SEISMIC RISK ASSESSMENT METHODS AND APPLICATION IN CHINA

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SUMMARY

The paper briefly introduces Seismic Risk Assessment (SRA) methods and application in the recent ten years in China. The paper focuses on structural vulnerability analysis as the followings:

Pocedures of seismic risk assessment of buildings

- un-reinforced masonry structures
- reinforced masonry structures
- reinforced concrete frames
- mill buildings with RC columns and mill buildings with masonry columns
- inventory database for industry and household buildings and the knowledge system for earthquake damage assessment;

SRA methods for lifeline system

- buried pipeline system
- transportation system
- electric power system and communication system.

The last part is the introduction of the case studies of SRA in China.

INTRODUCTION

Seismic Risk Assessment (SRA) is to predict the probability of the building and infrastructure damage and economic losses according to potential seismic hazard or scenario earthquakes. Generally, it consists of two procedures: analyzing seismic hazard and assessing structural vulnerability. Assessment of structural vulnerability is the major aspect of SRA.

Structure Vulnerability Analysis (SVA) in SRA is a kind of pattern recognition method on the base of practical earthquake damage data. SVA methods can be divided into two categories: direct experimental judgment method and earthquake response analysis based judgment method. The first approach identifies the relationship between structural damage and the major factors controlling the structural vulnerability through statistical analysis of the data of damage. Usually, structural damage index representing the earthquake resistant capacity is used to define the damage states. The second approach is to determine the threshold values for different damage states by using of seismic design code and/or dynamic response analysis. The threshold values can be modified considering the quality and status of the structures.

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PROCEDURES OF SEISMIC RISK ASSESSMENT FOR BUILDING

In the paper, the five discrete states used to describe earthquake damage of buildings are: intact, slight, moderate, extensive and complete destroy.

Un-reinforced Masonry Structure

Un-reinforced Masonry building is the typical structure in China. The procedures to assess the structure damage are as follows:

* calculate the yielding shear force of floors considering section area and limit strength of the shear walls.
* calculate the maximum elastic shear force of floors by using of base shear method under the action of scenario earthquake.
* obtain the yielding shear coefficients and the ductility rates of floors through step I and II.
* consider the factors affecting structure ductility, such as seismic design, quality of construction and present situation, to determine damage states.
* identify the relationship between structural ductility rate and damage states through statistical analysis of damage data.

Reinforced Masonry Structure

The experimental measurement method of vibration theory for the inverse question is used to assess the vulnerability of reinforced masonry structures. The method consists of the following steps:

* measure the vibration modes and periods of the structures.
* calculate the stiffness between floors by the vibration theory of inverse question.
* identify the constitutive relationship – skeleton curve (determine several control points) for each floor according to the stiffness between floors.
* determine the damage states corresponding to the position on the skeleton curve with the action of different earthquake intensity.

Reinforced Concrete Frame

Reinforced Concrete Frames are also the most popular structures in China. Considering the yielding strength coefficients of floors ξ_Y and deformation angles of floors θ_{ep}, the damage states of RC structures are defined as follows:

$\xi_Y > 0.8$	Intact
$0.5 < \xi_Y \le 0.8$	Slight
$0.35 < \xi_Y \le 0.5$	Moderate
$0.2 < \xi_Y \le 0.35$	Extensive
$\xi_Y \le 0.2$	Complete

$\theta_{ep} < 1/350$	Intact
$1/350 < \theta_{ep} \le 1/150$	Slight
$1/150 < \theta_{ep} \le 1/80$	Moderate
$1/80 < \theta_{ep} \le 1/30$	Extensive
$\theta_{ep} > 1/30$	Complete

The damage states are determined by the more severe condition according to the above two criteria.

MILL BUILDINGS WITH RC COLUMNS AND MILL BUILDINGS WITH MASONRY COLUMNS

For mill buildings with RC columns and mill buildings with masonry columns, the critical components borne earthquake force are RC columns and masonry columns respectively. The stress of RC column is related to its height, section size, design code and quality of construction. The structure vulnerability analyses of the two kinds of buildings are corresponding to calculating the stresses of columns and walls.

