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Autor: Berrais, Abbes

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Knowledge-Based System for Dynamic Analysis and Design of Structures

Abbes BERRAIS
Assist. Prof.
Abha College of Technology
Abha, Saudi Arabia

Abbes Berrais, born 1961, received his civil eng. degree form Algeris Univ. in 1985, MCs from Liverpool Univ. in 1988, and PhD from Leeds Univ. in 1992. He is currently an assist. prof. in the construction dept Abha College of Techn., KSA.

Summary

Dynamic analysis techniques for high-rise structures under earthquake effects are rapidly being developed and have been recognized as indispensable tools. The valid use of these techniques requires from the design engineer a comprehensive understanding of the limitations and inaccuracies of the analysis, and constant review of the results for errors. Computer-based structural design assistants are needed to provide engineers with decision support tools and to guide them through the dynamic analysis and design of high-rise structures. Therefore, the incorporation of knowledge-based systems techniques will play a great role in helping carrying out the complicated dynamic analysis and design process. This paper describes the development of a knowledge-based design tool for the dynamic analysis and design of high-rise structures subjected to earthquake forces.

1. Introduction

As structures become more complex in shape, taller and lighter, so the need grows for better and more reliable tools to help in the analysis and design of such structures. Dynamic analysis and design techniques for high-rise structures under earthquake effects are rapidly being developed and have been recognized as indispensable tools. However, their use in design offices requires specially trained and skilled engineers. Understanding the dynamic behavior and ultimate capacity is essential for the design of safe and economical structures. Computer-based structural design assistants are needed to provide practicing engineers with decision support tools and to guide them through the dynamic analysis and design processes. Therefore, the incorporation of knowledge-based systems techniques (KBES) will play a great role in helping carrying out complicated dynamic analysis and design of high-rise structures. This paper is concerned with the following: Development of a knowledge-based design tool (KBDT) for the dynamic analysis and design of high-rise structures subjected to earthquake forces. The design methodology included in this KBDT is based on the *ductility* concept, and is briefly described. Knowledge representation and the coupling of numerical methods with symbolic processing are also considered.

2. Earthquake Design Methodology

In earthquake analysis/design process, the engineer should consider the different factors that control the inelastic behavior of a building. The most critical factors to be considered in earthquake design are *ductility* and the detailing requirements. The earthquake design methodology (EDM) adopted in this research is divided into two phases (see Fig. 1): *preliminary design phase* and *detailed design phase*. In the first phase a simple elastic analysis is employed to establish an initial deployment of reinforcement. In the second an inelastic dynamic analysis is performed to allow a detailed review and refinement of this reinforcement. The EDM has been applied to a particular type of lateral resisting system, coupled shear wall structures.

2.1 Preliminary Design Phase

This phase comprises three stages (see Fig. 1): conceptual design, preliminary analysis (elastic), and allocate reinforcement: in the *Conceptual design stage*, the overall form of the building is specified together with the relative positions of the lateral load resisting elements. The regularity requirements are checked against codes limitations. In the *Preliminary analysis stage*, an elastic analysis is carried out of the structure under the effect of the lateral static forces obtained in the previous stage. In the *Allocate reinforcement stage*, an initial estimate of elements reinforcement is carried out.

2.2 Detailed Design Phase

This phase comprises three stages (see Fig. 1): *detailed analysis* (inelastic dynamic), *review ductility*, and *refine reinforcement*. In the *Detailed analysis stage*, an inelastic dynamic analysis is carried out by choosing a suitable earthquake record to critically excite the structure. The inelastic dynamic analysis is carried out using the program DRAIN-2D [1]. In the *review ductility satge*, the rotational *ductility* of each structural element is estimated as [2]:

$$\mu_r = \frac{\theta_{max}}{\theta_y} = \frac{\theta_y + \theta_p}{\theta_y} = 1 + \frac{\theta_p}{\theta_y} \tag{1}$$

Where: μ_r is the rotational ductility; θ_{max} is the maximum rotation; θ_p is the plastic rotation; and θ_y is the yielding rotation

The purpose of the *ductility review stage* is to check the performance of the structure as designed. In the *Refine reinforcement stage*, the reinforcement adopted in the *allocate reinforcement stage* is refined based on the result of the *ductility* requirements in the *review ductility stage*.

