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PRESENT AND FUTURE IN RC BUILDING ANALYSIS

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SUMMARY

Strategies to rationally exploit low-cost automated analysis in design of new and maintenance of existing constructed facilities are discussed.

INTRODUCTION

General Since the 8WCEE in 1984, the revolution in microcomputer hardware and software has brought low-cost automated analysis within reach of the practicing engineer. While some design documents such as the ACI 318 have not yet incorporated automated analysis in their provisions, design documents that do may not be exploiting this capability rationally. For example, the 1985 revision to SEAOC and 1985 UBC require the designer to establish the demands of "irregular" systems based on the dynamic analyses of a mathematical model representing the "spatial distribution of the mass and stiffness of the structure". The writer is concerned that such provisions may be easily misconstrued to imply confidence in the results of automated analysis.

A distinctly different application of analysis which has recently gained significance is in evaluating existing buildings. Pertinent documents such as the NEHRP recommendations or ATC-14 incorporate automated analysis for this purpose, however, they do not emphasize any distinction between analysis for design of new vs. evaluation of existing facilities.

Objective The objective of this paper is to discuss how automated analysis may be rationally exploited in the two distinct types of application by practicing engineers: (a) Design and construction of new; and, (b) evaluation, maintenance and upgrading of existing facilities.

DESIGN ANALYSIS

The Reliability in Analysis of Linearized Models U.S. building codes prescribe linear analysis to check serviceability and to establish member strength demands in design. Micro-computer software such as SUPER-ETABS (Ref. 10) and SAP-80 (Ref. 9) facilitate linear analysis of 3D models of complete building-foundations mainly by idealizing in-plane diaphragm stiffness as infinite.

Dynamic tests of prototype buildings have been carried out to test the validity of linearized modeling of buildings in general, and validity of the 3D modeling idealizations incorporated in ETABS and SAP-80 in particular (Ref. 11). It is important to note that these tests were carried out on buildings which did not have significant mass or stiffness discontinuities. Moreover these test buildings had plan symmetries and layouts with desirable torsional attributes. The studies indicated that the measured GLOBAL frequency, mode shape and flexibility characteristics of the buildings could be reasonably simulated by the models incorporated in the computer analyses, provided that the flexibilities at the foundation level were incorporated.

It has not been possible in field tests to evaluate whether the 3D analytical models simulated local responses such as interstory drifts and member forces and distortions as reliably as the global responses. Recent experiences with a 1/5-scale symmetric and bare 7-story RC frame-wall model indicated that while the global flexibilities could be simulated reasonably by a linearized analytical model, local forces and distortions measured at the serviceability limit states were over 200% apart from their analytical counterparts (Ref. 1).

The local responses could not be reliably simulated due to the inability to consistently linearize different types of nonlinear responses exhibited by the governing elements within the structure (Ref. 5). For example, the axial-flexural and shear responses of walls exhibited different levels and types of nonlinearity. Some of the mechanisms which were observed to influence the nonlinear local responses of the structure were not anticipated before measurements in the laboratory. For example, changes in the ambient conditions in the laboratory were observed to lead to responses which were comparable in magnitude to those caused by gravity and other serviceability level loads. The residual forces which accumulated in the elements during the so-called "elastic" stage were also observed to be significant.

Noting that "unknown-unknown" phenomena cannot be studied or simulated let alone predicted, it is possible to assert that the local demands of an actual building-foundation-soil system, particularly if it is irregular, cannot be predicted with any confidence. This will be true irrespective of the sophistication of the model and its analyses, i.e. whether hand analyses of subassemblages isolated from the structure or finite-element analysis of 3D models of the complete structure are conducted.

Fortunately, adequate performance of a design is not necessarily dependent on an accurate prediction of the local distortion and force demands which will occur in the facility after its construction. The performance will be influenced by the selection of systems and materials, by the quality of the proportioning, design and detailing efforts as well as the quality and effectiveness of construction, inspection and maintenance. If time-tested conceptual principles are followed in design, construction and maintenance, the existing knowledge-base regarding the past performance of RC building-foundation systems on firm soil assures adequate performance even under potentially damaging seismic events (Ref. 2).

Similarly, successful seismic performance of an "irregular" building-foundation system cannot be ascertained even if its demands may be established by refined analyses during the design stage. The current UBC provision which regulates the design of such systems based on their 3D dynamic analysis should be revised as recommended in the following.

<u>The Reliability in Non-Linear Analyses</u> Research on non-linear analysis of RC buildings has been in progress since the 1960's. It has been possible to simulate global dynamic responses of small-scale idealized models as long as their responses were governed by localized flexural yielding. Dynamic time-history responses of a recently tested 1/5-scale 7-story building model, however, could not be successfully simulated (Ref. 7). The mechanisms which

governed the time-responses of this medium-scale replica model, in spite of the idealized architecture and uni-directional excitation, were discovered to be more complex than can be reliably simulated by the typical modeling procedures and existing non-linear analysis tools.

