Phase I Practice Summary

1. Methodology

The state of practice inquiry sought information about the use of inelastic analysis procedures for a broad sample of building applications from different practicing structural engineering firms. The ultimate goal of the inquiry is to obtain a representative picture of the following, with respect to the current state of application of inelastic procedures:

- Types of buildings and structural systems for which the procedures are used;
- Types of procedures used;
- Types of software used for analysis, if any;
- Engineers' thoughts about the implementation of procedures, including problems encountered.

This chapter summarizes the information obtained from practicing engineers who responded to the state of practice inquiry, and the relation of their responses to the issues identified by the Working Group.

The respondents' information was solicited through three primary means. First, the existence of the ATC website was made known through e-mail and professional newsletters. The website contained a "Summary of Practice Building Data" questionnaire form to be filled out by each respondent for each building example to be submitted. Second, the Working Group appealed directly by e-mail to a number of engineering firms, some of whom were known to have completed applications of inelastic procedures. Lastly, the e-mail requests were followed with personal phone calls by the Working Group to emphasize the importance of the requested information. The above solicitations took place over the period from March, 2001 to the time of this writing. At this time, information on over 70 examples have been obtained from 32 respondents in 14 different structural engineering offices, and information continues to be submitted. The summary data sheets are contained in the attached "Master summary of Building Data" table, followed by the "Reference List of Comments" table of information provided by respondents.

The practice inquiry was not posed to the respondents in the context of addressing the specific issues identified by the Working Group, since the "major" issues had not been distilled at the initiation of the inquiry. However, the information received from the respondents was ultimately finally related to the issues by the Working Group. The relationship of the respondents information to the issues is discussed herein.

2. Input from Practicing Engineers

2.1 Types of Buildings and Structural Systems

Types of example buildings are designated by the following categories, for purposes of identifying percentages relative to the total number of examples submitted:

- Ownership type (private or institutional)
- Purpose of analysis (evaluation, upgrade, or new)
- Year of construction
- Height (number of stories)
- Floor area
- Seismic system(s)
- Gravity system(s)
- Foundation system(s)

The percentages of the total number of buildings for each category are listed below:

<u>Ownership Type</u>

Private:	36%
Institutional	59%
Test specimen	5%

<u>Purpose of Analysis</u>

Evaluation only	32%
Upgrade or Evaluation/Upgrade	45%
New	23%

<u>Year of Construction</u>

Earliest	1916
Latest	2001
Mean	1966
Median	1967

<u>Height (stories)</u>

1-2	14%
3-6	39%
7-11	27%
12+	20%

Floor Area (sf)

< 10,000	3%
10,000 – 50,000	13%
50,000 – 100,000	20%
100,000-200,000	61%
200,000-500,000	1%
>500,000	1%

Seismic System(s)	Number	Fraction of Total
Concrete shear walls	25	35%
Concrete moment frame	10	14%
Concrete frame/brick infill	6	8%
Steel CBF	3	4%
Steel EBF	4	6%
Steel BRBF(unbonded brace)	2	3%
Steel moment frame	7	10%
Steel frame/brick infill	3	4%
Steel truss moment frame	1	1%
Plywood or OSB shear walls	3	5%
Reinforced masonry walls	1	1%
Passive damped frame	1	1%
Other	5	8%

Gravity System(s)	Number	Fraction of Total
Concrete columns/beams and/or slab	29	40%
Concrete bearing walls	2	3%
Wood frame	5	7%
Steel frame /wood infill	3	4%
Steel frame/concrete slab	26	36%
Other	6	10%

Foundation System(s)	Number	Fraction of Total
Spread Footings	41	58%
Mat	9	13%
Piles	15	20%

Drilled Piers	4	6%
Unknown/Other	2	3%

Types of Procedures Used

The procedures used by the respondents included the following:

