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SISA: A KBS for seismic risk assessment

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ABSTRACT: SISA (Seismic Intelligent System Adviser) is an object oriented environment for the seismic risk assessment of buildings which integrates knowledge based modules, procedural programs and graphics tools. The system, implemented on a portable computer, will assist - in the field - in the data acquisition and seismic risk evaluation of buildings. Increasing the efficiency and improving the quality of the data acquisition and processing for the seismic risk evaluation is the main purpose of SISA. An important feature of the system is the capability of operating at several levels of accuracy, according to a unified assessment methodology in order to meet the objectives of the survey while optimizing the resources allocated to the project. The system may be employed for: large scale seismic assessments, seismic classifications of buildings, and evaluation of single buildings for possible retrofitting. SISA, based on seismic engineering knowledge, suggests the appropriate level of accuracy, or evaluates the user choice, with respect to the intended aim of the survey and the complexity of the case in exam. Intelligent assistance capabilities have been provided in order to expedite the survey.

1 INTRODUCTION

The seismic risk of buildings has become a subject of worldwide concern.
Different approaches to the risk evaluation have been proposed in the guidelines adopted in various countries such as the U.S. (ATC 14 1987), Japan (BDPA 1977), and Italy (GNDT 1984).
While empirical and subjective methods are suited for regional seismic risk estimations, analytical and objective approaches are more appropriate for the assessment and possible retrofitting of a single building.
These methods, though, developed with different philosophies, appear incompatible or even contradictory when compared among themselves. Both from a conceptual and operational viewpoint a unified methodology of seismic risk assessment is strongly needed. Such a methodology should allow various levels of complexity in the assessment, and it should be suited for the entire spectrum of objectives, from the estimation of global large scale damage scenarios, to the seismic redesign of single buildings.
Recently one of the authors has been involved in several pilot projects, in Italy, aiming at the risk assessment of several hundreds of buildings: 2652 buildings in Emilia Romagna, 20 buildings in Augusta, and 35 ones in Potenza. This experience has evidenced critical aspects of the data acquisition phase:

1. Heavy resource demand in large scale projects.

2. Limited qualified personnel available.

3. Rigid and crude description of the building due to the nature of the traditional methods of data collection (forms and questionnaires). This could also prevent the use of the data for future aims which may require a more complete set of information (Gavarini et al., 1990).

4. Disuniformity in the assessment and inconsistency in the acquired data due to limited experience of the inspectors.

5. Difficulties in acquiring original design data.

6. The surveyor is not capable to determine the appropriate level of accuracy of the data acquisition according to the building condition. Consequently, for some buildings excessive information are available while for others there is a lack of data.

The attempt to develop a unified seismic assessment methodology as well as to overcome the mentioned difficulties in the data acquisition phase has resulted in the development of an object oriented environment for the seismic risk assessment

of buildings which integrates knowledge based modules, procedural programs and graphics tools.
The proposed system named SISA, implemented on portable computers, is intended to assist - in the field - an inspector in the data acquisition and seismic risk evaluation of buildings.

2 OBJECTIVES

Increasing the efficiency and improving the quality of the data acquisition and processing for the seismic risk evaluation is the main purpose of SISA. An important feature of the system is the capability of operating at several levels of accuracy in order to meet the objectives of the survey while optimizing the resources allocated for the project.
The possible intents of the survey include: large scale seismic assessments, seismic classifications of buildings, and evaluation of a single building for possible retrofitting. The system, based on seismic engineering knowledge, suggests the appropriate level of accuracy, or evaluates the user choice, with respect to the intended aim of the survey.
Since the previous experience has shown that the data acquisition, resource wise, is the most demanding phase of the risk assessment, special attention has been given in the system design in order to expedite the survey by providing the system with intelligent assistance capabilities. This is obtained by:

1. Providing an interactive multilevel incremental data acquisition strategy. The system should allow several levels of detail in the survey, and should suggest the minimum acceptable one for a satisfactory assessment of the building. At a later time, the system should use this data to minimize the effort in performing more detailed survey, should additional information be required.

