | 0 | 755 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 706 | 0.175 | 1 | 0 | 0 | 0 | 0 | 756 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 707 | 0.175 | 1 | 0 | 0 | 0 | 0 | 757 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 708 | 0.175 | 1 | 0 | 0 | 0 | 0 | 758 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 709 | 0.175 | 1 | 0 | 0 | 0 | 0 | 759 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 710 | 0.175 | 1 | 0 | 0 | 0 | 0 | 760 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 711 | 0.175 | 1 | 0 | 0 | 0 | 0 | 761 | 0.183 | 1 | 0 | 0 | 0 | 0 |
| 712 | 0.175 | 1 | 0 | 0 | 0 | 0 | 762 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 713 | 0.176 | 1 | 0 | 0 | 0 | 0 | 763 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 714 | 0.176 | 1 | 0 | 0 | 0 | 0 | 764 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 715 | 0.176 | 1 | 0 | 0 | 0 | 0 | 765 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 716 | 0.176 | 1 | 0 | 0 | 0 | 0 | 766 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 717 | 0.177 | 1 | 0 | 0 | 0 | 0 | 767 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 718 | 0.177 | 1 | 0 | 0 | 0 | 0 | 768 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 719 | 0.177 | 1 | 0 | 0 | 0 | 0 | 769 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 720 | 0.177 | 1 | 0 | 0 | 0 | 0 | 770 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 721 | 0.177 | 1 | 0 | 0 | 0 | 0 | 771 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 722 | 0.177 | 1 | 0 | 0 | 0 | 0 | 772 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 723 | 0.177 | 1 | 0 | 0 | 0 | 0 | 773 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 724 | 0.177 | 1 | 0 | 0 | 0 | 0 | 774 | 0.184 | 1 | 0 | 0 | 0 | 0 |
| 725 | 0.177 | 1 | 0 | 0 | 0 | 0 | 775 | 0.185 | 1 | 0 | 0 | 0 | 0 |
| 726 | 0.178 | 1 | 0 | 0 | 0 | 0 | 776 | 0.185 | 1 | 0 | 0 | 0 | 0 |
| 727 | 0.178 | 1 | 0 | 0 | 0 | 0 | 777 | 0.185 | 1 | 0 | 0 | 0 | 0 |
| 728 | 0.178 | 1 | 0 | 0 | 0 | 0 | 778 | 0.185 | 1 | 0 | 0 | 0 | 0 |
| 729 | 0.178 | 1 | 0 | 0 | 0 | 0 | 779 | 0.186 | 1 | 0 | 0 | 0 | 0 |
| 730 | 0.178 | 1 | 0 | 0 | 0 | 0 | 780 | 0.186 | 1 | 0 | 0 | 0 | 0 |
| 731 | 0.178 | 1 | 0 | 0 | 0 | 0 | 781 | 0.188 | 1 | 0 | 0 | 0 | 0 |
| 732 | 0.178 | 1 | 0 | 0 | 0 | 0 | 782 | 0.188 | 1 | 0 | 0 | 0 | 0 |
| 733 | 0.178 | 1 | 0 | 0 | 0 | 0 | 783 | 0.188 | 1 | 0 | 0 | 0 | 0 |
| 734 | 0.178 | 1 | 0 | 0 | 0 | 0 | 784 | 0.189 | 1 | 0 | 0 | 0 | 0 |
| 735 | 0.179 | 1 | 0 | 0 | 0 | 0 | 785 | 0.189 | 1 | 0 | 0 | 0 | 0 |
| 736 | 0.179 | 1 | 0 | 0 | 0 | 0 | 786 | 0.189 | 1 | 0 | 0 | 0 | 0 |
| 737 | 0.179 | 1 | 0 | 0 | 0 | 0 | 787 | 0.190 | 1 | 0 | 0 | 0 | 0 |
| 738 | 0.179 | 1 | 0 | 0 | 0 | 0 | 788 | 0.191 | 1 | 0 | 0 | 0 | 0 |
| 739 | 0.179 | 1 | 0 | 0 | 0 | 0 | 789 | 0.191 | 1 | 0 | 0 | 0 | 0 |
| 740 | 0.179 | 1 | 0 | 0 | 0 | 0 | 790 | 0.193 | 1 | 0 | 0 | 0 | 0 |
| 741 | 0.179 | 1 | 0 | 0 | 0 | 0 | 791 | 0.193 | 1 | 0 | 0 | 0 | 0 |
| 742 | 0.179 | 1 | 0 | 0 | 0 | 0 | 792 | 0.194 | 1 | 0 | 0 | 0 | 0 |
| 743 | 0.179 | 1 | 0 | 0 | 0 | 0 | 793 | 0.194 | 1 | 0 | 0 | 0 | 0 |
| 744 | 0.179 | 1 | 0 | 0 | 0 | 0 | 794 | 0.194 | 1 | 0 | 0 | 0 | 0 |
| 745 | 0.179 | 1 | 0 | 0 | 0 | 0 | 795 | 0.194 | 1 | 0 | 0 | 0 | 0 |
| 746 | 0.179 | 1 | 0 | 0 | 0 | 0 | 796 | 0.195 | 1 | 0 | 0 | 0 | 0 |
| 747 | 0.179 | 1 | 0 | 0 | 0 | 0 | 797 | 0.195 | 1 | 0 | 0 | 0 | 0 |
| 748 | 0.181 | 1 | 0 | 0 | 0 | 0 | 798 | 0.195 | 1 | 0 | 0 | 0 | 0 |
| 749 | 0.181 | 1 | 0 | 0 | 0 | 0 | 799 | 0.196 | 1 | 0 | 0 | 0 | 0 |
| 750 | 0.181 | 1 | 0 | 0 | 0 | 0 | 800 | 0.196 | 1 | 0 | 0 | 0 | 0 |

**TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 801 | 0.196 | 1 | 0 | 0 | 0 | 0 | 851 | 0.211 | 1 | 0 | 0 | 0 | 0 |
| 802 | 0.196 | 1 | 0 | 0 | 0 | 0 | 852 | 0.212 | 1 | 0 | 0 | 0 | 0 |
| 803 | 0.196 | 1 | 0 | 0 | 0 | 0 | 853 | 0.213 | 1 | 0 | 0 | 0 | 0 |
| 804 | 0.196 | 1 | 0 | 0 | 0 | 0 | 854 | 0.213 | 1 | 1 | 1 | 0 | 0 |
| 805 | 0.196 | 1 | 0 | 0 | 0 | 0 | 855 | 0.213 | 1 | 0 | 0 | 0 | 0 |
| 806 | 0.197 | 1 | 0 | 0 | 0 | 0 | 856 | 0.213 | 1 | 0 | 0 | 0 | 0 |
| 807 | 0.197 | 1 | 0 | 0 | 0 | 0 | 857 | 0.213 | 1 | 0 | 0 | 0 | 0 |
| 808 | 0.198 | 1 | 0 | 0 | 0 | 0 | 858 | 0.214 | 1 | 0 | 0 | 0 | 0 |
| 809 | 0.198 | 1 | 0 | 0 | 0 | 0 | 859 | 0.215 | 1 | 0 | 0 | 0 | 0 |
| 810 | 0.200 | 1 | 0 | 0 | 0 | 0 | 860 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 811 | 0.200 | 1 | 0 | 0 | 0 | 0 | 861 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 812 | 0.200 | 1 | 0 | 0 | 0 | 0 | 862 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 813 | 0.200 | 1 | 0 | 0 | 0 | 0 | 863 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 814 | 0.200 | 1 | 0 | 0 | 0 | 0 | 864 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 815 | 0.201 | 1 | 0 | 0 | 0 | 0 | 865 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 816 | 0.202 | 1 | 0 | 0 | 0 | 0 | 866 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 817 | 0.202 | 1 | 0 | 0 | 0 | 0 | 867 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 818 | 0.202 | 1 | 0 | 0 | 0 | 0 | 868 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 819 | 0.203 | 1 | 0 | 0 | 0 | 0 | 869 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 820 | 0.203 | 1 | 0 | 0 | 0 | 0 | 870 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 821 | 0.203 | 1 | 0 | 0 | 0 | 0 | 871 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 822 | 0.203 | 1 | 0 | 0 | 0 | 0 | 872 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 823 | 0.203 | 1 | 0 | 0 | 0 | 0 | 873 | 0.217 | 1 | 0 | 0 | 0 | 0 |
| 824 | 0.204 | 1 | 0 | 0 | 0 | 0 | 874 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 825 | 0.205 | 1 | 0 | 0 | 0 | 0 | 875 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 826 | 0.206 | 1 | 0 | 0 | 0 | 0 | 876 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 827 | 0.206 | 1 | 0 | 0 | 0 | 0 | 877 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 828 | 0.206 | 1 | 0 | 0 | 0 | 0 | 878 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 829 | 0.206 | 1 | 0 | 0 | 0 | 0 | 879 | 0.221 | 1 | 0 | 0 | 0 | 0 |
| 830 | 0.207 | 1 | 0 | 0 | 0 | 0 | 880 | 0.222 | 1 | 0 | 0 | 0 | 0 |
| 831 | 0.207 | 1 | 0 | 0 | 0 | 0 | 881 | 0.222 | 1 | 0 | 0 | 0 | 0 |
| 832 | 0.207 | 1 | 0 | 0 | 0 | 0 | 882 | 0.222 | 1 | 0 | 0 | 0 | 0 |
| 833 | 0.207 | 1 | 0 | 0 | 0 | 0 | 883 | 0.222 | 1 | 0 | 0 | 0 | 0 |
| 834 | 0.207 | 1 | 0 | 0 | 0 | 0 | 884 | 0.223 | 1 | 0 | 0 | 0 | 0 |
| 835 | 0.207 | 1 | 0 | 0 | 0 | 0 | 885 | 0.223 | 1 | 0 | 0 | 0 | 0 |
| 836 | 0.207 | 1 | 0 | 0 | 0 | 0 | 886 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 837 | 0.207 | 1 | 0 | 0 | 0 | 0 | 887 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 838 | 0.207 | 1 | 0 | 0 | 0 | 0 | 888 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 839 | 0.207 | 1 | 0 | 0 | 0 | 0 | 889 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 840 | 0.207 | 1 | 0 | 0 | 0 | 0 | 890 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 841 | 0.207 | 1 | 0 | 0 | 0 | 0 | 891 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 842 | 0.209 | 1 | 0 | 0 | 0 | 0 | 892 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 843 | 0.209 | 1 | 0 | 0 | 0 | 0 | 893 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 844 | 0.209 | 1 | 0 | 0 | 0 | 0 | 894 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 845 | 0.210 | 1 | 0 | 0 | 0 | 0 | 895 | 0.226 | 1 | 0 | 0 | 0 | 0 |
| 846 | 0.210 | 1 | 0 | 0 | 0 | 0 | 896 | 0.227 | 1 | 0 | 0 | 0 | 0 |
| 847 | 0.210 | 1 | 0 | 0 | 0 | 0 | 897 | 0.227 | 1 | 0 | 0 | 0 | 0 |
| 848 | 0.210 | 1 | 0 | 0 | 0 | 0 | 898 | 0.227 | 1 | 0 | 0 | 0 | 0 |
| 849 | 0.210 | 1 | 0 | 0 | 0 | 0 | 899 | 0.227 | 1 | 0 | 0 | 0 | 0 |
| 850 | 0.211 | 1 | 0 | 0 | 0 | 0 | 900 | 0.227 | 1 | 1 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 901 | 0.227 | 1 | 0 | 0 | 0 | 0 | 951 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 902 | 0.227 | 1 | 0 | 0 | 0 | 0 | 952 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 903 | 0.227 | 1 | 0 | 0 | 0 | 0 | 953 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 904 | 0.228 | 1 | 0 | 0 | 0 | 0 | 954 | 0.245 | 1 | 1 | 0 | 0 | 0 |
| 905 | 0.228 | 1 | 0 | 0 | 0 | 0 | 955 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 906 | 0.228 | 1 | 0 | 0 | 0 | 0 | 956 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 907 | 0.228 | 1 | 0 | 0 | 0 | 0 | 957 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 908 | 0.228 | 1 | 0 | 0 | 0 | 0 | 958 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 909 | 0.228 | 1 | 0 | 0 | 0 | 0 | 959 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 910 | 0.228 | 1 | 0 | 0 | 0 | 0 | 960 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 911 | 0.228 | 1 | 0 | 0 | 0 | 0 | 961 | 0.245 | 1 | 0 | 0 | 0 | 0 |
| 912 | 0.229 | 1 | 0 | 0 | 0 | 0 | 962 | 0.247 | 1 | 0 | 0 | 0 | 0 |
| 913 | 0.229 | 1 | 0 | 0 | 0 | 0 | 963 | 0.248 | 1 | 1 | 1 | 0 | 0 |
| 914 | 0.229 | 1 | 0 | 0 | 0 | 0 | 964 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 915 | 0.229 | 1 | 0 | 0 | 0 | 0 | 965 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 916 | 0.229 | 1 | 0 | 0 | 0 | 0 | 966 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 917 | 0.230 | 1 | 0 | 0 | 0 | 0 | 967 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 918 | 0.233 | 1 | 1 | 0 | 0 | 0 | 968 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 919 | 0.233 | 1 | 0 | 0 | 0 | 0 | 969 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 920 | 0.236 | 1 | 1 | 1 | 0 | 0 | 970 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 921 | 0.237 | 1 | 0 | 0 | 0 | 0 | 971 | 0.248 | 1 | 1 | 1 | 0 | 0 |
| 922 | 0.237 | 1 | 0 | 0 | 0 | 0 | 972 | 0.248 | 1 | 0 | 0 | 0 | 0 |
| 923 | 0.237 | 1 | 0 | 0 | 0 | 0 | 973 | 0.249 | 1 | 1 | 0 | 0 | 0 |
| 924 | 0.237 | 1 | 0 | 0 | 0 | 0 | 974 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 925 | 0.237 | 1 | 0 | 0 | 0 | 0 | 975 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 926 | 0.237 | 1 | 0 | 0 | 0 | 0 | 976 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 927 | 0.237 | 1 | 0 | 0 | 0 | 0 | 977 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 928 | 0.238 | 1 | 0 | 0 | 0 | 0 | 978 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 929 | 0.238 | 1 | 0 | 0 | 0 | 0 | 979 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 930 | 0.238 | 1 | 0 | 0 | 0 | 0 | 980 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 931 | 0.238 | 1 | 0 | 0 | 0 | 0 | 981 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 932 | 0.239 | 1 | 0 | 0 | 0 | 0 | 982 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 933 | 0.239 | 1 | 0 | 0 | 0 | 0 | 983 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 934 | 0.239 | 1 | 0 | 0 | 0 | 0 | 984 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 935 | 0.240 | 1 | 0 | 0 | 0 | 0 | 985 | 0.249 | 1 | 0 | 0 | 0 | 0 |
| 936 | 0.240 | 1 | 0 | 0 | 0 | 0 | 986 | 0.250 | 1 | 0 | 0 | 0 | 0 |
| 937 | 0.240 | 1 | 0 | 0 | 0 | 0 | 987 | 0.250 | 1 | 0 | 0 | 0 | 0 |
| 938 | 0.241 | 1 | 0 | 0 | 0 | 0 | 988 | 0.250 | 1 | 0 | 0 | 0 | 0 |
| 939 | 0.241 | 1 | 0 | 0 | 0 | 0 | 989 | 0.250 | 1 | 0 | 0 | 0 | 0 |
| 940 | 0.241 | 1 | 0 | 0 | 0 | 0 | 990 | 0.252 | 1 | 0 | 0 | 0 | 0 |
| 941 | 0.241 | 1 | 0 | 0 | 0 | 0 | 991 | 0.253 | 1 | 0 | 0 | 0 | 0 |
| 942 | 0.242 | 1 | 0 | 0 | 0 | 0 | 992 | 0.253 | 1 | 0 | 0 | 0 | 0 |
| 943 | 0.242 | 1 | 0 | 0 | 0 | 0 | 993 | 0.253 | 1 | 0 | 0 | 0 | 0 |
| 944 | 0.242 | 1 | 0 | 0 | 0 | 0 | 994 | 0.253 | 1 | 0 | 0 | 0 | 0 |
| 945 | 0.242 | 1 | 0 | 0 | 0 | 0 | 995 | 0.253 | 1 | 0 | 0 | 0 | 0 |
| 946 | 0.243 | 1 | 0 | 0 | 0 | 0 | 996 | 0.256 | 1 | 0 | 0 | 0 | 0 |
| 947 | 0.243 | 1 | 0 | 0 | 0 | 0 | 997 | 0.256 | 1 | 0 | 0 | 0 | 0 |
| 948 | 0.244 | 1 | 0 | 0 | 0 | 0 | 998 | 0.256 | 1 | 0 | 0 | 0 | 0 |
| 949 | 0.244 | 1 | 0 | 0 | 0 | 0 | 999 | 0.256 | 1 | 0 | 0 | 0 | 0 |
| 950 | 0.244 | 1 | 0 | 0 | 0 | 0 | 1000 | 0.257 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1001 | 0.259 | 1 | 0 | 0 | 0 | 0 | 1051 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1002 | 0.259 | 1 | 0 | 0 | 0 | 0 | 1052 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1003 | 0.260 | 1 | 1 | 1 | 0 | 0 | 1053 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1004 | 0.262 | 1 | 0 | 0 | 0 | 0 | 1054 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1005 | 0.262 | 1 | 0 | 0 | 0 | 0 | 1055 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1006 | 0.262 | 1 | 0 | 0 | 0 | 0 | 1056 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1007 | 0.262 | 1 | 0 | 0 | 0 | 0 | 1057 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1008 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1058 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1009 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1059 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1010 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1060 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1011 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1061 | 0.270 | 1 | 0 | 0 | 0 | 0 |
| 1012 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1062 | 0.271 | 1 | 0 | 0 | 0 | 0 |
| 1013 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1063 | 0.271 | 1 | 0 | 0 | 0 | 0 |
| 1014 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1064 | 0.271 | 1 | 0 | 0 | 0 | 0 |
| 1015 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1065 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1016 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1066 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1017 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1067 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1018 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1068 | 0.272 | 1 | 1 | 0 | 0 | 0 |
| 1019 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1069 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1020 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1070 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1021 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1071 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1022 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1072 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1023 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1073 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1024 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1074 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1025 | 0.263 | 1 | 0 | 0 | 0 | 0 | 1075 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1026 | 0.264 | 1 | 0 | 0 | 0 | 0 | 1076 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1027 | 0.265 | 1 | 0 | 0 | 0 | 0 | 1077 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1028 | 0.265 | 1 | 0 | 0 | 0 | 0 | 1078 | 0.272 | 1 | 0 | 0 | 0 | 0 |
| 1029 | 0.265 | 1 | 0 | 0 | 0 | 0 | 1079 | 0.272 | 1 | 1 | 1 | 0 | 0 |
| 1030 | 0.265 | 1 | 0 | 0 | 0 | 0 | 1080 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1031 | 0.265 | 1 | 0 | 0 | 0 | 0 | 1081 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1032 | 0.266 | 1 | 0 | 0 | 0 | 0 | 1082 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1033 | 0.266 | 1 | 0 | 0 | 0 | 0 | 1083 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1034 | 0.266 | 1 | 0 | 0 | 0 | 0 | 1084 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1035 | 0.266 | 1 | 0 | 0 | 0 | 0 | 1085 | 0.273 | 1 | 1 | 0 | 0 | 0 |
| 1036 | 0.267 | 1 | 0 | 0 | 0 | 0 | 1086 | 0.273 | 1 | 0 | 0 | 0 | 0 |
| 1037 | 0.267 | 1 | 0 | 0 | 0 | 0 | 1087 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1038 | 0.267 | 1 | 0 | 0 | 0 | 0 | 1088 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1039 | 0.267 | 1 | 0 | 0 | 0 | 0 | 1089 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1040 | 0.267 | 1 | 0 | 0 | 0 | 0 | 1090 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1041 | 0.268 | 1 | 0 | 0 | 0 | 0 | 1091 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1042 | 0.268 | 1 | 0 | 0 | 0 | 0 | 1092 | 0.274 | 1 | 0 | 0 | 0 | 0 |
| 1043 | 0.268 | 1 | 0 | 0 | 0 | 0 | 1093 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1044 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1094 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1045 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1095 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1046 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1096 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1047 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1097 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1048 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1098 | 0.275 | 1 | 0 | 0 | 0 | 0 |
| 1049 | 0.269 | 1 | 0 | 0 | 0 | 0 | 1099 | 0.276 | 1 | 0 | 0 | 0 | 0 |
| 1050 | 0.270 | 1 | 0 | 0 | 0 | 0 | 1100 | 0.276 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1101 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1151 | 0.282 | 1 | 0 | 0 | 0 | 0 |
| 1102 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1152 | 0.283 | 1 | 0 | 0 | 0 | 0 |
| 1103 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1153 | 0.283 | 1 | 0 | 0 | 0 | 0 |
| 1104 | 0.276 | 1 | 1 | 1 | 0 | 0 | 1154 | 0.283 | 1 | 0 | 0 | 0 | 0 |
| 1105 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1155 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1106 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1156 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1107 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1157 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1108 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1158 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1109 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1159 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1110 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1160 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1111 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1161 | 0.284 | 1 | 0 | 0 | 0 | 0 |
| 1112 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1162 | 0.285 | 1 | 0 | 0 | 0 | 0 |
| 1113 | 0.276 | 1 | 0 | 0 | 0 | 0 | 1163 | 0.285 | 1 | 0 | 0 | 0 | 0 |
| 1114 | 0.277 | 1 | 0 | 0 | 0 | 0 | 1164 | 0.285 | 1 | 0 | 0 | 0 | 0 |
| 1115 | 0.277 | 1 | 0 | 0 | 0 | 0 | 1165 | 0.285 | 1 | 0 | 0 | 0 | 0 |
| 1116 | 0.277 | 1 | 0 | 0 | 0 | 0 | 1166 | 0.285 | 1 | 0 | 0 | 0 | 0 |
| 1117 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1167 | 0.286 | 1 | 0 | 0 | 0 | 0 |
| 1118 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1168 | 0.286 | 1 | 1 | 1 | 0 | 0 |
| 1119 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1169 | 0.286 | 1 | 0 | 0 | 0 | 0 |
| 1120 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1170 | 0.286 | 1 | 0 | 0 | 0 | 0 |
| 1121 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1171 | 0.287 | 1 | 0 | 0 | 0 | 0 |
| 1122 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1172 | 0.287 | 1 | 0 | 0 | 0 | 0 |
| 1123 | 0.278 | 1 | 1 | 1 | 0 | 0 | 1173 | 0.287 | 1 | 1 | 0 | 0 | 0 |
| 1124 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1174 | 0.287 | 1 | 0 | 0 | 0 | 0 |
| 1125 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1175 | 0.287 | 1 | 0 | 0 | 0 | 0 |
| 1126 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1176 | 0.287 | 1 | 0 | 0 | 0 | 0 |
| 1127 | 0.278 | 1 | 0 | 0 | 0 | 0 | 1177 | 0.287 | 1 | 1 | 1 | 0 | 0 |
| 1128 | 0.278 | 1 | 1 | 1 | 0 | 0 | 1178 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1129 | 0.279 | 1 | 0 | 0 | 0 | 0 | 1179 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1130 | 0.279 | 1 | 0 | 0 | 0 | 0 | 1180 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1131 | 0.279 | 1 | 0 | 0 | 0 | 0 | 1181 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1132 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1182 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1133 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1183 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1134 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1184 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1135 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1185 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1136 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1186 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1137 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1187 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1138 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1188 | 0.288 | 1 | 0 | 0 | 0 | 0 |
| 1139 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1189 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1140 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1190 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1141 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1191 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1142 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1192 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1143 | 0.280 | 1 | 0 | 0 | 0 | 0 | 1193 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1144 | 0.281 | 1 | 0 | 0 | 0 | 0 | 1194 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1145 | 0.281 | 1 | 0 | 0 | 0 | 0 | 1195 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1146 | 0.281 | 1 | 0 | 0 | 0 | 0 | 1196 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1147 | 0.281 | 1 | 1 | 1 | 0 | 0 | 1197 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1148 | 0.281 | 1 | 0 | 0 | 0 | 0 | 1198 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1149 | 0.282 | 1 | 0 | 0 | 0 | 0 | 1199 | 0.289 | 1 | 0 | 0 | 0 | 0 |
| 1150 | 0.282 | 1 | 0 | 0 | 0 | 0 | 1200 | 0.289 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1201 | 0.289 | 1 | 0 | 0 | 0 | 0 | 1251 | 0.299 | 1 | 0 | 0 | 0 | 0 |
| 1202 | 0.289 | 1 | 0 | 0 | 0 | 0 | 1252 | 0.299 | 1 | 0 | 0 | 0 | 0 |
| 1203 | 0.289 | 1 | 0 | 0 | 0 | 0 | 1253 | 0.300 | 1 | 0 | 0 | 0 | 0 |
| 1204 | 0.289 | 1 | 0 | 0 | 0 | 0 | 1254 | 0.300 | 1 | 0 | 0 | 0 | 0 |
| 1205 | 0.290 | 1 | 0 | 0 | 0 | 0 | 1255 | 0.300 | 1 | 0 | 0 | 0 | 0 |
| 1206 | 0.290 | 1 | 0 | 0 | 0 | 0 | 1256 | 0.301 | 1 | 0 | 0 | 0 | 0 |
| 1207 | 0.291 | 1 | 0 | 0 | 0 | 0 | 1257 | 0.301 | 1 | 0 | 0 | 0 | 0 |
| 1208 | 0.291 | 1 | 0 | 0 | 0 | 0 | 1258 | 0.301 | 1 | 0 | 0 | 0 | 0 |
| 1209 | 0.291 | 1 | 0 | 0 | 0 | 0 | 1259 | 0.301 | 1 | 0 | 0 | 0 | 0 |
| 1210 | 0.291 | 1 | 0 | 0 | 0 | 0 | 1260 | 0.302 | 1 | 0 | 0 | 0 | 0 |
| 1211 | 0.291 | 1 | 0 | 0 | 0 | 0 | 1261 | 0.303 | 1 | 0 | 0 | 0 | 0 |
| 1212 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1262 | 0.303 | 1 | 0 | 0 | 0 | 0 |
| 1213 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1263 | 0.303 | 1 | 0 | 0 | 0 | 0 |
| 1214 | 0.292 | 1 | 1 | 0 | 0 | 0 | 1264 | 0.304 | 1 | 0 | 0 | 0 | 0 |
| 1215 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1265 | 0.304 | 1 | 0 | 0 | 0 | 0 |
| 1216 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1266 | 0.305 | 1 | 0 | 0 | 0 | 0 |
| 1217 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1267 | 0.307 | 1 | 0 | 0 | 0 | 0 |
| 1218 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1268 | 0.307 | 1 | 0 | 0 | 0 | 0 |
| 1219 | 0.292 | 1 | 0 | 0 | 0 | 0 | 1269 | 0.307 | 1 | 0 | 0 | 0 | 0 |
| 1220 | 0.293 | 1 | 1 | 1 | 0 | 0 | 1270 | 0.308 | 1 | 0 | 0 | 0 | 0 |
| 1221 | 0.293 | 1 | 0 | 0 | 0 | 0 | 1271 | 0.309 | 1 | 1 | 0 | 0 | 0 |
| 1222 | 0.293 | 1 | 0 | 0 | 0 | 0 | 1272 | 0.309 | 1 | 0 | 0 | 0 | 0 |
| 1223 | 0.293 | 1 | 0 | 0 | 0 | 0 | 1273 | 0.310 | 1 | 0 | 0 | 0 | 0 |
| 1224 | 0.293 | 1 | 0 | 0 | 0 | 0 | 1274 | 0.310 | 1 | 0 | 0 | 0 | 0 |
| 1225 | 0.293 | 1 | 0 | 0 | 0 | 0 | 1275 | 0.311 | 1 | 0 | 0 | 0 | 0 |
| 1226 | 0.294 | 1 | 1 | 0 | 0 | 0 | 1276 | 0.311 | 1 | 0 | 0 | 0 | 0 |
| 1227 | 0.294 | 1 | 0 | 0 | 0 | 0 | 1277 | 0.311 | 1 | 0 | 0 | 0 | 0 |
| 1228 | 0.295 | 1 | 0 | 0 | 0 | 0 | 1278 | 0.312 | 1 | 0 | 0 | 0 | 0 |
| 1229 | 0.295 | 1 | 0 | 0 | 0 | 0 | 1279 | 0.312 | 1 | 0 | 0 | 0 | 0 |
| 1230 | 0.295 | 1 | 0 | 0 | 0 | 0 | 1280 | 0.312 | 1 | 0 | 0 | 0 | 0 |
| 1231 | 0.295 | 1 | 0 | 0 | 0 | 0 | 1281 | 0.313 | 1 | 0 | 0 | 0 | 0 |
| 1232 | 0.296 | 1 | 1 | 0 | 0 | 0 | 1282 | 0.314 | 1 | 0 | 0 | 0 | 0 |
| 1233 | 0.296 | 1 | 0 | 0 | 0 | 0 | 1283 | 0.315 | 1 | 0 | 0 | 0 | 0 |
| 1234 | 0.296 | 1 | 0 | 0 | 0 | 0 | 1284 | 0.316 | 1 | 0 | 0 | 0 | 0 |
| 1235 | 0.296 | 1 | 0 | 0 | 0 | 0 | 1285 | 0.316 | 1 | 0 | 0 | 0 | 0 |
| 1236 | 0.296 | 1 | 0 | 0 | 0 | 0 | 1286 | 0.316 | 1 | 0 | 0 | 0 | 0 |
| 1237 | 0.296 | 1 | 1 | 0 | 0 | 0 | 1287 | 0.317 | 1 | 0 | 0 | 0 | 0 |
| 1238 | 0.297 | 1 | 0 | 0 | 0 | 0 | 1288 | 0.317 | 1 | 0 | 0 | 0 | 0 |
| 1239 | 0.297 | 1 | 0 | 0 | 0 | 0 | 1289 | 0.317 | 1 | 0 | 0 | 0 | 0 |
| 1240 | 0.297 | 1 | 0 | 0 | 0 | 0 | 1290 | 0.318 | 1 | 0 | 0 | 0 | 0 |
| 1241 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1291 | 0.318 | 1 | 0 | 0 | 0 | 0 |
| 1242 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1292 | 0.318 | 1 | 0 | 0 | 0 | 0 |
| 1243 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1293 | 0.319 | 1 | 0 | 0 | 0 | 0 |
| 1244 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1294 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1245 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1295 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1246 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1296 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1247 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1297 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1248 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1298 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1249 | 0.298 | 1 | 0 | 0 | 0 | 0 | 1299 | 0.320 | 1 | 0 | 0 | 0 | 0 |
| 1250 | 0.299 | 1 | 0 | 0 | 0 | 0 | 1300 | 0.320 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1301 | 0.320 | 1 | 0 | 0 | 0 | 0 | 1351 | 0.333 | 1 | 0 | 0 | 0 | 0 |
| 1302 | 0.321 | 1 | 0 | 0 | 0 | 0 | 1352 | 0.334 | 1 | 1 | 1 | 0 | 0 |
| 1303 | 0.322 | 1 | 0 | 0 | 0 | 0 | 1353 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1304 | 0.322 | 1 | 0 | 0 | 0 | 0 | 1354 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1305 | 0.322 | 1 | 0 | 0 | 0 | 0 | 1355 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1306 | 0.322 | 1 | 0 | 0 | 0 | 0 | 1356 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1307 | 0.323 | 1 | 1 | 1 | 1 | 0 | 1357 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1308 | 0.323 | 1 | 1 | 0 | 0 | 0 | 1358 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1309 | 0.323 | 1 | 1 | 0 | 0 | 0 | 1359 | 0.334 | 1 | 0 | 0 | 0 | 0 |
| 1310 | 0.323 | 1 | 0 | 0 | 0 | 0 | 1360 | 0.335 | 1 | 0 | 0 | 0 | 0 |
| 1311 | 0.323 | 1 | 0 | 0 | 0 | 0 | 1361 | 0.335 | 1 | 0 | 0 | 0 | 0 |
| 1312 | 0.323 | 1 | 1 | 0 | 0 | 0 | 1362 | 0.335 | 1 | 0 | 0 | 0 | 0 |
| 1313 | 0.323 | 1 | 0 | 0 | 0 | 0 | 1363 | 0.335 | 1 | 0 | 0 | 0 | 0 |
| 1314 | 0.323 | 1 | 1 | 0 | 0 | 0 | 1364 | 0.336 | 1 | 0 | 0 | 0 | 0 |
| 1315 | 0.324 | 1 | 0 | 0 | 0 | 0 | 1365 | 0.336 | 1 | 0 | 0 | 0 | 0 |
| 1316 | 0.324 | 1 | 0 | 0 | 0 | 0 | 1366 | 0.336 | 1 | 0 | 0 | 0 | 0 |
| 1317 | 0.324 | 1 | 0 | 0 | 0 | 0 | 1367 | 0.336 | 1 | 0 | 0 | 0 | 0 |
| 1318 | 0.324 | 1 | 0 | 0 | 0 | 0 | 1368 | 0.336 | 1 | 0 | 0 | 0 | 0 |
| 1319 | 0.324 | 1 | 0 | 0 | 0 | 0 | 1369 | 0.337 | 1 | 0 | 0 | 0 | 0 |
| 1320 | 0.325 | 1 | 1 | 0 | 0 | 0 | 1370 | 0.337 | 1 | 0 | 0 | 0 | 0 |
| 1321 | 0.327 | 1 | 0 | 0 | 0 | 0 | 1371 | 0.337 | 1 | 1 | 0 | 0 | 0 |
| 1322 | 0.327 | 1 | 1 | 1 | 0 | 0 | 1372 | 0.337 | 1 | 0 | 0 | 0 | 0 |
| 1323 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1373 | 0.337 | 1 | 1 | 1 | 0 | 0 |
| 1324 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1374 | 0.337 | 1 | 0 | 0 | 0 | 0 |
| 1325 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1375 | 0.337 | 1 | 1 | 0 | 0 | 0 |
| 1326 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1376 | 0.337 | 1 | 1 | 0 | 0 | 0 |
| 1327 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1377 | 0.337 | 1 | 0 | 0 | 0 | 0 |
| 1328 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1378 | 0.338 | 1 | 0 | 0 | 0 | 0 |
| 1329 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1379 | 0.338 | 1 | 0 | 0 | 0 | 0 |
| 1330 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1380 | 0.339 | 1 | 0 | 0 | 0 | 0 |
| 1331 | 0.329 | 1 | 0 | 0 | 0 | 0 | 1381 | 0.339 | 1 | 0 | 0 | 0 | 0 |
| 1332 | 0.331 | 1 | 0 | 0 | 0 | 0 | 1382 | 0.339 | 1 | 0 | 0 | 0 | 0 |
| 1333 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1383 | 0.339 | 1 | 0 | 0 | 0 | 0 |
| 1334 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1384 | 0.340 | 1 | 0 | 0 | 0 | 0 |
| 1335 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1385 | 0.340 | 1 | 0 | 0 | 0 | 0 |
| 1336 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1386 | 0.341 | 1 | 0 | 0 | 0 | 0 |
| 1337 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1387 | 0.341 | 1 | 0 | 0 | 0 | 0 |
| 1338 | 0.332 | 1 | 0 | 0 | 0 | 0 | 1388 | 0.341 | 1 | 0 | 0 | 0 | 0 |
| 1339 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1389 | 0.342 | 1 | 0 | 0 | 0 | 0 |
| 1340 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1390 | 0.343 | 1 | 0 | 0 | 0 | 0 |
| 1341 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1391 | 0.343 | 1 | 0 | 0 | 0 | 0 |
| 1342 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1392 | 0.343 | 1 | 0 | 0 | 0 | 0 |
| 1343 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1393 | 0.343 | 1 | 0 | 0 | 0 | 0 |
| 1344 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1394 | 0.344 | 1 | 0 | 0 | 0 | 0 |
| 1345 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1395 | 0.344 | 1 | 0 | 0 | 0 | 0 |
| 1346 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1396 | 0.344 | 1 | 0 | 0 | 0 | 0 |
| 1347 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1397 | 0.345 | 1 | 1 | 1 | 0 | 0 |
| 1348 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1398 | 0.345 | 1 | 0 | 0 | 0 | 0 |
| 1349 | 0.333 | 1 | 0 | 0 | 0 | 0 | 1399 | 0.346 | 1 | 0 | 0 | 0 | 0 |
| 1350 | 0.333 | 1 | 1 | 1 | 0 | 0 | 1400 | 0.346 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1401 | 0.346 | 1 | 0 | 0 | 0 | 0 | 1451 | 0.358 | 1 | 0 | 0 | 0 | 0 |
| 1402 | 0.346 | 1 | 0 | 0 | 0 | 0 | 1452 | 0.358 | 1 | 0 | 0 | 0 | 0 |
| 1403 | 0.347 | 1 | 0 | 0 | 0 | 0 | 1453 | 0.358 | 1 | 0 | 0 | 0 | 0 |
| 1404 | 0.347 | 1 | 0 | 0 | 0 | 0 | 1454 | 0.359 | 1 | 0 | 0 | 0 | 0 |
| 1405 | 0.347 | 1 | 0 | 0 | 0 | 0 | 1455 | 0.359 | 1 | 1 | 1 | 0 | 0 |
| 1406 | 0.348 | 1 | 0 | 0 | 0 | 0 | 1456 | 0.359 | 1 | 0 | 0 | 0 | 0 |
| 1407 | 0.348 | 1 | 0 | 0 | 0 | 0 | 1457 | 0.359 | 1 | 1 | 1 | 1 | 0 |
| 1408 | 0.348 | 1 | 0 | 0 | 0 | 0 | 1458 | 0.360 | 1 | 0 | 0 | 0 | 0 |
| 1409 | 0.348 | 1 | 0 | 0 | 0 | 0 | 1459 | 0.360 | 1 | 1 | 0 | 0 | 0 |
| 1410 | 0.349 | 1 | 0 | 0 | 0 | 0 | 1460 | 0.360 | 1 | 0 | 0 | 0 | 0 |
| 1411 | 0.349 | 1 | 0 | 0 | 0 | 0 | 1461 | 0.361 | 1 | 0 | 0 | 0 | 0 |
| 1412 | 0.350 | 1 | 1 | 1 | 0 | 0 | 1462 | 0.361 | 1 | 1 | 1 | 1 | 0 |
| 1413 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1463 | 0.361 | 1 | 1 | 1 | 0 | 0 |
| 1414 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1464 | 0.361 | 1 | 1 | 1 | 0 | 0 |
| 1415 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1465 | 0.361 | 1 | 1 | 1 | 1 | 0 |
| 1416 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1466 | 0.363 | 1 | 0 | 0 | 0 | 0 |
| 1417 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1467 | 0.363 | 1 | 0 | 0 | 0 | 0 |
| 1418 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1468 | 0.363 | 1 | 0 | 0 | 0 | 0 |
| 1419 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1469 | 0.363 | 1 | 0 | 0 | 0 | 0 |
| 1420 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1470 | 0.364 | 1 | 1 | 0 | 0 | 0 |
| 1421 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1471 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1422 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1472 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1423 | 0.350 | 1 | 0 | 0 | 0 | 0 | 1473 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1424 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1474 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1425 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1475 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1426 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1476 | 0.364 | 1 | 0 | 0 | 0 | 0 |
| 1427 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1477 | 0.366 | 1 | 0 | 0 | 0 | 0 |
| 1428 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1478 | 0.367 | 1 | 0 | 0 | 0 | 0 |
| 1429 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1479 | 0.367 | 1 | 0 | 0 | 0 | 0 |
| 1430 | 0.351 | 1 | 0 | 0 | 0 | 0 | 1480 | 0.369 | 1 | 1 | 0 | 0 | 0 |
| 1431 | 0.351 | 1 | 1 | 1 | 1 | 0 | 1481 | 0.369 | 1 | 1 | 0 | 0 | 0 |
| 1432 | 0.353 | 1 | 0 | 0 | 0 | 0 | 1482 | 0.369 | 1 | 1 | 0 | 0 | 0 |
| 1433 | 0.353 | 1 | 0 | 0 | 0 | 0 | 1483 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1434 | 0.353 | 1 | 1 | 0 | 0 | 0 | 1484 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1435 | 0.353 | 1 | 1 | 0 | 0 | 0 | 1485 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1436 | 0.353 | 1 | 0 | 0 | 0 | 0 | 1486 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1437 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1487 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1438 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1488 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1439 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1489 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1440 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1490 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1441 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1491 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1442 | 0.354 | 1 | 0 | 0 | 0 | 0 | 1492 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1443 | 0.354 | 1 | 1 | 1 | 0 | 0 | 1493 | 0.369 | 1 | 0 | 0 | 0 | 0 |
| 1444 | 0.355 | 1 | 0 | 0 | 0 | 0 | 1494 | 0.370 | 1 | 0 | 0 | 0 | 0 |
| 1445 | 0.355 | 1 | 0 | 0 | 0 | 0 | 1495 | 0.370 | 1 | 0 | 0 | 0 | 0 |
| 1446 | 0.356 | 1 | 0 | 0 | 0 | 0 | 1496 | 0.371 | 1 | 0 | 0 | 0 | 0 |
| 1447 | 0.357 | 1 | 0 | 0 | 0 | 0 | 1497 | 0.371 | 1 | 0 | 0 | 0 | 0 |
| 1448 | 0.357 | 1 | 0 | 0 | 0 | 0 | 1498 | 0.371 | 1 | 0 | 0 | 0 | 0 |
| 1449 | 0.357 | 1 | 0 | 0 | 0 | 0 | 1499 | 0.372 | 1 | 1 | 0 | 0 | 0 |
| 1450 | 0.358 | 1 | 0 | 0 | 0 | 0 | 1500 | 0.372 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1501 | 0.372 | 1 | 0 | 0 | 0 | 0 | 1551 | 0.383 | 1 | 0 | 0 | 0 | 0 |
| 1502 | 0.372 | 1 | 0 | 0 | 0 | 0 | 1552 | 0.383 | 1 | 0 | 0 | 0 | 0 |
| 1503 | 0.372 | 1 | 0 | 0 | 0 | 0 | 1553 | 0.383 | 1 | 1 | 1 | 0 | 0 |
| 1504 | 0.372 | 1 | 0 | 0 | 0 | 0 | 1554 | 0.383 | 1 | 1 | 0 | 0 | 0 |
| 1505 | 0.372 | 1 | 0 | 0 | 0 | 0 | 1555 | 0.384 | 1 | 0 | 0 | 0 | 0 |
| 1506 | 0.372 | 1 | 1 | 0 | 0 | 0 | 1556 | 0.385 | 1 | 1 | 0 | 0 | 0 |
| 1507 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1557 | 0.385 | 1 | 0 | 0 | 0 | 0 |
| 1508 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1558 | 0.385 | 1 | 1 | 0 | 0 | 0 |
| 1509 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1559 | 0.385 | 1 | 0 | 0 | 0 | 0 |
| 1510 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1560 | 0.385 | 1 | 0 | 0 | 0 | 0 |
| 1511 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1561 | 0.385 | 1 | 1 | 1 | 1 | 1 |
| 1512 | 0.373 | 1 | 0 | 0 | 0 | 0 | 1562 | 0.385 | 1 | 1 | 1 | 1 | 0 |
| 1513 | 0.373 | 1 | 1 | 1 | 1 | 0 | 1563 | 0.385 | 1 | 0 | 0 | 0 | 0 |
| 1514 | 0.373 | 1 | 1 | 1 | 0 | 0 | 1564 | 0.385 | 1 | 0 | 0 | 0 | 0 |
| 1515 | 0.374 | 1 | 0 | 0 | 0 | 0 | 1565 | 0.386 | 1 | 1 | 0 | 0 | 0 |
| 1516 | 0.375 | 1 | 0 | 0 | 0 | 0 | 1566 | 0.386 | 1 | 0 | 0 | 0 | 0 |
| 1517 | 0.375 | 1 | 1 | 0 | 0 | 0 | 1567 | 0.387 | 1 | 0 | 0 | 0 | 0 |
| 1518 | 0.375 | 1 | 1 | 1 | 0 | 0 | 1568 | 0.387 | 1 | 0 | 0 | 0 | 0 |
| 1519 | 0.376 | 1 | 0 | 0 | 0 | 0 | 1569 | 0.387 | 1 | 0 | 0 | 0 | 0 |
| 1520 | 0.376 | 1 | 0 | 0 | 0 | 0 | 1570 | 0.387 | 1 | 0 | 0 | 0 | 0 |
| 1521 | 0.376 | 1 | 0 | 0 | 0 | 0 | 1571 | 0.388 | 1 | 1 | 1 | 0 | 0 |
| 1522 | 0.377 | 1 | 1 | 0 | 0 | 0 | 1572 | 0.388 | 1 | 0 | 0 | 0 | 0 |
| 1523 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1573 | 0.389 | 1 | 0 | 0 | 0 | 0 |
| 1524 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1574 | 0.390 | 1 | 1 | 0 | 0 | 0 |
| 1525 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1575 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1526 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1576 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1527 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1577 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1528 | 0.377 | 1 | 0 | 0 | 0 | 0 | 1578 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1529 | 0.378 | 1 | 0 | 0 | 0 | 0 | 1579 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1530 | 0.378 | 1 | 0 | 0 | 0 | 0 | 1580 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1531 | 0.378 | 1 | 0 | 0 | 0 | 0 | 1581 | 0.390 | 1 | 1 | 1 | 0 | 0 |
| 1532 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1582 | 0.390 | 1 | 1 | 1 | 0 | 0 |
| 1533 | 0.380 | 1 | 1 | 0 | 0 | 0 | 1583 | 0.390 | 1 | 0 | 0 | 0 | 0 |
| 1534 | 0.380 | 1 | 1 | 1 | 0 | 0 | 1584 | 0.390 | 1 | 1 | 0 | 0 | 0 |
| 1535 | 0.380 | 1 | 1 | 0 | 0 | 0 | 1585 | 0.390 | 1 | 1 | 1 | 0 | 0 |
| 1536 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1586 | 0.390 | 1 | 1 | 1 | 1 | 0 |
| 1537 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1587 | 0.391 | 1 | 0 | 0 | 0 | 0 |
| 1538 | 0.380 | 1 | 1 | 0 | 0 | 0 | 1588 | 0.391 | 1 | 0 | 0 | 0 | 0 |
| 1539 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1589 | 0.392 | 1 | 1 | 0 | 0 | 0 |
| 1540 | 0.380 | 1 | 1 | 0 | 0 | 0 | 1590 | 0.393 | 1 | 0 | 0 | 0 | 0 |
| 1541 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1591 | 0.393 | 1 | 1 | 0 | 0 | 0 |
| 1542 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1592 | 0.393 | 1 | 1 | 0 | 0 | 0 |
| 1543 | 0.380 | 1 | 0 | 0 | 0 | 0 | 1593 | 0.394 | 1 | 0 | 0 | 0 | 0 |
| 1544 | 0.381 | 1 | 0 | 0 | 0 | 0 | 1594 | 0.394 | 1 | 1 | 1 | 0 | 0 |
| 1545 | 0.381 | 1 | 0 | 0 | 0 | 0 | 1595 | 0.395 | 1 | 0 | 0 | 0 | 0 |
| 1546 | 0.381 | 1 | 0 | 0 | 0 | 0 | 1596 | 0.395 | 1 | 0 | 0 | 0 | 0 |
| 1547 | 0.381 | 1 | 0 | 0 | 0 | 0 | 1597 | 0.395 | 1 | 0 | 0 | 0 | 0 |
| 1548 | 0.381 | 1 | 0 | 0 | 0 | 0 | 1598 | 0.395 | 1 | 0 | 0 | 0 | 0 |
| 1549 | 0.382 | 1 | 0 | 0 | 0 | 0 | 1599 | 0.395 | 1 | 0 | 0 | 0 | 0 |
| 1550 | 0.383 | 1 | 0 | 0 | 0 | 0 | 1600 | 0.395 | 1 | 0 | 0 | 0 | 0 |

**TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1601 | 0.395 | 1 | 0 | 0 | 0 | 0 | 1651 | 0.429 | 1 | 1 | 0 | 0 | 0 |
| 1602 | 0.397 | 1 | 0 | 0 | 0 | 0 | 1652 | 0.429 | 1 | 0 | 0 | 0 | 0 |
| 1603 | 0.398 | 1 | 0 | 0 | 0 | 0 | 1653 | 0.429 | 1 | 0 | 0 | 0 | 0 |
| 1604 | 0.398 | 1 | 0 | 0 | 0 | 0 | 1654 | 0.429 | 1 | 0 | 0 | 0 | 0 |
| 1605 | 0.399 | 1 | 0 | 0 | 0 | 0 | 1655 | 0.429 | 1 | 0 | 0 | 0 | 0 |
| 1606 | 0.401 | 1 | 0 | 0 | 0 | 0 | 1656 | 0.431 | 1 | 0 | 0 | 0 | 0 |
| 1607 | 0.401 | 1 | 1 | 1 | 0 | 0 | 1657 | 0.431 | 1 | 1 | 1 | 0 | 0 |
| 1608 | 0.401 | 1 | 0 | 0 | 0 | 0 | 1658 | 0.432 | 1 | 0 | 0 | 0 | 0 |
| 1609 | 0.402 | 1 | 1 | 1 | 0 | 0 | 1659 | 0.432 | 1 | 0 | 0 | 0 | 0 |
| 1610 | 0.402 | 1 | 1 | 1 | 1 | 0 | 1660 | 0.433 | 1 | 0 | 0 | 0 | 0 |
| 1611 | 0.404 | 1 | 0 | 0 | 0 | 0 | 1661 | 0.433 | 1 | 0 | 0 | 0 | 0 |
| 1612 | 0.404 | 1 | 0 | 0 | 0 | 0 | 1662 | 0.433 | 1 | 0 | 0 | 0 | 0 |
| 1613 | 0.404 | 1 | 1 | 1 | 0 | 0 | 1663 | 0.433 | 1 | 0 | 0 | 0 | 0 |
| 1614 | 0.405 | 1 | 0 | 0 | 0 | 0 | 1664 | 0.433 | 1 | 0 | 0 | 0 | 0 |
| 1615 | 0.407 | 1 | 0 | 0 | 0 | 0 | 1665 | 0.434 | 1 | 0 | 0 | 0 | 0 |
| 1616 | 0.407 | 1 | 0 | 0 | 0 | 0 | 1666 | 0.434 | 1 | 1 | 1 | 0 | 0 |
| 1617 | 0.409 | 1 | 0 | 0 | 0 | 0 | 1667 | 0.435 | 1 | 0 | 0 | 0 | 0 |
| 1618 | 0.409 | 1 | 1 | 1 | 1 | 0 | 1668 | 0.436 | 1 | 1 | 1 | 0 | 0 |
| 1619 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1669 | 0.436 | 1 | 1 | 1 | 1 | 0 |
| 1620 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1670 | 0.436 | 1 | 1 | 1 | 0 | 0 |
| 1621 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1671 | 0.438 | 1 | 1 | 1 | 1 | 0 |
| 1622 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1672 | 0.438 | 1 | 0 | 0 | 0 | 0 |
| 1623 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1673 | 0.438 | 1 | 0 | 0 | 0 | 0 |
| 1624 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1674 | 0.439 | 1 | 0 | 0 | 0 | 0 |
| 1625 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1675 | 0.439 | 1 | 1 | 0 | 0 | 0 |
| 1626 | 0.412 | 1 | 1 | 1 | 0 | 0 | 1676 | 0.441 | 1 | 0 | 0 | 0 | 0 |
| 1627 | 0.412 | 1 | 0 | 0 | 0 | 0 | 1677 | 0.442 | 1 | 0 | 0 | 0 | 0 |
| 1628 | 0.413 | 1 | 0 | 0 | 0 | 0 | 1678 | 0.442 | 1 | 0 | 0 | 0 | 0 |
| 1629 | 0.417 | 1 | 1 | 1 | 1 | 0 | 1679 | 0.444 | 1 | 0 | 0 | 0 | 0 |
| 1630 | 0.418 | 1 | 0 | 0 | 0 | 0 | 1680 | 0.444 | 1 | 0 | 0 | 0 | 0 |
| 1631 | 0.418 | 1 | 0 | 0 | 0 | 0 | 1681 | 0.444 | 1 | 0 | 0 | 0 | 0 |
| 1632 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1682 | 0.444 | 1 | 0 | 0 | 0 | 0 |
| 1633 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1683 | 0.445 | 1 | 0 | 0 | 0 | 0 |
| 1634 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1684 | 0.445 | 1 | 0 | 0 | 0 | 0 |
| 1635 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1685 | 0.446 | 1 | 0 | 0 | 0 | 0 |
| 1636 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1686 | 0.448 | 1 | 0 | 0 | 0 | 0 |
| 1637 | 0.420 | 1 | 0 | 0 | 0 | 0 | 1687 | 0.448 | 1 | 1 | 1 | 1 | 0 |
| 1638 | 0.421 | 1 | 0 | 0 | 0 | 0 | 1688 | 0.448 | 1 | 1 | 1 | 1 | 0 |
| 1639 | 0.421 | 1 | 0 | 0 | 0 | 0 | 1689 | 0.448 | 1 | 1 | 1 | 0 | 0 |
| 1640 | 0.421 | 1 | 0 | 0 | 0 | 0 | 1690 | 0.448 | 1 | 1 | 1 | 0 | 0 |
| 1641 | 0.421 | 1 | 0 | 0 | 0 | 0 | 1691 | 0.448 | 1 | 0 | 0 | 0 | 0 |
| 1642 | 0.422 | 1 | 0 | 0 | 0 | 0 | 1692 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1643 | 0.422 | 1 | 0 | 0 | 0 | 0 | 1693 | 0.451 | 1 | 1 | 1 | 0 | 0 |
| 1644 | 0.423 | 1 | 0 | 0 | 0 | 0 | 1694 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1645 | 0.423 | 1 | 0 | 0 | 0 | 0 | 1695 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1646 | 0.424 | 1 | 1 | 1 | 1 | 0 | 1696 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1647 | 0.425 | 1 | 0 | 0 | 0 | 0 | 1697 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1648 | 0.426 | 1 | 0 | 0 | 0 | 0 | 1698 | 0.451 | 1 | 0 | 0 | 0 | 0 |
| 1649 | 0.426 | 1 | 0 | 0 | 0 | 0 | 1699 | 0.452 | 1 | 0 | 0 | 0 | 0 |
| 1650 | 0.428 | 1 | 0 | 0 | 0 | 0 | 1700 | 0.452 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1701 | 0.453 | 1 | 0 | 0 | 0 | 0 | 1751 | 0.507 | 1 | 0 | 0 | 0 | 0 |
| 1702 | 0.454 | 1 | 0 | 0 | 0 | 0 | 1752 | 0.508 | 1 | 0 | 0 | 0 | 0 |
| 1703 | 0.456 | 1 | 0 | 0 | 0 | 0 | 1753 | 0.511 | 1 | 0 | 0 | 0 | 0 |
| 1704 | 0.457 | 1 | 0 | 0 | 0 | 0 | 1754 | 0.512 | 1 | 0 | 0 | 0 | 0 |
| 1705 | 0.457 | 1 | 0 | 0 | 0 | 0 | 1755 | 0.512 | 1 | 1 | 1 | 0 | 0 |
| 1706 | 0.457 | 1 | 0 | 0 | 0 | 0 | 1756 | 0.512 | 1 | 0 | 0 | 0 | 0 |
| 1707 | 0.460 | 1 | 0 | 0 | 0 | 0 | 1757 | 0.517 | 1 | 1 | 1 | 0 | 0 |
| 1708 | 0.460 | 1 | 0 | 0 | 0 | 0 | 1758 | 0.517 | 1 | 1 | 1 | 1 | 0 |
| 1709 | 0.461 | 1 | 0 | 0 | 0 | 0 | 1759 | 0.521 | 1 | 1 | 0 | 0 | 0 |
| 1710 | 0.464 | 1 | 0 | 0 | 0 | 0 | 1760 | 0.522 | 1 | 1 | 1 | 0 | 0 |
| 1711 | 0.466 | 1 | 1 | 1 | 1 | 0 | 1761 | 0.523 | 1 | 0 | 0 | 0 | 0 |
| 1712 | 0.466 | 1 | 1 | 1 | 0 | 0 | 1762 | 0.524 | 1 | 0 | 0 | 0 | 0 |
| 1713 | 0.467 | 1 | 1 | 0 | 0 | 0 | 1763 | 0.524 | 1 | 0 | 0 | 0 | 0 |
| 1714 | 0.467 | 1 | 0 | 0 | 0 | 0 | 1764 | 0.527 | 1 | 1 | 1 | 0 | 0 |
| 1715 | 0.469 | 1 | 0 | 0 | 0 | 0 | 1765 | 0.527 | 1 | 1 | 1 | 0 | 0 |
| 1716 | 0.469 | 1 | 0 | 0 | 0 | 0 | 1766 | 0.536 | 1 | 0 | 0 | 0 | 0 |
| 1717 | 0.471 | 1 | 0 | 0 | 0 | 0 | 1767 | 0.537 | 1 | 1 | 1 | 1 | 0 |
| 1718 | 0.471 | 1 | 0 | 0 | 0 | 0 | 1768 | 0.539 | 1 | 0 | 0 | 0 | 0 |
| 1719 | 0.474 | 1 | 0 | 0 | 0 | 0 | 1769 | 0.540 | 1 | 0 | 0 | 0 | 0 |
| 1720 | 0.476 | 1 | 0 | 0 | 0 | 0 | 1770 | 0.540 | 1 | 0 | 0 | 0 | 0 |
| 1721 | 0.476 | 1 | 0 | 0 | 0 | 0 | 1771 | 0.541 | 1 | 0 | 0 | 0 | 0 |
| 1722 | 0.477 | 1 | 0 | 0 | 0 | 0 | 1772 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1723 | 0.479 | 1 | 0 | 0 | 0 | 0 | 1773 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1724 | 0.482 | 1 | 1 | 1 | 0 | 0 | 1774 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1725 | 0.482 | 1 | 1 | 1 | 0 | 0 | 1775 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1726 | 0.482 | 1 | 0 | 0 | 0 | 0 | 1776 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1727 | 0.482 | 1 | 1 | 1 | 1 | 0 | 1777 | 0.543 | 1 | 0 | 0 | 0 | 0 |
| 1728 | 0.487 | 1 | 0 | 0 | 0 | 0 | 1778 | 0.552 | 1 | 0 | 0 | 0 | 0 |
| 1729 | 0.487 | 1 | 0 | 0 | 0 | 0 | 1779 | 0.553 | 1 | 0 | 0 | 0 | 0 |
| 1730 | 0.488 | 1 | 0 | 0 | 0 | 0 | 1780 | 0.553 | 1 | 0 | 0 | 0 | 0 |
| 1731 | 0.488 | 1 | 1 | 0 | 0 | 0 | 1781 | 0.559 | 1 | 1 | 1 | 0 | 0 |
| 1732 | 0.488 | 1 | 0 | 0 | 0 | 0 | 1782 | 0.559 | 1 | 1 | 1 | 0 | 0 |
| 1733 | 0.490 | 1 | 0 | 0 | 0 | 0 | 1783 | 0.559 | 1 | 1 | 0 | 0 | 0 |
| 1734 | 0.491 | 1 | 0 | 0 | 0 | 0 | 1784 | 0.559 | 1 | 0 | 0 | 0 | 0 |
| 1735 | 0.491 | 1 | 0 | 0 | 0 | 0 | 1785 | 0.561 | 1 | 0 | 0 | 0 | 0 |
| 1736 | 0.491 | 1 | 0 | 0 | 0 | 0 | 1786 | 0.561 | 1 | 0 | 0 | 0 | 0 |
| 1737 | 0.493 | 1 | 1 | 1 | 0 | 0 | 1787 | 0.561 | 1 | 1 | 1 | 0 | 0 |
| 1738 | 0.494 | 1 | 0 | 0 | 0 | 0 | 1788 | 0.563 | 1 | 0 | 0 | 0 | 0 |
| 1739 | 0.495 | 1 | 0 | 0 | 0 | 0 | 1789 | 0.563 | 1 | 1 | 0 | 0 | 0 |
| 1740 | 0.496 | 1 | 0 | 0 | 0 | 0 | 1790 | 0.563 | 1 | 1 | 1 | 0 | 0 |
| 1741 | 0.497 | 1 | 1 | 1 | 1 | 0 | 1791 | 0.567 | 1 | 0 | 0 | 0 | 0 |
| 1742 | 0.499 | 1 | 0 | 0 | 0 | 0 | 1792 | 0.567 | 1 | 0 | 0 | 0 | 0 |
| 1743 | 0.500 | 1 | 1 | 1 | 0 | 0 | 1793 | 0.574 | 1 | 0 | 0 | 0 | 0 |
| 1744 | 0.500 | 1 | 1 | 1 | 0 | 0 | 1794 | 0.581 | 1 | 0 | 0 | 0 | 0 |
| 1745 | 0.502 | 1 | 1 | 0 | 0 | 0 | 1795 | 0.581 | 1 | 0 | 0 | 0 | 0 |
| 1746 | 0.502 | 1 | 1 | 1 | 1 | 0 | 1796 | 0.581 | 1 | 1 | 1 | 0 | 0 |
| 1747 | 0.502 | 1 | 0 | 0 | 0 | 0 | 1797 | 0.581 | 1 | 1 | 1 | 0 | 0 |
| 1748 | 0.505 | 1 | 0 | 0 | 0 | 0 | 1798 | 0.582 | 1 | 0 | 0 | 0 | 0 |
| 1749 | 0.506 | 1 | 0 | 0 | 0 | 0 | 1799 | 0.582 | 1 | 0 | 0 | 0 | 0 |
| 1750 | 0.506 | 1 | 0 | 0 | 0 | 0 | 1800 | 0.585 | 1 | 0 | 0 | 0 | 0 |

**TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1801 | 0.585 | 1 | 0 | 0 | 0 | 0 | 1851 | 0.670 | 1 | 0 | 0 | 0 | 0 |
| 1802 | 0.586 | 1 | 0 | 0 | 0 | 0 | 1852 | 0.673 | 1 | 0 | 0 | 0 | 0 |
| 1803 | 0.586 | 1 | 0 | 0 | 0 | 0 | 1853 | 0.675 | 1 | 0 | 0 | 0 | 0 |
| 1804 | 0.589 | 1 | 1 | 1 | 1 | 0 | 1854 | 0.675 | 1 | 0 | 0 | 0 | 0 |
| 1805 | 0.589 | 1 | 1 | 1 | 0 | 0 | 1855 | 0.675 | 1 | 0 | 0 | 0 | 0 |
| 1806 | 0.591 | 1 | 0 | 0 | 0 | 0 | 1856 | 0.675 | 1 | 1 | 0 | 0 | 0 |
| 1807 | 0.594 | 1 | 1 | 1 | 0 | 0 | 1857 | 0.675 | 1 | 0 | 0 | 0 | 0 |
| 1808 | 0.600 | 1 | 1 | 1 | 0 | 0 | 1858 | 0.677 | 1 | 0 | 0 | 0 | 0 |
| 1809 | 0.600 | 1 | 0 | 0 | 0 | 0 | 1859 | 0.680 | 1 | 1 | 1 | 1 | 0 |
| 1810 | 0.604 | 1 | 1 | 1 | 0 | 0 | 1860 | 0.682 | 1 | 1 | 1 | 0 | 0 |
| 1811 | 0.608 | 1 | 0 | 0 | 0 | 0 | 1861 | 0.682 | 1 | 1 | 1 | 1 | 1 |
| 1812 | 0.609 | 1 | 0 | 0 | 0 | 0 | 1862 | 0.682 | 1 | 1 | 1 | 1 | 1 |
| 1813 | 0.612 | 1 | 1 | 1 | 1 | 0 | 1863 | 0.682 | 1 | 0 | 0 | 0 | 0 |
| 1814 | 0.612 | 1 | 0 | 0 | 0 | 0 | 1864 | 0.682 | 1 | 0 | 0 | 0 | 0 |
| 1815 | 0.613 | 1 | 0 | 0 | 0 | 0 | 1865 | 0.682 | 1 | 0 | 0 | 0 | 0 |
| 1816 | 0.613 | 1 | 0 | 0 | 0 | 0 | 1866 | 0.682 | 1 | 1 | 0 | 0 | 0 |
| 1817 | 0.619 | 1 | 1 | 0 | 0 | 0 | 1867 | 0.688 | 1 | 0 | 0 | 0 | 0 |
| 1818 | 0.620 | 1 | 1 | 0 | 0 | 0 | 1868 | 0.695 | 1 | 1 | 0 | 0 | 0 |
| 1819 | 0.621 | 1 | 0 | 0 | 0 | 0 | 1869 | 0.695 | 1 | 1 | 0 | 0 | 0 |
| 1820 | 0.623 | 1 | 1 | 0 | 0 | 0 | 1870 | 0.697 | 1 | 0 | 0 | 0 | 0 |
| 1821 | 0.623 | 1 | 1 | 0 | 0 | 0 | 1871 | 0.697 | 1 | 1 | 1 | 1 | 1 |
| 1822 | 0.629 | 1 | 1 | 0 | 0 | 0 | 1872 | 0.697 | 1 | 1 | 1 | 1 | 0 |
| 1823 | 0.629 | 1 | 1 | 0 | 0 | 0 | 1873 | 0.697 | 1 | 0 | 0 | 0 | 0 |
| 1824 | 0.629 | 1 | 0 | 0 | 0 | 0 | 1874 | 0.697 | 1 | 0 | 0 | 0 | 0 |
| 1825 | 0.630 | 1 | 0 | 0 | 0 | 0 | 1875 | 0.698 | 1 | 0 | 0 | 0 | 0 |
| 1826 | 0.630 | 1 | 0 | 0 | 0 | 0 | 1876 | 0.698 | 1 | 0 | 0 | 0 | 0 |
| 1827 | 0.638 | 1 | 1 | 1 | 1 | 0 | 1877 | 0.698 | 1 | 0 | 0 | 0 | 0 |
| 1828 | 0.638 | 1 | 1 | 0 | 0 | 0 | 1878 | 0.698 | 1 | 1 | 1 | 1 | 0 |
| 1829 | 0.638 | 1 | 1 | 1 | 0 | 0 | 1879 | 0.698 | 1 | 1 | 1 | 0 | 0 |
| 1830 | 0.639 | 1 | 0 | 0 | 0 | 0 | 1880 | 0.698 | 1 | 1 | 1 | 1 | 0 |
| 1831 | 0.639 | 1 | 0 | 0 | 0 | 0 | 1881 | 0.699 | 1 | 1 | 1 | 0 | 0 |
| 1832 | 0.639 | 1 | 0 | 0 | 0 | 0 | 1882 | 0.699 | 1 | 0 | 0 | 0 | 0 |
| 1833 | 0.639 | 1 | 0 | 0 | 0 | 0 | 1883 | 0.699 | 1 | 1 | 0 | 0 | 0 |
| 1834 | 0.642 | 1 | 0 | 0 | 0 | 0 | 1884 | 0.699 | 1 | 1 | 0 | 0 | 0 |
| 1835 | 0.642 | 1 | 0 | 0 | 0 | 0 | 1885 | 0.699 | 1 | 1 | 1 | 0 | 0 |
| 1836 | 0.645 | 1 | 0 | 0 | 0 | 0 | 1886 | 0.700 | 1 | 0 | 0 | 0 | 0 |
| 1837 | 0.645 | 1 | 0 | 0 | 0 | 0 | 1887 | 0.702 | 1 | 0 | 0 | 0 | 0 |
| 1838 | 0.645 | 1 | 0 | 0 | 0 | 0 | 1888 | 0.702 | 1 | 1 | 1 | 1 | 0 |
| 1839 | 0.646 | 1 | 0 | 0 | 0 | 0 | 1889 | 0.702 | 1 | 1 | 1 | 1 | 0 |
| 1840 | 0.648 | 1 | 0 | 0 | 0 | 0 | 1890 | 0.702 | 1 | 1 | 1 | 1 | 0 |
| 1841 | 0.648 | 1 | 0 | 0 | 0 | 0 | 1891 | 0.703 | 1 | 1 | 1 | 0 | 0 |
| 1842 | 0.649 | 1 | 0 | 0 | 0 | 0 | 1892 | 0.703 | 1 | 1 | 1 | 0 | 0 |
| 1843 | 0.650 | 1 | 0 | 0 | 0 | 0 | 1893 | 0.703 | 1 | 1 | 0 | 0 | 0 |
| 1844 | 0.654 | 1 | 0 | 0 | 0 | 0 | 1894 | 0.703 | 1 | 1 | 1 | 1 | 0 |
| 1845 | 0.662 | 1 | 1 | 1 | 0 | 0 | 1895 | 0.703 | 1 | 0 | 0 | 0 | 0 |
| 1846 | 0.670 | 1 | 0 | 0 | 0 | 0 | 1896 | 0.703 | 1 | 0 | 0 | 0 | 0 |
| 1847 | 0.670 | 1 | 0 | 0 | 0 | 0 | 1897 | 0.703 | 1 | 0 | 0 | 0 | 0 |
| 1848 | 0.670 | 1 | 0 | 0 | 0 | 0 | 1898 | 0.703 | 1 | 1 | 1 | 1 | 0 |
| 1849 | 0.670 | 1 | 0 | 0 | 0 | 0 | 1899 | 0.706 | 1 | 0 | 0 | 0 | 0 |
| 1850 | 0.670 | 1 | 0 | 0 | 0 | 0 | 1900 | 0.707 | 1 | 0 | 0 | 0 | 0 |

## TABLE 2-2 Damage Data for Caltrans' Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1901 | 0.708 | 1 | 0 | 0 | 0 | 0 | 1951 | 0.771 | 1 | 0 | 0 | 0 | 0 |
| 1902 | 0.708 | 1 | 1 | 1 | 0 | 0 | 1952 | 0.775 | 1 | 0 | 0 | 0 | 0 |
| 1903 | 0.708 | 1 | 1 | 1 | 1 | 1 | 1953 | 0.776 | 1 | 0 | 0 | 0 | 0 |
| 1904 | 0.708 | 1 | 1 | 1 | 1 | 0 | 1954 | 0.776 | 1 | 1 | 1 | 0 | 0 |
| 1905 | 0.708 | 1 | 0 | 0 | 0 | 0 | 1955 | 0.780 | 1 | 0 | 0 | 0 | 0 |
| 1906 | 0.708 | 1 | 0 | 0 | 0 | 0 | 1956 | 0.780 | 1 | 0 | 0 | 0 | 0 |
| 1907 | 0.710 | 1 | 0 | 0 | 0 | 0 | 1957 | 0.782 | 1 | 0 | 0 | 0 | 0 |
| 1908 | 0.710 | 1 | 0 | 0 | 0 | 0 | 1958 | 0.785 | 1 | 0 | 0 | 0 | 0 |
| 1909 | 0.711 | 1 | 0 | 0 | 0 | 0 | 1959 | 0.785 | 1 | 0 | 0 | 0 | 0 |
| 1910 | 0.711 | 1 | 0 | 0 | 0 | 0 | 1960 | 0.785 | 1 | 0 | 0 | 0 | 0 |
| 1911 | 0.714 | 1 | 0 | 0 | 0 | 0 | 1961 | 0.785 | 1 | 0 | 0 | 0 | 0 |
| 1912 | 0.714 | 1 | 0 | 0 | 0 | 0 | 1962 | 0.786 | 1 | 0 | 0 | 0 | 0 |
| 1913 | 0.714 | 1 | 0 | 0 | 0 | 0 | 1963 | 0.793 | 1 | 1 | 1 | 0 | 0 |
| 1914 | 0.716 | 1 | 0 | 0 | 0 | 0 | 1964 | 0.807 | 1 | 0 | 0 | 0 | 0 |
| 1915 | 0.718 | 1 | 1 | 0 | 0 | 0 | 1965 | 0.808 | 1 | 0 | 0 | 0 | 0 |
| 1916 | 0.718 | 1 | 1 | 1 | 1 | 0 | 1966 | 0.816 | 1 | 0 | 0 | 0 | 0 |
| 1917 | 0.718 | 1 | 1 | 1 | 1 | 0 | 1967 | 0.816 | 1 | 0 | 0 | 0 | 0 |
| 1918 | 0.718 | 1 | 0 | 0 | 0 | 0 | 1968 | 0.821 | 1 | 1 | 1 | 0 | 0 |
| 1919 | 0.719 | 1 | 0 | 0 | 0 | 0 | 1969 | 0.826 | 1 | 0 | 0 | 0 | 0 |
| 1920 | 0.720 | 1 | 0 | 0 | 0 | 0 | 1970 | 0.831 | 1 | 1 | 1 | 0 | 0 |
| 1921 | 0.720 | 1 | 0 | 0 | 0 | 0 | 1971 | 0.832 | 1 | 1 | 1 | 0 | 0 |
| 1922 | 0.720 | 1 | 0 | 0 | 0 | 0 | 1972 | 0.832 | 1 | 0 | 0 | 0 | 0 |
| 1923 | 0.720 | 1 | 0 | 0 | 0 | 0 | 1973 | 0.841 | 1 | 1 | 1 | 1 | 0 |
| 1924 | 0.726 | 1 | 0 | 0 | 0 | 0 | 1974 | 0.841 | 1 | 1 | 1 | 1 | 1 |
| 1925 | 0.726 | 1 | 0 | 0 | 0 | 0 | 1975 | 0.841 | 1 | 1 | 1 | 1 | 0 |
| 1926 | 0.726 | 1 | 1 | 1 | 0 | 0 | 1976 | 0.841 | 1 | 0 | 0 | 0 | 0 |
| 1927 | 0.726 | 1 | 1 | 1 | 0 | 0 | 1977 | 0.846 | 1 | 1 | 0 | 0 | 0 |
| 1928 | 0.726 | 1 | 1 | 1 | 0 | 0 | 1978 | 0.846 | 1 | 1 | 1 | 0 | 0 |
| 1929 | 0.728 | 1 | 0 | 0 | 0 | 0 | 1979 | 0.847 | 1 | 1 | 1 | 0 | 0 |
| 1930 | 0.728 | 1 | 0 | 0 | 0 | 0 | 1980 | 0.847 | 1 | 0 | 0 | 0 | 0 |
| 1931 | 0.732 | 1 | 0 | 0 | 0 | 0 | 1981 | 0.850 | 1 | 1 | 1 | 1 | 0 |
| 1932 | 0.738 | 1 | 0 | 0 | 0 | 0 | 1982 | 0.850 | 1 | 1 | 1 | 0 | 0 |
| 1933 | 0.745 | 1 | 1 | 1 | 0 | 0 | 1983 | 0.850 | 1 | 1 | 1 | 1 | 0 |
| 1934 | 0.745 | 1 | 1 | 1 | 1 | 0 | 1984 | 0.853 | 1 | 0 | 0 | 0 | 0 |
| 1935 | 0.746 | 1 | 1 | 1 | 0 | 0 | 1985 | 0.862 | 1 | 1 | 0 | 0 | 0 |
| 1936 | 0.746 | 1 | 0 | 0 | 0 | 0 | 1986 | 0.864 | 1 | 1 | 1 | 1 | 0 |
| 1937 | 0.750 | 1 | 1 | 1 | 1 | 0 | 1987 | 0.864 | 1 | 1 | 1 | 0 | 0 |
| 1938 | 0.751 | 1 | 1 | 1 | 0 | 0 | 1988 | 0.864 | 1 | 1 | 0 | 0 | 0 |
| 1939 | 0.751 | 1 | 1 | 1 | 1 | 0 | 1989 | 0.864 | 1 | 1 | 1 | 1 | 0 |
| 1940 | 0.752 | 1 | 1 | 1 | 0 | 0 | 1990 | 0.865 | 1 | 0 | 0 | 0 | 0 |
| 1941 | 0.753 | 1 | 1 | 1 | 0 | 0 | 1991 | 0.866 | 1 | 0 | 0 | 0 | 0 |
| 1942 | 0.755 | 1 | 1 | 0 | 0 | 0 | 1992 | 0.866 | 1 | 0 | 0 | 0 | 0 |
| 1943 | 0.756 | 1 | 0 | 0 | 0 | 0 | 1993 | 0.868 | 1 | 1 | 0 | 0 | 0 |
| 1944 | 0.760 | 1 | 0 | 0 | 0 | 0 | 1994 | 0.871 | 1 | 1 | 1 | 0 | 0 |
| 1945 | 0.765 | 1 | 0 | 0 | 0 | 0 | 1995 | 0.875 | 1 | 1 | 0 | 0 | 0 |
| 1946 | 0.765 | 1 | 0 | 0 | 0 | 0 | 1996 | 0.875 | 1 | 0 | 0 | 0 | 0 |
| 1947 | 0.765 | 1 | 0 | 0 | 0 | 0 | 1997 | 0.887 | 1 | 0 | 0 | 0 | 0 |
| 1948 | 0.765 | 1 | 1 | 0 | 0 | 0 | 1998 | 0.889 | 1 | 1 | 1 | 1 | 0 |
| 1949 | 0.766 | 1 | 0 | 0 | 0 | 0 | | | | | | | |
| 1950 | 0.771 | 1 | 0 | 0 | 0 | 0 | | | | | | | |

## TABLE 2-3 Damage Data for HEPC's Bridge

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 1 | 0.370 | 1 | 0 | 0 | 0 | 1 | 51 | 0.408 | 1 | 0 | 0 | 0 | 51 |
| 2 | 0.370 | 1 | 0 | 0 | 0 | 2 | 52 | 0.408 | 1 | 0 | 0 | 0 | 52 |
| 3 | 0.370 | 1 | 0 | 0 | 0 | 3 | 53 | 0.410 | 1 | 0 | 0 | 0 | 53 |
| 4 | 0.375 | 1 | 0 | 0 | 0 | 4 | 54 | 0.410 | 1 | 0 | 0 | 0 | 54 |
| 5 | 0.375 | 1 | 0 | 0 | 0 | 5 | 55 | 0.410 | 1 | 0 | 0 | 0 | 55 |
| 6 | 0.375 | 1 | 0 | 0 | 0 | 6 | 56 | 0.410 | 1 | 0 | 0 | 0 | 56 |
| 7 | 0.388 | 1 | 0 | 0 | 0 | 7 | 57 | 0.410 | 1 | 0 | 0 | 0 | 57 |
| 8 | 0.388 | 1 | 0 | 0 | 0 | 8 | 58 | 0.410 | 1 | 0 | 0 | 0 | 58 |
| 9 | 0.388 | 1 | 0 | 0 | 0 | 9 | 59 | 0.410 | 1 | 1 | 0 | 0 | 59 |
| 10 | 0.390 | 1 | 0 | 0 | 0 | 10 | 60 | 0.410 | 1 | 1 | 0 | 0 | 60 |
| 11 | 0.390 | 1 | 0 | 0 | 0 | 11 | 61 | 0.410 | 1 | 0 | 0 | 0 | 61 |
| 12 | 0.390 | 1 | 0 | 0 | 0 | 12 | 62 | 0.430 | 1 | 1 | 0 | 0 | 62 |
| 13 | 0.392 | 1 | 0 | 0 | 0 | 13 | 63 | 0.430 | 1 | 1 | 0 | 0 | 63 |
| 14 | 0.392 | 1 | 0 | 0 | 0 | 14 | 64 | 0.430 | 1 | 1 | 0 | 0 | 64 |
| 15 | 0.392 | 1 | 0 | 0 | 0 | 15 | 65 | 0.430 | 1 | 1 | 0 | 0 | 65 |
| 16 | 0.392 | 1 | 0 | 0 | 0 | 16 | 66 | 0.430 | 1 | 1 | 0 | 0 | 66 |
| 17 | 0.394 | 1 | 0 | 0 | 0 | 17 | 67 | 0.430 | 1 | 1 | 0 | 0 | 67 |
| 18 | 0.394 | 1 | 0 | 0 | 0 | 18 | 68 | 0.430 | 1 | 1 | 0 | 0 | 68 |
| 19 | 0.394 | 1 | 0 | 0 | 0 | 19 | 69 | 0.428 | 1 | 1 | 0 | 0 | 69 |
| 20 | 0.394 | 1 | 0 | 0 | 0 | 20 | 70 | 0.428 | 1 | 1 | 0 | 0 | 70 |
| 21 | 0.394 | 1 | 0 | 0 | 0 | 21 | 71 | 0.428 | 1 | 1 | 0 | 0 | 71 |
| 22 | 0.394 | 1 | 0 | 0 | 0 | 22 | 72 | 0.428 | 1 | 1 | 0 | 0 | 72 |
| 23 | 0.394 | 1 | 0 | 0 | 0 | 23 | 73 | 0.428 | 1 | 1 | 0 | 0 | 73 |
| 24 | 0.397 | 1 | 0 | 0 | 0 | 24 | 74 | 0.434 | 1 | 1 | 0 | 0 | 74 |
| 25 | 0.397 | 1 | 0 | 0 | 0 | 25 | 75 | 0.434 | 1 | 1 | 0 | 0 | 75 |
| 26 | 0.397 | 1 | 0 | 0 | 0 | 26 | 76 | 0.443 | 1 | 1 | 0 | 0 | 76 |
| 27 | 0.397 | 1 | 0 | 0 | 0 | 27 | 77 | 0.443 | 1 | 1 | 0 | 0 | 77 |
| 28 | 0.398 | 1 | 0 | 0 | 0 | 28 | 78 | 0.443 | 1 | 1 | 0 | 0 | 78 |
| 29 | 0.398 | 1 | 0 | 0 | 0 | 29 | 79 | 0.443 | 1 | 1 | 0 | 0 | 79 |
| 30 | 0.398 | 1 | 0 | 0 | 0 | 30 | 80 | 0.443 | 1 | 1 | 0 | 0 | 80 |
| 31 | 0.398 | 1 | 0 | 0 | 0 | 31 | 81 | 0.448 | 1 | 1 | 0 | 0 | 81 |
| 32 | 0.400 | 1 | 0 | 0 | 0 | 32 | 82 | 0.448 | 1 | 1 | 0 | 0 | 82 |
| 33 | 0.400 | 1 | 0 | 0 | 0 | 33 | 83 | 0.448 | 1 | 1 | 0 | 0 | 83 |
| 34 | 0.400 | 1 | 0 | 0 | 0 | 34 | 84 | 0.448 | 1 | 1 | 0 | 0 | 84 |
| 35 | 0.403 | 1 | 1 | 0 | 0 | 35 | 85 | 0.448 | 1 | 1 | 0 | 0 | 85 |
| 36 | 0.403 | 1 | 0 | 0 | 0 | 36 | 86 | 0.448 | 1 | 1 | 0 | 0 | 86 |
| 37 | 0.403 | 1 | 0 | 0 | 0 | 37 | 87 | 0.458 | 1 | 1 | 1 | 1 | 87 |
| 38 | 0.395 | 1 | 0 | 0 | 0 | 38 | 88 | 0.458 | 1 | 1 | 0 | 0 | 88 |
| 39 | 0.395 | 1 | 0 | 0 | 0 | 39 | 89 | 0.458 | 1 | 1 | 1 | 1 | 89 |
| 40 | 0.395 | 1 | 0 | 0 | 0 | 40 | 90 | 0.456 | 1 | 1 | 0 | 0 | 90 |
| 41 | 0.405 | 1 | 0 | 0 | 0 | 41 | 91 | 0.456 | 1 | 0 | 0 | 0 | 91 |
| 42 | 0.405 | 1 | 0 | 0 | 0 | 42 | 92 | 0.456 | 1 | 1 | 0 | 0 | 92 |
| 43 | 0.405 | 1 | 1 | 0 | 0 | 43 | 93 | 0.473 | 1 | 0 | 0 | 0 | 93 |
| 44 | 0.405 | 1 | 1 | 0 | 0 | 44 | 94 | 0.473 | 1 | 0 | 0 | 0 | 94 |
| 45 | 0.406 | 1 | 0 | 0 | 0 | 45 | 95 | 0.473 | 1 | 0 | 0 | 0 | 95 |
| 46 | 0.406 | 1 | 0 | 0 | 0 | 46 | 96 | 0.473 | 1 | 0 | 0 | 0 | 96 |
| 47 | 0.406 | 1 | 0 | 0 | 0 | 47 | 97 | 0.473 | 1 | 0 | 0 | 0 | 97 |
| 48 | 0.406 | 1 | 0 | 0 | 0 | 48 | 98 | 0.473 | 1 | 0 | 0 | 0 | 98 |
| 49 | 0.406 | 1 | 0 | 0 | 0 | 49 | 99 | 0.473 | 1 | 0 | 0 | 0 | 99 |
| 50 | 0.406 | 1 | 0 | 0 | 0 | 50 | 100 | 0.473 | 1 | 0 | 0 | 0 | 100 |

**TABLE 2-3 Damage Data for HEPC's Bridge (Cont'd)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 101 | 0.473 | 1 | 0 | 0 | 0 | 101 | 151 | 0.504 | 1 | 1 | 1 | 1 | 151 |
| 102 | 0.473 | 1 | 0 | 0 | 0 | 102 | 152 | 0.504 | 1 | 1 | 0 | 0 | 152 |
| 103 | 0.473 | 1 | 0 | 0 | 0 | 103 | 153 | 0.504 | 1 | 0 | 0 | 0 | 153 |
| 104 | 0.473 | 1 | 0 | 0 | 0 | 104 | 154 | 0.504 | 1 | 1 | 1 | 0 | 154 |
| 105 | 0.473 | 1 | 0 | 0 | 0 | 105 | 155 | 0.504 | 1 | 0 | 0 | 0 | 155 |
| 106 | 0.473 | 1 | 0 | 0 | 0 | 106 | 156 | 0.504 | 1 | 0 | 0 | 0 | 156 |
| 107 | 0.473 | 1 | 0 | 0 | 0 | 107 | 157 | 0.504 | 1 | 1 | 1 | 1 | 157 |
| 108 | 0.473 | 1 | 0 | 0 | 0 | 108 | 158 | 0.504 | 1 | 1 | 1 | 1 | 158 |
| 109 | 0.473 | 1 | 1 | 0 | 0 | 109 | 159 | 0.504 | 1 | 1 | 1 | 1 | 159 |
| 110 | 0.473 | 1 | 0 | 0 | 0 | 110 | 160 | 0.504 | 1 | 1 | 1 | 1 | 160 |
| 111 | 0.487 | 1 | 0 | 0 | 0 | 111 | 161 | 0.504 | 1 | 0 | 0 | 0 | 161 |
| 112 | 0.487 | 1 | 0 | 0 | 0 | 112 | 162 | 0.504 | 1 | 0 | 0 | 0 | 162 |
| 113 | 0.487 | 1 | 0 | 0 | 0 | 113 | 163 | 0.504 | 1 | 0 | 0 | 0 | 163 |
| 114 | 0.487 | 1 | 0 | 0 | 0 | 114 | 164 | 0.504 | 1 | 1 | 1 | 0 | 164 |
| 115 | 0.487 | 1 | 1 | 0 | 0 | 115 | 165 | 0.528 | 1 | 1 | 0 | 0 | 165 |
| 116 | 0.487 | 1 | 0 | 0 | 0 | 116 | 166 | 0.528 | 1 | 1 | 1 | 1 | 166 |
| 117 | 0.487 | 1 | 0 | 0 | 0 | 117 | 167 | 0.528 | 1 | 0 | 0 | 0 | 167 |
| 118 | 0.487 | 1 | 0 | 0 | 0 | 118 | 168 | 0.528 | 1 | 0 | 0 | 0 | 168 |
| 119 | 0.487 | 1 | 0 | 0 | 0 | 119 | 169 | 0.528 | 1 | 0 | 0 | 0 | 169 |
| 120 | 0.487 | 1 | 0 | 0 | 0 | 120 | 170 | 0.528 | 1 | 1 | 1 | 0 | 170 |
| 121 | 0.487 | 1 | 0 | 0 | 0 | 121 | 171 | 0.528 | 1 | 0 | 0 | 0 | 171 |
| 122 | 0.487 | 1 | 0 | 0 | 0 | 122 | 172 | 0.528 | 1 | 1 | 0 | 0 | 172 |
| 123 | 0.487 | 1 | 0 | 0 | 0 | 123 | 173 | 0.528 | 1 | 1 | 1 | 0 | 173 |
| 124 | 0.487 | 1 | 0 | 0 | 0 | 124 | 174 | 0.528 | 1 | 0 | 0 | 0 | 174 |
| 125 | 0.494 | 1 | 0 | 0 | 0 | 125 | 175 | 0.531 | 1 | 0 | 0 | 0 | 175 |
| 126 | 0.494 | 1 | 1 | 0 | 0 | 126 | 176 | 0.531 | 1 | 0 | 0 | 0 | 176 |
| 127 | 0.501 | 1 | 0 | 0 | 0 | 127 | 177 | 0.531 | 1 | 0 | 0 | 0 | 177 |
| 128 | 0.501 | 1 | 1 | 0 | 0 | 128 | 178 | 0.531 | 1 | 1 | 1 | 0 | 178 |
| 129 | 0.501 | 1 | 1 | 1 | 1 | 129 | 179 | 0.531 | 1 | 0 | 0 | 0 | 179 |
| 130 | 0.501 | 1 | 1 | 1 | 0 | 130 | 180 | 0.531 | 1 | 0 | 0 | 0 | 180 |
| 131 | 0.501 | 1 | 1 | 0 | 0 | 131 | 181 | 0.531 | 1 | 0 | 0 | 0 | 181 |
| 132 | 0.501 | 1 | 1 | 1 | 0 | 132 | 182 | 0.531 | 1 | 0 | 0 | 0 | 182 |
| 133 | 0.501 | 1 | 1 | 1 | 0 | 133 | 183 | 0.531 | 1 | 0 | 0 | 0 | 183 |
| 134 | 0.501 | 1 | 1 | 0 | 0 | 134 | 184 | 0.531 | 1 | 0 | 0 | 0 | 184 |
| 135 | 0.501 | 1 | 1 | 0 | 0 | 135 | 185 | 0.531 | 1 | 1 | 1 | 1 | 185 |
| 136 | 0.501 | 1 | 1 | 0 | 0 | 136 | 186 | 0.531 | 1 | 1 | 1 | 1 | 186 |
| 137 | 0.501 | 1 | 1 | 1 | 1 | 137 | 187 | 0.534 | 1 | 1 | 1 | 1 | 187 |
| 138 | 0.501 | 1 | 1 | 1 | 0 | 138 | 188 | 0.534 | 1 | 0 | 0 | 0 | 188 |
| 139 | 0.511 | 1 | 1 | 1 | 1 | 139 | 189 | 0.534 | 1 | 0 | 0 | 0 | 189 |
| 140 | 0.511 | 1 | 1 | 1 | 1 | 140 | 190 | 0.534 | 1 | 0 | 0 | 0 | 190 |
| 141 | 0.511 | 1 | 1 | 1 | 0 | 141 | 191 | 0.534 | 1 | 1 | 0 | 0 | 191 |
| 142 | 0.511 | 1 | 1 | 1 | 1 | 142 | 192 | 0.534 | 1 | 0 | 0 | 0 | 192 |
| 143 | 0.511 | 1 | 1 | 0 | 0 | 143 | 193 | 0.534 | 1 | 1 | 1 | 0 | 193 |
| 144 | 0.515 | 1 | 1 | 0 | 0 | 144 | 194 | 0.534 | 1 | 0 | 0 | 0 | 194 |
| 145 | 0.515 | 1 | 1 | 0 | 0 | 145 | 195 | 0.537 | 1 | 0 | 0 | 0 | 195 |
| 146 | 0.515 | 1 | 0 | 0 | 0 | 146 | 196 | 0.537 | 1 | 0 | 0 | 0 | 196 |
| 147 | 0.515 | 1 | 1 | 1 | 0 | 147 | 197 | 0.537 | 1 | 0 | 0 | 0 | 197 |
| 148 | 0.515 | 1 | 1 | 1 | 1 | 148 | 198 | 0.537 | 1 | 1 | 1 | 0 | 198 |
| 149 | 0.515 | 1 | 1 | 1 | 1 | 149 | 199 | 0.537 | 1 | 1 | 0 | 0 | 199 |
| 150 | 0.515 | 1 | 1 | 1 | 1 | 150 | 200 | 0.537 | 1 | 1 | 1 | 0 | 200 |

**TABLE 2-3 Damage Data for HEPC's Bridge (Cont'd)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 201 | 0.537 | 1 | 0 | 0 | 0 | 201 | 251 | 0.493 | 1 | 1 | 1 | 0 | 251 |
| 202 | 0.537 | 1 | 1 | 0 | 0 | 202 | 252 | 0.493 | 1 | 1 | 0 | 0 | 252 |
| 203 | 0.537 | 1 | 0 | 0 | 0 | 203 | 253 | 0.493 | 1 | 1 | 1 | 0 | 253 |
| 204 | 0.537 | 1 | 1 | 1 | 1 | 204 | 254 | 0.493 | 1 | 1 | 1 | 0 | 254 |
| 205 | 0.537 | 1 | 1 | 0 | 0 | 205 | 255 | 0.493 | 1 | 1 | 1 | 0 | 255 |
| 206 | 0.537 | 1 | 1 | 0 | 0 | 206 | 256 | 0.493 | 1 | 0 | 0 | 0 | 256 |
| 207 | 0.537 | 1 | 0 | 0 | 0 | 207 | 257 | 0.493 | 1 | 1 | 1 | 1 | 257 |
| 208 | 0.541 | 1 | 1 | 1 | 0 | 208 | 258 | 0.493 | 1 | 1 | 0 | 0 | 258 |
| 209 | 0.541 | 1 | 1 | 1 | 0 | 209 | 259 | 0.493 | 1 | 0 | 0 | 0 | 259 |
| 210 | 0.541 | 1 | 0 | 0 | 0 | 210 | 260 | 0.493 | 1 | 0 | 0 | 0 | 260 |
| 211 | 0.541 | 1 | 1 | 0 | 0 | 211 | 261 | 0.495 | 1 | 0 | 0 | 0 | 261 |
| 212 | 0.541 | 1 | 1 | 1 | 1 | 212 | 262 | 0.495 | 1 | 0 | 0 | 0 | 262 |
| 213 | 0.487 | 1 | 1 | 0 | 0 | 213 | 263 | 0.495 | 1 | 1 | 0 | 0 | 263 |
| 214 | 0.489 | 1 | 0 | 0 | 0 | 214 | 264 | 0.495 | 1 | 0 | 0 | 0 | 264 |
| 215 | 0.489 | 1 | 1 | 1 | 0 | 215 | 265 | 0.495 | 1 | 1 | 1 | 0 | 265 |
| 216 | 0.489 | 1 | 1 | 0 | 0 | 216 | 266 | 0.495 | 1 | 1 | 1 | 1 | 266 |
| 217 | 0.489 | 1 | 1 | 1 | 0 | 217 | 267 | 0.495 | 1 | 1 | 1 | 0 | 267 |
| 218 | 0.489 | 1 | 0 | 0 | 0 | 218 | 268 | 0.495 | 1 | 1 | 1 | 0 | 268 |
| 219 | 0.489 | 1 | 1 | 1 | 1 | 219 | 269 | 0.495 | 1 | 1 | 1 | 0 | 269 |
| 220 | 0.489 | 1 | 1 | 1 | 1 | 220 | 270 | 0.498 | 1 | 1 | 0 | 0 | 270 |
| 221 | 0.489 | 1 | 1 | 1 | 1 | 221 | 271 | 0.498 | 1 | 1 | 1 | 1 | 271 |
| 222 | 0.490 | 1 | 0 | 0 | 0 | 222 | 272 | 0.498 | 1 | 1 | 0 | 0 | 272 |
| 223 | 0.490 | 1 | 1 | 0 | 0 | 223 | 273 | 0.498 | 1 | 0 | 0 | 0 | 273 |
| 224 | 0.490 | 1 | 1 | 1 | 1 | 224 | 274 | 0.498 | 1 | 1 | 0 | 0 | 274 |
| 225 | 0.490 | 1 | 0 | 0 | 0 | 225 | 275 | 0.498 | 1 | 1 | 1 | 1 | 275 |
| 226 | 0.490 | 1 | 0 | 0 | 0 | 226 | 276 | 0.498 | 1 | 1 | 0 | 0 | 276 |
| 227 | 0.491 | 1 | 0 | 0 | 0 | 227 | 277 | 0.502 | 1 | 0 | 0 | 0 | 277 |
| 228 | 0.491 | 1 | 0 | 0 | 0 | 228 | 278 | 0.502 | 1 | 0 | 0 | 0 | 278 |
| 229 | 0.491 | 1 | 0 | 0 | 0 | 229 | 279 | 0.502 | 1 | 0 | 0 | 0 | 279 |
| 230 | 0.491 | 1 | 1 | 0 | 0 | 230 | 280 | 0.502 | 1 | 1 | 0 | 0 | 280 |
| 231 | 0.491 | 1 | 1 | 1 | 1 | 231 | 281 | 0.502 | 1 | 1 | 1 | 1 | 281 |
| 232 | 0.491 | 1 | 1 | 1 | 1 | 232 | 282 | 0.507 | 1 | 0 | 0 | 0 | 282 |
| 233 | 0.491 | 1 | 1 | 1 | 1 | 233 | 283 | 0.507 | 1 | 0 | 0 | 0 | 283 |
| 234 | 0.491 | 1 | 1 | 0 | 0 | 234 | 284 | 0.507 | 1 | 0 | 0 | 0 | 284 |
| 235 | 0.491 | 1 | 1 | 0 | 0 | 235 | 285 | 0.507 | 1 | 0 | 0 | 0 | 285 |
| 236 | 0.491 | 1 | 1 | 0 | 0 | 236 | 286 | 0.507 | 1 | 0 | 0 | 0 | 286 |
| 237 | 0.491 | 1 | 1 | 0 | 0 | 237 | 287 | 0.507 | 1 | 0 | 0 | 0 | 287 |
| 238 | 0.491 | 1 | 0 | 0 | 0 | 238 | 288 | 0.507 | 1 | 1 | 1 | 1 | 288 |
| 239 | 0.492 | 1 | 1 | 0 | 0 | 239 | 289 | 0.512 | 1 | 1 | 1 | 1 | 289 |
| 240 | 0.492 | 1 | 1 | 0 | 0 | 240 | 290 | 0.512 | 1 | 1 | 1 | 1 | 290 |
| 241 | 0.492 | 1 | 1 | 1 | 0 | 241 | 291 | 0.512 | 1 | 1 | 1 | 0 | 291 |
| 242 | 0.492 | 1 | 1 | 0 | 0 | 242 | 292 | 0.512 | 1 | 1 | 1 | 0 | 292 |
| 243 | 0.492 | 1 | 1 | 0 | 0 | 243 | 293 | 0.512 | 1 | 1 | 1 | 1 | 293 |
| 244 | 0.492 | 1 | 1 | 0 | 0 | 244 | 294 | 0.516 | 1 | 1 | 1 | 1 | 294 |
| 245 | 0.492 | 1 | 1 | 0 | 0 | 245 | 295 | 0.516 | 1 | 1 | 1 | 1 | 295 |
| 246 | 0.493 | 1 | 1 | 0 | 0 | 246 | 296 | 0.516 | 1 | 1 | 1 | 1 | 296 |
| 247 | 0.493 | 1 | 1 | 0 | 0 | 247 | 297 | 0.516 | 1 | 1 | 1 | 1 | 297 |
| 248 | 0.493 | 1 | 1 | 0 | 0 | 248 | 298 | 0.516 | 1 | 1 | 1 | 1 | 298 |
| 249 | 0.493 | 1 | 1 | 1 | 1 | 249 | 299 | 0.520 | 1 | 1 | 1 | 0 | 299 |
| 250 | 0.493 | 1 | 1 | 1 | 0 | 250 | 300 | 0.520 | 1 | 1 | 1 | 0 | 300 |

## TABLE 2-3  Damage Data for HEPC's Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 351 | 0.542 | 1 | 1 | 1 | 1 | 351 | 0.542 | 1 | 1 | 1 | 1 | 351 | 0.542 |
| 352 | 0.542 | 1 | 0 | 0 | 0 | 352 | 0.542 | 1 | 0 | 0 | 0 | 352 | 0.542 |
| 353 | 0.538 | 1 | 1 | 0 | 0 | 353 | 0.538 | 1 | 1 | 0 | 0 | 353 | 0.538 |
| 354 | 0.538 | 1 | 0 | 0 | 0 | 354 | 0.538 | 1 | 0 | 0 | 0 | 354 | 0.538 |
| 355 | 0.542 | 1 | 0 | 0 | 0 | 355 | 0.542 | 1 | 0 | 0 | 0 | 355 | 0.542 |
| 356 | 0.542 | 1 | 1 | 1 | 0 | 356 | 0.542 | 1 | 1 | 1 | 0 | 356 | 0.542 |
| 357 | 0.542 | 1 | 0 | 0 | 0 | 357 | 0.542 | 1 | 0 | 0 | 0 | 357 | 0.542 |
| 358 | 0.542 | 1 | 1 | 0 | 0 | 358 | 0.542 | 1 | 1 | 0 | 0 | 358 | 0.542 |
| 359 | 0.542 | 1 | 0 | 0 | 0 | 359 | 0.542 | 1 | 0 | 0 | 0 | 359 | 0.542 |
| 360 | 0.542 | 1 | 0 | 0 | 0 | 360 | 0.542 | 1 | 0 | 0 | 0 | 360 | 0.542 |
| 361 | 0.542 | 1 | 0 | 0 | 0 | 361 | 0.542 | 1 | 0 | 0 | 0 | 361 | 0.542 |
| 362 | 0.542 | 1 | 0 | 0 | 0 | 362 | 0.542 | 1 | 0 | 0 | 0 | 362 | 0.542 |
| 363 | 0.542 | 1 | 1 | 0 | 0 | 363 | 0.542 | 1 | 1 | 0 | 0 | 363 | 0.542 |
| 364 | 0.542 | 1 | 1 | 0 | 0 | 364 | 0.542 | 1 | 1 | 0 | 0 | 364 | 0.542 |
| 365 | 0.542 | 1 | 1 | 1 | 0 | 365 | 0.542 | 1 | 1 | 1 | 0 | 365 | 0.542 |
| 366 | 0.542 | 1 | 1 | 0 | 0 | 366 | 0.542 | 1 | 1 | 0 | 0 | 366 | 0.542 |
| 367 | 0.542 | 1 | 1 | 0 | 0 | 367 | 0.542 | 1 | 1 | 0 | 0 | 367 | 0.542 |
| 368 | 0.542 | 1 | 0 | 0 | 0 | 368 | 0.542 | 1 | 0 | 0 | 0 | 368 | 0.542 |
| 369 | 0.542 | 1 | 0 | 0 | 0 | 369 | 0.542 | 1 | 0 | 0 | 0 | 369 | 0.542 |
| 370 | 0.590 | 1 | 1 | 0 | 0 | 370 | 0.590 | 1 | 1 | 0 | 0 | 370 | 0.590 |
| 371 | 0.590 | 1 | 1 | 0 | 0 | 371 | 0.590 | 1 | 1 | 0 | 0 | 371 | 0.590 |
| 372 | 0.590 | 1 | 1 | 0 | 0 | 372 | 0.590 | 1 | 1 | 0 | 0 | 372 | 0.590 |
| 373 | 0.590 | 1 | 1 | 1 | 1 | 373 | 0.590 | 1 | 1 | 1 | 1 | 373 | 0.590 |
| 374 | 0.590 | 1 | 1 | 1 | 1 | 374 | 0.590 | 1 | 1 | 1 | 1 | 374 | 0.590 |
| 375 | 0.590 | 1 | 1 | 0 | 0 | 375 | 0.590 | 1 | 1 | 0 | 0 | 375 | 0.590 |
| 376 | 0.590 | 1 | 1 | 0 | 0 | 376 | 0.590 | 1 | 1 | 0 | 0 | 376 | 0.590 |
| 377 | 0.590 | 1 | 0 | 0 | 0 | 377 | 0.590 | 1 | 0 | 0 | 0 | 377 | 0.590 |
| 378 | 0.590 | 1 | 1 | 0 | 0 | 378 | 0.590 | 1 | 1 | 0 | 0 | 378 | 0.590 |
| 379 | 0.590 | 1 | 1 | 1 | 1 | 379 | 0.590 | 1 | 1 | 1 | 1 | 379 | 0.590 |
| 380 | 0.590 | 1 | 1 | 1 | 1 | 380 | 0.590 | 1 | 1 | 1 | 1 | 380 | 0.590 |
| 381 | 0.590 | 1 | 1 | 1 | 1 | 381 | 0.590 | 1 | 1 | 1 | 1 | 381 | 0.590 |
| 382 | 0.590 | 1 | 1 | 0 | 0 | 382 | 0.590 | 1 | 1 | 0 | 0 | 382 | 0.590 |
| 383 | 0.590 | 1 | 1 | 0 | 0 | 383 | 0.590 | 1 | 1 | 0 | 0 | 383 | 0.590 |
| 384 | 0.590 | 1 | 1 | 0 | 0 | 384 | 0.590 | 1 | 1 | 0 | 0 | 384 | 0.590 |
| 385 | 0.590 | 1 | 1 | 0 | 0 | 385 | 0.590 | 1 | 1 | 0 | 0 | 385 | 0.590 |
| 386 | 0.590 | 1 | 1 | 0 | 0 | 386 | 0.590 | 1 | 1 | 0 | 0 | 386 | 0.590 |
| 387 | 0.590 | 1 | 1 | 1 | 0 | 387 | 0.590 | 1 | 1 | 1 | 0 | 387 | 0.590 |
| 388 | 0.590 | 1 | 1 | 0 | 0 | 388 | 0.590 | 1 | 1 | 0 | 0 | 388 | 0.590 |
| 389 | 0.590 | 1 | 1 | 0 | 0 | 389 | 0.590 | 1 | 1 | 0 | 0 | 389 | 0.590 |
| 390 | 0.590 | 1 | 1 | 0 | 0 | 390 | 0.590 | 1 | 1 | 0 | 0 | 390 | 0.590 |
| 391 | 0.590 | 1 | 1 | 1 | 1 | 391 | 0.590 | 1 | 1 | 1 | 1 | 391 | 0.590 |
| 392 | 0.590 | 1 | 1 | 0 | 0 | 392 | 0.590 | 1 | 1 | 0 | 0 | 392 | 0.590 |
| 393 | 0.590 | 1 | 1 | 0 | 0 | 393 | 0.590 | 1 | 1 | 0 | 0 | 393 | 0.590 |
| 394 | 0.590 | 1 | 1 | 0 | 0 | 394 | 0.590 | 1 | 1 | 0 | 0 | 394 | 0.590 |
| 395 | 0.696 | 1 | 1 | 0 | 0 | 395 | 0.696 | 1 | 1 | 0 | 0 | 395 | 0.696 |
| 396 | 0.696 | 1 | 1 | 0 | 0 | 396 | 0.696 | 1 | 1 | 0 | 0 | 396 | 0.696 |
| 397 | 0.696 | 1 | 1 | 0 | 0 | 397 | 0.696 | 1 | 1 | 0 | 0 | 397 | 0.696 |
| 398 | 0.696 | 1 | 1 | 0 | 0 | 398 | 0.696 | 1 | 1 | 0 | 0 | 398 | 0.696 |
| 399 | 0.696 | 1 | 0 | 0 | 0 | 399 | 0.696 | 1 | 0 | 0 | 0 | 399 | 0.696 |
| 400 | 0.698 | 1 | 1 | 0 | 0 | 400 | 0.698 | 1 | 1 | 0 | 0 | 400 | 0.698 |

## TABLE 2-3 Damage Data for HEPC's Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 401 | 0.698 | 1 | 0 | 0 | 0 | 401 | 451 | 0.574 | 1 | 0 | 0 | 0 | 451 |
| 402 | 0.698 | 1 | 0 | 0 | 0 | 402 | 452 | 0.574 | 1 | 0 | 0 | 0 | 452 |
| 403 | 0.698 | 1 | 1 | 0 | 0 | 403 | 453 | 0.574 | 1 | 0 | 0 | 0 | 453 |
| 404 | 0.698 | 1 | 0 | 0 | 0 | 404 | 454 | 0.574 | 1 | 0 | 0 | 0 | 454 |
| 405 | 0.698 | 1 | 0 | 0 | 0 | 405 | 455 | 0.574 | 1 | 0 | 0 | 0 | 455 |
| 406 | 0.695 | 1 | 1 | 1 | 0 | 406 | 456 | 0.574 | 1 | 0 | 0 | 0 | 456 |
| 407 | 0.696 | 1 | 1 | 0 | 0 | 407 | 457 | 0.574 | 1 | 0 | 0 | 0 | 457 |
| 408 | 0.696 | 1 | 1 | 1 | 1 | 408 | 458 | 0.597 | 1 | 1 | 0 | 0 | 458 |
| 409 | 0.696 | 1 | 1 | 1 | 1 | 409 | 459 | 0.597 | 1 | 0 | 0 | 0 | 459 |
| 410 | 0.696 | 1 | 1 | 0 | 0 | 410 | 460 | 0.603 | 1 | 0 | 0 | 0 | 460 |
| 411 | 0.696 | 1 | 1 | 0 | 0 | 411 | 461 | 0.762 | 1 | 0 | 0 | 0 | 461 |
| 412 | 0.697 | 1 | 1 | 0 | 0 | 412 | 462 | 0.762 | 1 | 0 | 0 | 0 | 462 |
| 413 | 0.697 | 1 | 1 | 0 | 0 | 413 | 463 | 0.762 | 1 | 1 | 0 | 0 | 463 |
| 414 | 0.697 | 1 | 1 | 0 | 0 | 414 | 464 | 0.762 | 1 | 1 | 0 | 0 | 464 |
| 415 | 0.697 | 1 | 1 | 0 | 0 | 415 | 465 | 0.600 | 1 | 1 | 0 | 0 | 465 |
| 416 | 0.695 | 1 | 1 | 0 | 0 | 416 | 466 | 0.600 | 1 | 0 | 0 | 0 | 466 |
| 417 | 0.695 | 1 | 0 | 0 | 0 | 417 | 467 | 0.600 | 1 | 1 | 0 | 0 | 467 |
| 418 | 0.695 | 1 | 1 | 1 | 1 | 418 | 468 | 0.600 | 1 | 1 | 0 | 0 | 468 |
| 419 | 0.695 | 1 | 1 | 1 | 1 | 419 | 469 | 0.600 | 1 | 0 | 0 | 0 | 469 |
| 420 | 0.695 | 1 | 1 | 1 | 1 | 420 | 470 | 0.600 | 1 | 0 | 0 | 0 | 470 |
| 421 | 0.749 | 1 | 0 | 0 | 0 | 421 | 471 | 0.600 | 1 | 0 | 0 | 0 | 471 |
| 422 | 0.749 | 1 | 0 | 0 | 0 | 422 | 472 | 0.600 | 1 | 0 | 0 | 0 | 472 |
| 423 | 0.749 | 1 | 0 | 0 | 0 | 423 | 473 | 0.600 | 1 | 0 | 0 | 0 | 473 |
| 424 | 0.749 | 1 | 0 | 0 | 0 | 424 | 474 | 0.600 | 1 | 1 | 0 | 0 | 474 |
| 425 | 0.749 | 1 | 0 | 0 | 0 | 425 | 475 | 0.600 | 1 | 1 | 0 | 0 | 475 |
| 426 | 0.749 | 1 | 0 | 0 | 0 | 426 | 476 | 0.600 | 1 | 1 | 1 | 0 | 476 |
| 427 | 0.749 | 1 | 0 | 0 | 0 | 427 | 477 | 0.600 | 1 | 1 | 0 | 0 | 477 |
| 428 | 0.749 | 1 | 0 | 0 | 0 | 428 | 478 | 0.600 | 1 | 1 | 1 | 0 | 478 |
| 429 | 0.749 | 1 | 1 | 1 | 1 | 429 | 479 | 0.600 | 1 | 1 | 0 | 0 | 479 |
| 430 | 0.749 | 1 | 0 | 0 | 0 | 430 | 480 | 0.600 | 1 | 1 | 0 | 0 | 480 |
| 431 | 0.750 | 1 | 1 | 1 | 1 | 431 | 481 | 0.600 | 1 | 0 | 0 | 0 | 481 |
| 432 | 0.750 | 1 | 1 | 0 | 0 | 432 | 482 | 0.600 | 1 | 1 | 1 | 0 | 482 |
| 433 | 0.750 | 1 | 1 | 1 | 1 | 433 | 483 | 0.600 | 1 | 1 | 0 | 0 | 483 |
| 434 | 0.750 | 1 | 1 | 0 | 0 | 434 | 484 | 0.600 | 1 | 1 | 1 | 0 | 484 |
| 435 | 0.750 | 1 | 1 | 0 | 0 | 435 | 485 | 0.600 | 1 | 0 | 0 | 0 | 485 |
| 436 | 0.750 | 1 | 1 | 1 | 1 | 436 | 486 | 0.600 | 1 | 1 | 0 | 0 | 486 |
| 437 | 0.746 | 1 | 1 | 0 | 0 | 437 | 487 | 0.696 | 1 | 1 | 1 | 1 | 487 |
| 438 | 0.746 | 1 | 1 | 1 | 1 | 438 | 488 | 0.696 | 1 | 1 | 1 | 1 | 488 |
| 439 | 0.746 | 1 | 0 | 0 | 0 | 439 | 489 | 0.696 | 1 | 1 | 0 | 0 | 489 |
| 440 | 0.746 | 1 | 1 | 0 | 0 | 440 | 490 | 0.696 | 1 | 1 | 1 | 1 | 490 |
| 441 | 0.746 | 1 | 0 | 0 | 0 | 441 | 491 | 0.595 | 1 | 1 | 1 | 0 | 491 |
| 442 | 0.744 | 1 | 1 | 1 | 1 | 442 | 492 | 0.595 | 1 | 1 | 0 | 0 | 492 |
| 443 | 0.744 | 1 | 1 | 0 | 0 | 443 | 493 | 0.592 | 1 | 1 | 1 | 0 | 493 |
| 444 | 0.744 | 1 | 1 | 1 | 1 | 444 | 494 | 0.592 | 1 | 1 | 1 | 0 | 494 |
| 445 | 0.743 | 1 | 1 | 0 | 0 | 445 | 495 | 0.592 | 1 | 1 | 0 | 0 | 495 |
| 446 | 0.743 | 1 | 0 | 0 | 0 | 446 | 496 | 0.592 | 1 | 1 | 0 | 0 | 496 |
| 447 | 0.742 | 1 | 0 | 0 | 0 | 447 | 497 | 0.592 | 1 | 1 | 0 | 0 | 497 |
| 448 | 0.574 | 1 | 0 | 0 | 0 | 448 | 498 | 0.592 | 1 | 1 | 0 | 0 | 498 |
| 449 | 0.574 | 1 | 0 | 0 | 0 | 449 | 499 | 0.592 | 1 | 1 | 0 | 0 | 499 |
| 450 | 0.574 | 1 | 0 | 0 | 0 | 450 | 500 | 0.690 | 1 | 1 | 1 | 1 | 500 |

## TABLE 2-3 Damage Data for HEPC's Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 501 | 0.691 | 1 | 1 | 1 | 0 | 501 | 551 | 0.619 | 1 | 0 | 0 | 0 | 551 |
| 502 | 0.747 | 1 | 1 | 0 | 0 | 502 | 552 | 0.619 | 1 | 1 | 1 | 0 | 552 |
| 503 | 0.747 | 1 | 1 | 1 | 1 | 503 | 553 | 0.619 | 1 | 1 | 0 | 0 | 553 |
| 504 | 0.747 | 1 | 1 | 1 | 1 | 504 | 554 | 0.619 | 1 | 1 | 0 | 0 | 554 |
| 505 | 0.747 | 1 | 1 | 1 | 0 | 505 | 555 | 0.619 | 1 | 0 | 0 | 0 | 555 |
| 506 | 0.747 | 1 | 1 | 0 | 0 | 506 | 556 | 0.620 | 1 | 0 | 0 | 0 | 556 |
| 507 | 0.747 | 1 | 1 | 1 | 1 | 507 | 557 | 0.620 | 1 | 1 | 1 | 0 | 557 |
| 508 | 0.747 | 1 | 1 | 1 | 1 | 508 | 558 | 0.620 | 1 | 1 | 1 | 1 | 558 |
| 509 | 0.747 | 1 | 1 | 1 | 1 | 509 | 559 | 0.620 | 1 | 1 | 1 | 1 | 559 |
| 510 | 0.747 | 1 | 1 | 1 | 1 | 510 | 560 | 0.620 | 1 | 1 | 1 | 1 | 560 |
| 511 | 0.747 | 1 | 1 | 1 | 1 | 511 | 561 | 0.620 | 1 | 1 | 1 | 1 | 561 |
| 512 | 0.747 | 1 | 0 | 0 | 0 | 512 | 562 | 0.620 | 1 | 1 | 1 | 1 | 562 |
| 513 | 0.615 | 1 | 1 | 1 | 1 | 513 | 563 | 0.620 | 1 | 0 | 0 | 0 | 563 |
| 514 | 0.617 | 1 | 1 | 1 | 1 | 514 | 564 | 0.620 | 1 | 1 | 0 | 0 | 564 |
| 515 | 0.617 | 1 | 1 | 1 | 1 | 515 | 565 | 0.620 | 1 | 0 | 0 | 0 | 565 |
| 516 | 0.617 | 1 | 1 | 1 | 1 | 516 | 566 | 0.620 | 1 | 0 | 0 | 0 | 566 |
| 517 | 0.617 | 1 | 1 | 1 | 1 | 517 | 567 | 0.620 | 1 | 0 | 0 | 0 | 567 |
| 518 | 0.617 | 1 | 0 | 0 | 0 | 518 | 568 | 0.620 | 1 | 1 | 0 | 0 | 568 |
| 519 | 0.617 | 1 | 0 | 0 | 0 | 519 | 569 | 0.624 | 1 | 0 | 0 | 0 | 569 |
| 520 | 0.617 | 1 | 0 | 0 | 0 | 520 | 570 | 0.624 | 1 | 1 | 0 | 0 | 570 |
| 521 | 0.617 | 1 | 1 | 1 | 1 | 521 | 571 | 0.624 | 1 | 0 | 0 | 0 | 571 |
| 522 | 0.618 | 1 | 1 | 1 | 1 | 522 | 572 | 0.624 | 1 | 0 | 0 | 0 | 572 |
| 523 | 0.618 | 1 | 1 | 1 | 1 | 523 | 573 | 0.629 | 1 | 1 | 0 | 0 | 573 |
| 524 | 0.618 | 1 | 1 | 1 | 0 | 524 | 574 | 0.629 | 1 | 0 | 0 | 0 | 574 |
| 525 | 0.618 | 1 | 1 | 1 | 1 | 525 | 575 | 0.659 | 1 | 1 | 0 | 0 | 575 |
| 526 | 0.618 | 1 | 1 | 1 | 1 | 526 | 576 | 0.659 | 1 | 0 | 0 | 0 | 576 |
| 527 | 0.618 | 1 | 1 | 1 | 1 | 527 | 577 | 0.659 | 1 | 0 | 0 | 0 | 577 |
| 528 | 0.618 | 1 | 1 | 1 | 1 | 528 | 578 | 0.663 | 1 | 0 | 0 | 0 | 578 |
| 529 | 0.618 | 1 | 1 | 0 | 0 | 529 | 579 | 0.663 | 1 | 0 | 0 | 0 | 579 |
| 530 | 0.618 | 1 | 1 | 1 | 1 | 530 | 580 | 0.666 | 1 | 1 | 1 | 1 | 580 |
| 531 | 0.618 | 1 | 1 | 1 | 1 | 531 | 581 | 0.666 | 1 | 1 | 1 | 1 | 581 |
| 532 | 0.618 | 1 | 1 | 0 | 0 | 532 | 582 | 0.666 | 1 | 1 | 1 | 1 | 582 |
| 533 | 0.618 | 1 | 1 | 1 | 0 | 533 | 583 | 0.666 | 1 | 1 | 0 | 0 | 583 |
| 534 | 0.618 | 1 | 1 | 1 | 1 | 534 | 584 | 0.666 | 1 | 1 | 1 | 0 | 584 |
| 535 | 0.618 | 1 | 1 | 1 | 1 | 535 | 585 | 0.666 | 1 | 1 | 1 | 0 | 585 |
| 536 | 0.618 | 1 | 1 | 0 | 0 | 536 | 586 | 0.670 | 1 | 1 | 1 | 1 | 586 |
| 537 | 0.618 | 1 | 1 | 0 | 0 | 537 | 587 | 0.670 | 1 | 1 | 1 | 1 | 587 |
| 538 | 0.618 | 1 | 1 | 1 | 1 | 538 | 588 | 0.670 | 1 | 1 | 1 | 1 | 588 |
| 539 | 0.618 | 1 | 1 | 1 | 1 | 539 | 589 | 0.670 | 1 | 1 | 1 | 1 | 589 |
| 540 | 0.618 | 1 | 1 | 1 | 1 | 540 | 590 | 0.674 | 1 | 0 | 0 | 0 | 590 |
| 541 | 0.618 | 1 | 1 | 0 | 0 | 541 | 591 | 0.674 | 1 | 0 | 0 | 0 | 591 |
| 542 | 0.618 | 1 | 1 | 1 | 1 | 542 | 592 | 0.674 | 1 | 0 | 0 | 0 | 592 |
| 543 | 0.618 | 1 | 1 | 1 | 1 | 543 | 593 | 0.674 | 1 | 0 | 0 | 0 | 593 |
| 544 | 0.618 | 1 | 1 | 1 | 1 | 544 | 594 | 0.678 | 1 | 0 | 0 | 0 | 594 |
| 545 | 0.618 | 1 | 1 | 1 | 1 | 545 | 595 | 0.683 | 1 | 1 | 1 | 0 | 595 |
| 546 | 0.619 | 1 | 1 | 1 | 1 | 546 | 596 | 0.683 | 1 | 0 | 0 | 0 | 596 |
| 547 | 0.619 | 1 | 0 | 0 | 0 | 547 | 597 | 0.683 | 1 | 0 | 0 | 0 | 597 |
| 548 | 0.619 | 1 | 1 | 1 | 0 | 548 | 598 | 0.683 | 1 | 0 | 0 | 0 | 598 |
| 549 | 0.619 | 1 | 1 | 1 | 0 | 549 | 599 | 0.232 | 1 | 0 | 0 | 0 | 599 |
| 550 | 0.619 | 1 | 0 | 0 | 0 | 550 | 600 | 0.232 | 1 | 0 | 0 | 0 | 600 |

