A Database Integration Approach to Support Earthquake Hazard Assessment and Seismic Retrofit of Buildings

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SUMMARY:

With the recent advances in technology, e.g. satellites, GPS, and GIS, a great deal of data has been gathered from observed earthquake damage from field reconnaissance following destructive earthquakes. Additionally, a significant body of knowledge has been accumulated from experimental testing of building structural and non-structural systems. This paper proposes an integrated approach through developing an intelligent framework for assessment of the available body of knowledge, and developing intelligent design agents, that serve as analysis tools in different areas of the seismic design process. These tools will interactively clarify lessons learned, and help collaboratively in the improvement of seismic design practices for buildings. The results will provide an intelligent framework for systematically deriving and updating lessons from observed earthquake damage data, and databases of results of seismic testing. This will help advance the state of knowledge in the performance-based approaches for improving seismic design practices.

Keywords: Earthquake Hazard Mitigation, Intelligent Agents, Data Integration, Intelligent Design Environment.

1. INTRODUCTION:

The world has experienced devastation on an unprecedented scale during recent catastrophic earthquakes e.g., Haiti 2010, Chile 2010, Christchurch, New Zealand 2010 & Tohoku, Japan 2011. The resulting human toll of hundreds of thousands of lives lost, and economic losses amounting to billions of dollars seriously affected countries' economies in various sectors, e.g., housing, infrastructure, health, education, industry and cultural heritage. The recent advances in technology e.g. satellites, GPS, and GIS, have made it possible to gather extensive amount of observed earthquake damage data from field reconnaissance following the destructive earthquakes. Recent advances in technology have also made it possible to compile a knowledge base based on seismic testing programs for structures and components.

The earthquake hazard assessment and seismic retrofit of buildings is a complex problem on both the architectural and engineering levels. It involves many related issues or variables. These issues should not be considered in isolation. Some of the variables may be partially defined and some of the required information may be missing. Decisions have to be made on the basis of incomplete information. Reevaluation of performance objectives of buildings contributes to the design complexity.

In This paper, we propose an approach to integrate multiple data sources through developing an intelligent framework for critical assessment of the available body of knowledge, and developing intelligent design agents, that serve as analysis tools in different areas of the seismic design process, e.g. historical and heritage buildings, building non-structural components, buildings with earthquake protection systems etc. The framework will collect lessons-learned and make them available interactively to the seismic design practitioners, in a collaborative environment. The resulting system will derive and update lessons from observed earthquake damage data, and from databases of seismic testing of structures. The intelligent design agents/tools will also serve as mentors for design professionals, helping advance the state of knowledge in the performance based design of buildings.

The intelligent framework will manage the complexity of analysis and design, in collaboration with the human user, by creating information models for buildings, over which intelligent agents can operate to analyze the design and provide feedback to the designer. The internal model is based on a domain ontology to represent design elements and the rich and complex relationships that exist among them. By embedding knowledge into the design environment we provide context for the analysis tools to provide more meaningful results and recommendations to the designer. The information model represents the building under analysis and the agents encapsulate the knowledge in narrow domains, such as building configuration, structural system, enclosure systems, environmental control systems etc.

2. TYPES OF RECORDED EARTHQUAKE DATA

Recorded earthquake data track information about the response of the ground, and structures during an earthquake event. In addition to data collected through sensors and monitoring stations, damage data is collected in the field after an event and relies on surveys and eye witness reports.

2.1. The recorded data for earthquake events may be classified as follows:

Ground Response Data (GrRD): For an earthquake event, recorded data obtained from recording stations consists of time-history data of ground displacements, velocity & acceleration, as well as ground response spectra.

Building Response Data (BuRD): For an earthquake event, recorded data obtained from recording stations consists of time-history response data of displacements, velocity & acceleration, as well as response spectra at the ground level and different levels in the instrumented buildings.

Bridge Recording Station (BrRS) Data: For an earthquake event, recorded data from recording stations consists of time-history response data of displacements, velocity & acceleration, as well as response spectra at the ground level, superstructure level, and at the piers and abutments in the instrumented bridge structures.