2. Intelligent procedures which attempt to construct a model of the structural resisting system based on minimum user information.
The geometrical model is built from the floor plans and limited information on the structural components.
Hypotheses on the quantity of reinforcements, when exact data are unavailable, are derived using a set of euristics based on: code prescriptions adopted in the building design, local construction customs, data obtained from detailed surveys of representative buildings with the same typology, and back calculation of reinforcements necessary for the vertical loads only.
The proposed model, however, should always be validated and possibly modified by the surveyor.

3. Context sensitive graphical and textual helps which indicates the data to be collected and explain why and how this data should be acquired. This, in addition to automatic data cross checking, will facilitate less experienced operators, and will improve the reliability of the acquired data.

4. Computer aided drafting facilities in order to describe more easily the geometry of the building.

5. An on-line data base of inspected buildings, relieves the operator from the burden of manually recording and storing the data, and provides potentially useful information on previously inspected buildings.

3 MULTILEVEL ASSESSMENT METHODOLOGY

The aim of the system is the evaluation of the seismic risk of masonry and reinforced concrete buildings.

The seismic risk, as proposed in (Petrini 1988), is evaluated from the Seismicity of the site, the Exposure and the Vulnerability of the building, and it may be interpreted as an estimate of the average yearly damage associated to the building due to seismic actions.

The Seismicity is defined by the probability density distribution of peak ground acceleration and the average yearly number of earthquakes at the site of the building.

The Exposure is an index related to the number of occupants and to the importance of the building.

The Vulnerability is defined by a relationship between the peak ground acceleration and a measure of the associated expected damage (the damage curve of the building).

The Seismicity and the Exposure index are determined according to the method proposed in Petrini (1988) and will not be further described here.

Previous experiences in the seismic risk evaluation of numerous buildings have shown that the cost of the project is mainly due to the data acquisition phase. In addition, it appears that the Vulnerability can be obtained with different methods - depending on the structural regularity in plan and elevation, Seismicity, and Exposure of the building - retaining an acceptable level of

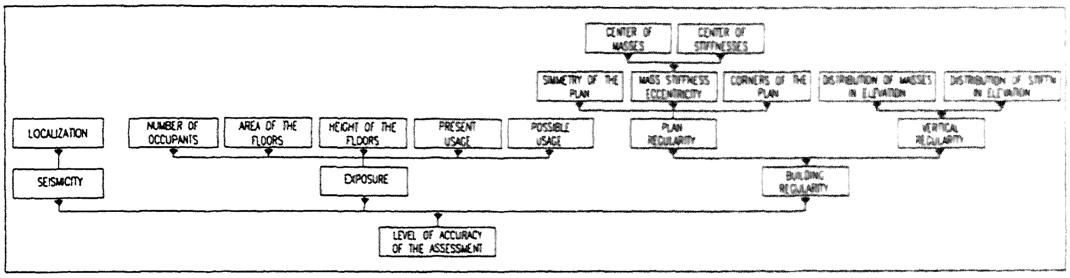

Fig. 1 Flow-chart of the decisional process to evaluate the level of accuracy of the assessment.

accuracy with respect to the specific objective of the project (Fig. 1).
Therefore, the system has been provided with four alternative methods for the determination of the Vulnerability, as described in the following (Fig. 2). The system, based on euristic rules, suggests the selection of the most cost effective one, among those acceptable for the case in exam.
Four corresponding levels of completeness in the data acquisition are also available.

At the first level the data acquisition requires - following (G.N.D.T. 1984) - a limited set of information on the building, such as: typology of structural components, number of floors, area and height of each floor, soil data, usage, and location.
According to the typology of the components and the number of floors, a global structural typology for the building is selected among the 8 typologies which are currently considered in the system.
A damage curve has been associated to each global structural typology as the average of the damage curves obtained with the third level method for the buildings with the same typology in a population of about 400 buildings recently surveyed in Emilia Romagna. At this level the system associates to the building the damage curve of the corresponding global structural typology.

For the higher levels, in addition to the first level data, information are required about the lateral resisting system, as illustrated in the following, and on load distribution and floor geometry as specified in (Gavarini, Sanpaolesi et al. 1989).