3. The Knowledge-Based Design Tool (KBDT)

The aim of the developed KBDT is to assists design engineers in the following tasks:
- Check the regularity requirements of a building.
- Estimate the different earthquake factors used in UBC [3] code requirements.
- Model and perform the inelastic dynamic analysis of the structure under earthquake records.
- Estimate the required reinforcement in structural elements.

A macro level schematic view of the KBDT architecture is shown in Fig. 2. The architecture has the following components:

- *Knowledge base:* comprises of several modules, each module is responsible for a specific task;
- *Context*: contains the collection of facts which represent the current state of the problem in hand;
- *Inference Mechanism*: controls the system by modifying and updating the context using the knowledge in the knowledge base;
- *External analysis programs*: contain the structural analysis program DRAIN-2D, which is interfaced to the system;
- *Explanation facility*: provides the user with the necessary explanations about the task being performed; and
- *User interface*: provides a channel through which the user can interact with the modules of the system.

4. Non-linear Dynamic Analysis Module

The non-linear dynamic module is one of the knowledge-base modules of the system. It is concerned with the inelastic dynamic analysis of RC structures under earthquake records. It uses the DRAIN-2D finite element program [1]. Interfacing with the program DRAIN-2D takes place on three levels:

Input Data Level: At this level data needed for the dynamic analysis is prepared and checked for consistency. The earthquake record is selected from a set of records. The data in the resulting file DRAIN.IN, is read by DRAIN-2D.

Solution Process Level: At this level, the module executes the analysis program DRAIN-2D as a background process. During the inelastic analysis, limited information is displayed on the screen to inform the user of progress. More detailed information is directed to an output file DRAIN.OUT which is investigated at the evaluation level.

Evaluation Level: At this level a quantitative-qualitative transformation of the dynamic analysis results is carried out for the user. The module interfaces to the output file DRAIN.OUT, reads the results it contains, and transforms them into formats and graphical displays suitable for assimilation by the user (see Fig. 3). The results that are displayed and interpreted in this way include the following: Elastic/inelastic lateral deflections; Lateral drift at each floor level; beams moment, axial and shear forces, and bending moments; and rotational ductility.

In case the ductility requirements are not satisfied, or if the walls yield at the base before the beams, the user is informed by the system. The module then assists the user to carry out further inelastic analysis with modified element strength until the design is satisfactory. During the re-analysis phase, the module automatically modifies the input data for DRAIN-2D. The general steps taken to carry out the dynamic inelastic analysis of coupled shear walls are shown in Fig. 4.

5. Knowledge Representation

The knowledge representations used in this system include production rules, frames and data-driven procedures, these being provided by Quintec-Prolog and Quintec-Flex [4,5]. Additionally, the numeric procedures are represented using FORTRAN 77 as external programs. An example of a typical rule that decides on the type of reinforcement configuration to be used in the beams follows:

Rule Beam_reinf1
    IF Vbcr is the critical beam shear stress
    AND min_cal_beam_shear_stress > Vbcr
    THEN compute_diag_steel_area
    BECAUSE
    minum cal_beam_shear stress is > 0.1*beam_length*fcu**0.5/beam_height

An example of using Quintec-Flex frames is the representation of earthquake records for use by the program DRAIN-2D. The San Francisco record is represented as frame with slot values as shown in Fig. 5.