Furthermore, sensitivity studies indicate that local response maxima obtained by time-history analysis may be significantly affected by slight variations in the analytical model, excitation and the numerical features of the analysis (Ref. 3). It is possible to assert that their low reliability/expense payoff ratios do not justify nonlinear time-history analyses of complex analytical models in design or evaluation applications. On the other hand, 3D static collapse analysis of buildings has been identified as a nonlinear analysis procedure with the greatest payoff potential in design or evaluation applications (Ref. 5).

Recommended Analysis Strategy In Design In view of the lack of reliability in predicted local responses of buildings by linearized or nonlinear models, analysis in design can only be approached within a sensitivity study context. The objective in design analysis is to facilitate a design with desirable seismic attributes and not to predict response. The automated analysis capability available to engineers is especially suitable for this purpose and should not be viewed as a means to DETERMINE ABSOLUTE DESIGN DEMANDS. Building codes should emphasize the lack of reliability in analytically predicted design demands and regulate seismic design of "irregular" buildings more effectively than just requiring their 3D analyses.

For example, an eigenvalue analysis of a 3D analytical model would reveal invaluable insight into the torsional response characteristics of the building-foundation. A strong participation of torsion in the translational mode shapes would help reveal a layout having undesirable torsional attributes (Ref. 11). Similarly, comparing the mode shapes to those of a uniform beam, or checking for abrupt changes in interstory drifts may reveal undesirable stiffness and/or mass distributions. Hence dynamic and static sensitivity analyses would be invaluable in identifying undesirable systems, in optimizing the plan and elevation layouts and in proportioning a selected configuration. To establish demand envelopes, a series of sensitivity analyses incorporating the possible extremes of element, joint and soil-foundation stiffnesses may be carried out with the currently available automated analysis capabilities. Such an analysis capability would not have been available to most designers before the advent of micro-computers.

The use of nonlinear analysis in design would be meaningful if 3D static collapse analyses are carried out. Incomplete mechanisms would indicate an undesirable distribution of axial-flexural resistances. If mechanisms such as shear failure or instability are modeled reliably, it may even be possible to diagnose possible undesirable failure modes. Naturally, these purposes cannot be served unless the collapse analyses are carried out within the context of a carefully planned sensitivity study.

ANALYSIS IN EVALUATION

Differences Between Design and Evaluation Analyses The objective of analysis in evaluating an existing facility is entirely different from that in new design. The existing supplies of a facility influenced by accumulated damage and deterioration due to aging, previous overloads or seismic events have to be reliably predicted in evaluation. Satisfactory seismic performance of a facility being designed with conceptual principles would not be affected by the lack of reliability in its design analyses. In evaluating a constructed facility with undesirable seismic attributes and accumulated damage, however, there is a definite need to estimate existing stiffness, strength and energy dissipation supplies with reasonable confidence. Not only estimates of global supplies, but, more importantly, estimates of the distribution of supplies at the critical regions will also be required. Since a knowledge base which has been time-tested by adequate statistical data does not yet exist in building evaluation and upgrading, it may not be possible to arrive at a rational and successful solution to these problems without reliable analytical prediction of the supplies.

The reliability demanded of analysis becomes exceptionally high in upgrade design. Since most upgrade applications involve a new structural system constructed within or around an existing building-foundation-soil, global as well as regional stiffness, strength, deformability and energy dissipation characteristics of the existing facility would have to be established with a high degree of confidence to insure compatibility with the new system. This cannot be accomplished by following the same modeling and analysis procedures which are used in designing new facilities.

Structural Identification For Evaluation To determine the supplies of an existing facility and their distribution with the high level of confidence needed in evaluation, its analytical modeling should be carried out within the context of "structural identification" (Ref. 8). It has been possible to identify the global characteristics of linearized models of a number of building-foundation-soil systems (Ref. 11). Unfortunately, it has not been possible to identify the local response characteristics of an existing aged building-foundation-soil.

Recently, an identification methodology which permitted regional identification of civil-structures by measuring their impact induced transient excitations has been developed (Ref. 4). In this approach, the structure is conceptually divided into sub-structures and analytical models of these sub-structures are developed including their stiffness and inertia continuity with the parent structure. Impacts are used to excite each substructure locally. Each is individually identified including its continuity parameters.

This methodology, while still in the developmental stage, shows significant promise for practical identification of the critical regions. First a complex structure is simplified into smaller regions which are easier to perceive and model, secondly the sub-structures may be excited practically with local impacts. Research in collaboration with the "Structural Dynamics Research Laboratory" is in progress at the "Infrastructure Research Institute" of the University of Cincinnati to further develop this identification methodology and implement it to buildings as well as bridges.

