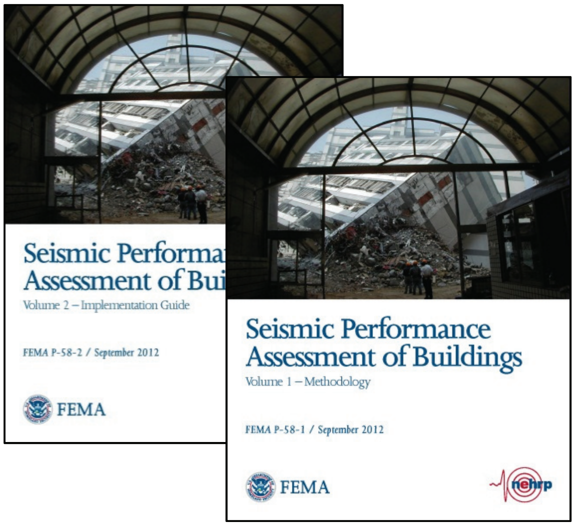

Background Document

FEMA P-58/BD-3.7.3

Validation and Verification Plan

Prepared by

Ronald O. Hamburger
Simpson Gumpertz & Heger
The Landmark @ One Market, Suite 600
San Francisco, California 94105

Submitted to

APPLIED TECHNOLOGY COUNCIL
201 Redwood Shores Parkway, Suite 240
Redwood City, California 94065
www.ATCouncil.org

Prepared for

FEDERAL EMERGENCY MANAGEMENT AGENCY
U.S. Department of Homeland Security
500 C Street, SW
Washington, D.C. 20472

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FEMA

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Background Documentation

FEMA P-58 Background Documents are a series of reports documenting the technical background and source information for key aspects of the FEMA P-58 methodology and its implementation. These reports were developed over the course of the 10-year ATC-58/ATC-58-1 Projects funded under FEMA Contracts EMW-2001-RP-0056 and HSFEHQ-06-D-1105.

Background Documents were developed by consultants, serving at various levels within the project hierarchy, reporting the results of: (1) decisions on technical development protocols; (2) focused studies on the development of key aspects of the methodology; (3) documentation of recommended procedures; and (4) collection of available data for the development of structural and nonstructural fragilities. They were initially intended to serve as a record of the technical state-of-knowledge at the time they were produced, and as resources for the development of the eventual project reports. As such, they represent a snapshot in time, and may, or may not, match the technical content, recommended procedures, or data incorporated into the final methodology and its implementation.

This Background Document is intended for the purpose of providing supplemental knowledge to users of the FEMA P-58 methodology. Information contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology. Users of information in this document assume all liability arising from such use.

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Cover illustration – Primary resource documents for the FEMA P-58 *Seismic Performance Assessment of Buildings, Methodology and Implementation* series of products: FEMA P-58-1, *Volume 1 – Methodology*, and FEMA P-58-2, *Volume 2 – Implementation Guide*.

ATC-58-1

DEVELOPMENT OF NEXT-GENERATION PERFORMANCE-BASED SESIMIC DESIGN GUIDELINES

VALIDATION AND VERIFICATON PLAN

Revised/Final

AUGUST 2008

Ronald O. Hamburger
Project Technical Director

1. Introduction

1.1 Purpose

This report describes a plan for validation and verification of the methodology and products produced by the ATC-58.1 project to produce Next-generation Performance-based Seismic Design Criteria for Buildings. This plan was produced by the Project Technical Director on behalf of the Project Management Committee and in response to a request of theATC-58 Project Steering Committee. It is intended that this plan will be approved by the ATC-58.1 Project Management Committee, with advice from the Project Steering Committee, and then implemented by the project team as a means of quality assurance for the project's products.

1.2 Background

The Applied Technology Council under contract to the Federal Emergency Management Agency of the Department of Homeland Security is engaged in a multi-year, multi-phase program to develop Next-generation Performance-based Seismic Design Criteria for Buildings. First-generation performance-based seismic design criteria were developed by the Applied Technology Council in the mid-1990s under the FEMA-funded ATC-33 project which produced performance-based seismic design criteria for seismic rehabilitation of existing buildings published as FEMA-273/274, later enhanced and standardized as FEMA-356 and most recently ASCE-41.06. The demand for performance-based seismic design criteria originated from the large economic losses experienced by California communities in the 1980s and 1990s as a result of heightened earthquake activity in the State during that period. Frequent earthquakes during that period of approximately 20 years created awareness that:

a) Much of the nation's stock of existing buildings, constructed prior to the adoption of reliable earthquake design and construction practices was highly damageable and posed a substantial life and economic risk.

b) It was neither practical nor effective to upgrade existing buildings to conform to current building code criteria.

c) Even current building codes did not provide adequate protection against damage and economic loss in the relatively frequent but strong earthquakes that were affecting the Western United States in this period.