INVENTORY DATABASE FOR INDUSTRY AND HOUSEHOLD BUILDINGS AND THE KNOWLEDGE SYSTEM FOR EARTHQUAKE DAMAGE ASSESSMENT

Inventory database

By the end of 1992, there are 2365 cities and counties in China. The database covers the industry and household buildings of 2289 cities and counties. Most of the absent data belongs to Tibet.
In the database, the structures are divided into six categories: steel structure, steel and RC structure, RC structure, mixed structure, masonry and wood structure, the other structures, according to the materials of the main components sustaining the structure weight
.
There are five discrete damage states of buildings, which are intact, slight, moderate, extensive and complete destroy.

Intelligent system

The intelligent system for earthquake damage assessment integrates the abundant damage experience of various structures, the vulnerability analysis methodology and expert judgment. The intelligent system can be used to assess the earthquake damage and losses for regional buildings and individual structure.

SRA METHODS FOR LIFELINE SYSTEMS

Lifeline systems exist in the form of point and line integration network, such as water system, traffic system, electric power system and communication system, which play significant role in society and daily life.
SRA for lifeline systems are very complicated problems. It relates to the followings:
* seismic hazard analysis and microzonation
* ground failure assessment
* structural dynamic analysis and assessment for system component damage
* network analysis (function analysis) for system
* secondary disaster analysis.

SRA methods for lifeline systems are not well developed as the methods for buildings due to the following unsolved problems:
* Both of seismic hazard analysis and ground failure assessment are not satisfied with the requirement of damage analysis.
* Because of the complex and diversity of lifeline systems, the damage mechanisms of some structures and facilities are not well known. It is hard to develop suitable analysis methods for lifeline systems.
* The damage states of the systems and components have not been uniformly defined. It is difficult to carry out theoretical analysis with the insufficient damage data.

In spite of these difficulties, a number of researchers are exploring methods to assess the earthquake damage of lifeline systems.

Buried Pipeline System

The major factors related to the earthquake damage of buried pipelines are the followings:
a. site condition such as active fault, liquefaction, ground settlement, landslide
b. intensity of ground movement
c. material and quality of pipeline
d. joint type, form of pipeline construction, and diameter of pipeline, etc.

Conclusively, the parameters used in pipe damage assessment are the followings:
a. ground motion parameters
b. soil parameters
c. buried pipeline depth under soil surface
d. pipeline sizes
e. erosion factors
f. curvature radius of curved pipelines

g. transfer coefficients between pipeline and soil.

The damage phenomena of buried pipelines are deformation, bending, yielding, joint loose, crack and break. The pipeline damage can be divided into three states: intact, moderate and destroy. There are two kinds of assessment methods for buried pipeline damage: experimental methods and theoretical methods.

(1) Experimental methods

Through the statistical analysis of earthquake damage data for pipelines, the methods use curves and experimental formulas to represent the relations between intensity of ground movement and pipeline damage states.

(2) Theoretical methods

Theoretical methods calculate the stresses of continuous pipelines and the strain of pipe joints. Two criteria are used to define the damage states of continuous pipelines.

The stress criterion: the yielding stress and the limited stress are the two critical points, which should be modified according to pipeline quality.

The strain criterion: on the condition of half apparent wave length and one apparent wave length, the two permit deformations of inner pipe joint are the two critical points.

The procedures of damage assessment for buried pipeline system are as follows:
a. Simulate pipeline system as an integration network of points and lines.
b. Calculate the probability of losing function for each pipe, considering earthquake action, ground failure and pipe status.
c. calculate the probability of losing function for network, According to the network features of pipeline system.

Transportation Systems

Transportation systems include highway, railway, airline and waterway. Highway and railway are the major transportation methods in China and the critical aspects of earthquake disaster prevention and mitigation in transportation system.

Highway and railway

The major factors related to earthquake damage for highway and railway are the followings
* soil liquefaction and settlement of soft soil
* inhomogeneous soil density and low strength of road base
* unfavorable water influence
* river bank slide
* landslide
* Intensity and characteristics of ground motion.

Presently, it is difficult to assess the damage of highway and railway by means of experimental formula. The common used methods are to evaluate the vulnerable section of the systems considering the factors mentioned above and damage experience.