- FEMA 273 (coefficient method)
- Nonlinear time history analysis (NLTH)
- FEMA 351/SAC method
- ATC 40 (capacity spectrum)
- Unspecified nonlinear static

A number of the respondents used two or more procedures for the same building example. The number of primary uses of each procedure (i.e., not accounting for secondary procedures), and the respective percentage of the total number of buildings are listed below:

Primary Procedure	Number
FEMA 273 (coefficient method)	29
Nonlinear time history analysis (NLTH)	12
FEMA 351/SAC method	3
ATC 40 (capacity spectrum)	10
Unspecified nonlinear static	16
Multiple of above procedures	8

The heading "Unspecified nonlinear static" indicates entries such as "NSP," "CSM," and "Equal Displacement." It was noted that most such entries were associated with analyses that were implemented prior to the publication of ATC 40 and FEMA 273. Several examples cited the use of the Miranda-Bertero procedure, and one example cited the Army TM-5-809-10-1 document.

2.2 Types of Software Used

With one exception, the inelastic procedures were implemented with the aid of computer analysis software. The following table lists the programs used, the number of listings of each program name, and the ratio of listings of usage of a given program relative to the total number of program usage listings.

Program Name	Number of Listings	Fraction of Listings
ABAQUS	1	1%
ANSYS	3	4%
CASHEW / RUAUMOKO	3	4%
(Custom software)	6	8%
DRAIN 2D	9	11%
DRAIN 2DX	8	10%
ETABS	4	5%
FEM-I	2	3%
FEM-II	1	1%
SAP 90	6	8%
SAP 2000	31	39%
Other	5	1%
Total Listings	79	

Several examples utilized multiple linear elastic analyses with sequential stiffness modification to represent progressive yielding and even degradation. These applications utilized extensive spreadsheet-type bookkeeping to sum member forces and check member demands against capacities from one analysis to the next.

2.3 Implementation of Procedures

A total of 79 comments were submitted relating to the implementation of the inelastic procedures. All of the comments are listed in the attached "Reference List of Comments" table. A synopsis of how the respondents comments reflected on major issues follows:

Relative Accuracy of Procedures

The majority of the comments submitted were related to this issue. Engineers' preoccupation with the topic of relative accuracy was indicated by the techniques used, such as variation of parameters (or "bounding"), by comments about the sensitivity of procedures to various assumptions, and by the implementation of comparative analyses using multiple procedures for the same building. Interestingly, the potentially significant variation of ground motion parameters was not mentioned in any of the practitioners' comments, although one respondent expressed doubt in the validity of using a static procedure to represent the effect of ground motion at a near-field location, due to the likely occurrence of high velocity pulses. Three of the example buildings were full-scale test specimens of wood buildings that were shaken on a simulator and evaluated using a NLTH procedure, for the purpose of research and comparison. Several of the respondents commented on the difficulty of reasonably accounting for cyclic degradation and P-delta effects with existing procedures and/or software. Also, difficulty in establishing a suitable target displacement or ultimate drift was mentioned in two examples.

Fundamental Bases and Relationships

It is evident that some respondents question the theoretical correctness of procedures to determine the target displacement. One respondent wrote "FEMA 273 shear strain ratios [were] exceeded in local areas – deemed not to be hazardous." Another wrote "Immediate Occupancy provisions [of FEMA 273] are too conservative." A third wrote "Analysis was straightforward. Determination of target displacement was problematic."

There were several comments regarding the complexity of the procedures. For example, one respondent wrote "The most troublesome problem in implementing the FEMA [273] procedures was developing nonlinear hinge properties(strength and ductility)." Another wrote: "The shear capacity of the concrete columns was difficult to evaluate by the FEMA 273 methods (Eq. 6-4) due to constantly changing parameters." A third wrote: "Convergence was difficult to achieve even for a relatively simple model and depended greatly on the method of solution used."

Several respondents commented during verbal discussions that the established analyses procedures did not allow the evaluation of behavior in the range of severe damage prior to collapse, such as damage to many structures observed in post-earthquake reconnaissance.

