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A HYBRID SYSTEM FOR DYNAMIC ANALYSIS AND DESIGN OF COUPLED SHEAR WALLS

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Abstract

Non-linear dynamic analysis techniques are rapidly being developed and have been recognized as indispensable tools. However, their use in the design office requires special experience. Consequently they are not generally accepted as analysis/design tools. Additionally, uncertainties are associated with the determination of the earthquake forces, the stiffness and strength of the structure; the selection of the mathematical models; and the form of the earthquake.

In this paper a hybrid system for the non-linear dynamic analysis/design of coupled shear walls is briefly described. The system combines expert system technology with finite element method to carry out the dynamic analysis of coupled walls under earthquake forces. The system has been implemented using Quintec-Prolog, Quintec-Flex and FORTRAN 77, and runs on a SUN SPARC station under Unix system.

Key words: *Expert systems, Non-linear dynamic analysis, Earthquake design, Coupled wall.*

Résumé

Les techniques d'analyse dynamique non-linéaire ont rapidement été développées et reconnues comme étant des outils indispensables. Cependant, leurs utilisations dans la conception exige une expérience spéciale. En conséquence, elles ne sont généralement pas acceptées comme outils d'analyse/conception. De plus, des incertitudes sont associées à la détermination des forces sismiques, de la rigidité, de la résistance de la structure, du choix des modèles mathématiques et de la nature du séisme.

Dans cet article, un système hybride pour l'analyse dynamique non-linéaire des parois de cisaillement couplés est brièvement décrit. Le système combine la technologie de système expert avec la méthode des éléments finis qui permet d'exécuter l'analyse dynamique des parois couplées sous des forces sismiques. Le système a été mis en application en utilisant Quintec-Prolog, Quintec-Flex et Fortran 77, et développé à la station RUN SUN grâce au système Unix.

Mots clés: *Systèmes experts, analyse dynamique non-linéaire, conception sismique, parois couplés.*

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ملخص

لقد أصبحت طرق التحليل الغير المرنة من التقنيات المستعملة في مجال البحث العلمي، وهي غير مستعملة في مكاتب التصميم وهذا راجع إلى أن هذه الطرق صعبة وتحتاج إلي خبرة ومعرفة خاصة، إضافة إلى ذلك فان التحليل والتصميم ضد قوى الزلازل يرتبط بالاحتمالات المقترنة لحساب القوى الفعلية للزلازل وحساب القيمة التقريبية لصلابة المنشأ، إضافة إلى كيفية اختيار النماذج الرياضية وكيفية تفسير نتائج التحليل الديناميكي. في هذا البحث نقدم عرضا لنظام هجيني لتحليل و تصميم جدران القص المتصلة ضد قوى الزلازل باستعمال طرق التحليل الديناميكي الغير المرنة. وقد استخدم في هذا النظام تقنيات النظم الخبيرة، وقد طور هذا النظام باستخدام لغة البرمجة المنطقية Quintec-Prolog و Quintec-Flex ولغة فورتران.

كلمات المفتاح: *النظم الخبيرة، التحليل الديناميكي الغير المرن، التصميم ضد قوى الزلازل، جدران القص المتصلة.*

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 expert systems techniques (ES) will play a great role in helping carrying out complicated dynamic analysis and design of high-rise structures.

The numerous computer analysis techniques used by design engineers for concrete structures are based on a large number of questionable assumptions about earthquake characteristics and about structural behavior. The valid use of these techniques requires from the design engineer a comprehensive understanding of the limitations and inaccuracies of the analysis, constant review of the results for errors and acceptance of full responsibility of the results. The majority of engineers dealing with earthquake of these techniques requires from the design engineer a comprehensive understanding of the limitations and

