GIS-based seismic hazard prediction system for urban earthquake disaster prevention planning

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Abstract

A basic framework of a GIS-based seismic hazard prediction system for urban earthquake disaster prevention planning is developed in this study, incorporating structural vulnerability analysis, program development, and GIS. The system is integrated with proven building vulnerability analysis models, data search function, spatial analysis function, and plotting function, realizing the batching and automation of seismic hazard prediction and the interactive visualization of predicted results. The system is applied to a test area and the results are compared with results from previous studies to verify that the system can provide data support and aid decision-making for the establishment and implementation of urban earthquake disaster prevention planning. Results from this study are essentially the same as the results of 2003 and slightly better than the results of 1993, which highlights the reliability of the fragility analysis method applied in this system.

Keyword: GIS; Urban Earthquake Disaster Prevention Planning; Seismic hazard Prediction; Aid Decision Making

Introduction

An earthquake is one of the most severe natural disasters facing humanity today, especially in urban regions (Wang F, Jiang JQ, 2005). Recent earthquakes both within and outside China (Thomas C M, Rad F N, 1997; Ye YX, 1989; King S A, Kiremidjian A S,1990) have shown that it is important to implement urban earthquake disaster prevention planning before the disaster to reduce losses due to earthquakes. Therefore, to tackle earthquake hazards in China, it is necessary to establish urban earthquake disaster prevention planning in China. Seismic hazard prediction is one of the basic methods that can be employed for earthquake disaster prevention.

Geographic information system (GIS) is a computer system that can collect, store, analyze, and display geo-referenced information. City buildings are characterized geographically by their types, functional diversity, and large quantity. Hence it is prominently efficient to apply GIS into dynamic spatial analysis of city buildings, and it will also be of benefit in some related activities, such as post-earthquake loss fast evaluation and disaster relief.

GIS has been used for earthquake disaster prevention for more than 20 years. The research in American and Japan is relatively established such that the system developed by these two countries is universally applied in civilian areas (Mejia N M, 1996; CL Ho, TA Hadj-Hamou & M Nilsson, 1995; Shinozuka M et al., 2006). China started late in this field, but has also recorded great success (Tang AP, Dong Y & Wen AH, 1999; Li G et al., 2006); GIS-based information management systems for urban earthquake disaster prevention have been set up successively in Quanzhou, Shantou, and Hefei. However, the application of GIS for earthquake disaster prevention has concentrated more on the management and acquisition of basic data and research results (Zhou XY, Chen YP, 1986), which cannot meet the growing need for damage evaluation and display.

Based on the above background and previous research, a seismic hazard prediction system for urban earthquake disaster prevention planning was developed based on ArcGIS, and the Weifang Street in Pudong New Area, Shanghai was selected as the test area in this study. From the practical demand for urban earthquake disaster planning, the system uses data requirement and process procedure to predict building seismic hazard to minimize human intervention and make it more applicable. Therefore, the system implements visual management of urban seismic hazard prediction, assisted planning of disaster prevention, and decision-making in emergency rescue.

Data used in this study was from the Pudong branch of the Shanghai Institute of Surveying and Mapping. Compared with results from previous studies, results from this study are essentially the same and even slightly better, which highlights the reliability of the analysis method implemented in this system.

System framework design and function realization

The seismic hazard prediction system developed in this study is based on ArcGIS, which has three external toolboxes: the statistics toolbox of seismic hazard matrix, the prediction toolbox of earthquake damage evaluation, and the assignment toolbox of the construction time and predictive results. The flow chart of the system is illustrated in Fig 1.

Statistics toolbox of seismic hazard matrix

The major function of the statistics toolbox of the seismic hazard matrix is to establish seismic hazard data in the working area. Building vulnerability analysis models are embedded in the toolbox. After inputting fact-finding samples, it implements batch computing and statistical analysis of data through simple interaction and generates a separate project file, which includes parameter information and analysis results of all samples, the earthquake damage matrix of all buildings in various structure types, and the damage index calculated chronologically. Only structural types were considered in assigning predictive results to buildings in a previous study (Zhou GQ et al., 2010); however, in reality, the seismic capacity of buildings is obviously related to the construction time. Therefore, the construction time of buildings was taken into account in this study, and as a result, the prediction accuracy improved as one more dimension was added （Hu SQ, 2007）. The project file will be inputted into the assignment toolbox of the construction times and predictive results as data source.

Buildings were classified into six types, these are multistory masonry structure, reinforced concrete structure, inner frame and bottom frame masonry structure, single-story industrial building, and empty house, old house, and important building; vulnerability analysis models were established for each building type.

Prediction toolbox of earthquake damage evaluation

The integrity of the feature attribution of building layer files in GIS is the foundation for building seismic hazard prediction. Attribution assignment consists of structural types and construction time. The prediction toolbox of earthquake damage evaluation mainly realizes the perfection of building structural types and data connection of external programs. There are four submodules of the prediction toolbox: the pretreatment module of building polygon, the assignment module of structure attribution, the output module of xls file, and the match module of damage evaluation, as shown in Fig 2.

The pretreatment module of building polygon chiefly pretreats layer files, including deleting redundant field information, calculating total area of buildings, screening important buildings, such as schools and high-rise buildings, and defining their attribution fields. The field processing function of the data management tools in the Arc Toolbox was used and some codes scripted in Python 9.3 and VB under ArcGIS Engine were used for reclassification. Through the pretreatment module, important buildings can be defined, but approximately half of the buildings still lack structural types (Liu W, 2012).