**TABLE 2-3  Damage Data for HEPC's Bridge (Cont'd)**

| (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col | (1) # | (2) PGA(g) | (3) N | (4) ≥ Min | (5) ≥ Mod | (6) ≥ Maj | (7) ≥ Col |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 601 | 0.232 | 1 | 0 | 0 | 0 | 601 | 651 | 0.259 | 1 | 1 | 1 | 0 | 651 |
| 602 | 0.232 | 1 | 0 | 0 | 0 | 602 | 652 | 0.259 | 1 | 1 | 0 | 0 | 652 |
| 603 | 0.232 | 1 | 0 | 0 | 0 | 603 | 653 | 0.259 | 1 | 1 | 0 | 0 | 653 |
| 604 | 0.232 | 1 | 0 | 0 | 0 | 604 | 654 | 0.259 | 1 | 1 | 0 | 0 | 654 |
| 605 | 0.234 | 1 | 0 | 0 | 0 | 605 | 655 | 0.259 | 1 | 1 | 0 | 0 | 655 |
| 606 | 0.234 | 1 | 0 | 0 | 0 | 606 | 656 | 0.259 | 1 | 1 | 0 | 0 | 656 |
| 607 | 0.234 | 1 | 0 | 0 | 0 | 607 | 657 | 0.259 | 1 | 1 | 0 | 0 | 657 |
| 608 | 0.234 | 1 | 0 | 0 | 0 | 608 | 658 | 0.259 | 1 | 1 | 0 | 0 | 658 |
| 609 | 0.238 | 1 | 1 | 0 | 0 | 609 | 659 | 0.259 | 1 | 1 | 0 | 0 | 659 |
| 610 | 0.238 | 1 | 1 | 0 | 0 | 610 | 660 | 0.259 | 1 | 1 | 0 | 0 | 660 |
| 611 | 0.238 | 1 | 1 | 0 | 0 | 611 | 661 | 0.259 | 1 | 1 | 0 | 0 | 661 |
| 612 | 0.238 | 1 | 1 | 0 | 0 | 612 | 662 | 0.259 | 1 | 1 | 0 | 0 | 662 |
| 613 | 0.239 | 1 | 0 | 0 | 0 | 613 | 663 | 0.259 | 1 | 0 | 0 | 0 | 663 |
| 614 | 0.241 | 1 | 0 | 0 | 0 | 614 | 664 | 0.262 | 1 | 1 | 0 | 0 | 664 |
| 615 | 0.241 | 1 | 0 | 0 | 0 | 615 | 665 | 0.262 | 1 | 1 | 0 | 0 | 665 |
| 616 | 0.241 | 1 | 0 | 0 | 0 | 616 | 666 | 0.262 | 1 | 1 | 0 | 0 | 666 |
| 617 | 0.241 | 1 | 0 | 0 | 0 | 617 | 667 | 0.262 | 1 | 1 | 0 | 0 | 667 |
| 618 | 0.243 | 1 | 0 | 0 | 0 | 618 | 668 | 0.262 | 1 | 1 | 0 | 0 | 668 |
| 619 | 0.243 | 1 | 0 | 0 | 0 | 619 | 669 | 0.262 | 1 | 1 | 0 | 0 | 669 |
| 620 | 0.243 | 1 | 0 | 0 | 0 | 620 | 670 | 0.262 | 1 | 1 | 0 | 0 | 670 |
| 621 | 0.243 | 1 | 0 | 0 | 0 | 621 | 671 | 0.262 | 1 | 1 | 0 | 0 | 671 |
| 622 | 0.243 | 1 | 0 | 0 | 0 | 622 | 672 | 0.266 | 1 | 1 | 0 | 0 | 672 |
| 623 | 0.243 | 1 | 0 | 0 | 0 | 623 | 673 | 0.266 | 1 | 1 | 0 | 0 | 673 |
| 624 | 0.243 | 1 | 0 | 0 | 0 | 624 | 674 | 0.266 | 1 | 0 | 0 | 0 | 674 |
| 625 | 0.243 | 1 | 0 | 0 | 0 | 625 | 675 | 0.266 | 1 | 0 | 0 | 0 | 675 |
| 626 | 0.243 | 1 | 0 | 0 | 0 | 626 | 676 | 0.266 | 1 | 0 | 0 | 0 | 676 |
| 627 | 0.245 | 1 | 0 | 0 | 0 | 627 | 677 | 0.266 | 1 | 0 | 0 | 0 | 677 |
| 628 | 0.245 | 1 | 0 | 0 | 0 | 628 | 678 | 0.266 | 1 | 0 | 0 | 0 | 678 |
| 629 | 0.245 | 1 | 0 | 0 | 0 | 629 | 679 | 0.266 | 1 | 0 | 0 | 0 | 679 |
| 630 | 0.245 | 1 | 0 | 0 | 0 | 630 | 680 | 0.268 | 1 | 0 | 0 | 0 | 680 |
| 631 | 0.245 | 1 | 0 | 0 | 0 | 631 | 681 | 0.268 | 1 | 0 | 0 | 0 | 681 |
| 632 | 0.245 | 1 | 0 | 0 | 0 | 632 | 682 | 0.268 | 1 | 0 | 0 | 0 | 682 |
| 633 | 0.245 | 1 | 0 | 0 | 0 | 633 | 683 | 0.268 | 1 | 0 | 0 | 0 | 683 |
| 634 | 0.245 | 1 | 0 | 0 | 0 | 634 | 684 | 0.268 | 1 | 0 | 0 | 0 | 684 |
| 635 | 0.245 | 1 | 0 | 0 | 0 | 635 | 685 | 0.268 | 1 | 0 | 0 | 0 | 685 |
| 636 | 0.245 | 1 | 0 | 0 | 0 | 636 | 686 | 0.280 | 1 | 0 | 0 | 0 | 686 |
| 637 | 0.249 | 1 | 0 | 0 | 0 | 637 | 687 | 0.280 | 1 | 0 | 0 | 0 | 687 |
| 638 | 0.249 | 1 | 0 | 0 | 0 | 638 | 688 | 0.278 | 1 | 0 | 0 | 0 | 688 |
| 639 | 0.249 | 1 | 0 | 0 | 0 | 639 | 689 | 0.280 | 1 | 0 | 0 | 0 | 689 |
| 640 | 0.249 | 1 | 0 | 0 | 0 | 640 | 690 | 0.287 | 1 | 0 | 0 | 0 | 690 |
| 641 | 0.253 | 1 | 0 | 0 | 0 | 641 | 691 | 0.287 | 1 | 0 | 0 | 0 | 691 |
| 642 | 0.253 | 1 | 0 | 0 | 0 | 642 | 692 | 0.287 | 1 | 0 | 0 | 0 | 692 |
| 643 | 0.253 | 1 | 0 | 0 | 0 | 643 | 693 | 0.287 | 1 | 0 | 0 | 0 | 693 |
| 644 | 0.253 | 1 | 0 | 0 | 0 | 644 | 694 | 0.288 | 1 | 0 | 0 | 0 | 694 |
| 645 | 0.253 | 1 | 0 | 0 | 0 | 645 | 695 | 0.288 | 1 | 0 | 0 | 0 | 695 |
| 646 | 0.253 | 1 | 0 | 0 | 0 | 646 | 696 | 0.288 | 1 | 0 | 0 | 0 | 696 |
| 647 | 0.253 | 1 | 0 | 0 | 0 | 647 | 697 | 0.288 | 1 | 0 | 0 | 0 | 697 |
| 648 | 0.253 | 1 | 0 | 0 | 0 | 648 | 698 | 0.288 | 1 | 0 | 0 | 0 | 698 |
| 649 | 0.253 | 1 | 0 | 0 | 0 | 649 | 699 | 0.288 | 1 | 0 | 0 | 0 | 699 |
| 650 | 0.257 | 1 | 0 | 0 | 0 | 650 | 700 | 0.288 | 1 | 0 | 0 | 0 | 700 |

## TABLE 2-3 Damage Data for HEPC's Bridge (Cont'd)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col | # | PGA(g) | N | ≥ Min | ≥ Mod | ≥ Maj | ≥ Col |
| 701 | 0.288 | 1 | 0 | 0 | 0 | 701 | 751 | 0.309 | 1 | 0 | 0 | 0 | 751 |
| 702 | 0.288 | 1 | 0 | 0 | 0 | 702 | 752 | 0.309 | 1 | 0 | 0 | 0 | 752 |
| 703 | 0.288 | 1 | 0 | 0 | 0 | 703 | 753 | 0.309 | 1 | 0 | 0 | 0 | 753 |
| 704 | 0.288 | 1 | 0 | 0 | 0 | 704 | 754 | 0.309 | 1 | 0 | 0 | 0 | 754 |
| 705 | 0.288 | 1 | 0 | 0 | 0 | 705 | 755 | 0.309 | 1 | 0 | 0 | 0 | 755 |
| 706 | 0.288 | 1 | 0 | 0 | 0 | 706 | 756 | 0.309 | 1 | 0 | 0 | 0 | 756 |
| 707 | 0.288 | 1 | 0 | 0 | 0 | 707 | 757 | 0.309 | 1 | 0 | 0 | 0 | 757 |
| 708 | 0.288 | 1 | 0 | 0 | 0 | 708 | 758 | 0.309 | 1 | 0 | 0 | 0 | 758 |
| 709 | 0.288 | 1 | 0 | 0 | 0 | 709 | 759 | 0.309 | 1 | 0 | 0 | 0 | 759 |
| 710 | 0.288 | 1 | 0 | 0 | 0 | 710 | 760 | 0.309 | 1 | 0 | 0 | 0 | 760 |
| 711 | 0.289 | 1 | 0 | 0 | 0 | 711 | 761 | 0.309 | 1 | 0 | 0 | 0 | 761 |
| 712 | 0.289 | 1 | 0 | 0 | 0 | 712 | 762 | 0.309 | 1 | 0 | 0 | 0 | 762 |
| 713 | 0.289 | 1 | 0 | 0 | 0 | 713 | 763 | 0.309 | 1 | 0 | 0 | 0 | 763 |
| 714 | 0.289 | 1 | 0 | 0 | 0 | 714 | 764 | 0.309 | 1 | 0 | 0 | 0 | 764 |
| 715 | 0.289 | 1 | 0 | 0 | 0 | 715 | 765 | 0.309 | 1 | 0 | 0 | 0 | 765 |
| 716 | 0.289 | 1 | 0 | 0 | 0 | 716 | 766 | 0.316 | 1 | 0 | 0 | 0 | 766 |
| 717 | 0.290 | 1 | 0 | 0 | 0 | 717 | 767 | 0.316 | 1 | 0 | 0 | 0 | 767 |
| 718 | 0.290 | 1 | 0 | 0 | 0 | 718 | 768 | 0.316 | 1 | 0 | 0 | 0 | 768 |
| 719 | 0.294 | 1 | 0 | 0 | 0 | 719 | 769 | 0.316 | 1 | 0 | 0 | 0 | 769 |
| 720 | 0.294 | 1 | 0 | 0 | 0 | 720 | 770 | 0.321 | 1 | 0 | 0 | 0 | 770 |
| 721 | 0.297 | 1 | 0 | 0 | 0 | 721 | | | | | | | |
| 722 | 0.297 | 1 | 0 | 0 | 0 | 722 | | | | | | | |
| 723 | 0.297 | 1 | 0 | 0 | 0 | 723 | | | | | | | |
| 724 | 0.299 | 1 | 1 | 0 | 0 | 724 | | | | | | | |
| 725 | 0.303 | 1 | 1 | 0 | 0 | 725 | | | | | | | |
| 726 | 0.303 | 1 | 1 | 0 | 0 | 726 | | | | | | | |
| 727 | 0.303 | 1 | 0 | 0 | 0 | 727 | | | | | | | |
| 728 | 0.303 | 1 | 0 | 0 | 0 | 728 | | | | | | | |
| 729 | 0.303 | 1 | 0 | 0 | 0 | 729 | | | | | | | |
| 730 | 0.303 | 1 | 0 | 0 | 0 | 730 | | | | | | | |
| 731 | 0.303 | 1 | 0 | 0 | 0 | 731 | | | | | | | |
| 732 | 0.303 | 1 | 0 | 0 | 0 | 732 | | | | | | | |
| 733 | 0.303 | 1 | 0 | 0 | 0 | 733 | | | | | | | |
| 734 | 0.303 | 1 | 0 | 0 | 0 | 734 | | | | | | | |
| 735 | 0.303 | 1 | 0 | 0 | 0 | 735 | | | | | | | |
| 736 | 0.303 | 1 | 0 | 0 | 0 | 736 | | | | | | | |
| 737 | 0.303 | 1 | 0 | 0 | 0 | 737 | | | | | | | |
| 738 | 0.303 | 1 | 0 | 0 | 0 | 738 | | | | | | | |
| 739 | 0.303 | 1 | 0 | 0 | 0 | 739 | | | | | | | |
| 740 | 0.303 | 1 | 0 | 0 | 0 | 740 | | | | | | | |
| 741 | 0.303 | 1 | 0 | 0 | 0 | 741 | | | | | | | |
| 742 | 0.303 | 1 | 0 | 0 | 0 | 742 | | | | | | | |
| 743 | 0.303 | 1 | 0 | 0 | 0 | 743 | | | | | | | |
| 744 | 0.306 | 1 | 0 | 0 | 0 | 744 | | | | | | | |
| 745 | 0.306 | 1 | 0 | 0 | 0 | 745 | | | | | | | |
| 746 | 0.309 | 1 | 0 | 0 | 0 | 746 | | | | | | | |
| 747 | 0.309 | 1 | 0 | 0 | 0 | 747 | | | | | | | |
| 748 | 0.309 | 1 | 0 | 0 | 0 | 748 | | | | | | | |
| 749 | 0.309 | 1 | 0 | 0 | 0 | 749 | | | | | | | |
| 750 | 0.309 | 1 | 0 | 0 | 0 | 750 | | | | | | | |

## 2.4 Fragility Curves for Structural Sub-Sets of Caltrans' Bridges

In the preceding analysis, it was assumed that the sample of bridges inspected after the earthquake is statistically homogeneous. This assumption is not quite reasonable for the Caltrans' bridges, while it is reasonable for the HEPC's bridge columns as mentioned earlier. In the present study, therefore, the sample of the HEPC's bridge columns considered is treated statistically as homogeneous and figures 2-16 and 2-17 represent the families of fragility curves assignable to any bridge column arbitrarily chosen from the underlying homogenous population of bridge columns. For the mathematical reasons mentioned earlier, it is recommended even then that the fragility curves (figure 2-17) obtained by means of Method 2 be considered for applications, although later statistical analysis will indicate that the fragility curves (figure 2-16) obtained by Method 1 cannot mathematically be rejected. As opposed to the case of HEPC's bridge columns, the statistical homogeneity would be an oversimplification for the sample of the Caltrans' bridges. In fact, it is reasonable to sub-divide the sample of the Caltrans' bridges into a number of sub-sets in accordance with the pertinent bridge attributes and their combinations. This should be done in such a way that each sub-sample can be considered to be drawn from the corresponding sub-population which is more homogeneous than the initial population. In this regard, it is recognized each bridge can easily be associated with one of the following three distinct attributes; (A) It is either single span (S) or multiple span (M) bridge, (B) it is built on either hard soil ($S_1$), medium soil ($S_2$) or soft soil ($S_3$) in the definition of UBC 93, and (C) it has a skew angle $\theta_1$ (less than $20^o$), $\theta_2$ (between $20^o$ and $60^o$) or $\theta_3$ (larger than $60^o$). The sample can then be sub-divided into a number of sub-sets. To begin with, one might consider the first level hypothesis that the entire sample is taken from a statistically homogenous population of bridges. The second level sub-sets are created by dividing the sample either (A) into two groups of bridges, one with single spans and the other with multiple spans, (B) into three groups, the first with soil condition $S_1$, the second with $S_2$ and the third with $S_3$, or (C) into three groups depending on the skew angles $\theta_1$, $\theta_2$ and $\theta_3$. The third level sub-sets consists of either (D) 6 groups each with a particular combination between (S, M) and ($S_1$, $S_2$, $S_3$), (E) 6 groups each with a combination between (S, M) and ($\theta_1$, $\theta_2$, $\theta_3$), or (F) 9 groups each with a combination between ($\theta_1$, $\theta_2$, $\theta_3$) and ($S_1$, $S_2$, $S_3$). Finally, the fourth level sub-sets comprises of 18 groups each with a combination of the attributes (S, M), ($S_1$, $S_2$, $S_3$) and ($\theta_1$, $\theta_2$, $\theta_3$).

As alluded to in the preceding paragraph, the higher the level of sub-sets, more statistically homogeneous the corresponding sub-population is compared with the population at the level at least one rank lower. For example, each sample of the fourth level sub-sets is taken from the population with identical span, skewness and soil characteristics as they are defined here. While this by no means implies that the corresponding population is purely homogeneous, it is much more homogeneous in engineering sense than the population corresponding to the first, second or even third level sub-sets.

The first level represents nothing but the entire sample taken from the underlying homogeneous population. The fragility curves are developed under this assumption in figures 2-3 and 2-4 for the Caltrans' bridges. The second, third and fourth level sub-sets are all considered and analyzed for the fragility curve development with the aid of Method 2. The median values and log-standard deviations of all levels of attribute combinations are listed in table 2-4. Note that, if an element of a matrix in table 2-4 shows NA, it indicates that null sub-sample was found for the particular combination of bridge attributes the element signifies. The families of fragility curves corresponding to the fourth level subsets consisting of 18 groups are plotted in figures 2-24~2-36. Fragility curves associated with some damage states are missing from the plots for some subsets that do not have bridges suffering from these damage states. For example, the subset representing the combination of bridge attributes M/$\theta_1$/ *a* (multiple span/skew angle between 0 and $20^{\circ}$/soil condition A) does not have empirical fragility curves for at least major and collapse states of damage (see table 2-4). Also, there exist, at the fourth level of subdivision, five empty subsets (S/20~60/*a*, S/20~60/*b*, S/60~90/*a*, S/60~90/*b*, M/0~20/*b*) for which these are no empirical fragility curves at all. The higher the level of sub-sets, fragility curves obtained by Method 1 tend to more easily to intersect each other when they are plotted within the same family having a specific combination of attributes because of the smaller sample size it tends to consist of. A typical example of this is shown in figure 2-37. This indeed is the reason for not utilizing the fragility curves developed at level four by Method 1 in the ensuing system performance analysis.

The families of fragility curves shown in figures 2-24~2-36 play a pivotal role in the seismic performance assessment of the expressway network in the Los Angeles area. More will be mentioned about this later in this report.

**Table 2-4 Median and Log-Standard Deviation at Different Levels of Sample Sub-Division**

(a) First Level (Composite)

| | Median | Log. St. Dev. |
|---|---|---|
| Min | 0.83 | 0.82 |
| Mod | 1.07 | 0.82 |
| Maj | 1.76 | 0.82 |
| Col | 3.96 | 0.82 |

(b) Second Level (Span)

| | | Median | Log. St. Dev. |
|---|---|---|---|
| Single | Min | 1.22 | 0.78 |
| | Mod | 1.60 | 0.78 |
| | Maj | 2.65 | 0.78 |
| | Col | N/A | 0.78 |
| Multiple | Min | 0.72 | 0.72 |
| | Mod | 0.92 | 0.92 |
| | Maj | 1.51 | 1.51 |
| | Col | 3.26 | 3.26 |

(c) Second Level (Skew)

| | | Median | Log. St. Dev. |
|---|---|---|---|
| Sk1 $0^o \sim 20^o$ | Min | 0.99 | 0.95 |
| | Mod | 1.38 | 0.95 |
| | Maj | 2.52 | 0.95 |
| | Col | 5.15 | 0.95 |
| Sk2 $21^o \sim 60^o$ | Min | 0.71 | 0.73 |
| | Mod | 0.87 | 0.73 |
| | Maj | 1.38 | 0.73 |
| | Col | 3.93 | 0.73 |
| Sk3 $>60^o$ | Min | 0.50 | 0.59 |
| | Mod | 0.63 | 0.59 |
| | Maj | 0.93 | 0.59 |
| | Col | 1.69 | 0.59 |

(d) Second Level (Soil)

| | | Median | Log. St. Dev. |
|---|---|---|---|
| Soil A | Min | 1.35 | 0.94 |
| | Mod | 1.79 | 0.94 |
| | Maj | 2.62 | 0.94 |
| | Col | N/A | 0.94 |
| Soil B | Min | 0.97 | 0.94 |
| | Mod | 1.36 | 0.94 |
| | Maj | 2.19 | 0.94 |
| | Col | N/A | 0.94 |
| Soil C | Min | 0.79 | 0.79 |
| | Mod | 1.01 | 0.79 |
| | Maj | 1.70 | 0.79 |
| | Col | 3.57 | 0.79 |

**Table 2-4 Median and Log-Standard Deviation at different Levels of Sample Sub-Division (Cont'd)**

(e) Third Level (Span/Skew)

| | Single | Sk1 | | Sk2 | | Sk3 |
|---|---|---|---|---|---|---|
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 2.15 | 0.98 | 0.73 | 0.43 | 0.48 | 0.52 |
| Mod | 3.42 | 0.98 | 0.82 | 0.43 | 0.57 | 0.52 |
| Maj | 6.41 | 0.98 | 1.13 | 0.43 | 0.85 | 0.52 |
| Col | N/A | 0.98 | N/A | 0.43 | N/A | 0.52 |
| | Multiple | Sk1 | | Sk2 | | Sk3 |
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 1.03 | 0.93 | 0.70 | 0.83 | 0.47 | 0.51 |
| Mod | 1.46 | 0.93 | 0.88 | 0.83 | 0.56 | 0.51 |
| Maj | 2.75 | 0.93 | 1.48 | 0.83 | 0.80 | 0.51 |
| Col | 5.80 | 0.93 | 4.63 | 0.83 | 1.35 | 0.51 |

(f) Third Level (Skew\Soil)

| | Sk1 | Soil A | | Soil B | | Soil C |
|---|---|---|---|---|---|---|
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 1.69 | 0.69 | 1.36 | 0.76 | 1.01 | 0.85 |
| Mod | 1.96 | 0.69 | N/A | N/A | 1.38 | 0.85 |
| Maj | N/A | 0.69 | N/A | N/A | 2.44 | 0.85 |
| Col | N/A | 0.69 | N/A | N/A | 4.97 | 0.85 |
| | | | | | | |
| | Sk2 | Soil A | | Soil B | | Soil C |
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 0.84 | 0.5 | 0.54 | 0.53 | 0.68 | 0.76 |
| Mod | 0.91 | 0.5 | 0.68 | 0.53 | 0.84 | 0.76 |
| Maj | 1.01 | 0.5 | 0.8 | 0.53 | 1.48 | 0.76 |
| Col | N/A | 0.5 | N/A | 0.53 | 4.01 | 0.76 |
| | | | | | | |
| | Sk3 | Soil A | | Soil B | | Soil C |
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 0.54 | 0.66 | 0.34 | 0.24 | 0.52 | 0.61 |
| Mod | 0.69 | 0.66 | 0.43 | 0.24 | 0.65 | 0.61 |
| Maj | 1.06 | 0.66 | 0.72 | 0.24 | 0.94 | 0.61 |
| Col | N/A | 0.66 | N/A | 0.24 | 1.64 | 0.61 |

**Table 2-4 Median and Log-Standard Deviation at different Levels of Sample Sub-Division (Cont'd)**

(g) Third Level (Span\Soil)

| | Single | Soil A | | Soil B | | Soil C |
|---|---|---|---|---|---|---|
| | Median | Log. St. Dev. | Median | Log. St. Dev. | Median | Log. St. Dev. |
| Min | 1.1 | 0.86 | 1.1 | 0.78 | 0.97 | 0.65 |
| Mod | N/A | 0.86 | N/A | 0.78 | 1.21 | 0.65 |
| Maj | N/A | 0.86 | N/A | 0.78 | 1.90 | 0.65 |
| Col | N/A | 0.86 | N/A | 0.78 | N/A | 0.65 |
| | Multiple | Soil A | | Soil B | | Soil C |
| Min | 1.06 | 0.9 | 0.59 | 0.51 | 0.71 | 0.78 |
| Mod | 1.36 | 0.9 | 0.72 | 0.51 | 0.91 | 0.78 |
| Maj | 2.03 | 0.9 | 0.99 | 0.51 | 1.53 | 0.78 |
| Col | N/A | 0.9 | N/A | 0.51 | 3.13 | 0.78 |

(h) Forth Level (Span/Skew/Soil)

| Case \ Damage | Min | Mod | Maj | Col | Log. Std. Dev. |
|---|---|---|---|---|---|
| S/0-20/a | 0.71 | N/A | N/A | N/A | 0.20 |
| S/0-20/b | 0.61 | N/A | N/A | N/A | 0.41 |
| S/0-20/c | 1.23 | 1.49 | 2.29 | N/A | 0.57 |
| S/20-60/a | N/A | N/A | N/A | N/A | N/A |
| S/20-60/b | N/A | N/A | N/A | N/A | N/A |
| S/20-60/c | 0.62 | 0.70 | 0.98 | N/A | 0.39 |
| S/60-90/a | N/A | N/A | N/A | N/A | N/A |
| S/60-90/b | N/A | N/A | N/A | N/A | N/A |
| S/60-90/c | 0.56 | 1.08 | 2.04 | N/A | 0.83 |
| M/0-20/a | 1.16 | 1.38 | N/A | N/A | 0.80 |
| M/0-20/b | N/A | N/A | N/A | N/A | N/A |
| M/0-20/c | 0.84 | 1.16 | 2.05 | 4.06 | 0.81 |
| M/20-60/a | 0.59 | 0.59 | 0.72 | N/A | 0.41 |
| M/20-60/b | 0.50 | 0.64 | 0.64 | N/A | 0.48 |
| M/20-60/c | 0.69 | 0.88 | 1.64 | 4.63 | 0.85 |
| M/60-90/a | 0.39 | 0.48 | 0.70 | N/A | 0.43 |
| M/60-90/b | 0.34 | 0.43 | 0.72 | N/A | 0.25 |
| M/60-90/c | 0.50 | 0.57 | 0.81 | 1.33 | 0.53 |

Note S=Single Span M=Multiple Span
a=Soil A b=Soil B c=Soil C
Number: Indicates the Skewness Angle

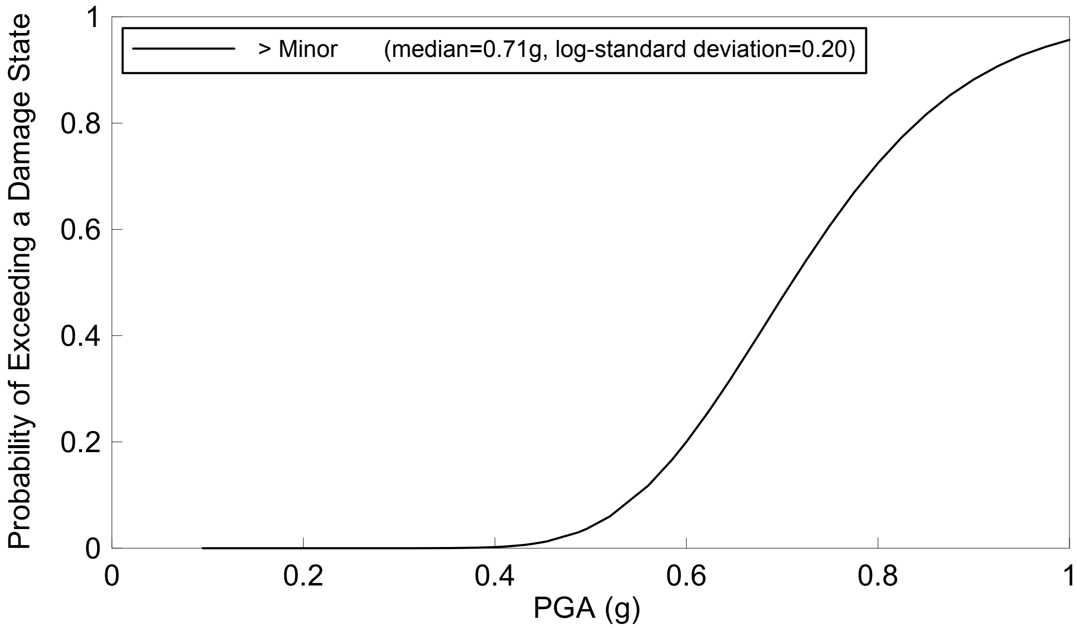



**FIGURE 2-24 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; single span/0 ≤ skew ≤ 20/soil A) by Method 2**

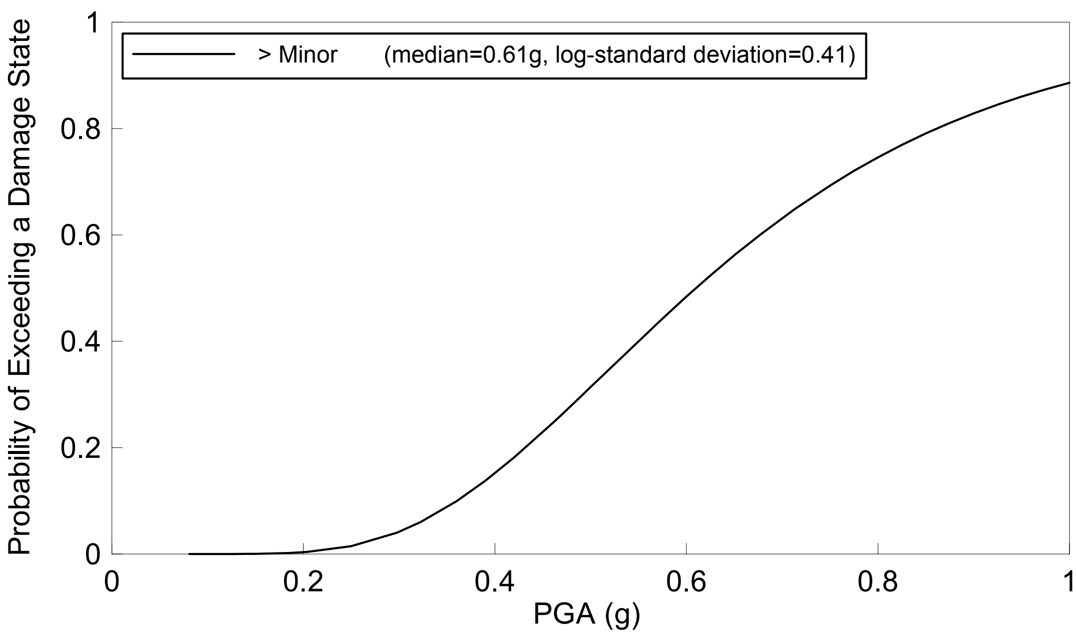



**FIGURE 2-25 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; single span/0 ≤ skew ≤ 20/soil B) by Method 2**

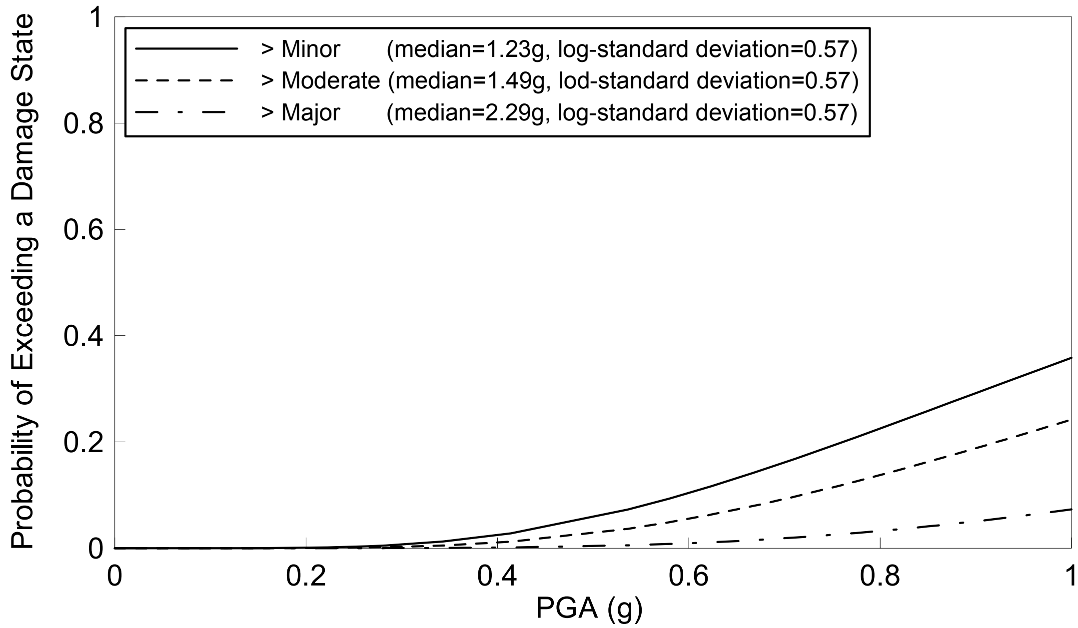



**FIGURE 2-26 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; single span/0 ≤ skew ≤ 20/soil C) by Method 2**

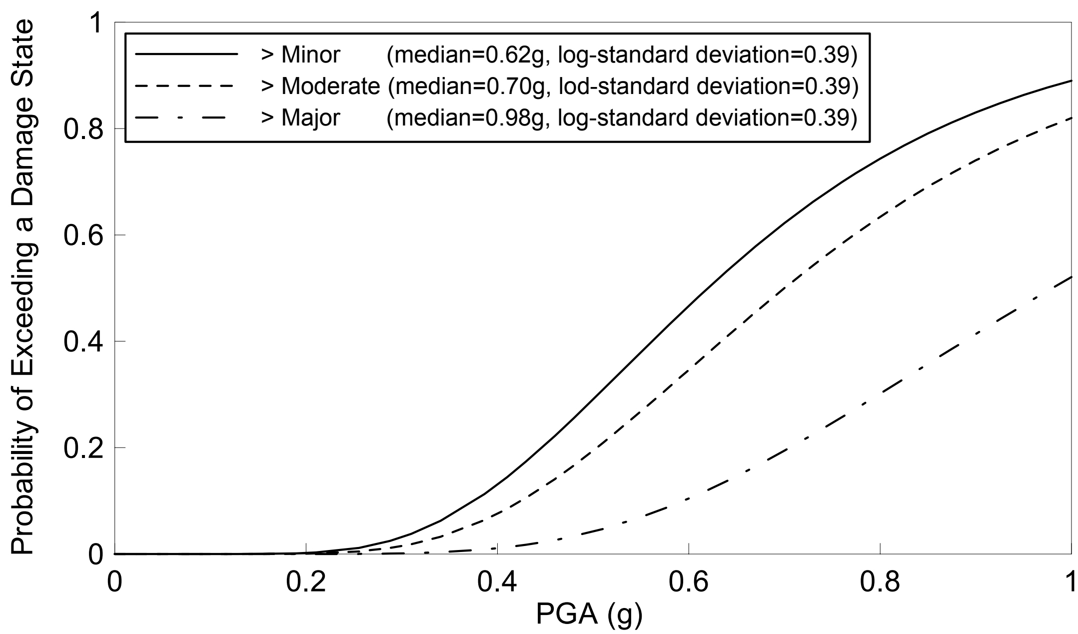



**FIGURE 2-27 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; single span/20<skew ≤ 60/soil C) by Method 2**

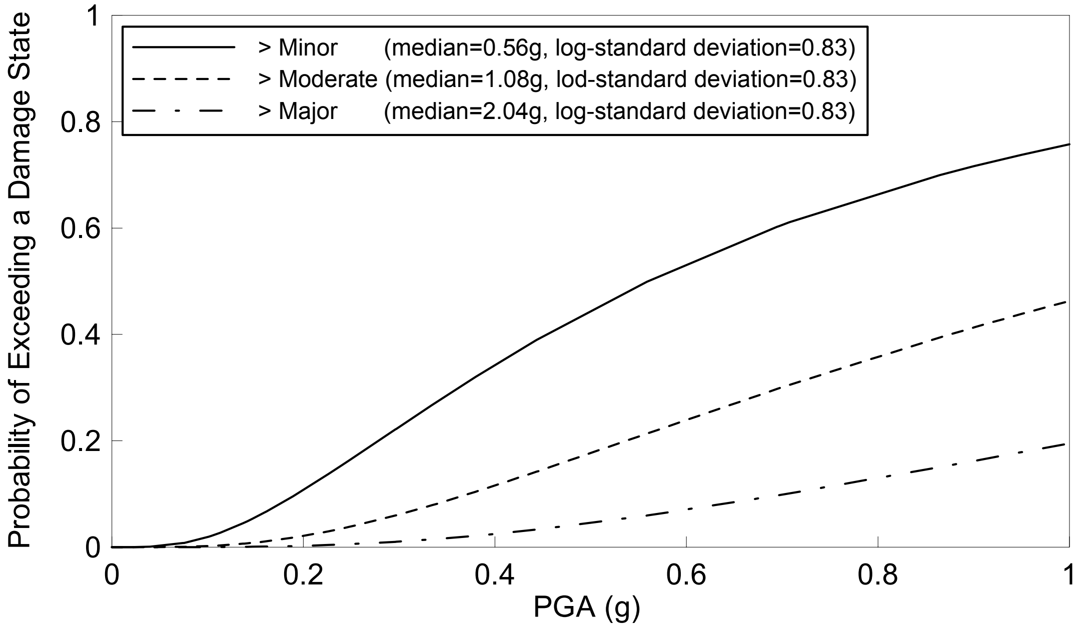



**FIGURE 2-28 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; single span/60<skew/soil C) by Method 2**

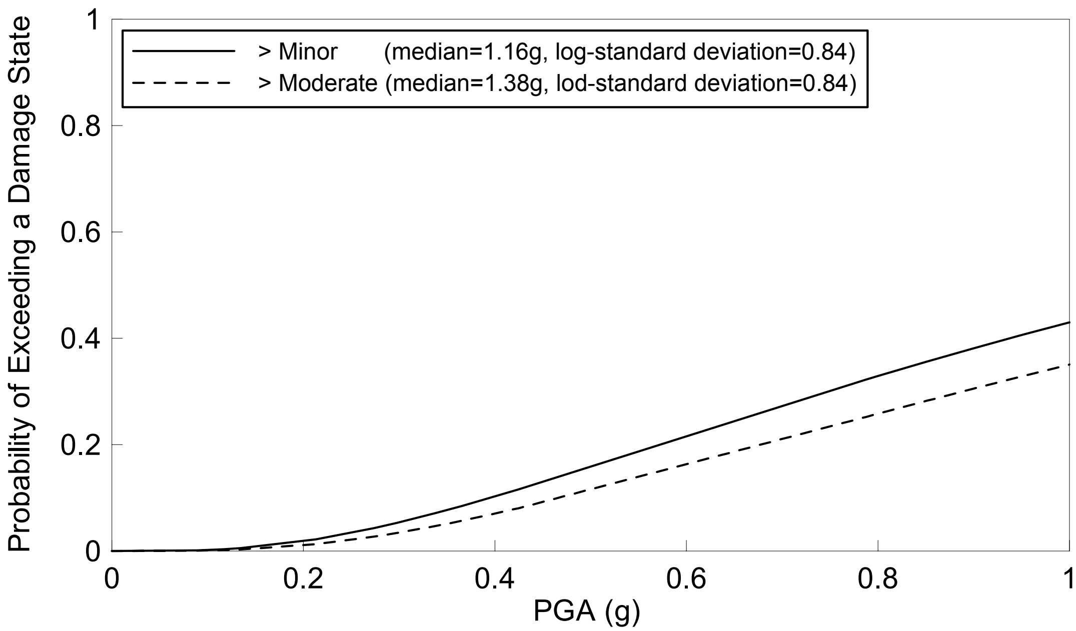



**FIGURE 2-29 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/0 ≤ skew ≤ 20/soil A) by Method 2**

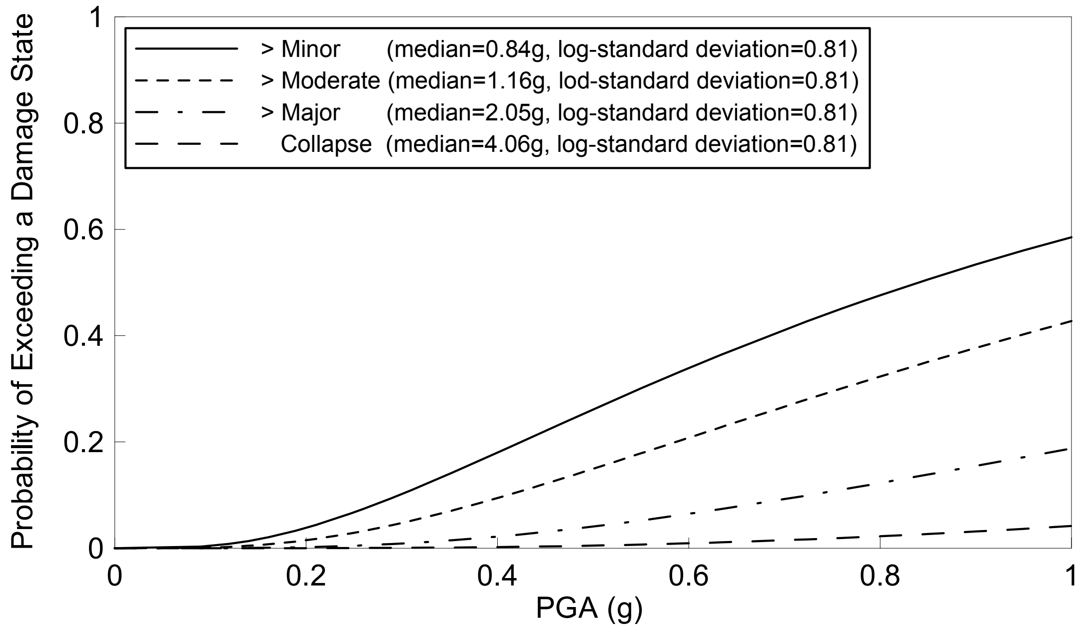



**FIGURE 2-30 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/0 ≤ skew ≤ 20/soil C) by Method 2**

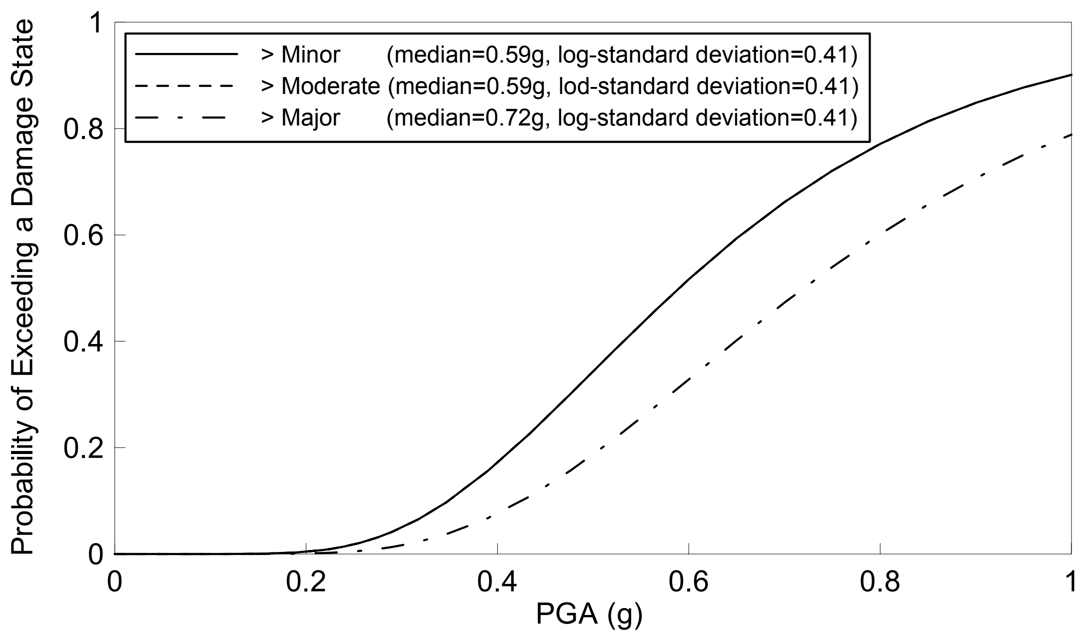



**FIGURE 2-31 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/20<skew ≤ 60/soil A) by Method 2**

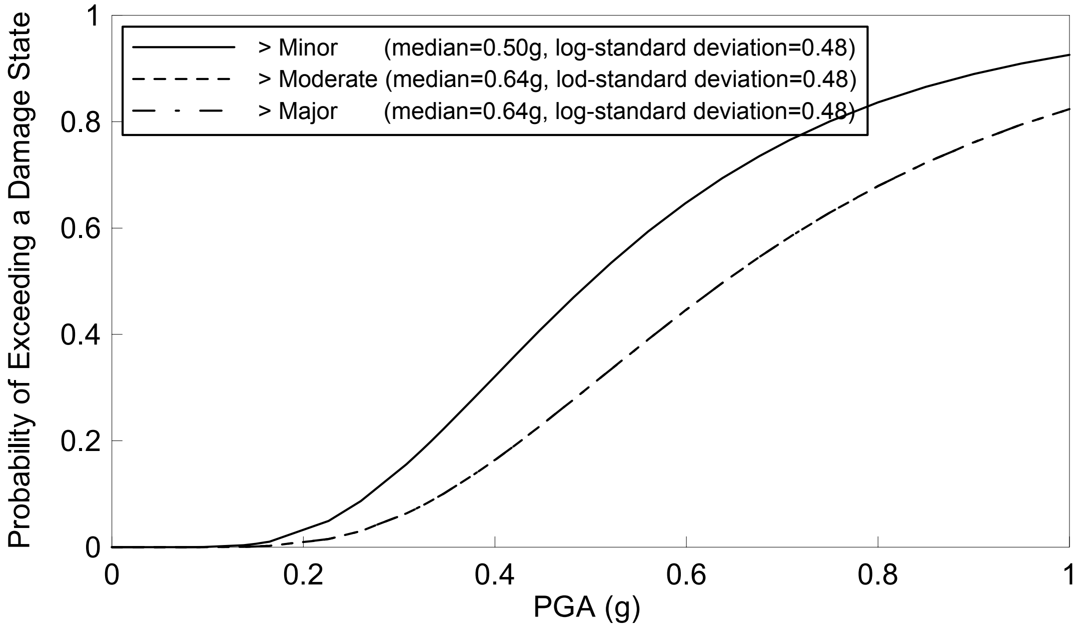



**FIGURE 2-32 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/20<skew ≤ 60/soil B) by Method 2**

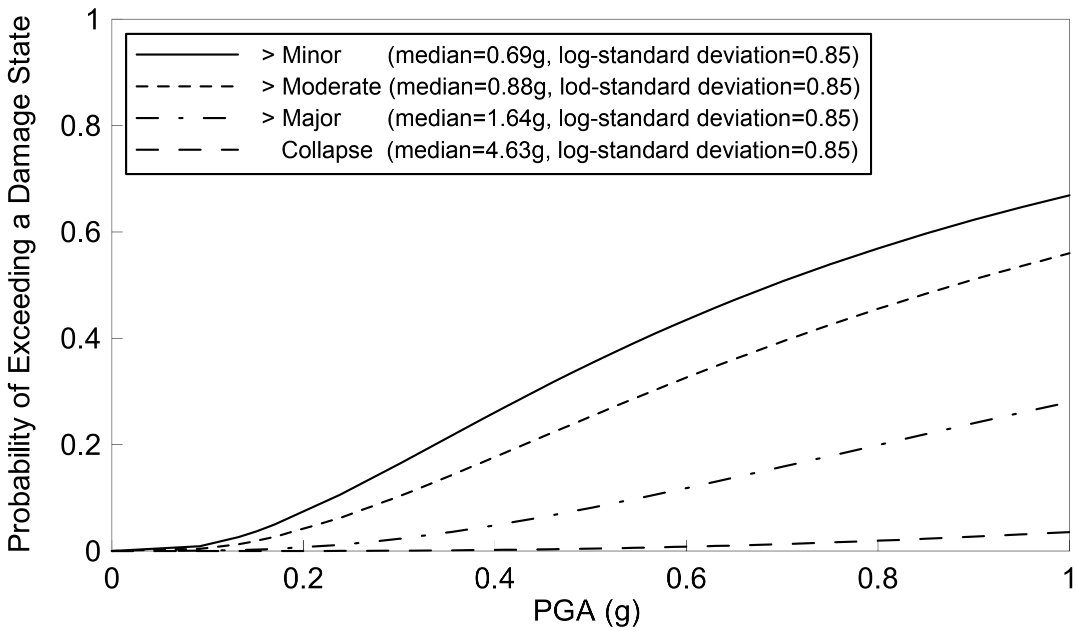



**FIGURE 2-33 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/20<skew ≤ 60/soil C) by Method 2**

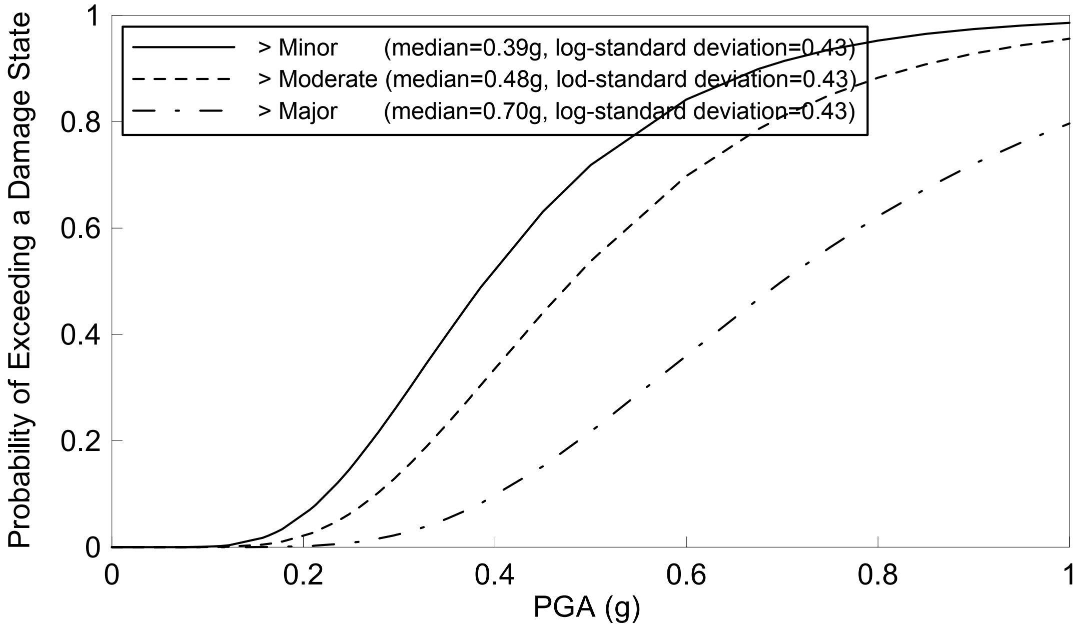



**FIGURE 2-34 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/60<skew/soil A) by Method 2**

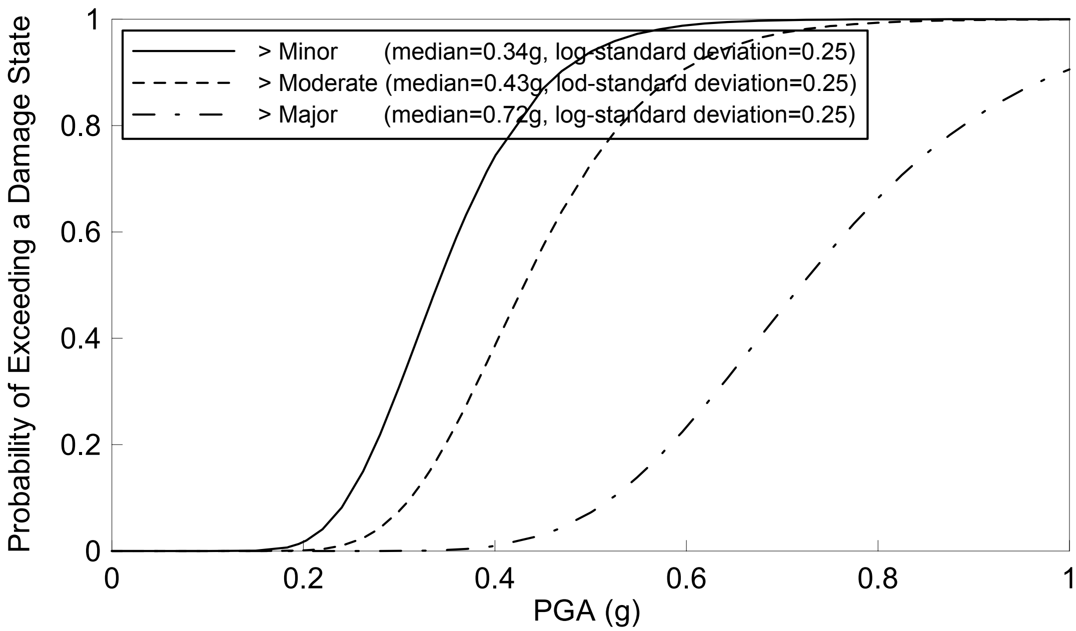



**FIGURE 2-35 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/60<skew/soil B) by Method 2**

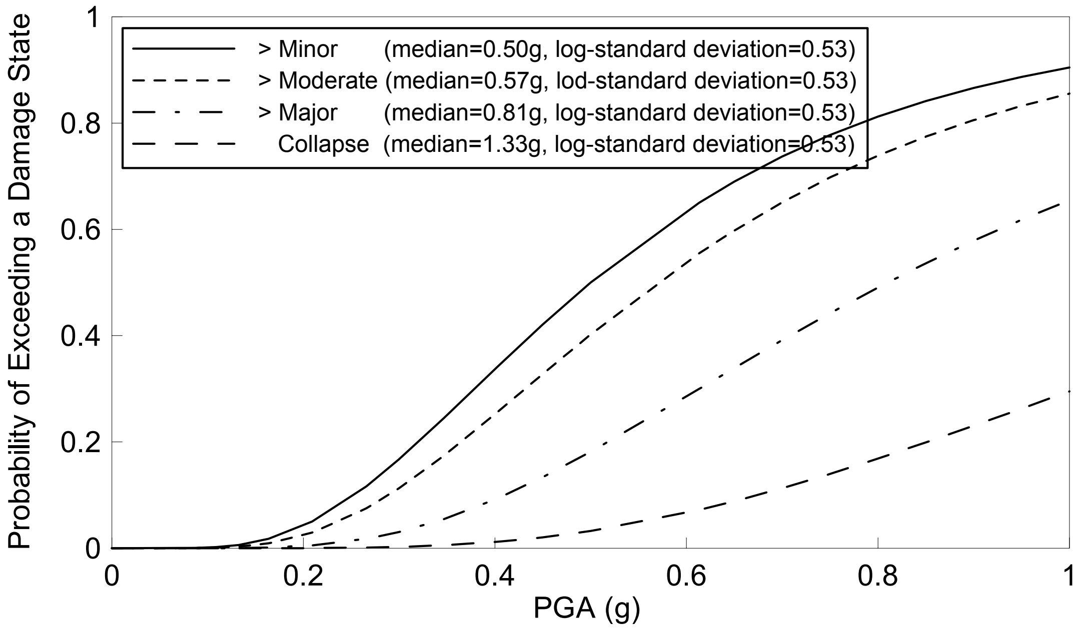



**FIGURE 2-36 Fragility Curves for a Fourth Level Subset**

**(Caltrans' Bridges; multiple span/60<skew/soil C) by Method 2**

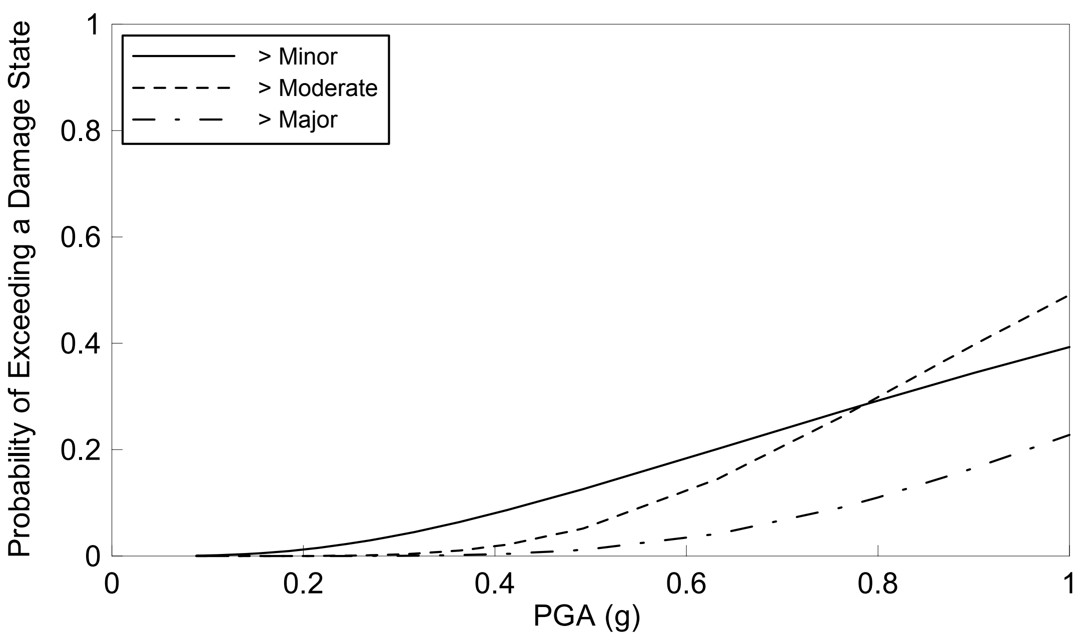



**FIGURE 2-37 Fragility Curves for Second Subset of Single Span Bridges**

# SECTION 3
# ANALYTICAL FRAGILITY CURVES

To demonstrate the development of analytical fragility curves, two representative bridges with a precast prestressed continuous deck in the Memphis, Tennessee area studied by Jernigan and Hwang (1997) are used. The plan, elevation and column cross-section of Bridge 1 are depicted in figure 3-1. Geometry and configuration of Bridge 2 is similar to Bridge 1. Bridge 2 also has a precast prestressed continuous deck. However, the deck is supported by 2 abutments and 4 bents with 5 spans equal to 10.7 m (35'), 16.8 m (55'), 16.8 m (55'), 16.8 m (55') and 10.7 m (35'). Each bent has 3 columns 5.8 m (19') high with the same cross-sectional and reinforcing characteristics as those of Bridge 1. Following Jernigan and Hwang (1997), the strength $f_c$ of 20.7 MPa (3000 psi) concrete used for the bridge is assumed to be best described by a normal distribution with a mean strength of 31.0 MPa (4500 psi) and a standard deviation of 6.2 MPa (900 psi), whereas the yield strength $f_y$ of grade 40 reinforcing bars used in design is described by a lognormal distribution having a mean strength of 336.2 MPa (48.8 ksi) with a standard deviation of 36.0 MPa (5.22 ksi). Then, a sample of ten nominally identical but statistically different bridges are created by simulating ten realizations of $f_c$ and $f_y$ according to respective probability distribution functions assumed. Other parameters that could contribute to variability of structural response were not considered in the present analysis under the assumption that their contributions are disregardable.

For the seismic ground motion, the time histories generated by Hwang and Huo (1996) at the Center for Earthquake Research and Information, the University of Memphis are used. These time histories are generated by making use of the Fourier acceleration amplitude on the base rock derived under the assumption of a far-field point source by Boore (1983). In fact, the study area is located 40 km to 100 km from Marked Tree, Arkansas (see figure 3-2), the epicenter of the 1846 earthquake of magnitude of 6.5 and of all the scenario earthquakes considered in this study. Use of more widely distributed sources of seismic events that represent better the New Madrid seismic zone is a worthwhile subject of future study. Marked Tree is currently considered to define the southwestern edge of the New Madrid fault. Upon using seismologically consistent values for the parameters in the Boore and other related models and converting the Fourier amplitude to a power spectrum, corresponding histories are generated on the base rock by means of the spectral representation method by Shinozuka and Deodatis (1991). The seismic wave represented by these time histories is propagated through the surface layer to the ground surface by means of the SHAKE 91 computer code by Idriss and Sun (1992) and used, upon modulating in the time domain, for the response analysis. To minimize computational effort, samples of 10 time histories are randomly selected from 50 histories generated by Hwang and Huo (1996) for each of the following eight (8) combinations of M (magnitude) and R (epicentral distance); M = 6.5 with R = 80 km and 100 km, M = 7.0 with R = 60 km and 80 km, M=7.5 with R= 40 km and 60 km, and M = 8.0 with R = 40 km and 60 km.

Typical ground motion time histories for two extreme combinations M = 8.0 with R = 40 km and M = 6.5 with R = 100 km are shown in figure 3-3. For the purpose of response analysis, a sample of ten time histories generated from each M and R combination is matched with a sample of ten bridges in a pseudo Latin Hypercube format; pseudo in the sense that the sample of ten bridges is the same for all the combinations of M and R. Hence, each statistical representation of Bridges 1 and 2 are subjected to 80 ground motion time histories. The spectral accelerations averaged over 10 acceleration time histories used in this study from each of the combinations M = 7.5 for R = 40 km, and 60 km are shown in figure 3-4 to provide an insight to the frequency content of these ground motion time histories.

The present study utilizes the SAP 2000 finite element code, which is user-friendly particularly for bridge design and analysis, in order to simulate the state of damage of each structure under ground acceleration time history. This computer code can provide hysteretic elements that are in essence bilinear without strength or stiffness degeneration. The results from SAP 2000 code was validated for the bilinear behavior by analyzing the same problem using ANSYS computer code. Similarly, validation should be made using ANSYS, DIANA and other up-scale codes to account for bilinear hysteresis with strength and stiffness degradation in order to identify the extent of the approximation the SAP 2000 code provides. Such validation and adjustment would provide an analytical basis for possibly improving SAP 2000 results in a systematic fashion to derive more realistic fragility curves in an efficient fashion. This indeed is an interesting future study.

The states of damage considered for both Bridges 1 and 2 are major (all the columns subjected to ductility demand $\geq 2$) and "at least minor" (all the columns subjected to ductility demand $\geq 1$) under the longitudinal applications of ground motion. For the Memphis bridges, the median and log-standard deviation parameters for the log-normal fragility curves were estimated by Method 1. Figure 3-5 shows the fragility curves associated with these states of damage for Bridges 1 and 2. Eighty diamonds are plotted in figure 3-5 and also more clearly in figure 3-6 on the two horizontal axes represent $x_i = 0$ (for state of less than major damage) and $x_i = 1$ (for state of major damage) in relation to (2-1) for Bridge 1 under the eighty earthquakes generated. The corresponding fragility curve is derived on the basis of these diamonds and replotted in figure 3-6 to demonstrate more easily how well the corresponding fragility curves fit to the input damage data. Similar eighty diamonds associated with the state of minor damage for Bridge1 are plotted in figure 3-7 together with the corresponding fragility curve. Actually, the empirical fragility curves for the Caltrans' and HEPC's bridges are developed also in this fashion. However, visual demonstration of curve fitting in this format by plotting respectively 1998 and 770 points on the two horizontal axes is not very effective. This is the reason why the graphical demonstration was made in figures 2-7~2-14 and figures 2-18~2-23 on the basis of the appropriate grouping of individual damage events.

Figures 3-8 and 3-9 plot the fragility curves for Bridge 1 associated with at least minor damage and with major damage, respectively with solid curves based on 80 earthquakes and dashed curves on 60 earthquakes (in accordance with the pseudo-hyper Latin cube procedure described earlier). The results suggest that the reduction of sample size from 80 to 60 may be tolerable for the fragility curve development. Caution should be exercised, however, to recognize that the key to develop a reasonable fragility curve is not only to have an adequate sample size (a minimum of 30 or so) but also to have the sample covering appropriately the three ranges of PGA for no damage, damage and variable fragility (e.g., PGA $\leqq$ 0.20g, PGA $\geqq$ 0.35g and PGA between the two in figure 3-9). The intermediate range is where the fragility value rises from zero to unity. Unfortunately, the adequacy of such a coverage can only be judged after the fact. Hence, depending on the simulation result at hand, decision must be made whether to terminate or continue with the simulation primarily on the basis of judgment. It is mentioned in passing that this option of increasing the sample size at the expense of additional computational effort does not exist for the empirical fragility curve development in the sense that the source of data is limited to the damage report. The analysis performed under the ground motion in the transverse direction produced states of lesser damage and hence not given in this report.

The relatively simplistic definition of the damage state used in this analysis can be improved in order to reflect the most advanced state of the art in dealing with both computational and damage-related mechanics. This, however, can only be achieved at the expense of additional effort of significant dimension which would delay dissemination of information and findings presented here that the structural engineering community might find useful and interesting in the interim. This observation is also consistent with the view expressed in relation to the damage state categorization issues mentioned in Section 2.

It is important to recognize that mixed modes of failure can occur simultaneously as well as sequentially depending on the specific process of dynamic response each bridge experiences. The following modes of failure are more obvious examples to which due consideration must be given. The columns can fail not only in a single mode under bending or under shear, but also in a mixed bending and shear mode as demonstrated for HEPC's bridge columns in figure 2-1. Prior to these serious failures that could induce a state of collapse of a bridge, however, bearings located on bents could fail when bridge columns and decks are not monolithically constructed. The bearing failure can not only induce states of physical damage such as unseating and falling-off of the decks, but also potentially result in traffic closure by creating abrupt deck surface irregularity even when essential bridge structural components such as decks themselves, columns and abutments suffer from little damage. Similar failures including those arising from pounding between adjacent decks could occur, particularly at expansion joints. At present, however, these modes of failure present a significant technical challenge to be included in the dynamic analysis in the sequence they occur. Indeed, it is one thing to analytically formulate the failure criteria, but it is entirely another to reproduce computationally the sequence of these failures. Quasi-static and related approaches may provide additional information to circumvent this difficulty.