2.2. Observed Damage Data

Observed damage data obtained from field reconnaissance following disastrous earthquakes is found to be scattered across multiple agencies, departments and sites. Depending on the nature of the earthquake event, the damage data is collected for a broad class of building types, bridge structures, and dams, to compile patterns & distribution of observed damage. For different building types, the damage data may be classified into the following categories:

- *Building type, age & configuration*
  These include description of building e.g. low-rise, medium-rise, high-rise; material; age of construction; and form & configuration including plan and elevation irregularities.
- *Structural framing system including foundation systems*
  This includes a description of the gravity load & lateral load resisting system; the respective

materials, as well as the foundation system

- *Patterns of structural damage*
  These may include damage to the primary structural system members; the types of damage & their distribution across the building system
- *Interior architectural systems*
  Based on experience during the past several decades, observed damage to architectural systems has become an important part of the overall earthquake hazard & loss mitigation. Observed damage may include damage to interior partition & ceiling systems; lighting systems; including the types of damage and their distribution across the building
- *Exterior architectural systems e.g. facades /cladding*
  Observed damage may include damage to exterior enclosure /envelope / façade/ cladding systems, including types of damage & their overall distribution
- *MEP systems*
  As MEP systems constitute a significant part of the overall cost of a building, the mitigation of hazard & damages to these systems is considered a very important issue. Observed damage may include damage to mechanical & electrical equipment, air-conditioning, plumbing, and fire protection systems
- *Contents*
  This issue is extremely important in heritage buildings e.g. museums with their priceless art collections; warehouse type of stores; hospitals, libraries, laboratories. With increasing reliance on information technology in all sectors of a nation's economy, the mitigation of damage to IT equipment is crucial for survival and recovery following an earthquake event.

For bridge infrastructure systems the damage data may be classified into the following categories:

- Bridge type, age & configuration
- Bridge layout and structural framing system
  This may include the overall layout of the bridge structure, description of the bridge structural framing system including the foundation system
- Patterns of structural damage to sub-structure system
  This may include description of the damage to the bridge foundation system
- Patterns of structural damage to super-structure system
  This may include description of the damage to the bridge super-structure system
- Patterns of damage to pier & abutment system
  This may include description of the damage to the bridge pier & abutment system

2.3. Existing data sources

The major sources for recorded strong motion data from earthquakes are listed below. These sources provide the recorded strong motion data from all recording stations for not only U. S. Earthquakes, but also worldwide earthquake events. By and large these sources allow a search of the archived data based on a selectable name of the earthquake, year, magnitude, epicentral distance etc., and the name of the recording station.

The combined strong motion data source is the CESMD (Center for Engineering Strong Motion Data)

- CESMD: U.S. structural and ground response data (http://www.strongmotioncenter.org)
- VDC (Virtual Data Center) sponsored by COSMOS (http://db.cosmos-eq.org/scripts/default.plx)
- National Geophysical Data Center (http://www.ngdc.noaa.gov/hazard/strong.shtml)
- California Integrated Seismic Network- CISN: (http://www.cisn.org/shakemap.html)
- PEER Center – U. C. Berkeley: (http://peer.berkeley.edu/smcat)

An exciting software tool named "CSMIP-3DV" for 3D visualization of the earthquake response of instrumented buildings during the 1994 Northridge earthquake has been developed by John A. Martin & Associates in co-operation with the California Geological Survey. It is available through the NEEShub network.

The sources of earthquake damage data based on field reconnaissance following disastrous earthquakes are scattered across multiple agencies, departments and sites in the U.S. and around the globe. There is no single point of access that provides all the information in one location. Users have to collect the information from multiple sites and integrate it manually according to their needs, with very little support for integration from the data sources. The major sources of earthquake damage data may be outlined as follows:

- USGS: Provides a major source of damage data from destructive earthquakes around the globe. This damage data includes a photographic library of the damaging effects of earthquakes not only in the U.S. but also around the world.

- PAGER: (Prompt Assessment of Global Earthquakes for Response) is being developed by USGS under their earthquake hazards program, and provides shaking and loss estimates from disastrous earthquakes anywhere in the world.

- NEES: The NEEShub provides access to databases including the 2010 Haiti earthquake database. This database includes results of field reconnaissance of damage suffered by buildings built with reinforced concrete and masonry units. NEES project warehouse is the major source of experimental test data, and serves as a centralized repository of earthquake engineering research data.

- NIST: A disaster and Failure Events Data Repository is being developed at NIST, which will host a national archival database of disaster events, including photos, videos & other documentation.

- QUAKELINE: A bibliographic database developed and maintained by MCEER, that covers earthquakes, earthquake engineering & natural hazards mitigation.

- EQECAT (An ABS Group Company) provides tools and consulting services to insurance, and financial clients to help manage their business risk due to catastrophic events.