Naturally, identifying a linearized model of a building-foundation-soil does not directly permit the estimation of its supplies of strength, deformability and energy dissipation at the advanced limit states. However, by helping to improve the analytical perception of the facility and by quantifying its existing mechanical characteristics, a reliable starting point for non-linear analyses is obtained. 3D static collapse analyses of the building may then follow to project the damageability and failure limit state supplies of the structure (Ref. 6).

In certain cases, information gained during regional identification may be used to design, fabricate and test scaled subassembly models to experimentally study the damageability and failure limit state response characteristics of the critical regions. If similitude with the parent structure may be maintained by the help of regional identification, such experimentation may be invaluable in identifying the advanced limit state response parameters of the nonlinear model with reasonable confidence.

CONCLUSIONS

A desirable seismic performance of an "irregular" building-foundation-soil cannot be ascertained even if the design is based on demands predicted by refined analyses of 3D models. In view of the lack of reliability in predicted local responses of buildings by linearized or nonlinear models, irrespective of the modeling effort and analysis tools, design analysis should be approached within a sensitivity study context. The low-cost automated analysis capability now available to practicing engineers is especially suited for this. Building codes should emphasize the lack of confidence in analytically predicted design demands and regulate seismic design of "irregular" buildings more effectively than just requiring their 3D analyses.

A low reliability/expense ratio does not justify nonlinear time-history analyses of complex analytical models in design or evaluation applications. 3D static collapse analysis of buildings is the nonlinear analysis procedure with the greatest payoff potential in building design or evaluation. Research is needed to develop microcomputer software which will permit practical 3D collapse analysis of buildings. Nonlinear modeling of complete RC building-foundation-soil systems requires experience which is possessed by very few engineers. Therefore, knowledge-engineering should be incorporated in nonlinear modeling and analysis. Any general-purpose nonlinear collapse analysis software should interact with expert-system software to facilitate rational utilization by design engineers.

Analysis should be approached in existing facility evaluation in a manner entirely different from that in new design. The accumulated damage and deterioration due to aging, previous overloads or seismic events would have to be incorporated in analysis. Since a knowledge base which has been time-tested by statistical data does not yet exist in building evaluation and upgrading, reliable analytical prediction is the only way to ascertain reliable and optimum solutions in evaluation and upgrade design.

Practical and reliable global and regional structural identification is needed to complement analysis in order to determine the supplies of an existing facility and their distribution with the level of confidence necessary in evaluation and upgrading applications. Intensive research is needed to develop the tools of such a comprehensive identification methodology since in the future, evaluation, maintenance and upgrading of existing constructed facilities will have to incorporate in-situ identifications of building-foundation-soil.

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REFERENCES

1. Aktan, A.E, Bertero, V.V., Chowdhury, A. and Nagashima, T., "Experimental and Analytical Predictions of the Mechanical Characteristics of a 7-Story 1/5-Scale Model RC Frame-Wall Building Structure," Report No. UCB/EERC-83/13, University of California, Berkeley, 1983.
2. Aktan, A.E. and Bertero, V.V., "Conceptual Seismic Resistant Design of Frame-Wall Structures," Journal of Structural Engineering, Nov., 1984.
3. Aktan, A.E. and Nam, D.H., "Inelastic Analysis for Vulnerability Assessment," Proceedings, 6th ASCE Structures Congress, Orlando, 1987.

4. Aktan, A.E., Hogue, T.D. and Hoyos, A., "Regional Identification of Civil Structures," Proceedings, International Workshop on Nondestructive Evaluation for Performance of Civil Structures, University of Southern California, 1988.
5. Aktan, A.E. and Gordon, G.E., "Problems in Predicting Seismic Responses of RC Buildings," Journal of Structural Engineering, Sept., 1988.
6. Aktan, A.E. and Bertero, V.V., "Evaluating and Improving the Reliability of Existing Constructed Facilities: Seismic Vulnerability and Upgrading of Buildings," Umbrella Proposal Submitted to NSF-NCEER, Buffalo, 1988.
7. Charney, F.A., "Correlation of the Analytical and Experimental Seismic Response of a 1/5th-Scale Seven-Story Reinforced Concrete Frame-Wall Structure", Ph.D. Thesis, University of California, Berkeley, 1986.
8. Liu, S.C. and Yao, J.T.P., "Structural Identification Concept," Journal of the Structural Division, Dec., 1978.
9. SAP80 Structural Analysis Programs, Computers and Structures, Inc., Berkeley, CA, 1986.
10. SUPER-ETABS, Extended Three-Dimensional Analysis of Building Systems, NISEE, UNiversity of California, Berkeley, 1985.
11. Wilson, E.L. and Stephen, R.M., "Computer Analysis and Experimental Verification of the Dynamic Response of Three- Dimensional Buildings," ASCE Spring Convention, Nashville, 1988.