To further perfect structure attributions, the assignment module of structure attribution was developed using the space connection function of the overlay analysis tool in the Arc Toolbox. Space connection means that attributions are transferred to feature classes according to the space relationship between two features (Wei Q, 2012). As long as specified space relationships or matching options were found, the attribution of connection features will be added in the target features. In building layer files, features with intersection relationship can be considered to belong to one building with identical structural type. Except the attribution transfer according to the intersection relationship between surface features, comprehensive screening and fuzzy classification of building information, such as name, use, area, and number of stories can be carried out to perfect the structural types of features.

The integrity of the structural type feature of the layer data processed through the assignment module of structure attribution was close to 100%. A text area before and after pretreatment is taken as an example as illustrated in Fig 3. Before pretreatment, there were many features with unassigned structure attributions and the structural type was single; however, after pretreatment, almost all features were well-defined and in rich structural type.

The output module of the xls file writes the layer files processed in xls files. The attribution data of the GIS layer was in dbf format; therefore, it cannot be read by other external software. Therefore, a program was scripted in Python to export layer attributions to the default working directory of ArcGIS for the assignment toolbox of the construction time and predictive results for recall (Wang WD, Zeng K & Fang LG, 2011).

The match module of the damage evaluation results sets a connection between layer files and the exported files of the assignment toolbox of the construction time and predictive results in order to obtain results of seismic hazard prediction and attribution values of the construction time while sorting data formats for laying the foundation for the final 2D/3D visualized presentation of the predictive results. The processed layer attributions contain intact and visual information as shown in Fig 4.

Assignment toolbox of the construction time and predictive results

The structure attributions of the building features processed through the modules of the ArcGIS prediction toolbox of the earthquake damage evaluation have been perfected; however, it is still necessary to supplement the construction time of buildings in subsequent works. It will be difficult to import information about thousands of buildings in an area, even in a city, manually; it will consume enormous manpower and resources.

The assignment toolbox of the construction time and predictive results in the system was developed in C#, and web crawler was applied to complete the construction time of buildings. Web crawler is an important part of a search engine that accesses webpages tactically without user intervention (Cho J, 2013) as shown in Fig 5.

The tool takes attribution files exported from ArcGIS as data source, fetches building names therein to search subject terms, roams network from an initial URL, and evaluates the dependency between subject terms (the construction times of buildings) and contents in pages, while weighting and transmitting the significance of parent pages through the chain structure of pages.

Content-based evaluation is in accordance with subject terms and current linkage text, including the similarity among URL character strings and anchor texts. A common algorithm called best-first search was adopted in this study (P B A, 2003). Its general formula is:

$$¿(q,p)=\frac{\sum^{k\in q\cap p} f_{kq}\cdot f_{kp}}{\sqrt{\left(\sum^{k\in q} f_{kq}^{2}\right)\cdot\left(\sum^{k\in p} f_{kp}^{2}\right)}} \tag{1}$$

In the above equation, q is the subject, p indicate the crawled pages, f_{kq} is the appearance frequency of the word k in q, and f_{kp} is the appearance frequency of the word p in q.

The web is a type of semi-structured document, including large structural information, such as outlink and inlink. The evaluation method based on the link structure weights the significance between linkages through the mutual reference among pages. The most representative one is the PageRank algorithm (S B, L P, 1998). It is described by:

$$R(i)=(1-d)+d\times\sum_{j\in B(i)}\left[R(j)/N(j)\right] \tag{2}$$

In Equation (2), $B(i)$ is the assemblage of the pages orientating page i, $N(i)$ is the number of hyperlink orientating other pages in page i, $R(i)$ is the significance of page i, and d is the decay factor.

Pages with high dependency and significance will be listed in candidate queues to be accessed first, while pages beside subject terms will be discarded. If the accessed page contains the construction time of buildings, data will be written in the attribution files under the default working directory of ArcGIS (Wang ZY, 2012).

After the assignment of the construction time, select the project file generated by the statistics toolbox of the seismic hazard matrix so that predictive results can be assigned according to the construction time and structural types of buildings

Results

The seismic hazard prediction system developed in this study was integrated in ArcGIS with powerful drawing and displaying function (Leng XP, 2012). According to the damage index calculated by the system, 2D and 3D seismic hazard prediction maps of the test area were drawn.

The 2D seismic hazard prediction map characterizes the global seismic behavior of buildings in a certain area through the mean damage index as shown in Fig 6. The damage index is a non-dimensional index to evaluate the seismic hazard of a certain structure or component under seismic action, and it is an important indicator that quantitatively evaluates the seismic hazard of a structure. The mean damage index is the mean of the damage index of all buildings (Zhou GQ, 2011). It can be calculated by the following equation:

$$D_z=\sum(D_j\times A_j)/\sum A_j \tag{3}$$

In Equation (3), D_z is the area mean damage index under a certain seismic intensity, D_j is the damage index corresponding to the damage classification j under a certain seismic intensity, A_j is the area of the building corresponding to the damage classification j under a certain seismic intensity.

The 2D seismic hazard prediction map characterizes the macroscopic seismic behavior of buildings rather than the seismic hazard of various structural types. Based on the damage evaluation results in various levels generated by the system, the ArcScene module in ArcGIS was used to create 3D scene models to visually show the predictive results of buildings as shown in Fig 7. The 3D seismic hazard prediction map characterizes the impact of structural types, building function, and construction time on seismic behavior. There are numerous multistory masonry buildings that present different seismic hazards according to the variety of construction time and function in the test area. As a result, the prediction accuracy improved greatly compared with the previous prediction results when only structural types were considered.

