DEVELOPMENT OF EARTHQUAKE ASSESSMENT METHODOLOGY IN NCREE

Chin-Hsun Yeh, Chin-Hsiung Loh and Keh-Chyuan Tsai
National Center for Research on Earthquake Engineering, Taipei, Taiwan
chyeh@ncree.gov.tw, lohc@ncree.gov.tw, kctsai@ncree.gov.tw

Abstract

In order to promote researches in seismic hazard analysis, engineering structural damage assessment, and socio-economic loss estimation in Taiwan, the National Science Council started the HAZ-Taiwan project in 1998. The National Center for Research on Earthquake Engineering also develops the associated application software "Taiwan Earthquake Loss Estimation System" to integrate various inventory data and analysis modules. The analysis framework of TELES follows the approach of HAZUS, which has been developed in the United States. However, individual analysis modules and parameter values have been modified according to Taiwan local environment. There are three main functions in TELES. First, it helps to obtain reliable estimates of potential seismic hazards and losses soon after the occurrence of earthquakes. Second, it helps to simulate earthquake scenarios and to provide useful data when local governments propose their seismic mitigation plans. Third, it helps to provide seismic hazard assessment and catastrophic risk management tools, such as the seismic insurance policy for residential buildings. This paper focuses on the analysis modules used in early loss estimation sub-system including assessment of ground motion intensity, soil liquefaction potential, building damages and the induced casualties.

BACKGROUND

In general, risk can be defined by probability of occurrence of a seismic event, exposure of people and property to the event, and consequences of that exposure. Based on the previous definition of risk, an earthquake loss-estimation methodology, integrated with geographic information system (GIS) and designed to run on personal computers, has been developed in the United States. The methodology and associated application software are contained in HAZUS (RMS, 1997). Essentially, the HAZ-Taiwan project and the associated application software "Taiwan Earthquake Loss Estimation System" follow a similar approach used in HAZUS. However, TELES has made major modifications in analysis models and parameter values, not only to accommodate the special environment and engineering practices in Taiwan, but also to reflect the state-of-the-art technology after the introduction of HAZ-Taiwan project in 1998. Furthermore, TELES has functions to estimate automatically the induced disastrous regions and scales soon after the occurrence of strong earthquakes, and to integrate probabilistic seismic hazard analysis and loss estimation. HAZUS does not have the similar features of early loss estimation and seismic risk assessment.

The results of the HAZ-Taiwan project help to plan and stimulate efforts to reduce risk from earthquakes, and to prepare for emergency response and recovery from an earthquake. It also provides a standard risk assessment and loss estimation methodology. Expected benefits of a standard methodology include consistency of approach, more economic use of available resources, improved sharing of knowledge, and more consistent performance measurement in hazard mitigation efforts, and providing effective means to set local, regional and national priorities.

FRAMEWORK OF METHODOLOGY

The HAZ-Taiwan project is mainly composed of three parts: collection of database; development or modification of analysis modules; and update of application software, as shown in Fig. 1. The input database consists of three types of data: inventory data with GIS information, earthquake hazard and geologic data maps, and analysis parameters. The analysis modules take the required inventory data and analysis parameters as inputs, conduct risk and loss estimations based on the site-specific outputs from hazard analysis, and output estimates in the result databases. The third part, integrated with commercial GIS software, is the PC-based application software to execute user's requests, to display input/output databases in both tabular and graphical forms, to generate summary reports, and so on.