At the second level - generally suited for building with regular plan and elevation - the resisting elements (frames, walls, infilled frames) of the first floor only, are considered. Data are required about: material mechanical properties, size of the elements, and critical details which could reduce the element ductility. The quantity of reinforcements is estimated based on previously mentioned empirical considerations.
The damage curve is evaluated according to the procedure proposed in (Gavarini and Nistico' 1991) which is briefly described in the following.
The assumptions of the model are: the floors are rigid and can only translate, and the constitutive models of the elements, as described in (Gavarini and Paolone 1991), are elasto-plastic.
Based on the previous assumptions the force-displacement curve of the first floor is evaluated.
The seismic loads are described by a static equivalent load distribution - proportional to the peak ground acceleration - according to the G.N.D.T. seismic code (G.N.D.T. 1984).
For the two main perpendicular directions of the building, an incremental nonlinear static analysis is performed in order to determine the maximum acceleration a_e for which all elements are still elastic in both directions, and the minimum acceleration a_c for which a failure criteria for the first floor is reached. The structure is considered undamaged (damage level $d_e=0$) for accelerations lower than a_e, and completely damaged (damage level $d_c=1$) for accelerations greater or equal to a_c*k, where k is the ductility factor of the structure. The damage level for intermediate values of the acceleration is obtained by linear interpolation between the two limiting points previously determined.

At the third level - generally suited for building with an irregular plan, but regular elevation - in addition to the second level data, - and for every floor - the position of each resisting element is required, and the structural model is extended in order to include also the rotational degree of freedom at each floor.

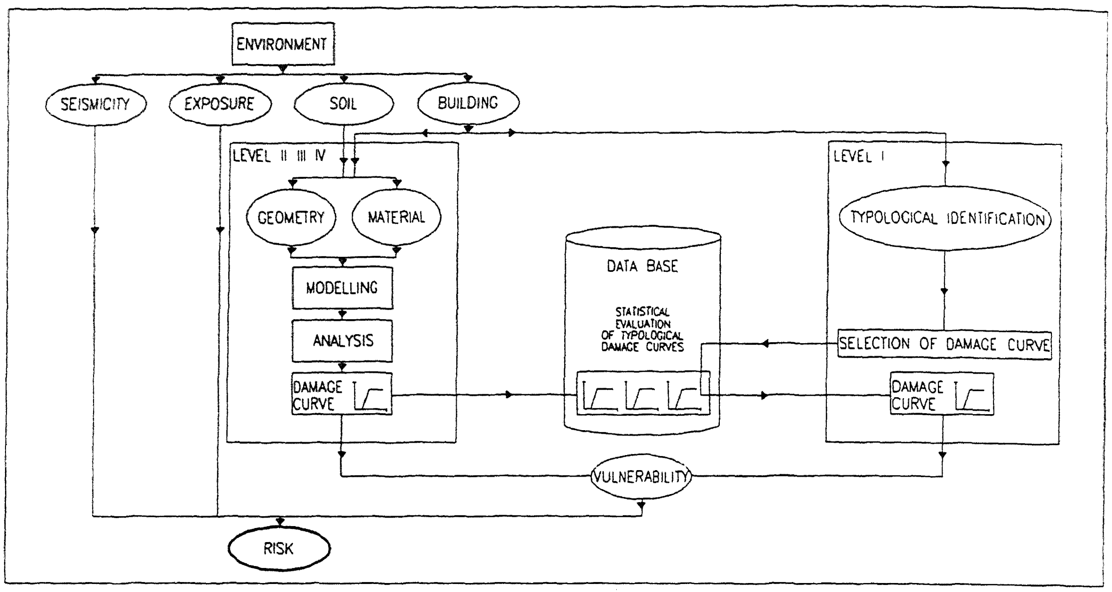

Fig. 2 Flow-chart of the multilevel seismic risk assessment procedure.

In order to simplify the data acquisition process the position of the resisting elements is identified by few parameters only. The generation of the structural model is obtained from an euristic data processing of the approximate available geometrical data.
Similarly to the previous level, two damage curves for each floor are computed. The two limiting points of the acceleration for the global damage curve of the building are determined respectively as the minimum a_e and a_c of all the floor damage curves.

At the fourth level - generally used for irregular buildings - a much more complete data acquisition is required to accurately define: the geometry and position of each element; the mechanical characteristics of the materials; and the quantity and position of reinforcements if available.
A complete three-dimensional frame analysis, with stiffness degrading cyclic element is performed at this level. The damage curve may be obtained either with a static analysis using the prescribed static equivalent forces, or with a dynamic time stepping procedure using several accelerograms generated from the corresponding design spectrum.

