ANALYSIS OF GROUND MOTION PARAMETERS AND GROUND LIQUEFACTION PREDICTION USING GIS FOR KUNMING BASIN, CHINA

Xiangxin Li [a,*], Gang Li [a], Cunzhi Li [b]

[a] Dept. of Geomatic and Surveying Engineering, Faulty of Land Resources Engineering, Kunming University of Science and Technology, Kunming, Yunnan 650093, China - lixiangxin2001@yahoo.com.cn.
[b] Seismological Bureau of Yunnan Province，Kunming, Yunnan 650041, China.

KEY WORDS: Geological Structure, Earthquake, Fractures, Ground Motion Parameters, Zonation, Attenuation Model, Ground Liquefaction, GIS.

ABSTRACT:

In this paper the geological structure and earthquake activity nearby Kunming Basin, Yunnan, China, have been studied. Different ground motion attenuation models used in Japan and in Yunnan, China, have been reviewed, and quantitative comparisons between the models have been made. The zonation of peak horizontal acceleration corresponding to a seldom happened earthquake and the zonation of the characteristic period of the seismic response spectrum of the basin have been suggested. To analyze ground liquefaction, the liquefaction prediction models popular in China and Japan have been briefly introduced. A GIS-based liquefaction prediction system has been developed by the authors. With the aid of the liquefaction prediction system the ground liquefaction risk of the basin due to the seldom happen earthquake has been clarified.

1. INTRODUCTION

Located at the middle part of Xiaojiang fracture zone and the north bank of the downfaulted basin of the Dianchi Lake, Kunming, the capital city of Yunnan province, China, is directly influenced and threatened by the earthquake activities of the fractures zone.

Early in 1988, the city planning division of Kunming put forward a preliminary city development plan, in which earthquake risk due to the active fracture zones nearby Kunming basin was stressed. Since then, a lot of geological investigation and soil testing had been done at the populated area of the city, and results form field investigations and laboratory tests on geological structure, ground formations, soil properties, site classifications and bearing capacity of the ground had been systematically summarized(Zhang Qiutian, et al., 1988). In the reports, it was pointed out that further studies to properly evaluate ground motion parameters of the ground were necessary.

In 2001, China issued its national standard, Seismic ground motion parameter zonation map of China (GB18306—2001), in which the seismic peak ground acceleration, $A_{max,}$ at a probability of exceedance of 10% for a 50 years period and the characteristic period of the seismic response spectrum, Tg, have been specified for all the regions of the country. In the standard, it has been announced that the index to evaluate earthquake hazard should be shifted from the earthquake intensity to the peak acceleration in the specification. The peak accelerations was related to different levels of earthquake intensity, and the characteristic period of the seismic response spectrum was related to different site classifications. According to the standard, the horizontal peak acceleration for Kunming region varies from 0.2g to 0.3g, which corresponds to basic intensity level of VIII, and the characteristic period varies from 0.4s to 0.45s, corresponding to site classifications from meddle hard to soft ground. Because the earthquake basic fortification intensity level of Kunming was level VII before, it is clear that the earthquake fortification intensity level of the city have been increased one rank up after the publication of the standard. However, the zonation map in the standard do not give details about the spatial variation of the ground acceleration of an area in case of a seldom occurred earthquake, which is similar to the one happened in May 12, 2008, Wenchuan, Sichuan Province, China, which caused huge damage of buildings and enormous loss of lives.

2. GEOLOGICAL STURCTURES AND EARTHQUAKES

The city, Kunming, is located at Sichuan and Yunnan meridional tectonic zone, which has very complex geological structure and is composed of many active fracture zones (Fig.1). Among the fracture zones, the three ones, the Pudu River fracture zone at the west side of the city, the Heilongtan-Guandu Fracture zone at the middle part of the city and Xiaojiang Fracture zone at the East side of the city are very important to take account of the earthquake influence (Fig.2).