The ATC-33 project developed a flexible performance-based approach for evaluation and upgrade of existing buildings that permitted design to achieve desired limited levels of damage, defined in terms of standardized structural and nonstructural performance levels at different design earthquake intensities. This approach was received with great enthusiasm by the earthquake engineering community. However, the ATC-33 project was intended to address seismically-vulnerable existing buildings. Stakeholders also identified the need for procedures and criteria to enable seismic design of new buildings using performance-based approaches. In recognition of this, even before the ATC-33 project was completed, FEMA commissioned a series of studies, first by the Earthquake Engineering Research Center at the University of California at Berkeley and later by the Earthquake Engineering Research Institute (EERI), to prepare action plans for the development of performance-based seismic design criteria for new buildings. FEMA published the action plan developed by EERI as FEMA-349 *Action Plan for Performance Based Seismic Design* in April 2000. This action plan called for a broad program of research and development that went beyond development of performance-based design criteria for new buildings but also to improve the procedures and approaches then in use for existing buildings. The projected schedule for this effort extended over 10 years.

In September 2000, FEMA entered into contract with the Applied Technology Council to initiate a project, the ATC-58 project to implement the FEMA 349 Action Plan. Under the ATC-58 project, the Applied Technology Council conducted a series of tasks that included:

a) Development of a project management structure and team

b) Held a series of workshops with stakeholders and the earthquake engineering community to validate the program goals and objectives and seek input into the work plan

c) Review and update the FEMA 349 Action plan, published as FEMA 445 in 2004

d) Prepare a framework for performance assessment of new and existing buildings as an initial part of the performance-based design process

The ATC-58 project concluded in September 2006 with publication of 35% Draft Guidelines for Performance Assessment of Buildings. Following completion of the ATC-58 project, FEMA entered into contract with the Applied Technology Council to complete the development of Performance-based Seismic Assessment procedures and guidelines. ATC is performing this work, following the FEMA 445 Program Plan under its ATC-58.1 project.

The primary products that ATC-58.1 project will produce will include:

a) A complete methodology and framework for seismic performance assessment of individual new or existing buildings

b) A publication (guidelines) intended for use by structural engineers, that will guide them through implementation of this methodology for real buildings

c) A rudimentary software companion to the guidelines that will facilitate the extensive mathematical calculation procedures embodied into the guidelines.

Upon completion, in 2011, the ATC-58.1 project will produce guidelines and companion software that will enable engineers to assess the probable seismic performance of both new and existing individual buildings, in terms of the risk of incurring economic and human losses in future earthquakes. It is anticipated that publication of the ATC-58.1 products will be followed with additional projects that will guide engineers and stakeholders in the use of this methodology to economically and effectively design and upgrade buildings.

The ATC-58.1 project team recognizes that performance-based seismic assessment and design is a rapidly developing area of practice. It is the project team's intent to enable rather than constrain the development and implementation of performance-based design. Accordingly, the guidelines are written as one acceptable implementation of the overall performance assessment methodology. The project team fully expects that following publication of the guidelines, additional development will be performed by others to modify and improve this implementation.

1.3 Intent

The intent of this validation/verification plan is to respond to the question – "How do we know that performance assessments conducted in accordance with the guidelines are reasonable?" This question was first asked by the ATC-58 Project Steering Committee in somewhat modified form, specifically, "How do we know that the performance assessments are correct?"