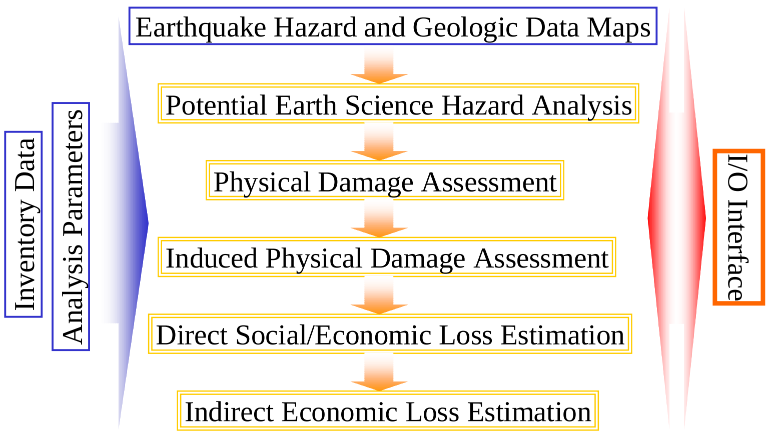

Fig. 1: Methodology framework of HAZ-Taiwan.

The analysis part contains four groups of analysis modules, namely, potential earth science hazard (PESH) analysis, direct physical damage assessment, induced damage assessment, and social/economic loss estimation. These modules and sub-modules are interdependent. The output from one module acts as input to another. The modular approach allows estimates based on simplified models and limited inventory data. Addition or replacement of existing modules/data may be done without reworking the entire methodology. The modular approach also facilitates the rapid transfer of information and technology between the academic/research communities and the end users. Specific regional analysis models and data can be incorporated in the framework. Another advantage of modular approach is that it enables users to limit studies to selected losses, which may be desirable because of limited budget and inventory constraints. In general, each module requires a comprehensive loss estimation study. However, the degree of required sophistication and associated cost varies greatly by user and application. It is necessary and appropriate that the modules accept multiple levels of detail and precision of input data.

ESTIMATION OF GROUND MOTION INTENSITY

The PESH module generates estimates of ground motion intensity and ground failure extent. Based on the source parameters of a scenario earthquake and the local site conditions, the ground motion demands are generally in terms of response spectra and peak values (PGA and PGV). The response spectra are simplified and mainly determined by S_{as} and S_{a1}, which represent the short-period and the long-period spectral accelerations, respectively. So far, the ground failure estimations consider only the effect of soil liquefaction and are in terms of occurrence probability and the induced permanent ground deformation (PGD). Other related earth science hazards, such as tsunami and inundation, may affect social/economic environment, but are not considered in the current framework of TELES.

The first step in scenario simulation is to set source parameters. In general, there are three ways to define source parameters in a deterministic approach, that is, historical events, active faults and arbitrary events. The basic source parameters include event date, time, magnitude, epicenter location and focal depth. If the earthquake accompanies fault rupture, the fault mechanism (reverse, normal or strike), orientation of trace, inclination angle, length and width of rupture plane are required to define the source parameters. In case there is no information about the rupture fault, it may be assumed to be a rectangle passing through the hypocenter of scenario earthquake. If the active fault traces are known, they may compose of many line segments, though not necessarily continuous, to depict the traces realistically. Default length and width of the rupture plane are provided using Wells et al (1994) empirical formula; however, they can be customized to match the actual observation.

Since different attenuation laws use different definitions for earthquake magnitude and source-to-site distance, TELES internally converts magnitude scale and selects proper definition for source-to-site distance. Both moment magnitude (M_w) and local magnitude (M_L) are generally used in Taiwan. They are converted by using the following equation (Wu et al, 2001),

$$M_L = 4.533 \ln M_w - 2.091 \quad (1)$$

For example, Jean (2001) uses local magnitude and shortest distance to fault plane, while Boore et al (1994) uses moment magnitude and shortest distance to the horizontal projection of fault plane. If the rupture length reduces to zero, the source-to-site distance automatically uses the definition of focal distance in the attenuation laws. TELES can consider the effect of seismogenic rupture zone when evaluating the source-to-site distance.