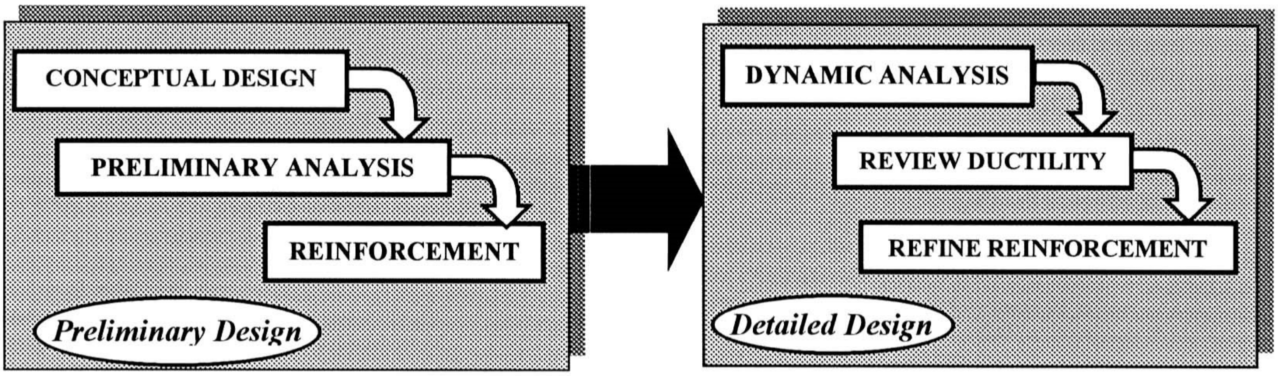

Figure 1 : Earthquake design methodology

inaccuracies of the analysis, constant review of the results for errors and acceptance of full responsibility of the results. The majority of engineers dealing with earthquake design problems use simplified code methods such as the *Equivalent Lateral Static* method, and *Modal Response Spectrum Analysis*, which cannot accurately reflect the true non-linear behavior of structures during earthquakes. Inelastic dynamic analysis procedures are more accurate, but have not been widely adopted as design tools in design offices because of their complexity. New computer techniques are required to bridge the gap between the complexity of these procedures and the practicing structural engineer. A computer-based non-linear analysis/design assistant is needed to provide practicing engineers with decision support systems and to guide them through the non-linear analysis and design process. The demand for such design assistants is growing as the construction industry relies more heavily on information technology.

This paper is concerned with the development of a hybrid system for the dynamic analysis and design of coupled wall structures subjected to earthquake input motions. The design methodology included in this system is based on the *ductility* concept, and is briefly described. Knowledge representation and the coupling of numerical methods with symbolic processing are also considered. The hybrid system has been implemented on a SUN SPARCstation using Quintec-Prolog, Quintec-Flex and FORTRAN 77.

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.

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.

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 stage,* 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.

It is advisable that the *ductility* of the coupling beams be in the range of 3 to 6 and 1 to 3 in the base of the walls [3,4]. 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*.

THE HYBRID SYSTEM

The developed hybrid system is considered to be a coupling between an expert system and the external finite element program DRAIN-2D [1]. Expert systems (ES) are one of the more fruitful areas of artificial intelligence research to date. Gasching *et al* [5] have defined ES as: "*An ES is an interactive computer program incorporating judgement, human experience, rules of thumb, intuition,*