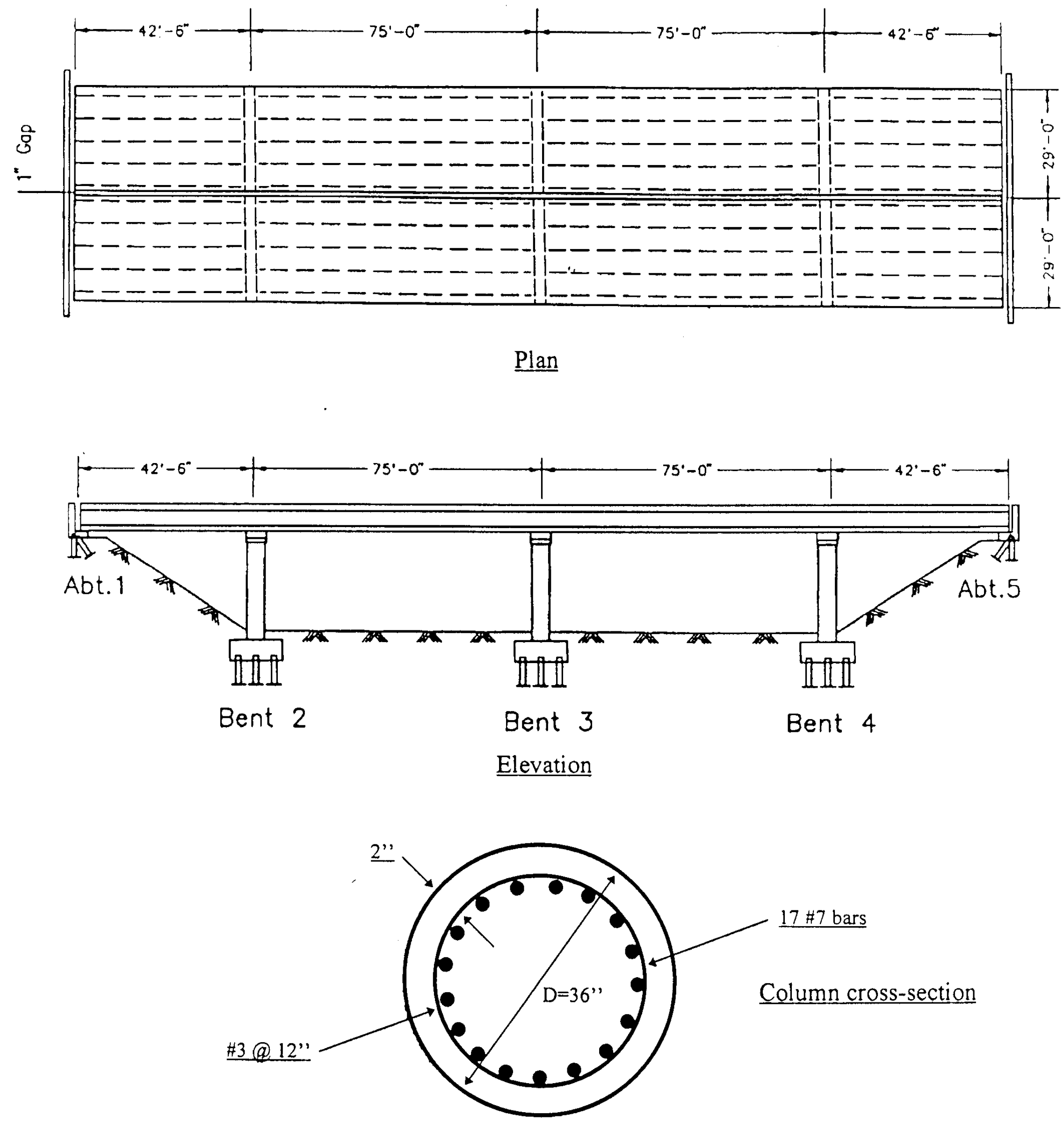



**FIGURE 3-1 A Representative Memphis Bridge**

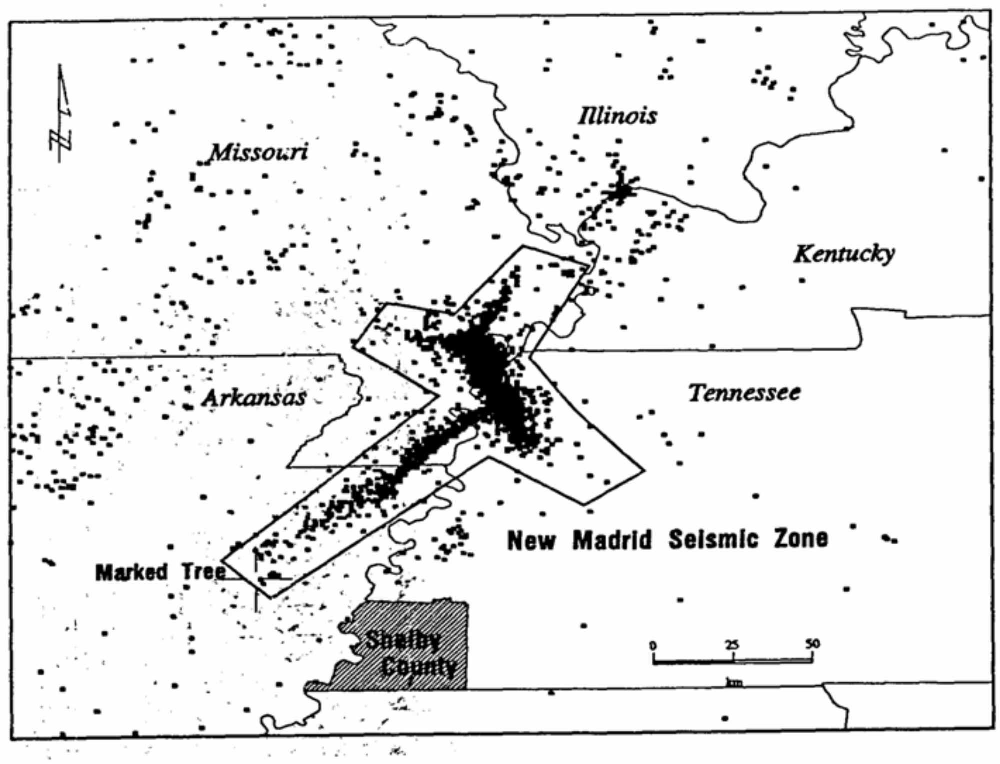



**FIGURE 3-2 New Madrid Seismic Zone and Marked Tree, AR**

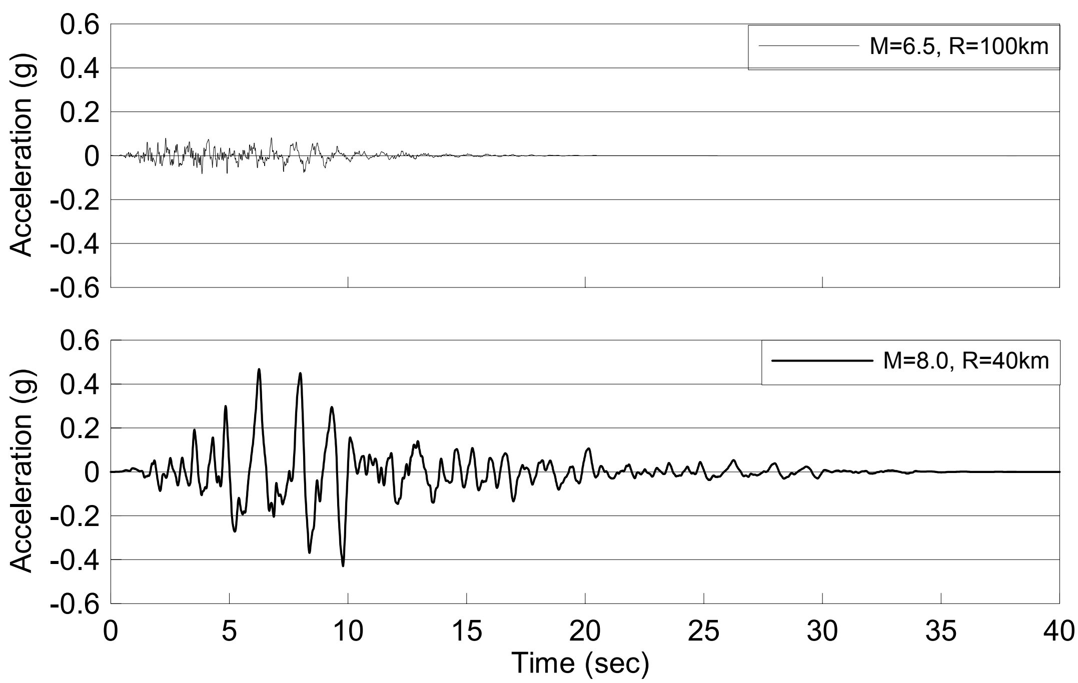



**FIGURE 3-3 Typical Ground Acceleration Time Histories in the Memphis Area**

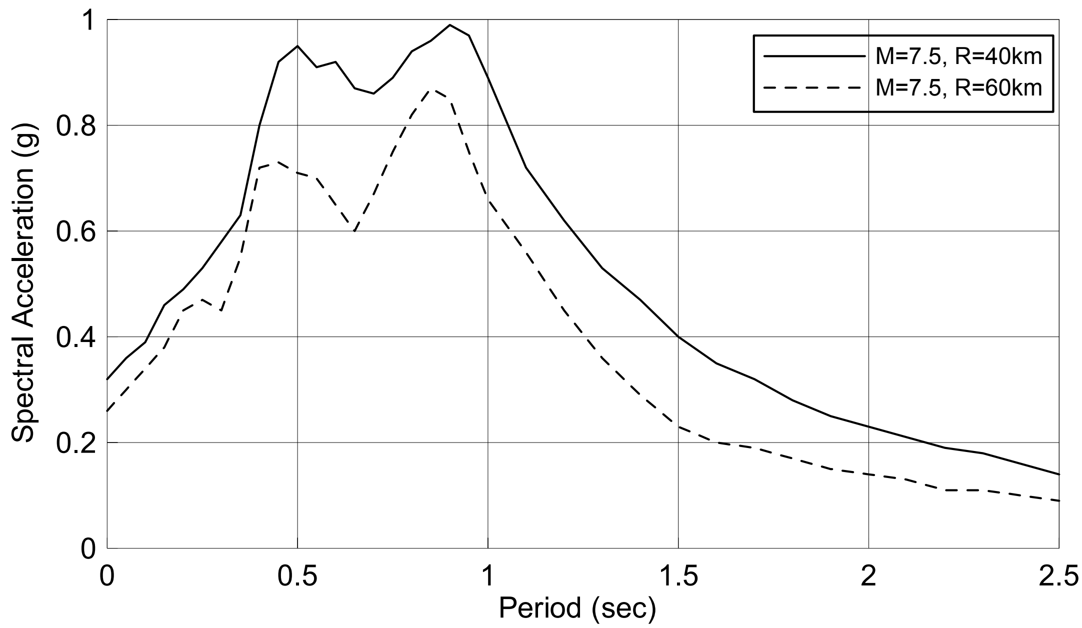



**FIGURE 3-4 Average Spectral Accelerations in the Memphis Area**

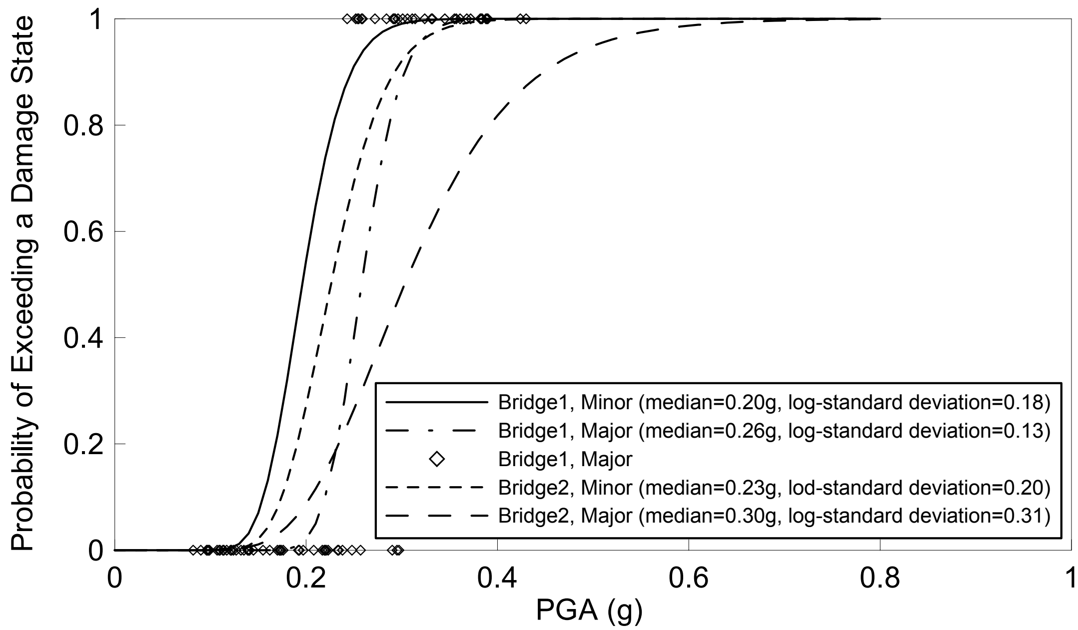



**FIGURE 3-5 Fragility Curves for Memphis Bridges 1 and 2**

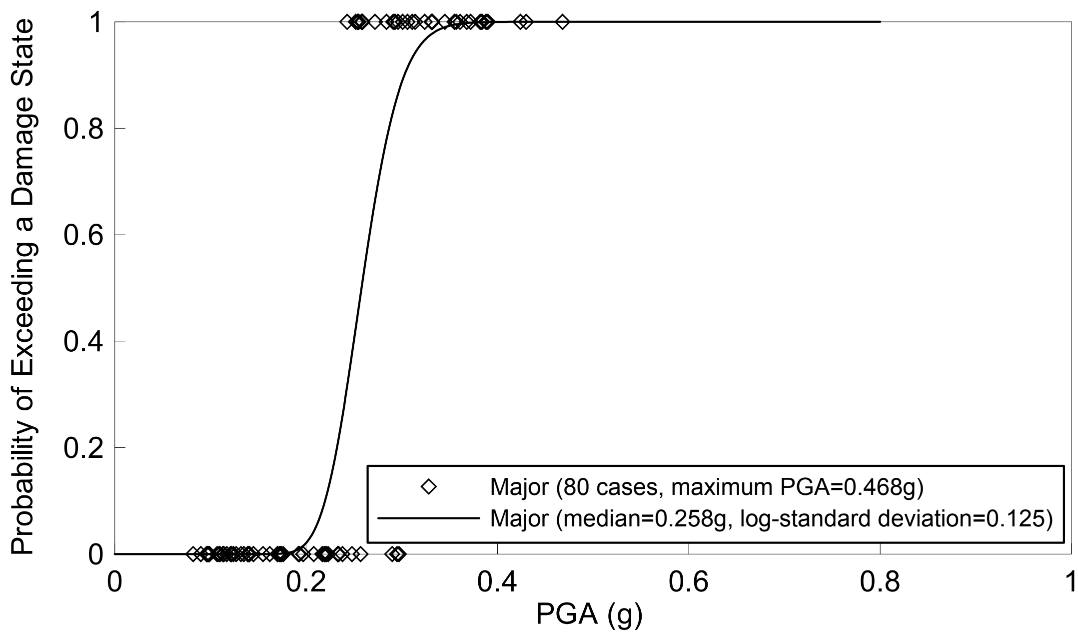



**FIGURE 3-6 Fragility Curve for Bridge 1**
**with Major Damage and Input Damage Data**

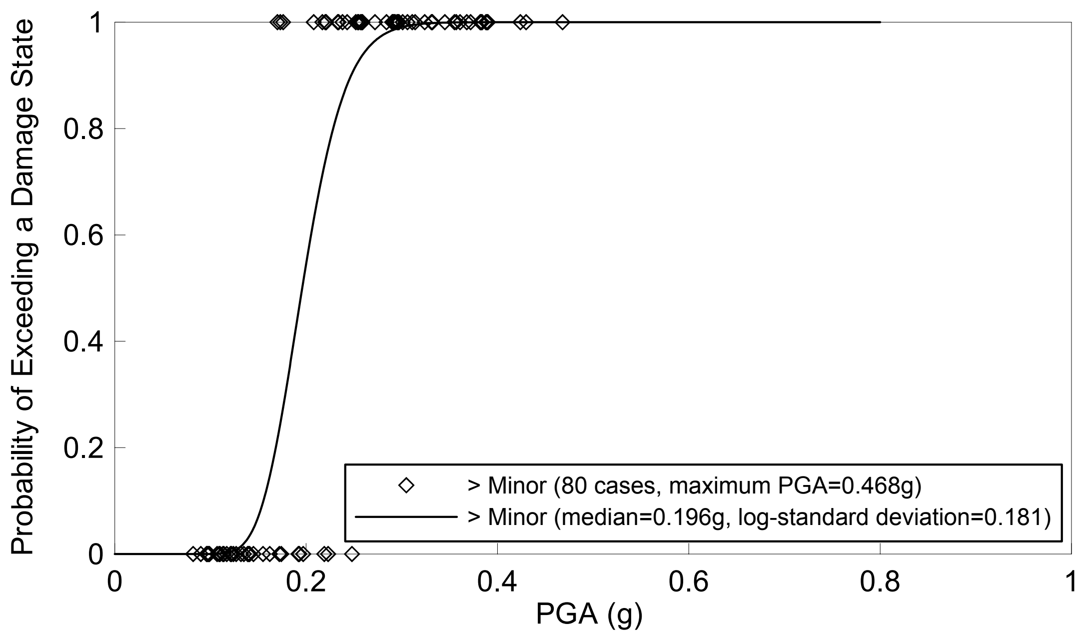



**FIGURE 3-7 Fragility Curve for Bridge 1**
**with at least Minor Damage and Input Damage Data**

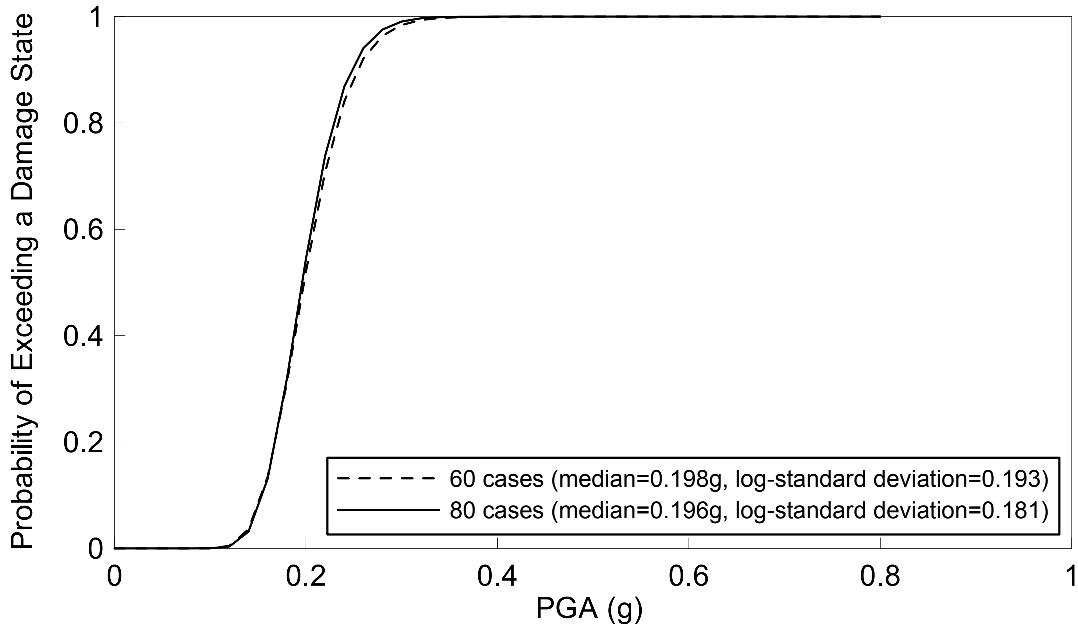



**FIGURE 3-8 Comparison of Fragility Curves**

**based on Sample Size 80 and 60 (Bridge 1 with at least Minor Damage)**

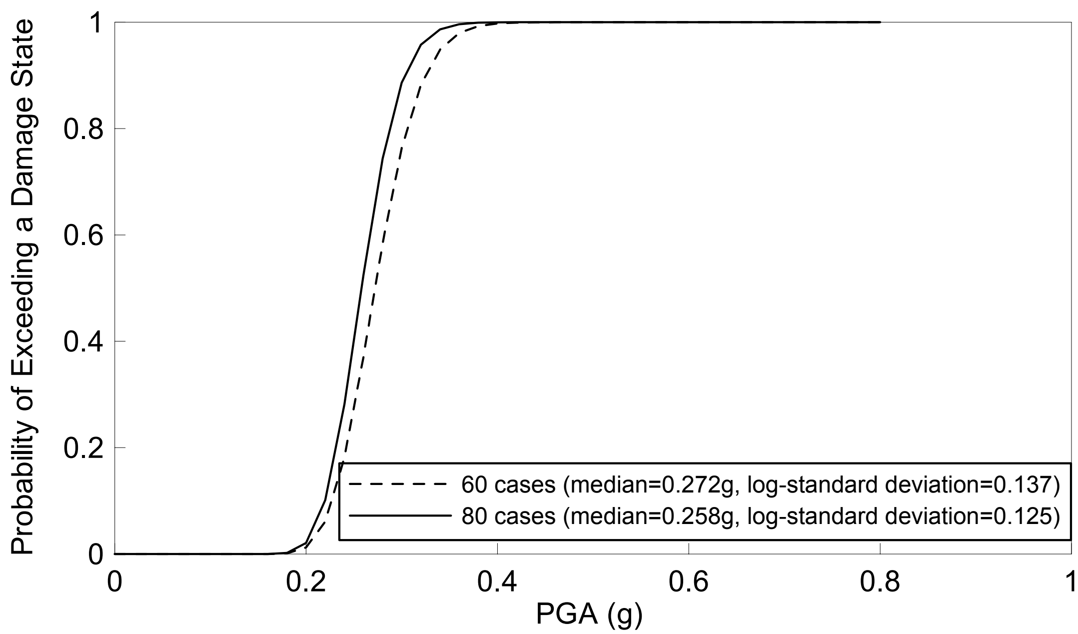



**FIGURE 3-9 Comparison of Fragility Curves**

**based on Sample Size 80 and 60 (Bridge 1 with Major Damage)**

# SECTION 4
# MEASURES OF GROUND MOTION ITENSITY

Expressing the fragility curves as a function of other measures of earthquake ground motion intensity, rather than PGA, has been advocated and promoted by many researchers and practitioners. The spectral acceleration (SA) is the most prominent among these alternative measures. Indeed, the spectral acceleration is a good measure under the conditions that the structural response is primarily in the linear range, structural dynamic characteristics including damping properties are reasonably well known, geotechnically consistent earthquake ground motion time histories are either easily specifiable or readily available from pertinent database, and the state of damage for which the fragility curve is to be developed depends mainly on the instantaneous maximum inertia force exerted by an episode of the ground motion. However, when one tries to develop empirical fragility curves on the basis of a large sample of structures, all different in structural detail if not in geometry, configuration and structural type, subjected to a severe earthquake, none of these conditions is satisfactorily met, particularly when the damage state of interest involves, as it usually does, significantly nonlinear structural deformation and/or the effect of repeated stress or strain cycles. Even for a structure with well-known dynamic characteristics, the implication of idealizing it as a single-degree-of-freedom system often well into a nonlinear range is not always palatable. Nevertheless, this study develops fragility curves for Memphis Bridge 1 as functions of SA. Some researchers also claim that ground velocity-related quantities are more appropriate for this purpose. They include PGV (peak ground velocity), SV (spectral velocity) and SI (spectrum intensity). This study also develops fragility curves as functions of these velocity-related intensity parameters. PGV is the absolute maximum value of the ground velocity associated with a particular ground velocity time history, SV is the maximum pseudo (relative) response velocity of a damped single-degree-of-freedom system to the acceleration time history as a function of natural period, and SI is the average of SV over the natural period between 0.1 and 2.5 sec following the original Housner's definition (Housner, 1952). The structural damping coefficient is assumed in all calculations to be 5%, although Housner used 2% for SI calculations (Housner, 1952).

The simulated damage data and the estimated Bridge 1 fragility curves are shown in figures 4-1 and 4-2 as functions of SA respectively for the at least minor and the major state of damage. Since the simulation is performed primarily under linear analysis when the at least minor damage (ductility demand $\geq$ 1.0 for all columns) is considered, figure 4-1 shows the fragility curve taking in essence the shape of unit step function. This reflects the damage condition primarily depending on SA and the small effect of the statistical variation associated with structural materials (fundamental period varies between 1.22 and 1.33 sec) on the damage condition. On the other hand, the fragility curve for the major damage state (ductility demand $\geq$ 2.0 for all columns) rises from zero at SA approximately equal to 0.20g and approaches unity at SA about equal to 0.45g. Clearly, the shape is no longer close to that of the unit step function, because of the damage condition that depends on many other factors, mentioned earlier in addition to SA.

Figures 4-3 and 4-4 plot the fragility curves for the same two damage states as functions of PGV. Since the log-standard deviation represents in approximation the coefficient of variation $V$ of the lognormal variable, it can be used to measure how sharply the fragility curve rises from zero to unity. For example, the fragility curves shown in figures 3-7 and 4-3 for the at least minor damage for Bridge 1 have $V$ = 0.181 and $V$ = 0.207 respectively indicating the fragility curve developed as a function of PGA has a sharper rise than as a function PGV. On the other hand, the curves shown in figures 3-6 and 4-4 for the major damage have $V$ = 0.125 as a function of PGA and $V$ = 0.083 as a function of PGV respectively indicating the opposite trend. These results suggest that, if a sharper rise of the fragility curve or a smaller log-standard deviation represents a better measure of the ground motion intensity as a function of which the fragility curve is developed, PGA is a better measure than PGV in one case but PGV is better for the other case. Thus, a more elaborate study is needed to resolve this question.

The spectral velocity SV appears to discriminate sharply the occurrence of the state of at least minor damage as shown in figure 4-5, while such sharpness is not repeated for the state of major damage as shown in figure 4-6. The reason for this appears to stem from the fact that the discriminating value of SV in figure 4-5 corresponds to that of SA in figure 4-1 through the standard tripartite relationship.

Finally, fragility curves are developed as functions of spectrum intensity SI as shown in figures 4-7 and 4-8. Four (4) intervals, 0~2.5, 0~3.0, 0~3.5 and 0~4.0 sec, are used over which the average of SV is taken for the computation of SI. It is of interest to note that the fragility curves take the shape of the unit step function for the state of major damage as distinctly shown in figure 4-8, but not for the state of at least minor damage as shown in figure 4-7.

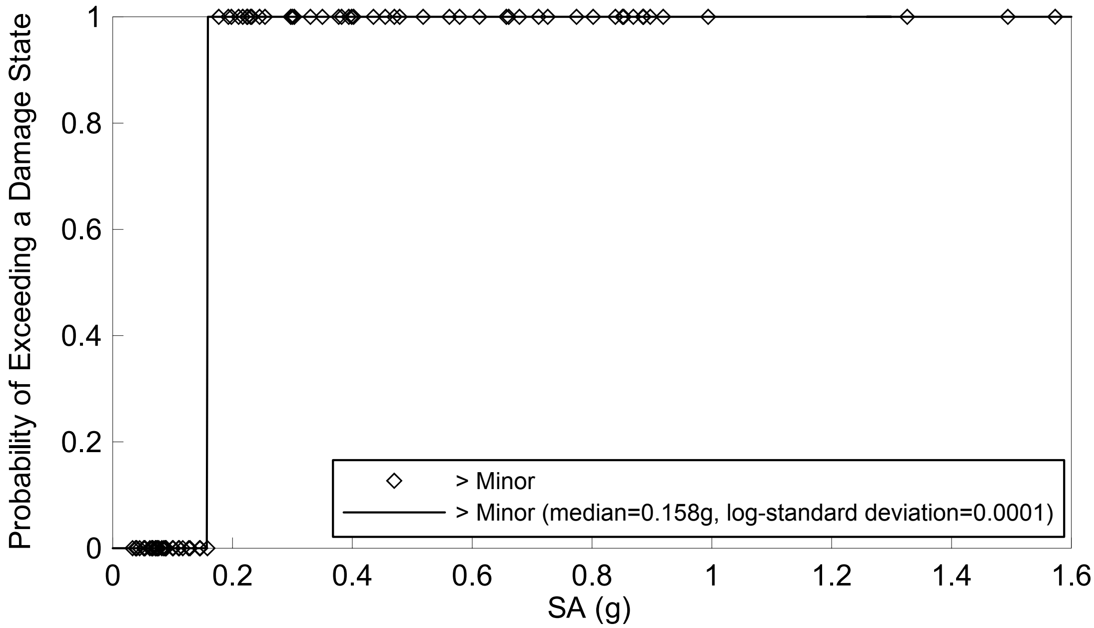



**FIGURE 4-1 Fragility Curve as a Function of Spectral Acceleration (at least Minor Damage or Ductility Demand ≥ 1.0) and Input Damage Data**

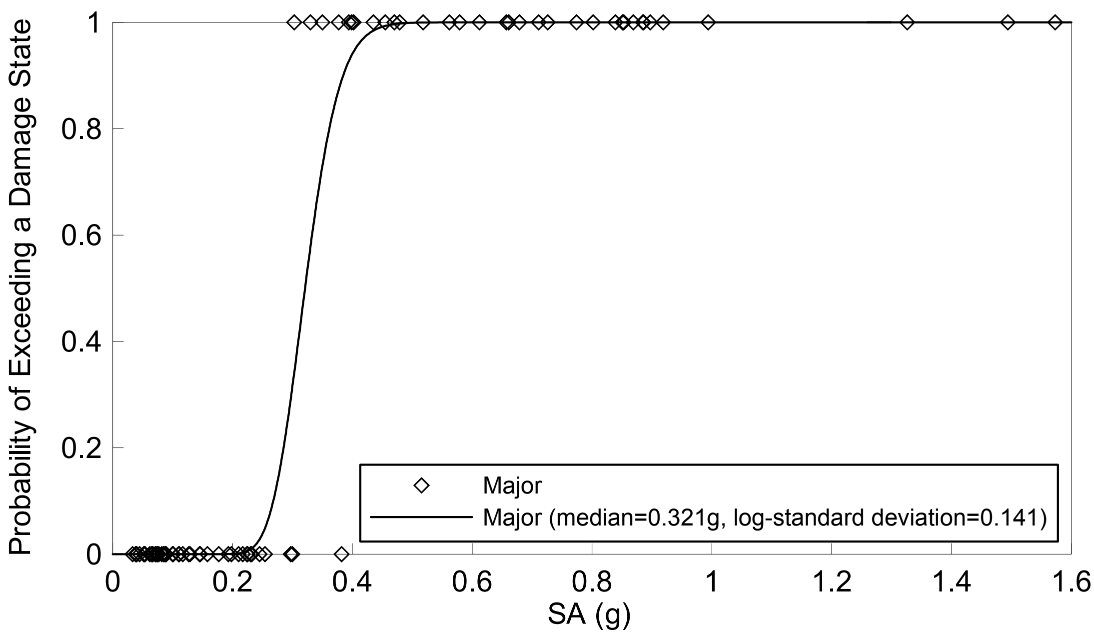



**FIGURE 4-2 Fragility Curve as a Function of Spectral Acceleration (Major Damage or Ductility Demand ≥ 2.0) and Input Damage Data**

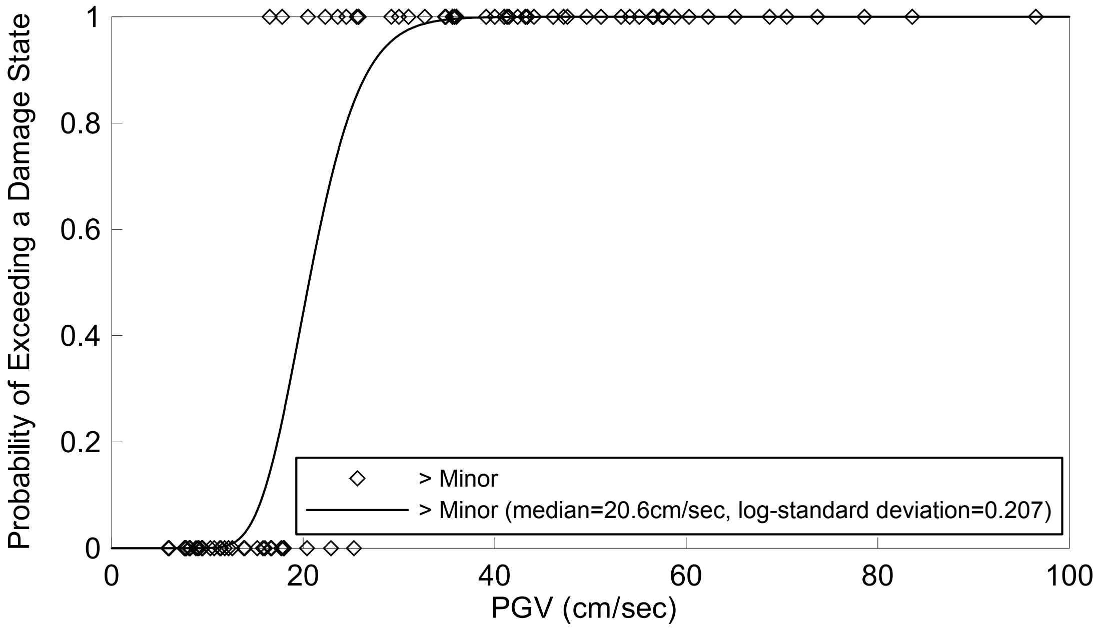



**FIGURE 4-3 Fragility Curve as a Function of Peak Ground Velocity (at least Minor Damage or Ductility Demand ≥ 1.0) and Input Damage Data**

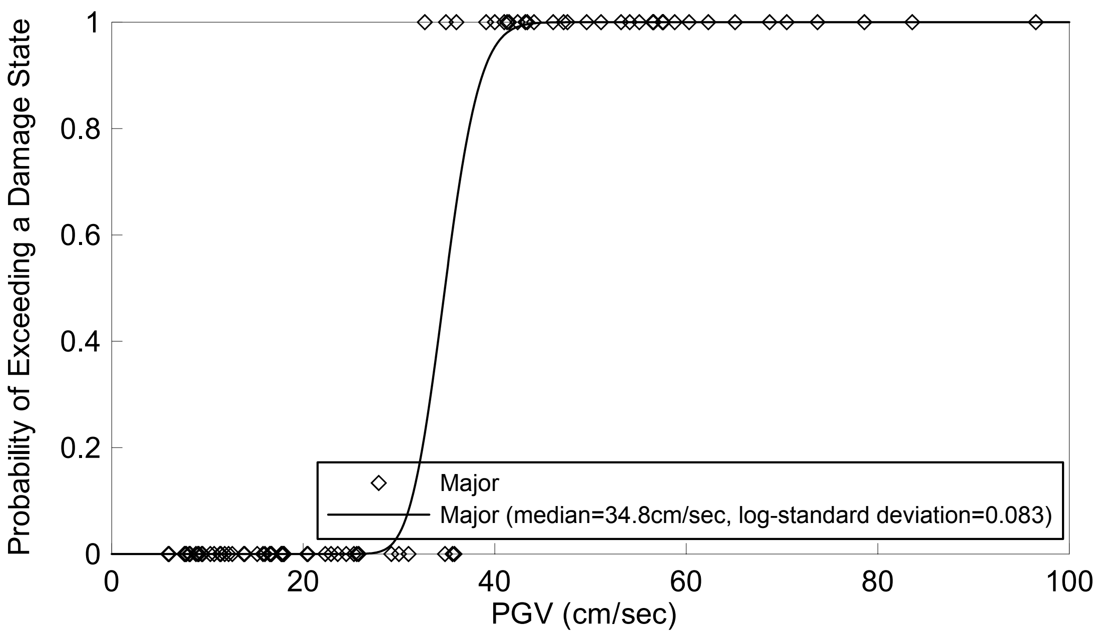



**FIGURE 4-4 Fragility Curve as a Function of Peak Ground Velocity (Major Damage or Ductility Demand ≥ 2.0) and Input Damage Data**

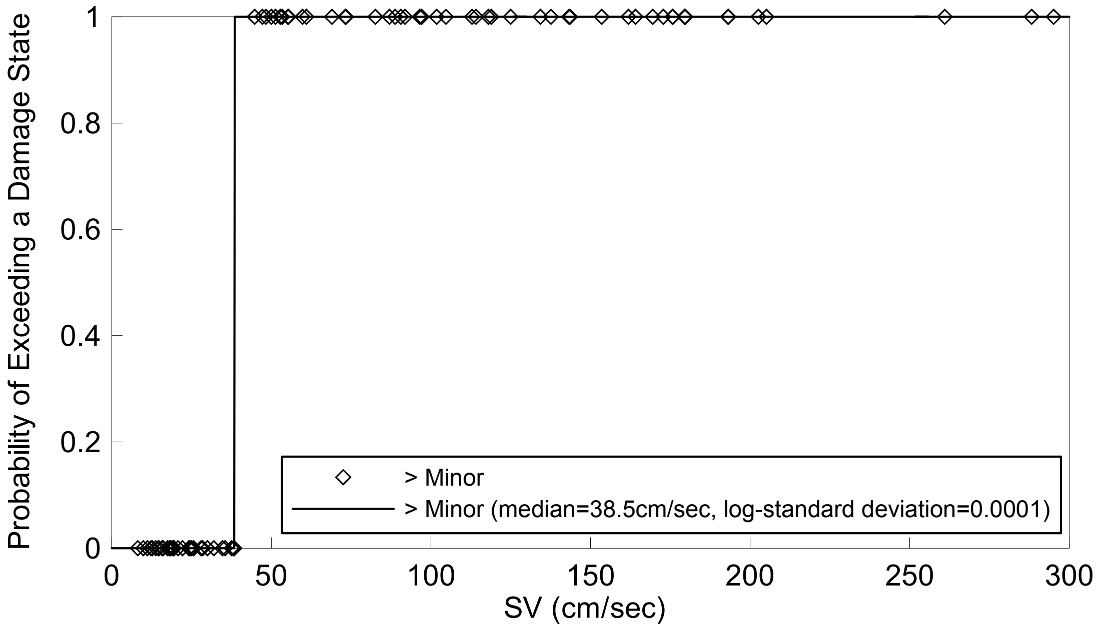



**FIGURE 4-5 Fragility Curve as a Function of Spectral Velocity (at least Minor Damage or Ductility Demand ≥ 1.0) and Input Damage Data**

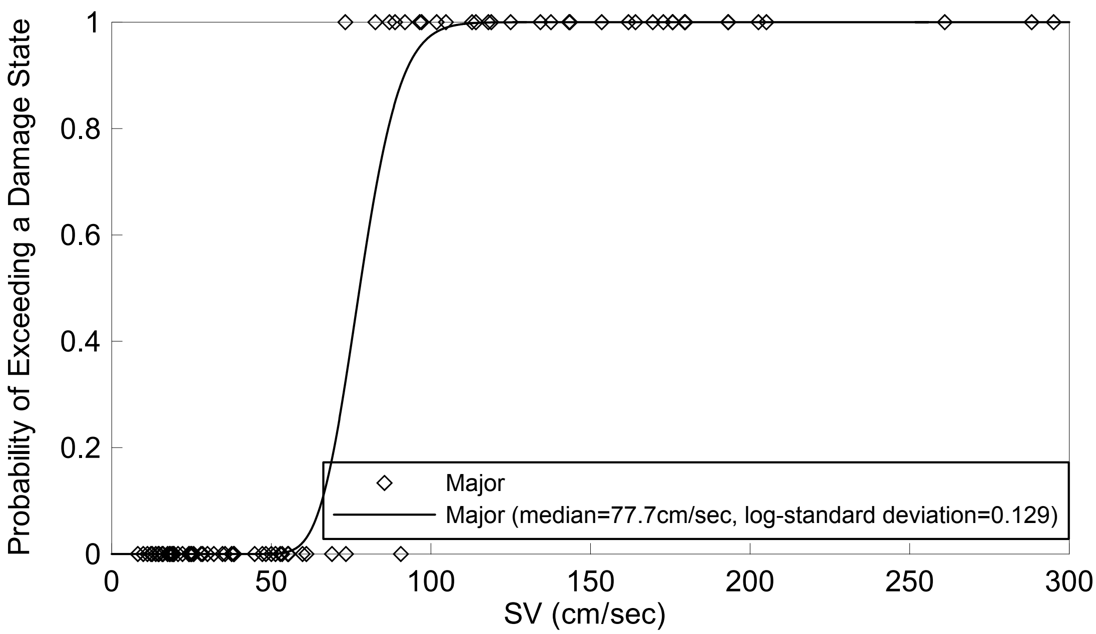



**FIGURE 4-6 Fragility Curve as a Function of Spectral Velocity (Major Damage or Ductility Demand ≥ 2.0) and Input Damage Data**

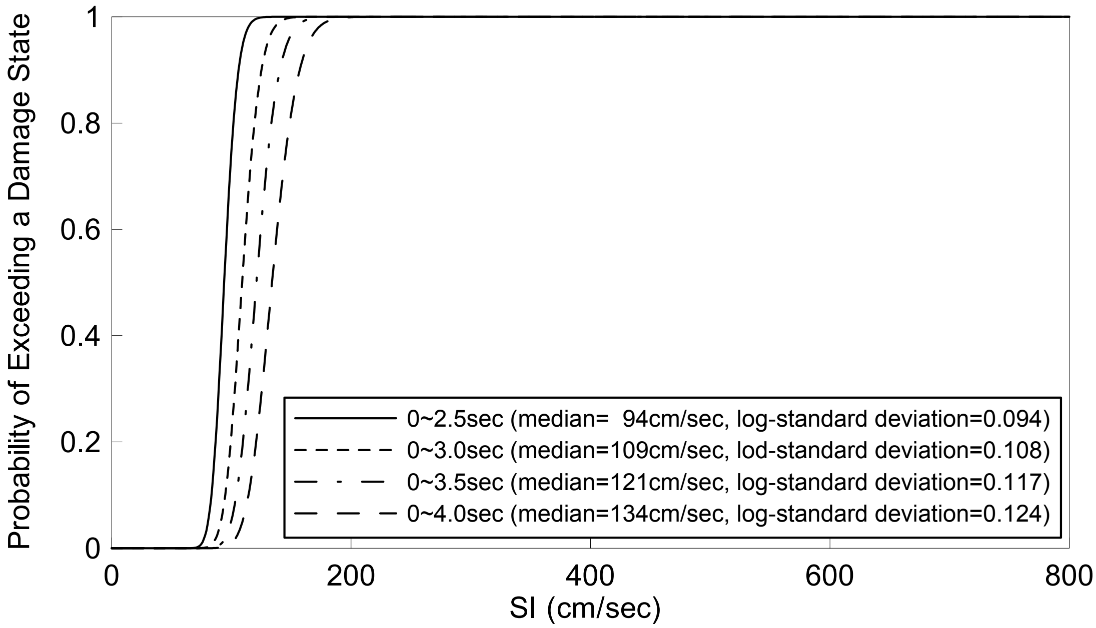



**FIGURE 4-7 Fragility Curve as a Function of Spectral Intensity (at least Minor Damage or Ductility Demand ≥ 1.0) and Input Damage Data**

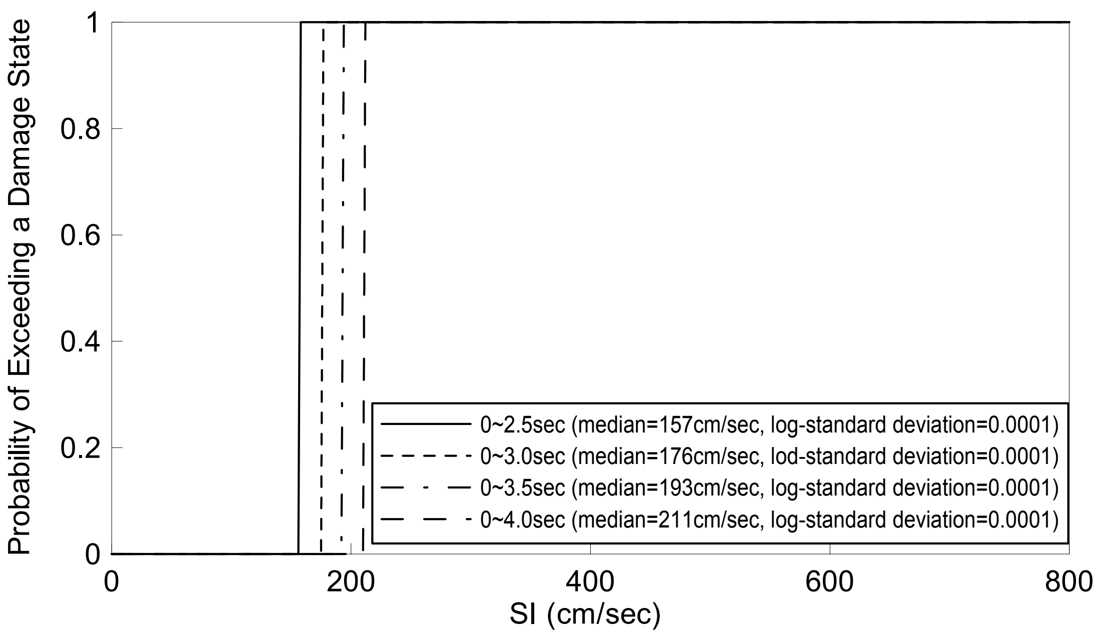



**FIGURE 4-8 Fragility Curve as a Function of Spectral Intensity (Major Damage or Ductility Demand ≥ 2.0) and Input Damage Data**

# SECTION 5
# OTHER STATISTICAL ANALYSES

The issues of hypothesis testing and confidence intervals relating to fragility curve development have not been addressed in the literature so far. This appears primarily because of the fact that the earthquake engineering community has never had the opportunity to collect damage data of a sufficiently large sample that can be used to develop fragility curves on the basis of legitimate statistical analysis. However, the 1994 Northridge and the 1995 Kobe earthquake, inflicting devastating damage upon many bridges, buildings, port facilities and other engineered structures, made it possible to consider statistical methods to analyze the probabilistic characteristics of damage in a more judicious fashion rather than relying on an ad hoc curve fitting exercise. In the following, goodness of fit of the estimated fragility curves to the input damage data is tested by separate statistical procedures depending on whether the parameters of the fragility curves are estimated by Method 1 or Method 2. Then, the statistical confidence of these parameters are in turn estimated separately depending on the use of Method 1 or Method 2 for the parameter estimation.

## 5.1 Test of Goodness of Fit; Method 1

The fundamental probabilistic interpretation of a fragility curve $F(a)$ as a function of "$a$" suggests that a bridge will sustain a designated state of damage with probability $F(a)$ and will not sustain the damage state with probability $1-F(a)$ under the earthquake intensity represented by PGA equal to "$a$". This means that, under each PGA value, the probabilistic phenomena one deals with can be described by random variable $X_i$ following the Bernoulli distribution such that $X_i = 1$ when the state of damage is reached under PGA $= a_i$, and $X_i = 0$ otherwise. Then,

$$Y_i^2 = \left(X_i - p_i\right)^2 \tag{5-1}$$

has mean and variance equal to

$$\mu_{Y_i^2} = p_i\left(1-p_i\right) \tag{5-2}$$

and

$$\sigma^2{}_{Y_i^2} = Var\left(Y_i^2\right) = p_i\left(1-p_i\right)\left(1-2p_i\right)^2 \tag{5-3}$$

respectively, where $p_i = F\left(a_i\right)$.

The sum of $Y_i^2$ shown below

$$Y^2 = \sum_{i=1}^{N}\left(X_i - p_i\right)^2 \tag{5-4}$$

approaches asymptotically Gaussian as $N$ becomes large under the assumption that each Bernoulli event is independent, where $N$ is the sample size (the total number of the bridges inspected) and in this analysis it is indeed a large value (>>1).

Recalling that $X_i$ is independent of $X_j$ $\left(i \neq j\right)$ and governed by the Bernoulli distribution, a straightforward analysis shows that the expected value $\mu_{Y^2} = \mathrm{E}\left(Y^2\right)$ and the variance $\sigma^2{}_{Y^2} = Var\left(Y^2\right)$ can be written as

$$\mu_{Y^2} = \mathrm{E}\left(Y^2\right) = \sum_{i=1}^{N} p_i\left(1-p_i\right) \tag{5-5}$$

and

$$\sigma^2{}_{Y^2} = Var\left(Y^2\right) = \sum_{i=1}^{N} p_i\left(1-p_i\right)\left(1-2p_i\right)^2 \tag{5-6}$$

On the other hand, if $x_i$ represents the realization (observation) of $X_i$ as defined in the likelihood function given by (2-1),

$$y^2 = \sum_{i=1}^{N}\left(x_i - p_i\right)^2 \tag{5-7}$$

is the realization of $Y^2$.

Since $p_i$ depends on the values of $c_0$ and $\zeta_0$, the standard procedure of hypothesis testing suggests that if $\alpha$ represents the level of statistical significance such that

$$P_{y^2} = \Phi\left(\frac{y^2 - \mu_{y^2}}{\sigma_{y^2}}\right) \le 1 - \alpha \tag{5-8}$$

then, the hypothesis that $c_0$ and $\zeta_0$ are indeed the true values of $c$ and $\zeta$ cannot be rejected with the significance level $\alpha$ usually set equal to 0.05 or 0.10.

The $P_{y^2}$ values for the fragility curve developed for Caltrans' bridges (figure 2-3), HPEC's bridges (figure 2-16), and Memphis Bridges 1 and 2 (figure 3-5) are given in table 5-1. The work sheets that describe in detail the computational procedures of obtaining $P_{y^2}$ associated with Caltrans', and HEPC's bridges as well as Memphis Bridges 1 and 2 are exhibited in tables 5-2, 5-3, 5-4 and 5-5. Table 5-2 does not constitute a complete set of work sheets but only demonstrate the first and the last page of the work sheets for each damage state. Table 5-3 shows abbreviated sets of sheets based on 14 subgroups of 55 bridges columns, each subgroup subjected to approximately the same PGA. On the other hand, tables 5-4 and 5-5 represent complete sets of work sheets, providing the simulated input damage data for Memphis Bridges 1 and 2, respectively. These values of $P_{y^2}$ indicate that the hypotheses involved in all the cases cannot be discarded at the significance level of 10%. It is noted here that this method can test the goodness of fit of fragility curves only over the range of PGA where damage data sufficiently exist. For example, the fragility curve for a Caltrans' bridge associated with the state of minor damage in figure 2-7 is not necessarily valid beyond 0.8g.

Figures 5-1~5-4 show the validity of the assumption of in (5-4) being asymptotically normal by means of plotting 100 simulated realizations of $Y^2$ associated with the corresponding state of damage, respectively. This requires simulation of $X_i$ at each $a_i$ using $p_i$ based on $c_0$ and $\zeta_0$ obtained from the empirically or analytically observed damage data for each state of damage. Upon simulating all $X_i$ for all $a_i$ and obtaining their realizations $x_i$, (5-7) is evaluated. This process is repeated n times (n=100 here) to produce 100 realizations of $Y^2$, each representing one set of simulation of $x_i$ ($i$ = 1,2,…,$N$). This sample of $y^2$ is indeed plotted in figures 5-1~5-4 for the corresponding states of damage using the normal probability paper; the dashed line represents the least square fit of the sample, while the solid line indicates the theoretical normal distribution with the mean and standard deviation given by (5-5) and (5-6) respectively for the fragility curves for Caltrans' bridges. For fragility curves demonstrated above for other types of bridges, the simulated realizations of $Y^2$ can also be shown to distribute in accordance with normal distributions with their respective mean and standard deviation derivable from (5-5) and (5-6), and demonstrate the validity of the asymptotic normality of $Y^2$.

**Table 5-1 $P_{y^2}$ Values for Goodness of Fit (Method 1)**

| Damage State (1) | Caltrans' Bridges (2) | HEPC's Bridges (3) | Memphis Bridge 1 (4) | Memphis Bridge 2 (5) |
|---|---|---|---|---|
| Minor | 0.38 | 0.38 | 0.64 | 0.48 |
| Moderate | 0.58 | 0.86 | ------- | ------- |
| Major | 0.56 | 0.72 | 0.57 | 0.64 |
| Collapse | 0.50 | ------- | ------- | ------- |

## Table 5-2(a) Work-Sheet for Test of Goodness of Fit (Minor Damage/Caltrans' Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1\text{-Pi})^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ | $N{*}Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ |
| 1 | 0 | 1 | 0.0688 | 0.001401 | 0 | 1 | 0.9972000 | 0.00000196 | 0.00000196 | 0.001399 | 0.001399 | 0.001391173 | 0.001391173 |
| 2 | 0 | 1 | 0.0717 | 0.001644 | 0 | 1 | 0.9967155 | 0.00000270 | 0.00000270 | 0.001641 | 0.001641 | 0.001630119 | 0.001630119 |
| 3 | 0 | 1 | 0.0717 | 0.001644 | 0 | 1 | 0.9967155 | 0.00000270 | 0.00000270 | 0.001641 | 0.001641 | 0.001630119 | 0.001630119 |
| 4 | 0 | 1 | 0.0721 | 0.001679 | 0 | 1 | 0.9966447 | 0.00000282 | 0.00000282 | 0.001676 | 0.001676 | 0.001665001 | 0.001665001 |
| 5 | 0 | 1 | 0.0721 | 0.001679 | 0 | 1 | 0.9966447 | 0.00000282 | 0.00000282 | 0.001676 | 0.001676 | 0.001665001 | 0.001665001 |
| 6 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 7 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 8 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 9 | 0 | 1 | 0.0731 | 0.001770 | 0 | 1 | 0.9964633 | 0.00000313 | 0.00000313 | 0.001767 | 0.001767 | 0.001754279 | 0.001754279 |
| 10 | 0 | 1 | 0.0732 | 0.001779 | 0 | 1 | 0.9964449 | 0.00000317 | 0.00000317 | 0.001776 | 0.001776 | 0.001763371 | 0.001763371 |
| 11 | 0 | 1 | 0.0732 | 0.001779 | 0 | 1 | 0.9964449 | 0.00000317 | 0.00000317 | 0.001776 | 0.001776 | 0.001763371 | 0.001763371 |
| 12 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 13 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 14 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 15 | 0 | 1 | 0.0744 | 0.001893 | 0 | 1 | 0.9962183 | 0.00000358 | 0.00000358 | 0.001889 | 0.001889 | 0.001874807 | 0.001874807 |
| 16 | 0 | 1 | 0.0746 | 0.001912 | 0 | 1 | 0.9961796 | 0.00000366 | 0.00000366 | 0.001908 | 0.001908 | 0.001893802 | 0.001893802 |
| 17 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 18 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 19 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 20 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 21 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 22 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 23 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 24 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 25 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 26 | 0 | 1 | 0.0753 | 0.001981 | 0 | 1 | 0.9960423 | 0.00000392 | 0.00000392 | 0.001977 | 0.001977 | 0.001961237 | 0.001961237 |
| 27 | 0 | 1 | 0.0753 | 0.001981 | 0 | 1 | 0.9960423 | 0.00000392 | 0.00000392 | 0.001977 | 0.001977 | 0.001961237 | 0.001961237 |
| 28 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 29 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 30 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 31 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 32 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 33 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 34 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 35 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 36 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 37 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 38 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 39 | 0 | 1 | 0.0764 | 0.002092 | 0 | 1 | 0.9958203 | 0.00000438 | 0.00000438 | 0.002088 | 0.002088 | 0.002070225 | 0.002070225 |
| 40 | 0 | 1 | 0.0767 | 0.002123 | 0 | 1 | 0.9957584 | 0.00000451 | 0.00000451 | 0.002119 | 0.002119 | 0.002100593 | 0.002100593 |
| 41 | 0 | 1 | 0.0769 | 0.002144 | 0 | 1 | 0.9957168 | 0.00000460 | 0.00000460 | 0.002139 | 0.002139 | 0.002120993 | 0.002120993 |
| 42 | 0 | 1 | 0.0770 | 0.002154 | 0 | 1 | 0.9956959 | 0.00000464 | 0.00000464 | 0.002150 | 0.002150 | 0.002131239 | 0.002131239 |
| 43 | 0 | 1 | 0.0770 | 0.002154 | 0 | 1 | 0.9956959 | 0.00000464 | 0.00000464 | 0.002150 | 0.002150 | 0.002131239 | 0.002131239 |
| 44 | 0 | 1 | 0.0771 | 0.002165 | 0 | 1 | 0.9956750 | 0.00000469 | 0.00000469 | 0.002160 | 0.002160 | 0.002141515 | 0.002141515 |
| 45 | 0 | 1 | 0.0772 | 0.002175 | 0 | 1 | 0.9956539 | 0.00000473 | 0.00000473 | 0.002171 | 0.002171 | 0.002151823 | 0.002151823 |
| 46 | 0 | 1 | 0.0773 | 0.002186 | 0 | 1 | 0.9956328 | 0.00000478 | 0.00000478 | 0.002181 | 0.002181 | 0.002162162 | 0.002162162 |
| 47 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 48 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 49 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 50 | 0 | 1 | 0.0776 | 0.002218 | 0 | 1 | 0.9955692 | 0.00000492 | 0.00000492 | 0.002213 | 0.002213 | 0.002193363 | 0.002193363 |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 1979. | 1 | 1 | 0.8470 | 0.500000 | 1 | 0 | 0.2500000 | 0.25000000 | 0.25000000 | 0.250000 | 0.250000 | 0.000000000 | 0.000000000 |
| 1980 | 0 | 1 | 0.8470 | 0.500000 | 0 | 1 | 0.2500000 | 0.25000000 | 0.25000000 | 0.250000 | 0.250000 | 0.000000000 | 0.000000000 |
| 1981 | 1 | 1 | 0.8504 | 0.501903 | 1 | 0 | 0.2481010 | 0.25190626 | 0.24810098 | 0.249996 | 0.249996 | 0.000003620 | 0.000003620 |
| 1982 | 1 | 1 | 0.8504 | 0.501903 | 1 | 0 | 0.2481010 | 0.25190626 | 0.24810098 | 0.249996 | 0.249996 | 0.000003620 | 0.000003620 |
| 1983 | 1 | 1 | 0.8504 | 0.501903 | 1 | 0 | 0.2481010 | 0.25190626 | 0.24810098 | 0.249996 | 0.249996 | 0.000003620 | 0.000003620 |
| 1984 | 0 | 1 | 0.8526 | 0.503130 | 0 | 1 | 0.2468801 | 0.25313949 | 0.25313949 | 0.249990 | 0.249990 | 0.000009795 | 0.000009795 |
| 1985 | 1 | 1 | 0.8619 | 0.508282 | 1 | 0 | 0.2417870 | 0.25835015 | 0.24178702 | 0.249931 | 0.249931 | 0.000068565 | 0.000068565 |
| 1986 | 1 | 1 | 0.8635 | 0.509162 | 1 | 0 | 0.2409218 | 0.25924613 | 0.24092176 | 0.249916 | 0.249916 | 0.000083917 | 0.000083917 |
| 1987 | 1 | 1 | 0.8643 | 0.509602 | 1 | 0 | 0.2404903 | 0.25969406 | 0.24049033 | 0.249908 | 0.249908 | 0.000092162 | 0.000092162 |
| 1988 | 1 | 1 | 0.8643 | 0.509602 | 1 | 0 | 0.2404903 | 0.25969406 | 0.24049033 | 0.249908 | 0.249908 | 0.000092162 | 0.000092162 |
| 1989 | 1 | 1 | 0.8643 | 0.509602 | 1 | 0 | 0.2404903 | 0.25969406 | 0.24049033 | 0.249908 | 0.249908 | 0.000092162 | 0.000092162 |
| 1990 | 0 | 1 | 0.8652 | 0.510096 | 0 | 1 | 0.2400059 | 0.26019794 | 0.26019794 | 0.249898 | 0.249898 | 0.000101888 | 0.000101888 |
| 1991 | 0 | 1 | 0.8661 | 0.510590 | 0 | 1 | 0.2395225 | 0.26070176 | 0.26070176 | 0.249888 | 0.249888 | 0.000112090 | 0.000112090 |
| 1992 | 0 | 1 | 0.8661 | 0.510590 | 0 | 1 | 0.2395225 | 0.26070176 | 0.26070176 | 0.249888 | 0.249888 | 0.000112090 | 0.000112090 |
| 1993 | 1 | 1 | 0.8676 | 0.511411 | 1 | 0 | 0.2387191 | 0.26154135 | 0.23871908 | 0.249870 | 0.249870 | 0.000130146 | 0.000130146 |
| 1994 | 1 | 1 | 0.8711 | 0.513322 | 1 | 0 | 0.2368552 | 0.26349978 | 0.23685519 | 0.249823 | 0.249823 | 0.000177357 | 0.000177357 |
| 1995 | 1 | 1 | 0.8745 | 0.515171 | 1 | 0 | 0.2350589 | 0.26540138 | 0.23505895 | 0.249770 | 0.249770 | 0.000229954 | 0.000229954 |
| 1996 | 0 | 1 | 0.8751 | 0.515497 | 0 | 1 | 0.2347434 | 0.26573687 | 0.26573687 | 0.249760 | 0.249760 | 0.000239918 | 0.000239918 |
| 1997 | 0 | 1 | 0.8868 | 0.521797 | 0 | 1 | 0.2286777 | 0.27227261 | 0.27227261 | 0.249525 | 0.249525 | 0.000474227 | 0.000474227 |
| 1998 | 1 | 1 | 0.8887 | 0.522812 | 1 | 0 | 0.2277080 | 0.27333276 | 0.22770805 | 0.249480 | 0.249480 | 0.000519320 | 0.000519320 |
| SUM | 231 | 1998 | | | 231 | 1767 | | | 169.825738 | | 172.40460 | | 65.52027318 |
| | | | | | | | | | standard deviation = 8.15599615 | | | P = 0.37592858 | |

