ATC 55: EVALUATION AND IMPROVEMENT OF INELASTIC SEISMIC ANALYSIS PROCEDURES

Phase II Work Plan

Objectives and Scope

The focus of Phase II will be the development of written guidelines for the application of improvements to inelastic analysis procedures. Key improvements are expected for the following:

a.) Estimating inelastic displacements when using nonlinear static procedures (NSP's)

There are currently two alternatives. FEMA 356 documents the Displacement Coefficient Method (DCM). The basis of this approach is the statistical analyses of the results of time histories of SDOF oscillators used to generate inelastic spectra or R-μ-T relationships. The results are used to formulate coefficients used to modify the response of a linear system. This basic approach is termed **displacement modification**. The development of improved procedures is outlined below under Task 3.

The other alternative is documented in ATC 40 as the Capacity Spectrum Method (CSM). This approach relies on **equivalent linearization** of the inelastic system utilizing both a period shift (decrease in stiffness) and equivalent viscous damping to represent hysteretic energy loss. These parameters are specific to each system. They are also a function of ductility and current methods require iteration for solution. The development of improved procedures is outlined below under Task 4.

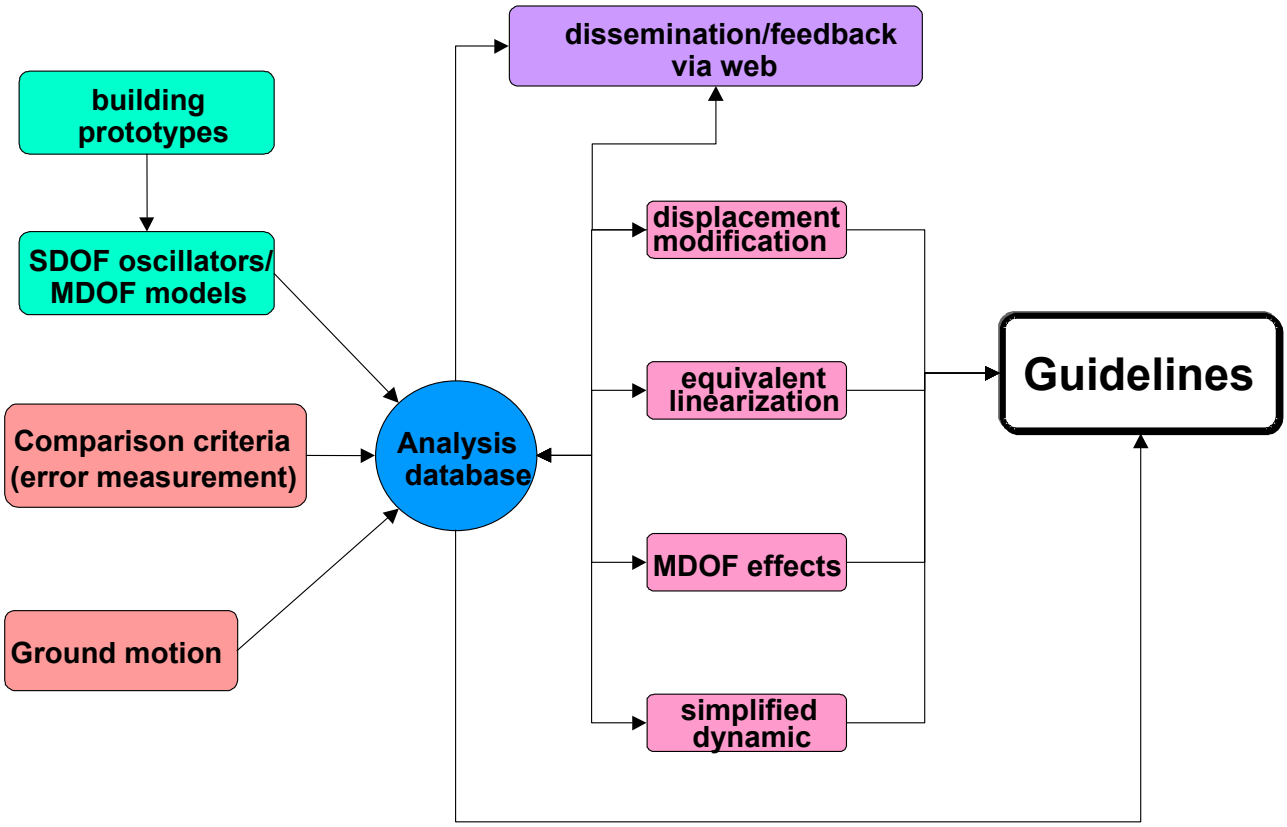
The results of the Phase I effort did not identify any fundamentally different alternatives. However, it seems clear that both methods of practical application (DCM and CSM) can be improved with modifications based on recent research on their underlying bases (displacement modification and equivalent linearization).