Estimation of ground motion intensity due to a scenario earthquake may divide into three steps. Referring to Fig. 2, the first step uses the attenuation laws to predict the intensity at bedrock level. The second step uses the local site modification factors to obtain the intensity at ground surface. Finally, if the monitored data at nearby strong-motion stations are available in early seismic loss estimation, the local intensity can be updated accordingly. HAZUS classify the local site conditions into six categories by soil profiles and properties, such as shear velocity and SPT-N value. The site modification factors depend on the soil type as well as the ground motion intensity. However, topography and geology are very complex in Taiwan, basin effects or topographic conditions may influence the ground motion intensity significantly. To overcome the shortage of rough classification scheme of soil types, micro-zonation of site effect is necessary. Since the strong-motion stations installed by the Central Weather Bureau are dense enough, the site modification factors for each chun-li are determined from both the recorded accelerograms and local geology (Yeh et al, 2003).

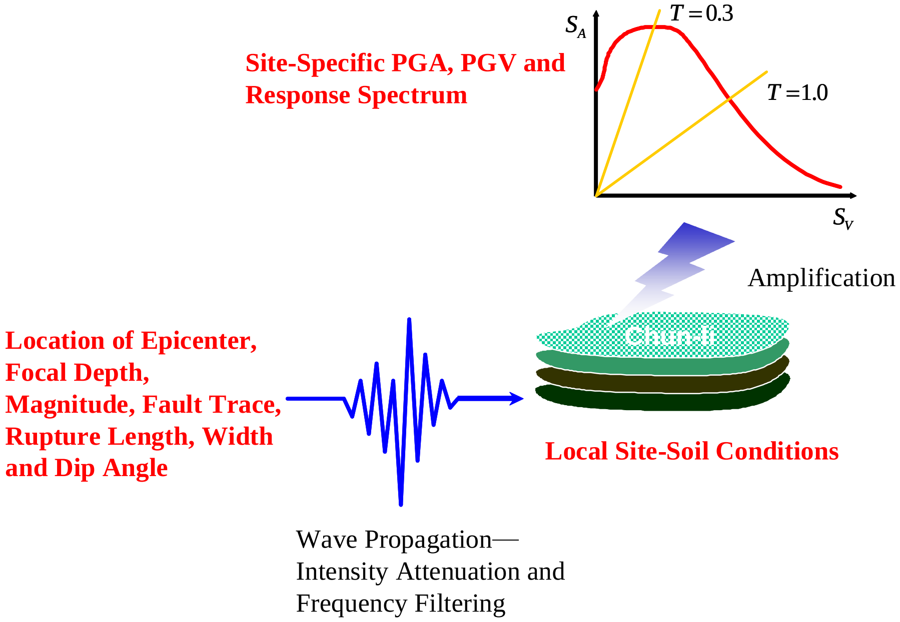

Fig. 2: Procedures in estimation of ground motion intensities.

ESTIMATION OF SOIL LIQUEFACTION POTENTIAL AND SETTLEMENT

When saturated loose soil subject to cyclic loadings, the particles in the soil rearrange their relative positions and the volume of the soil tends to shrink due to gravity. The excessive pore water cannot be drained out in a short period and thus causes rapid increasing in the pore-water pressure. If the vibration is large enough and lasts for a long time, the effective shear strength of the soil will reduce to zero and liquefaction phenomenon will happen. Thus, the influence factors in soil liquefaction are the intensity level and the time duration of ground excitation and the ground water depth. The peak ground acceleration (PGA) is commonly used to indicate the excitation intensity, while the earthquake magnitude is used to indicate the duration of excitation.

Yeh et al (2002a) analyzed more than 11,000 borehole data in Taiwan and proposed a classification scheme to identify the liquefaction susceptibility category of each borehole. The soil liquefaction susceptibility is classified into six categories, that is, "very high", "high", "moderate", "low", "very low" and "none". Based on the knowledge of liquefaction susceptibility for each borehole, the liquefaction susceptibility map for each chun-li is roughly estimated. Furthermore, the semi-empirical formulas to estimate the liquefaction probability and the amount of settlement due to liquefaction are obtained from nonlinear regression analysis and statistics (Yeh et al, 2002b). The influence factors in the semi-empirical formulas include earthquake magnitude, peak ground acceleration and ground water depth.