## Table 5-2(b) Work-Sheet for Test of Goodness of Fit (Moderate Damage/Caltrans' Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1\text{-}Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ | $N{*}Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ |
| 1 | 0 | 1 | 0.0688 | 0.000002 | 0 | 1 | 0.9999958 | 0.00000000 | 0.00000000 | 0.000002 | 0.000002 | 0.000002119 | 0.000002119 |
| 2 | 0 | 1 | 0.0717 | 0.000003 | 0 | 1 | 0.9999943 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000002873 | 0.000002873 |
| 3 | 0 | 1 | 0.0717 | 0.000003 | 0 | 1 | 0.9999943 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000002873 | 0.000002873 |
| 4 | 0 | 1 | 0.0721 | 0.000003 | 0 | 1 | 0.9999940 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000002992 | 0.000002992 |
| 5 | 0 | 1 | 0.0721 | 0.000003 | 0 | 1 | 0.9999940 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000002992 | 0.000002992 |
| 6 | 0 | 1 | 0.0724 | 0.000003 | 0 | 1 | 0.9999938 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003084 | 0.000003084 |
| 7 | 0 | 1 | 0.0724 | 0.000003 | 0 | 1 | 0.9999938 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003084 | 0.000003084 |
| 8 | 0 | 1 | 0.0724 | 0.000003 | 0 | 1 | 0.9999938 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003084 | 0.000003084 |
| 9 | 0 | 1 | 0.0731 | 0.000003 | 0 | 1 | 0.9999934 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003308 | 0.000003308 |
| 10 | 0 | 1 | 0.0732 | 0.000003 | 0 | 1 | 0.9999933 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003341 | 0.000003341 |
| 11 | 0 | 1 | 0.0732 | 0.000003 | 0 | 1 | 0.9999933 | 0.00000000 | 0.00000000 | 0.000003 | 0.000003 | 0.000003341 | 0.000003341 |
| 12 | 0 | 1 | 0.0738 | 0.000004 | 0 | 1 | 0.9999929 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003546 | 0.000003546 |
| 13 | 0 | 1 | 0.0738 | 0.000004 | 0 | 1 | 0.9999929 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003546 | 0.000003546 |
| 14 | 0 | 1 | 0.0738 | 0.000004 | 0 | 1 | 0.9999929 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003546 | 0.000003546 |
| 15 | 0 | 1 | 0.0744 | 0.000004 | 0 | 1 | 0.9999925 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003760 | 0.000003760 |
| 16 | 0 | 1 | 0.0746 | 0.000004 | 0 | 1 | 0.9999923 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003834 | 0.000003834 |
| 17 | 0 | 1 | 0.0747 | 0.000004 | 0 | 1 | 0.9999923 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003871 | 0.000003871 |
| 18 | 0 | 1 | 0.0747 | 0.000004 | 0 | 1 | 0.9999923 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003871 | 0.000003871 |
| 19 | 0 | 1 | 0.0747 | 0.000004 | 0 | 1 | 0.9999923 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003871 | 0.000003871 |
| 20 | 0 | 1 | 0.0747 | 0.000004 | 0 | 1 | 0.9999923 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000003871 | 0.000003871 |
| 21 | 0 | 1 | 0.0751 | 0.000004 | 0 | 1 | 0.9999920 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004023 | 0.000004023 |
| 22 | 0 | 1 | 0.0751 | 0.000004 | 0 | 1 | 0.9999920 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004023 | 0.000004023 |
| 23 | 0 | 1 | 0.0751 | 0.000004 | 0 | 1 | 0.9999920 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004023 | 0.000004023 |
| 24 | 0 | 1 | 0.0751 | 0.000004 | 0 | 1 | 0.9999920 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004023 | 0.000004023 |
| 25 | 0 | 1 | 0.0751 | 0.000004 | 0 | 1 | 0.9999920 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004023 | 0.000004023 |
| 26 | 0 | 1 | 0.0753 | 0.000004 | 0 | 1 | 0.9999918 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004101 | 0.000004101 |
| 27 | 0 | 1 | 0.0753 | 0.000004 | 0 | 1 | 0.9999918 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004101 | 0.000004101 |
| 28 | 0 | 1 | 0.0754 | 0.000004 | 0 | 1 | 0.9999917 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004140 | 0.000004140 |
| 29 | 0 | 1 | 0.0754 | 0.000004 | 0 | 1 | 0.9999917 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004140 | 0.000004140 |
| 30 | 0 | 1 | 0.0754 | 0.000004 | 0 | 1 | 0.9999917 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004140 | 0.000004140 |
| 31 | 0 | 1 | 0.0762 | 0.000004 | 0 | 1 | 0.9999911 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004467 | 0.000004467 |
| 32 | 0 | 1 | 0.0762 | 0.000004 | 0 | 1 | 0.9999911 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004467 | 0.000004467 |
| 33 | 0 | 1 | 0.0762 | 0.000004 | 0 | 1 | 0.9999911 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004467 | 0.000004467 |
| 34 | 0 | 1 | 0.0762 | 0.000004 | 0 | 1 | 0.9999911 | 0.00000000 | 0.00000000 | 0.000004 | 0.000004 | 0.000004467 | 0.000004467 |
| 35 | 0 | 1 | 0.0763 | 0.000005 | 0 | 1 | 0.9999910 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004509 | 0.000004509 |
| 36 | 0 | 1 | 0.0763 | 0.000005 | 0 | 1 | 0.9999910 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004509 | 0.000004509 |
| 37 | 0 | 1 | 0.0763 | 0.000005 | 0 | 1 | 0.9999910 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004509 | 0.000004509 |
| 38 | 0 | 1 | 0.0763 | 0.000005 | 0 | 1 | 0.9999910 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004509 | 0.000004509 |
| 39 | 0 | 1 | 0.0764 | 0.000005 | 0 | 1 | 0.9999909 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004552 | 0.000004552 |
| 40 | 0 | 1 | 0.0767 | 0.000005 | 0 | 1 | 0.9999906 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004682 | 0.000004682 |
| 41 | 0 | 1 | 0.0769 | 0.000005 | 0 | 1 | 0.9999905 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004770 | 0.000004770 |
| 42 | 0 | 1 | 0.0770 | 0.000005 | 0 | 1 | 0.9999904 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004814 | 0.000004814 |
| 43 | 0 | 1 | 0.0770 | 0.000005 | 0 | 1 | 0.9999904 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004814 | 0.000004814 |
| 44 | 0 | 1 | 0.0771 | 0.000005 | 0 | 1 | 0.9999903 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004859 | 0.000004859 |
| 45 | 0 | 1 | 0.0772 | 0.000005 | 0 | 1 | 0.9999902 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004905 | 0.000004905 |
| 46 | 0 | 1 | 0.0773 | 0.000005 | 0 | 1 | 0.9999901 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000004950 | 0.000004950 |
| 47 | 0 | 1 | 0.0775 | 0.000005 | 0 | 1 | 0.9999899 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000005042 | 0.000005042 |
| 48 | 0 | 1 | 0.0775 | 0.000005 | 0 | 1 | 0.9999899 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000005042 | 0.000005042 |
| 49 | 0 | 1 | 0.0775 | 0.000005 | 0 | 1 | 0.9999899 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000005042 | 0.000005042 |
| 50 | 0 | 1 | 0.0776 | 0.000005 | 0 | 1 | 0.9999898 | 0.00000000 | 0.00000000 | 0.000005 | 0.000005 | 0.000005089 | 0.000005089 |
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| 1979. | 1 | 1 | 0.8470 | 0.430295 | 1 | 0 | 0.3245642 | 0.18515348 | 0.32456419 | 0.245141 | 0.245141 | 0.004764403 | 0.004764403 |
| 1980 | 0 | 1 | 0.8470 | 0.430295 | 0 | 1 | 0.3245642 | 0.18515348 | 0.18515348 | 0.245141 | 0.245141 | 0.004764403 | 0.004764403 |
| 1981 | 1 | 1 | 0.8504 | 0.432485 | 1 | 0 | 0.3220738 | 0.18704285 | 0.32207383 | 0.245442 | 0.245442 | 0.004475227 | 0.004475227 |
| 1982 | 1 | 1 | 0.8504 | 0.432485 | 1 | 0 | 0.3220738 | 0.18704285 | 0.32207383 | 0.245442 | 0.245442 | 0.004475227 | 0.004475227 |
| 1983 | 1 | 1 | 0.8504 | 0.432485 | 1 | 0 | 0.3220738 | 0.18704285 | 0.32207383 | 0.245442 | 0.245442 | 0.004475227 | 0.004475227 |
| 1984 | 0 | 1 | 0.8526 | 0.433898 | 0 | 1 | 0.3204716 | 0.18826742 | 0.18826742 | 0.245631 | 0.245631 | 0.004293114 | 0.004293114 |
| 1985 | 0 | 1 | 0.8619 | 0.439842 | 0 | 1 | 0.3137772 | 0.19346084 | 0.19346084 | 0.246381 | 0.246381 | 0.003566615 | 0.003566615 |
| 1986 | 1 | 1 | 0.8635 | 0.440859 | 1 | 0 | 0.3126382 | 0.19435699 | 0.31263824 | 0.246502 | 0.246502 | 0.003448680 | 0.003448680 |
| 1987 | 1 | 1 | 0.8643 | 0.441368 | 1 | 0 | 0.3120702 | 0.19480534 | 0.31207018 | 0.246562 | 0.246562 | 0.003390488 | 0.003390488 |
| 1988 | 0 | 1 | 0.8643 | 0.441368 | 0 | 1 | 0.3120702 | 0.19480534 | 0.19480534 | 0.246562 | 0.246562 | 0.003390488 | 0.003390488 |
| 1989 | 1 | 1 | 0.8643 | 0.441368 | 1 | 0 | 0.3120702 | 0.19480534 | 0.31207018 | 0.246562 | 0.246562 | 0.003390488 | 0.003390488 |
| 1990 | 0 | 1 | 0.8652 | 0.441939 | 0 | 1 | 0.3114322 | 0.19530996 | 0.19530996 | 0.246629 | 0.246629 | 0.003325638 | 0.003325638 |
| 1991 | 0 | 1 | 0.8661 | 0.442510 | 0 | 1 | 0.3107955 | 0.19581482 | 0.19581482 | 0.246695 | 0.246695 | 0.003261441 | 0.003261441 |
| 1992 | 0 | 1 | 0.8661 | 0.442510 | 0 | 1 | 0.3107955 | 0.19581482 | 0.19581482 | 0.246695 | 0.246695 | 0.003261441 | 0.003261441 |
| 1993 | 0 | 1 | 0.8676 | 0.443460 | 0 | 1 | 0.3097368 | 0.19665676 | 0.19665676 | 0.246803 | 0.246803 | 0.003155896 | 0.003155896 |
| 1994 | 1 | 1 | 0.8711 | 0.445672 | 1 | 0 | 0.3072793 | 0.19862374 | 0.30727927 | 0.247048 | 0.247048 | 0.002916661 | 0.002916661 |
| 1995 | 0 | 1 | 0.8745 | 0.447814 | 0 | 1 | 0.3049089 | 0.20053773 | 0.20053773 | 0.247277 | 0.247277 | 0.002693672 | 0.002693672 |
| 1996 | 0 | 1 | 0.8751 | 0.448192 | 0 | 1 | 0.3044924 | 0.20087581 | 0.20087581 | 0.247316 | 0.247316 | 0.002655281 | 0.002655281 |
| 1997 | 0 | 1 | 0.8868 | 0.455507 | 0 | 1 | 0.2964725 | 0.20748670 | 0.20748670 | 0.248020 | 0.248020 | 0.001963944 | 0.001963944 |
| 1998 | 1 | 1 | 0.8887 | 0.456687 | 1 | 0 | 0.2951886 | 0.20856339 | 0.29518857 | 0.248124 | 0.248124 | 0.001861903 | 0.001861903 |
| SUM | 147 | 1998 | | | 147 | 1767 | | | 116.046926 | | 114.64548 | | 50.350948977 |
| | | | | | | | | | standard deviation = 7.09584026 | | | P = 0.57828269 | |

# Table 5-2(c)  Work-Sheet for Test of Goodness of Fit (Major Damage/Caltrans' Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1\text{-Pi})^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ | $N{*}Pi(1\text{-}Pi)(1\text{-}2Pi)^2$ |
| 1 | 0 | 1 | 0.0688 | 0.001401 | 0 | 1 | 0.9972000 | 0.00000196 | 0.00000196 | 0.001399 | 0.001399 | 0.001391173 | 0.001391173 |
| 2 | 0 | 1 | 0.0717 | 0.001644 | 0 | 1 | 0.9967155 | 0.00000270 | 0.00000270 | 0.001641 | 0.001641 | 0.001630119 | 0.001630119 |
| 3 | 0 | 1 | 0.0717 | 0.001644 | 0 | 1 | 0.9967155 | 0.00000270 | 0.00000270 | 0.001641 | 0.001641 | 0.001630119 | 0.001630119 |
| 4 | 0 | 1 | 0.0721 | 0.001679 | 0 | 1 | 0.9966447 | 0.00000282 | 0.00000282 | 0.001676 | 0.001676 | 0.001665001 | 0.001665001 |
| 5 | 0 | 1 | 0.0721 | 0.001679 | 0 | 1 | 0.9966447 | 0.00000282 | 0.00000282 | 0.001676 | 0.001676 | 0.001665001 | 0.001665001 |
| 6 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 7 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 8 | 0 | 1 | 0.0724 | 0.001706 | 0 | 1 | 0.9965909 | 0.00000291 | 0.00000291 | 0.001703 | 0.001703 | 0.001691473 | 0.001691473 |
| 9 | 0 | 1 | 0.0731 | 0.001770 | 0 | 1 | 0.9964633 | 0.00000313 | 0.00000313 | 0.001767 | 0.001767 | 0.001754279 | 0.001754279 |
| 10 | 0 | 1 | 0.0732 | 0.001779 | 0 | 1 | 0.9964449 | 0.00000317 | 0.00000317 | 0.001776 | 0.001776 | 0.001763371 | 0.001763371 |
| 11 | 0 | 1 | 0.0732 | 0.001779 | 0 | 1 | 0.9964449 | 0.00000317 | 0.00000317 | 0.001776 | 0.001776 | 0.001763371 | 0.001763371 |
| 12 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 13 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 14 | 0 | 1 | 0.0738 | 0.001835 | 0 | 1 | 0.9963327 | 0.00000337 | 0.00000337 | 0.001832 | 0.001832 | 0.001818548 | 0.001818548 |
| 15 | 0 | 1 | 0.0744 | 0.001893 | 0 | 1 | 0.9962183 | 0.00000358 | 0.00000358 | 0.001889 | 0.001889 | 0.001874807 | 0.001874807 |
| 16 | 0 | 1 | 0.0746 | 0.001912 | 0 | 1 | 0.9961796 | 0.00000366 | 0.00000366 | 0.001908 | 0.001908 | 0.001893802 | 0.001893802 |
| 17 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 18 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 19 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 20 | 0 | 1 | 0.0747 | 0.001922 | 0 | 1 | 0.9961602 | 0.00000369 | 0.00000369 | 0.001918 | 0.001918 | 0.001903344 | 0.001903344 |
| 21 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 22 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 23 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 24 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 25 | 0 | 1 | 0.0751 | 0.001961 | 0 | 1 | 0.9960819 | 0.00000385 | 0.00000385 | 0.001957 | 0.001957 | 0.001941818 | 0.001941818 |
| 26 | 0 | 1 | 0.0753 | 0.001981 | 0 | 1 | 0.9960423 | 0.00000392 | 0.00000392 | 0.001977 | 0.001977 | 0.001961237 | 0.001961237 |
| 27 | 0 | 1 | 0.0753 | 0.001981 | 0 | 1 | 0.9960423 | 0.00000392 | 0.00000392 | 0.001977 | 0.001977 | 0.001961237 | 0.001961237 |
| 28 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 29 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 30 | 0 | 1 | 0.0754 | 0.001991 | 0 | 1 | 0.9960225 | 0.00000396 | 0.00000396 | 0.001987 | 0.001987 | 0.001970992 | 0.001970992 |
| 31 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 32 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 33 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 34 | 0 | 1 | 0.0762 | 0.002072 | 0 | 1 | 0.9958613 | 0.00000429 | 0.00000429 | 0.002067 | 0.002067 | 0.002050134 | 0.002050134 |
| 35 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 36 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 37 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 38 | 0 | 1 | 0.0763 | 0.002082 | 0 | 1 | 0.9958408 | 0.00000433 | 0.00000433 | 0.002077 | 0.002077 | 0.002060164 | 0.002060164 |
| 39 | 0 | 1 | 0.0764 | 0.002092 | 0 | 1 | 0.9958203 | 0.00000438 | 0.00000438 | 0.002088 | 0.002088 | 0.002070225 | 0.002070225 |
| 40 | 0 | 1 | 0.0767 | 0.002123 | 0 | 1 | 0.9957584 | 0.00000451 | 0.00000451 | 0.002119 | 0.002119 | 0.002100593 | 0.002100593 |
| 41 | 0 | 1 | 0.0769 | 0.002144 | 0 | 1 | 0.9957168 | 0.00000460 | 0.00000460 | 0.002139 | 0.002139 | 0.002120993 | 0.002120993 |
| 42 | 0 | 1 | 0.0770 | 0.002154 | 0 | 1 | 0.9956959 | 0.00000464 | 0.00000464 | 0.002150 | 0.002150 | 0.002131239 | 0.002131239 |
| 43 | 0 | 1 | 0.0770 | 0.002154 | 0 | 1 | 0.9956959 | 0.00000464 | 0.00000464 | 0.002150 | 0.002150 | 0.002131239 | 0.002131239 |
| 44 | 0 | 1 | 0.0771 | 0.002165 | 0 | 1 | 0.9956750 | 0.00000469 | 0.00000469 | 0.002160 | 0.002160 | 0.002141515 | 0.002141515 |
| 45 | 0 | 1 | 0.0772 | 0.002175 | 0 | 1 | 0.9956539 | 0.00000473 | 0.00000473 | 0.002171 | 0.002171 | 0.002151823 | 0.002151823 |
| 46 | 0 | 1 | 0.0773 | 0.002186 | 0 | 1 | 0.9956328 | 0.00000478 | 0.00000478 | 0.002181 | 0.002181 | 0.002162162 | 0.002162162 |
| 47 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 48 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 49 | 0 | 1 | 0.0775 | 0.002207 | 0 | 1 | 0.9955905 | 0.00000487 | 0.00000487 | 0.002202 | 0.002202 | 0.002182932 | 0.002182932 |
| 50 | 0 | 1 | 0.0776 | 0.002218 | 0 | 1 | 0.9955692 | 0.00000492 | 0.00000492 | 0.002213 | 0.002213 | 0.002193363 | 0.002193363 |
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| 1979. | 0 | 1 | 0.8470 | 0.235963 | 0 | 1 | 0.5837523 | 0.05567863 | 0.05567863 | 0.180285 | 0.180285 | 0.050274469 | 0.050274469 |
| 1980 | 0 | 1 | 0.8470 | 0.235963 | 0 | 1 | 0.5837523 | 0.05567863 | 0.05567863 | 0.180285 | 0.180285 | 0.050274469 | 0.050274469 |
| 1981 | 1 | 1 | 0.8504 | 0.237874 | 1 | 0 | 0.5808353 | 0.05658428 | 0.58083529 | 0.181290 | 0.181290 | 0.049825645 | 0.049825645 |
| 1982 | 0 | 1 | 0.8504 | 0.237874 | 0 | 1 | 0.5808353 | 0.05658428 | 0.05658428 | 0.181290 | 0.181290 | 0.049825645 | 0.049825645 |
| 1983 | 1 | 1 | 0.8504 | 0.237874 | 1 | 0 | 0.5808353 | 0.05658428 | 0.58083529 | 0.181290 | 0.181290 | 0.049825645 | 0.049825645 |
| 1984 | 0 | 1 | 0.8526 | 0.239112 | 0 | 1 | 0.5789511 | 0.05717438 | 0.05717438 | 0.181937 | 0.181937 | 0.049532591 | 0.049532591 |
| 1985 | 0 | 1 | 0.8619 | 0.244345 | 0 | 1 | 0.5710151 | 0.05970426 | 0.05970426 | 0.184640 | 0.184640 | 0.048272140 | 0.048272140 |
| 1986 | 1 | 1 | 0.8635 | 0.245245 | 1 | 0 | 0.5696547 | 0.06014525 | 0.56965467 | 0.185100 | 0.185100 | 0.048051942 | 0.048051942 |
| 1987 | 0 | 1 | 0.8643 | 0.245696 | 0 | 1 | 0.5689750 | 0.06036637 | 0.06036637 | 0.185329 | 0.185329 | 0.047941492 | 0.047941492 |
| 1988 | 0 | 1 | 0.8643 | 0.245696 | 0 | 1 | 0.5689750 | 0.06036637 | 0.06036637 | 0.185329 | 0.185329 | 0.047941492 | 0.047941492 |
| 1989 | 1 | 1 | 0.8643 | 0.245696 | 1 | 0 | 0.5689750 | 0.06036637 | 0.56897498 | 0.185329 | 0.185329 | 0.047941492 | 0.047941492 |
| 1990 | 0 | 1 | 0.8652 | 0.246202 | 0 | 1 | 0.5682108 | 0.06061564 | 0.06061564 | 0.185587 | 0.185587 | 0.047816961 | 0.047816961 |
| 1991 | 0 | 1 | 0.8661 | 0.246709 | 0 | 1 | 0.5674470 | 0.06086543 | 0.06086543 | 0.185844 | 0.185844 | 0.047692141 | 0.047692141 |
| 1992 | 0 | 1 | 0.8661 | 0.246709 | 0 | 1 | 0.5674470 | 0.06086543 | 0.06086543 | 0.185844 | 0.185844 | 0.047692141 | 0.047692141 |
| 1993 | 0 | 1 | 0.8676 | 0.247554 | 0 | 1 | 0.5661751 | 0.06128293 | 0.06128293 | 0.186271 | 0.186271 | 0.047483477 | 0.047483477 |
| 1994 | 0 | 1 | 0.8711 | 0.249525 | 0 | 1 | 0.5632125 | 0.06226279 | 0.06226279 | 0.187262 | 0.187262 | 0.046993607 | 0.046993607 |
| 1995 | 0 | 1 | 0.8745 | 0.251440 | 0 | 1 | 0.5603415 | 0.06322226 | 0.06322226 | 0.188218 | 0.188218 | 0.046513882 | 0.046513882 |
| 1996 | 0 | 1 | 0.8751 | 0.251778 | 0 | 1 | 0.5598356 | 0.06339236 | 0.06339236 | 0.188386 | 0.188386 | 0.046428845 | 0.046428845 |
| 1997 | 0 | 1 | 0.8868 | 0.258371 | 0 | 1 | 0.5500139 | 0.06675546 | 0.06675546 | 0.191615 | 0.191615 | 0.044749598 | 0.044749598 |
| 1998 | 1 | 1 | 0.8887 | 0.259441 | 1 | 0 | 0.5484270 | 0.06730985 | 0.54842700 | 0.192132 | 0.192132 | 0.044473408 | 0.044473408 |
| SUM | 53 | 1998 | | | 53 | 1945 | | | 47.308159 | | 46.47609 | | 28.171349867 |
| | | | | | | | | | standard deviation = 5.3076668967 | | | P = 0.56228589 | |

## Table 5-2(d) Work-Sheet for Test of Goodness of Fit (Collapse Damage/Caltrans' Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 1 | 0.0688 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000017 | 0.000000017 |
| 2 | 0 | 1 | 0.0717 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000024 | 0.000000024 |
| 3 | 0 | 1 | 0.0717 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000024 | 0.000000024 |
| 4 | 0 | 1 | 0.0721 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000026 | 0.000000026 |
| 5 | 0 | 1 | 0.0721 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000026 | 0.000000026 |
| 6 | 0 | 1 | 0.0724 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000026 | 0.000000026 |
| 7 | 0 | 1 | 0.0724 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000026 | 0.000000026 |
| 8 | 0 | 1 | 0.0724 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000026 | 0.000000026 |
| 9 | 0 | 1 | 0.0731 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000029 | 0.000000029 |
| 10 | 0 | 1 | 0.0732 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000029 | 0.000000029 |
| 11 | 0 | 1 | 0.0732 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000029 | 0.000000029 |
| 12 | 0 | 1 | 0.0738 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000031 | 0.000000031 |
| 13 | 0 | 1 | 0.0738 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000031 | 0.000000031 |
| 14 | 0 | 1 | 0.0738 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000031 | 0.000000031 |
| 15 | 0 | 1 | 0.0744 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000033 | 0.000000033 |
| 16 | 0 | 1 | 0.0746 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000034 | 0.000000034 |
| 17 | 0 | 1 | 0.0747 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000034 | 0.000000034 |
| 18 | 0 | 1 | 0.0747 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000034 | 0.000000034 |
| 19 | 0 | 1 | 0.0747 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000034 | 0.000000034 |
| 20 | 0 | 1 | 0.0747 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000034 | 0.000000034 |
| 21 | 0 | 1 | 0.0751 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000036 | 0.000000036 |
| 22 | 0 | 1 | 0.0751 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000036 | 0.000000036 |
| 23 | 0 | 1 | 0.0751 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000036 | 0.000000036 |
| 24 | 0 | 1 | 0.0751 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000036 | 0.000000036 |
| 25 | 0 | 1 | 0.0751 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000036 | 0.000000036 |
| 26 | 0 | 1 | 0.0753 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000037 | 0.000000037 |
| 27 | 0 | 1 | 0.0753 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000037 | 0.000000037 |
| 28 | 0 | 1 | 0.0754 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000037 | 0.000000037 |
| 29 | 0 | 1 | 0.0754 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000037 | 0.000000037 |
| 30 | 0 | 1 | 0.0754 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000037 | 0.000000037 |
| 31 | 0 | 1 | 0.0762 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 32 | 0 | 1 | 0.0762 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 33 | 0 | 1 | 0.0762 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 34 | 0 | 1 | 0.0762 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 35 | 0 | 1 | 0.0763 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 36 | 0 | 1 | 0.0763 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 37 | 0 | 1 | 0.0763 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 38 | 0 | 1 | 0.0763 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 39 | 0 | 1 | 0.0764 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 40 | 0 | 1 | 0.0767 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000043 | 0.000000043 |
| 41 | 0 | 1 | 0.0769 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000044 | 0.000000044 |
| 42 | 0 | 1 | 0.0770 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000044 | 0.000000044 |
| 43 | 0 | 1 | 0.0770 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000044 | 0.000000044 |
| 44 | 0 | 1 | 0.0771 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000045 | 0.000000045 |
| 45 | 0 | 1 | 0.0772 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000045 | 0.000000045 |
| 46 | 0 | 1 | 0.0773 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000046 | 0.000000046 |
| 47 | 0 | 1 | 0.0775 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000047 | 0.000000047 |
| 48 | 0 | 1 | 0.0775 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000047 | 0.000000047 |
| 49 | 0 | 1 | 0.0775 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000047 | 0.000000047 |
| 50 | 0 | 1 | 0.0776 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000047 | 0.000000047 |
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| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 1979. | 0 | 1 | 0.8470 | 0.039230 | 0 | 1 | 0.9230783 | 0.00153902 | 0.00153902 | 0.037691 | 0.037691 | 0.032008786 | 0.032008786 |
| 1980 | 0 | 1 | 0.8470 | 0.039230 | 0 | 1 | 0.9230783 | 0.00153902 | 0.00153902 | 0.037691 | 0.037691 | 0.032008786 | 0.032008786 |
| 1981 | 0 | 1 | 0.8504 | 0.039742 | 0 | 1 | 0.9220959 | 0.00157941 | 0.00157941 | 0.038162 | 0.038162 | 0.032336882 | 0.032336882 |
| 1982 | 0 | 1 | 0.8504 | 0.039742 | 0 | 1 | 0.9220959 | 0.00157941 | 0.00157941 | 0.038162 | 0.038162 | 0.032336882 | 0.032336882 |
| 1983 | 0 | 1 | 0.8504 | 0.039742 | 0 | 1 | 0.9220959 | 0.00157941 | 0.00157941 | 0.038162 | 0.038162 | 0.032336882 | 0.032336882 |
| 1984 | 0 | 1 | 0.8526 | 0.040074 | 0 | 1 | 0.9214571 | 0.00160596 | 0.00160596 | 0.038468 | 0.038468 | 0.032549173 | 0.032549173 |
| 1985 | 0 | 1 | 0.8619 | 0.041496 | 0 | 1 | 0.9187297 | 0.00172193 | 0.00172193 | 0.039774 | 0.039774 | 0.033446237 | 0.033446237 |
| 1986 | 0 | 1 | 0.8635 | 0.041743 | 0 | 1 | 0.9182561 | 0.00174249 | 0.00174249 | 0.040001 | 0.040001 | 0.033600473 | 0.033600473 |
| 1987 | 0 | 1 | 0.8643 | 0.041867 | 0 | 1 | 0.9180188 | 0.00175285 | 0.00175285 | 0.040114 | 0.040114 | 0.033677576 | 0.033677576 |
| 1988 | 0 | 1 | 0.8643 | 0.041867 | 0 | 1 | 0.9180188 | 0.00175285 | 0.00175285 | 0.040114 | 0.040114 | 0.033677576 | 0.033677576 |
| 1989 | 0 | 1 | 0.8643 | 0.041867 | 0 | 1 | 0.9180188 | 0.00175285 | 0.00175285 | 0.040114 | 0.040114 | 0.033677576 | 0.033677576 |
| 1990 | 0 | 1 | 0.8652 | 0.042007 | 0 | 1 | 0.9177515 | 0.00176455 | 0.00176455 | 0.040242 | 0.040242 | 0.033764305 | 0.033764305 |
| 1991 | 0 | 1 | 0.8661 | 0.042146 | 0 | 1 | 0.9174838 | 0.00177631 | 0.00177631 | 0.040370 | 0.040370 | 0.033851019 | 0.033851019 |
| 1992 | 0 | 1 | 0.8661 | 0.042146 | 0 | 1 | 0.9174838 | 0.00177631 | 0.00177631 | 0.040370 | 0.040370 | 0.033851019 | 0.033851019 |
| 1993 | 0 | 1 | 0.8676 | 0.042380 | 0 | 1 | 0.9170367 | 0.00179604 | 0.00179604 | 0.040584 | 0.040584 | 0.033995509 | 0.033995509 |
| 1994 | 0 | 1 | 0.8711 | 0.042927 | 0 | 1 | 0.9159891 | 0.00184271 | 0.00184271 | 0.041084 | 0.041084 | 0.034332471 | 0.034332471 |
| 1995 | 0 | 1 | 0.8745 | 0.043462 | 0 | 1 | 0.9149657 | 0.00188891 | 0.00188891 | 0.041573 | 0.041573 | 0.034659527 | 0.034659527 |
| 1996 | 0 | 1 | 0.8751 | 0.043556 | 0 | 1 | 0.9147845 | 0.00189715 | 0.00189715 | 0.041659 | 0.041659 | 0.034717211 | 0.034717211 |
| 1997 | 0 | 1 | 0.8868 | 0.045423 | 0 | 1 | 0.9112164 | 0.00206329 | 0.00206329 | 0.043360 | 0.043360 | 0.035839744 | 0.035839744 |
| 1998 | 0 | 1 | 0.8887 | 0.045730 | 0 | 1 | 0.9106307 | 0.00209126 | 0.00209126 | 0.043639 | 0.043639 | 0.036021557 | 0.036021557 |
| SUM | 6 | 1998 | | | 6 | 1992 | | | 5.893995 | | 5.90058 | | 5.408124995 |
| | | | | | | | | | standard deviation = 2.32553727 | | | P = 0.49887110 | |

## Table 5-3(a) Work-Sheet for Test of Goodness of Fit (Minor Damage/HEPC's Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 7 | 55 | 239.12 | 0.130996 | 7 | 48 | 0.7551687 | 0.01715984 | 6.1098532 | 0.113836 | 6.260966 | 0.062001438 | 3.410079067 |
| 2 | 19 | 55 | 267.60 | 0.175846 | 19 | 36 | 0.6792303 | 0.03092172 | 14.0185568 | 0.144924 | 7.970821 | 0.060912135 | 3.350167417 |
| 3 | 3 | 55 | 295.83 | 0.223149 | 3 | 52 | 0.6034976 | 0.04979545 | 4.3998560 | 0.173353 | 9.534442 | 0.053147760 | 2.923126809 |
| 4 | 3 | 55 | 376.31 | 0.361500 | 3 | 52 | 0.4076827 | 0.13068200 | 8.0185120 | 0.230818 | 12.694971 | 0.017710497 | 0.974077318 |
| 5 | 33 | 55 | 431.04 | 0.450393 | 33 | 22 | 0.3020679 | 0.20285386 | 14.4310240 | 0.247539 | 13.614653 | 0.002436631 | 0.134014714 |
| 6 | 26 | 55 | 477.50 | 0.519348 | 26 | 29 | 0.2310265 | 0.26972215 | 13.8286320 | 0.249626 | 13.729411 | 0.000373777 | 0.020557746 |
| 7 | 40 | 55 | 487.85 | 0.533800 | 40 | 15 | 0.2173426 | 0.28494227 | 12.9678375 | 0.248858 | 13.687166 | 0.001137209 | 0.062546484 |
| 8 | 41 | 55 | 504.65 | 0.556493 | 41 | 14 | 0.1966989 | 0.30968395 | 12.4002288 | 0.246809 | 13.574473 | 0.003150667 | 0.173286672 |
| 9 | 27 | 55 | 521.94 | 0.578901 | 27 | 28 | 0.1773241 | 0.33512680 | 14.1712998 | 0.243775 | 13.407602 | 0.006070402 | 0.333872129 |
| 10 | 25 | 55 | 534.82 | 0.594967 | 25 | 30 | 0.1640515 | 0.35398605 | 14.7208694 | 0.240981 | 13.253967 | 0.008693429 | 0.478138583 |
| 11 | 45 | 55 | 581.95 | 0.649230 | 45 | 10 | 0.1230395 | 0.42149973 | 9.7517756 | 0.227730 | 12.525171 | 0.020285880 | 1.115723396 |
| 12 | 44 | 55 | 604.34 | 0.672612 | 44 | 11 | 0.1071832 | 0.45240628 | 9.6925301 | 0.220205 | 12.111289 | 0.026243836 | 1.443410980 |
| 13 | 34 | 55 | 655.05 | 0.720208 | 34 | 21 | 0.0782837 | 0.51869913 | 13.5543286 | 0.201509 | 11.082971 | 0.039085755 | 2.149716518 |
| 14 | 35 | 55 | 721.85 | 0.772704 | 35 | 20 | 0.0516635 | 0.59707121 | 13.7496484 | 0.175633 | 9.659794 | 0.052245350 | 2.873494265 |
| SUM | 382 | 770 | | | 382 | 388 | | | 161.814952 | | 163.10770 | | 19.442212099 |
| | | | | | | | | | standard deviation = 4.40933239 | | | P = 0.38469092 | |

## Table 5-3(b) Work-Sheet for Test of Goodness of Fit (Moderate Damage/HEPC's Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 55 | 239.12 | 0.010382 | 0 | 55 | 0.9793433 | 0.00010779 | 0.0059285 | 0.010274 | 0.565096 | 0.009852215 | 0.541871849 |
| 2 | 1 | 55 | 267.60 | 0.019542 | 1 | 54 | 0.9612985 | 0.00038188 | 0.9819199 | 0.019160 | 1.053790 | 0.017691430 | 0.973028675 |
| 3 | 0 | 55 | 295.83 | 0.032781 | 0 | 55 | 0.9355123 | 0.00107460 | 0.0591031 | 0.031707 | 1.743859 | 0.027685312 | 1.522692176 |
| 4 | 0 | 55 | 376.31 | 0.095259 | 0 | 55 | 0.8185564 | 0.00907427 | 0.4990846 | 0.086185 | 4.740157 | 0.056473481 | 3.106041481 |
| 5 | 2 | 55 | 431.04 | 0.156583 | 2 | 53 | 0.7113519 | 0.02451831 | 2.7221740 | 0.132065 | 7.263571 | 0.062300348 | 3.426519116 |
| 6 | 11 | 55 | 477.50 | 0.217061 | 11 | 44 | 0.6129933 | 0.04711553 | 8.8160095 | 0.169946 | 9.347007 | 0.054419577 | 2.993076712 |
| 7 | 23 | 55 | 487.85 | 0.231266 | 23 | 32 | 0.5909515 | 0.05348409 | 15.3033762 | 0.177782 | 9.778020 | 0.051356162 | 2.824588936 |
| 8 | 36 | 55 | 504.65 | 0.254685 | 36 | 19 | 0.5554939 | 0.06486463 | 21.2302092 | 0.189821 | 10.440140 | 0.045693095 | 2.513120230 |
| 9 | 17 | 55 | 521.94 | 0.279177 | 17 | 38 | 0.5195853 | 0.07793998 | 11.7946698 | 0.201237 | 11.068054 | 0.039251470 | 2.158830842 |
| 10 | 12 | 55 | 534.82 | 0.297591 | 12 | 43 | 0.4933783 | 0.08856046 | 9.7286391 | 0.209031 | 11.496685 | 0.034255408 | 1.884047428 |
| 11 | 13 | 55 | 581.95 | 0.365237 | 13 | 42 | 0.4029239 | 0.13339816 | 10.8407334 | 0.231839 | 12.751143 | 0.016841741 | 0.926295740 |
| 12 | 34 | 55 | 604.34 | 0.397064 | 34 | 21 | 0.3635314 | 0.15766008 | 15.6709302 | 0.239404 | 13.167234 | 0.010146673 | 0.558067018 |
| 13 | 21 | 55 | 655.05 | 0.467042 | 21 | 34 | 0.2840447 | 0.21812782 | 13.3812845 | 0.248914 | 13.690256 | 0.001081539 | 0.059484640 |
| 14 | 17 | 55 | 721.85 | 0.552566 | 17 | 38 | 0.2001974 | 0.30532888 | 15.0058538 | 0.247237 | 13.598026 | 0.002732615 | 0.150293852 |
| SUM | 187 | 770 | | | 187 | 583 | | | 126.039916 | | 120.70304 | | 23.637958696 |
| | | | | | | | | | standard deviation = 4.86188839 | | | P = 0.86383141 | |

## Table 5-3(c) Work-Sheet for Test of Goodness of Fit (Major Damage/HEPC's Bridges / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 55 | 239.12 | 0.003129 | 0 | 55 | 0.9937510 | 0.00000979 | 0.0005386 | 0.003120 | 0.171578 | 0.003080677 | 0.169437242 |
| 2 | 0 | 55 | 267.60 | 0.006691 | 0 | 55 | 0.9866634 | 0.00004477 | 0.0024621 | 0.006646 | 0.365526 | 0.006469249 | 0.355808681 |
| 3 | 0 | 55 | 295.83 | 0.012504 | 0 | 55 | 0.9751485 | 0.00015635 | 0.0085992 | 0.012348 | 0.679118 | 0.011737739 | 0.645575656 |
| 4 | 0 | 55 | 376.31 | 0.046064 | 0 | 55 | 0.9099941 | 0.00212188 | 0.1167035 | 0.043942 | 2.416810 | 0.036218403 | 1.992012167 |
| 5 | 2 | 55 | 431.04 | 0.085356 | 2 | 53 | 0.8365737 | 0.00728564 | 2.0592864 | 0.078070 | 4.293868 | 0.053690423 | 2.952973286 |
| 6 | 7 | 55 | 477.50 | 0.128609 | 7 | 48 | 0.7593231 | 0.01654016 | 6.1091891 | 0.112068 | 6.163762 | 0.061831094 | 3.400710176 |
| 7 | 10 | 55 | 487.85 | 0.139333 | 10 | 45 | 0.7407478 | 0.01941366 | 8.2810930 | 0.119919 | 6.595559 | 0.062396744 | 3.431820932 |
| 8 | 26 | 55 | 504.65 | 0.157451 | 26 | 29 | 0.7098892 | 0.02479074 | 19.1760515 | 0.132660 | 7.296301 | 0.062265297 | 3.424591320 |
| 9 | 10 | 55 | 521.94 | 0.176961 | 10 | 45 | 0.6773934 | 0.03131514 | 8.1831158 | 0.145646 | 8.010514 | 0.060795019 | 3.343726058 |
| 10 | 4 | 55 | 534.82 | 0.191996 | 4 | 51 | 0.6528712 | 0.03686228 | 4.4914612 | 0.155133 | 8.532328 | 0.058867951 | 3.237737327 |
| 11 | 6 | 55 | 581.95 | 0.249816 | 6 | 49 | 0.5627764 | 0.06240793 | 6.4346466 | 0.187408 | 10.307432 | 0.046921036 | 2.580656971 |
| 12 | 27 | 55 | 604.34 | 0.278380 | 27 | 28 | 0.5207351 | 0.07749554 | 16.2297234 | 0.200885 | 11.048657 | 0.039466068 | 2.170633753 |
| 13 | 16 | 55 | 655.05 | 0.344150 | 16 | 39 | 0.4301392 | 0.11843923 | 11.5013573 | 0.225711 | 12.414093 | 0.021929355 | 1.206114550 |
| 14 | 16 | 55 | 721.85 | 0.430005 | 16 | 39 | 0.3248943 | 0.18490430 | 12.4095765 | 0.245101 | 13.480539 | 0.004803287 | 0.264180808 |
| SUM | 124 | 770 | | | 124 | 646 | | | 95.0038042 | | 91.776084 | | 29.175978924 |
| | | | | | | | | | standard deviation = 5.40147933 | | | P = 0.72493405 | |

## Table 5-4(a) Work-Sheet for Test of Goodness of Fit (Minor Damage/Memphis Bridge1 / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 1 | 0.0820 | 0.000001 | 0 | 1 | 0.9999985 | 0.00000000 | 0.00000000 | 0.000001 | 0.000001 | 0.000000739 | 0.000000739 |
| 2 | 0 | 1 | 0.0900 | 0.000009 | 0 | 1 | 0.9999829 | 0.00000000 | 0.00000000 | 0.000009 | 0.000009 | 0.000008545 | 0.000008545 |
| 3 | 0 | 1 | 0.0960 | 0.000040 | 0 | 1 | 0.9999197 | 0.00000000 | 0.00000000 | 0.000040 | 0.000040 | 0.000040166 | 0.000040166 |
| 4 | 0 | 1 | 0.0970 | 0.000051 | 0 | 1 | 0.9998981 | 0.00000000 | 0.00000000 | 0.000051 | 0.000051 | 0.000050918 | 0.000050918 |
| 5 | 0 | 1 | 0.0980 | 0.000064 | 0 | 1 | 0.9998716 | 0.00000000 | 0.00000000 | 0.000064 | 0.000064 | 0.000064193 | 0.000064193 |
| 6 | 0 | 1 | 0.0980 | 0.000064 | 0 | 1 | 0.9998716 | 0.00000000 | 0.00000000 | 0.000064 | 0.000064 | 0.000064193 | 0.000064193 |
| 7 | 0 | 1 | 0.1070 | 0.000413 | 0 | 1 | 0.9991746 | 0.00000017 | 0.00000017 | 0.000413 | 0.000413 | 0.000411923 | 0.000411923 |
| 8 | 0 | 1 | 0.1090 | 0.000594 | 0 | 1 | 0.9988125 | 0.00000035 | 0.00000035 | 0.000594 | 0.000594 | 0.000592175 | 0.000592175 |
| 9 | 0 | 1 | 0.1100 | 0.000708 | 0 | 1 | 0.9985843 | 0.00000050 | 0.00000050 | 0.000708 | 0.000708 | 0.000705609 | 0.000705609 |
| 10 | 0 | 1 | 0.1140 | 0.001377 | 0 | 1 | 0.9972484 | 0.00000190 | 0.00000190 | 0.001375 | 0.001375 | 0.001367288 | 0.001367288 |
| 11 | 0 | 1 | 0.1140 | 0.001377 | 0 | 1 | 0.9972484 | 0.00000190 | 0.00000190 | 0.001375 | 0.001375 | 0.001367288 | 0.001367288 |
| 12 | 0 | 1 | 0.1170 | 0.002183 | 0 | 1 | 0.9956396 | 0.00000476 | 0.00000476 | 0.002178 | 0.002178 | 0.002158848 | 0.002158848 |
| 13 | 0 | 1 | 0.1210 | 0.003852 | 0 | 1 | 0.9923107 | 0.00001484 | 0.00001484 | 0.003837 | 0.003837 | 0.003778312 | 0.003778312 |
| 14 | 0 | 1 | 0.1220 | 0.004406 | 0 | 1 | 0.9912083 | 0.00001941 | 0.00001941 | 0.004386 | 0.004386 | 0.004309175 | 0.004309175 |
| 15 | 0 | 1 | 0.1240 | 0.005712 | 0 | 1 | 0.9886089 | 0.00003263 | 0.00003263 | 0.005679 | 0.005679 | 0.005550215 | 0.005550215 |
| 16 | 0 | 1 | 0.1270 | 0.008256 | 0 | 1 | 0.9835558 | 0.00006816 | 0.00006816 | 0.008188 | 0.008188 | 0.007919826 | 0.007919826 |
| 17 | 0 | 1 | 0.1320 | 0.014479 | 0 | 1 | 0.9712511 | 0.00020965 | 0.00020965 | 0.014270 | 0.014270 | 0.013455158 | 0.013455158 |
| 18 | 0 | 1 | 0.1350 | 0.019705 | 0 | 1 | 0.9609792 | 0.00038827 | 0.00038827 | 0.019316 | 0.019316 | 0.017823779 | 0.017823779 |
| 19 | 0 | 1 | 0.1390 | 0.028811 | 0 | 1 | 0.9432088 | 0.00083005 | 0.00083005 | 0.027981 | 0.027981 | 0.024848914 | 0.024848914 |
| 20 | 0 | 1 | 0.1400 | 0.031516 | 0 | 1 | 0.9379610 | 0.00099327 | 0.00099327 | 0.030523 | 0.030523 | 0.026796300 | 0.026796300 |
| 21 | 0 | 1 | 0.1410 | 0.034407 | 0 | 1 | 0.9323700 | 0.00118383 | 0.00118383 | 0.033223 | 0.033223 | 0.028807974 | 0.028807974 |
| 22 | 0 | 1 | 0.1450 | 0.047948 | 0 | 1 | 0.9064038 | 0.00229897 | 0.00229897 | 0.045649 | 0.045649 | 0.037313430 | 0.037313430 |
| 23 | 0 | 1 | 0.1550 | 0.097380 | 0 | 1 | 0.8147232 | 0.00948282 | 0.00948282 | 0.087897 | 0.087897 | 0.056993460 | 0.056993460 |
| 24 | 0 | 1 | 0.1620 | 0.146265 | 0 | 1 | 0.7288633 | 0.02139348 | 0.02139348 | 0.124872 | 0.124872 | 0.062499934 | 0.062499934 |
| 25 | 1 | 1 | 0.1700 | 0.215852 | 1 | 0 | 0.6148874 | 0.04659226 | 0.61488745 | 0.169260 | 0.169260 | 0.054664158 | 0.054664158 |
| 26 | 0 | 1 | 0.1730 | 0.245213 | 0 | 1 | 0.5697029 | 0.06012957 | 0.06012957 | 0.185084 | 0.185084 | 0.048059774 | 0.048059774 |
| 27 | 1 | 1 | 0.1730 | 0.245213 | 1 | 0 | 0.5697029 | 0.06012957 | 0.56970294 | 0.185084 | 0.185084 | 0.048059774 | 0.048059774 |
| 28 | 0 | 1 | 0.1750 | 0.265616 | 0 | 1 | 0.5393194 | 0.07055202 | 0.07055202 | 0.195064 | 0.195064 | 0.042863984 | 0.042863984 |
| 29 | 1 | 1 | 0.1750 | 0.265616 | 1 | 0 | 0.5393194 | 0.07055202 | 0.53931941 | 0.195064 | 0.195064 | 0.042863984 | 0.042863984 |
| 30 | 0 | 1 | 0.1920 | 0.454651 | 0 | 1 | 0.2974055 | 0.20670759 | 0.20670759 | 0.247943 | 0.247943 | 0.002039609 | 0.002039609 |
| 31 | 0 | 1 | 0.1930 | 0.466044 | 0 | 1 | 0.2851091 | 0.21719696 | 0.21719696 | 0.248847 | 0.248847 | 0.001147696 | 0.001147696 |
| 32 | 0 | 1 | 0.1970 | 0.511215 | 0 | 1 | 0.2389104 | 0.26134118 | 0.26134118 | 0.249874 | 0.249874 | 0.000125722 | 0.000125722 |
| 33 | 1 | 1 | 0.2080 | 0.628660 | 1 | 0 | 0.1378935 | 0.39521321 | 0.13789350 | 0.233447 | 0.233447 | 0.015457303 | 0.015457303 |
| 34 | 1 | 1 | 0.2170 | 0.713056 | 1 | 0 | 0.0823367 | 0.50844922 | 0.08233672 | 0.204607 | 0.204607 | 0.037150881 | 0.037150881 |
| 35 | 0 | 1 | 0.2200 | 0.738326 | 0 | 1 | 0.0684733 | 0.54512522 | 0.54512522 | 0.193201 | 0.193201 | 0.043894637 | 0.043894637 |
| 36 | 1 | 1 | 0.2200 | 0.738326 | 1 | 0 | 0.0684733 | 0.54512522 | 0.06847331 | 0.193201 | 0.193201 | 0.043894637 | 0.043894637 |
| 37 | 1 | 1 | 0.2210 | 0.746414 | 1 | 0 | 0.0643056 | 0.55713457 | 0.06430562 | 0.189280 | 0.189280 | 0.045972375 | 0.045972375 |
| 38 | 0 | 1 | 0.2230 | 0.762084 | 0 | 1 | 0.0566039 | 0.58077237 | 0.58077237 | 0.181312 | 0.181312 | 0.049815898 | 0.049815898 |
| 39 | 1 | 1 | 0.2330 | 0.830307 | 1 | 0 | 0.0287956 | 0.68941013 | 0.02879563 | 0.140897 | 0.140897 | 0.061489126 | 0.061489126 |
| 40 | 1 | 1 | 0.2330 | 0.830307 | 1 | 0 | 0.0287956 | 0.68941013 | 0.02879563 | 0.140897 | 0.140897 | 0.061489126 | 0.061489126 |
| 41 | 1 | 1 | 0.2380 | 0.858294 | 1 | 0 | 0.0200807 | 0.73666819 | 0.02008066 | 0.121626 | 0.121626 | 0.062454453 | 0.062454453 |
| 42 | 1 | 1 | 0.2430 | 0.882495 | 1 | 0 | 0.0138075 | 0.77879711 | 0.01380747 | 0.103698 | 0.103698 | 0.060684850 | 0.060684850 |
| 43 | 0 | 1 | 0.2480 | 0.903213 | 0 | 1 | 0.0093678 | 0.81579334 | 0.81579334 | 0.087419 | 0.087419 | 0.056850809 | 0.056850809 |
| 44 | 1 | 1 | 0.2520 | 0.917504 | 1 | 0 | 0.0068056 | 0.84181377 | 0.00680557 | 0.075690 | 0.075690 | 0.052774224 | 0.052774224 |
| 45 | 1 | 1 | 0.2540 | 0.923950 | 1 | 0 | 0.0057836 | 0.85368336 | 0.00578362 | 0.070267 | 0.070267 | 0.050516980 | 0.050516980 |
| 46 | 1 | 1 | 0.2550 | 0.927008 | 1 | 0 | 0.0053279 | 0.85934304 | 0.00532789 | 0.067665 | 0.067665 | 0.049350578 | 0.049350578 |
| 47 | 1 | 1 | 0.2570 | 0.932807 | 1 | 0 | 0.0045150 | 0.87012801 | 0.00451496 | 0.062679 | 0.062679 | 0.046964129 | 0.046964129 |
| 48 | 1 | 1 | 0.2580 | 0.935553 | 1 | 0 | 0.0041534 | 0.87525996 | 0.00415338 | 0.060293 | 0.060293 | 0.045752188 | 0.045752188 |
| 49 | 1 | 1 | 0.2590 | 0.938202 | 1 | 0 | 0.0038190 | 0.88022280 | 0.00381901 | 0.057979 | 0.057979 | 0.044532795 | 0.044532795 |
| 50 | 1 | 1 | 0.2720 | 0.964885 | 1 | 0 | 0.0012330 | 0.93100366 | 0.00123304 | 0.033882 | 0.033882 | 0.029289785 | 0.029289785 |
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| 61 | 1 | 1 | 0.3110 | 0.994625 | 1 | 0 | 0.0000289 | 0.98927843 | 0.00002889 | 0.005346 | 0.005346 | 0.005232007 | 0.005232007 |
| 62 | 1 | 1 | 0.3140 | 0.995389 | 1 | 0 | 0.0000213 | 0.99080013 | 0.00002126 | 0.004589 | 0.004589 | 0.004505061 | 0.004505061 |
| 63 | 1 | 1 | 0.3240 | 0.997256 | 1 | 0 | 0.0000075 | 0.99452033 | 0.00000753 | 0.002736 | 0.002736 | 0.002706125 | 0.002706125 |
| 64 | 1 | 1 | 0.3320 | 0.998203 | 1 | 0 | 0.0000032 | 0.99640858 | 0.00000323 | 0.001794 | 0.001794 | 0.001781217 | 0.001781217 |
| 65 | 1 | 1 | 0.3320 | 0.998203 | 1 | 0 | 0.0000032 | 0.99640858 | 0.00000323 | 0.001794 | 0.001794 | 0.001781217 | 0.001781217 |
| 66 | 1 | 1 | 0.3450 | 0.999108 | 1 | 0 | 0.0000008 | 0.99821608 | 0.00000080 | 0.000892 | 0.000892 | 0.000888382 | 0.000888382 |
| 67 | 1 | 1 | 0.3550 | 0.999484 | 1 | 0 | 0.0000003 | 0.99896863 | 0.00000027 | 0.000516 | 0.000516 | 0.000514491 | 0.000514491 |
| 68 | 1 | 1 | 0.3570 | 0.999538 | 1 | 0 | 0.0000002 | 0.99907651 | 0.00000021 | 0.000462 | 0.000462 | 0.000460787 | 0.000460787 |
| 69 | 1 | 1 | 0.3610 | 0.999630 | 1 | 0 | 0.0000001 | 0.99926022 | 0.00000014 | 0.000370 | 0.000370 | 0.000369276 | 0.000369276 |
| 70 | 1 | 1 | 0.3680 | 0.999750 | 1 | 0 | 0.0000001 | 0.99949947 | 0.00000006 | 0.000250 | 0.000250 | 0.000249983 | 0.000249983 |
| 71 | 1 | 1 | 0.3720 | 0.999800 | 1 | 0 | 0.0000000 | 0.99960016 | 0.00000004 | 0.000200 | 0.000200 | 0.000199741 | 0.000199741 |
| 72 | 1 | 1 | 0.3830 | 0.999893 | 1 | 0 | 0.0000000 | 0.99978538 | 0.00000001 | 0.000107 | 0.000107 | 0.000107257 | 0.000107257 |
| 73 | 1 | 1 | 0.3830 | 0.999893 | 1 | 0 | 0.0000000 | 0.99978538 | 0.00000001 | 0.000107 | 0.000107 | 0.000107257 | 0.000107257 |
| 74 | 1 | 1 | 0.3840 | 0.999899 | 1 | 0 | 0.0000000 | 0.99979725 | 0.00000001 | 0.000101 | 0.000101 | 0.000101330 | 0.000101330 |
| 75 | 1 | 1 | 0.3890 | 0.999924 | 1 | 0 | 0.0000000 | 0.99984754 | 0.00000001 | 0.000076 | 0.000076 | 0.000076205 | 0.000076205 |
| 76 | 1 | 1 | 0.3890 | 0.999924 | 1 | 0 | 0.0000000 | 0.99984754 | 0.00000001 | 0.000076 | 0.000076 | 0.000076205 | 0.000076205 |
| 77 | 1 | 1 | 0.3900 | 0.999928 | 1 | 0 | 0.0000000 | 0.99985601 | 0.00000001 | 0.000072 | 0.000072 | 0.000071973 | 0.000071973 |
| 78 | 1 | 1 | 0.4240 | 0.999990 | 1 | 0 | 0.0000000 | 0.99997982 | 0.00000000 | 0.000010 | 0.000010 | 0.000010087 | 0.000010087 |
| 79 | 1 | 1 | 0.4300 | 0.999993 | 1 | 0 | 0.0000000 | 0.99998579 | 0.00000000 | 0.000007 | 0.000007 | 0.000007106 | 0.000007106 |
| 80 | 1 | 1 | 0.4680 | 0.999999 | 1 | 0 | 0.0000000 | 0.99999848 | 0.00000000 | 0.000001 | 0.000001 | 0.000000761 | 0.000000761 |
| SUM | 48 | 80 | | | 48 | 32 | | | 4.99635960 | | 4.510080 | | 1.532224182 |
| | | | | | | | | | standard deviation = 1.23783043 | | | P = 0.63905036 | |

## Table 5-4(b) Work-Sheet for Test of Goodness of Fit (Major Damage/Memphis Bridge1 / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 1 | 0.0820 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 2 | 0 | 1 | 0.0900 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 3 | 0 | 1 | 0.0960 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 4 | 0 | 1 | 0.0970 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 5 | 0 | 1 | 0.0980 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 6 | 0 | 1 | 0.0980 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 7 | 0 | 1 | 0.1070 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 8 | 0 | 1 | 0.1090 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 9 | 0 | 1 | 0.1100 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 10 | 0 | 1 | 0.1140 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 11 | 0 | 1 | 0.1140 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 12 | 0 | 1 | 0.1170 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000000 | 0.000000000 |
| 13 | 0 | 1 | 0.1210 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000001 | 0.000000001 |
| 14 | 0 | 1 | 0.1220 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000001 | 0.000000001 |
| 15 | 0 | 1 | 0.1240 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000002 | 0.000000002 |
| 16 | 0 | 1 | 0.1270 | 0.000000 | 0 | 1 | 1.0000000 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000007 | 0.000000007 |
| 17 | 0 | 1 | 0.1320 | 0.000000 | 0 | 1 | 0.9999999 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000041 | 0.000000041 |
| 18 | 0 | 1 | 0.1350 | 0.000000 | 0 | 1 | 0.9999998 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000110 | 0.000000110 |
| 19 | 0 | 1 | 0.1390 | 0.000000 | 0 | 1 | 0.9999992 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000376 | 0.000000376 |
| 20 | 0 | 1 | 0.1400 | 0.000001 | 0 | 1 | 0.9999990 | 0.00000000 | 0.00000000 | 0.000001 | 0.000001 | 0.000000504 | 0.000000504 |
| 21 | 0 | 1 | 0.1410 | 0.000001 | 0 | 1 | 0.9999987 | 0.00000000 | 0.00000000 | 0.000001 | 0.000001 | 0.000000671 | 0.000000671 |
| 22 | 0 | 1 | 0.1450 | 0.000002 | 0 | 1 | 0.9999960 | 0.00000000 | 0.00000000 | 0.000002 | 0.000002 | 0.000002017 | 0.000002017 |
| 23 | 0 | 1 | 0.1550 | 0.000023 | 0 | 1 | 0.9999542 | 0.00000000 | 0.00000000 | 0.000023 | 0.000023 | 0.000022891 | 0.000022891 |
| 24 | 0 | 1 | 0.1620 | 0.000099 | 0 | 1 | 0.9998030 | 0.00000001 | 0.00000001 | 0.000098 | 0.000098 | 0.000098452 | 0.000098452 |
| 25 | 0 | 1 | 0.1700 | 0.000423 | 0 | 1 | 0.9991541 | 0.00000018 | 0.00000018 | 0.000423 | 0.000423 | 0.000422161 | 0.000422161 |
| 26 | 0 | 1 | 0.1730 | 0.000694 | 0 | 1 | 0.9986134 | 0.00000048 | 0.00000048 | 0.000693 | 0.000693 | 0.000691159 | 0.000691159 |
| 27 | 0 | 1 | 0.1730 | 0.000694 | 0 | 1 | 0.9986134 | 0.00000048 | 0.00000048 | 0.000693 | 0.000693 | 0.000691159 | 0.000691159 |
| 28 | 0 | 1 | 0.1750 | 0.000950 | 0 | 1 | 0.9981005 | 0.00000090 | 0.00000090 | 0.000949 | 0.000949 | 0.000945705 | 0.000945705 |
| 29 | 0 | 1 | 0.1750 | 0.000950 | 0 | 1 | 0.9981005 | 0.00000090 | 0.00000090 | 0.000949 | 0.000949 | 0.000945705 | 0.000945705 |
| 30 | 0 | 1 | 0.1920 | 0.009046 | 0 | 1 | 0.9819891 | 0.00008184 | 0.00008184 | 0.008965 | 0.008965 | 0.008643090 | 0.008643090 |
| 31 | 0 | 1 | 0.1930 | 0.010112 | 0 | 1 | 0.9798777 | 0.00010226 | 0.00010226 | 0.010010 | 0.010010 | 0.009609208 | 0.009609208 |
| 32 | 0 | 1 | 0.1970 | 0.015462 | 0 | 1 | 0.9693150 | 0.00023907 | 0.00023907 | 0.015223 | 0.015223 | 0.014296010 | 0.014296010 |
| 33 | 0 | 1 | 0.2080 | 0.042411 | 0 | 1 | 0.9169775 | 0.00179866 | 0.00179866 | 0.040612 | 0.040612 | 0.034014620 | 0.034014620 |
| 34 | 0 | 1 | 0.2170 | 0.083103 | 0 | 1 | 0.8406999 | 0.00690612 | 0.00690612 | 0.076197 | 0.076197 | 0.052973055 | 0.052973055 |
| 35 | 0 | 1 | 0.2200 | 0.101216 | 0 | 1 | 0.8078135 | 0.01024458 | 0.01024458 | 0.090971 | 0.090971 | 0.057868093 | 0.057868093 |
| 36 | 0 | 1 | 0.2200 | 0.101216 | 0 | 1 | 0.8078135 | 0.01024458 | 0.01024458 | 0.090971 | 0.090971 | 0.057868093 | 0.057868093 |
| 37 | 0 | 1 | 0.2210 | 0.107789 | 0 | 1 | 0.7960412 | 0.01161838 | 0.01161838 | 0.096170 | 0.096170 | 0.059175370 | 0.059175370 |
| 38 | 0 | 1 | 0.2230 | 0.121746 | 0 | 1 | 0.7713298 | 0.01482212 | 0.01482212 | 0.106924 | 0.106924 | 0.061193035 | 0.061193035 |
| 39 | 0 | 1 | 0.2330 | 0.207430 | 0 | 1 | 0.6281664 | 0.04302741 | 0.04302741 | 0.164403 | 0.164403 | 0.056289589 | 0.056289589 |
| 40 | 0 | 1 | 0.2330 | 0.207430 | 0 | 1 | 0.6281664 | 0.04302741 | 0.04302741 | 0.164403 | 0.164403 | 0.056289589 | 0.056289589 |
| 41 | 0 | 1 | 0.2380 | 0.259298 | 0 | 1 | 0.5486396 | 0.06723539 | 0.06723539 | 0.192062 | 0.192062 | 0.044510488 | 0.044510488 |
| 42 | 1 | 1 | 0.2430 | 0.315903 | 1 | 0 | 0.4679881 | 0.09979500 | 0.46798806 | 0.216108 | 0.216108 | 0.029296988 | 0.029296988 |
| 43 | 0 | 1 | 0.2480 | 0.375908 | 0 | 1 | 0.3894912 | 0.14130659 | 0.14130659 | 0.234601 | 0.234601 | 0.014450396 | 0.014450396 |
| 44 | 1 | 1 | 0.2520 | 0.425343 | 1 | 0 | 0.3302310 | 0.18091642 | 0.33023100 | 0.244426 | 0.244426 | 0.005449446 | 0.005449446 |
| 45 | 1 | 1 | 0.2540 | 0.450261 | 1 | 0 | 0.3022133 | 0.20273472 | 0.30221327 | 0.247526 | 0.247526 | 0.002449513 | 0.002449513 |
| 46 | 1 | 1 | 0.2550 | 0.462726 | 1 | 0 | 0.2886634 | 0.21411533 | 0.28866338 | 0.248611 | 0.248611 | 0.001381632 | 0.001381632 |
| 47 | 0 | 1 | 0.2570 | 0.487608 | 0 | 1 | 0.2625460 | 0.23776117 | 0.23776117 | 0.249846 | 0.249846 | 0.000153477 | 0.000153477 |
| 48 | 1 | 1 | 0.2580 | 0.500000 | 1 | 0 | 0.2500000 | 0.25000000 | 0.25000000 | 0.250000 | 0.250000 | 0.000000000 | 0.000000000 |
| 49 | 1 | 1 | 0.2590 | 0.512344 | 1 | 0 | 0.2378079 | 0.26249686 | 0.23780791 | 0.249848 | 0.249848 | 0.000152293 | 0.000152293 |
| 50 | 1 | 1 | 0.2720 | 0.663757 | 1 | 0 | 0.1130591 | 0.44057392 | 0.11305907 | 0.223184 | 0.223184 | 0.023939997 | 0.023939997 |
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| 61 | 1 | 1 | 0.3110 | 0.932499 | 1 | 0 | 0.0045564 | 0.86955482 | 0.00455635 | 0.062944 | 0.062944 | 0.047096416 | 0.047096416 |
| 62 | 1 | 1 | 0.3140 | 0.941963 | 1 | 0 | 0.0033683 | 0.88729413 | 0.00336830 | 0.054669 | 0.054669 | 0.042714081 | 0.042714081 |
| 63 | 1 | 1 | 0.3240 | 0.965793 | 1 | 0 | 0.0011701 | 0.93275641 | 0.00117011 | 0.033037 | 0.033037 | 0.028671034 | 0.028671034 |
| 64 | 1 | 1 | 0.3320 | 0.978173 | 1 | 0 | 0.0004764 | 0.95682308 | 0.00047640 | 0.021350 | 0.021350 | 0.019526926 | 0.019526926 |
| 65 | 1 | 1 | 0.3320 | 0.978173 | 1 | 0 | 0.0004764 | 0.95682308 | 0.00047640 | 0.021350 | 0.021350 | 0.019526926 | 0.019526926 |
| 66 | 1 | 1 | 0.3450 | 0.989955 | 1 | 0 | 0.0001009 | 0.98001179 | 0.00010089 | 0.009944 | 0.009944 | 0.009548153 | 0.009548153 |
| 67 | 1 | 1 | 0.3550 | 0.994664 | 1 | 0 | 0.0000285 | 0.98935661 | 0.00002847 | 0.005307 | 0.005307 | 0.005194780 | 0.005194780 |
| 68 | 1 | 1 | 0.3570 | 0.995314 | 1 | 0 | 0.0000220 | 0.99065076 | 0.00002195 | 0.004664 | 0.004664 | 0.004576644 | 0.004576644 |
| 69 | 1 | 1 | 0.3610 | 0.996399 | 1 | 0 | 0.0000130 | 0.99281066 | 0.00001297 | 0.003588 | 0.003588 | 0.003536684 | 0.003536684 |
| 70 | 1 | 1 | 0.3680 | 0.997751 | 1 | 0 | 0.0000051 | 0.99550751 | 0.00000506 | 0.002244 | 0.002244 | 0.002223578 | 0.002223578 |
| 71 | 1 | 1 | 0.3720 | 0.998291 | 1 | 0 | 0.0000029 | 0.99658551 | 0.00000292 | 0.001706 | 0.001706 | 0.001694147 | 0.001694147 |
| 72 | 1 | 1 | 0.3830 | 0.999213 | 1 | 0 | 0.0000006 | 0.99842606 | 0.00000062 | 0.000787 | 0.000787 | 0.000784185 | 0.000784185 |
| 73 | 1 | 1 | 0.3830 | 0.999213 | 1 | 0 | 0.0000006 | 0.99842606 | 0.00000062 | 0.000787 | 0.000787 | 0.000784185 | 0.000784185 |
| 74 | 1 | 1 | 0.3840 | 0.999267 | 1 | 0 | 0.0000005 | 0.99853508 | 0.00000054 | 0.000732 | 0.000732 | 0.000730048 | 0.000730048 |
| 75 | 1 | 1 | 0.3890 | 0.999490 | 1 | 0 | 0.0000003 | 0.99898017 | 0.00000026 | 0.000510 | 0.000510 | 0.000508747 | 0.000508747 |
| 76 | 1 | 1 | 0.3890 | 0.999490 | 1 | 0 | 0.0000003 | 0.99898017 | 0.00000026 | 0.000510 | 0.000510 | 0.000508747 | 0.000508747 |
| 77 | 1 | 1 | 0.3900 | 0.999526 | 1 | 0 | 0.0000002 | 0.99905203 | 0.00000022 | 0.000474 | 0.000474 | 0.000472975 | 0.000472975 |
| 78 | 1 | 1 | 0.4240 | 0.999965 | 1 | 0 | 0.0000000 | 0.99992935 | 0.00000000 | 0.000035 | 0.000035 | 0.000035319 | 0.000035319 |
| 79 | 1 | 1 | 0.4300 | 0.999978 | 1 | 0 | 0.0000000 | 0.99995620 | 0.00000000 | 0.000022 | 0.000022 | 0.000021896 | 0.000021896 |
| 80 | 1 | 1 | 0.4680 | 0.999999 | 1 | 0 | 0.0000000 | 0.99999810 | 0.00000000 | 0.000001 | 0.000001 | 0.000000950 | 0.000000950 |
| SUM | 34 | 80 | | | 34 | 46 | | | 4.95138817 | | 4.694810 | | 1.382762000 |
| | | | | | | | | | standard deviation = 1.17590907 | | | P = 0.57360295 | |