Earthquakes records of Kunming area can be backdated to 1500 years ago. At Xiaojiang Fracture zones in Fig.1 and Fig.2, the Dongchuan-Songming earthquake zone is the nearest earthquake zone to Kunming, the distance from which to Kunming is about 35 km. From the A.D. 886 to 1981, earthquakes of magnitude greater than 5.0 were recorded 29 times at the earthquake zone, whereas earthquakes of magnitude great than 6.0 were recorded 10 times. The earthquake time, epicenter, magnitude and intensity of the earthquakes （M>6.0） originated from the earthquake zone have been listed in Table 1. It is cleared that earthquakes of the largest

* Corresponding author. lixiangxin2001@yahoo.com.cn

earthquake magnitude (M=8.0) is the one happened in September 6, 1833, between Songmings and Yiliang, about 40 km far from Kunming. Compared to the largest earthquake in history the other earthquakes are of smaller magnitude and farther distance from Kunming, so the earthquake in September 6, 1833, is the most unfavorable earthquake if the ground motion of Kunming is taken into account.

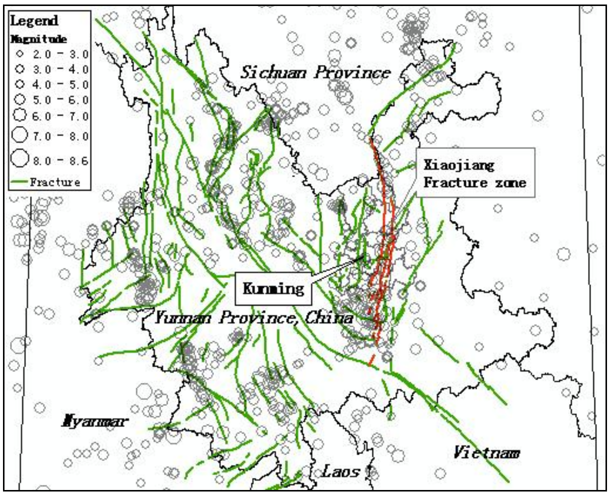

Figure 1. Fracture zones and earthquakes of Yunnan, China.

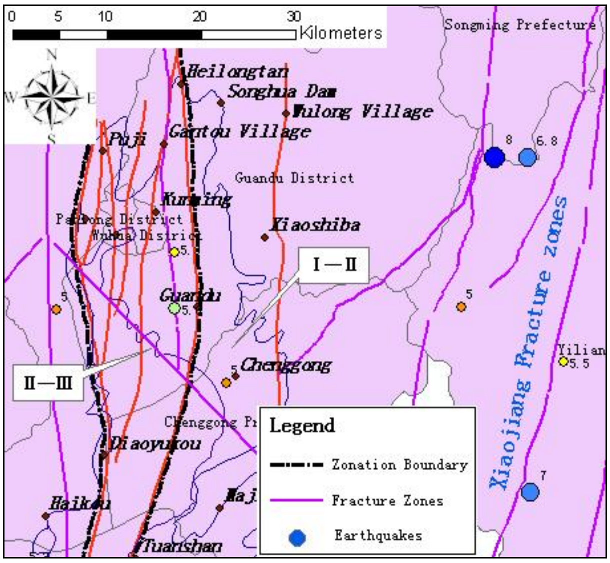

Figure 2. Main fracture zones and crust activity zonation of Kunming Basin

Beside the earthquake zone mentioned above, there are other earthquake zones that might influence the evaluation of ground motion parameters of the basin, which are Tonghai-Shipin earthquake zone, 110km far south of Kunming, Tanglang-Yimen Fracture zone, 40 km far west of Kunming, Pudu River fracture zone at the west side of the city. However, compared to the Dongchuan-Songming earthquake zone, they are of less importance when to calculate the maximum ground motion of the basin because of the same reason.

Studies on activity of the fractures in Kunming Basin have been reported (Zhang Qiutian, et al., 1988). The crust of the basin is divided into two regions by the fracture zones，which are the region I-II and the region II-III, and shown in Fig.2. The Puji-Xishan fracture zone and the Heilongtan-Guandu fracture zone is the left and right boundary of the region II-III, respectively. The region at the east side of Heilongtan-Guandu fracture zone is the region I-II. The region I-II is considered as more stable than the region II-III.