DAMAGE ASSESSMENT OF GENERAL BUILDING STOCKS

The general building stocks consist of many buildings of different structural types, seismic response behavior and usages. They are grouped into several model building types, seismic design levels, and specific occupancy classes in order to facilitate damage assessment, casualty and loss estimation. The building tax data from ministry of finance and local governments have been used to calculate various statistics of general building stocks, since it is the only database that provides consistent format and up-to-date information of buildings in Taiwan. The model building types are mainly defined by their construction material and building height. There are 15 model building types, namely, wood (L), steel (L, M, H), light steel (L), reinforced concrete (L, M, H), pre-cast concrete (L), reinforced masonry (L, M), un-reinforced masonry (L), and steel reinforced concrete (L, M, H) buildings. The letters L, M and H in the parenthesis indicate low-rise, mid-rise and high-rise buildings, respectively. Each modeling building type is further divided into four seismic design levels, namely, high-, moderate-, low- and pre-seismic design levels. The total floor areas for each model building type and seismic design level are calculated according to their construction years, seismic zoning factors, and local site conditions.

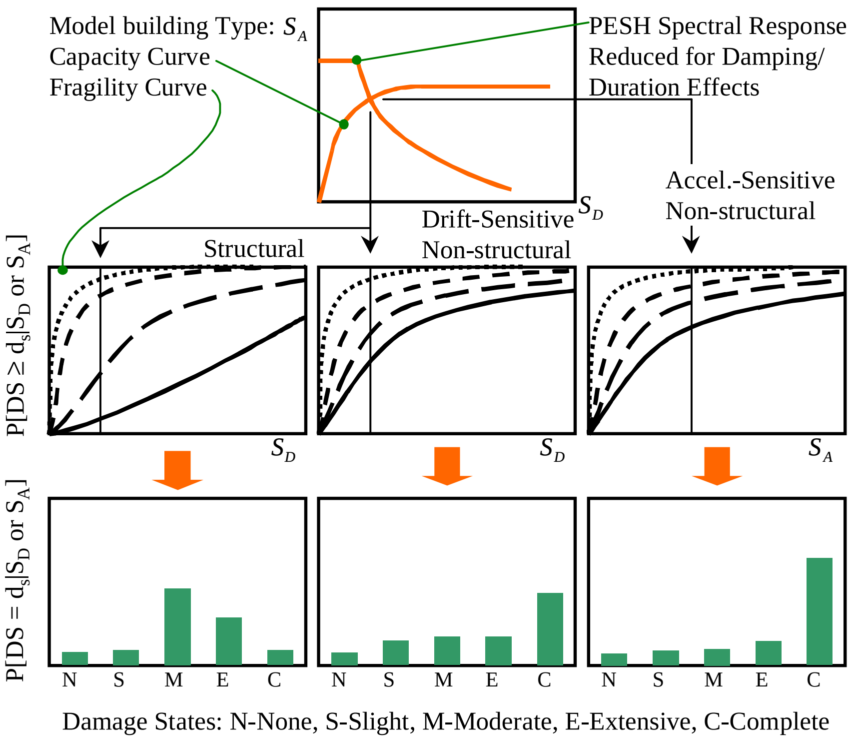

Fig. 3: Damage assessment of general building stocks.

Some inventory data, such as bridges and tunnels, may be treated as point objects. Some others, such as highway segments and airport runway, may be treated as line objects. However, for general building stocks, it is neither necessary nor practical to evaluate individual building. In this case, the mapping scheme of specific occupancy class to model building type plays an important role in the framework to estimate various social impacts and economic losses. Since the model building type and the occupancy class in each record of building tax data are available, it is possible to obtain the mapping scheme of specific occupancy class to model building type for each chun-li.

TELES evaluate the damage state probabilities for each model building type and seismic design level due to site-specific ground motion intensity and liquefaction-induced settlement. The procedures in building damage assessment are depicted in Fig. 3, where damages in structural systems and nonstructural components are evaluated separately. The effects of hysteretic damping and system degradation are taken into consideration in calculating the seismic demand. The seismic capacity and fragility curves for each model building type and seismic design level are determined by reference to seismic design codes in various periods, nonlinear push-over analysis, and historical data collected after Chi-Chi, Taiwan earthquake.