This topic of fundamental bases and relationships is related to those of relative accuracy of procedures and behavior mode effects.

Behavior Mode Effects

Several respondents indicated that the results of inelastic procedures are very sensitive to assumptions regarding such parameters as initial stiffness, and pushover loading profile. There is also recognition among respondents that the dynamic and MDOF effects that would be captured in a NLTH procedure could be quite different from the results of a nonlinear static procedure. Several respondents attempted to account for dynamic behavior, yielding, and MDOF effects by such techniques as adapting pushover loading profiles and use of simplified dynamic analysis.

One respondent discussed the inability of static procedures to represent the response of structures to near-field earthquake pulse-type motions.

Two other respondents collaborated in a comparison of the capacity spectrum approach for a single degree of freedom system with NLTH analyses. They identified that the differences in results between the two methods could be largely explained by the dynamic response of the structure to the predominant velocity pulses in the time history records. They developed a simplified technique to calculate the SDOF dynamic displacement response for a single velocity pulse. They applied this technique to several structures, evaluating the response of each structure to various pulses for site-specific ground motion records.

One respondent questioned the validity of static procedures for high-rise buildings that would experience significant higher mode components in their response.

MDOF/Inelastic Mechanism Effects

There seems to be a lack of understanding among practitioners about how to represent MDOF effects for static procedures. Only one respondent commented about the sensitivity of the static solution to such parameters as initial period and pushover profile. Another used an adaptive load pattern based on modal response at each significant step in the analysis process. A third simply assumed that all stories experienced equal drift.

Practical Guidance and Education

Respondents provided feedback (either in writing, verbally, or implicitly) about the following topics or questions related to the issue of practical guidance and education:

- *The various methods lead to different results. Why?*

  It is evident that practicing engineers do not necessarily know why the various NSP methods result in different answers, or why the answers may differ significantly from those resulting from the NLTH method. Consequently, engineers may lack a way to answer the next item:

- *Which method is the most effective for a given project?*

  There is a general lack of understanding about how to select a method. In numerous cases, the methods had been dictated by the owner/client. For instance, FEMA 273 is quickly being adopted as the governing guideline by government agencies and istherefore required for evaluations and design of government-funded retrofits.

- *Certain guidelines or evaluation techniques require an impractical expense of effort.*

  For example, some engineers chose to adopt an approach using sequential elastic analyses to developing a "backbone" resistance curve for their pushover analysis, wherein a cumbersome amount of "bookkeeping" was required to keep track of individual member stresses, and to compare these stresses with estimated stress or strain capacities as they changed the model to simulate yielding or degradation. As another example, a respondent commented indicated that the use of FEMA 273 to calculate the shear capacity of concrete columns (Equation 6-4) was difficult due to constantly changing parameters. A third respondent, using FEMA 273 and SAP 2000, implied that there were an excessive number of load cases to cover.

- *What is the most efficient way to compute results for a given method?*

  It is evident that practicing engineers have searched for efficient ways to handle the large amount of computational effort required for nonlinear analysis. One respondent who was clearly discouraged by the NSP process indicated that convergence was difficult to achieve even for a relatively simple model and depended greatly on the method of solution used.

- *More effective software tools are needed.*

  The software programs that are currently being used by practicing engineers for inelastic analysis are sometimes difficult to use, or do not allow the user to model important aspects of the structure, such as degradation.

Other topics related to practical guidance and education include the following:

- Clients who require these evaluations need to be educated about effort and fees required. Normally, this information comes from the engineer. However, without sufficient experience, the engineer would not be able to accurately estimate the required effort. This relates to the next topic:

- Some practicing engineers have embraced these methods as an improvement. Others have avoided them as requiring a steep learning curve and more effort, with an uncertain outcome. The methods are therefore more risky for the owner as well as the engineer.