Table 1. Earthquakes (M>6.0) Originated from Xiaojiang Fracture Zone (Zhang Qiutian, et al., 1988)

Date	Earthquake Epicenter			Magnitude	Intensity
	Location	Latitude	Longitude		
1500. 1. 4	Yiliang	24°0’	103°1’	6.8	Ⅸ
1713. 2. 26	Xundian	25°6’	103°2’	6.5	Ⅸ
1725. 1. 8	Yiliang	25°1’	103°1’	6.2	Ⅷ
1733. 8. 2	Dongchuan	26°2’	103°1’	7.5	Ⅹ
1833. 9. 6	Between Songming and Yiliang	25°1’	103°1’	8.0	≧Ⅹ
1909. 5. 11	Mile	25°4’	103°1’	6.5	Ⅷ+
1927. 3. 3	Xundian	25°4’	103°1’	6.0	Ⅷ
1927. 3. 15	Xundian	25°4’	103°1’	6.0	Ⅷ
1966. 2. 5	Dongchuan	26°12’	103°12’	6.5	Ⅸ
1966. 2. 13	Dongchuan	25°6’	103°6’	6.2	Ⅸ

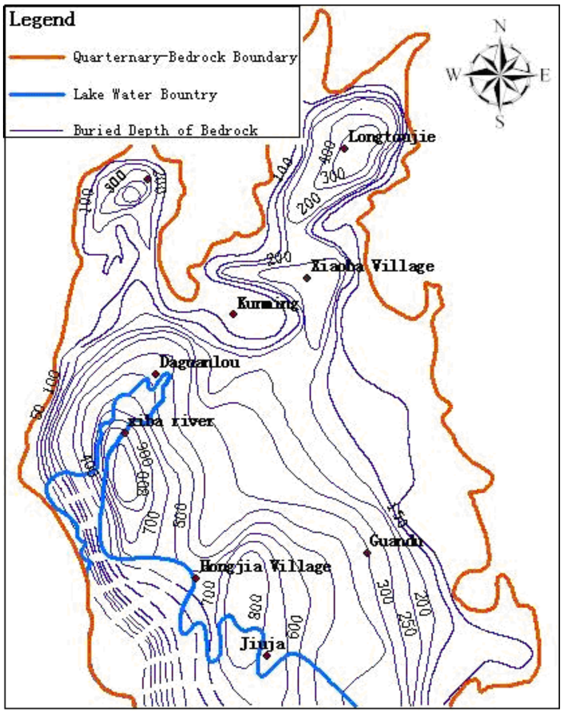

Figure 3. The buried depth of bedrock of Kunming Basin

The stratum of the region I-II is formed by Proterozoic and Paleozoic strata that have massive rock structures. During the period of quaternary, the region rises at the rate of 0.095 mm/year in average and shows relative stability compared to the other region. It was estimated from historical earthquake records that the maximum earthquake magnitude M of this region is small than 5.5, the earthquake basic intensity of the region is small than VII, the strain energy of the crust of the region is small than 2×10^{19} erg. The stratum in region II-III is composed of strata formed from Proterozoic to Cenozoic ages. As shown in Fig.3 there are four groups of fractures in directions of south-north, east-west, north-east, north-west in the region, which maks the crust of the region fragmental. The active fractures in the region is the Puji-Xishan fractures zones, Heilongtan-Guandu fracture zones. Controlled by Heilongtan-Guandu Fracture zone, during the 2.48 million year quaternary period, the thickness of deposition of Jiujia sinking center reached to 662.5 m, subsiding at the average rate of 0.27mm/year in average.

Controlled by Puji-Xishan fracture zone, the thickness of deposition of Hanjiacun sinking center of Xiba River concave reached 810 m, subsiding at the average rate of 0.33mm/year in average. The Xisan Mt. block at the left side of the region rose against the region at the average rate of 0.526 to 2.33 mm/year. Dislocation of some quaternary strata in the region has been found. According to results of geophysical exploration, the maximum fault throw of the quaternary systems of the basin is 150 m at Guandu and Jiujia area. From historical earthquake records of the region, it was estimated that during the 100 years in future, the possible maximum earthquake magnitude M of the region is in the rage from 5.0 to 6.0, the earthquake basic intensity of the region varies from VII to VIII, the strain energy of the crust of the region varies from 2×10^{19} to 6.3×10^{20}erg.