Performance assessment of buildings is an inherently uncertain endeavor. It is impossible, given current knowledge and technology to predict the precise timing, location and magnitude of future earthquakes, let alone the intensity of earthquake effects that will be experienced at a particular building, the condition and occupancy of the building at the time it experiences these effects or the actions taken by building officials, building owners, tenants, engineers and contractors after the earthquake to regulate building occupancy, repair it, and restore it to service. As a result, it is impossible to precisely predict the performance of a building in future earthquakes, and therefore, equally impossible to understand if assessments of the probable future performance is "right." As a consequence, the Project Management Committee responded to the Project Steering Committee's request by commissioning an effort to develop a plan to assure that assessments would be reasonable. The performance assessments produced using the methodology developed by this project will project the probable performance of buildings, considering the above uncertainties and will project performance in terms of the probability of incurring losses of different magnitude. As a result of these uncertainties, the range of probable performance projected by these procedures is quite large. The project team will judge that the procedures are "reasonable" if:

a) the actual performance of real buildings generally falls within the range of probable performance indicated by these procedures

b) the actual performance of a large, unbiased sets of buildings assessed by these procedures generally falls near the median performance indicated by these procedures

1.4 Plan Development

The need to develop a plan for verification and validation of project products was identified by the ATC-58 Steering Committee in a meeting held in 2007. Following this, the Project Management Committee appointed a project Verification Team to develop a plan for action by the project team to respond to this need. This team was chaired by Dr. Charles Scawthorn and included Dr. Jack Baker, Mr. David Bonneville and Ms. Hope Seligson as members. The team developed a length report, in draft form, suggesting a comprehensive program of activities to validate, but not verify the correctness of the project products. In review of these draft reports, the Project Management Committee felt both that the plan was too comprehensive and costly in scope and also that verification was necessary as well as validation. As a result, the Project Management Committee charged the Project Technical Director to prepare the plan outlined in this document. The information and ideas contained in the draft reports prepared by the Verification Team was invaluable to the preparation of this plan.

1.5 Report Organization

Section 2 of this report presents a brief overview of the performance assessment methodology adopted by the project. Section 3 presents a brief discussion of the issues of validation, verification and documentation that will be undertaken by the project.

2. Performance Assessment Methodology

2.1 General

The ATC-58 project has adopted the general performance assessment methodology originally developed by the Pacific Earthquake Engineering Research Center (PEER). This methodology projects performance in terms of the probability of incurring certain economic and human losses, considering uncertainties associated with the occurrence of earthquake ground shaking and deformation, as represented by Intensity Measures; the forces, accelerations and deformations induced in building structures and nonstructural components, as represented by Engineering Demand Parameters; the damage incurred by these structural and nonstructural components as a result (Damage Measures); and the Decision Variables (losses) that result from this damage. As described by Baker and Cornell.[1] Under the PEER methodology, the annual probability of these exceeding losses of given value can be computed by the formula:

$$\lambda_{DV}\left(z\right)=\int\iiint G_{DV}(z,u)f_{DV|DM}\left(u,v\right)f_{DM|EDP}\left(v,y\right)f_{EDP|IM}(y,x)d\lambda m\left(x\right) \qquad (2\text{-}1)$$

Where:

λ_{DV} is the annual rate of exceeding a total loss, e.g. repair cost, number of casualties, etc,

G_{DV} is the Complimentary Cumulative Distribution function (CCDF) of DV conditioned on the vector of damage values of each element

$f_{DVE|DM}\left(u,v\right)$ is the probability density function of the vector of damage values of each element, given the vector of damage states of each element

$f_{DM|EDP}\left(v,y\right)$ is the probability density function of the vector of damage states, given the vector of engineering demand parameters

$f_{EDP|IM}\left(y,x\right)$ is the probability density function of the vector of engineering demand parameters, given the intensity measure

$d\lambda_{IM}\left(x\right)$ is the derivative of the annual rate of exceeding a given value of the intensity measure.

The ATC-58 project has adopted, adapted and simplified this methodology as explained in the following sections.

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[1] Baker, J.W., Cornell, A.C., Uncertainty Specification and Propagation for Loss Estimation Using FOSM Method, Pacific Earthquake Engineering Research Center, Sept. 2003

2.2 Terminology

Under the ATC-58 project, the following simplified terminology is used to represent the various terms in equation 2-1.:

Intensity is the amplitude of earthquake shaking or permanent ground deformation experienced at a building site

Demand – is the peak amplitude of one or more parameters that describe the response of a structure when subjected to ground motion of given intensity. Demands can include accelerations, velocities, displacements, story drifts, and forces and deformations in individual elements and components.

Damage State – is the condition of a building component or system following an earthquake

Loss is the consequence of earthquake-induced damage. Losses can include casualties, direct economic loss and downtime.