CASUALTY ESTIMATION

TELES consider only the casualties due to damage or collapse of buildings. Although other factors, such as fire following earthquakes, sudden failure of critical dams, unseat of bridges, etc may cause significant casualties, they are not considered in the current methodology. Referring to Fig. 4, the first step in casualty assessment is to estimate the spatial distribution of population at different times. For simplicity, only three population migration patterns are taken into consideration, that is, daytime, nighttime, and commute time. It is assumed that the population density (number of persons per unit floor area) can be estimated for each specific occupancy at the different times. Since the total floor area of each specific occupancy class has been obtained from the building tax data, multiplication of the population density and the floor area of each specific occupancy class in each chun-li obtain the population migration patterns. Assuming the population is uniformly distributed within the same occupancy class, the mapping schemes of specific occupancy class to model building type are used to calculate the number of people in each model building type.

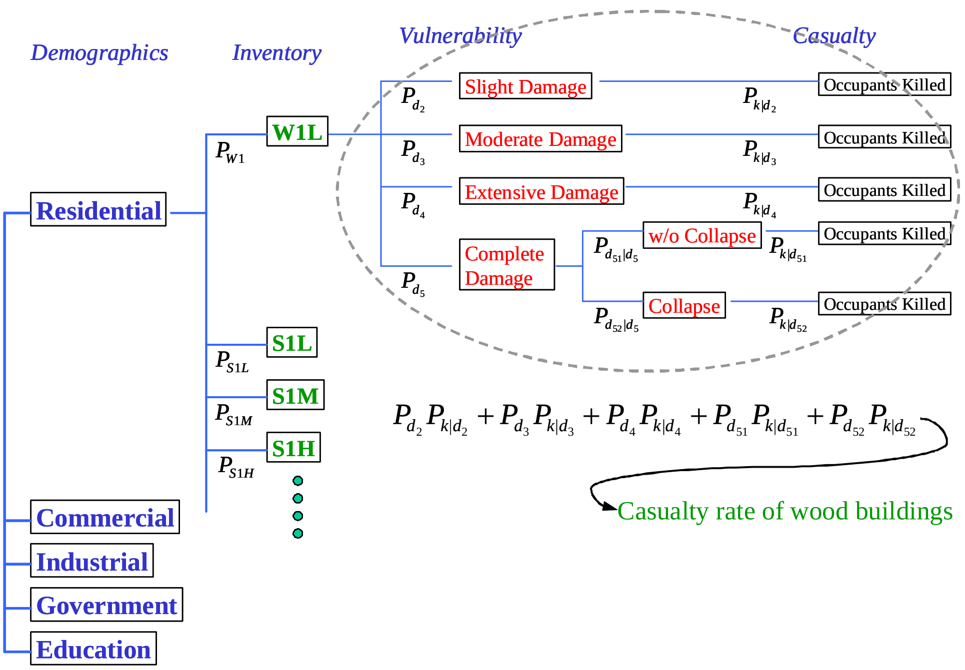

Fig. 4: Assessment of casualties caused by building damages.

The output of casualty module contains estimates breakdown into four injury severity levels. The four severity levels are "injuries requiring basic medical aid without hospitalization," "injuries requiring a greater degree of medical care but not expected to threaten life," "injuries requiring adequate and expeditious treatment to avoid loss-of-life," and "instantaneous killed or mortally injured." The casualty rates for different model building types and in various damage states are calibrated considering the effects of structural and nonstructural damages. Buildings in complete damage state are further divided into collapse and without collapse. By combining casualty information with loss-of-function estimates for hospitals, alternate plans may be prepared for treatment of victims outside of the affected area.