It can be concluded that the possible maximum earthquake magnitude of the two regions will not excess 6.0 in 100 years in future. However, in this paper, to calculate the possible maximum ground motion caused by earthquake near Kunming Basin, the largest historical earthquake in Table 1 will be taken into account.

3. THE QUATERNARY STRATA AND ITS GEOTECHNICAL PROPERTIES

As mentioned above, the ground of the basin is composed of strata formed from Proterozoic to Cenozoic ages. Most parts of bedrock of the basin are sedimentary rocks, whereas only small parts are metamorphic sedimentary rock, basic volcanic rock and intrusive rock. The buried depth of the bedrock of the basin is shown in Fig.3 (Zhu Tongwen et al., 1977). Because the quaternary strata deposited over the bedrock, the buried depth of bedrock is equal to the deposition thickness of the quaternary strata, which varies from 0 m at Yuantong Mt. in city center and about 1000 m at lake area. In this paper the soft strata of quaternary system have been focused on. According to depositing sequences, the quaternary strata are classified into five strata named as I～V, as shown in Table 2. The bedrock under quaternary strata is represented as VI.

The average shear velocity of Holocene and Pleistocene strata are summarized in Table 3, which are calculated by the authors of the paper from in situ P-S logging data of 64 borings at the central of the city.
From past studies it is know that the physical properties of the same soil in the substrata in Table 2 are approximately equal. For purpose of liquefaction prediction, the indexes of soil physical properties, such as, the natural unit weight, saturated unit weight, fine grain content, average grain size, 10% grain size, plasticity index, clay content are calculated from past soil tests and summarized by the authors.

Table 2. Engineering Geological Layering of Quaternary Strata of Kunming Basin (Xu Shixin et al., 1990)

Name of Strata and depositing sequenced		substrata
Q_4^{ml}	I	-
Q_4^{al}、Q_4^{al+pl}	II	II_{1-5}
Q_4^{al+pl}、Q_4^{al+l}	III	III_{1-5}
Q_3^{al+pl}、Q_3^{al+l}、Q_3^{l}	IV	IV_{1-5}
Q_3^{dl+el}、Q_3^{dl+pl}、Q_{2-3}^{l}	V	V_{1-5}
Bedrock	VI	-
Note: the subscripts of substrata vary from 1 to 5, where 1 stands for soft soil or mud, 2 for clay, 3 for silty clay, 4 for silty clay, silt, 5 for round gravel, pebble.		

Table 3. Average Shear Velocity of Holocene and Pleistocene Strata of Kunming Basin

Geological time and cause of formation	Substrata	Average shear velocity
artificial fill Q_4^{ml}	I	145
Holocene alluvial layer, Q_4^{al} lacustrine layer, Q_4^{l} alluvial and proluvial layer, Q_4^{al+pl}	II_1	128
	II_2	160
	II_3	182
	II_4	192
	II_5	336
Holocene alluvial and proluvial layer, Q_4^{al+pl} alluvial and lacustrine layer, Q_4^{al+l}	III_1	184
	III_2	191
	III_3	181
	III_4	175
	III_5	380
Upper Pleistocene alluvial and proluvial layer, Q_3^{al+pl} alluvial and lacustrine layer, Q_3^{al+l}	IV_1	146
	IV_2	222
	IV_3	215
	IV_4	231
	IV_5	410
Upper-Middle Pleistocene lacustrine layer, Q_3^{l} Q_3^{el+dl} Q_3^{dl+pl}	V_1	307
	V_2	254
	V_3	235
	V_4	318
	V_5	319
Bedrock	V	1311

4. ATTENUATION MODELS AND GROUND MOTION PARAMETERS

The strong motion record in an earthquake is fundamental to study ground motions. From large amount of ground motion records, the influence of the factors, such as, site, patterns of earthquake have been taken into account in ground motion attenuation models in USA (Seed, H. B., et al., 1976) and Japan (Editorial Committee of Hanshin-Awaji Great Earthquake Investigation Report, 1997). In China, studies on attenuation models of ground motion began in 1980s, and achievements in this area have been reported [8]. However, for a long time, the influence of site classifications on peak acceleration was not distinguished form other factors in codes for seismic design of building in China, because of lacking related strong motion observation records and the complexity to deal with it. Although earthquake hazard of high-rise building on soft ground had been frequently reported, because of lacking shear wave velocity of the soil layers of the ground, it had been discussed for a long time whether the earthquake effect would increase on a soft ground. After the 1989's Loma Prieta Earthquake, the influence of site condition on peak acceleration have been taken into account in USA. It is known that earthquake peak acceleration vary with rapture pattern of fracture that produces earthquake, and vary with site conditions, besides earthquake magnitude, earthquake epicentral distance.