b) Multi-degree-of-freedom and higher mode effects

The current NSP's of both FEMA 356 and ATC 40 rely primarily on single-degree-of-freedom analysis of response. Both documents touch upon variations in load vectors or other attempts to recognize the potential effects of higher modes of vibration. The results from Phase I indicate that there may be potential improvements. First, several studies suggest that modification of the load vector during the pushover analysis to reflect changes in the vertical distribution of forces resulting from inelastic behavior can improve NSP results compared with actual MDOF analyses. Secondly, other studies appear to show that combining the results of several pushovers representative of different mode shapes for the same structure can lead to improved comparisons with actual MDOF analyses. The Phase II objective is to explore the possibility of modifying current application procedures based on these two general approaches. Extensive analyses or further research are not contemplated. The development of improved procedures is outlined below under Task 5.

c) Simplified dynamic analysis

Some practitioners have been using SDOF oscillators or simplified MDOF models to run time histories directly. Usually the oscillators or models are based on pushover analyses to some extent. This approach allows the user to run multiple records and determine dispersion and reliability directly. Also the effects of impulsive loading are included directly. Guidelines for the application of procedures for these types of simplified analyses are not yet available. It is not the objective of the Phase II effort to formulate detailed step-by-step prescriptions for these applications. However, it is apparent that some guidance and commentary can be assembled to assist the practitioner. The development of this material is outlined below under Task 6.



Analysis database

In order to develop and verify the proposed improvements, the Phase II scope will include the formulation of an **analysis database** (see Task 2). This will comprise a number of representative SDOF oscillators based on parametric variations (period, strength, hysteretic characteristics) of realistic prototypical buildings. The demand side will include time histories of varying characteristics (magnitude, distance, site conditions) and corresponding real and design-oriented spectra. These data will be used in conjunction with a comparison criteria to assess the relative accuracy of NSP's (as currently documented and as modified) to time history analyses. This information will be disseminated to interested parties via the web.

The primary project benefit of the ATC-55 Analysis Database is to provide a consistent platform for evaluating and comparing the results of various analysis procedures. This is important for the development of the anticipated improvements (see Tasks 3, 4, 5, & 6). Beyond the focus of the current project, however, the ATC-55 Analysis Database is expected to provide benefit to the performance based earthquake engineering community in the future. Different researchers can then use the same data to test and validate their work hopefully making future research results more directly comparable and compatible. Practitioners will find ground motions, prototypical buildings, hysteretic models, SDOF oscillators and other information they may use to tailor their own analysis and possibly compare results.

Focus Groups

The basic approach to the development of the envisioned improvements to inelastic analysis procedures is similar for each (see Tasks 3, 4, 5, & 6). The first step is to assemble the basic underlying research. Then an initial formulation of the propose improvement will be generated. This initial formulation will be subject to evaluation using the ATC-55 Analysis Database. The initial formulation and the results of the evaluation will be reviewed by a focus group comprised of ATC-55 project personnel and selected additional participants. The focus groups will conduct a workshop to discuss the initial formulation and analysis results. Based on the results of the workshops, the initial formulations will be revised and re-evaluated. Final changes will be subject to review by the focus groups. It is anticipated the focus groups will use email exchanges and discussions to supplement the workshops.