SOFTWARE ARCHITECTURE

The application software, TELES, is written in Visual C++, which is an object-oriented programming (OOP) language, and MapBasic, which is the language used to communicate with MapInfo. Through the object linking and embedding (OLE) technology, the TELES integrate functionalities and custom usages of MapInfo, which is famous application software of geographical information system (GIS). The main functions of MapInfo in TELES are to view and to edit records and map objects in various kinds of database. All the numerical analysis is written in C++ and FORTRAN. The software architecture of TELES has module design, so addition and modification of individual module will not affect the other modules. TELES allows users to open multiple documents and multiple map windows at the same time, so the users can compare different thematic maps and obtain in-depth understanding of the relationships between input and output database. TELES allows users to monitor the earthquake occurrence and run scenario simulation in separate application windows at the same time, so the users will not miss any message sent from the Central Weather Bureau.

APPLICATION OF EARLY SEISMIC LOSS ESTIMATION

Like HAZUS, TELES is used to simulate earthquake scenarios. The results facilitate to propose local seismic disaster mitigation plans and to rank the priorities of local and national resources. Since the damage assessment of engineered structures depend on the completeness of inventory database, it is necessary to collect spatial distribution and to calibrate seismic resistant parameters of essential facilities and lifeline systems. However, the analysis should be auto-trigger and easy-to-use when TELES acts as a decision support system in emergency responses. Therefore, the analysis procedures and items are prescribed before earthquake occurrence.

An early seismic loss estimation module has been developed and integrated in TELES. When an earthquake occurs, the Central Weather Bureau detects it within 90 seconds and sends earthquake reports to all clients. Since TELES monitors the mailbox continuously, it will be triggered automatically and start analysis when a strong earthquake happens. The time delay between earthquake occurrence and analysis start is normally within two minutes. The affected region of the earthquake is determined by ground motion intensity. All the towns with PGA greater than 80 $cm/\sec^2$ are selected in the study region. The ground motion intensity, soil liquefaction potential and induced settlement, damage-state probability and quantity of general building stocks and casualty assessment are calculated for each town. Some of the important outputs are saved in the formats of raster map and digital table automatically. Those maps and tables can be used in the presentation to chief commander of central emergency response center, or in the notification to local governments, and so on. Since the required work force and equipment are different to rescue people in a low-rise or a high-rise building. Statistics of severe-damage building counts are obtained for each town and for low-rise, med-rise and high-rise buildings, separately.

In practice, application of early seismic loss estimation system divides into three stages. At the first stage, only earthquake magnitude, focal depth and epicenter location are available. So, it uses point source model to predict the ground motion intensity and the associated disasters, when TELES receive email from the Central Weather Bureau. If the earthquake is large enough, it is likely to company with fault rupture. Before the actual source mechanism is available, reasonable assumptions can be made about the orientation, inclination, length and width of the rupture fault. Therefore, the second stage of early seismic loss estimation uses several artificial sets of source parameters to predict the disaster scale and distribution. In the meantime, actual disaster information are gathered and studied to identify the true source mechanism. Once the true source mechanism and rupture fault are identified, early seismic loss estimation enters the third stage and obtains the most reliable results. Figures 5, 6 and 7 show the estimated results of PGA, building damage count and induced casualty in 1999 Chi-Chi Taiwan Earthquake. These figures are only part of the raster maps that are automatically generated by TELES after occurrence of strong earthquakes.

CONCLUDING REMARKS

Taiwan Earthquake Loss Estimation System (TELES) is part of the research accomplishment of HAZ-Taiwan project. It can be applied in proposing local seismic disaster mitigation plans and act as a decision support system soon after occurrence of strong earthquakes. In the near future, TELES will also integrate probabilistic seismic hazard analysis and may have applications in proposing maximum probable earthquakes for each county and in proposing adequate seismic insurance policies.

REFERENCES

Risk Management Solutions, Inc. (1997), Earthquake Loss Estimation Method – HAZUS 97 Technical Manual, National Institute of Building Sciences, Washington, D.C.

Wells, D. L. and Coppersmith, K. J. (1994), "New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement," Bulletin of Seismological Society of America, 84, 4, pp. 974-1002.