Bridge

Railway bridge

The damage of 123 railway bridges in Tangshan Earthquake were divided into five classes: intact, slight, moderate, extensive and destroy. Each class corresponds to one damage index. The formula to calculate the damage index is from multiple linear regression method with least square principle. The major factors relative to bridge damage index are earthquake intensity, height of pier, foundation type, liquefaction, soil condition, length of beam and span, etc..

Highway bridge

The method of damage assessment for highway is similar to railway's. It is developed on the base of the damage data more than 100 bridges in Tangshan Earthquake, Haicheng Earthquake and Tonghai Earthquake. The major factors relative to bridge damage index are somewhat different from railway's.

Electric Power System and Communication System

The analysis methods for buildings in electric power system and communication system are same as the methods mentioned above.

An electric power system consists of substations, distribution circuits, generation plants and transmission towers. A communication system consists of telephone central offices, wires and other facilities. The two systems are so complicated and diversified that it is difficult to deal with. Additionally, there are few damage data for the same kind of components. Two factors are involved in the damage of the systems. The first is that the facilities are improperly braced or stroked by other objects, which is the engineering aspect of damage. The second is loosing function due to strong shaking, which relates to the reliability of the facilities. Combination of the two factors increases the difficulty of the analysis.

Some researchers attempt to verify the strength of the facility brace and to assess the damage of the systems through simplified models according to principles of static and dynamic theory. Some factories producing the facilities try to measure and improve the reliability of the facilities through shaking table experiments. Undoubtedly, both attempts are beneficial to the analysis. However, it will take a long time to develop an acceptable method.

CASE STUDIES OF SEISMIC RISK ASSESSMENT

In 1980's, some cities and industry enterprises conducted seismic risk assessment in China focusing on structural vulnerability in order to realize the earthquake resistant capacity of buildings and facilities and to take corresponding countermeasures. Datong, Taiyuan Steel Factory, Anyang are typical cases.

Seismic risk assessment continues to develop in 1990's.

In the fist five years of 90's, SRA methods integrated seismic hazard analysis, site effect and structure vulnerability. The critical project "Mapping Earthquake Damage Assessment with Various Scales" was scheduled in "85" program by State Seismological Bureau (SSB, present title CSB). SRA was conducted for some regions in 14 provinces focusing on aggregated buildings (see Table 1).

Table 1

Number	1	2	3	4	5
Location	Dianxi	Mianning and Other 6 Counties	Stressed Regions	Qingxu	Lunan
Province	Yunnan	Sichuan	Jiangsu	Shanxi	Shandong

Number	6	7	8	9	10
Location	Western Area	South East Area	Middle East Area	North Tianshan Mountain	Boai County
Province	Liaoning	Gansu	Shannxi	Xinjian	Henan

Number	11	12	13	14
Location	Tianjin	Zhujiang Delta	Northern Area	Northern Area
Province	Tianjin	Guangdong	Hebei	North China

The working area (500,000km^2) covers 43 cities, 140 counties and 14 enterprises. The typical case studies are for Linfen, Daqing and Tianshan District of Urmuqi. The characteristics of the projects are:

a. detail investigation to seismo-tectonic features and seismic hazard analysis
b. adoption of computer graphics

c. The Tianshan, Urmuqi project adopted GIS technique to analyze individual building.

In the second half of 1990's, the attention is changed to metropolis where people densely live and economy well developed and GIS application. The results of SRA are not only used in earthquake resistance and prevention, but also applied in planning, land use and emergency response. The application of GIS overcomes the limitation of SRA, extends the application of SRA.

The critical project "Case study and Application of Earthquake Disaster Prevention and Reduction for Urban in China" in "95" program is put into operation by China Seismological Bureau (CSB, pre-title SSB) (table 2).

Table 2

Number	1	2	3	4	5	6
Location	Zigong	Binhai District	Urumqi	Zhangzhou & Fuzhou	Dalian	Taian
Province	Sichun	Tianjin Municipality	Xinjiang	Fujian	Liaoning	Shandong

It should be mentioned that the critical project in "95" program for Zigong is combined with RADIUS Project of IDNDR.

Fig. 1 and Fig 2 are parts of the results of the case study in Urmuqi City.

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