## Table 5-5(a) Work-Sheet for Test of Goodness of Fit (Minor Damage/Memphis Bridge2 / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 1 | 0.0820 | 0.000000 | 0 | 1 | 0.9999995 | 0.00000000 | 0.00000000 | 0.000000 | 0.000000 | 0.000000228 | 0.000000228 |
| 2 | 0 | 1 | 0.0900 | 0.000002 | 0 | 1 | 0.9999954 | 0.00000000 | 0.00000000 | 0.000002 | 0.000002 | 0.000002319 | 0.000002319 |
| 3 | 0 | 1 | 0.0960 | 0.000010 | 0 | 1 | 0.9999795 | 0.00000000 | 0.00000000 | 0.000010 | 0.000010 | 0.000010244 | 0.000010244 |
| 4 | 0 | 1 | 0.0970 | 0.000013 | 0 | 1 | 0.9999742 | 0.00000000 | 0.00000000 | 0.000013 | 0.000013 | 0.000012885 | 0.000012885 |
| 5 | 0 | 1 | 0.0980 | 0.000016 | 0 | 1 | 0.9999677 | 0.00000000 | 0.00000000 | 0.000016 | 0.000016 | 0.000016127 | 0.000016127 |
| 6 | 0 | 1 | 0.0980 | 0.000016 | 0 | 1 | 0.9999677 | 0.00000000 | 0.00000000 | 0.000016 | 0.000016 | 0.000016127 | 0.000016127 |
| 7 | 0 | 1 | 0.1070 | 0.000100 | 0 | 1 | 0.9998007 | 0.00000001 | 0.00000001 | 0.000100 | 0.000100 | 0.000099618 | 0.000099618 |
| 8 | 0 | 1 | 0.1090 | 0.000143 | 0 | 1 | 0.9997141 | 0.00000002 | 0.00000002 | 0.000143 | 0.000143 | 0.000142858 | 0.000142858 |
| 9 | 0 | 1 | 0.1100 | 0.000170 | 0 | 1 | 0.9996594 | 0.00000003 | 0.00000003 | 0.000170 | 0.000170 | 0.000170145 | 0.000170145 |
| 10 | 0 | 1 | 0.1140 | 0.000331 | 0 | 1 | 0.9993375 | 0.00000011 | 0.00000011 | 0.000331 | 0.000331 | 0.000330736 | 0.000330736 |
| 11 | 0 | 1 | 0.1140 | 0.000331 | 0 | 1 | 0.9993375 | 0.00000011 | 0.00000011 | 0.000331 | 0.000331 | 0.000330736 | 0.000330736 |
| 12 | 0 | 1 | 0.1170 | 0.000528 | 0 | 1 | 0.9989451 | 0.00000028 | 0.00000028 | 0.000527 | 0.000527 | 0.000526179 | 0.000526179 |
| 13 | 0 | 1 | 0.1210 | 0.000941 | 0 | 1 | 0.9981183 | 0.00000089 | 0.00000089 | 0.000940 | 0.000940 | 0.000936857 | 0.000936857 |
| 14 | 0 | 1 | 0.1220 | 0.001080 | 0 | 1 | 0.9978405 | 0.00000117 | 0.00000117 | 0.001079 | 0.001079 | 0.001074493 | 0.001074493 |
| 15 | 0 | 1 | 0.1240 | 0.001412 | 0 | 1 | 0.9971784 | 0.00000199 | 0.00000199 | 0.001410 | 0.001410 | 0.001401839 | 0.001401839 |
| 16 | 0 | 1 | 0.1270 | 0.002069 | 0 | 1 | 0.9958656 | 0.00000428 | 0.00000428 | 0.002065 | 0.002065 | 0.002048006 | 0.002048006 |
| 17 | 0 | 1 | 0.1320 | 0.003733 | 0 | 1 | 0.9925474 | 0.00001394 | 0.00001394 | 0.003719 | 0.003719 | 0.003664018 | 0.003664018 |
| 18 | 0 | 1 | 0.1350 | 0.005181 | 0 | 1 | 0.9896640 | 0.00002685 | 0.00002685 | 0.005155 | 0.005155 | 0.005048281 | 0.005048281 |
| 19 | 0 | 1 | 0.1390 | 0.007798 | 0 | 1 | 0.9844639 | 0.00006082 | 0.00006082 | 0.007738 | 0.007738 | 0.007498143 | 0.007498143 |
| 20 | 0 | 1 | 0.1400 | 0.008597 | 0 | 1 | 0.9828807 | 0.00007390 | 0.00007390 | 0.008523 | 0.008523 | 0.008232139 | 0.008232139 |
| 21 | 0 | 1 | 0.1410 | 0.009459 | 0 | 1 | 0.9811714 | 0.00008947 | 0.00008947 | 0.009370 | 0.009370 | 0.009018427 | 0.009018427 |
| 22 | 0 | 1 | 0.1450 | 0.013623 | 0 | 1 | 0.9729391 | 0.00018559 | 0.00018559 | 0.013438 | 0.013438 | 0.012715382 | 0.012715382 |
| 23 | 0 | 1 | 0.1550 | 0.030316 | 0 | 1 | 0.9402871 | 0.00091906 | 0.00091906 | 0.029397 | 0.029397 | 0.025940222 | 0.025940222 |
| 24 | 0 | 1 | 0.1620 | 0.048819 | 0 | 1 | 0.9047448 | 0.00238332 | 0.00238332 | 0.046436 | 0.046436 | 0.037810755 | 0.037810755 |
| 25 | 1 | 1 | 0.1700 | 0.078300 | 1 | 0 | 0.8495308 | 0.00613089 | 0.84953083 | 0.072169 | 0.072169 | 0.051335599 | 0.051335599 |
| 26 | 0 | 1 | 0.1730 | 0.091830 | 0 | 1 | 0.8247724 | 0.00843278 | 0.00843278 | 0.083397 | 0.083397 | 0.055576897 | 0.055576897 |
| 27 | 0 | 1 | 0.1730 | 0.091830 | 0 | 1 | 0.8247724 | 0.00843278 | 0.00843278 | 0.083397 | 0.083397 | 0.055576897 | 0.055576897 |
| 28 | 0 | 1 | 0.1750 | 0.101619 | 0 | 1 | 0.8070892 | 0.01032633 | 0.01032633 | 0.091292 | 0.091292 | 0.057955145 | 0.057955145 |
| 29 | 0 | 1 | 0.1750 | 0.101619 | 0 | 1 | 0.8070892 | 0.01032633 | 0.01032633 | 0.091292 | 0.091292 | 0.057955145 | 0.057955145 |
| 30 | 0 | 1 | 0.1920 | 0.208642 | 0 | 1 | 0.6262477 | 0.04353143 | 0.04353143 | 0.165110 | 0.165110 | 0.056064608 | 0.056064608 |
| 31 | 0 | 1 | 0.1930 | 0.216139 | 0 | 1 | 0.6144373 | 0.04671628 | 0.04671628 | 0.169423 | 0.169423 | 0.054606312 | 0.054606312 |
| 32 | 0 | 1 | 0.1970 | 0.247227 | 0 | 1 | 0.5666665 | 0.06112143 | 0.06112143 | 0.186106 | 0.186106 | 0.047564201 | 0.047564201 |
| 33 | 1 | 1 | 0.2080 | 0.339833 | 1 | 0 | 0.4358209 | 0.11548623 | 0.43582092 | 0.224346 | 0.224346 | 0.023021154 | 0.023021154 |
| 34 | 1 | 1 | 0.2170 | 0.419889 | 1 | 0 | 0.3365287 | 0.17630683 | 0.33652869 | 0.243582 | 0.243582 | 0.006253011 | 0.006253011 |
| 35 | 0 | 1 | 0.2200 | 0.446753 | 0 | 1 | 0.3060817 | 0.19958867 | 0.19958867 | 0.247165 | 0.247165 | 0.002803039 | 0.002803039 |
| 36 | 0 | 1 | 0.2200 | 0.446753 | 0 | 1 | 0.3060817 | 0.19958867 | 0.19958867 | 0.247165 | 0.247165 | 0.002803039 | 0.002803039 |
| 37 | 0 | 1 | 0.2210 | 0.455687 | 0 | 1 | 0.2962764 | 0.20765083 | 0.20765083 | 0.248036 | 0.248036 | 0.001948200 | 0.001948200 |
| 38 | 0 | 1 | 0.2230 | 0.473496 | 0 | 1 | 0.2772062 | 0.22419874 | 0.22419874 | 0.249298 | 0.249298 | 0.000700473 | 0.000700473 |
| 39 | 0 | 1 | 0.2330 | 0.560311 | 0 | 1 | 0.1933262 | 0.31394875 | 0.31394875 | 0.246363 | 0.246363 | 0.003584529 | 0.003584529 |
| 40 | 1 | 1 | 0.2330 | 0.560311 | 1 | 0 | 0.1933262 | 0.31394875 | 0.19332615 | 0.246363 | 0.246363 | 0.003584529 | 0.003584529 |
| 41 | 1 | 1 | 0.2380 | 0.601562 | 1 | 0 | 0.1587531 | 0.36187640 | 0.15875313 | 0.239685 | 0.239685 | 0.009889187 | 0.009889187 |
| 42 | 1 | 1 | 0.2430 | 0.640886 | 1 | 0 | 0.1289629 | 0.41073481 | 0.12896290 | 0.230151 | 0.230151 | 0.018272945 | 0.018272945 |
| 43 | 0 | 1 | 0.2480 | 0.678016 | 0 | 1 | 0.1036737 | 0.45970564 | 0.45970564 | 0.218310 | 0.218310 | 0.027672737 | 0.027672737 |
| 44 | 1 | 1 | 0.2520 | 0.706009 | 1 | 0 | 0.0864309 | 0.49844824 | 0.08643090 | 0.207560 | 0.207560 | 0.035235102 | 0.035235102 |
| 45 | 1 | 1 | 0.2540 | 0.719410 | 1 | 0 | 0.0787305 | 0.51755139 | 0.07873050 | 0.201859 | 0.201859 | 0.038870742 | 0.038870742 |
| 46 | 1 | 1 | 0.2550 | 0.725960 | 1 | 0 | 0.0750979 | 0.52701792 | 0.07509792 | 0.198942 | 0.198942 | 0.040630277 | 0.040630277 |
| 47 | 1 | 1 | 0.2570 | 0.738754 | 1 | 0 | 0.0682496 | 0.54575714 | 0.06824959 | 0.192997 | 0.192997 | 0.044005830 | 0.044005830 |
| 48 | 1 | 1 | 0.2580 | 0.744997 | 1 | 0 | 0.0650264 | 0.55502084 | 0.06502642 | 0.189976 | 0.189976 | 0.045612286 | 0.045612286 |
| 49 | 1 | 1 | 0.2590 | 0.751138 | 1 | 0 | 0.0619323 | 0.56420827 | 0.06193230 | 0.186930 | 0.186930 | 0.047158842 | 0.047158842 |
| 50 | 1 | 1 | 0.2720 | 0.821664 | 1 | 0 | 0.0318036 | 0.67513247 | 0.03180357 | 0.146532 | 0.146532 | 0.060645495 | 0.060645495 |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
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| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 61 | 1 | 1 | 0.3110 | 0.943896 | 1 | 0 | 0.0031476 | 0.89093993 | 0.00314764 | 0.052956 | 0.052956 | 0.041738771 | 0.041738771 |
| 62 | 1 | 1 | 0.3140 | 0.949092 | 1 | 0 | 0.0025917 | 0.90077499 | 0.00259166 | 0.048317 | 0.048317 | 0.038978672 | 0.038978672 |
| 63 | 1 | 1 | 0.3240 | 0.963440 | 1 | 0 | 0.0013366 | 0.92821692 | 0.00133662 | 0.035223 | 0.035223 | 0.030260524 | 0.030260524 |
| 64 | 1 | 1 | 0.3320 | 0.972154 | 1 | 0 | 0.0007754 | 0.94508287 | 0.00077541 | 0.027071 | 0.027071 | 0.024139533 | 0.024139533 |
| 65 | 1 | 1 | 0.3320 | 0.972154 | 1 | 0 | 0.0007754 | 0.94508287 | 0.00077541 | 0.027071 | 0.027071 | 0.024139533 | 0.024139533 |
| 66 | 1 | 1 | 0.3450 | 0.982334 | 1 | 0 | 0.0003121 | 0.96497950 | 0.00031210 | 0.017354 | 0.017354 | 0.016149527 | 0.016149527 |
| 67 | 1 | 1 | 0.3550 | 0.987670 | 1 | 0 | 0.0001520 | 0.97549166 | 0.00015203 | 0.012178 | 0.012178 | 0.011584922 | 0.011584922 |
| 68 | 1 | 1 | 0.3570 | 0.988536 | 1 | 0 | 0.0001314 | 0.97720340 | 0.00013142 | 0.011333 | 0.011333 | 0.010818877 | 0.010818877 |
| 69 | 1 | 1 | 0.3610 | 0.990099 | 1 | 0 | 0.0000980 | 0.98029534 | 0.00009804 | 0.009803 | 0.009803 | 0.009418893 | 0.009418893 |
| 70 | 1 | 1 | 0.3680 | 0.992359 | 1 | 0 | 0.0000584 | 0.98477578 | 0.00005839 | 0.007583 | 0.007583 | 0.007352914 | 0.007352914 |
| 71 | 1 | 1 | 0.3720 | 0.993420 | 1 | 0 | 0.0000433 | 0.98688282 | 0.00004330 | 0.006537 | 0.006537 | 0.006366016 | 0.006366016 |
| 72 | 1 | 1 | 0.3830 | 0.995660 | 1 | 0 | 0.0000188 | 0.99133803 | 0.00001884 | 0.004322 | 0.004322 | 0.004246864 | 0.004246864 |
| 73 | 1 | 1 | 0.3830 | 0.995660 | 1 | 0 | 0.0000188 | 0.99133803 | 0.00001884 | 0.004322 | 0.004322 | 0.004246864 | 0.004246864 |
| 74 | 1 | 1 | 0.3840 | 0.995822 | 1 | 0 | 0.0000175 | 0.99166174 | 0.00001745 | 0.004160 | 0.004160 | 0.004091166 | 0.004091166 |
| 75 | 1 | 1 | 0.3890 | 0.996551 | 1 | 0 | 0.0000119 | 0.99311347 | 0.00001190 | 0.003437 | 0.003437 | 0.003390054 | 0.003390054 |
| 76 | 1 | 1 | 0.3890 | 0.996551 | 1 | 0 | 0.0000119 | 0.99311347 | 0.00001190 | 0.003437 | 0.003437 | 0.003390054 | 0.003390054 |
| 77 | 1 | 1 | 0.3900 | 0.996681 | 1 | 0 | 0.0000110 | 0.99337305 | 0.00001102 | 0.003308 | 0.003308 | 0.003264197 | 0.003264197 |
| 78 | 1 | 1 | 0.4240 | 0.999127 | 1 | 0 | 0.0000008 | 0.99825459 | 0.00000076 | 0.000872 | 0.000872 | 0.000869280 | 0.000869280 |
| 79 | 1 | 1 | 0.4300 | 0.999313 | 1 | 0 | 0.0000005 | 0.99862726 | 0.00000047 | 0.000686 | 0.000686 | 0.000684252 | 0.000684252 |
| 80 | 1 | 1 | 0.4680 | 0.999854 | 1 | 0 | 0.0000000 | 0.99970712 | 0.00000002 | 0.000146 | 0.000146 | 0.000146345 | 0.000146345 |
| SUM | 41 | 80 | | | 41 | 39 | | | 6.08694493 | | 6.174071 | | 1.767572433 |
| | | | | | | | | | standard deviation = 1.32950085 | | | P = 0.48034346 | |

# Table 5-5(b) Work-Sheet for Test of Goodness of Fit (Major Damage/Memphis Bridge2 / Method1)

| No. | Xi | N | PGA (g) | Pi | A | B | C | D | AC+BD | each mean | MEAN | each variation | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | | probability | # of failed | # of not failed | $(1-Pi)^2$ | $Pi^2$ | $Y^2$ | Pi(1-Pi) | n*Pi(1-Pi) | $Pi(1-Pi)(1-2Pi)^2$ | $N*Pi(1-Pi)(1-2Pi)^2$ |
| 1 | 0 | 1 | 0.0820 | 0.000010 | 0 | 1 | 0.9999806 | 0.00000000 | 0.00000000 | 0.000010 | 0.000010 | 0.000009724 | 0.000009724 |
| 2 | 0 | 1 | 0.0900 | 0.000036 | 0 | 1 | 0.9999272 | 0.00000000 | 0.00000000 | 0.000036 | 0.000036 | 0.000036390 | 0.000036390 |
| 3 | 0 | 1 | 0.0960 | 0.000086 | 0 | 1 | 0.9998274 | 0.00000001 | 0.00000001 | 0.000086 | 0.000086 | 0.000086260 | 0.000086260 |
| 4 | 0 | 1 | 0.0970 | 0.000099 | 0 | 1 | 0.9998025 | 0.00000001 | 0.00000001 | 0.000099 | 0.000099 | 0.000098691 | 0.000098691 |
| 5 | 0 | 1 | 0.0980 | 0.000113 | 0 | 1 | 0.9997746 | 0.00000001 | 0.00000001 | 0.000113 | 0.000113 | 0.000112636 | 0.000112636 |
| 6 | 0 | 1 | 0.0980 | 0.000113 | 0 | 1 | 0.9997746 | 0.00000001 | 0.00000001 | 0.000113 | 0.000113 | 0.000112636 | 0.000112636 |
| 7 | 0 | 1 | 0.1070 | 0.000335 | 0 | 1 | 0.9993302 | 0.00000011 | 0.00000011 | 0.000335 | 0.000335 | 0.000334396 | 0.000334396 |
| 8 | 0 | 1 | 0.1090 | 0.000417 | 0 | 1 | 0.9991657 | 0.00000017 | 0.00000017 | 0.000417 | 0.000417 | 0.000416381 | 0.000416381 |
| 9 | 0 | 1 | 0.1100 | 0.000464 | 0 | 1 | 0.9990714 | 0.00000022 | 0.00000022 | 0.000464 | 0.000464 | 0.000463327 | 0.000463327 |
| 10 | 0 | 1 | 0.1140 | 0.000700 | 0 | 1 | 0.9985999 | 0.00000049 | 0.00000049 | 0.000700 | 0.000700 | 0.000697844 | 0.000697844 |
| 11 | 0 | 1 | 0.1140 | 0.000700 | 0 | 1 | 0.9985999 | 0.00000049 | 0.00000049 | 0.000700 | 0.000700 | 0.000697844 | 0.000697844 |
| 12 | 0 | 1 | 0.1170 | 0.000937 | 0 | 1 | 0.9981278 | 0.00000088 | 0.00000088 | 0.000936 | 0.000936 | 0.000932173 | 0.000932173 |
| 13 | 0 | 1 | 0.1210 | 0.001351 | 0 | 1 | 0.9973002 | 0.00000182 | 0.00000182 | 0.001349 | 0.001349 | 0.001341700 | 0.001341700 |
| 14 | 0 | 1 | 0.1220 | 0.001475 | 0 | 1 | 0.9970522 | 0.00000218 | 0.00000218 | 0.001473 | 0.001473 | 0.001464151 | 0.001464151 |
| 15 | 0 | 1 | 0.1240 | 0.001751 | 0 | 1 | 0.9965001 | 0.00000307 | 0.00000307 | 0.001748 | 0.001748 | 0.001736191 | 0.001736191 |
| 16 | 0 | 1 | 0.1270 | 0.002244 | 0 | 1 | 0.9955169 | 0.00000504 | 0.00000504 | 0.002239 | 0.002239 | 0.002218992 | 0.002218992 |
| 17 | 0 | 1 | 0.1320 | 0.003309 | 0 | 1 | 0.9933925 | 0.00001095 | 0.00001095 | 0.003298 | 0.003298 | 0.003254770 | 0.003254770 |
| 18 | 0 | 1 | 0.1350 | 0.004121 | 0 | 1 | 0.9917756 | 0.00001698 | 0.00001698 | 0.004104 | 0.004104 | 0.004036362 | 0.004036362 |
| 19 | 0 | 1 | 0.1390 | 0.005439 | 0 | 1 | 0.9891517 | 0.00002958 | 0.00002958 | 0.005409 | 0.005409 | 0.005292335 | 0.005292335 |
| 20 | 0 | 1 | 0.1400 | 0.005815 | 0 | 1 | 0.9884036 | 0.00003382 | 0.00003382 | 0.005781 | 0.005781 | 0.005647599 | 0.005647599 |
| 21 | 0 | 1 | 0.1410 | 0.006211 | 0 | 1 | 0.9876161 | 0.00003858 | 0.00003858 | 0.006173 | 0.006173 | 0.006020246 | 0.006020246 |
| 22 | 0 | 1 | 0.1450 | 0.008009 | 0 | 1 | 0.9840457 | 0.00006415 | 0.00006415 | 0.007945 | 0.007945 | 0.007692600 | 0.007692600 |
| 23 | 0 | 1 | 0.1550 | 0.014242 | 0 | 1 | 0.9717184 | 0.00020284 | 0.00020284 | 0.014039 | 0.014039 | 0.013250953 | 0.013250953 |
| 24 | 0 | 1 | 0.1620 | 0.020368 | 0 | 1 | 0.9596781 | 0.00041487 | 0.00041487 | 0.019954 | 0.019954 | 0.018360954 | 0.018360954 |
| 25 | 0 | 1 | 0.1700 | 0.029468 | 0 | 1 | 0.9419330 | 0.00086834 | 0.00086834 | 0.028599 | 0.028599 | 0.025327640 | 0.025327640 |
| 26 | 0 | 1 | 0.1730 | 0.033512 | 0 | 1 | 0.9340983 | 0.00112308 | 0.00112308 | 0.032389 | 0.032389 | 0.028193031 | 0.028193031 |
| 27 | 0 | 1 | 0.1730 | 0.033512 | 0 | 1 | 0.9340983 | 0.00112308 | 0.00112308 | 0.032389 | 0.032389 | 0.028193031 | 0.028193031 |
| 28 | 0 | 1 | 0.1750 | 0.036411 | 0 | 1 | 0.9285037 | 0.00132576 | 0.00132576 | 0.035085 | 0.035085 | 0.030161350 | 0.030161350 |
| 29 | 0 | 1 | 0.1750 | 0.036411 | 0 | 1 | 0.9285037 | 0.00132576 | 0.00132576 | 0.035085 | 0.035085 | 0.030161350 | 0.030161350 |
| 30 | 0 | 1 | 0.1920 | 0.067984 | 0 | 1 | 0.8686530 | 0.00462189 | 0.00462189 | 0.063363 | 0.063363 | 0.047303307 | 0.047303307 |
| 31 | 0 | 1 | 0.1930 | 0.070241 | 0 | 1 | 0.8644510 | 0.00493386 | 0.00493386 | 0.065308 | 0.065308 | 0.048247260 | 0.048247260 |
| 32 | 0 | 1 | 0.1970 | 0.079720 | 0 | 1 | 0.8469153 | 0.00635528 | 0.00635528 | 0.073365 | 0.073365 | 0.051835194 | 0.051835194 |
| 33 | 0 | 1 | 0.2080 | 0.109462 | 0 | 1 | 0.7930579 | 0.01198193 | 0.01198193 | 0.097480 | 0.097480 | 0.059470618 | 0.059470618 |
| 34 | 0 | 1 | 0.2170 | 0.137644 | 0 | 1 | 0.7436578 | 0.01894589 | 0.01894589 | 0.118698 | 0.118698 | 0.062341148 | 0.062341148 |
| 35 | 0 | 1 | 0.2200 | 0.147758 | 0 | 1 | 0.7263156 | 0.02183256 | 0.02183256 | 0.125926 | 0.125926 | 0.062496571 | 0.062496571 |
| 36 | 0 | 1 | 0.2200 | 0.147758 | 0 | 1 | 0.7263156 | 0.02183256 | 0.02183256 | 0.125926 | 0.125926 | 0.062496571 | 0.062496571 |
| 37 | 0 | 1 | 0.2210 | 0.151206 | 0 | 1 | 0.7204513 | 0.02286325 | 0.02286325 | 0.128343 | 0.128343 | 0.062455304 | 0.062455304 |
| 38 | 0 | 1 | 0.2230 | 0.158212 | 0 | 1 | 0.7086070 | 0.02503105 | 0.02503105 | 0.133181 | 0.133181 | 0.062232286 | 0.062232286 |
| 39 | 0 | 1 | 0.2330 | 0.195314 | 0 | 1 | 0.6475193 | 0.03814762 | 0.03814762 | 0.157167 | 0.157167 | 0.058361255 | 0.058361255 |
| 40 | 0 | 1 | 0.2330 | 0.195314 | 0 | 1 | 0.6475193 | 0.03814762 | 0.03814762 | 0.157167 | 0.157167 | 0.058361255 | 0.058361255 |
| 41 | 0 | 1 | 0.2380 | 0.215029 | 0 | 1 | 0.6161794 | 0.04623750 | 0.04623750 | 0.168792 | 0.168792 | 0.054829194 | 0.054829194 |
| 42 | 1 | 1 | 0.2430 | 0.235409 | 1 | 0 | 0.5845993 | 0.05541744 | 0.58459927 | 0.179992 | 0.179992 | 0.050403675 | 0.050403675 |
| 43 | 0 | 1 | 0.2480 | 0.256366 | 0 | 1 | 0.5529911 | 0.06572369 | 0.06572369 | 0.190643 | 0.190643 | 0.045264181 | 0.045264181 |
| 44 | 1 | 1 | 0.2520 | 0.273487 | 1 | 0 | 0.5278208 | 0.07479528 | 0.52782075 | 0.198692 | 0.198692 | 0.040777968 | 0.040777968 |
| 45 | 0 | 1 | 0.2540 | 0.282150 | 0 | 1 | 0.5153084 | 0.07960870 | 0.07960870 | 0.202541 | 0.202541 | 0.038449301 | 0.038449301 |
| 46 | 1 | 1 | 0.2550 | 0.286505 | 1 | 0 | 0.5090756 | 0.08208491 | 0.50907564 | 0.204420 | 0.204420 | 0.037270027 | 0.037270027 |
| 47 | 0 | 1 | 0.2570 | 0.295256 | 0 | 1 | 0.4966640 | 0.08717616 | 0.08717616 | 0.208080 | 0.208080 | 0.034890897 | 0.034890897 |
| 48 | 1 | 1 | 0.2580 | 0.299652 | 1 | 0 | 0.4904878 | 0.08979110 | 0.49048785 | 0.209861 | 0.209861 | 0.033694763 | 0.033694763 |
| 49 | 1 | 1 | 0.2590 | 0.304059 | 1 | 0 | 0.4843333 | 0.09245211 | 0.48433334 | 0.211607 | 0.211607 | 0.032496720 | 0.032496720 |
| 50 | 1 | 1 | 0.2720 | 0.362151 | 1 | 0 | 0.4068511 | 0.13115348 | 0.40685112 | 0.230998 | 0.230998 | 0.017557948 | 0.017557948 |
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| 61 | 0 | 1 | 0.3110 | 0.533934 | 0 | 1 | 0.2172171 | 0.28508601 | 0.28508601 | 0.248848 | 0.248848 | 0.001146243 | 0.001146243 |
| 62 | 0 | 1 | 0.3140 | 0.546386 | 0 | 1 | 0.2057653 | 0.29853808 | 0.29853808 | 0.247848 | 0.247848 | 0.002133177 | 0.002133177 |
| 63 | 1 | 1 | 0.3240 | 0.586671 | 1 | 0 | 0.1708411 | 0.34418257 | 0.17084107 | 0.242488 | 0.242488 | 0.007286110 | 0.007286110 |
| 64 | 0 | 1 | 0.3320 | 0.617415 | 0 | 1 | 0.1463710 | 0.38120179 | 0.38120179 | 0.236214 | 0.236214 | 0.013026122 | 0.013026122 |
| 65 | 0 | 1 | 0.3320 | 0.617415 | 0 | 1 | 0.1463710 | 0.38120179 | 0.38120179 | 0.236214 | 0.236214 | 0.013026122 | 0.013026122 |
| 66 | 1 | 1 | 0.3450 | 0.664298 | 1 | 0 | 0.1126961 | 0.44129133 | 0.11269608 | 0.223006 | 0.223006 | 0.024079068 | 0.024079068 |
| 67 | 1 | 1 | 0.3550 | 0.697631 | 1 | 0 | 0.0914272 | 0.48668848 | 0.09142724 | 0.210942 | 0.210942 | 0.032955796 | 0.032955796 |
| 68 | 0 | 1 | 0.3570 | 0.704006 | 0 | 1 | 0.0876124 | 0.49562451 | 0.49562451 | 0.208382 | 0.208382 | 0.034690079 | 0.034690079 |
| 69 | 1 | 1 | 0.3610 | 0.716464 | 1 | 0 | 0.0803925 | 0.51332109 | 0.08039249 | 0.203143 | 0.203143 | 0.038074557 | 0.038074557 |
| 70 | 0 | 1 | 0.3680 | 0.737329 | 0 | 1 | 0.0689963 | 0.54365350 | 0.54365350 | 0.193675 | 0.193675 | 0.043634909 | 0.043634909 |
| 71 | 1 | 1 | 0.3720 | 0.748718 | 1 | 0 | 0.0631426 | 0.56057875 | 0.06314261 | 0.188139 | 0.188139 | 0.046553705 | 0.046553705 |
| 72 | 0 | 1 | 0.3830 | 0.778071 | 0 | 1 | 0.0492526 | 0.60539401 | 0.60539401 | 0.172677 | 0.172677 | 0.053407734 | 0.053407734 |
| 73 | 1 | 1 | 0.3830 | 0.778071 | 1 | 0 | 0.0492526 | 0.60539401 | 0.04925262 | 0.172677 | 0.172677 | 0.053407734 | 0.053407734 |
| 74 | 0 | 1 | 0.3840 | 0.780598 | 0 | 1 | 0.0481372 | 0.60933355 | 0.60933355 | 0.171265 | 0.171265 | 0.053938328 | 0.053938328 |
| 75 | 1 | 1 | 0.3890 | 0.792891 | 1 | 0 | 0.0428943 | 0.62867558 | 0.04289428 | 0.164215 | 0.164215 | 0.056348714 | 0.056348714 |
| 76 | 1 | 1 | 0.3890 | 0.792891 | 1 | 0 | 0.0428943 | 0.62867558 | 0.04289428 | 0.164215 | 0.164215 | 0.056348714 | 0.056348714 |
| 77 | 1 | 1 | 0.3900 | 0.795281 | 1 | 0 | 0.0419099 | 0.63247156 | 0.04190995 | 0.162809 | 0.162809 | 0.056781843 | 0.056781843 |
| 78 | 1 | 1 | 0.4240 | 0.863907 | 1 | 0 | 0.0185214 | 0.74633486 | 0.01852138 | 0.117572 | 0.117572 | 0.062279292 | 0.062279292 |
| 79 | 1 | 1 | 0.4300 | 0.873680 | 1 | 0 | 0.0159567 | 0.76331722 | 0.01595667 | 0.110363 | 0.110363 | 0.061643039 | 0.061643039 |
| 80 | 1 | 1 | 0.4680 | 0.922299 | 1 | 0 | 0.0060375 | 0.85063465 | 0.00603751 | 0.071664 | 0.071664 | 0.051121050 | 0.051121050 |
| SUM | 24 | 80 | | | 24 | 56 | | | 10.44797579 | | 9.719031 | | 2.019099166 |
| | | | | | | | | | standard deviation = 1.42095009 | | | P = 0.64095938 | |

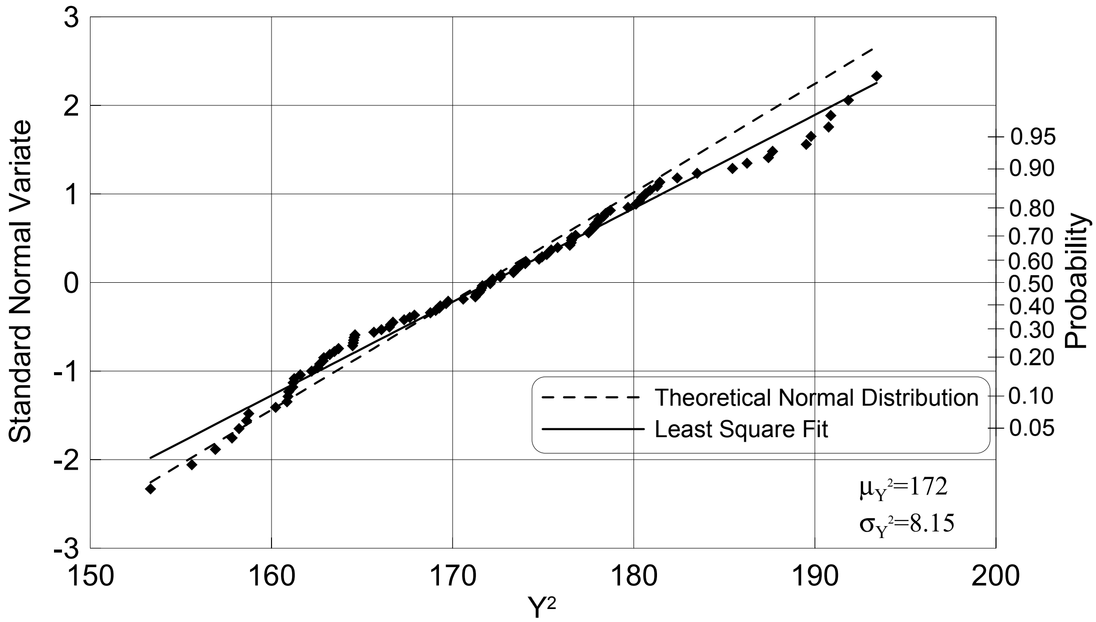


**FIGURE 5-1 Validity of Asymptotic Normality of Statistic $Y^2$**

**(Caltrans' Bridges with at least Minor Damage/Method 1)**

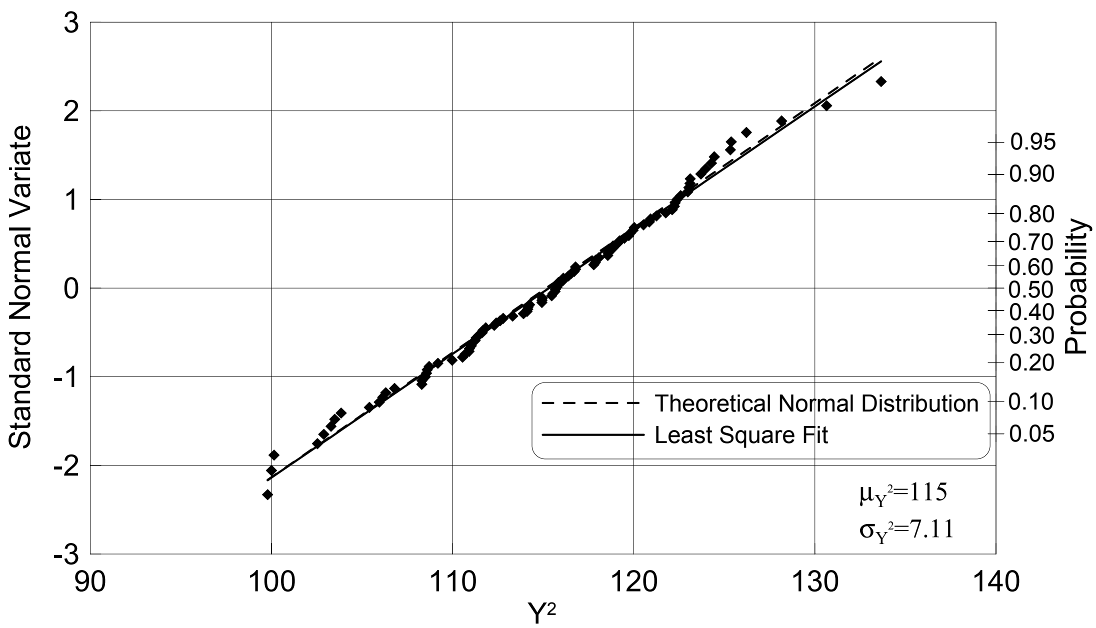


**FIGURE 5-2 Validity of Asymptotic Normality of Statistic $Y^2$**

**(Caltrans' Bridges with at least Moderate Damage/Method 1)**

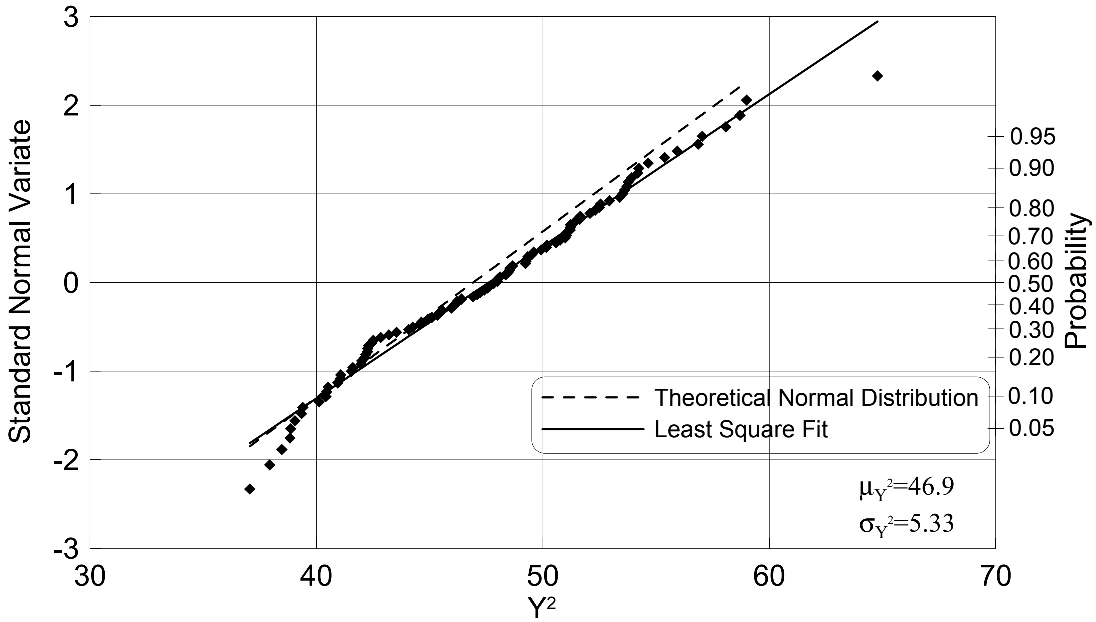


**FIGURE 5-3 Validity of Asymptotic Normality of Statistic $Y^2$**

**(Caltrans' Bridges with at least Major Damage/Method 1)**

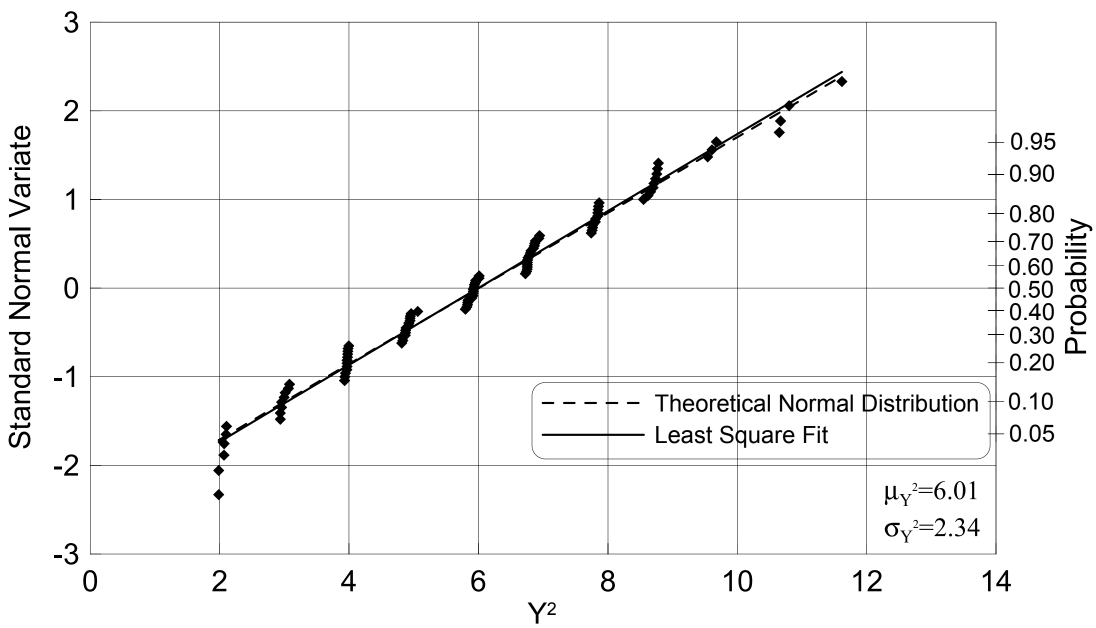


**FIGURE 5-4 Validity of Asymptotic Normality of Statistic $Y^2$**

**(Caltrans' Bridges with Collapse Damage/Method 1)**

## 5.2 Test of Goodness of Fit; Method 2

The probability $P_{y^2}$ for the test of goodness of fit with respect to the fragility curves developed on the basis of the parameters estimated by Method 2 must be derived in a manner consistent with the probabilistic nature of Method 2. The essential derivation is given as follows.

Let $m$ = the number of damage states and $N$ = the total sample size, and define

$$Y_i^2 = \sum_{k=1}^{m} \left(X_{ik} - p_{ik}\right)^2 \tag{5-9}$$

where $X_{ik}$ is the multi-outcome Bernoulli type random variable whose realizations $x_{ik}$ are introduced in Section 2.2 in such a way that $x_{ik}$ = 1 when the damage state $k$ occurs and $x_{ik}$ = 0 otherwise, and $p_{ik}$ = $F_k(a_i)$ = probability of occurrence of the damage state $k$ under PGA = $a_i$. The function $F_k(a_i)$ represents the fragility curve associated with the damage state $k$ and estimated at PGA = $a_i$. It can be shown that the mean value of $Y_i^2$ is

$$\mu_{Y_i^2} = 1 - \sum_{k=1}^{m} p_{ik}^2 \tag{5-10}$$

and the variance of $Y_i^2$ is

$$\sigma_{Y_i^2} = \text{Var}\left(Y_i^2\right) = 4\left\{\sum_{k=1}^{m} p_{ik}^3 - \left(\sum_{k=1}^{m} p_{ik}^2\right)^2\right\} \tag{5-11}$$

The sum of $Y_i^2$ shown below

$$Y^2 = \sum_{i=1}^{N} \sum_{k=1}^{m} \left(X_{ip} - p_{ik}\right)^2 \tag{5-12}$$

has the mean value and the variance, respectively equal to

$$\mu_{Y^2} = N - \sum_{i=1}^{N} \sum_{k=1}^{m} p_{ik}^2 \tag{5-13}$$

and

$$\sigma_{Y^2} = 4\sum_{i=1}^{N} \sum_{k=1}^{m} p_{ik}^3 - 4\sum_{i=1}^{N} \left( \sum_{k=1}^{m} p_{ik}^2 \right)^2 \tag{5-14}$$

The realization $y^2$ of $Y^2$ is obtained by

$$y^2 = \sum_{i=1}^{N} \sum_{k=1}^{m} \left( x_{ik} - p_{ik} \right)^2 \tag{5-15}$$

As in the case of $Y^2$ defined in Section 5.1, the random variable $Y^2$ given in (5-12) is also asymptotically normal and, as N→ ∞, its distribution approaches the normal distribution function as shown in (5-8) with $\mu_{Y^2}$ and $\sigma_{Y^2}$ provided by (5-13) and (5-14), respectively.

The $P_{y^2}$ values for the fragility curves developed for Caltrans' bridges (figure 2-4) and HEPC's bridge columns (figure 2-17) are computed, with the aide of work sheets in tables 5-6 and 5-7, to be 0.45 and 0.53, respectively. These values are both sufficiently small so that the family of fragility curves simultaneously estimated can be discarded neither in the case of Caltrans' bridges nor in the case of HEPC's bridge columns at the significance level of 10%. Thus, the use of $y^2$ to test goodness of fit under Method 2 applies to the entire family of fragility curves estimated simultaneously, but not necessarily to each fragility curve developed individually as done under Method 1. The validity of asymptotic normality is also checked by simulating 100 realizations of $Y^2$ in (5-12), each realization representing one set of simulation of $x_{ik}$ ($i$ = 1, 2,…, $N$; $k$ = 1, 2,…, $m$) with $N$ = 1998 and $m$ = 5 for Caltrans' bridges and $N$ = 770 and $m$ = 4 for HEPC's bridge columns. The 100 realizations each for Caltrans' and HEPC's data are plotted in the normal probability papers as shown in figures 5-5 and 5-6, respectively. These plots clearly support the validity of asymptotic normality of $Y^2$ in (5-12). The test of goodness of fit was not carried out for Memphis Bridges.

# Table 5-6 Work-Sheet for Test of Goodness of Fit (Caltrans' Bridges/Method2)

| No. | PGA (g) | Probability of Occurrence of a Damage State | | | | | Damage State | | | | | | MEAN | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NON | MIN | MOD | MAJ | COL | NON | MIN | MOD | MAJ | COL | $Yj^2$ | | |
| 1 | 0.0688 | 0.998805 | 0.000786 | 0.000371 | 0.000038 | 0.000000 | 1 | 0 | 0 | 0 | 0 | 0.00000219 | 0.002389 | 0.004758303 |
| 2 | 0.0717 | 0.998589 | 0.000921 | 0.000442 | 0.000047 | 0.000000 | 1 | 0 | 0 | 0 | 0 | 0.00000304 | 0.002819 | 0.005611781 |
| 3 | 0.0717 | 0.998589 | 0.000921 | 0.000442 | 0.000047 | 0.000000 | 1 | 0 | 0 | 0 | 0 | 0.00000304 | 0.002819 | 0.005611781 |
| 4 | 0.0721 | 0.998557 | 0.000941 | 0.000453 | 0.000048 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000317 | 0.002882 | 0.005736838 |
| 5 | 0.0721 | 0.998557 | 0.000941 | 0.000453 | 0.000048 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000317 | 0.002882 | 0.005736838 |
| 6 | 0.0724 | 0.998533 | 0.000956 | 0.000461 | 0.000049 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000328 | 0.002930 | 0.005831816 |
| 7 | 0.0724 | 0.998533 | 0.000956 | 0.000461 | 0.000049 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000328 | 0.002930 | 0.005831816 |
| 8 | 0.0724 | 0.998533 | 0.000956 | 0.000461 | 0.000049 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000328 | 0.002930 | 0.005831816 |
| 9 | 0.0731 | 0.998476 | 0.000991 | 0.000480 | 0.000052 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000354 | 0.003044 | 0.006057411 |
| 10 | 0.0732 | 0.998468 | 0.000996 | 0.000483 | 0.000052 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000358 | 0.003060 | 0.006090095 |
| 11 | 0.0732 | 0.998468 | 0.000996 | 0.000483 | 0.000052 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000358 | 0.003060 | 0.006090095 |
| 12 | 0.0738 | 0.998418 | 0.001027 | 0.000500 | 0.000054 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000381 | 0.003161 | 0.006288615 |
| 13 | 0.0738 | 0.998418 | 0.001027 | 0.000500 | 0.000054 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000381 | 0.003161 | 0.006288615 |
| 14 | 0.0738 | 0.998418 | 0.001027 | 0.000500 | 0.000054 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000381 | 0.003161 | 0.006288615 |
| 15 | 0.0744 | 0.998366 | 0.001059 | 0.000518 | 0.000057 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000406 | 0.003263 | 0.006491292 |
| 16 | 0.0746 | 0.998349 | 0.001070 | 0.000523 | 0.000057 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000415 | 0.003298 | 0.006559780 |
| 17 | 0.0747 | 0.998340 | 0.001075 | 0.000526 | 0.000058 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000419 | 0.003315 | 0.006594199 |
| 18 | 0.0747 | 0.998340 | 0.001075 | 0.000526 | 0.000058 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000419 | 0.003315 | 0.006594199 |
| 19 | 0.0747 | 0.998340 | 0.001075 | 0.000526 | 0.000058 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000419 | 0.003315 | 0.006594199 |
| 20 | 0.0747 | 0.998340 | 0.001075 | 0.000526 | 0.000058 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000419 | 0.003315 | 0.006594199 |
| 21 | 0.0751 | 0.998305 | 0.001097 | 0.000538 | 0.000059 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000437 | 0.003385 | 0.006733043 |
| 22 | 0.0751 | 0.998305 | 0.001097 | 0.000538 | 0.000059 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000437 | 0.003385 | 0.006733043 |
| 23 | 0.0751 | 0.998305 | 0.001097 | 0.000538 | 0.000059 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000437 | 0.003385 | 0.006733043 |
| 24 | 0.0751 | 0.998305 | 0.001097 | 0.000538 | 0.000059 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000437 | 0.003385 | 0.006733043 |
| 25 | 0.0751 | 0.998305 | 0.001097 | 0.000538 | 0.000059 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000437 | 0.003385 | 0.006733043 |
| 26 | 0.0753 | 0.998287 | 0.001108 | 0.000544 | 0.000060 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000446 | 0.003421 | 0.006803168 |
| 27 | 0.0753 | 0.998287 | 0.001108 | 0.000544 | 0.000060 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000446 | 0.003421 | 0.006803168 |
| 28 | 0.0754 | 0.998278 | 0.001113 | 0.000547 | 0.000060 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000451 | 0.003439 | 0.006838407 |
| 29 | 0.0754 | 0.998278 | 0.001113 | 0.000547 | 0.000060 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000451 | 0.003439 | 0.006838407 |
| 30 | 0.0754 | 0.998278 | 0.001113 | 0.000547 | 0.000060 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000451 | 0.003439 | 0.006838407 |
| 31 | 0.0762 | 0.998206 | 0.001158 | 0.000572 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000489 | 0.003583 | 0.007124564 |
| 32 | 0.0762 | 0.998206 | 0.001158 | 0.000572 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000489 | 0.003583 | 0.007124564 |
| 33 | 0.0762 | 0.998206 | 0.001158 | 0.000572 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000489 | 0.003583 | 0.007124564 |
| 34 | 0.0762 | 0.998206 | 0.001158 | 0.000572 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000489 | 0.003583 | 0.007124564 |
| 35 | 0.0763 | 0.998197 | 0.001163 | 0.000575 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000494 | 0.003602 | 0.007160866 |
| 36 | 0.0763 | 0.998197 | 0.001163 | 0.000575 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000494 | 0.003602 | 0.007160866 |
| 37 | 0.0763 | 0.998197 | 0.001163 | 0.000575 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000494 | 0.003602 | 0.007160866 |
| 38 | 0.0763 | 0.998197 | 0.001163 | 0.000575 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000494 | 0.003602 | 0.007160866 |
| 39 | 0.0764 | 0.998187 | 0.001169 | 0.000578 | 0.000064 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000499 | 0.003620 | 0.007197287 |
| 40 | 0.0767 | 0.998160 | 0.001186 | 0.000588 | 0.000066 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000514 | 0.003676 | 0.007307265 |
| 41 | 0.0769 | 0.998141 | 0.001197 | 0.000594 | 0.000067 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000525 | 0.003713 | 0.007381180 |
| 42 | 0.0770 | 0.998131 | 0.001203 | 0.000598 | 0.000067 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000530 | 0.003732 | 0.007418317 |
| 43 | 0.0770 | 0.998131 | 0.001203 | 0.000598 | 0.000067 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000530 | 0.003732 | 0.007418317 |
| 44 | 0.0771 | 0.998122 | 0.001209 | 0.000601 | 0.000067 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000535 | 0.003751 | 0.007455573 |
| 45 | 0.0772 | 0.998112 | 0.001215 | 0.000604 | 0.000068 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000541 | 0.003770 | 0.007492950 |
| 46 | 0.0773 | 0.998103 | 0.001221 | 0.000607 | 0.000068 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000546 | 0.003789 | 0.007530446 |
| 47 | 0.0775 | 0.998084 | 0.001232 | 0.000614 | 0.000069 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000557 | 0.003827 | 0.007605799 |
| 48 | 0.0775 | 0.998084 | 0.001232 | 0.000614 | 0.000069 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000557 | 0.003827 | 0.007605799 |
| 49 | 0.0775 | 0.998084 | 0.001232 | 0.000614 | 0.000069 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000557 | 0.003827 | 0.007605799 |
| 50 | 0.0776 | 0.998074 | 0.001238 | 0.000617 | 0.000070 | 0.000001 | 1 | 0 | 0 | 0 | 0 | 0.00000563 | 0.003846 | 0.007643656 |
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| . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 1979. | 0.8470 | 0.490137 | 0.122047 | 0.201596 | 0.156224 | 0.029996 | 0 | 0 | 1 | 0 | 0 | 0.91788408 | 0.678924 | 0.114033640 |
| 1980 | 0.8470 | 0.490137 | 0.122047 | 0.201596 | 0.156224 | 0.029996 | 1 | 0 | 0 | 0 | 0 | 0.34080258 | 0.678924 | 0.114033640 |
| 1981 | 0.8504 | 0.488189 | 0.122123 | 0.202157 | 0.157202 | 0.030330 | 0 | 0 | 0 | 1 | 0 | 1.00533730 | 0.680258 | 0.112439723 |
| 1982 | 0.8504 | 0.488189 | 0.122123 | 0.202157 | 0.157202 | 0.030330 | 0 | 0 | 1 | 0 | 0 | 0.91542854 | 0.680258 | 0.112439723 |
| 1983 | 0.8504 | 0.488189 | 0.122123 | 0.202157 | 0.157202 | 0.030330 | 0 | 0 | 0 | 1 | 0 | 1.00533730 | 0.680258 | 0.112439723 |
| 1984 | 0.8526 | 0.486932 | 0.122170 | 0.202516 | 0.157835 | 0.030547 | 1 | 0 | 0 | 0 | 0 | 0.34502189 | 0.681114 | 0.111417225 |
| 1985 | 0.8619 | 0.481658 | 0.122355 | 0.204013 | 0.160502 | 0.031472 | 0 | 1 | 0 | 0 | 0 | 1.07062730 | 0.684662 | 0.107171755 |
| 1986 | 0.8635 | 0.480757 | 0.122385 | 0.204266 | 0.160959 | 0.031632 | 0 | 0 | 0 | 1 | 0 | 0.99281965 | 0.685261 | 0.106453883 |
| 1987 | 0.8643 | 0.480307 | 0.122399 | 0.204393 | 0.161188 | 0.031713 | 0 | 0 | 1 | 0 | 0 | 0.90565485 | 0.685560 | 0.106096326 |
| 1988 | 0.8643 | 0.480307 | 0.122399 | 0.204393 | 0.161188 | 0.031713 | 0 | 1 | 0 | 0 | 0 | 1.06964112 | 0.685560 | 0.106096326 |
| 1989 | 0.8643 | 0.480307 | 0.122399 | 0.204393 | 0.161188 | 0.031713 | 0 | 0 | 0 | 1 | 0 | 0.99206356 | 0.685560 | 0.106096326 |
| 1990 | 0.8652 | 0.479801 | 0.122416 | 0.204534 | 0.161446 | 0.031803 | 1 | 0 | 0 | 0 | 0 | 0.35450279 | 0.685895 | 0.105695173 |
| 1991 | 0.8661 | 0.479296 | 0.122432 | 0.204676 | 0.161703 | 0.031894 | 1 | 0 | 0 | 0 | 0 | 0.35517925 | 0.686229 | 0.105295182 |
| 1992 | 0.8661 | 0.479296 | 0.122432 | 0.204676 | 0.161703 | 0.031894 | 1 | 0 | 0 | 0 | 0 | 0.35517925 | 0.686229 | 0.105295182 |
| 1993 | 0.8676 | 0.478455 | 0.122458 | 0.204910 | 0.162131 | 0.032045 | 0 | 1 | 0 | 0 | 0 | 1.06830174 | 0.686783 | 0.104631112 |
| 1994 | 0.8711 | 0.476500 | 0.122516 | 0.205454 | 0.163130 | 0.032400 | 0 | 0 | 1 | 0 | 0 | 0.90102623 | 0.688065 | 0.103094158 |
| 1995 | 0.8745 | 0.474608 | 0.122570 | 0.205977 | 0.164098 | 0.032746 | 0 | 1 | 0 | 0 | 0 | 1.06556274 | 0.689296 | 0.101617911 |
| 1996 | 0.8751 | 0.474275 | 0.122580 | 0.206069 | 0.164269 | 0.032807 | 1 | 0 | 0 | 0 | 0 | 0.36193759 | 0.689512 | 0.101359113 |
| 1997 | 0.8868 | 0.467831 | 0.122742 | 0.207826 | 0.167590 | 0.034012 | 1 | 0 | 0 | 0 | 0 | 0.37070469 | 0.693634 | 0.096415124 |
| 1998 | 0.8887 | 0.466793 | 0.122765 | 0.208106 | 0.168128 | 0.034209 | 0 | 0 | 0 | 1 | 0 | 0.96945672 | 0.694288 | 0.095630615 |
| SUM | | | | | | | | | | | | 380.387079 | 382.9516 | 356.4333835 |
| | | | | | | | | | | | | standard deviation = 18.88 | P = 0.45 | |