Casualty either a fatality or injury requiring hospitalization that results from building damage during an earthquake

Direct Economic Loss the cost of repairing damage sustained by a building, and in the extreme case of replacing a building that has been damaged beyond practical repair

Downtime the amount of time, following occurrence of an earthquake that a building cannot be occupied and used in its normal function, either because it is unsafe or because contractor activity to repair the building precludes its normal use.

2.3 ATC-58 Performance Assessment

Under the ATC-58 guidelines, three types of performance assessment can be performed. These are respectively, intensity-based performance assessment; scenario-based performance assessment; and time-based performance assessment.

Intensity-based assessments will project the conditional probability of losses (casualties, direct economic loss or downtime) exceeding various values, given that the building experiences ground shaking of a specified intensity. For this purpose, intensity is represented by a 5%-damped elastic acceleration response spectrum.

Scenario-based assessments will project the conditional probability of losses exceeding various values given that the building is subjected to ground shaking resulting from an earthquake of specific magnitude occurring on a given fault, or at a specified distance from the site. Time-based assessments will project the annual probability of exceedance for losses of various values considering all earthquakes that can occur and their individual probability of occurrence.

Performance assessments are expressed in the form of a complimentary cumulative probability distribution of the form illustrated in Figures 2-1, which shows the conditional probability of nonexceedance of downtime for a hypothetical building, expressed in days, given the occurrence either of a specific earthquake intensity or scenario. Similar distributions can be projected for direct economic losses, in dollars, and casualties. For time-based assessments, the vertical axis would be annual rather than conditional probability of exceedance.

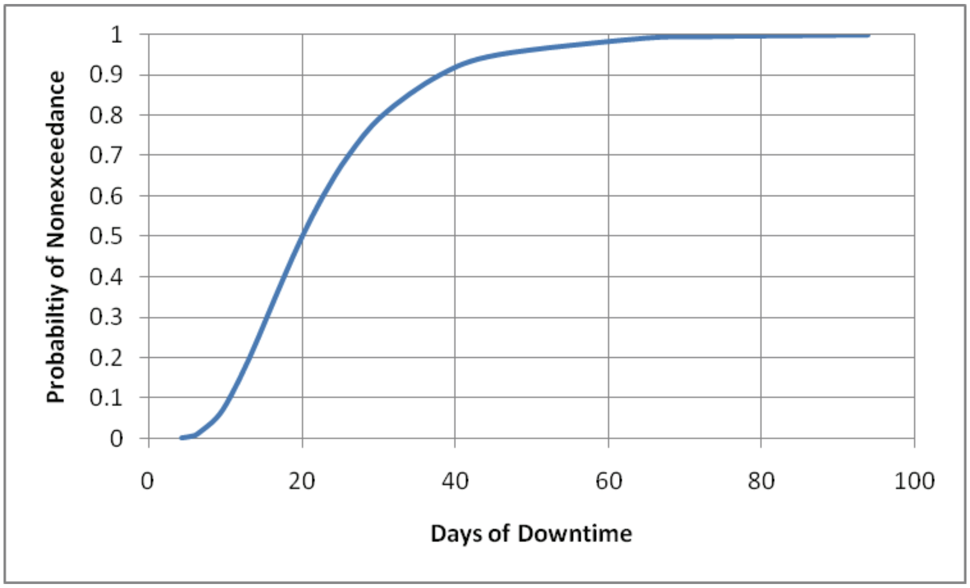

Figure 2-1 Complimentary cumulative probability distribution for downtime

It should be noted that although the general methodology allows consideration of all earthquake effects including ground shaking and permanent ground deformation, as implemented by the ATC-58 project, only ground shaking effects are considered. This implementation could be expanded in the future to address liquefaction, settlement landslide and other earthquake effects.

2.4 Implementation

Figure 2-2 presents the basic steps in the performance assessment methodology as implemented by the ATC-58 project. Each of these steps is described below.