Discussion

In this study, Weifang Street in Pudong New Area, Shanghai was selected as the test area owing to its rich structural types and long construction time.

Buildings were sampled according to the relative specification that the cumulative area of valid samples was approximately 8% of the total area of buildings in the test area. Applying the seismic hazard prediction system developed in this study to analyze samples and run statistics of seismic hazard matrix and compare the research results with results from the Shanghai Institute of Disaster Prevention and Relief in 1993 (SIDRP, 1993) and the Institute of Engineering Mechanics, China Earthquake Administration in 2003 (IEM, 2012), we can conclude that the predictive results presented in this paper are essentially the same as the results of 2003 and slightly better than the results of 1993. This is because the seismic behavior of new buildings is generally better than existing buildings; meanwhile, information on construction time was added based on the original methods, which improved the dimension of building information and made predictive results more objective and exact. Therefore, it is believed that the fragility analysis method applied in this system is reliable.

Conclusion

Seismic hazard prediction is one of the basic operation of urban earthquake disaster prevention planning and research, and GIS is an important tool to realize such disaster prevention planning. In this study, a seismic hazard prediction system was designed and developed in VB, Python, and C#. The system was integrated with proven building vulnerability analysis models, data search function, spatial analysis function, and plotting function, in order to realize batching and automation of seismic hazard prediction and the interactive visualization of predicted results. The precision of the seismic hazard prediction was improved because the construction time of the building was taken into consideration. Besides, the system is of high intelligence and minimal manual intervention, which meets the operating requirements of non-professionals and provides a feasible technique and operating procedure for large-scale urban seismic hazard prediction.

The system was applied in Weifang Street in Pudong New Area, Shanghai (test area), and the results were compared with previous studies to verify the reliability of the system. Results from this study were comparable with previous studies and even slightly better in some cases. Based on the prediction system, related departments can reinforce buildings in weak areas and improve the level of seismic hazard prediction and aid decision-making, which is a crucial technological approach to enhance urban anti-disaster capacity and relieve earthquake disaster loss.

Acknowledgments

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References

Wang F, Jiang JQ. Discussion on the Methods Analyzing Urban Earthquake Vulnerability. Journal of Seismological Research. 2005; 28(01): 95-101.

Thomas C M, Rad F N. An Earthquake Loss Estimation Methodology for Building Based on ATC-13 and ATC-21. Earthquake Spectra. 1997; 4(13): 605–621.

Ye YX. Promoting Disaster Prevention Technology, Making New Contribution at “IDNDR”. Earthquake Resistant Engineering. 1989; 3: 4-10.

King S A, Kiremidjian A S. Regional Seismic Hazard and Risk Analysis through Geographic Information System. Stanford, CA: Depart of Civil Engineering. Stanford University; 1994.

Mejia N M. Natural Hazard and Risk Assessment Using Decision Support System

Application: Glenwood Spring, Colorado. Engineering Geosciences. 1996; 2(3): 299-324.

CL Ho, TA Hadj-Hamou, M Nilsson. GIS Based Zonation of Infrastructure Damage Related to Seismologically Trigger Landslide Risk. Seismic Zonation. 1995.

Shinozuka M, C Park, PH Chou, Y Fukuda. Real-Time Damage Localization by Means of MEMS Sensors and Use of Wireless Data Transmission. Proc Spie. 2006; 61780A-61780A-11.

Tang AP, Dong Y, Wen AH. A Review on Applications of GIS to Seismic Disaster Reduction of Cities. Journal of Natural Disasters. 1999; 8(02): 67-72.

Li G, Ma DH, Su JY, etc. Auxiliary Decision-Making Information System for Planning Management of Urban Earthquake Reduction and Disaster Prevention. Journal of Natural Disasters. 2006; 15(2): 44-48.

Zhou XY, Chen YP. Research and Practice of Urban Earthquake Damage Prevention Planning. 40-Year Study on Engineering Seismology in China. Beijing: Seismological Press. 1986; 166-171.

Zhou GQ, Lu YK, Fei ML, etc. Research on Primary Evaluation of Earthquake Disaster Loss. Journal of Seismological Research. 2010; 33(2): 208-215.

Hu SQ. Research on Earthquake Damage Prediction of Building Groups and Discussion on Economic Loss Forecast Methods of Infrastructure. Harbin: Institute of Engineering Mechanics, China Earthquake Administration. 2007.

Liu W. Design and Implement of the Emergency Rescue and Command System Based on Mobile GIS. Shenyang: Shenyang institute of computing technology, Chinese academy of sciences. 2012.

Wei Q. Discussion on Data Processing Method of Forestland Border Definition in County Level of Forestland Protection and Utilization Planning. Forest Inventory and Planning. 2012; (06): 10-14.

Wang WD, Zeng K, Fang LG. Landslide Susceptibility Mapping Based on Geo-Processing Service. Journal of Central South University. 2011; (07): 2086-2094.

Cho J. Crawling the Web: Discovery and Maintenance of Large-scale Web

Data. L.A.: Stanford University. 2013; 3(3): 62-66.

P B A. TCP/IP Protocol Suite. Beijing: Tsinghua University Press. 2003

S B, L P. The Anatomy of a Large-scale Hypertexual Web Search Engine. Computer Networks. 1998; 4(30): 107-117.