Wu, Y. M., Shin, T. C., and Chang, C. H (2001), "Near real-time mapping of peak ground acceleration and peak ground velocity following a strong earthquake," Bulletin of Seismological Society of America, 91, 5, pp. 1218-1228.

Jean, W. Y. (2001), "A study on the characteristic earthquake and site effects and its application to the hazard evaluation", Report of National Center for Research on Earthquake Engineering, NCREE-01-036.

Boore, D. M., Joyner, W. B., and Fumal, T. E. (1997), "Equations for estimating horizontal response spectra and peak acceleration from western north American earthquakes: a summary of recent works," Seismological Research Letter, 68, pp. 128-153.

Yeh, C. H., Jean, W. Y., and Chung, L. L. (2003), "Development of early estimation system for seismic disasters in Taiwan", submit to review in Journal of the Chinese Institute of Civil and Hydraulic Engineering.

Yeh, C. H., Hsieh, M. Y., and Loh, C. H. (2002a), "Classification and parametric study on soil liquefaction potential", Proceedings of the Second Japan-Taiwan Workshop on Lifeline Performance and Disaster Mitigation, Kobe, Japan, May 13-15.

Yeh, C. H., Hsieh, M. Y., and Loh, C. H. (2002b), "Estimations of soil liquefaction potential and settlement in scenario earthquakes", Proceedings of the Canada-Taiwan National Hazards Mitigation Workshop, Ottawa, Canada, July 17-19.

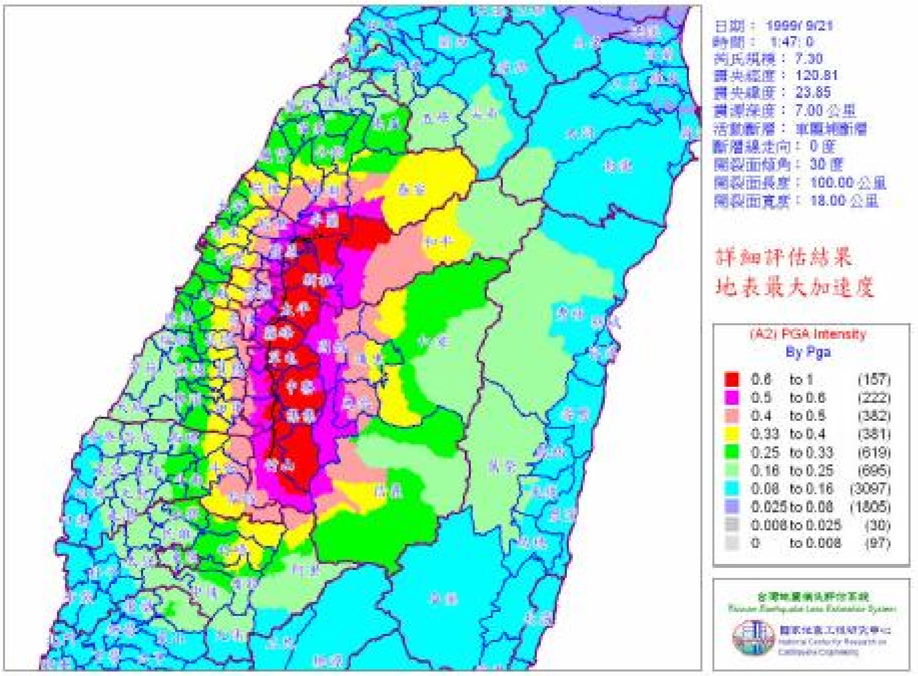

Fig. 5: Estimated distribution of peak ground acceleration in Chi-Chi Taiwan earthquake. The black line represents the trace of Chelongpu fault.