ATC will solicit interest in serving on the focus groups from the performanced-based earthquake engineering community. Researchers and practitioners with specialized experience and familiarity with the specific subject matter will selected to form four focus groups:

Displacement Modification Focus Group
Equivalent Linearization Focus Group
MDOF Effects Focus Group
Simplified Dynamic Analysis Focus Group

Guidelines

A final project document will present these improvements (see Task 7). The document will also address another important need identified in Phase I related to **practical guidance and education** for practitioners. The document will include background material on the fundamental bases of inelastic procedures and the inter-relationships among various alternatives. All procedures have limitations, and some may be better than others for specific circumstances. The document will highlight several important subjects that have been addressed extensively in the currently available guidelines. Examples include the inherent uncertainty and reliability of inelastic procedures and the effects of hysteretic characteristics (behavior modes) on estimates of inelastic displacements. A glossary and standardized nomenclature will mitigate current confusion related to semantics and inconsistent presentation of related materials.

Seminar

Upon completion of the guidelines a public seminar will be conducted by ATC. The seminar program will include a review of the development of the improved procedures. The application of the procedures will be illustrated with practical examples.

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
1.	**Project management and administration**	These are tasks performed by ATC staff for the overall management of the project including accounting, client contact, project records, arrangements for meetings, editorial review, etc. The effort of the Project Review Panel is included in this task. ATC will also continue to use the web site to provide information to interested parties and to gather comments and suggestions. Provide access through the web site. Receive comments and feedback. Phase I report on web Phase II work plan on web Solicit interest in Focus Groups Analysis database and THA/NSP(exist.) results Preliminary NSP(new) procedures and results Final NSP(new) procedures and results	Rojahn Mosby Mork

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
2.	**Analysis database**	The analysis database will be used to test current procedures and proposed improvements. It will also be published on the web for review and possible use by others.	Miranda
2.1	Formulate computer models	This task will culminate in a series of SDOF oscillators and selected MDOF examples representative of prototypical buildings likely to be encountered in practice. These models will cover a range prototypical values for three basic parameters: strength, period, and hysteretic type (behavior mode, loop shape).	
2.1.1	Identify realistic prototypes	Which structural types are of most interest (e.g. shear wall, moment frame, braced frame)?	PMC Miranda Aschheim
2.1.2	Develop hysteretic types	What types of behavior are associated with prototype buildings (e.g. elasto-plastic, Takeda, rocking, strength-degrading)?	PMC Miranda Aschheim
2.1.3	Establish parametric ranges for strength and period		PMC Miranda Aschheim
2.1.4	Specify oscillators in detail.	Develop computer models elasto-plastic, Takeda, rocking, strength-degrading) for analysis.	Miranda Aschheim
2.1.5	Select MDOF examples	This will result in a relatively few models of prototypes that will be used to illustrate techniques for evaluating MDOF effects. They will likely be based upon examples in existing published research.	Aschheim Miranda
2.2	Establish ground motion input.	These basic demand specifications will be used to compare the relative accuracy of the existing procedures and the proposed improvements. They will consist of both time histories and related spectra.	Iwan Miranda Aschheim
2.3	Establish criteria for relative comparison of procedures (error measures).	This criteria will specify how the efficacy of the NSP procedures in predicting the maximum obtained displacements from THA of the oscillators. This should be coordinated with the ground motion specification. Considerations include accuracy, dispersion, and reliability.	Iwan Miranda Aschheim
2.4	Conduct time history analyses	These analyses will serve as the baselines for comparison of the relative accuracy of the simplified procedures.	Miranda
2.4.1	SDOF oscillators		Miranda
2.4.2	MDOF examples		Aschheim