Wang ZY. Research on Key Problems in Web Text Mining. Beijing: Beijing University of Posts and Telecommunications. 2012.

Report on Earthquake Hazard Prediction Research of Shanghai. Shanghai: Shanghai Institute of Disaster Prevention and Relief. 1993.

Report on Earthquake Hazard Prediction of Pudong New Area. Harbin: Institute of Engineering Mechanics, China Earthquake Administration. 2003.

Leng XP. The Study of 3D Geo-Hazard Information Management Platform Based On G/S Model. Chengdu: Chengdu University of Technology. 2012.

Zhou GQ. Seismic-damage Index of Simple-buildings in Yunnan. Journal of Seismological Research. 2011; 34(01): 88-95.

Figure 1

Framework of seismic hazard prediction system

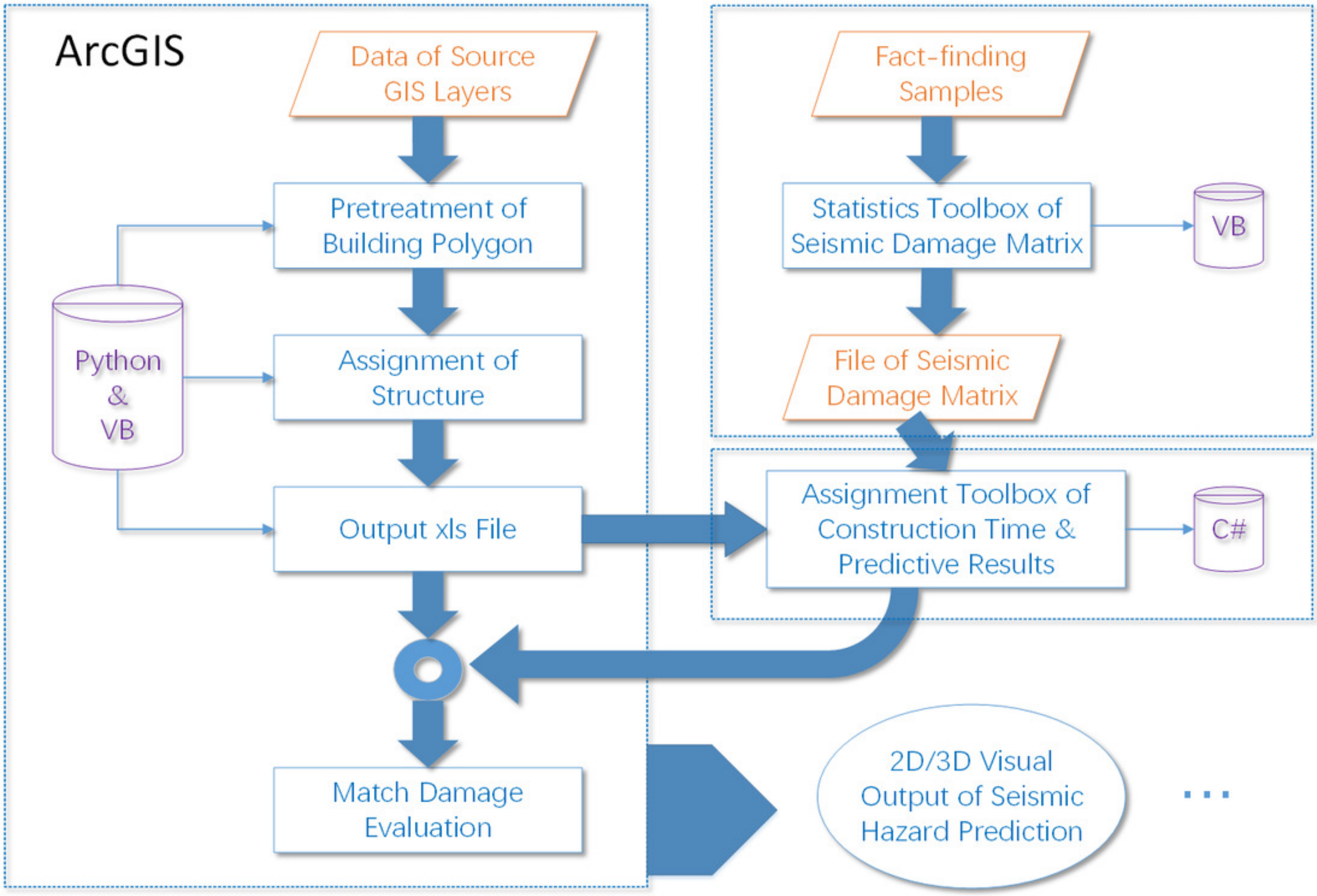

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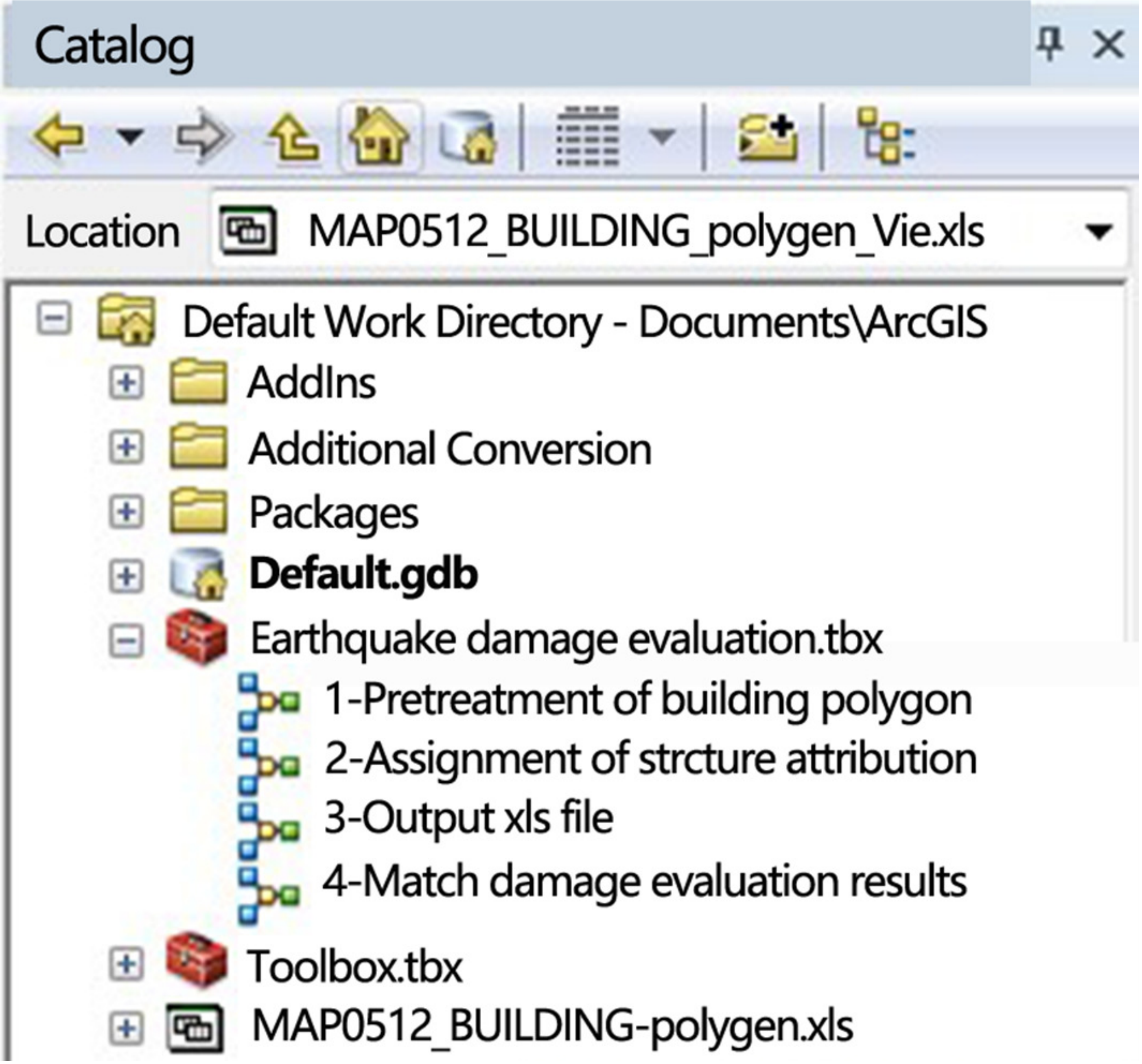
Figure 2

Prediction toolbox of earthquake damage evaluation



MAP0512_BUILDING_polygen_Vie.xls

- Default Work Directory - Documents\ArcGIS
  - AddIns
  - Additional Conversion
  - Packages
  - **Default.gdb**
  - Earthquake damage evaluation.tbx
    - 1-Pretreatment of building polygon
    - 2-Assignment of strcture attribution
    - 3-Output xls file
    - 4-Match damage evaluation results
  - Toolbox.tbx
  - MAP0512_BUILDING-polygen.xls