- UNITAR (United Nations Institute for Training & Research): Building damage assessment GIS datasets following the 2010 Haiti earthquake are available for downloads.

- GEM (Global Earthquake Model) provides models and tools for global risk assessment through its OpenGEM Risk Assessment Platform, to serve the needs of the global scientific & technical community, governments, engineering & building institutions, disaster & risk management programs & organizations, private industry, media, NGO's, and individuals.

- GRIP (Global Risk Identification Platform): Includes GRIPWeb, an innovative tool and platform for disaster information & knowledge sharing that aims to provide access to important loss data through centralized access to disaster databases around the globe.

- Cambridge Earthquake Impact Database: Includes damage and human casualty data from destructive earthquakes for vulnerability assessment and analysis of seismic risk.

3. CURRENT USE OF DATA

The users are limited to one or two data sources at the most, and access is not easily available.

The table below shows what types of recorded data may of interest to the current users of data e.g. designers, architects & engineers; planners, building officials & policy makers; government agencies & organizations; researchers; and private companies including developers of tools e.g. analysis, visualization, design, and code checking etc. For example the experimental test data available through the NEES project warehouse repository may be of special interest to researchers; designers/architects/engineers; and private companies.

Type of data	Designers – Architects, Engineers	Planners, Building Officials, Policy Makers	Government Agencies and Organizations	Researchers	Private Companies, Contractors, Insurance
Ground Motion					
- Ground motion Recorded data	X	X	X	X	X
- Recorded data from Instrumented Bldgs./Bridges /Dams	X			X	X
- Shakemaps	x	X	X		X
Field Observation of damage/ performance					
- Structures	X	X	X	X	X
- Systems: Interior, Exterior, MEP/Equip.	X X X			x x x	X X X
- Loss of life/Injury	X	X	X		X
Experimental Test Data	X			X	X

Table 1. Types of Users for Earthquake Data

4. THE NEED FOR INTEGRATION

The volume of the available data sources has the potential of providing a bigger picture to many user types and help them make better decisions. In order to build the bigger picture we need to integrate all the available data sources and provide an environment for users to access the data in many ways, depending on their needs and their specific use of the data.

The integrated environment can help advance earthquake engineering practice by providing architects/engineers with the data that is relevant to the design problem at hand, whether a building structure, a bridge or any other type of structure. Information about the behaviour of building elements under shaking conditions helps designers and engineers understand building performance and decide where to place their focus.

Information on damage in an earthquake-hit area provides help to improve recovery and reconstruction efforts. Historic damage information accumulates the experience of previous earthquake events and help recovery workers anticipate and better prepare for recovery efforts.

Policy makers and city planners can benefit from the integrated environment by having access to information about areas affected by earthquakes, the extent of damage with each earthquake, the current building codes and the building performance data under current building codes.

Government agencies, such as FEMA and insurance companies can improve loss estimation, if they have access to historic damage data, current conditions and building performance data. Loss estimation can also benefit from GIS information, satellite imaging information and general census information.

The ability of any decision maker to view multiple sources of information in the context of the issues they would like to address greatly enhances their ability to make better decisions. The integration of such sources provides a wider context for many types of users and a way to develop the bigger picture.

5. SYSTEM DESCRIPTION

This project aims to build an integrated view of multiple data sources in the area of earthquake engineering and make the data more manageable and available on-demand from multiple perspectives. The proposed system consists of three layers: data extraction layer, information model layer, and data access layer. It is designed in a Service-Oriented Architecture which provides benefits for scalability, high availability, easy access, and easy integration into other applications. Figure 1 shows the overall architecture of the proposed systems.

5.1. Data Extraction Layer

This layer will have services to interface with all of the existing databases in the earthquake domain and run checks on data to validate its cleanliness and its readiness for inclusion in the integrated model. Services in this layer include:

5.1.1. Data Cleansing

Data coming from multiple sources may have missing fields or incorrect entries. The data cleansing service detects and corrects or removes corrupt data records. Data cleansing ensures that the data that will flow into the next layer is clean and has no corrupt information.

5.1.2. Data Validation

Often, there are some rules that exist among the data items or constraints on allowed values, such as dates of a birth date field have to fall within a reasonable range or that start date of a task has to be earlier than the end date. Such rules ensure that the data accurately represent reality. The data validation service encodes validation rules and checks the in-coming data against these rules.