# Table 5-7 Work-Sheet for Test of Goodness of Fit (HEPC' Bridges/Method2)

| No. | PGA (g) | Probability of Occurrence of a Damage State | | | | | Damage State | | | | | | MEAN | VARIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NON | MIN | MOD | MAJ | COL | NON | MIN | MOD | MAJ | COL | $Y_j^2$ | | |
| 1 | 0.3704 | 0.664664 | 0.222483 | 0.054106 | 0.0587 | | 1 | 0 | 0 | 0 | | 0.16832738 | 0.502344 | 0.229386997 |
| 2 | 0.3704 | 0.664664 | 0.222483 | 0.054106 | 0.0587 | | 1 | 0 | 0 | 0 | | 0.16832738 | 0.502344 | 0.229386997 |
| 3 | 0.3704 | 0.664664 | 0.222483 | 0.054106 | 0.0587 | | 1 | 0 | 0 | 0 | | 0.16832738 | 0.502344 | 0.229386997 |
| 4 | 0.3753 | 0.656073 | 0.226518 | 0.055863 | 0.0615 | | 1 | 0 | 0 | 0 | | 0.17650487 | 0.511349 | 0.222580992 |
| 5 | 0.3753 | 0.656073 | 0.226518 | 0.055863 | 0.0615 | | 1 | 0 | 0 | 0 | | 0.17650487 | 0.511349 | 0.222580992 |
| 6 | 0.3753 | 0.656073 | 0.226518 | 0.055863 | 0.0615 | | 1 | 0 | 0 | 0 | | 0.17650487 | 0.511349 | 0.222580992 |
| 7 | 0.3882 | 0.633681 | 0.236636 | 0.060483 | 0.0692 | | 1 | 0 | 0 | 0 | | 0.19863281 | 0.534005 | 0.204431070 |
| 8 | 0.3882 | 0.633681 | 0.236636 | 0.060483 | 0.0692 | | 1 | 0 | 0 | 0 | | 0.19863281 | 0.534005 | 0.204431070 |
| 9 | 0.3882 | 0.633681 | 0.236636 | 0.060483 | 0.0692 | | 1 | 0 | 0 | 0 | | 0.19863281 | 0.534005 | 0.204431070 |
| 10 | 0.3903 | 0.629975 | 0.238254 | 0.061253 | 0.0705 | | 1 | 0 | 0 | 0 | | 0.20240786 | 0.537642 | 0.201388735 |
| 11 | 0.3903 | 0.629975 | 0.238254 | 0.061253 | 0.0705 | | 1 | 0 | 0 | 0 | | 0.20240786 | 0.537642 | 0.201388735 |
| 12 | 0.3903 | 0.629975 | 0.238254 | 0.061253 | 0.0705 | | 1 | 0 | 0 | 0 | | 0.20240786 | 0.537642 | 0.201388735 |
| 13 | 0.3915 | 0.627861 | 0.239170 | 0.061693 | 0.0713 | | 1 | 0 | 0 | 0 | | 0.20457555 | 0.539702 | 0.199650224 |
| 14 | 0.3915 | 0.627861 | 0.239170 | 0.061693 | 0.0713 | | 1 | 0 | 0 | 0 | | 0.20457555 | 0.539702 | 0.199650224 |
| 15 | 0.3915 | 0.627861 | 0.239170 | 0.061693 | 0.0713 | | 1 | 0 | 0 | 0 | | 0.20457555 | 0.539702 | 0.199650224 |
| 16 | 0.3915 | 0.627861 | 0.239170 | 0.061693 | 0.0713 | | 1 | 0 | 0 | 0 | | 0.20457555 | 0.539702 | 0.199650224 |
| 17 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 18 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 19 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 20 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 21 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 22 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 23 | 0.3940 | 0.623642 | 0.240982 | 0.062572 | 0.0728 | | 1 | 0 | 0 | 0 | | 0.20893339 | 0.543783 | 0.196174719 |
| 24 | 0.3966 | 0.619084 | 0.242916 | 0.063523 | 0.0745 | | 1 | 0 | 0 | 0 | | 0.21368736 | 0.548145 | 0.192414385 |
| 25 | 0.3966 | 0.619084 | 0.242916 | 0.063523 | 0.0745 | | 1 | 0 | 0 | 0 | | 0.21368736 | 0.548145 | 0.192414385 |
| 26 | 0.3966 | 0.619084 | 0.242916 | 0.063523 | 0.0745 | | 1 | 0 | 0 | 0 | | 0.21368736 | 0.548145 | 0.192414385 |
| 27 | 0.3966 | 0.619084 | 0.242916 | 0.063523 | 0.0745 | | 1 | 0 | 0 | 0 | | 0.21368736 | 0.548145 | 0.192414385 |
| 28 | 0.3982 | 0.616460 | 0.244017 | 0.064072 | 0.0755 | | 1 | 0 | 0 | 0 | | 0.21644522 | 0.550634 | 0.190248435 |
| 29 | 0.3982 | 0.616460 | 0.244017 | 0.064072 | 0.0755 | | 1 | 0 | 0 | 0 | | 0.21644522 | 0.550634 | 0.190248435 |
| 30 | 0.3982 | 0.616460 | 0.244017 | 0.064072 | 0.0755 | | 1 | 0 | 0 | 0 | | 0.21644522 | 0.550634 | 0.190248435 |
| 31 | 0.3982 | 0.616460 | 0.244017 | 0.064072 | 0.0755 | | 1 | 0 | 0 | 0 | | 0.21644522 | 0.550634 | 0.190248435 |
| 32 | 0.4002 | 0.612970 | 0.245471 | 0.064802 | 0.0768 | | 1 | 0 | 0 | 0 | | 0.22013923 | 0.553921 | 0.187365696 |
| 33 | 0.4002 | 0.612970 | 0.245471 | 0.064802 | 0.0768 | | 1 | 0 | 0 | 0 | | 0.22013923 | 0.553921 | 0.187365696 |
| 34 | 0.4002 | 0.612970 | 0.245471 | 0.064802 | 0.0768 | | 1 | 0 | 0 | 0 | | 0.22013923 | 0.553921 | 0.187365696 |
| 35 | 0.4028 | 0.608619 | 0.247262 | 0.065714 | 0.0784 | | 0 | 1 | 0 | 0 | | 0.94749797 | 0.557979 | 0.183772499 |
| 36 | 0.4028 | 0.608619 | 0.247262 | 0.065714 | 0.0784 | | 1 | 0 | 0 | 0 | | 0.22478316 | 0.557979 | 0.183772499 |
| 37 | 0.4028 | 0.608619 | 0.247262 | 0.065714 | 0.0784 | | 1 | 0 | 0 | 0 | | 0.22478316 | 0.557979 | 0.183772499 |
| 38 | 0.3950 | 0.621887 | 0.241729 | 0.062938 | 0.0734 | | 1 | 0 | 0 | 0 | | 0.21075784 | 0.545468 | 0.194727680 |
| 39 | 0.3950 | 0.621887 | 0.241729 | 0.062938 | 0.0734 | | 1 | 0 | 0 | 0 | | 0.21075784 | 0.545468 | 0.194727680 |
| 40 | 0.3950 | 0.621887 | 0.241729 | 0.062938 | 0.0734 | | 1 | 0 | 0 | 0 | | 0.21075784 | 0.545468 | 0.194727680 |
| 41 | 0.4046 | 0.605495 | 0.248533 | 0.066370 | 0.0796 | | 1 | 0 | 0 | 0 | | 0.22814447 | 0.560866 | 0.181193743 |
| 42 | 0.4046 | 0.605495 | 0.248533 | 0.066370 | 0.0796 | | 1 | 0 | 0 | 0 | | 0.22814447 | 0.560866 | 0.181193743 |
| 43 | 0.4046 | 0.605495 | 0.248533 | 0.066370 | 0.0796 | | 0 | 1 | 0 | 0 | | 0.94206778 | 0.560866 | 0.181193743 |
| 44 | 0.4046 | 0.605495 | 0.248533 | 0.066370 | 0.0796 | | 0 | 1 | 0 | 0 | | 0.94206778 | 0.560866 | 0.181193743 |
| 45 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| 46 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| 47 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| 48 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| 49 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| 50 | 0.4064 | 0.602378 | 0.249790 | 0.067025 | 0.0808 | | 1 | 0 | 0 | 0 | | 0.23152020 | 0.563723 | 0.178622996 |
| . | . | . | . | . | . | | . | . | . | . | | . | . | . |
| . | . | . | . | . | . | | . | . | . | . | | . | . | . |
| . | . | . | . | . | . | | . | . | . | . | | . | . | . |
| . | . | . | . | . | . | | . | . | . | . | | . | . | . |
| . | . | . | . | . | . | | . | . | . | . | | . | . | . |
| 751 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 752 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 753 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 754 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 755 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 756 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 757 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 758 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 759 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 760 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 761 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 762 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 763 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 764 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 765 | 0.3095 | 0.772192 | 0.165091 | 0.033086 | 0.0296 | | 1 | 0 | 0 | 0 | | 0.08112410 | 0.374492 | 0.294977550 |
| 766 | 0.3163 | 0.760238 | 0.172088 | 0.035317 | 0.0324 | | 1 | 0 | 0 | 0 | | 0.08939448 | 0.390130 | 0.290483593 |
| 767 | 0.3163 | 0.760238 | 0.172088 | 0.035317 | 0.0324 | | 1 | 0 | 0 | 0 | | 0.08939448 | 0.390130 | 0.290483593 |
| 768 | 0.3163 | 0.760238 | 0.172088 | 0.035317 | 0.0324 | | 1 | 0 | 0 | 0 | | 0.08939448 | 0.390130 | 0.290483593 |
| 769 | 0.3163 | 0.760238 | 0.172088 | 0.035317 | 0.0324 | | 1 | 0 | 0 | 0 | | 0.08939448 | 0.390130 | 0.290483593 |
| 770 | 0.3211 | 0.751810 | 0.176929 | 0.036908 | 0.0344 | | 1 | 0 | 0 | 0 | | 0.09544452 | 0.400935 | 0.286751119 |
| SUM | | | | | | | | | | | | 457.700340 | 456.9798 | 87.28667327 |
| | | | | | | | | | | | | standard deviation = 9.34 | P = 0.53 | |

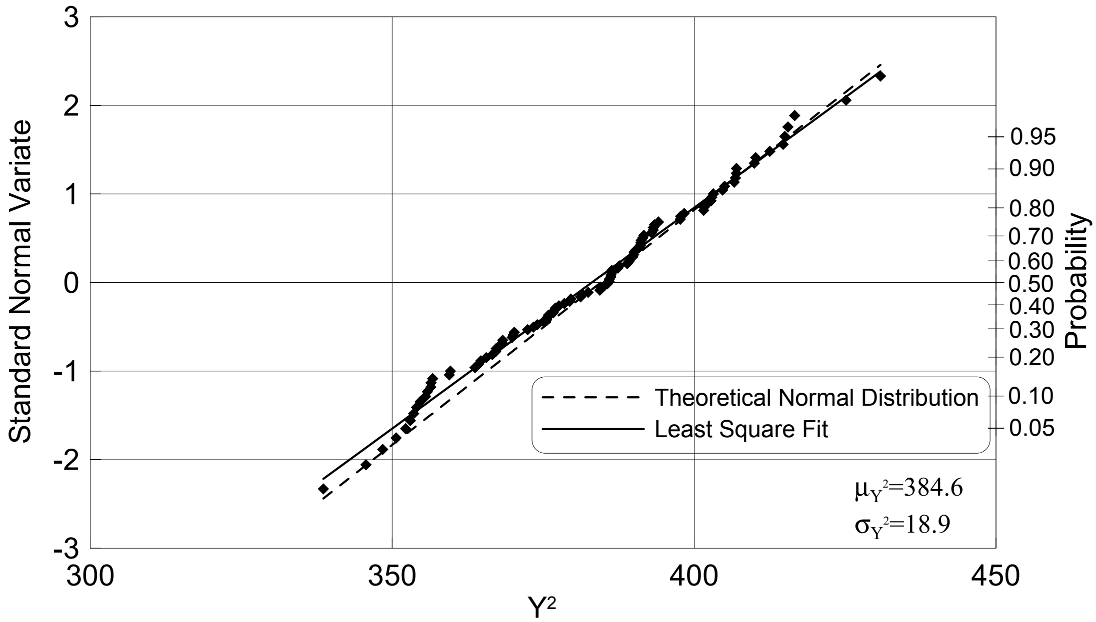


**FIGURE 5-5 Validity of Asymptotic Normality of Statistic $Y^2$ (Caltrans' Bridges/Method 2)**

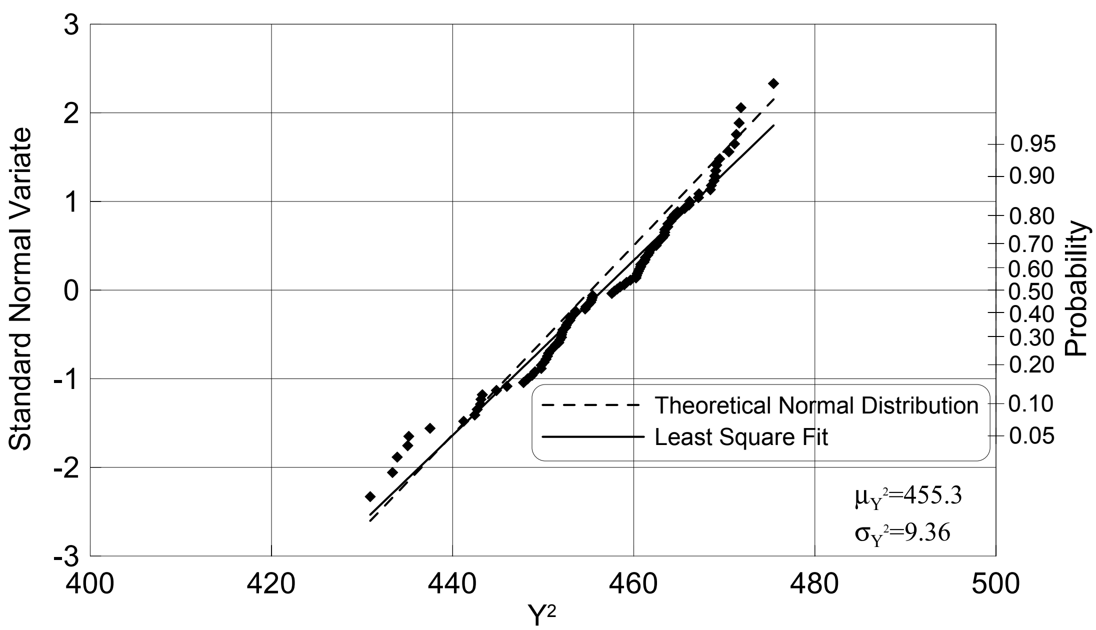


**FIGURE 5-6 Validity of Asymptotic Normality of Statistic $Y^2$ (HEPC's Bridge Columns/Method 2)**

## 5.3 Estimation of Confidence Intervals

The estimators $\hat{c}$ and $\hat{\zeta}$ of $c$ and $\zeta$ cannot be explicitly given in terms of analytical form as they represent optimal solutions obtained numerically by maximizing the logarithmic likelihood function. From the uncertainty analysis point of view, however, it is most desirable to demonstrate the extent of the statistical variations of these estimators by generating their realizations with the aid of a Monte Carlo simulation procedure. The following example is worked out for the fragility parameters $c_j$ ($j$=1, 2, 3, 4) and $\zeta$ of Caltrans' bridges estimated by Method 2 assuming that the sample is composite. The Monte Carlo procedure calls for the simulation of $X_{ik}$ ($i$=1, 2, …, N and $k$=1, 2, …, 5), based on the family of fragility curves with the parameters $c_{j,0}$ ($j$=1, 2, 3, 4) and $\zeta_0$ obtained from the maximum likelihood method. This much is the same procedure as executed for the validation of asymptotic normality of $Y^2$ under Method 2. In the present case, however, (2-12) must be solved for the maximum likelihood estimates $c^*_{j,0}$ and $\zeta^*_0$ using the simulated realizations $x_{ik}$ of $X_{ik}$ in (2-10) and (2-11). Repeating this process a large number of times (500 times in this case), one obtains 500 sets of realizations of $\hat{c}_j$ and $\hat{\zeta}$. This study contends that the statistical variation of these realizations presents a first approximation for the statistical variation of $\hat{c}_j$ and $\hat{\zeta}$. The nature of the maximum likelihood estimates $\hat{c}_j$ (and hence $\log \hat{c}_j$) and $\hat{\zeta}$ dictates that they are jointly distributed normally as $N \to \infty$ (i.e., asymptotically). For the ease of understanding, 500 sets of four points $(c^*_{1,0}, \zeta^*_0)$, $(c^*_{2,0}, \zeta^*_0)$, $(c^*_{3,0}, \zeta^*_0)$, $(c^*_{4,0}, \zeta^*_0)$ thus simulated are plotted in figure 5-7 respectively corresponding to the states of at lease minor, at least moderate, at lease major damage and collapse. Marginal distributions of $c^*_{j,0}$ are also separately plotted on log-normal probability papers for different states of damage in figures 5-8, 5-9, 5-10 and 5-11 respectively. Medians indicated in these figures are in good agreements with the corresponding values (i.e., $c_{1,0}$, $c_{2,0}$, $c_{3,0}$, $c_{4,0}$) in figure 2-4. Although $\zeta^*$ is asymptotically normal, it is plotted on a log-normal paper in figure 5-12. The median value 0.81 indicated in figure 5-12 agrees very with $\zeta_0$=0.82 shown in figure 2-4. Figures 5-8~5-12 show that marginal distributions of simulated parameter values fit quite well to log-normal distribution functions. Assuming the distribution of $\hat{c}_j$ being lognormal, and identifying, from the results in figures 5-8~5-11, the 90% confidence interval associated with exceedance probabilities 95% and 5% of $\hat{c}_j$, the fragility curves of Caltrans' bridges with the four states of damage are given in figures 5-13~5-16, respectively together with the confidence information. In each of these figures, the curves on the left, at the center and on the right respectively represent the fragility curves with 95%, 50% and 5% confidence consistent with figures 5-8~5-11. As in the risk assessment procedure for the nuclear power plant (NRC, 1983), the log-standard deviation associated with 50% confidence in figure 5-12 (0.81 in this case) is used for the three curves in each figure, although it is possible to use 95% and 5% confidence value of $\hat{\zeta}$ together with those of $\hat{c}_j$. This study contends as in PRA procedures Guide (NRC, 1983) that the use of 50% confidence value of $\hat{\zeta}$ only is justifiable because the variation in $\hat{c}_j$ has the first order effect on fragility values whereas that in $\hat{\zeta}$ has the second order effect in general. Figure 5-17 plots all these fragility curves at three levels of confidence for the ease of comparison.

Identification of the uncertainty as introduced above in the fragility parameters and resulting fragility curves in terms of differing levels of confidence is useful for the assessment of the uncertainty in the result of an ensuring transportation systems analysis. A typical example of this is the analysis of a highway network system to determine the reduction of its network capacity (as appropriately defined) due to the seismic damage sustained by bridges in the network. Traditionally as well as in this report, it is interpreted that the reduction in the network capacity exhibits randomness only arising from a most representative fragility curve assigned to each bridge of the network, if the uncertainty component is not taken into account in the analysis. It is further interpreted that the additional variability in the network capacity reduction is due to the uncertainty which originates and propagates from the uncertainty associated with the fragility curve of each and every bridge.

In the probabilistic risk assessment of nuclear power plants, an "average" fragility curve $F^*(a)$ associated with a particular state of damage is derived and utilized often. This "average" curve is obtained by unconditionalizing $F(a \mid c) = \Phi\left[\frac{\ln(a/c)}{\zeta}\right]$ under the assumption that $c$ is lognormally distributed:

$$F^*(a) = \int_z F(a \mid z) f_c(z) dz \tag{5-16}$$

where $f_c(z)$ is the lognormal density function of $c$ with median $\tilde{c}$ and log-standard deviation $\xi_c$ as shown below.

$$f_c(z) = \Phi\left[\frac{\ln(a/\tilde{c})}{\zeta_c}\right] \tag{5-17}$$

These median and log-standard deviation correspond to the respective values shown figures 5-8~5-12. $F^*(a)$ is not lognormal in general. However, in approximation, it may be and indeed was used in practice as lognormal distribution in PRA Procedures Guide, (NRC, 1983).

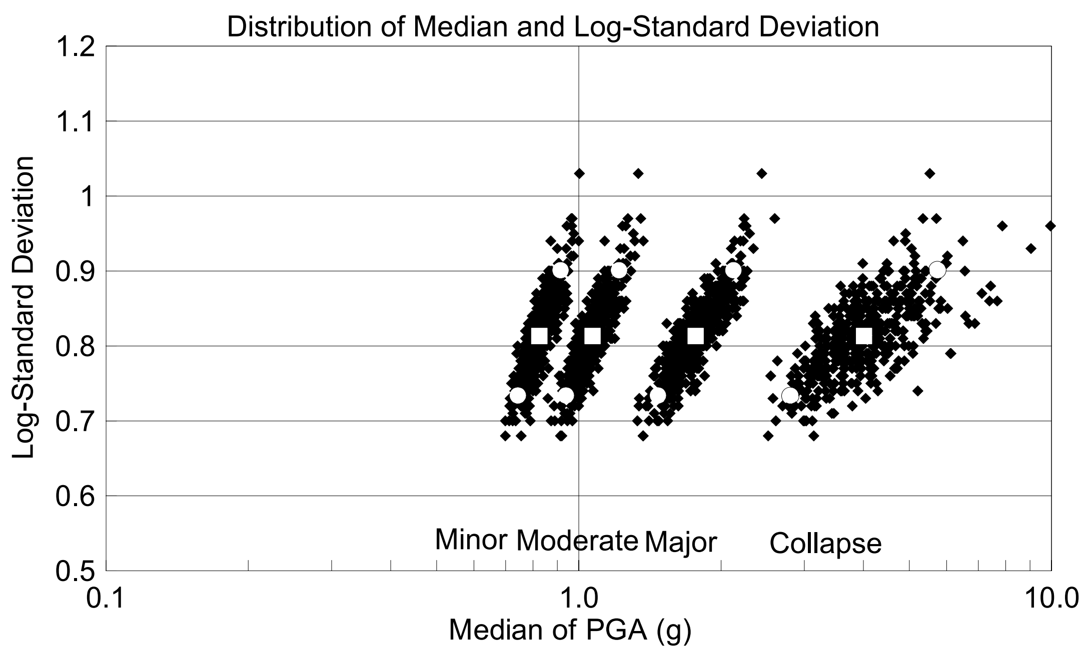


**FIGURE 5-7 Two-Dimensional Plot of 500 Sets of Simulated Realizations of Medians ($\hat{C}_1, \hat{C}_2, \hat{C}_3, \hat{C}_4$) and Log-Standard Deviations $\hat{\xi}$**

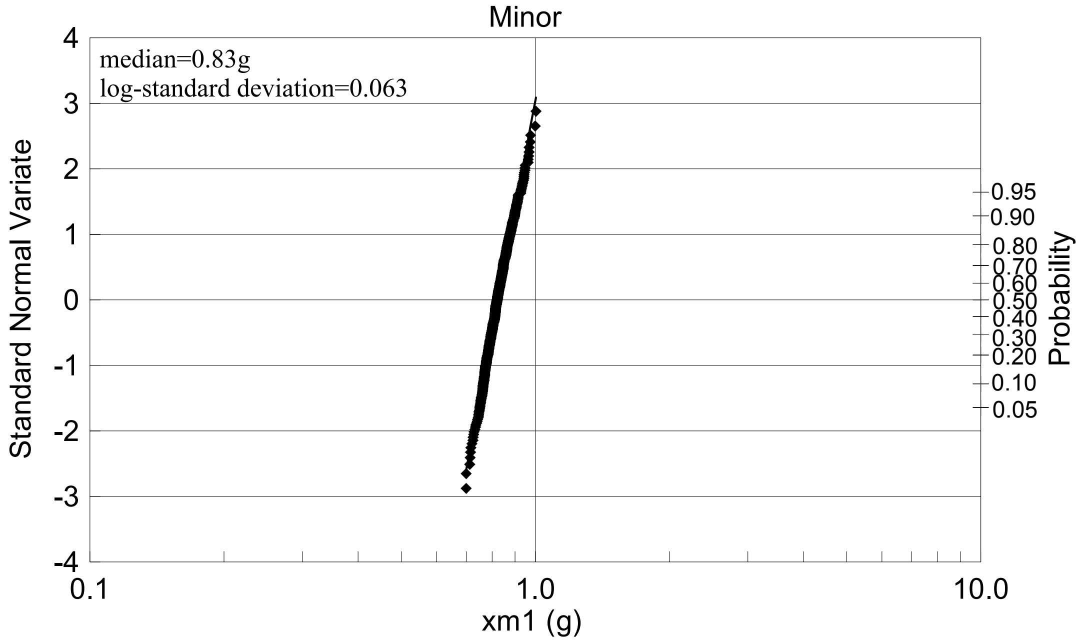


**FIGURE 5-8 Log-Normal Plot of Realizations of 500 Realizations of $\hat{C}_1$ (Caltrans' Bridges/Method 2)**

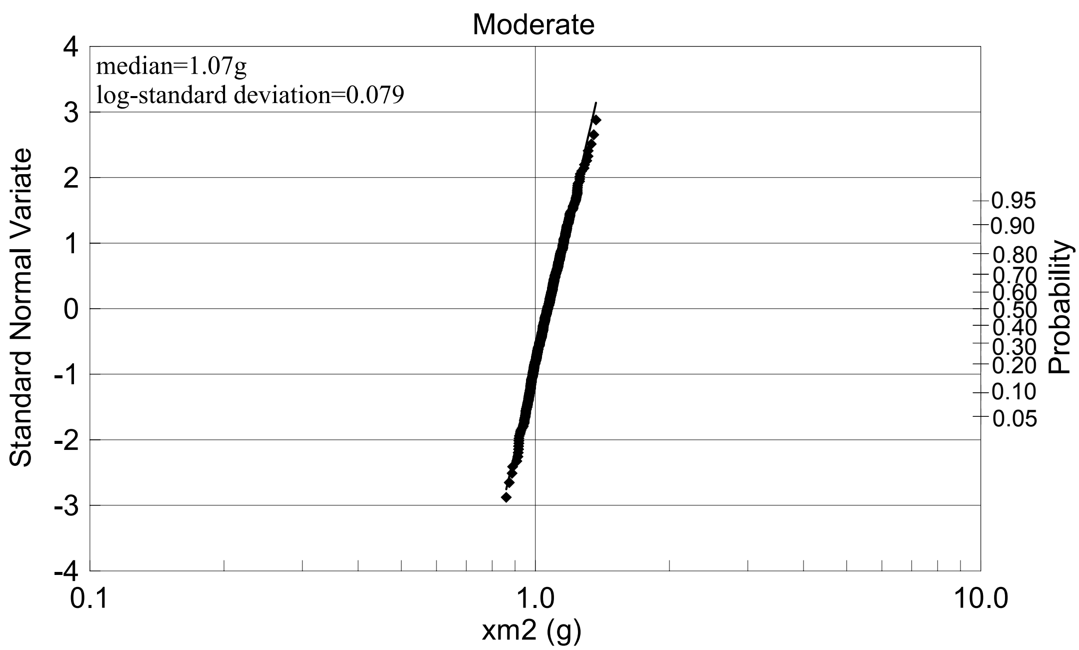


**FIGURE 5-9 Log-Normal Plot of Realizations of 500 Realizations of $\hat{C}_2$ (Caltrans' Bridges/Method 2)**

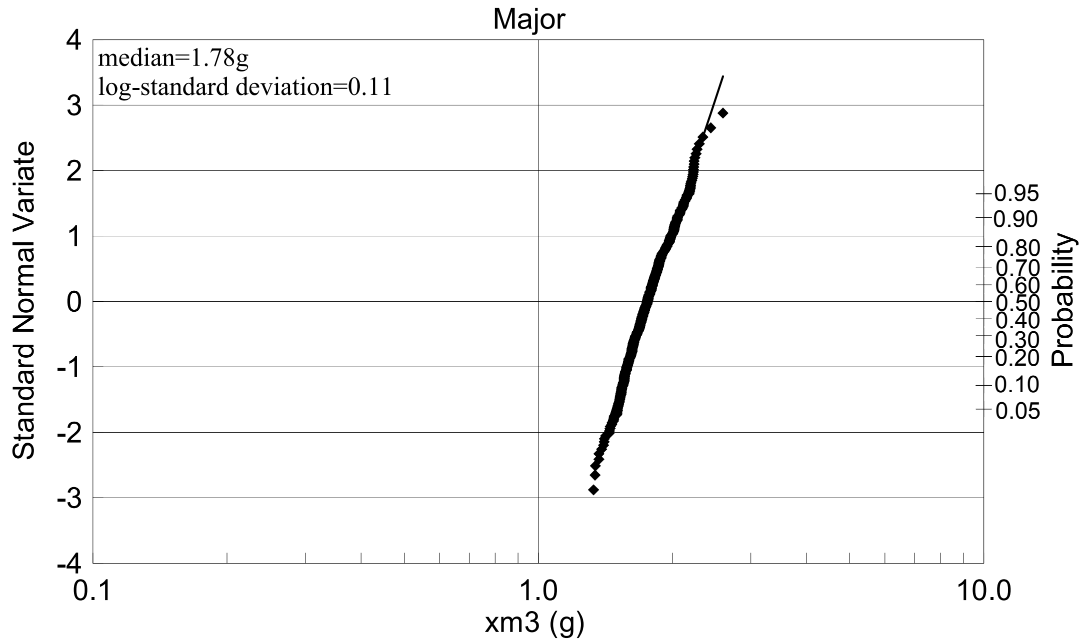


**FIGURE 5-10 Log-Normal Plot of Realizations of 500 Realizations of $\hat{C}_3$ (Caltrans' Bridges/Method 2)**

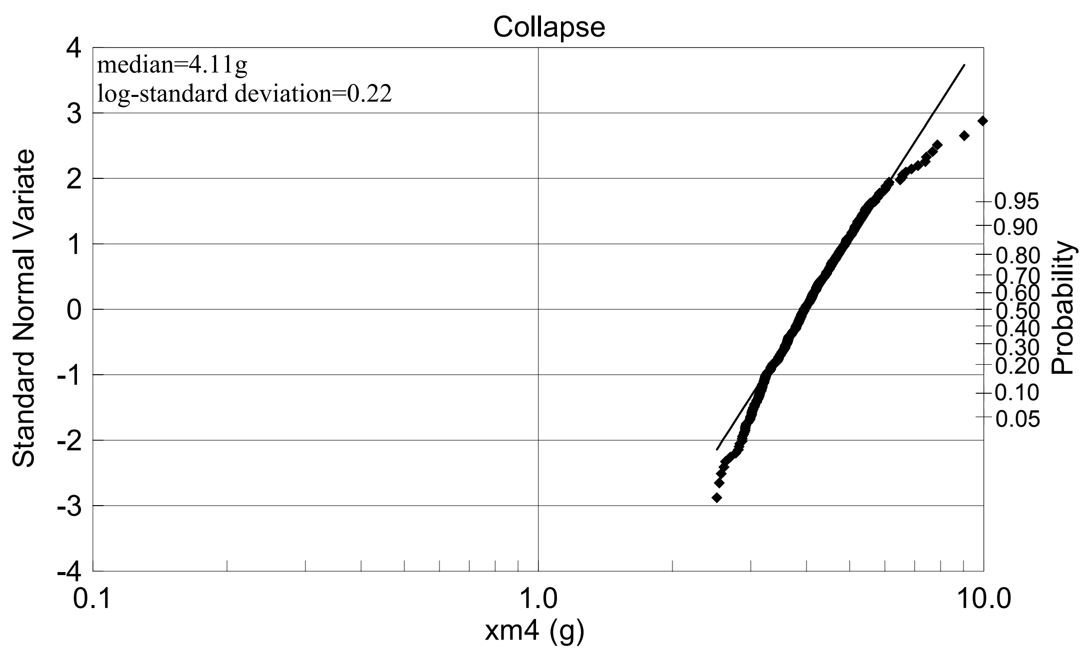


**FIGURE 5-11 Log-Normal Plot of Realizations of 500 Realizations of $\hat{C}_4$ (Caltrans' Bridges/Method 2)**

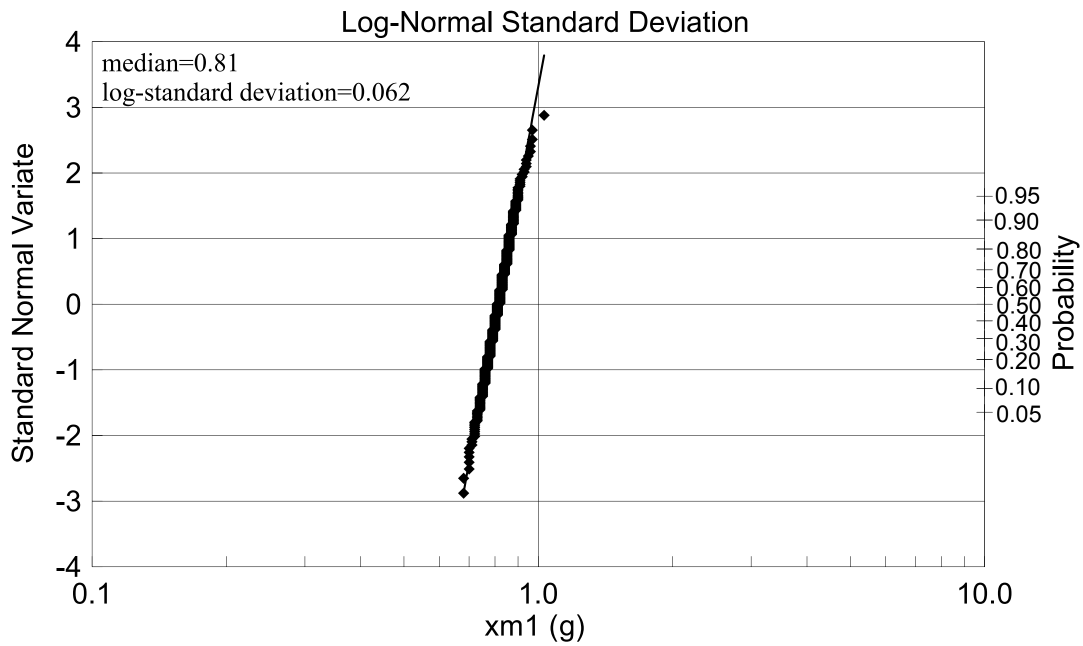


**FIGURE 5-12 Log-Normal Plot of Realizations of 500 Realizations of $\hat{\xi}$**

**(Caltrans' Bridges/Method 2)**

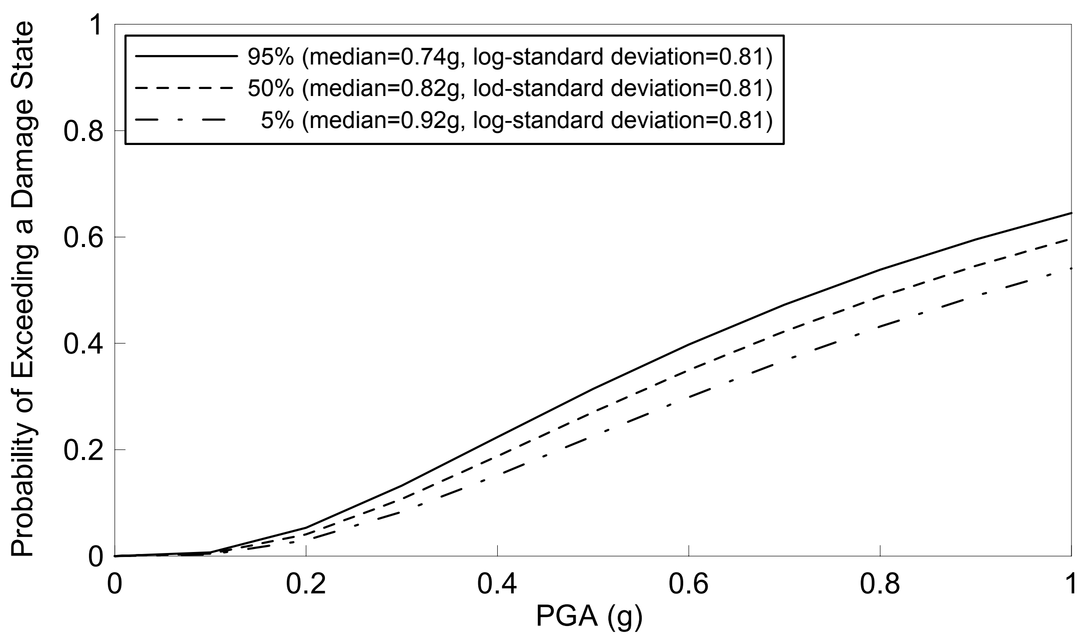


**FIGURE 5-13 Fragility Curves for State of at least Minor Damage**

**with 95%, 50% and 5% Statistical Confidence (Caltrans' Bridges/Method 2)**

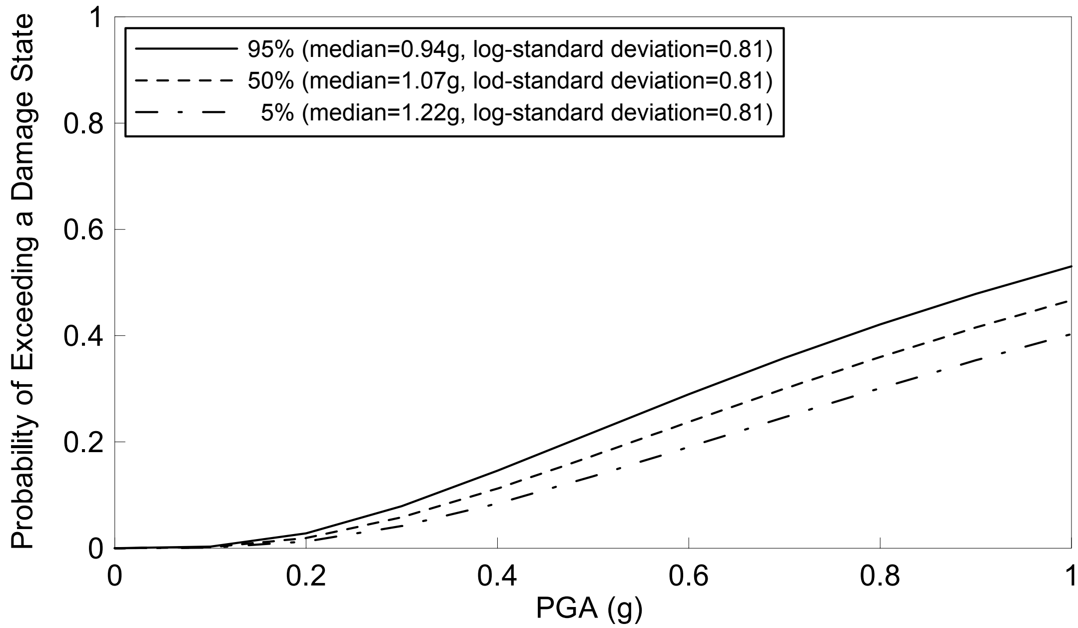


**FIGURE 5-14 Fragility Curves for State of at least Moderate Damage with 95%, 50% and 5% Statistical Confidence (Caltrans' Bridges/Method 2)**

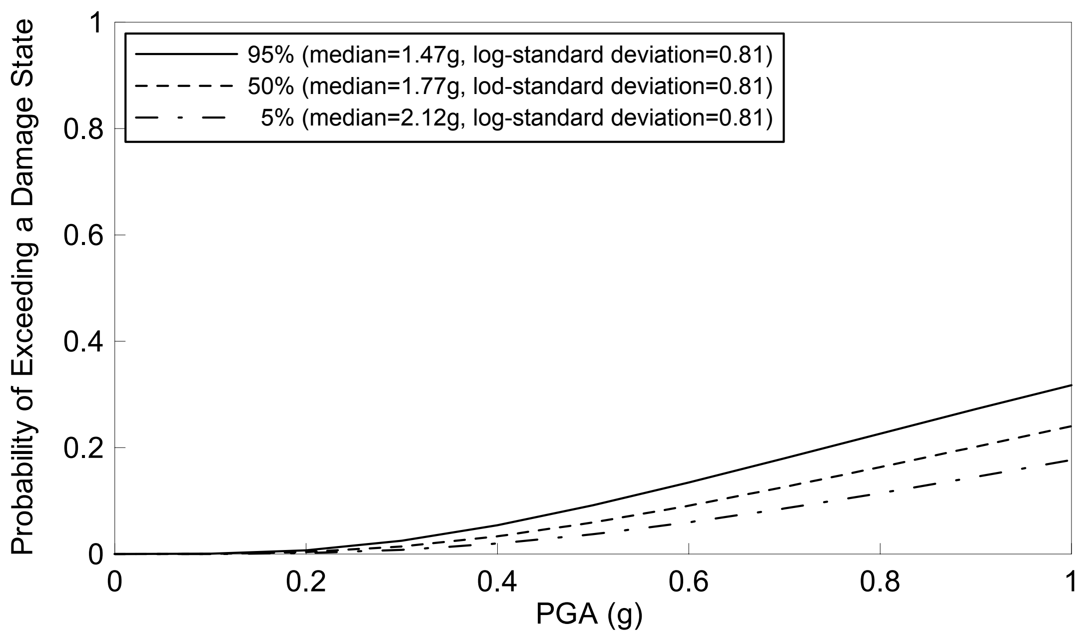


**FIGURE 5-15 Fragility Curves for State of at least Major Damage with 95%, 50% and 5% Statistical Confidence (Caltrans' Bridges/Method 2)**

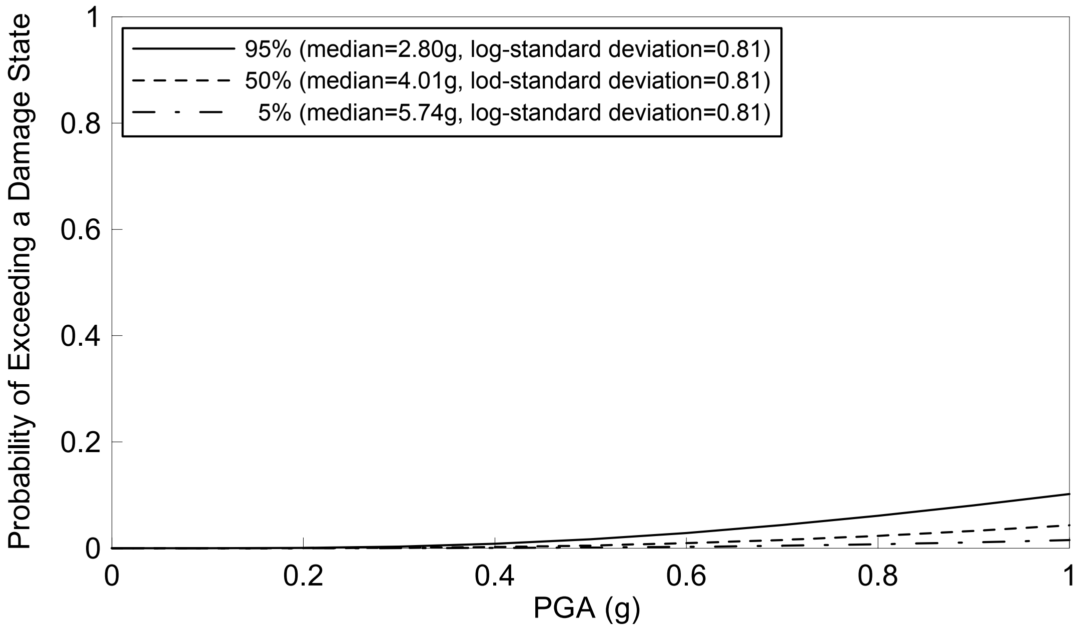


**FIGURE 5-16 Fragility Curves for State of Collapse Damage with 95%, 50% and 5% Statistical Confidence (Caltrans' Bridges/Method 2)**

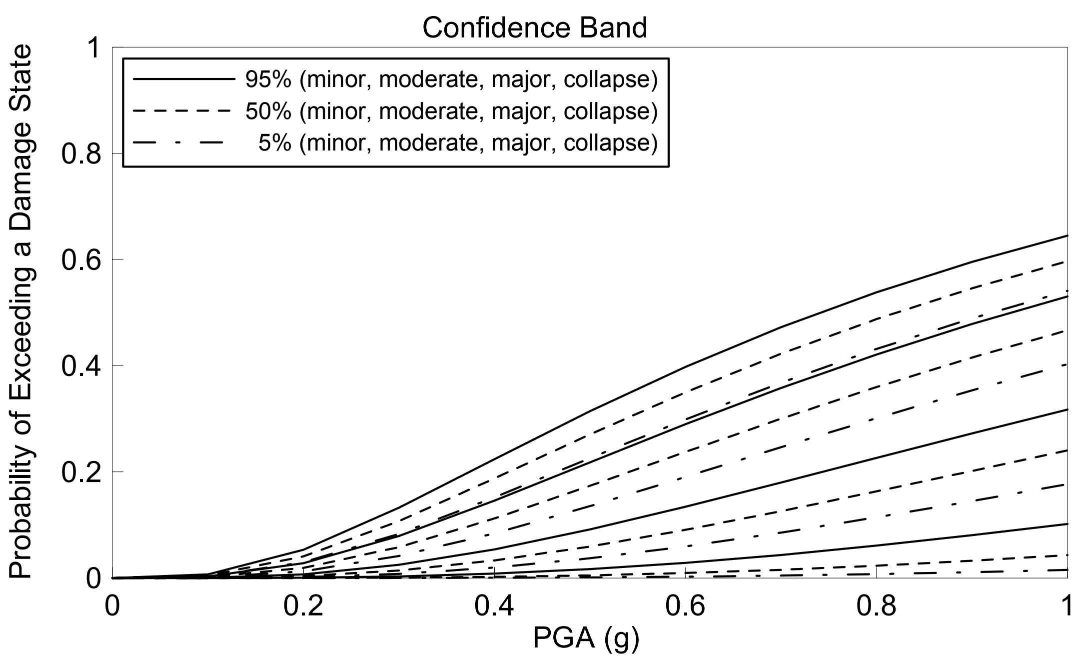


**FIGURE 5-17 Combined Plot of Fragility Curves for Caltrans' Bridges with 95%, 50% and 5% Statistical Confidence (Method 2)**

## 5.4 Development of Combined Fragility Curves

Use of a fragility curve representing a family of bridges with similar structural attributes, primarily categorized in specific structural types, expedites the process of urban earthquake disaster estimation. A well-known example of such a categorization is found in ATC-13 (ATC, 1985). Bridges 1 and 2 in the Memphis area analyzed in an earlier section belong to a family of bridges that can be categorized as precast prestressed continuous deck bridges with short to medium length. This section demonstrates how combined fragility curves for a category of bridges can be derived from individual fragility curves constructed for member bridges of the category.

The fragility curves (associated with specific states of damage) analytically developed for Bridges 1 and 2 in the Memphis area can be combined in the following fashion in order to develop a combined fragility curve for a mixed bridge set population in which there are $N_1$ and $N_2$ of Bridges 1 and 2, respectively. In this case, the combined fragility curve $F_C(a)$ is obtained as

$$F_C(a) = P_1.F_1(a) + P_2.F_2(a) \tag{5-18}$$

where $F_i(a)$ is the fragility curve for bridges $i$ and

$$P_i = \frac{N_i}{(N_1 + N_2)} \tag{5-19}$$

is the probability with which a bridge $i$ will be chosen at random from the combined population. The resulting fragility curve $F_C(a)$ is shown in figure 5-18 together with the fragility curves that are combined. It is noted that $F_C(a)$ thus developed is no longer a lognormal distribution. The corresponding density function is

$$f_C(a) = P_1 f_1(a) + P_2 f_2(a) \tag{5-20}$$

where $f_i(a)$ is a lognormal density function associated with $F_i(a)$. The expected value of $\alpha = \ln a$ for the combined distribution is given by

$$\overline{\alpha} = P_1 \ln c_1 + P_2 \ln c_2 = P_1\overline{\alpha}_1 + P_2\overline{\alpha}_2 \tag{5-21}$$

or

$$a_C = c_1^{P_1} \cdot c_2^{P_2} \tag{5-22}$$

in which $c_i$ is written for the median $c$ associated with $f_i(a)$ and

$$\overline{\alpha} = \ln a_c \tag{5-23}$$

In order to obtain the standard deviation $\zeta_c$ of $\alpha$ = ln $a$ of the combined distribution, one recognizes

$$\zeta_c^2 = E(\alpha - \overline{\alpha})^2 = E(\alpha^2) - \overline{\alpha}^2 \tag{5-24}$$

and

$$E(\alpha^2) = P_1 \int \alpha^2 \varphi_1(\alpha) d\alpha + P_2 \int \alpha^2 \varphi_2(\alpha) d\alpha \tag{5-25}$$

where $\varphi_i(\alpha)$ is normal density function of $\alpha$ with mean ln $c_i$ and standard deviation $\zeta_i$. One further recognizes that

$$E_i(\alpha \ \ - \overline{\alpha} \ \ )^2 = \int (\alpha \ \ - \overline{\alpha} \ \ )^2 \varphi_i(\alpha) d\alpha = E_i(\alpha^2) - \overline{\alpha}_i^2 = \zeta_i^2 \tag{5-26}$$

from which it follows that

$$E_i(\alpha^2) = \int \alpha^2 \varphi_i(\alpha) d\alpha = \zeta_i^2 + \overline{\alpha}_i^2 \tag{5-27}$$

Combining (5-21), (5-24), (5-25) and (5-27),

$$\zeta_c^2 = P_1\zeta_1^2 + P_2\zeta_2^2 + P_1(1 - P_2)\overline{\alpha}_1^2 + P_2(1 - P_2)\overline{\alpha}_2^2 - 2P_1P_2\overline{\alpha_1\alpha_2} \tag{5-28}$$

The last three terms of the right hand side of (5-28) are positive semi-definite with respect to $\overline{\alpha}_1$ and $\overline{\alpha}_2$; in fact, the sum of these terms are positive except when $\overline{\alpha}_1 = \overline{\alpha}_2$ in which case the sum is equal to zero. This indicates that combination of two fragility curves produces a variance including the terms that form a quadratic expression of logarithms of the medians which always increases the variance from its minimum value (the first two terms of right hand side of (5-28)) unless the medians are equal.

(5-18)~(5-22) and (5-28) can all be easily generalized and take the following forms when the population involves a large number ($M$) of bridges;

$$F_C(a) = \sum_{i=1}^{M} P_i F_i(a) \tag{5-29}$$

$$P_i = \frac{N_i}{N} \tag{5-30}$$

where $N = \sum_{i=1}^{M} N_i$ with $N_i$ being the number of bridge $i$ the population.

$$f_C(a) = \sum_{i=1}^{M} P_i f_i(a) \tag{5-31}$$

$$\overline{\alpha} = \ln a_c = \sum_{i=1}^{M} P_i \overline{\alpha}_i \tag{5-32}$$

$$a_C = \prod_{i=1}^{M} c_i^{P_i} \tag{5-33}$$

and

$$\zeta_c^2 = \underline{P}^T \underline{Z} + \underline{A}^T \underline{Q} \underline{A} \tag{5-34}$$

where

$$\underline{P}^T = \begin{bmatrix} P_1 & P_2 & \cdots & P_M \end{bmatrix} \tag{5-35}$$

$$Z^T = \begin{bmatrix} \zeta_1^2 & \zeta_2^2 & \cdots \zeta_M^2 \end{bmatrix} \tag{5-36}$$

$$A^T = \begin{bmatrix} \alpha_1 & \alpha_2 & \cdots \alpha_M \end{bmatrix} \tag{5-37}$$

and

$$\underline{Q} = \begin{bmatrix} P_1(1-P_1) & -P_1 P_2 & \cdots & -P_1 P_M \\ \vdots & & & \\ \vdots & & & \\ -P_M P_1 & -P_M P_2 & \cdots & P_M(1-P_M) \end{bmatrix} \tag{5-38}$$

The expression $\underline{A}^T Q\ \underline{A}$ is a quadratic form which is positive semi-definite being equal to zero when $\bar{\alpha}_1 = \bar{\alpha}_2 = \ldots = \bar{\alpha}_M$. Hence, the comment made above with respect to the increase of the value of variance is also valid for M>2.

The combined fragility curve is not lognormal as explained earlier. It seems reasonable to assume, however, that the combined curve is lognormal with the mean and variance estimated respectively by (5-32) and (5-34). This approximation is expected to be particularly valid when the bridges under consideration belong to a specific structural category as assumed here and are designed under the same design codes.

The fragility curves developed for Caltrans' bridges in figure 2-3 and 2-4 and HEPC's bridge columns in figure 2-16 and 2-17 are based on the total population, hypothetically homogeneous, of their respective expressway bridges and bridge columns. These are referred to as composite fragility curves in this study because they can be interpreted as composites of the combined fragility curves just introduced, each being associated with a specific bridge category. The first two moments of the composite fragility curves can also be derived from (a) the corresponding first two moments of the combined fragility curves associated with the bridge categories in the total population and (b) the relative size of sub-population of each bridge category to the size of the total population.

The composite fragility curves are in general not lognormal either. Nevertheless, lognormal assumption is used for composite curves as well in figures 2-3 and 2-4, and 2-16 and 2-17 for analytical convenience and for the ease in which comparisons can be made with the fragility curves developed for other structural and nonstructural systems many of which are traditionally based on the lognormal assumption. It is noted that the lognormal assumption deployed in constructing fragility curves throughout in this study indeed cannot be rejected according to the result of the hypothesis testing involving the specific samples that were used. The inverse analysis appears impossible that starts from the composite fragility curve to derive the combined fragility curves and then the fragility curves of individual bridges.

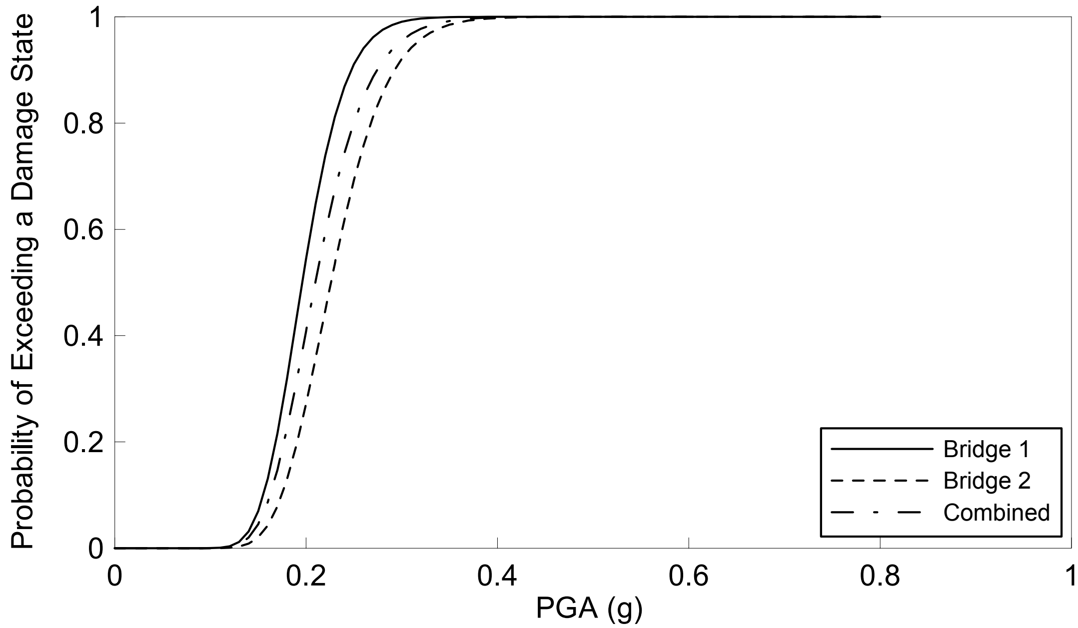


**FIGURE 5-18 Combined Fragility Curve**

# SECTION 6
# SEISMIC RISK ASSESSMENT OF HIGHWAY NETWORKS

In this report, a seismic risk analysis is performed on the Los Angeles area expressway network. For this purpose, the families of fragility curves for at least minor, at least moderate, at least major and collapsed states of damage at the fourth level subgroupings, developed in figures 2-24~2-36 are utilized. They are utilized to generate, in Monte Carlo simulation, the state of damage for each and every Caltrans' bridge in Los Angeles and Orange County (total number = 2,225) under postulated M = 7.1 Elysian Park earthquake. This means that if a bridge has a combination of such attributes as multiple span (M), skew angle ($\theta_2$) between 0° and 20° and soil condition C (c), then, the family of four fragility curves shown in figure 2-30 are to be used for that bridge. If no fragility curve is given for a particular state of damage, for example, as in the case of single span (see table 2-4(b)), a hypothetical fragility curve with median = 10g and log-standard derivation = 0.78 as computed is assigned to ensure this state of damage not to occur in simulation to be consistent with the empirical data. The five subgroups with such attribute combinations as S/$\theta_2$/a, S/$\theta_2$/b, S/$\theta_3$/a, S/$\theta_3$/b and M/$\theta_1$/b produced no empirical damage data. Assigned, in this case, to each state of damage for each of these subgroups is the same hypothetical fragility curve with the median = 10g and log standard deviation = 0.5 for the same reason. The simple procedure here is therefore to replace N/A in Median column by 10g and N/A if found in Log. St. Dev. column by 0.5 to develop hypothetical fragility curves for those attribute combinations for which table 2-4 does not provide complete information. This procedure is theoretically unconservative and its effect on the result of the systems analysis as undertaken in this section needs to be explored.

The state of damage thus simulated for each bridge is quantified using "bridge damage index," BDI, that is equal to 0.1, 0.3, 0.75 and 1.0 respectively for the minor, moderate, major and collapsed state of damage. The state of link damage is then quantified by making use of "link damage index", LDI, which is computed for each link as the square root of the sum of the squares of BDI values assigned to all bridges on the link under consideration. The LDI value is then translated into link traffic flow capacity. In this study it is considered reasonable to assume that the capacity of 100% (relative to the case with no damaged bridges on the link) if LDI ≤ 0.5 (no link damage), 75% if 0.5 < LDI ≤ 1.0 (minor link damage), 50% if 1.0 < LDI ≤ 1.5 (moderate link damage) and 25% if LDI > 1.5 (major link damage). Table 6-1 summarizes the relationship between bridge and link damage indices and traffic flow capacity. This relationship is developed as a result of calibration achieved by comparing the simulated link damage data (typical simulation result is shown in figure 6-1) with the post-earthquake traffic flow capacity of each link of the network postulated on the basis of the Northridge bridge damage map shown in figure 6-2 (Buckle, 1994). Overlaying figure 6-1 on figure 6-2 would confirm the reasonable agreement of the simulation with the damage data. Other sets of simulated link damage indicated similar reasonable agreements.

**Table 6-1 Bridge and Link Damage Index and Traffic Flow Capacity**

<table>
<tr><td>Bridge Damage State</td><td>Bridge Damage Index</td></tr>
<tr><td>Minor<br>Moderate<br>Major<br>Collapse</td><td>0.1<br>0.3<br>0.75<br>1.0</td></tr>
<tr><td colspan="2">Link Damage Index LDI for Link I<br><br>$$LDI = \sqrt{\sum_{J=1}^{JI} (BDIJ)^2}$$<br>where BDIJ = Bridge Damage Index for Bridge J on link I<br>JI = Total Number of Bridges on Link I</td></tr>
<tr><td>Link Damage Index</td><td>Traffic Flow Capacity (in terms of VPH)</td></tr>
<tr><td>$\mathrm{LDI} < 0.5$<br>$0.5 \le \mathrm{LDI} < 1.0$<br>$1.0 \le \mathrm{LDI} < 1.5$<br>$1.5 \le \mathrm{LDI}$</td><td>100% (No Link Damage)<br>75% (Minor Link Damage)<br>50% (Moderate Link Damage)<br>25% (Major Link Damage)</td></tr>
</table>

In an on-going research project sponsored by NSF and being carried out at USC, a computer code "USC-EPEDAT" is developed to perform the simulation of states of link damage and hence network damage efficiently. With USC-EPEDAT, each simulation of network damage in the format as shown in figure 6-1 takes less than 10 seconds with a 300 MHz or faster PC. Figure 6-3 shows the expressway network with a simulated state of damage (resulting from the Elysian Park earthquake) assigned to each link by one particular run of simulation, and figure 6-4 depicts the averaged result over 10 such simulations with averaging taken for each link over its link damage index values simulated 10 times. The information contained in figure 6-4 can be used to support decision making for post-earthquake response activities in near real-time. This is because the seismic source information including epicenter location and magnitude can be made available in near real-time with the aid of existing advanced acquisition and analysis capability for the data from dense arrays such as TriNet (D. J. Wald, 1999). This is also because the information thus transmitted can be used as an input to a computer code such as USC-EPEDAT to simulate the state of network damage repeatedly with each run executed in a few seconds resulting in visualization of network damage as shown in figure 6-4. Figure 6-5 furthermore depicts the state of expressway the network damage averaged over 10 simulations under the assumption that each bridge has family of improved fragility curves, each enhanced in such a way that the median parameter of the lognormal fragility curve is increased by 50% by appropriate seismic retrofitting. Figure 6-5 clearly indicates a better performance of the retrofitted network than figure 6-4 does for the network without seismic retrofit. In principle, such a comparison makes it possible to evaluate the cost-effectiveness of seismic retrofit by additional cost-benefit analysis, which is clearly an interesting and important subject of future research.