6. The User Interface

The acceptability of any KBDT depends largely on its user interface. The design of a good user interface must consider many aspects of human computer usage ranging from cognitive models of the user's thought processes to the aspect of usability. It is assumed that the user is knowledgeable

about structural design, but not necessarily about dynamic analysis concept. The following system requirements were identified and form the objective of the system implementation:
Easy to use; Takes the initiative and question the user; Teaches the user how to formulate the problem; Allows the user to invoke the system at any level of abstract; and informs the user about the next step in the design process. The user interface of KBDT is shown in Fig. 3.

7. Conclusions

In this paper a prototype KBDT for the dynamic analysis and design of high-rise structures was described. The prototype system helped on the iterative design to achieve a balance between element strength and stiffness to fulfil ductility requirements. The integration of symbolic processing and dynamic analysis methods is a necessity for a robust and practical computer-aided earthquake design. Moreover, KBES technology could be used in collecting and managing earthquake engineering expertise from different sources and formalizing this knowledge for future use by less experienced engineers. Heuristics alone are not sufficient to solve real design problems. The system needs to be linked to numerical and structural analysis modules.

The KBDT has accomplished the following:

- Automate much of the dynamic analysis/design process, which could free the design engineer from the more tedious aspects of design and allow him to concentrate on concepts such as ductility.
- Help the structural engineer on the efficient use of FEM programs, preparation of input data, modeling, and interpretation of results.
- Minimize the time spent to prepare the input data to the program DRAIN-2D, and help the structural engineer in the decision making process.
- Enable the designer to control the location and magnitude of inelasticity in structural members using inelastic dynamic methods. This allows the engineer to design the structure based on the ductility concept.

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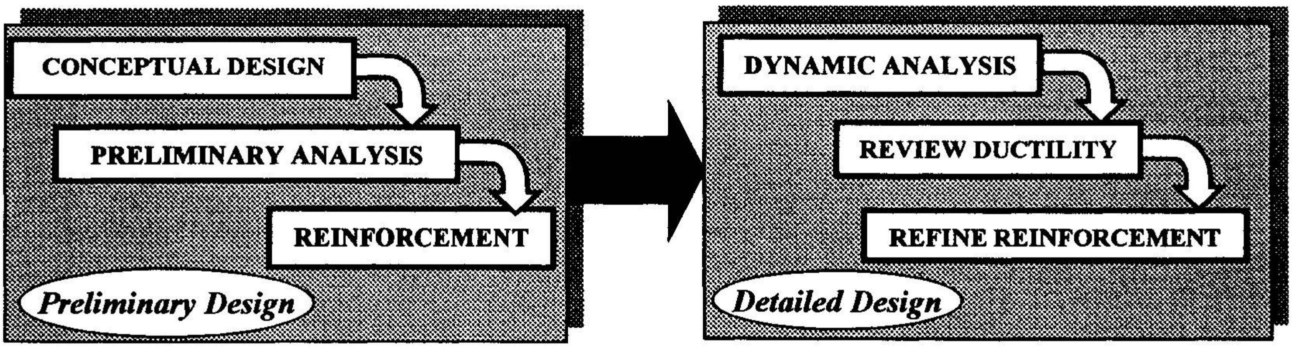