Figure 3

Distribution of structural types before and after pretreatment

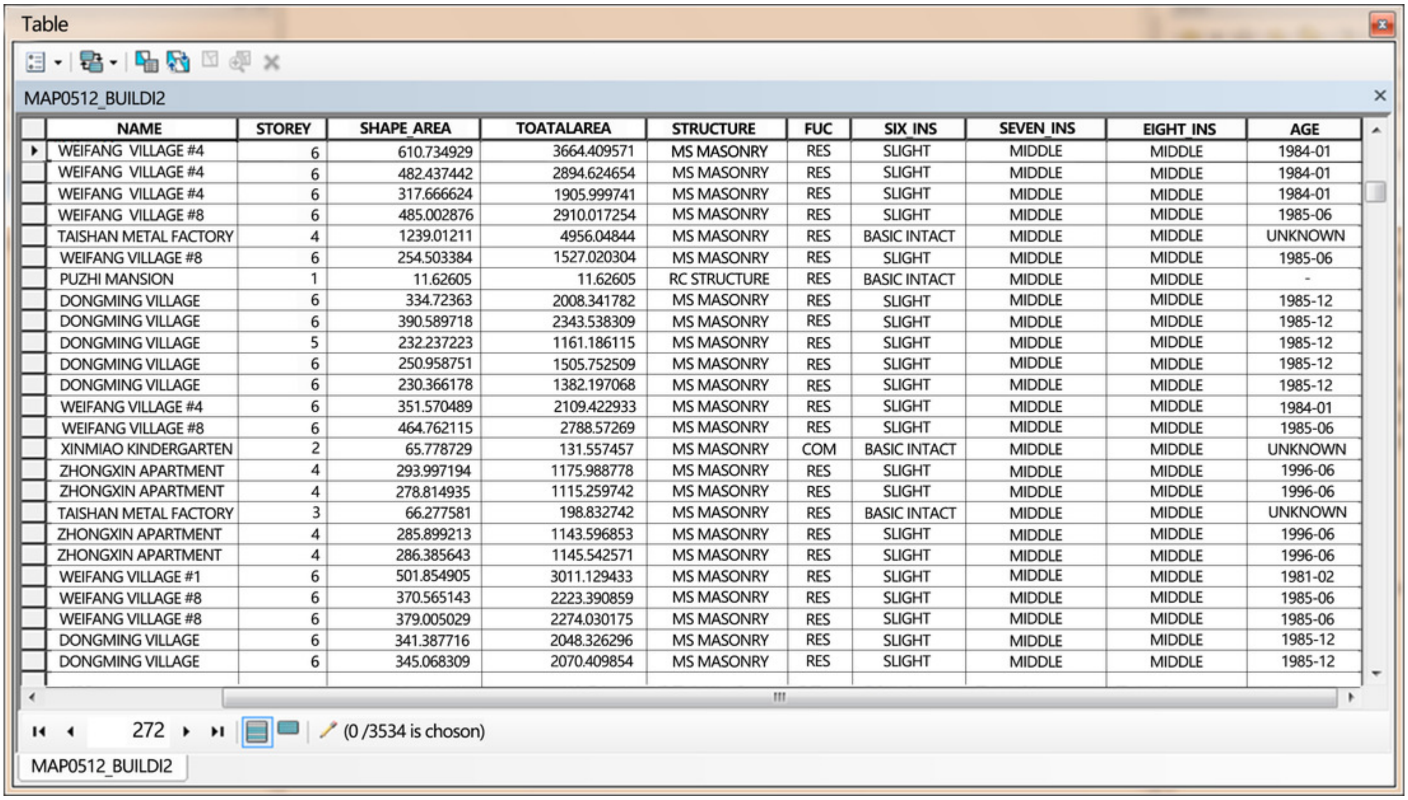
(A) Distribution of structural types before and before pretreatment

(B) Distribution of structural types before and after pretreatment


A
Undefined Structure
Reinforced concrete structure
Multistory masonry structure
B
Undefined structure
Reinforced concrete structure
Important building
Multistory masonry structure
Old house
Single-story industrial building

Figure 4

System-processed attribution table of building layers



NAME	STOREY	SHAPE_AREA	TOATALAREA	STRUCTURE	FUC	SIX_INS	SEVEN_INS	EIGHT_INS	AGE
WEIFANG VILLAGE #4	6	610.734929	3664.409571	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1984-01
WEIFANG VILLAGE #4	6	482.437442	2894.624654	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1984-01
WEIFANG VILLAGE #4	6	317.666624	1905.999741	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1984-01
WEIFANG VILLAGE #8	6	485.002876	2910.017254	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-06
TAISHAN METAL FACTORY	4	1239.01211	4956.04844	MS MASONRY	RES	BASIC INTACT	MIDDLE	MIDDLE	UNKNOWN
WEIFANG VILLAGE #8	6	254.503384	1527.020304	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-06
PUZHI MANSION	1	11.62605	11.62605	RC STRUCTURE	RES	BASIC INTACT	MIDDLE	MIDDLE	-
DONGMING VILLAGE	6	334.72363	2008.341782	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
DONGMING VILLAGE	6	390.589718	2343.538309	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
DONGMING VILLAGE	5	232.237223	1161.186115	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
DONGMING VILLAGE	6	250.958751	1505.752509	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
DONGMING VILLAGE	6	230.366178	1382.197068	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
WEIFANG VILLAGE #4	6	351.570489	2109.422933	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1984-01
WEIFANG VILLAGE #8	6	464.762115	2788.57269	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-06
XINMIAO KINDERGARTEN	2	65.778729	131.557457	MS MASONRY	COM	BASIC INTACT	MIDDLE	MIDDLE	UNKNOWN
ZHONGXIN APARTMENT	4	293.997194	1175.988778	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1996-06
ZHONGXIN APARTMENT	4	278.814935	1115.259742	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1996-06
TAISHAN METAL FACTORY	3	66.277581	198.832742	MS MASONRY	RES	BASIC INTACT	MIDDLE	MIDDLE	UNKNOWN
ZHONGXIN APARTMENT	4	285.899213	1143.596853	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1996-06
ZHONGXIN APARTMENT	4	286.385643	1145.542571	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1996-06
WEIFANG VILLAGE #1	6	501.854905	3011.129433	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1981-02
WEIFANG VILLAGE #8	6	370.565143	2223.390859	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-06
WEIFANG VILLAGE #8	6	379.005029	2274.030175	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-06
DONGMING VILLAGE	6	341.387716	2048.326296	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12
DONGMING VILLAGE	6	345.068309	2070.409854	MS MASONRY	RES	SLIGHT	MIDDLE	MIDDLE	1985-12

272 (0 /3534 is choson)