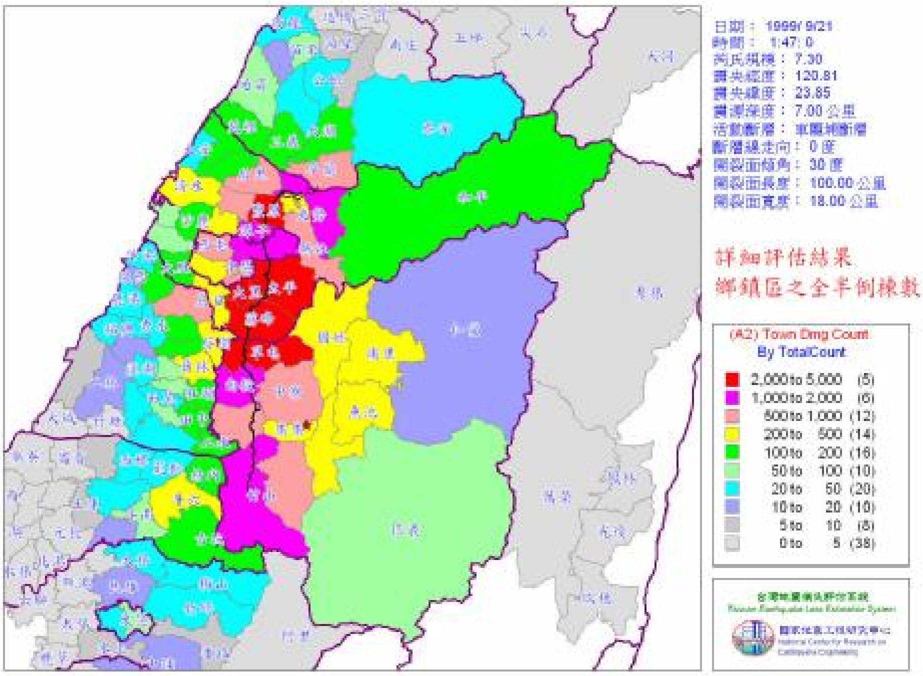

Fig. 6: Estimated distribution of building counts in at least severe-damage state in Chi-Chi Taiwan earthquake.

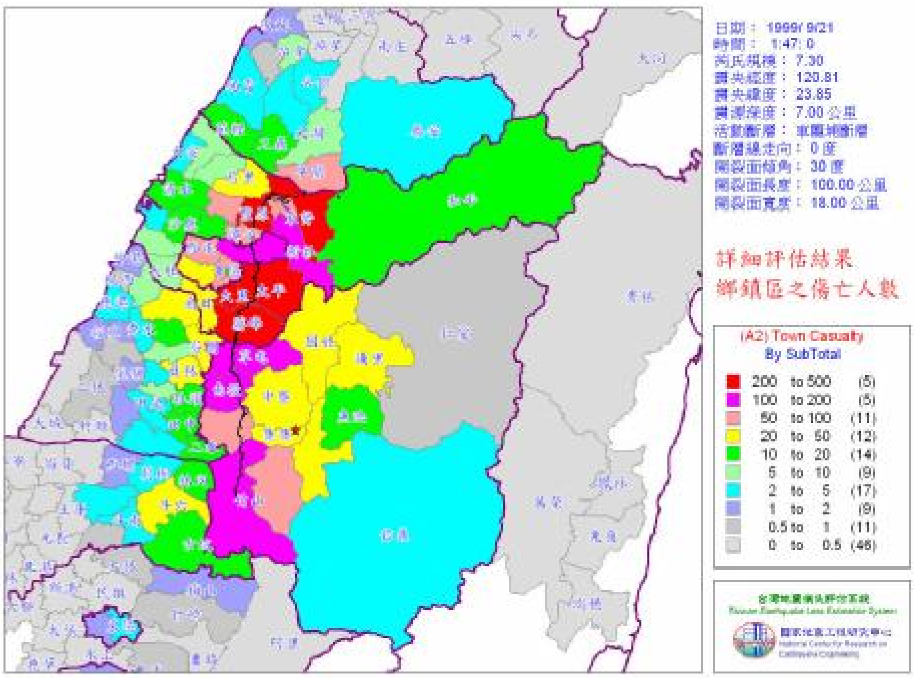

Fig. 7: Estimated distribution of casualties in injury levels 3 and 4 in Chi-Chi Taiwan earthquake.