Fig. 1 Earthquake design methodology

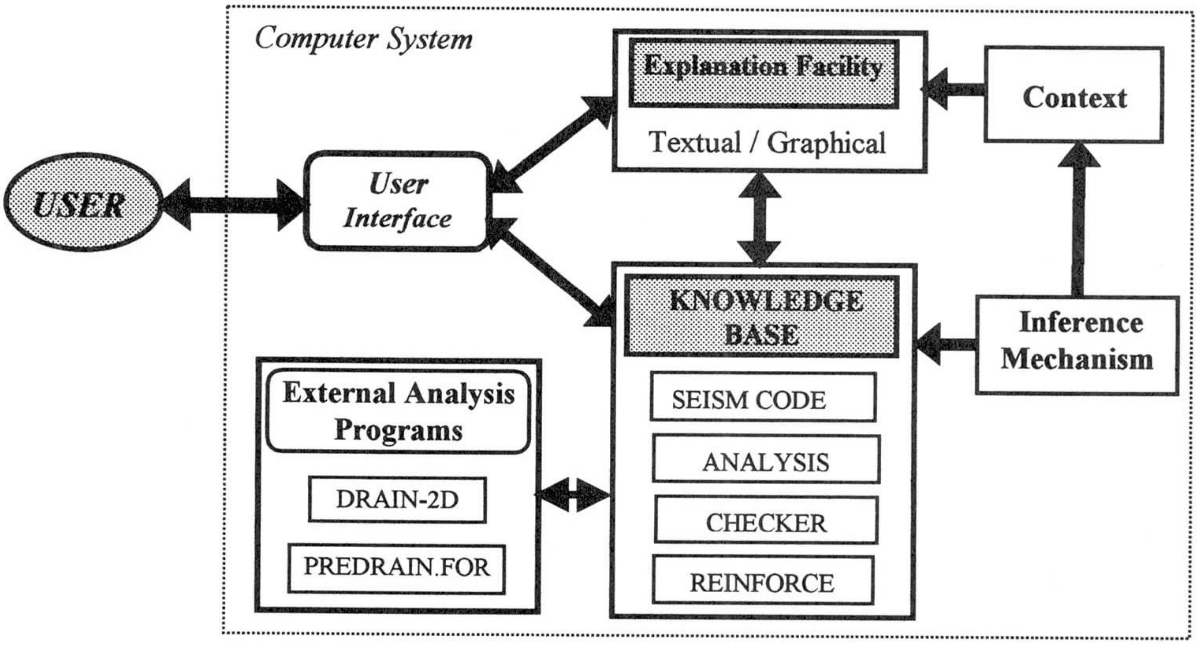

Fig. 2. Architecture of the KBDT system