4 KNOWLEDGE REPRESENTATION

SISA is an hybrid Object Oriented System: the knowledge is represented by Super Classes, Classes, Objects, Methods, Facets, Rules, Functions and Programs encapsuled in different linked Knowledge Islands.
Super Classes, Classes and Objects allow an hierarchical representation of the building elements.
Methods are procedures, embodied in each object, which return information about an object slot, if required by other objects.
Facets are procedural attachments: they are powerful tools to execute methods, to control the input and to execute the decisional process.
Rules are used to infer data and to drive the decisional process.
Functions are procedures which connect the system with specialized external programs.
The system is structured in the following four independent Knowledge Islands (KI): Localization, Geometry, Soil, Risk (as illustrated in Fig. 3).
Geometry and Risk are linked with other Knowledge Sub Islands (KSI): Geometry is linked with Lateral Resisting System, Floors and Stairs; Risk is linked with Exposure, Seismicity and Vulnerability.
Each of the previous KI and KSI is organized in Classes, Sub Classes and Objects. For example, in the Lateral Resisting System KSI there are four Classes: Resisting System, Section, Element, and Compound Element. Section is subdivided in two Sub Classes depending on the material (Reinforced Concrete Section and Masonry Section), and each of them is further expanded in other Sub Classes depending on the shape of the section (i.e. Rectangular Shape, Circular

Shape, Generic Shape).
The information stored in a KI can be shared by different classes of a single building, or by several buildings, allowing the reduction of the quantity of stored information: if, for example, two buildings have the same geometry they will share the same Geometry KI.
The shell of the system is Nexpert, which provides a fairly complete set of tools for the implementation of an hybrid expert system, together with interface to integrate the Knowledge Base with external programs. The C programming language was selected for the implementation of the internal and external procedural modules of the system. Autocad was used as the graphic environment, and DB3 as the database management system.

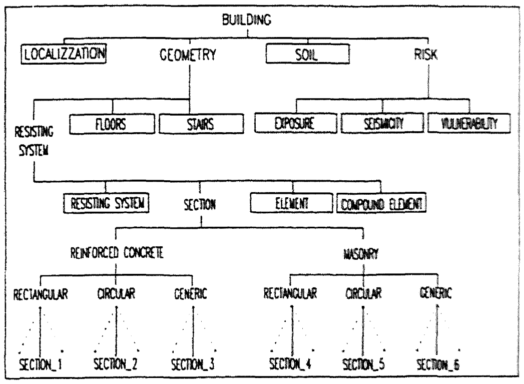

Fig. 3 Partial knowledge representation of the building (boxed objects are not expanded).

5 CONSULTATION

The system is portable and can be used on the field in an integrated and interactive manner for both the data acquisition and the risk assessment phases. The operator may select a partially assisted or a fully assisted consultation mode. The main options initially presented by the system are: data acquisition, data processing, text data review, graphic data review, knowledge base updating, and assisted consultation. The last option being for the fully assisted mode.
In the data acquisition option the user selects the desired level of completeness of data gathering, and then the system prompts for the input of the required data.
Specific graphics tools - which substantially improve the efficiency of the geometric data input and data validation - have been developed. The user may describe the structure by selecting among a library of predefined structural elements, or by defining new elements which augment the library and may later be used in other cases.
The system allows efficient incremental data acquisition: the data acquired at a certain level of completeness may later be used to perform a cost effective higher level survey of the building.
Data review and editing is available both in text and graphic modes.
As the data base of surveyed buildings grows, the knowledge base updating option allow to update the typological damage curves.
Finally, the assisted consultation option guides the user in the selection of the appropriate level of data acquisition and data processing. The assistance to the user is calibrated according to his level of expertise.

6 FURTHER DEVELOPMENTS

The first three levels of the assessment methodology have been implemented, while the fourth is currently under development. In addition, it is planned to extend the system, currently implemented for reinforced concrete and masonry buildings, to the evaluation of bridges, sheds, and monuments. Further developments of the system will deal with the integration with a G.I.S. for the evaluation of urban seismic risk. Finally, the system will also be endowed with post earthquake damage assessment capabilities by integration with AMADEUS, an existing knowledge based system for the usability assessment of damaged structure (Pagnoni et al. 1989).

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