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
2.5	Generate NSP approximation for global displacement using displacement modification and compare to THA.		Miranda
2.5.1	current procedure for displacement modification	Using *FEMA 356* as it currently reads, calculate inelastic displacements and compare to THA results for all oscillators.	
2.5.2	proposed improvements for displacement modification	Using the proposed modification to *FEMA 356* per Product 3.2, calculate inelastic displacements and compare to THA results for all oscillators.	
2.5.3	final improvements for displacement modification	Using the revised procedures of Product 3.3, calculate inelastic displacements and compare to THA results for all oscillators.	
2.6	Generate NSP approximation for global displacement using equivalent linearization and compare to THA:		Miranda Iwan
2.6.1	current procedure for equivalent linearization	Using *ATC 40* as it currently reads, calculate inelastic displacements and compare to THA results for all oscillators.	
2.6.2	proposed improvements for equivalent linearization	Using the proposed modification to *ATC 40* per Product 4.2, calculate inelastic displacements and compare to THA results for all oscillators.	
2.6.3	final improvements for equivalent linearization	Using the revised procedures of Product 4.3, calculate inelastic displacements and compare to THA results for all oscillators.	
2.7	Compare NSP approximations for story shears and drifts to THA for MDOF models:		Aschheim Miranda
2.7.1	current procedures for MDOF effects	Using *FEMA 356* and *ATC 40* as they currently reads, calculate story shears and drifts and compare to THA results for all MDOF models.	
2.7.2	proposed improvements for MDOF effects	Using the proposed modifications per Product 5.2, calculate inelastic displacements and compare to THA results for all oscillators.	
2.7.3	final improvements for MDOF effects	Using the revised procedures of Product 5.3, calculate inelastic displacements and compare to THA results for all oscillators.	

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
3.	**Improve procedures for displacement modification**	Using *FEMA 356* as a starting point, develop improved procedures based on currently available information and the results of the analysis of Task 2.	Miranda
3.1	Identify and assemble underlying research	This should be restricted to that work which is directly applicable to Task 3.2.	
3.2	Formulate proposed improvements	Determine a basic framework for the improvements to include consideration of potential changes in coefficients C_1, C_2, and C_3. Propose initial changes for evaluation in Task 2.5.2	
3.3	Displacement Modification Focus Group review	Focus Group will review Products 2.5.1, 2.5.2, and 3.2 in preparation for a one day meeting for discussion and refinement of the proposed improvements.	Miranda Holmes Hamburger
3.4	Finalize improved procedures	Based on the Work Group meeting develop revised improvements for evaluation in Task 2.5.3. Finalize improvements based on results.	

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
4.	**Improve procedures for equivalent linearization**		Iwan
4.1	Identify and assemble underlying research	This should be restricted to that work which is directly applicable to Task 4.2.	
4.2	Formulate proposed improvements	Determine a basic framework for the improvements to include consideration of potential changes in effective period and damping, etc. Propose initial changes for evaluation in Task 2.6.2	
4.3	Equivalent Linearization Focus Group review	Focus Group will review Products 2.6.1, 2.6.2, and 4.2 in preparation for a one day meeting for discussion and refinement of the proposed improvements.	Iwan Holmes Hamburger
4.4	Finalize improved procedures	Based on the Focus Group meeting develop revised improvements for evaluation in Task 2.6.3. Finalize improvements based on results.	

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
5.	**Improve procedures for MDOF effects**	Using *FEMA 356* and *ATC 40* as a starting points, develop improved procedures based on currently available information and the results of the analysis of Task 2.	Aschheim
5.1	Identify and assemble underlying research	This should be restricted to that work which is directly applicable to Task 5.2.	
5.2	Formulate proposed improvements	Determine changes to specified loading criteria, displaced shape vector, or modal combinations for improved treatment of MDOF effects. Propose initial changes for evaluation in Task 2.7.2	
5.3	MDOF Focus Group review	Focus Group will review Products 2.7.1, 2.7.2, and 5.2 in preparation for a one day meeting for discussion and refinement of the proposed improvements.	
5.4	Finalize improved procedures	Based on the Focus Group meeting develop revised improvements for evaluation in Task 2.7.3. Finalize improvements based on results.	