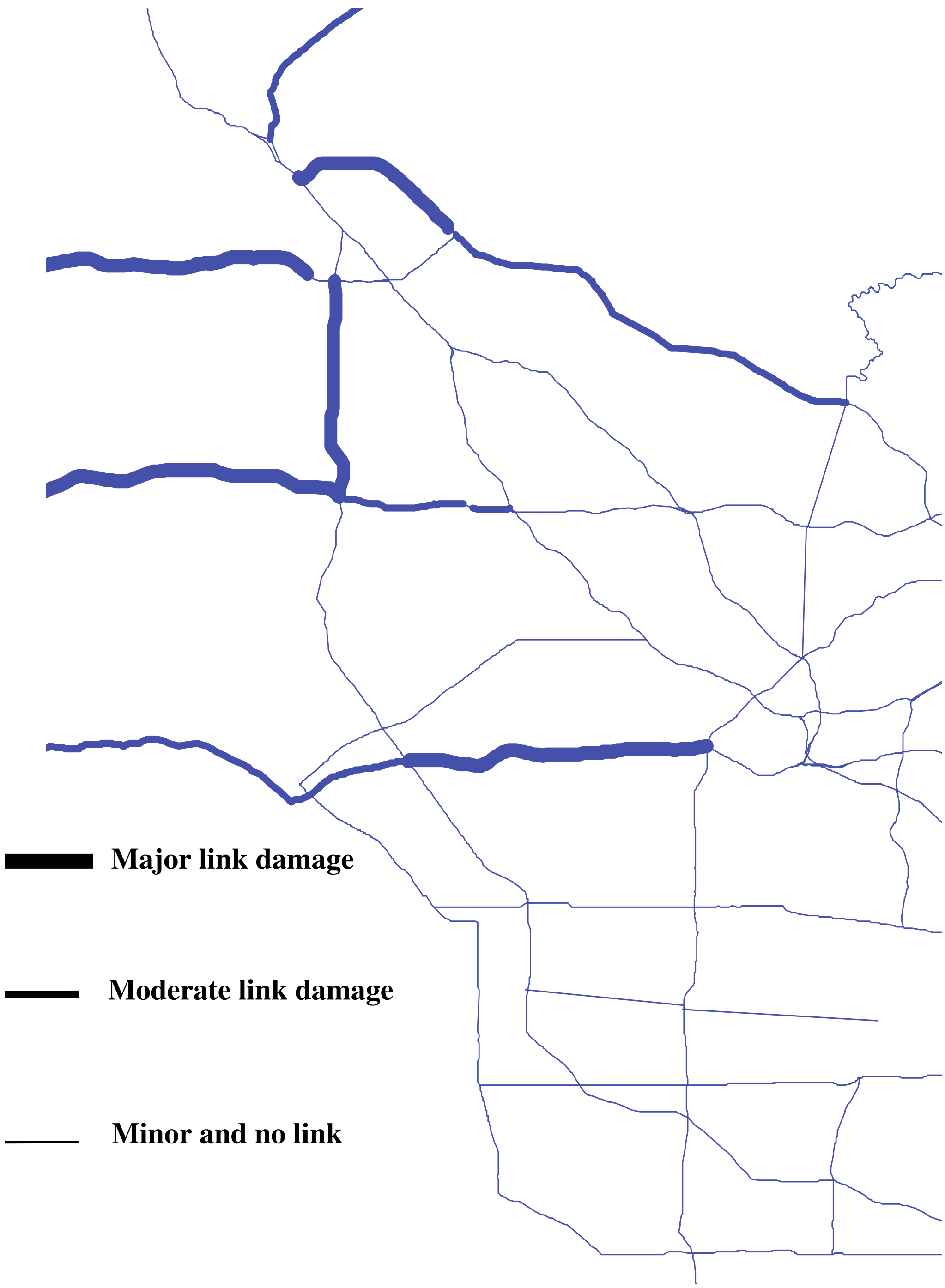


**FIGURE 6-1 Los Angeles Areas Highway Network**

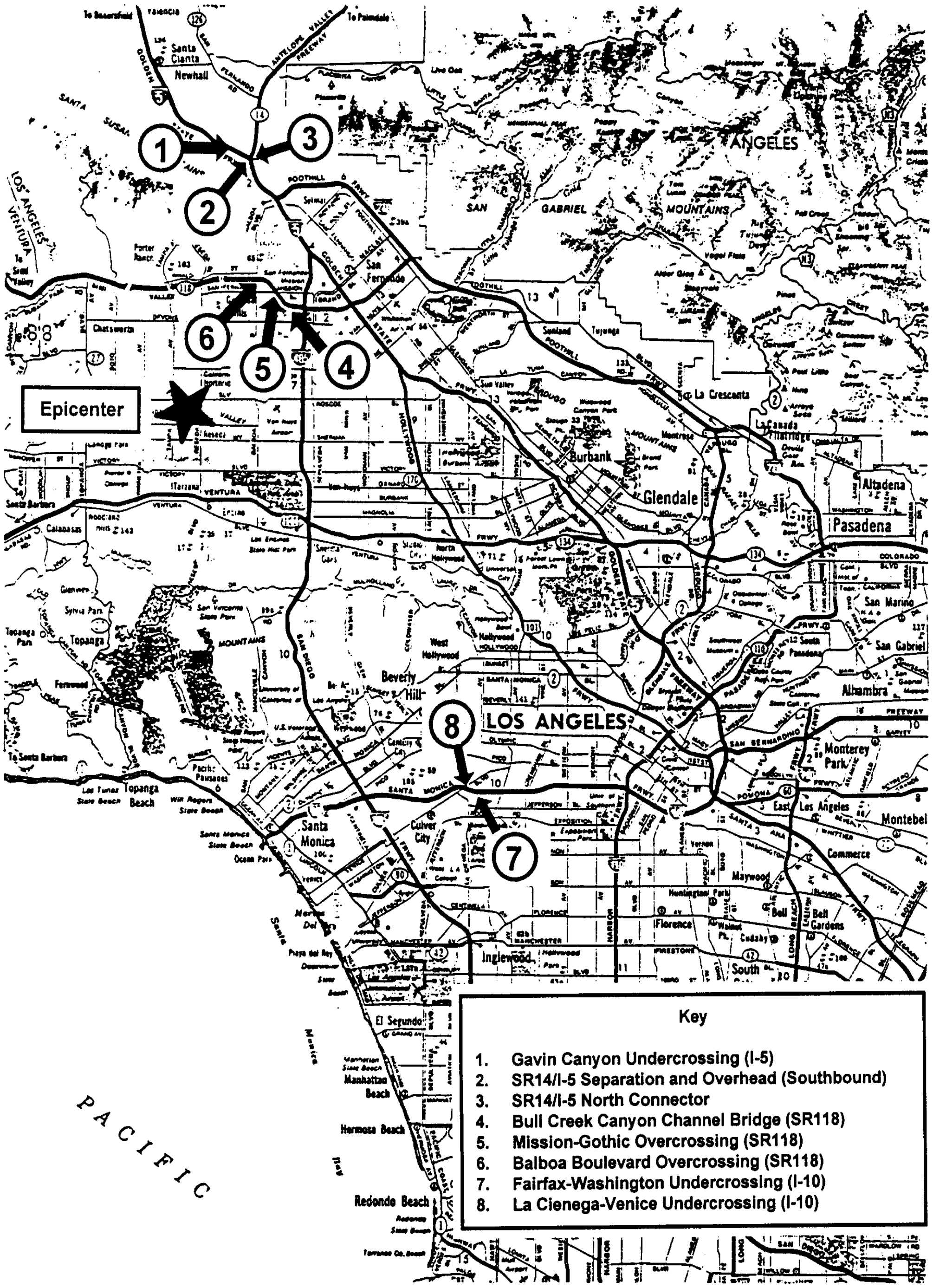


**FIGURE 6-2 Location Map of Bridges with Major Damage**

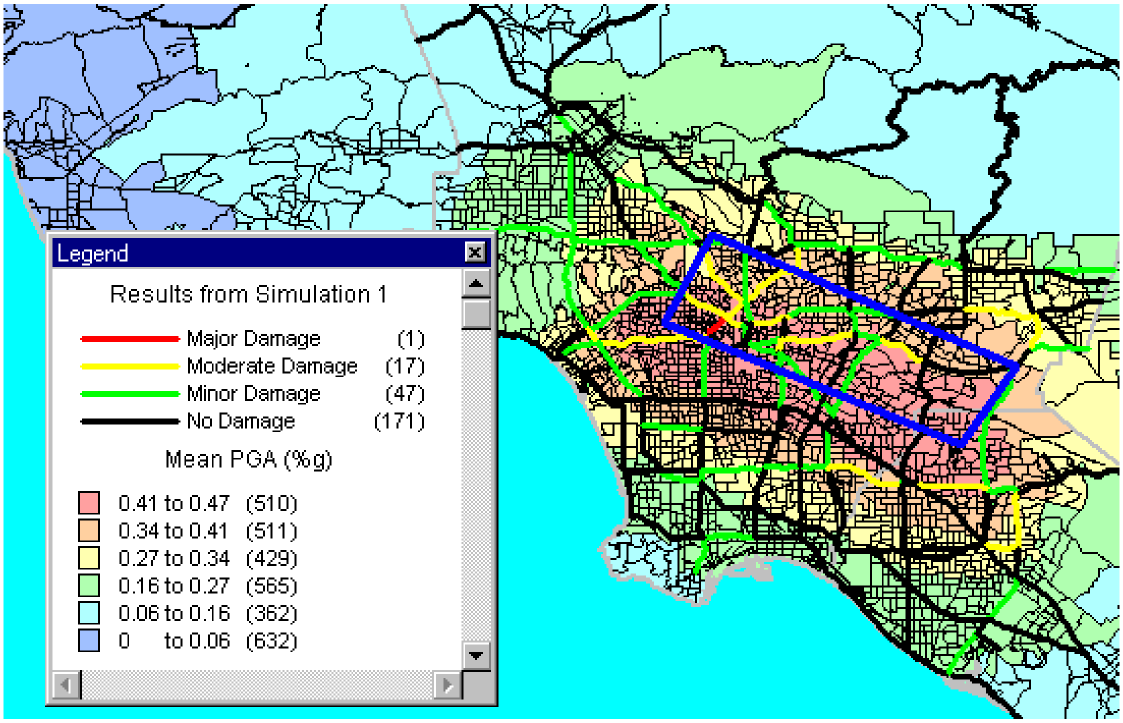


**FIGURE 6-3 Simulated Network Damage under Postulated Elysian Park Earthquake**

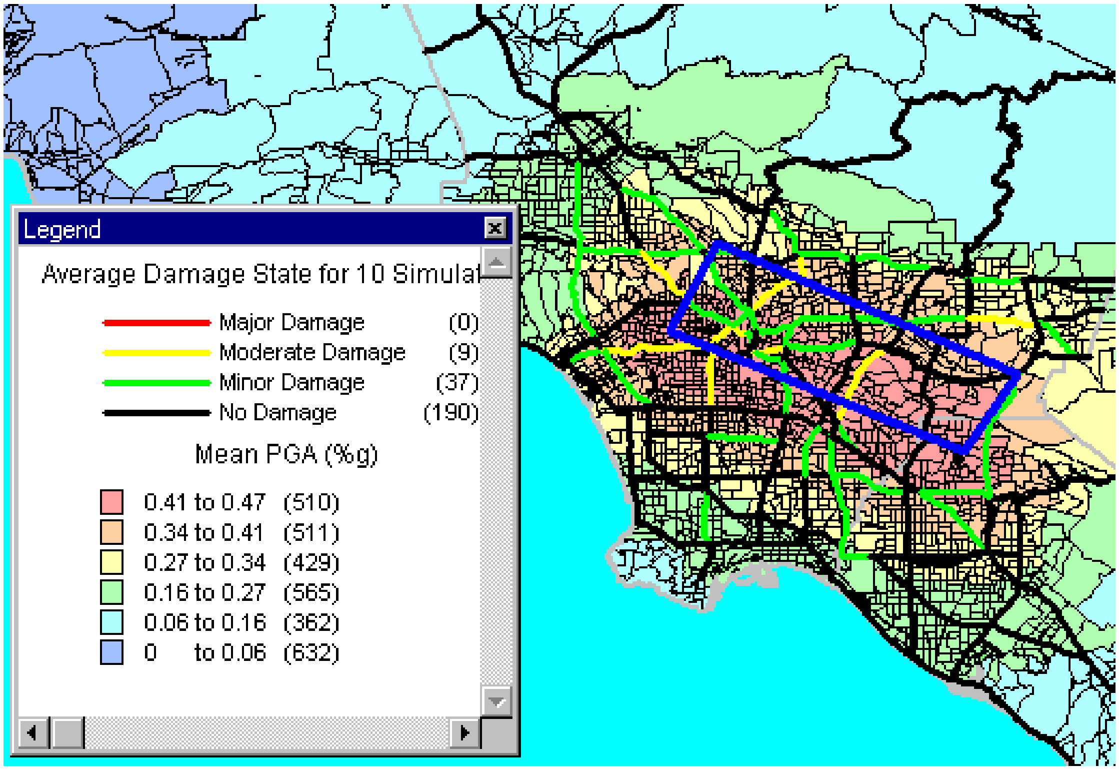


**FIGURE 6-4 Averaged Network Damage under Postulated Elysian Park Earthquake (10 Simulations)**

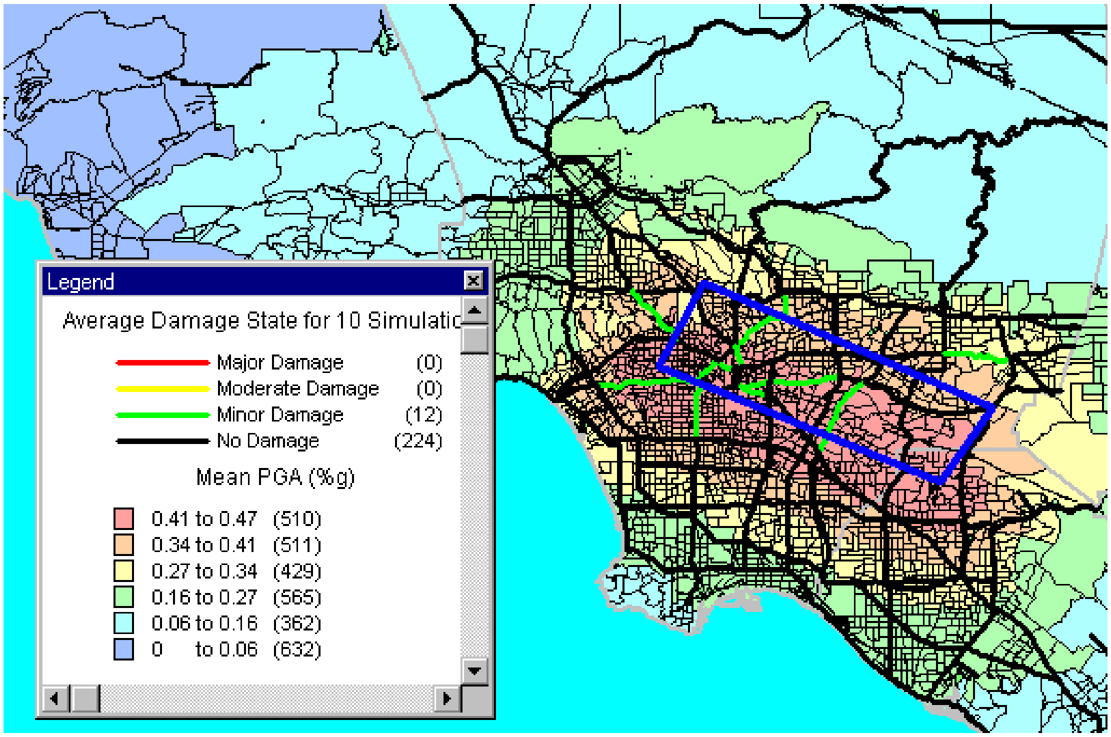


**FIGURE 6-5 Averaged Network Damage under Postulated Elysian Park Earthquake (10 Simulations on retrofitted Network with Fragility Enhancement of 50%)**

# SECTION 7
# NONLINEAR STATIC ANALYSIS PROCEDURE

Previous part of this report has presented the development of empirical and analytical fragility curves for bridges in detail. Empirical curves are developed by utilizing the damage data associated with past earthquakes while analytical ones by numerically simulating seismic response with the aid of structural dynamic analysis. Although the most reliable analytical method would be the use of complete nonlinear time history analysis, the present state of the art in general does not appear to be ready for the sophistication such a rigorous analysis represents.

Recently there has been an increasing interest in the simplified nonlinear analysis methods, referred to generally as nonlinear static analysis procedures. A variety of existing nonlinear static analysis procedures are currently being consolidated under such programs as ATC-40 (ATC, 1996) and FEMA-273 (FEMA, 1997a, b). Available nonlinear static analysis methods include (1) the capacity spectrum method (CSM) (e.g., ATC-40 (ATC, 1996)) that uses the intersection of the capacity (or pushover) curve and a reduced response spectrum to estimate maximum displacement; (2) the displacement coefficient method (e.g., FEMA-273 (FEMA, 1997a, b)) that uses pushover analysis and a modified version of the equal displacement approximation to estimate maximum displacement; and (3) the secant method (e.g., City of Los Angeles, Division 95 (COLA, 1995)) that uses a substitute structure and secant stiffness. These methods are basically targeted to the seismic evaluation and retrofit of buildings, not bridges. But similar concepts and procedures are currently under investigation by bridge engineers to introduce standardized simplified procedures for performance-based seismic evaluation of bridges.

Conforming to this current trend, and in an approach somewhat similar to Barron-Corvera (1999) and Dutta and Mander (1998), the present section considers a feasible means for developing fragility curves of bridges by utilizing the CSM. Fragility curves thus developed for Memphis bridges are compared with those by the time history analysis. Two key elements of the CSM are “Demand” and “Capacity”. Demand represents intensity of the earthquake ground motion to which bridges are subjected, while capacity represents the bridges' ability to resist the seismic demand. CSM requires determination of three primary elements: capacity spectrum, demand spectrum and performance point. Each of these elements utilized in this report basically conforms to ATC-40 (ATC, 1996) and briefly discussed below for better understanding.

### 7.1 CSM: Capacity Spectrum

In order to determine a capacity beyond the elastic limits, the pushover analysis is performed. The standard way to plot the force-displacement curve is by tracking the total shear force at column bottoms as a function of displacement of the superstructure.

The lateral forces are applied in proportion to the fundamental mode shape as shown in (7-1) below where $F_i$ is the lateral force on node $i$ $(i = 1, 2, \cdots, N)$, $w_i$ dead weight assigned to node $i$, $\phi_i$ amplitude of the fundamental mode at node $i$, $V$ the base shear and $N$ the number of nodes.

$$F_i = \left( w_i \phi_i \Big/ \sum_{i=1}^{N} w_i \phi_i \right) V \tag{7-1}$$

The corresponding natural period at any point on the capacity curve can be calculated by using of (7-2) below where $T$ is the period of the fundamental mode, $\delta_i$ lateral displacement at node $i$ due to lateral forces, $g$ acceleration due to gravity.

$$T = 2\pi \sqrt{\left( \sum_{i=1}^{N} w_i \delta_i^{\,2} \right) \Big/ \left( g \sum_{i=1}^{N} F_i \delta_i \right)} \tag{7-2}$$

To use the CSM, it is necessary to convert the capacity curve to capacity spectrum. The capacity curve expresses overall shear force on all supports as a function of the horizontal displacement of the superstructure, whereas the capacity spectrum represents the capacity curve in the ADRS (Acceleration-Displacement Response Spectra) format. The spectral acceleration $S_a$ and the spectral displacement $S_d$ can be calculated using modal parameters at any level of load magnitude as follows:

$$S_a = \frac{V/W}{\alpha} \tag{7-3}$$

$$S_d = \frac{\Delta_{girder}}{PF\phi_{girder}} \cong \frac{\theta_{pl}}{PF\phi_{pl}} \tag{7-4}$$

where $W$ is overall dead weight of bridge, $\Delta_{girder}$ horizontal displacement of girder, $\theta_{pl}$ rotation of plastic hinge, $\phi_{girder}$ and $\phi_{pl}$ amplitudes of the fundamental mode at girder and plastic hinge, respectively, $PF$ and $\alpha$ modal participation factor and modal mass coefficient of the fundamental mode defined as follows:

$$PF = \left[ \frac{\sum_{i=1}^{N} (w_i/\phi_i)/g}{\sum_{i=1}^{N} \left(w_i \phi_i^{\,2}\right)/g} \right] \tag{7-5}$$

$$\alpha = \frac{\left[ \sum_{i=1}^{N} (w_i \phi_i)/g \right]^2}{\left[ \sum_{i=1}^{N} w_i/g \right] \left[ \sum_{i=1}^{N} \left(w_i \phi_i^{\,2}\right)/g \right]} \tag{7-6}$$

The spectral displacement $S_d$ can be obtained from any displacement component of the structure as shown in (7-4). For bridge structures, the horizontal displacement of girder is a most critical displacement component for developing the capacity curve. However, the rotation of plastic hinge is more conveniently used to develop the capacity curve when the rotational ductility factor of plastic hinges at column bottoms is used to represent the damage states as in the present study. Figure 7-1 shows the capacity spectra developed for the 10 sample bridges introduced in Section 3.

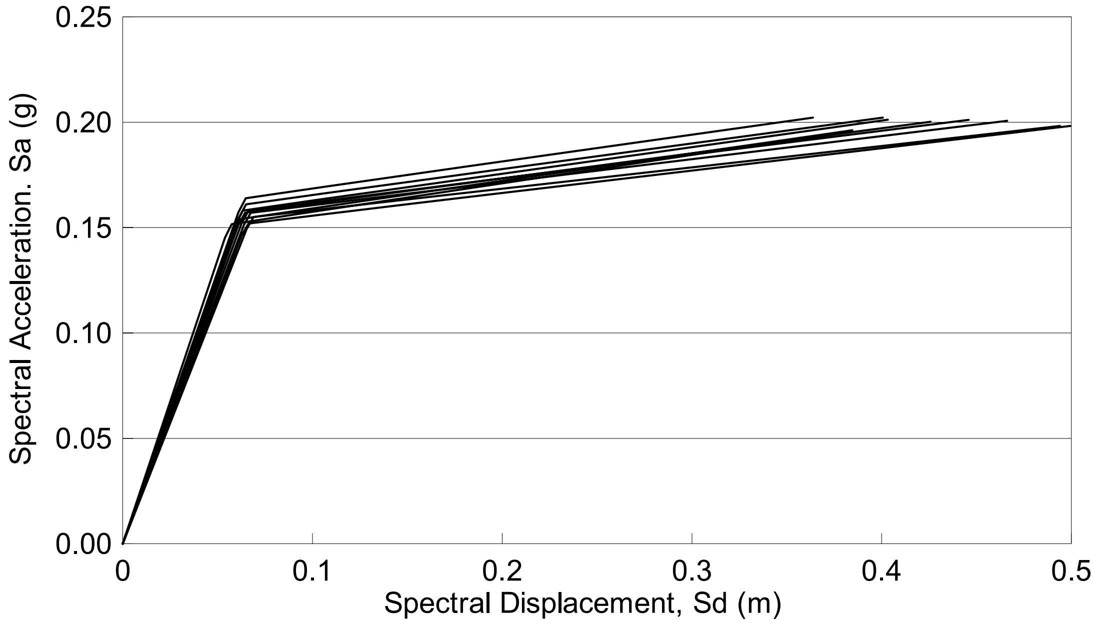


**FIGURE 7-1 Capacity Spectra**

### 7.2 CSM: Demand Spectrum

Standard elastic acceleration response spectrum can be converted to ADRS format with the help of following equation.

$$S_d = \frac{T^2}{4\pi^2} S_a g \tag{7-7}$$

According to ATC-40 (ATC, 1996), the reduced inelastic ADRS is developed by multiplying the reduction factors $SR_A$ and $SR_V$ for the range of constant spectral peak acceleration and constant spectral peak velocity, respectively as follows:

$$SR_A = \frac{3.21 - 0.68\ln(\beta_{eff})}{2.12} \geq \text{Values in table 7-1} \tag{7-8}$$

$$SR_V = \frac{2.31 - 0.41\ln(\beta_{eff})}{1.65} \geq \text{Values in table 7-1} \tag{7-9}$$

where $\beta_{eff}$ (in percentage) is the effective viscous damping including assumed 5% structural viscous damping as follows:

$$\beta_{eff} = \kappa\beta_0 + 5 = \frac{63.7\kappa\left(a_y d_{pi} - d_y a_{pi}\right)}{a_{pi} d_{pi}} + 5 \tag{7-10}$$

where $\beta_0$ is equivalent viscous damping associated with full hysteresis loop area of capacity spectrum, $\kappa$ is damping modification factor to compensate for the uncertainty in $\beta_0$ because of probable imperfections in real bridge hysteresis loops and defined as a function of structural behavior type as shown in table 7-2, $(d_y, a_y)$ represents the yielding point on the bilinear capacity spectrum, while $(d_{pi}, a_{pi})$ represents the performance point on the bilinear capacity spectrum at the $i^{th}$ trial; the significance of yield points and performance points will be graphically depicted later in figures 7-4~7-6.

**Table 7-1 Minimum Allowable $SR_A$ and $SR_V$ Values (ATC 1996)**

| Structural Behavior Type | $SR_A$ | $SR_V$ |
|---|---|---|
| Type A | 0.33 | 0.50 |
| Type B | 0.44 | 0.56 |
| Type C | 0.56 | 0.67 |

**Table 7-2 Values for Damping Modification Factor, $\kappa$ (ATC 1996)**

| Structural Behavior Type | $\beta_0$ | $\kappa$ |
|---|---|---|
| Type A | $\leq 16.25$<br>$> 16.25$ | 1.0<br>$1.13 - 0.008\beta_0 \geq 0.77$ |
| Type B | $\leq 25$<br>$> 25$ | 0.67<br>$0.845 - 0.007\beta_0 \geq 0.53$ |
| Type C | Any Value | 0.33 |

## 7.3 CSM: Performance Point

When the displacement $d_{pi}$ at the intersection of the reduced demand spectrum with the capacity spectrum falls within the $\pm 5$ percent range of the displacement of the performance point obtained at $(i-1)^{th}$ iteration i.e., $(0.95d_{p(i-1)} \le d_{pi} \le 1.05d_{p(i-1)})$, $d_{pi}$ becomes the performance point. If the intersection of the reduced demand spectrum and the capacity spectrum is not within the acceptable tolerance, then the iterative process will proceed. Basically, ATC-40 (ATC, 1996) suggests three different procedures that standardize and simplify this iterative process, so-called "Procedure A, B and C". These alternate procedures are all based on the same concepts and mathematical relationships but vary in their dependence on analytical versus graphical methods. This study utilizes "Procedure A" which is a more analytical method than a graphical method.

## 7.4 CSM-Based Fragility Curve

The CSM is considered as much a simplified and yet judicious procedure as possible in evaluating bridge response using a code-type predetermined response spectrum rather than an individual spectrum associated with a particular ground motion time history. To enjoy the most of the benefit the CSM offers, fragility curves are developed along with the following approaches.

Ground motion time histories are sorted by PGA and grouped to the nearest representative PGA (e.g. 0.10, 0.15, 0.20, $\cdots$, 0.40) with appropriate scaling. For each group of PGA, the mean and standard deviation of the elastic acceleration response spectra for all the time histories in the group are calculated for the considered range of structural period. By developing three elastic acceleration response spectra in this way (i.e., mean and mean $\pm$ one standard deviation) and transforming them to ADRS format, three ADRS, i.e., mean ($m$) and mean $\pm$ one standard deviation ($m \pm \sigma$) ADRS, can be developed. Examples of these ADRS are shown in figures 7-2 and 7-3 respectively for the time histories grouped with representative PGA=0.25g and 0.40g. The same ten bridges forming a sample of size 10 for Bridge 1 as used in the simulation analysis performed earlier also in conjunction with Bridge 1 are utilized to ensure most efficient comparison. These bridges are referred to as sample bridge 1, 2,$\cdots$, 10 to be distinguished from Bridge 1. Then a capacity spectrum for each sample bridge is one by one constructed and drawn on the same coordinates. The three performance points for each of the capacity spectrum are determined as its intersections with $m$ and $m \pm \sigma$ ADRS reduced properly using the reduction factors introduced in (7-8) and (7-9). These three spectral displacements are defined as $\overline{S}_d(a)$ and $\overline{S}_d(a) \pm \sigma_d(a)$, and shown in figures 7-4~7-6 for PGA=0.25g. Indeed, they are functions of $a$ (PGA) since the three ADRS on which they depend are developed on the time histories sorted and grouped by PGA.

Assuming the two-parameter lognormal distribution for the spectral displacement $S_d(a)$, the parameters can be obtained from following equations.

$$\overline{S}_d(a) = c(a)\exp[\{\zeta(a)\}^2/2] \tag{7-11}$$

$$\{\sigma_d(a)\}^2 = \{\overline{S}_d(a)\}^2\left[\exp(\{\zeta(a)\}^2) - 1\right] \tag{7-12}$$

The limit displacement $d_l$ which is defined as the spectral displacement $S_d(a)$ for the specified state of damage can be expressed by (7-13) with the aid of (7-4).

$$d_l = \frac{\theta_{pl}/\theta_y}{PF\phi_{pl}/\theta_y} = \frac{(Ductility\ Demand)_{damage}}{(PF\phi_{pl})_{damage}/\theta_y} \tag{7-13}$$

where $(X)_{damage}$ denotes the value of $X$ at the specified state of damage and $\theta_y$ is the yielding rotation of the plastic hinge. To be consistent with the analytical fragility curves for Bridge 1 in the Memphis area developed earlier, the state of damage described by ductility demand being larger than 1.0 or 2.0 simultaneously existing for all the bridge columns represent the minor or major states of damage. Hence, $(Ductility\ Demand)_{damage}$ in (7-13) should be 1.0 for the state of minor damage and 2.0 for the state of major damage. It should be addressed here that the limit displacement $d_l$ for each sample bridge is slightly different with each other for even the same state of damage because $(PF\phi_{pl})_{damage}$ is not identical for each sample bridge. The probability that sample bridge $j$ will have a state of damage exceeding $d_l$ is given by

$$P[S_d(a) \geq d_l \text{ for sample bridge } j] = P_j(a, d_l) = 1 - \Phi\left[\frac{\ln\left(\dfrac{d_{l,j}}{c_{,j}(a)}\right)}{\zeta_{,j}(a)}\right] \tag{7-14}$$

where $d_l = (d_l)_1$ and $d_l = (d_l)_2$ represent respectively the states of minor and major damage under the assumption that the same state of damage will be imposed on all the columns simultaneously as the nonlinear static analysis tends to imply. The subscript $j$ on $d_{l,j}$, $c_{,j}(a)$ and $\zeta_{,j}(a)$ in (7-14) explicitly denotes that these three parameters are dependent on each sample bridge $j$. The fragility value at PGA=$a$ for the state of damage represented by $d_l$ can be estimated by taking all $K$ bridges in the PGA group under consideration as follows:

$$F(a, d_l) = \frac{\sum_{j=1}^{K} P_j(a, d_l)}{K} \tag{7-15}$$

These values are plotted in terms of open squares in figures 7-7~7-9 whereas the values of $P_j(a, d_l)$ are plotted in terms of crosses to show the degree of fragility variation due to the variability in structural characteristics. The comparison of these results of nonlinear static analysis with those of the time history analysis indicates that the agreement is excellent for the at least minor state of damage, but it is not so for the major state of damage where nonlinear effects obviously play an important role. Overall, however, the agreement is adequate even in the case dealing with the major state of damage considering a large number of assumptions under which both analyses are performed. For the benefit of the reader interested in the details how CSM is applied in this study, the following sub-section is provided.

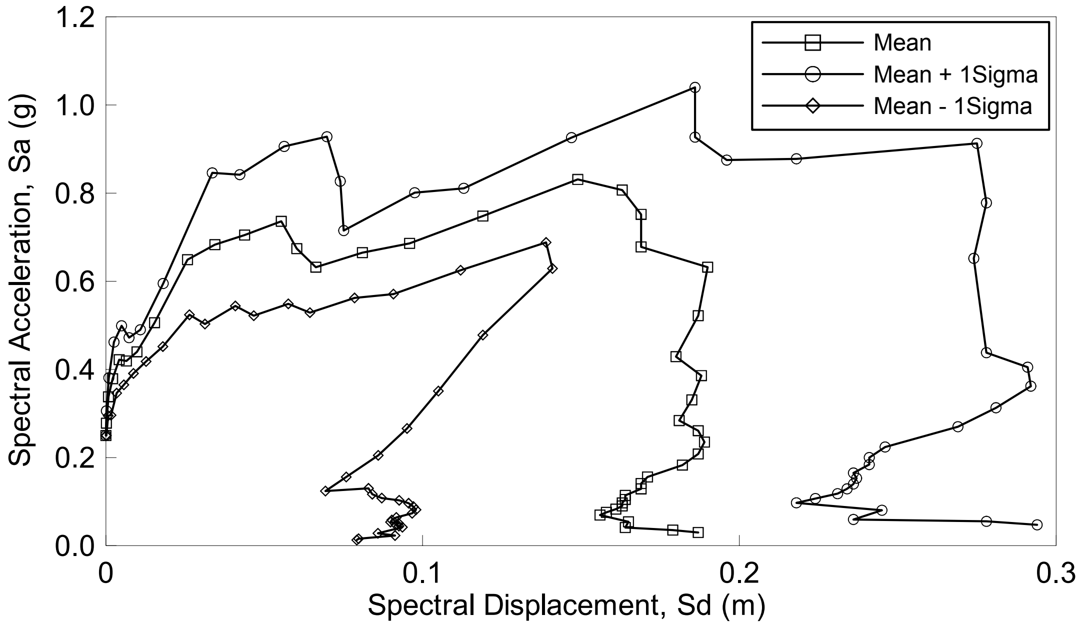


**FIGURE 7-2 Mean, Mean+1Sigma and Mean-1Sigma ADRS for PGA=0.25g**

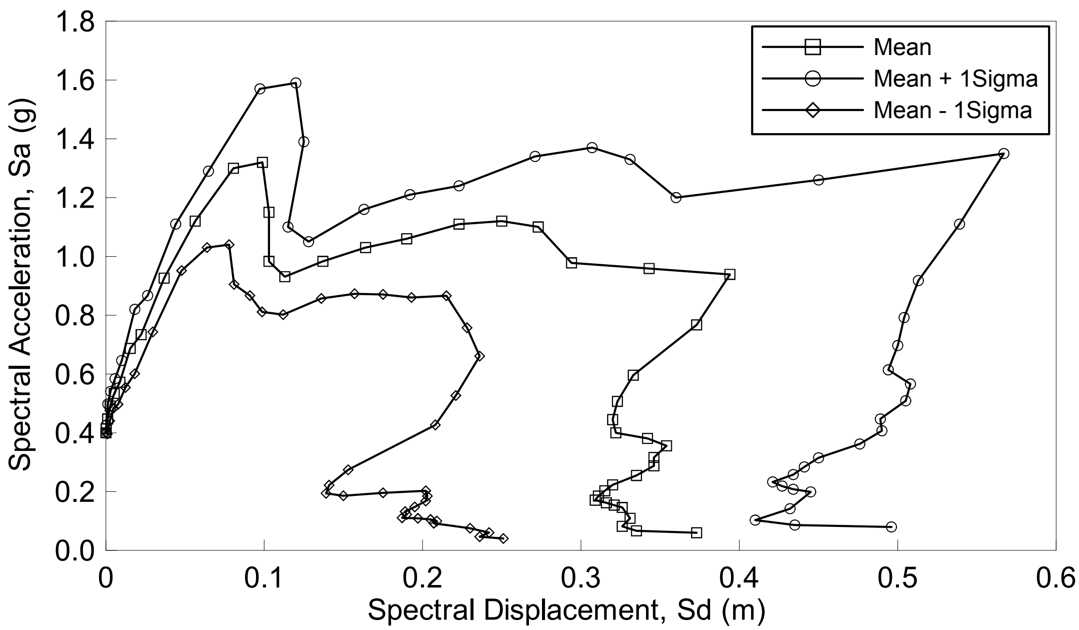


**FIGURE 7-3 Mean, Mean+1Sigma and Mean-1Sigma ADRS for PGA=0.40g**

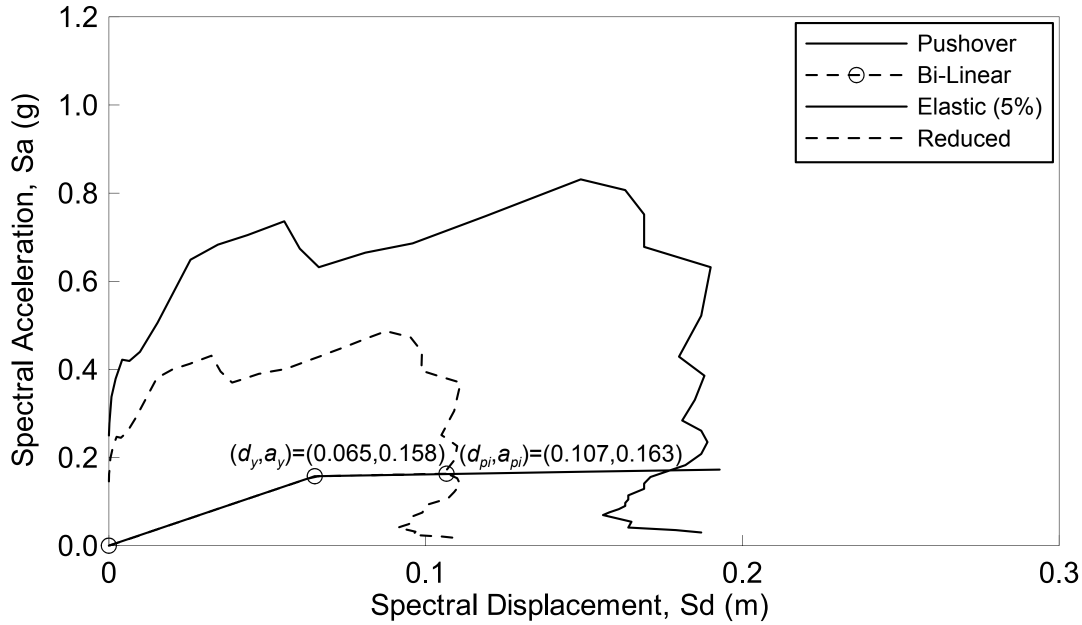


**FIGURE 7-4 Calculated Performance Displacement for Mean ADRS for PGA=0.25g**

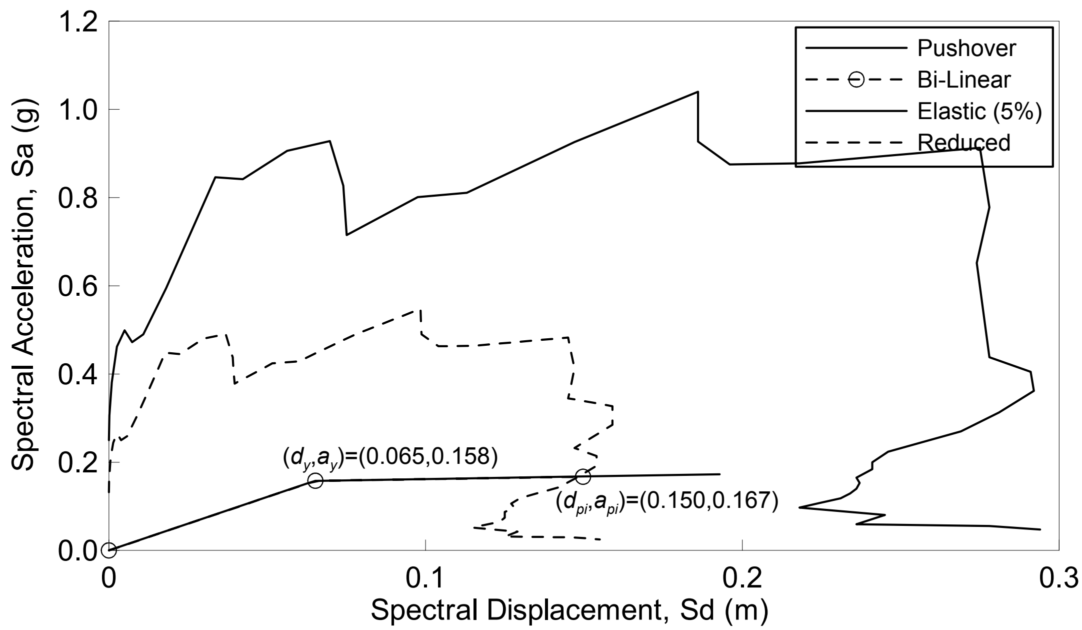


**FIGURE 7-5 Calculated Performance Displacement for Mean+1Sigma ADRS for PGA=0.25g**

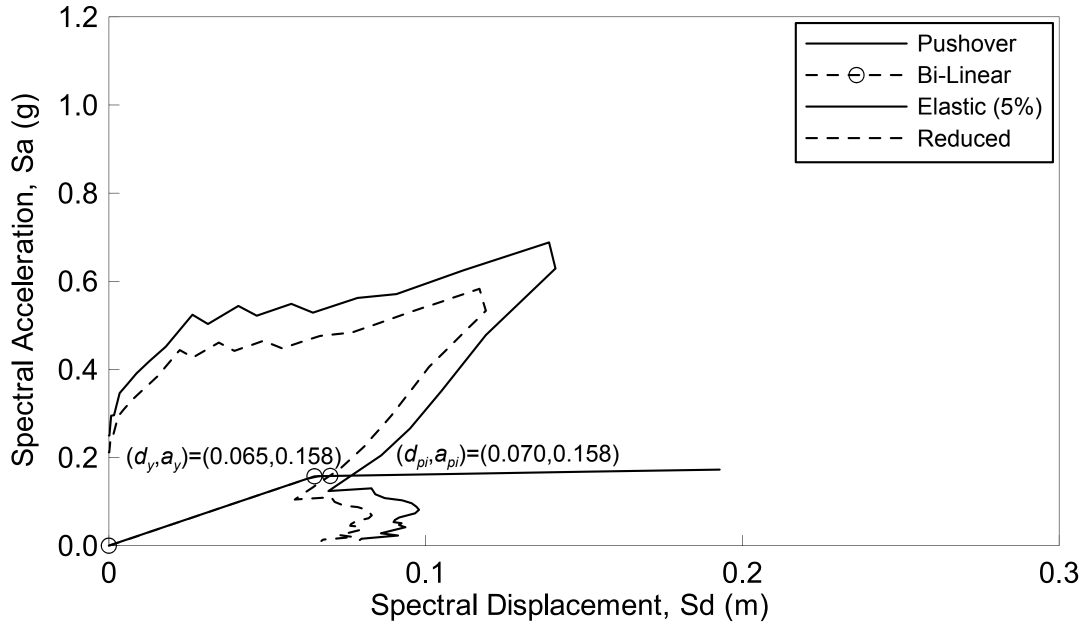


**FIGURE 7-6 Calculated Performance Displacement for Mean-1Sigma ADRS for PGA=0.25g**

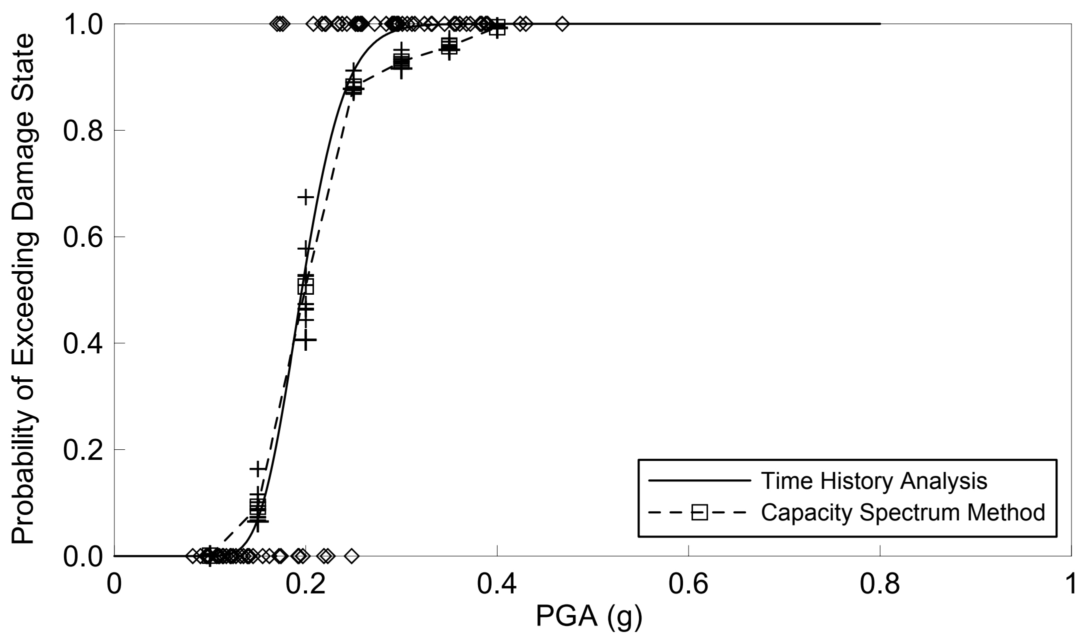


**FIGURE 7-7 Fragility Curves of 10 Sample Bridges for State of at least Minor Damage**

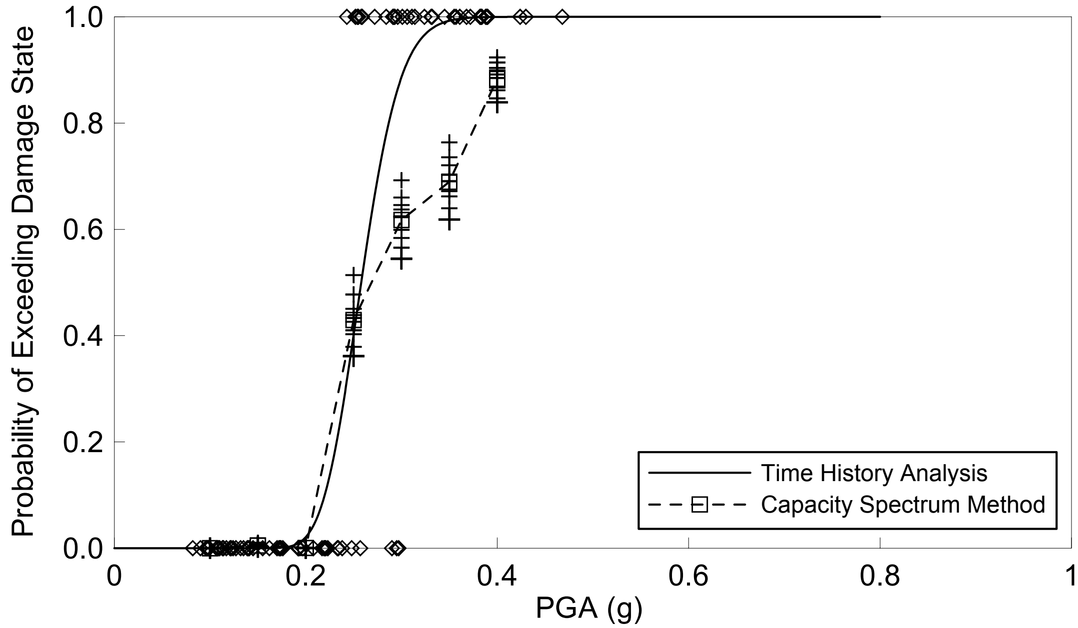


**FIGURE 7-8 Fragility Curves of 10 Sample Bridges for State of Major Damage**

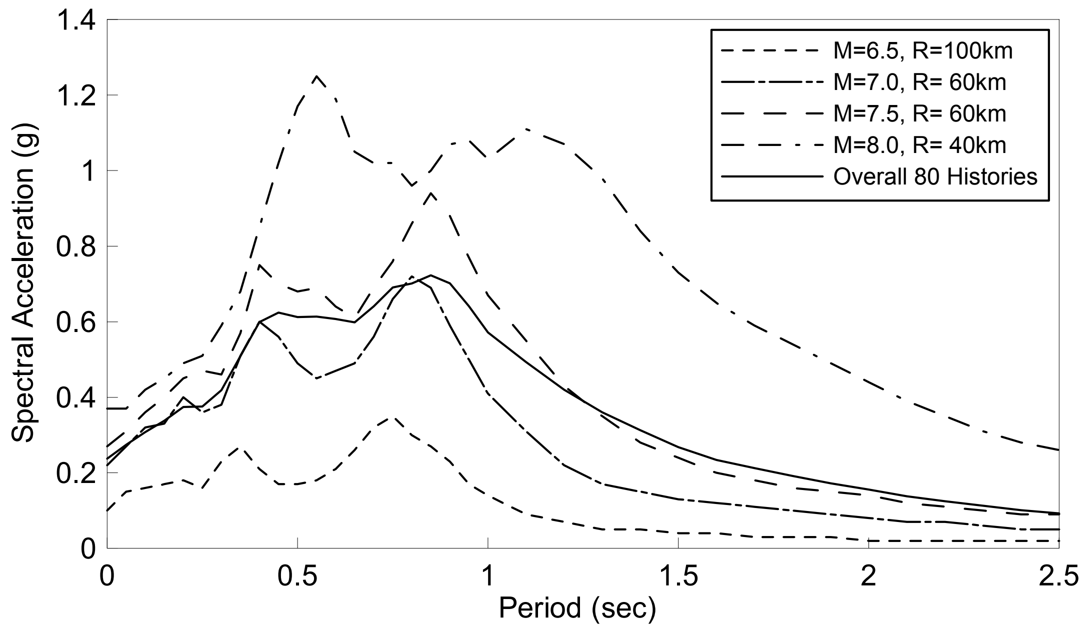


**FIGURE 7-9 Average Acceleration Response Spectra (5% Damping)**

## 7.5 Analytical Details

This section is devoted to examine how fragility curves developed by the nonlinear static analysis procedure conform well to those by nonlinear time history analysis approach. For this purpose, the Memphis bridge and the set of 80 time histories of ground motion which were used in earlier part of this report are adopted again.

For the nonlinear static analysis procedure, the DIANA 7.1 finite element code (DIANA, 1999) is utilized to develop pushover curves. The SAP2000 has special option for pushover analysis, but only with the elastic response spectrum in ATC-40 (ATC, 1996). Also the SAP2000 covers some local nonlinear problems in dynamics but not in statics, and this is the primary reason for the use of the DIANA 7.1 in this study. Both finite element models for nonlinear static pushover analysis and for nonlinear time history analysis are conceptually same even though they are developed for different computer codes.

The acceleration response spectra, averaged over 10 time histories from each combination of M and R, are shown in figure 7-9 for four combinations among eight. This figure also shows the acceleration response spectrum averaged over total 80 time histories to provide an insight to the frequency content of these ground motion time histories. Figures 7-10 and 7-11 also show the pseudo velocity response spectrum and the pseudo displacement response spectrum, respectively averaged over total 80 ground motions.

Static pushover analyses are performed for ten "normally identical but statistically different" sample bridges to develop capacity curves. The capacity curves are converted to the capacity spectrum with the help of modal parameters defined in (7-5) and (7-6). The bridge consists of three symmetrically positioned piers along the longitudinal axis. By increasing lateral forces, it is found that the internal pier yields first and the external piers later. This slightly delayed yielding of external piers results in smaller rotation of plastic hinges of external piers. To ensure the consistency in evaluating minimum ductility demand of all columns at performance point, the rotation of external pier is taken as $\theta_{pl}$ in (7-4).

The modal parameters in (7-5) and (7-6) gradually change while the plastic hinges undergo beyond the yielding limit. Hence, modal parameters are calculated in several loading states and linearly interpolated between the calculated points. These modal parameters are calculated on or near the ductility demand of plastic hinge equal to 1, 2, 3, 4 and 10. Fundamental natural periods of 10 bridges at these ductility demands are calculated using (7-2) and presented in figure 7-12. As shown in this figure, the fundamental natural periods for 10 bridges fall into the range from 1.2 sec to 3.0 sec approximately. Finally, figure 7-1 shows capacity spectra for the ten sample bridges.

Figures 7-2 and 7-3 show the $m$ and $m \pm \sigma$ ADRS for PGA=0.25g and 0.40g, respectively. The spectral displacement, $S_d$ can be determined by plotting the capacity spectrum on the same ADRS coordinates. Figures 7-4~7-6 show the representative procedure to evaluate the performance displacements for the $m$ and $m \pm \sigma$ ADRS which are defined as $\overline{S}_d$ and $\overline{S}_d \pm \sigma_d$, respectively.

The mean ($\overline{S}_d$) and mean$\pm$standard deviation ($\overline{S}_d \pm \sigma_d$) of displacement of one sample bridge for each PGA are shown in figure 7-13. This figure shows that $\overline{S}_d$, $\sigma_d^+$ and $\sigma_d^-$ increase gradually as PGA increases. It is also found that the magnitude of $\sigma_d^+$ at any PGA is not same as that of $\sigma_d^-$. In other words, the distribution of displacement according to PGA is not symmetric. This study assumes that the performance displacement has the mean $\overline{S}_d$ and standard deviation $\sigma_d$ redefined by $\sqrt{(\sigma_d^+)(\sigma_d^-)}$. The two-parameters, $c$ and $\zeta$ of lognormal distribution are obtained using (7-11) and (7-12) with $\sigma_d$ as defined here. The probability that each bridge will be in a state of specified damage is calculated using (7-14) for each damage state. The final fragility value is obtained from (7-15) by taking into consideration all the bridges in each PGA group at the corresponding value of PGA.

Figure 7-7 shows the fragility curves associated with state of at least minor damage developed by two methods. Eighty diamonds plotted on the two horizontal axes and the fragility curve by time history method are replotted here from the earlier part of this report. The open squares in figure

7-7 also show the overall trend of the fragility curve for the state of at least minor damage based on CSM for the case of structural behavior type A. Ten cross marks plotted vertically along each square denote the probability of exceeding state of at least minor damage by ten sample bridges, respectively. By averaging the probability represented by these ten cross marks, each square is determined as overall fragility for each PGA group at its representative PGA value. This figure shows that the fragility curve developed by CSM well conforms to that by the time history analysis in all considered range of PGA. Figure 7-8 also shows the fragility curve for state of major damage.

It is found that the fragility information derived by the two methods, one based on time history analysis and the other on CSM, is in good agreement up to PGA of 0.25g. But for higher PGA, CSM underestimates the fragility compared with the time history analysis. Although the fragility information based on these two methods tends to show some discrepancy in high ranges of PGA, the overall agreement is adequate considering a number of assumptions under which these results are derived.

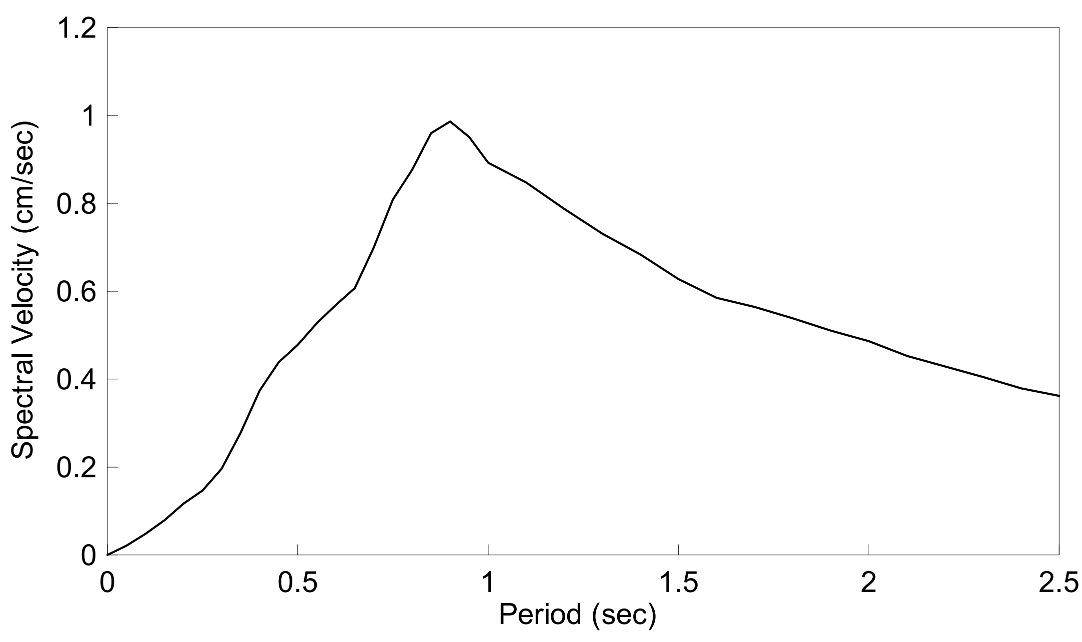


**FIGURE 7-10 Average Pseudo Velocity Response Spectrum (5% Damping)**

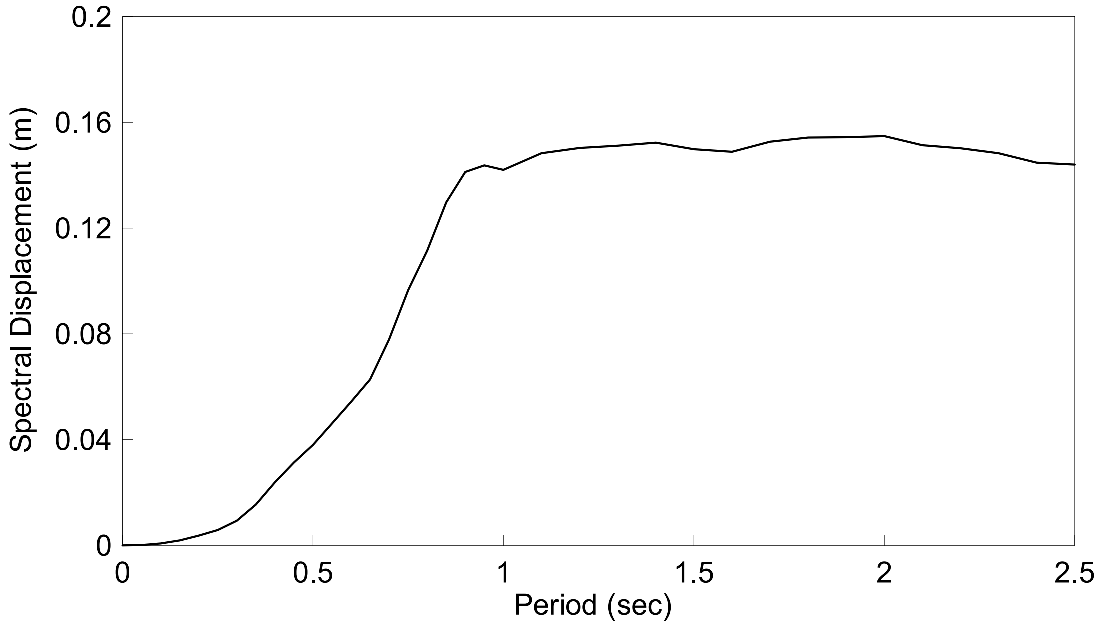


**FIGURE 7-11 Average Pseudo Displacement Response Spectrum (5% Damping)**

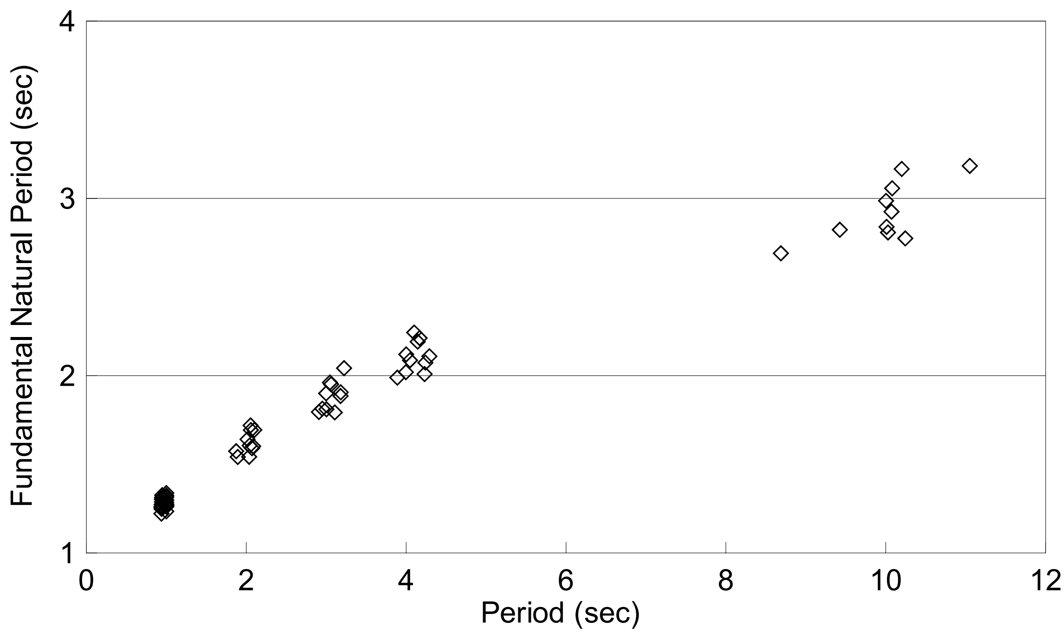


**FIGURE 7-12 Fundamental Natural Periods of 10 Sample Bridges**

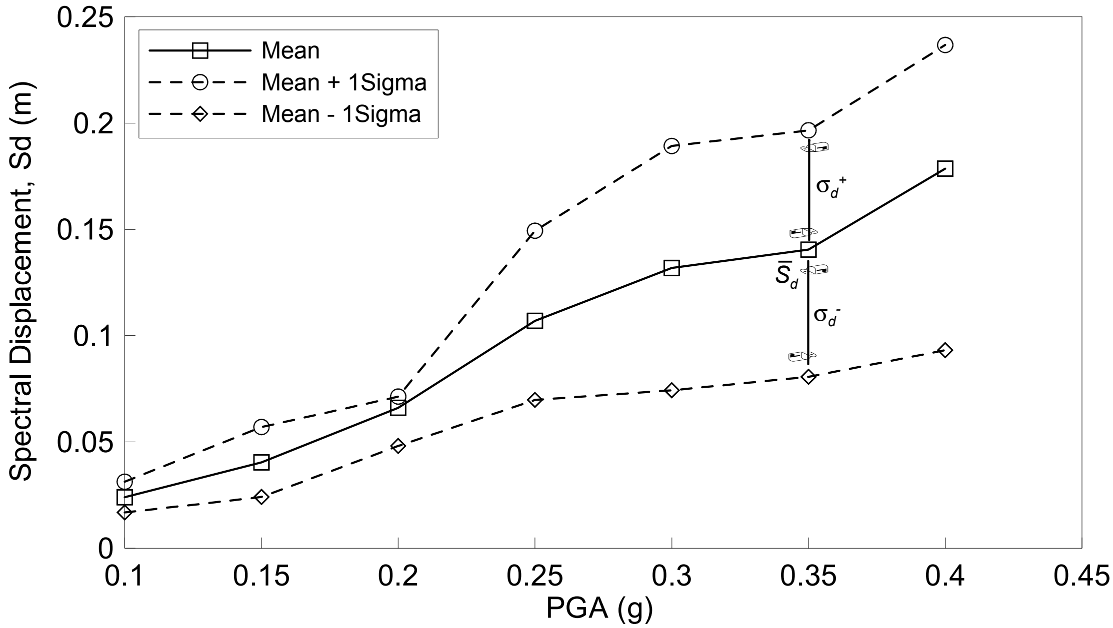


**FIGURE 7-13 Mean, Mean+1Sigma and Mean-1Sigma Displacement for One Sample Bridge**

# SECTION 8
# CONCLUSIONS

This report presents methods of bridge fragility curve development on the basis of statistical analysis. Both empirical and analytical fragility curves are considered. The empirical fragility curves are developed utilizing bridge damage data obtained from the past earthquakes, particularly the 1994 Northridge and the 1995 Hyogo-ken Nanbu (Kobe) earthquake. The analytical fragility curves are constructed for typical bridges in the Memphis, Tennessee area utilizing nonlinear dynamic analysis. Two-parameter lognormal distribution functions are used to represent the fragility curves. These two-parameters (referred to as fragility parameters) are estimated by two distinct methods. The first method is more traditional and uses the maximum likelihood procedure treating each event of bridge damage as a realization from a Bernoulli experiment, while the second method is unique in that it permits simultaneous estimation of the fragility parameters of the family of fragility curves, each representing a particular state of damage, associated with a population of bridges. The second method still utilizes the maximum likelihood procedure, however, with each event of bridge damage treated as a realization from a multi-outcome Bernoulli type experiment. These two methods of parameter estimation are used for each of the populations of bridges inspected for damage after the Northridge and the Kobe earthquake and for the population of typical Memphis area bridges with numerically simulated damage. Corresponding to these two methods of estimation, this report also introduces statistical procedures of testing goodness of fit of the fragility curves and of estimating the confidence intervals of the fragility parameters. In addition, some preliminary evaluations are made on the significance of the fragility curves developed as a function of ground intensity measures other than PGA. Furthermore, applications of fragility curves in the seismic performance estimation of expressway network systems are demonstrated by taking the Los Angeles area expressway network as example. In doing so, families of fragility curves developed for each sub-set of bridges are utilized. Each sub-set represents a particular combination of bridge attributes defining span multiplicity, skew angle and soil condition. Finally, an exploratory work is performed to compare the analytical fragility curves developed in the major part of this report with those constructed utilizing the nonlinear static method. While the authors are hopeful that the conceptual and theoretical treatment dealt in this study can provide theoretical basis and analytical tools of practical usefulness for the development of fragility curves, there are many analytical and implementational aspects that require further study including:

1. Physical definition of damage that can be used for post-earthquake damage inspection and analysis.
2. Use of other measures of ground motion intensity than PGA for fragility curve development.
3. Bridge categorization based on physical attributes.
4. Further study on the use of nonlinear static analysis procedures for fragility curve development.
5. Transportation systems analysis accounting for uncertainty in the fragility parameters.

# SECTION 9
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Red Jacket Quadrangle ■ Buffalo, New York 14261
Phone: (716) 645-3391 ■ Fax: (716) 645-3399
E-mail: *mceer@mceermail.buffalo.edu* ■ WWW Site *http://mceer.buffalo.edu*

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