5.1.3. Data Completion

In some cases, there are relationships between data items, which would allow the inference of one data item from another or from a group of other fields. This can be useful in expanding the database and filling-in missing information automatically, which provides more context to any application using the data. The data completion service works on such rules. It accepts a set of rules and runs them against available data.

5.1.4. Cataloguing

Since multiple data sources are integrated into one environment, there is a need to track each source and the type of information which it provided. The cataloguing service registers every data source and its structure of information. Other information can be kept about data sources, such as the last update time, frequency of update or type of information contained in it.

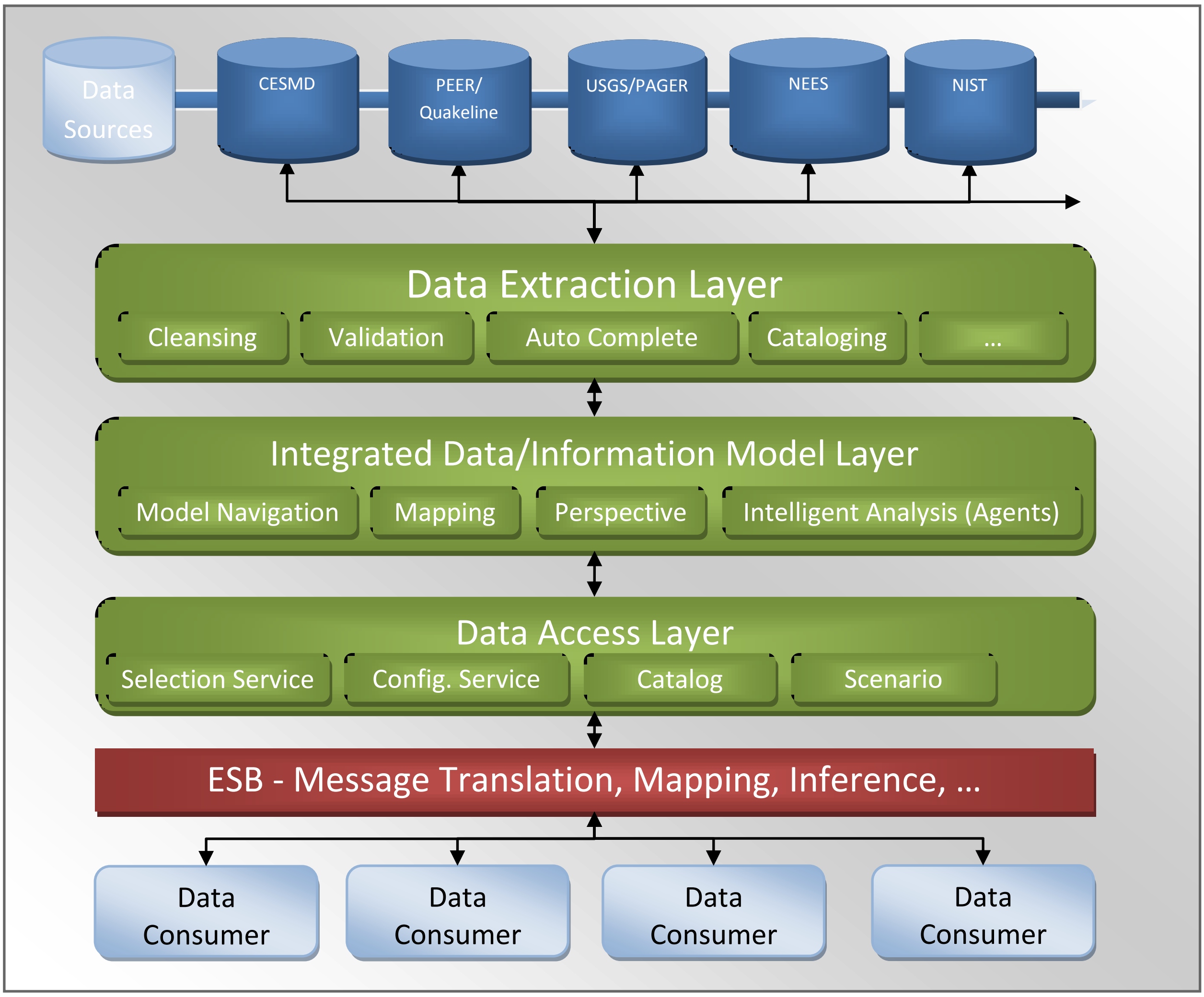

Figure 1. System Architecture for the Integrated Earthquake Data Environment

5.2. Information Model Layer

The internal model is based on domain ontology to represent design elements and the rich and complex relationships that exist among them. By embedding knowledge into the design environment we provide context for the analysis tools to provide more meaningful results and recommendations to the user.