Figure 5

Operating principle of web crawler

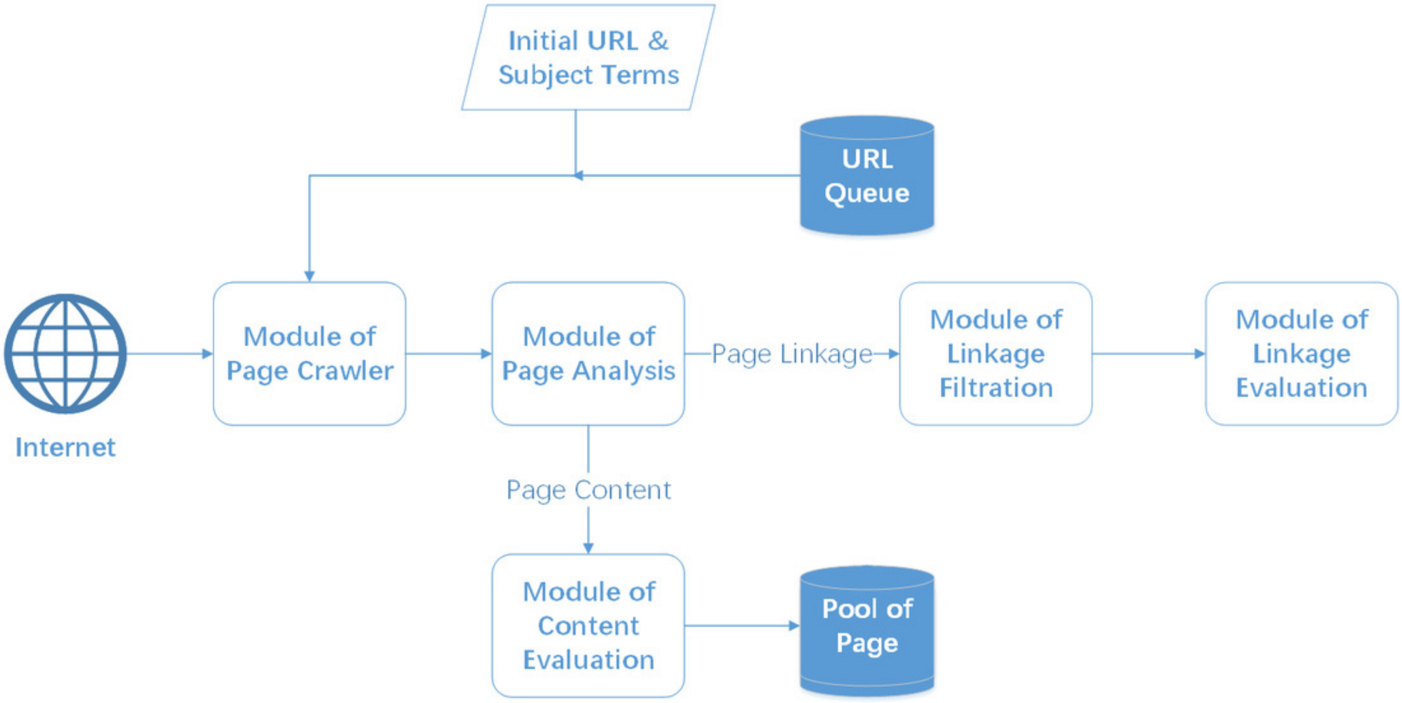


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Figure 6

2D seismic hazard prediction map

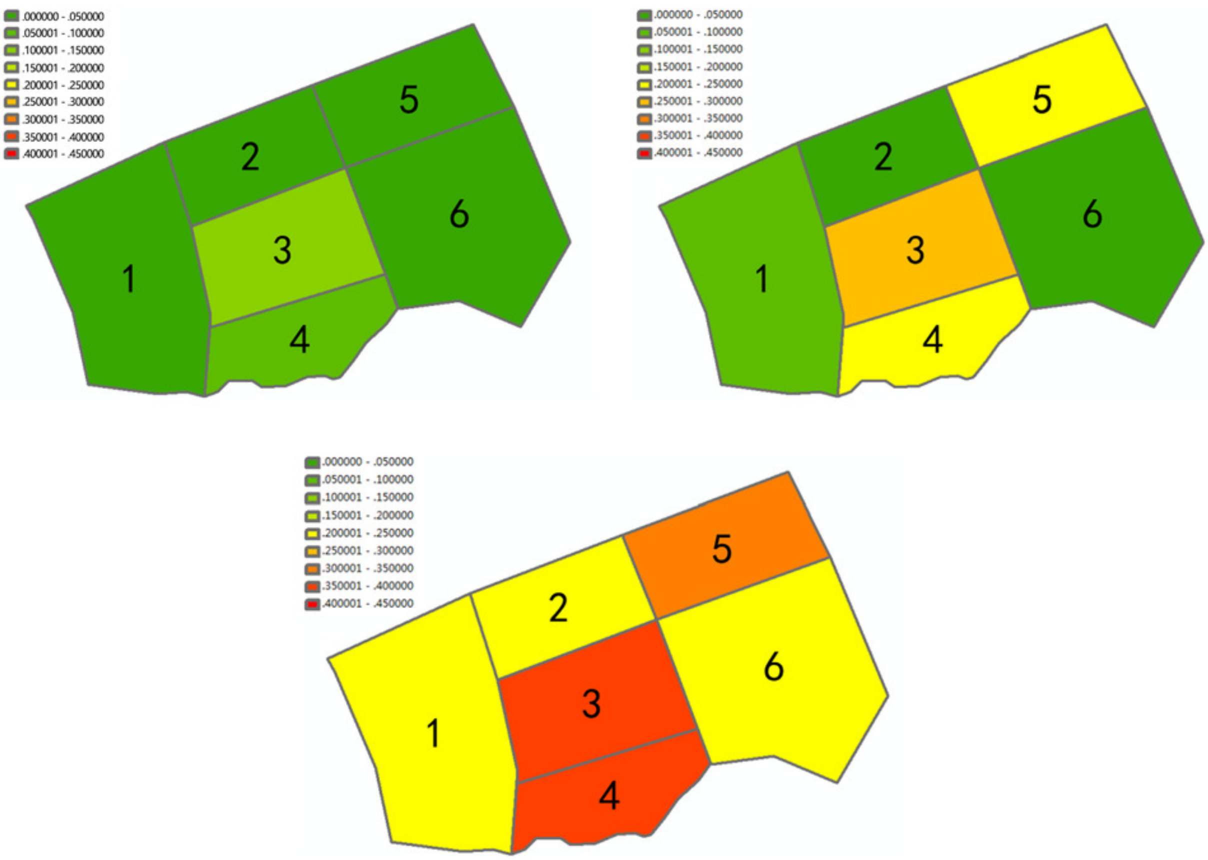
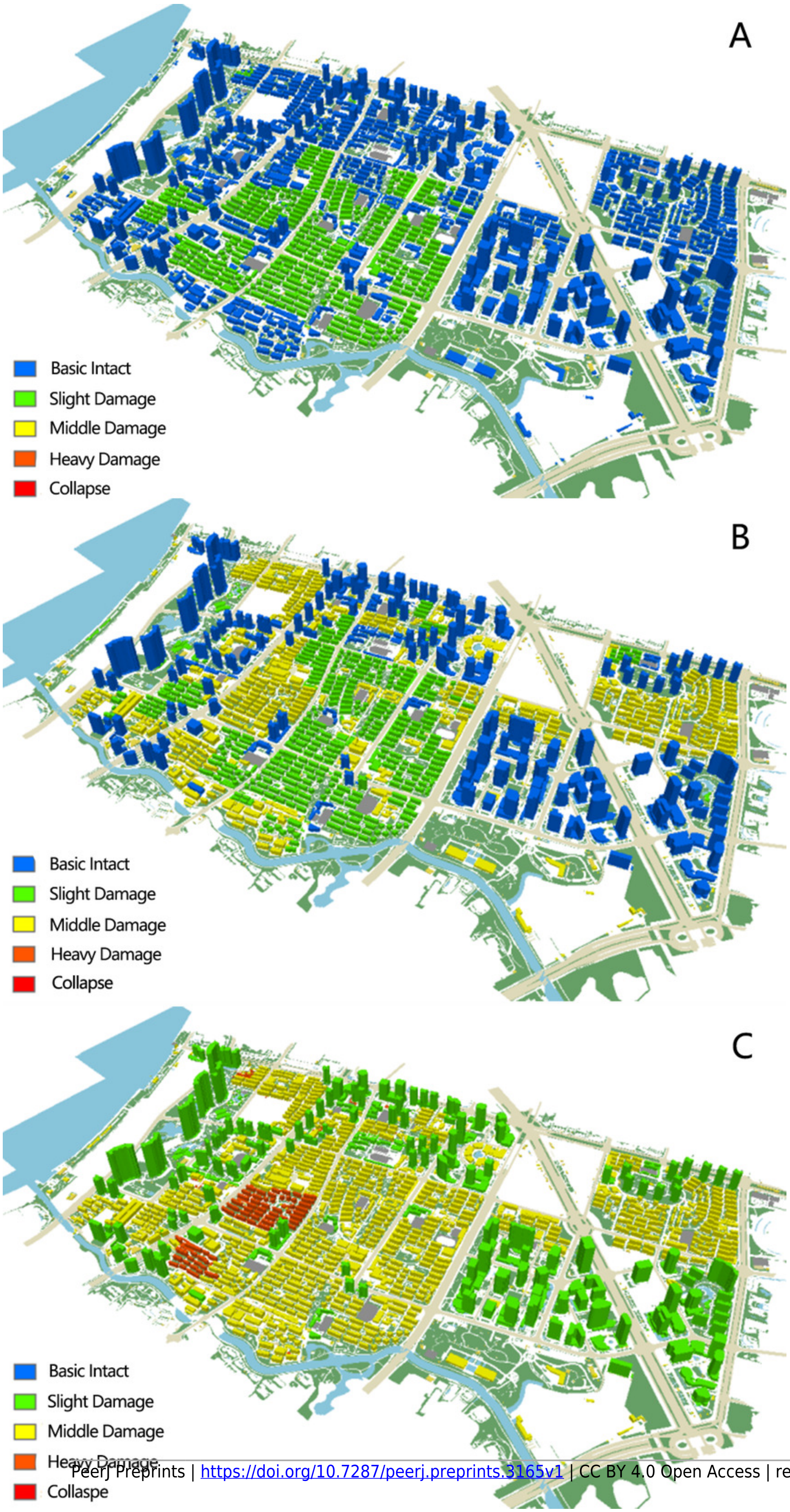


Figure 7

3D seismic hazard prediction map

(A) Seismic hazard under intensity Ⅵ. (B) Seismic hazard under intensity Ⅶ. (C) Seismic hazard under intensity Ⅷ.


A
Basic Intact
Slight Damage
Middle Damage
Heavy Damage
Collapse
B
Basic Intact
Slight Damage
Middle Damage
Heavy Damage
Collapse
C
Basic Intact
Slight Damage
Middle Damage
Heavy Damage
Collaspe