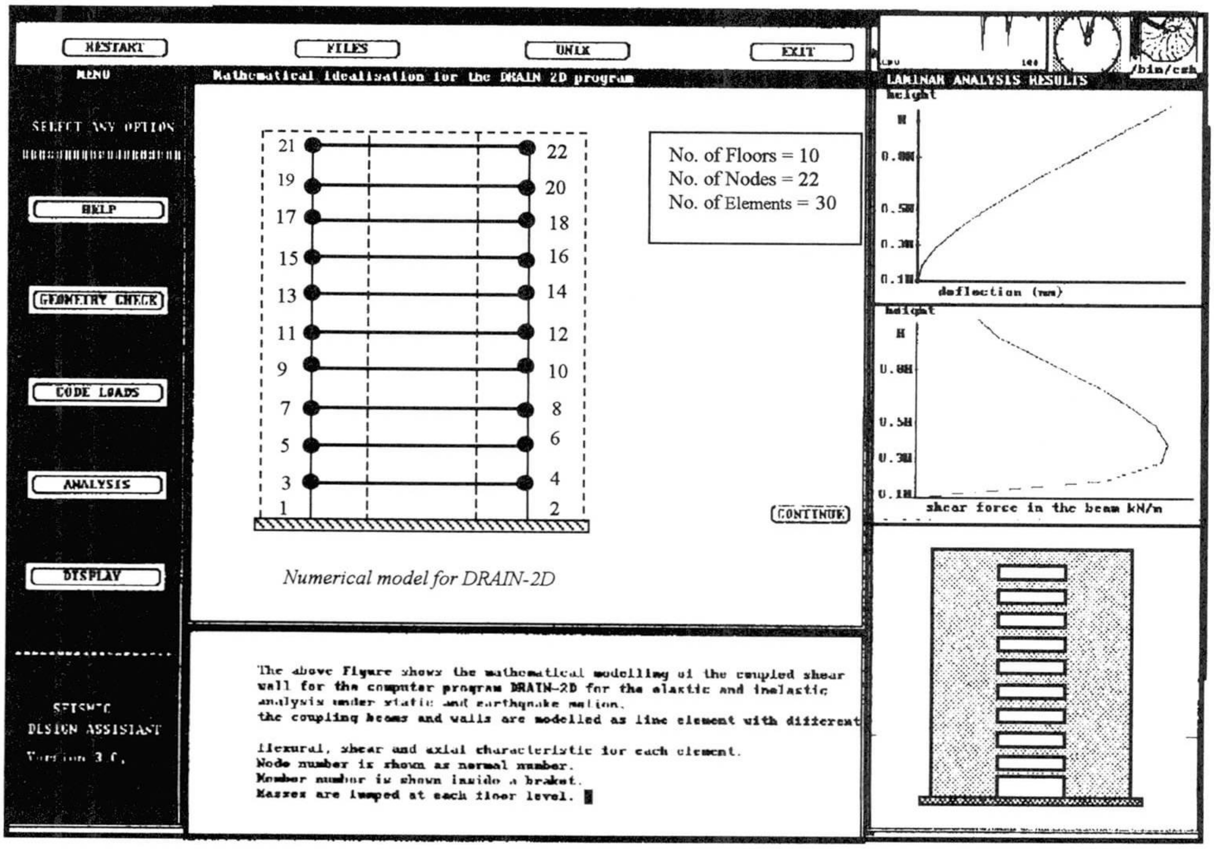

Fig. 3. User interface of the KBDT

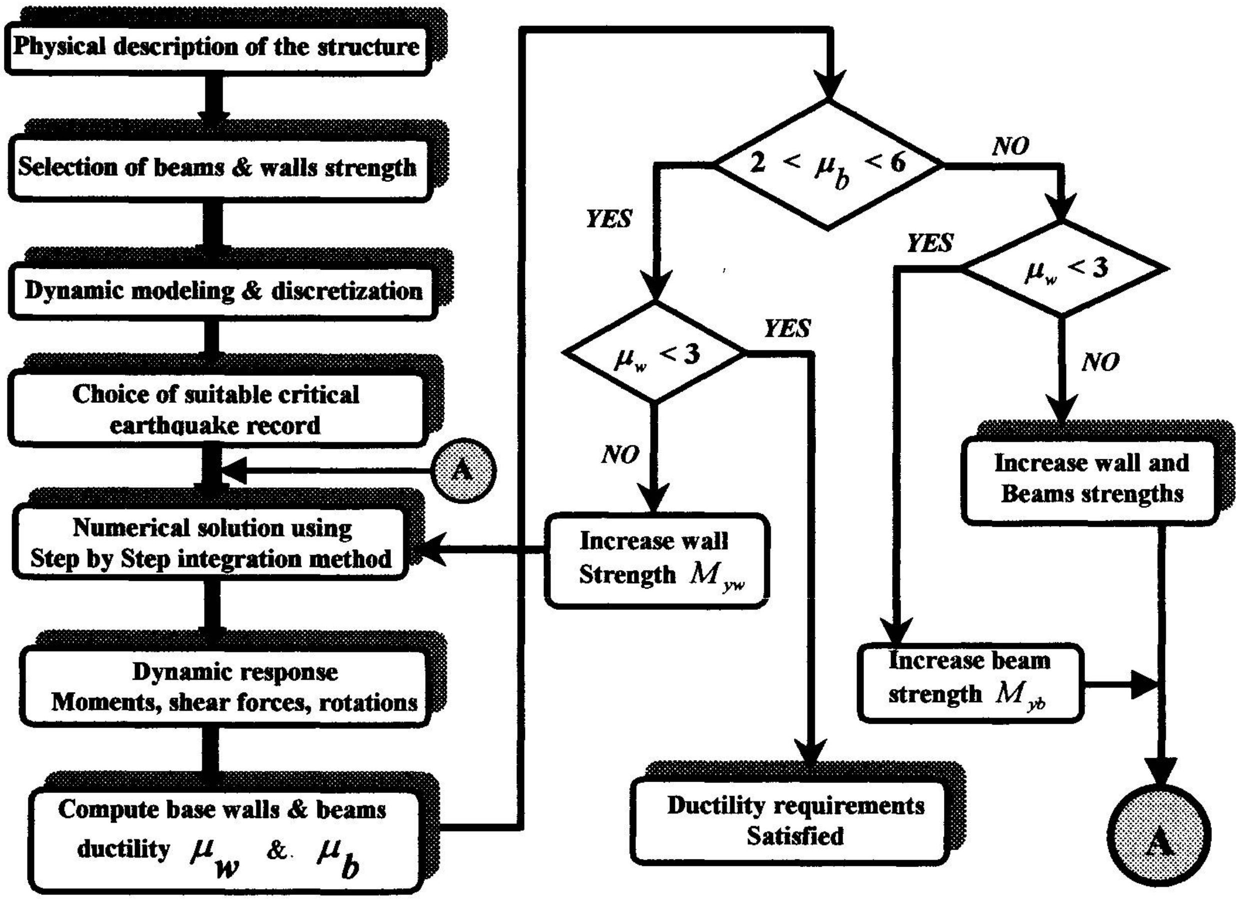

Fig. 4. Flowchart for dynamic