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
6.	**Simplified dynamic analysis**	This will introduce the prospect of dynamic analyses directly on both SDOF and simplified MDOF("sticks" and/or "fishbones"). It is expected that these approaches will be less prescriptive than the NSP's from an application standpoint. The purpose is offer guidance to those interested in more sophisticated analyses and to look ahead to what may be coming in the future. Considerations include: How to develop an equivalent oscillator Dealing with mixed hysteretic types Ground motion	Moehle
6.1	Identify and assemble underlying research	This should be restricted to that work which is directly applicable to Task 6.2.	
6.2	Formulate a basic approach to dynamic analysis using simplified SDOF and MDOF models	Describe process of using pushover results to convert to equivalent SDOF/MDOF models. Discuss selection of time histories for analysis and probabilistic interpretation of results. Include examples possibly taken from Task 2.	
6.3	Simplified Dynamic Analysis Focus Group review	Focus Group will review Products 2.5.1, 2.5.2, and 3.2 in preparation for a one day meeting for discussion and refinement of the proposed procedures.	Moehle Holmes Hamburger
6.4	Finalize improved procedures	Based on the Focus Group meeting develop revised procedures and examples.	

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
7.	**Guidelines development**		Comartin
7.1	Introduction and summary	This section will introduce the project and provide background data. The objectives of the project will be reviewed. An overview of the work done on the project will be included.	Comartin
7.2	Summary of inelastic analysis procedures	The section will provide the reader with a comprehensive summary of inelastic procedures from a general point of view.	Comartin
7.3	Nonlinear static procedures	This is an extension of the previous section devoted to NSP's. It will focus on aspects of pushover analyses that are common to both displacement modification and equivalent linearization (e.g. generation of load-deformation curves, spectral versus global ordinates, load vectors, MDOF effects). It will also provide an accessible discussion of the basic differences between displacement modification and equivalent linearization.	Comartin Iwan Miranda
7.4	Improved procedures for displacement modification	This will be the culmination of Task 2.1. The section will provide suggested modifications/additions/deletions to the provisions of FEMA 356 to update the coefficient method. These will also be applicable within the context of ATC 40. The discussion will include appropriate commentary to provide insight and guidance for the user.	Comartin Miranda
7.5	Improved procedures for equivalent linearization	This will be the culmination of Task 2.2. The section will provide suggested modifications/additions/deletions to the provisions of ATC40 to update the capacity spectrum method. These will also be applicable within the context of FEMA 356. The discussion will include appropriate commentary to provide insight and guidance for the user.	Comartin Iwan
7.6	Multi-degree of freedom effects in NSP's	This will be the culmination of Task 2.3. The section will provide suggested modifications/additions/deletions to both the current provisions of FEMA 356 and ATC40 to update the treatment of higher mode effects. The discussion will include appropriate commentary to provide insight and guidance for the user.	Comartin Aschheim
7.7	Simplified dynamic analysis	This section will introduce the use of SDOF oscillators and simplified MDOF	Comartin Moehle

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
		models for simplified dynamic analyses developed as Task 8. These procedures may be less prescriptive than those for the NSP modifications.	
7.8	References	All references will be consolidated into this section.	Comartin Aschheim Iwan Miranda Moehle
7.9	Glossary and nomenclature	This will be an attempt to simplify and clarify commonly used and misused terms and notations.	Comartin
7.10	Appendix on analyses	This appendix will document the analysis work done for the project. It will include: a) Prototype buildings b) SDOF oscillators and MDOF models c) Ground motions d) Comparison criteria e) Results	Miranda Comartin

ATC 55 Phase II Tasks

No.	Task	Description	Personnel
8.	**Project seminar**	The completed guidelines will be presented at a public seminar. The development of the improved procedures will be reviewed. Application examples will illustrate the use of the procedures.	All