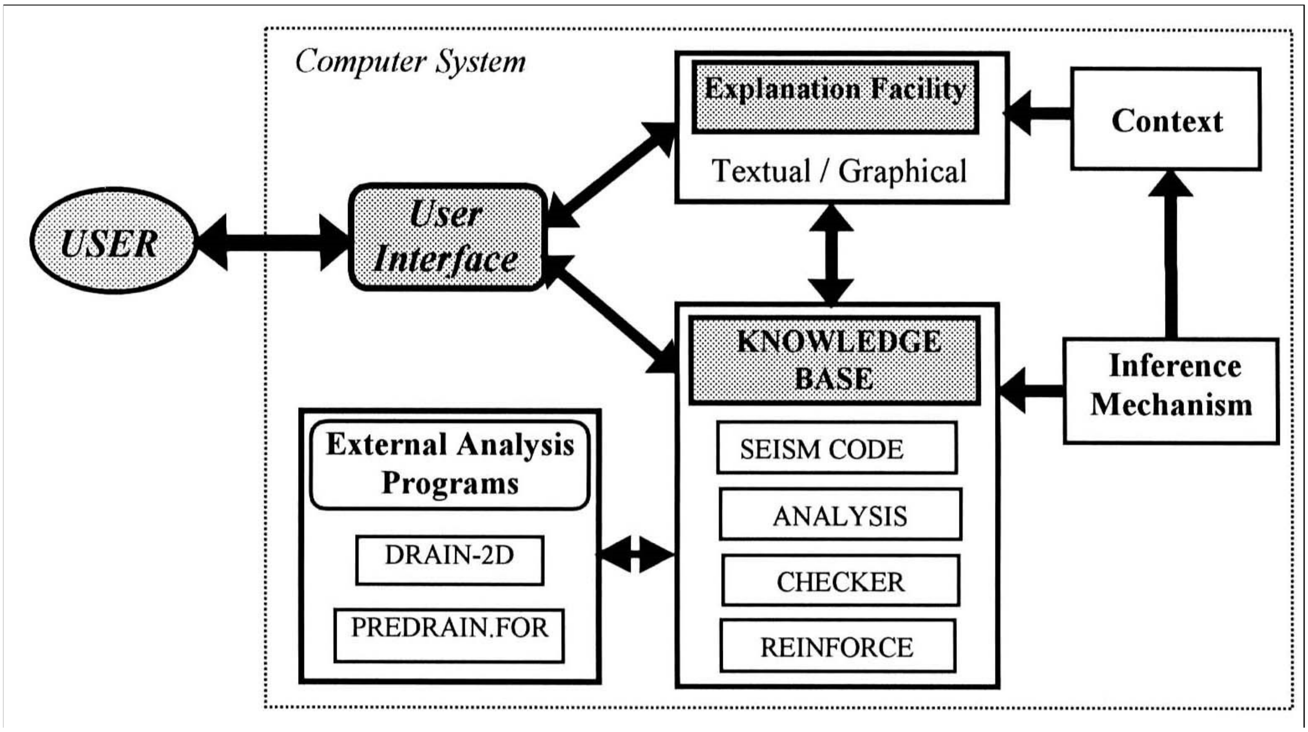

Figure 2 : Architecture of the hybrid system

and other expertise to provide knowledgeable advice about a variety of tasks". ES have been developed to solve many types of problem in different areas such as medicine, geology, and engineering. It is playing a great role in helping to solve problems that require knowledge and engineering judgement. ES technology can facilitate the transfer of earthquake engineering knowledge and expertise from humans to computers, and can explain this knowledge to less experienced engineers. Also, it can help link between symbolic concepts and earthquake engineering problems. Few prototype expert systems in earthquake design have been developed, these are reviewed in reference [6]. The aim of the hybrid system is to assists design engineers in the following tasks:

- Check the regularity requirements of a building.
- Estimate the different earthquake factors used in UBC [7] code requirements.
- Model and perform the inelastic dynamic analysis of the coupled wall under earthquake records.
- Estimate the required reinforcement in structural elements.

A macro level schematic view of the system 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.

NON-LINEAR DYNAMIC ANALYSIS MODULE

The non-linear dynamic module is one of several sub-modules that together form a comprehensive analysis module for coupled shear walls as shown in Fig. 2 [8]. The module is concerned with the inelastic dynamic analysis of coupled wall structures under earthquake records. It interfaces to the DRAIN-2D finite element program. 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