inelastic analysis procedure

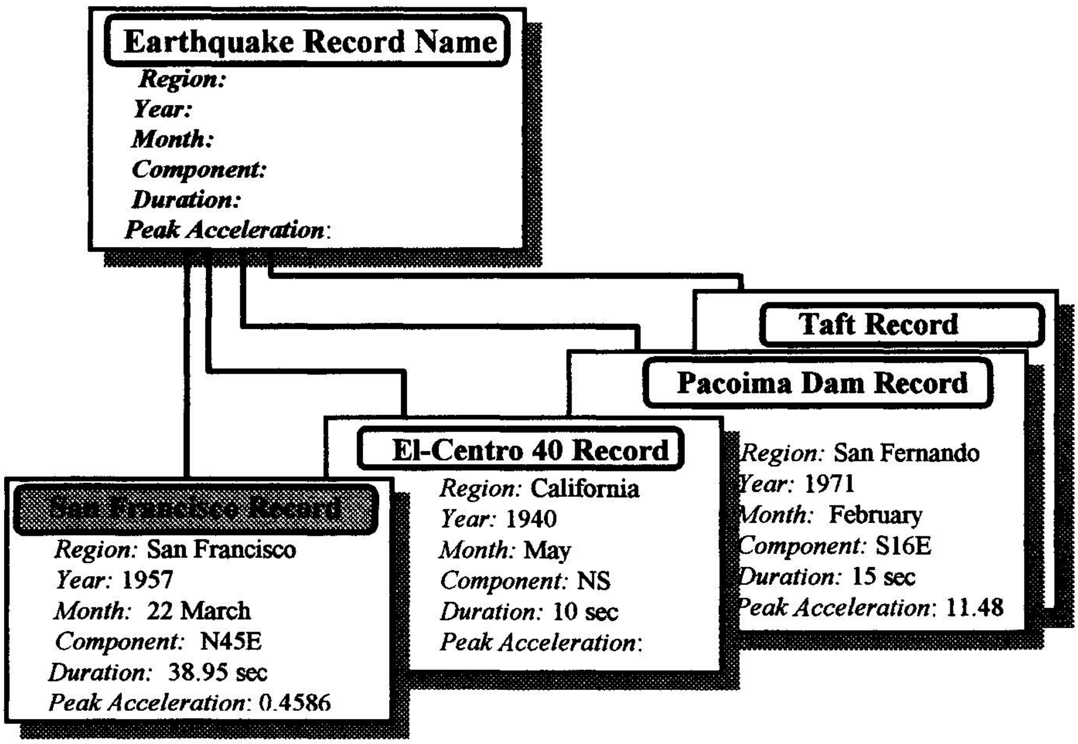

Fig. 5. Frame representation of different earthquake records