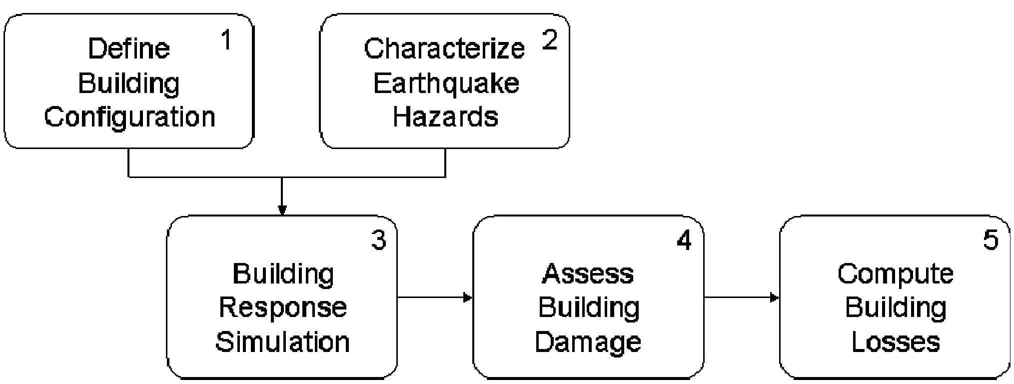

Figure 2-2 Steps in performance assessment

Step 1 - Define Building Configuration

Step 1 consists of defining the characteristics of the building being assessed. This includes categorization and identification of everything that comprises or occupies the building including the structural gravity and seismic force resisting systems; the architectural, mechanical and electrical components and systems; the tenant contents and occupants. Data that must be compiled includes:

- The quantity, value and location of each of these items within the building
- The types of earthquake damage that each can sustain
- The demand (force, acceleration, story drift, etc.) that best correlates with the onset of each damage state for each component
- A lognormal fragility functions consisting of the median value of demand at which each damage state is likely to initiate and a measure of the dispersion in the demand that may cause such damage to initiate
- A consequence function that relates the probable repair cost, downtime and casualty consequences associated with the damage state

For a given type of building component, data on the types of damage, the demand that produces this damage, and the consequence of this damage is collectively termed a fragility specification. The ATC-58 guidelines will include a database of default fragility specifications representing the types of building components most commonly found in buildings but will also define procedures to guide the development of additional fragility specifications, for those cases when the default specifications are inadequate to represent a particular building.

To facilitate the performance assessment computation process, components that have similar fragility, and which, are also located in a building such that they will experience the same demand during an earthquake are grouped together into collections called performance groups.

Step 2 – Characterize Earthquake Hazards

This step consists of representing the ground shaking for which the assessment is to be performed in a manner that can be used in structural analysis. Two types of structural analysis are considered in the ATC-58 guidelines: nonlinear response history analysis; and simplified linear static analysis. The ground motion representation used depends on the type of assessment that will be performed and the type of analysis.

For intensity-based assessments using the simplified linear static procedure, it is only necessary to define the spectral response acceleration at the fundamental period (in each direction) of building response. If nonlinear dynamic analysis is used, it is necessary to completely define the response spectrum that represents the intensity and also to select and scale a series of ground motion records that are compatible with this spectrum.

For scenario-based assessments, it is necessary to use one or more attenuation relationships to estimate the probable distribution of shaking intensity, given that the scenario occurs. Using the attenuation relationship(s) the median response spectrum is determined, together with a measure of the dispersion of the spectral response acceleration at the fundamental periods of the structure. For simplified analysis, this information is used directly. For nonlinear response history analysis, it is then necessary to select a suite of ground motions that represent the median spectrum as well as the dispersion in this spectrum.

For time-based assessment, it is necessary to determine a mean seismic hazard curve for the site, depicting the annual probability of exceedance of spectral response acceleration at the fundamental periods of building response. The hazard curve is divided into a series of intensity bands, ranging from low intensity having low probability of causing loss to the building, to high intensity, likely to cause complete building loss. The annual probability of occurrence of each intensity band is determined. Then, the median intensity within that band is used either to determine the spectral response acceleration at the fundamental period of building response for simplified analysis, or to select and scale suites of ground motion records for nonlinear dynamic analysis.

Step 3 Building Response Simulation

This step consists of performing structural analysis to derive a probabilistic representation of the distribution of demands as a function of ground motion intensity. For intensity-based assessment a single intensity is used. For scenario-based and time-based assessments, a range of intensities are considered.

For each intensity of motion, the engineer must perform either a simplified static analysis, together with an assessment of the yield properties of the structure, or a suite of nonlinear response history analyses. If simplified analysis is used, the computed drift at each story is used together with default dispersion coefficients to form a distribution of probable story drift and floor acceleration demand, given the intensity of motion. If nonlinear response history analysis is used, statistics on the distribution of demands from the suite of analyses are collected to form a joint lognormal probability distribution of demand, conditioned on the intensity of motion.