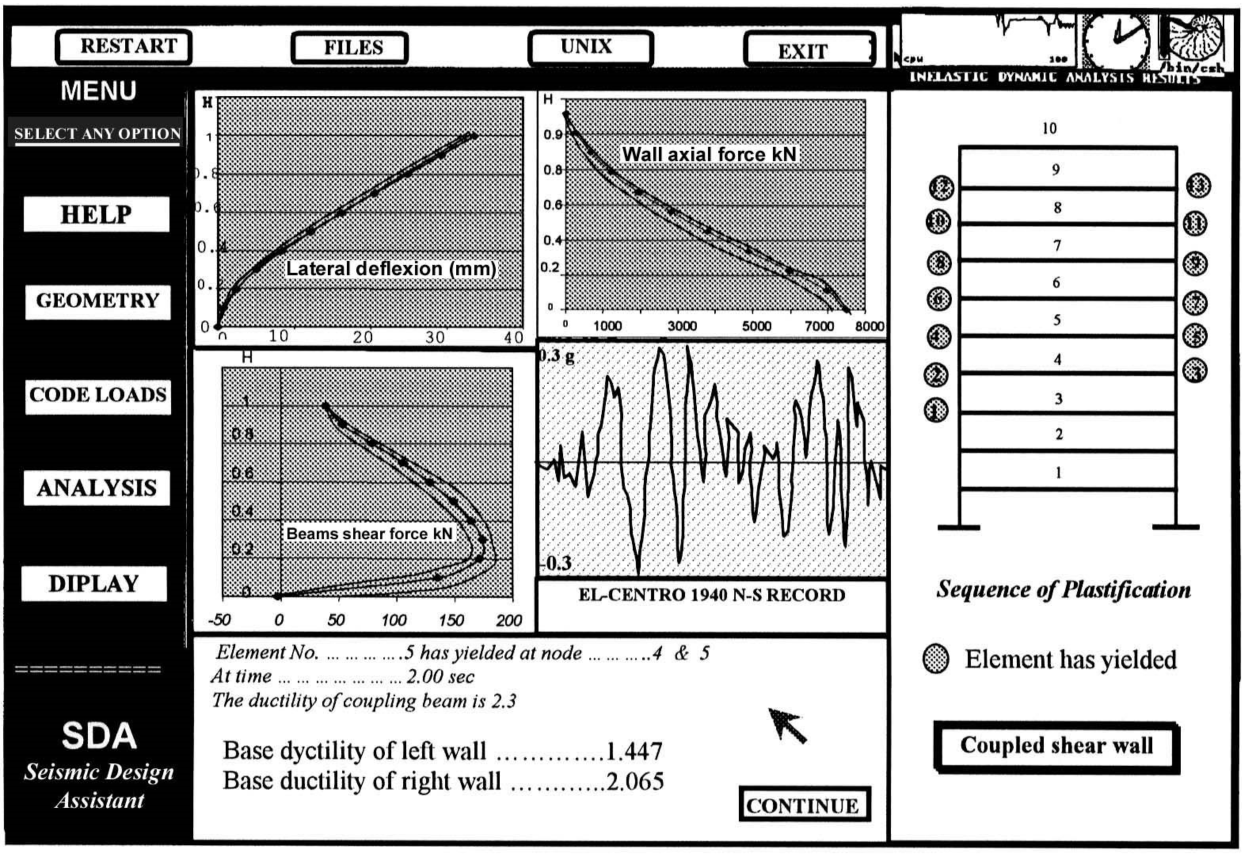

Figure 3 : User interface of the system

floor level; beams moment, axial and shear forces, and bending moments; and rotational ductility for the beams and walls.

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.

KNOWLEDGE REPRESENTATION

The knowledge representations used in this system include production rules, frames and data-driven procedures, these being provided by Quintec-Prolog [9] and Quintec-Flex [10]. 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 information related to different 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. An example of using Quintec-Flex frames is the representation of information relating to different earthquake records:

frame input_motion.
frame San Francisco record is an input_motion;
default region is San Francisco and
default year is 1957 and
default month is 22 March and
default component is N45E and
default duration is 38.95 sec and
default peak_acceleration is 0.4586.

THE USER INTERFACE

The acceptability of any hybrid system 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 system requirements which were identified and form the objective of the system implementation are: 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