5.2.1. Model Navigation

This service provides tools to the user to explore the information model and examine the data, which is contained in it. The Ontology manages the complexity of information in the domain and requires tools that can navigate that complexity and present a clear picture to the user from different perspectives.

5.2.2. Mapping

Data coming from different sources may have different representations for the same types of data. Integrating such data requires mapping some data elements from one representation to another to create a uniform representation and to match and validate similar data from different sources. The mapping service understands many representation schemas and can map information in one schema into another. More representation schemas can be added as more data sources emerge, which may have new representations.

5.2.3. Perspective

Different types of users look at the same information from different perspectives, depending on their needs, experience and type of activity they need to support. Having a central repository of earthquake data with feeds from different data sources allows us to create multiple perspectives according to users' defined need. The perspective service helps users define the perspective they need and generates that perspective for them.

5.2.4. Intelligent Analysis Agents

Intelligent agents play an important role in the analysis of large volumes of data and provide support to users in the form of recommendations, notifications, and alerts. The ontology-based system allows the development of intelligent agents and embedding them within the ontology to have them benefit from the evolving context. The specific agents will depend on the type of users and will respond to their needs. Agents can be added at run time and the user can select a subset of the available agents to run to support the type of analysis they are interested in. The user profile may store a default collection of agents for each user to facilitate their interaction with the system.

5.3. Data Access Layer

Access to the information model and its stored data requires a set of services to help the user find the information which suits their interest and build automated retrieval of collections of data for repeated types of analysis.

5.3.1. Catalogue

This service allows the user to browse the information model and find out what information exists and in what context.

5.3.2. Configuration

The integrated information model may grow large and the information may be overwhelming to some types of users. We provide a service that will allow the user to determine what parts of the information model are most relevant to their needs and present them with only the information they select. This configuration will be attached to their profile.

5.3.3. Scenario

To run an analysis the user can define a scenario with relevant information and analysis agents. This service helps the user define a scenario, e.g. experimental building performance under a given ground motion event, and define what data sources to use for this scenario. The user can select some analysis agents to help process this information and present it in an integrated picture.

5.3.4. Selection

The selection service helps the user determine what data sources to include in their profile and what data sets of each source they are interested in. The data selection can be stored in their profile and can be changed as their needs change and as more data sources become available.

5.4. The Enterprise Service Bus (ESB)

To support the service-oriented architecture (SOA), an existing enterprise service bus (ESB) will be used to facilitate communications, service registry and discovery, routing, and mapping requests for services.

5.5. Data Consumers

Users of the system can sign up for an account and setup a profile, which defines their interests and the different perspectives they may have. A user may have multiple perspectives to serve multiple roles they may play. For example, a city planner may need to view earthquake damage information by region to determine contingency plans in the case of an earthquake. He may also need to view building performance data to find out if the current building codes require improvements. Since the system is designed on SOA platform, it will be available on the internet. Users can sign up from different regions, organizations, educational institutions, etc.

6. CONCLUSION

The advancements in information technology has led to an explosion of data in many fields, including earthquake engineering. We presented the current state of earthquake data availability and noted the need to integrate multiple data sources into a contextual ontology, which will help practitioners, policy makers, emergency responders and other types of users make better decisions and plans. We proposed a system to integrate the data sources and provide the user with tools to interact with the ontology in many ways. The system is designed in a service oriented architecture, which will allow for addition of services and expansion of functionality as new needs emerge.

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WEB RESOURCES

USGS: http://earthquake.usgs.gov/learn/photos.php

PAGER: http://earthquake.usgs.gov/research/pager/

NEES: http://nees.org/resources/databases

QUAKELINE: http://mceer.buffalo.edu/utilities/quakeline.asp

EQECAT: http://www.eqecat.com/research-publications/reports/

UNITAR: http://www.unitar.org/unosat/haiti-earthquake-2010-remote-sensing-based-building-damage-assessment-data

GEM: http://www.globalquakemodel.org/

GRIPWEB: http://www.gripweb.org/gripweb/

Cambridge Earthquake Impact Database: (http://ceqid.org/CEQID/Home.aspx

SCEChttp://www.data.scec.org/significant/northridge1994.html

http://www.atcouncil.org/pdfs/atc54toc.pdf