In addition to determining the probable distribution of demands at a given intensity of motion, if it is desired to assess casualties, the methodology requires determination of a collapse fragility for a building. The collapse fragility identifies the median intensity of motion and dispersion, associated with one or more collapse modes. Collapse modes could include a single story, e.g. weak first story collapse; a localized gravity framing system failure, e.g. punching of flat slabs at a column; or complete building sidesway failure. Each collapse mode must be identified as to the amount of building included in the collapse and a lognormal fragility function consisting of the median and dispersion values of intensity that cause this collapse mode.

Step 4 Assess Building Damage

For each intensity of motion, the demand distribution obtained in Step 3 is used to generate a large number of “realizations.” Each realization consists of one possible set of demands (peak story drifts, peak floor accelerations, etc) that could occur if the building experiences shaking of the particular intensity. This process of forming the realizations is performed using a Cholesky decomposition of the joint probability distribution and random number generation to determine the number of standard deviations above or below the median, represented by the demands in the particular realization.

For each realization, a determination is made as to the building damage state. First, using a random selection algorithm, and the collapse fragilities, a determination is made as to whether the building has collapsed for the particular realization and in which mode. If collapse is found not to occur in the particular realization, then the demands from the realization are used together with random selection schemes and the fragilities functions for each performance group to determine the damage state of each component in the building. Where some types of damage preclude the occurrence of other types, or where the damage to some components is dependent on the behavior of other components, this logic is considered in the determination of damage. Finally, for each realization, a compilation of all damage that has occurred at each level of the building is assembled. This process is repeated for each realization, and for each intensity.

Step 5 – Compute Building Losses

For each realization, described under the previous step, it is necessary to determine the losses in terms of repair costs, downtime and casualties. For each of these loss types, there are a series of consequence functions that relate the probability of incurring loss of given value, given the occurrence of a damage state. It is necessary to apply these consequence functions to the building damage state, using random selection schemes and also considering the total quantity of damage throughout the building. For each realization, this results in a single value of the repair cost, the downtime, and the number of casualties. For each of these loss types, the scenarios are ordered from lowest loss to highest loss. Then, the loss curves, such as that shown in Figure 2-1 above is assembled as a plot of the value of the loss for each realization against the percentage of the total set of realizations that have that loss or less.

3. Validation, Verification and Documentation

3.1 General

Quality assurance for a developmental program like the ATC-58 project entails three basic processes. The first of these is validation, the second verification, and the third, documentation. This Section briefly discusses the importance of each of these. Section 4 of this report indicates the specific steps taken to perform each of these functions.

3.2 Validation

For this project, validation is the process of assuring that the overall methodology and process employed, as described above, is capable of producing unbiased and correct, or at least reasonable, assessments of the median losses associated with a building's earthquake performance, and the uncertainty associated with these losses. To validate this methodology it is necessary to identify all possible sources of bias and uncertainty in the basic methodology, and to the extent possible, identify that bias' have not been incorporated and that uncertainties have been properly identified and accounted for. To validate the implementation of the methodology it is also necessary to explore each of the assumptions that have been made, for example, that fragilities are lognormally distributed, and determine if this is an appropriate, or at least reasonable assumption.

Validation will primarily be the responsibility of the Project Management Committee. The Project Management Committee will perform validation through a variety of means including:

1. Adopting the best available technologies as the basis for implementation. In this case, ATC-58 project is relying heavily on the performance assessment methodology developed by the Pacific Earthquake Engineering Research Center, which has been widely published and presented.

2. Retaining and using the best available talent in the field to participate in the development activities. The Project Management Committee accepts exercises primary responsibility for this through its function of review and approval of project participants.

3. Performing all project development work in accordance with carefully developed and considered work plans that have been reviewed and approved by the Project Management Committee.

4. A validation panel will develop a list of the key assumptions and implementation procedures adopted by the project. The PMC and Technical team leaders will review this list to provide assurance that the project team has adopted valid approaches in this regard.