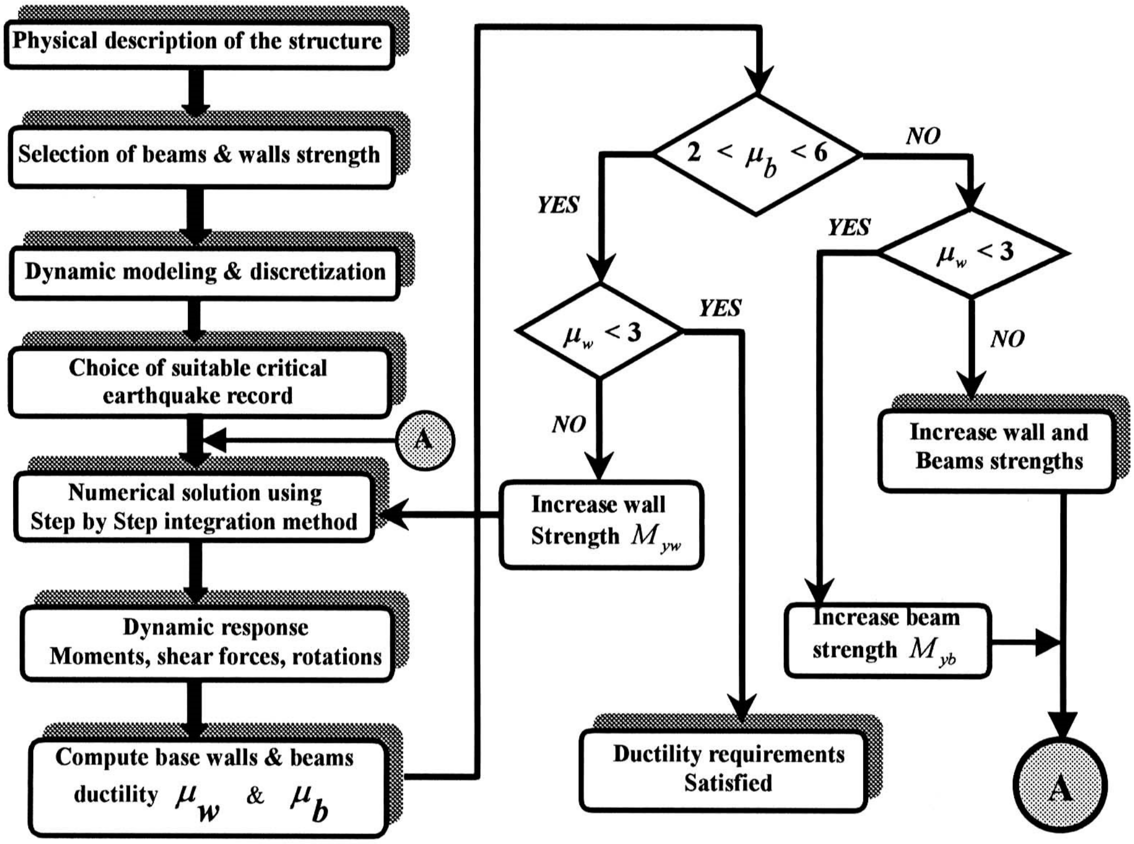

Figure 4: Flowchart for dynamic inelastic analysis procedure.

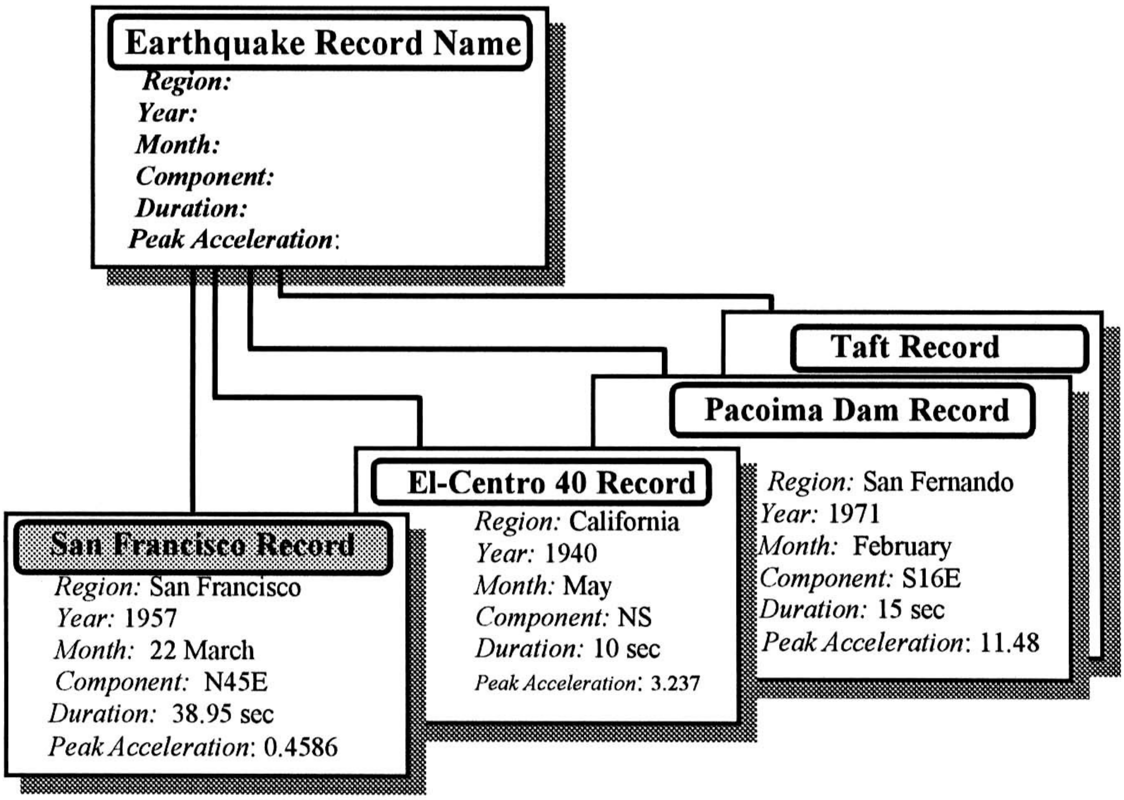

Figure 5: Frame representation of different earthquake records.

step in the design process. The user interface of the system is shown in Fig. 3.

CONCLUSION

In this paper a hybrid system for the dynamic analysis and design of coupled wall 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, expert systems 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 hybrid system has accomplished the following:

- Automate much of the non-linear 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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