5. Presenting the project implementation of this methodology, as it is developed to wide review, both by project team members and by others who are outside the project. Technical review activities include:

a. Project Management Committee review at quarterly PMC meetings and development team meetings

b. Invited expert review by outside specialists

c. Review and comment by project participants at regular intervals

d. Periodic workshops at which knowledgeable researchers and engineers are invited to review and comment on project progress.

e. Publication and presentation of the project products by team members at conferences and meetings for review and comment by the community.

3.3 Verification

Verification is a routine process associated with software development that is intended to assure that the intended algorithms have been properly implemented within the coding so that the intended mathematical operations are actually performed as intended.

Verification will include the following activities:

1. Default fragility functions will be reviewed by an expert panel to assure that the project procedures for fragility development have been correctly employed, and that uncertainties and biases have been appropriately characterized. A fragility quality rating will be applied to each fragility function. This team will document their findings in a report to the PMC.

2. The methodology and results of default building performance group templates will be subjected to review by an independent group of architects and construction cost estimators to ascertain that the performance group adequately represents building construction. This team will document their findings in a report to the PMC.

3. The consequence functions for downtime, direct economic loss and casualties will be subject to independent review by a panel of experts to assess the reasonableness of these functions. This team will document their findings in a report to the PMC.

4. During programming of PACT, the RMP team will perform hand evaluations of intermediate program results from particular routines including:

    a. Realization generation

    b. Fragility queries to determine damage states for a realization

    c. Consequence function queries to determine losses for a realization

5. The RMP team will perform tornado analyses using the software (Performance Assessment Computation Tool or PACT) to determine the extent to which changes in

data inputs affect the results of analyses and to assess whether this seems reasonable. Analyses will include:

a. Evaluation of the number of realizations necessary to obtain stability in assessments

b. Evaluation of the stability of assessments in general – that is, if identical sets of data are input, are essentially identical results obtained?

c. Evaluation of the effect of small changes in data on results – does addition or deletion of small value performance groups (or small changes in performance groups) result in negligible change in results?

d. Comparison of results for a single building using simplified analysis and nonlinear response history analysis – are the results within reasonable comparison?

e. Comparison of results for a single building using nonlinear response history analysis and different suites of ground motions – are the results within reasonable comparison?

f. Evaluation of results for "small-intensity" motion – Do the results seem reasonably small?

g. Evaluation of results for "extreme" motion – Do the results seem reasonably large?

6. A team will be appointed and charged with assembling data on a limited suite of instrumented buildings that have experienced shaking of varying intensities and for which the damage consequences are known. One possible source of this suite of buildings is the database assembled by the California Geologic Survey, Strong Motion Instrumentation Program. The team will be charged with running performance assessments of this suite of buildings, using the recorded ground motions (and potentially response data) as input, to determine the extent to which the methodology and PACT appear to provide unbiased and reasonable estimates. The results of this study will be documented and preserved.

3.4 Documentation

Documentation of the intended methodology and algorithms to be used is essential to a quality assurance effort. Until a procedure or methodology is documented, it is impossible to describe it sufficiently to allow its validation or verification of its correct programming. Further, documentation allows for future assessment of the methodology and implementation as well as improvement, by allowing others to understand what is being done, what the limitations are and where assumptions and judgment have necessarily been employed.

The documentation listed below will be generated for the ATC-58 project. All such documentation will be reviewed by the corresponding product development team and the Project Management Committee, prior to being published by ATC and/or FEMA.

1. Background Documents – A series of background reports documenting the basis for key procedures will be prepared and published by ATC. Background documents will include:

    a. Basis for the Simplified Analytical Procedure

    b. Basis for ground motion selection and scaling procedures

    c. Fragility function development. These will include the method used to develop the fragility, the basis of data, adjustments made and review comments and rating provided by the fragility review panel

    d. Casualty Model. This report will describe the sources of information and assumptions used in developing the casualty model contained in the guidelines and PACT

    e. Consequence Functions. This report will describe the consequence functions used for direct economic loss and downtime..

2. Guidelines – Within the body of the guidelines we will attempt to identify key assumptions and default data points that should receive further review/verification and perhaps improvement later. This may be done through sidebar or commentary like insets within the text.

3. Appendices – With appendices contained in the guidelines, fragility functions will be rated as to quality. Though the system for fragility rating has not yet been determined it will likely include ratings similar to: A – based on extensive test data, with well-defined conditions closely representing as-installed conditions in buildings; B- based on limited data or test conditions that deviate somewhat from as-installed conditions in buildings; C- based largely on expert judgment.