In this paper an attenuation model of ground motion parameters, such as, peak ground acceleration, A_{max}, peak ground velocity, V_{max}, and peak ground displacement, D_{max}, are focused on, which were regressed from 197 strong motion observation records in horizontal direction of the Great Hanshin Earthquake happened in Japan in 1997 (Editorial Committee of Hanshin-Awaji Great Earthquake Investigation Report, 1997). The model is given by the following equations:

$$A_{\max}=\begin{Bmatrix}987.4\times10^{0.216M}\\232.5\times10^{0.313M}\\403.8\times10^{0.265M}\end{Bmatrix}\times(\Delta+30)^{-1.218}\quad\begin{matrix}(\text{Type I})\\(\text{Type II})\\(\text{Type III})\end{matrix}\qquad(1)$$

$$V_{\max}=\begin{Bmatrix}20.82\times10^{0.263M}\\2.805\times10^{0.430M}\\5.105\times10^{0.404M}\end{Bmatrix}\times(\Delta+30)^{-1.222}\quad\begin{matrix}(\text{Type I})\\(\text{Type II})\\(\text{Type III})\end{matrix}\qquad(2)$$

$$D_{\max}=\begin{Bmatrix}0.626\times10^{0.327M}\\0.062\times10^{0.567M}\\0.070\times10^{0.584M}\end{Bmatrix}\times(\Delta+30)^{-1.254}\quad\begin{matrix}(\text{Type I})\\(\text{Type II})\\(\text{Type III})\end{matrix}\qquad(3)$$

Where, A_{max} is peak horizontal acceleration of ground surface (cm/s^2), V_{max} is peak horizontal velocity of ground surface (cm/s), D_{max} is peak horizontal velocity of ground surface (cm). M is earthquake magnitude, $\triangle$ is epicentral distance (km).

The attenuation mode given by Eq.(4) was regressed from 240 records of strong motion of earthquakes happened in Yunnan, China, during the period from 1988 to 1998. It is a model of surface horizontal peak acceleration without distinguishing site influence [8]. The magnitudes of the earthquakes varies from 3.0～7.9, and most of them are in the range of 3.0～5.0. The epicentral distance of the data is in the range of 5～25km. The model is given by the following equation:

$$A_{\max}=2.0\times10^{0.8717M}\times(\Delta+15)^{-1.7631}$$
(σ=0.353) (horizontal direction) (4)

Where, A_{max} is peak horizontal acceleration of ground surface (cm/s^2), M is Earthquake magnitude, $\triangle$ is epicentral distance (km).

Both attenuation models given in Eq.(5) and Eq(6) were regressed from strong motion records of the Lancang-Gengma Earthquake (M=7.6), which happened in 1989 in Lancang and Gengma prefectures, Yunnan, China. The Model described by Eq.(5) was suggested by researchers of China Academy of Architectural Sciences, and the model described by Eq.6 was suggested by researchers of Geophysical Institute of State Seismological Bureau of China (Zhao Yonqing, et al., 2003, Li Shicheng et al., 2003).

$$A_{\max}=195.0\times10^{0.38M}\times(\Delta+10)^{-1.97}$$
(east-west direction) (5)

$$A_{\max}=459.0\times10^{0.198M}\times(\Delta+r)^{-1.175}$$
(horizontal direction) (6)

Where, A_{max} is peak horizontal acceleration of ground surface (cm/s^2) in east-west direction, M is earthquake magnitude, $\triangle$ is epicentral distance (km), r will take one of the values as 5, 10 or 15 to modify epicentral distance.

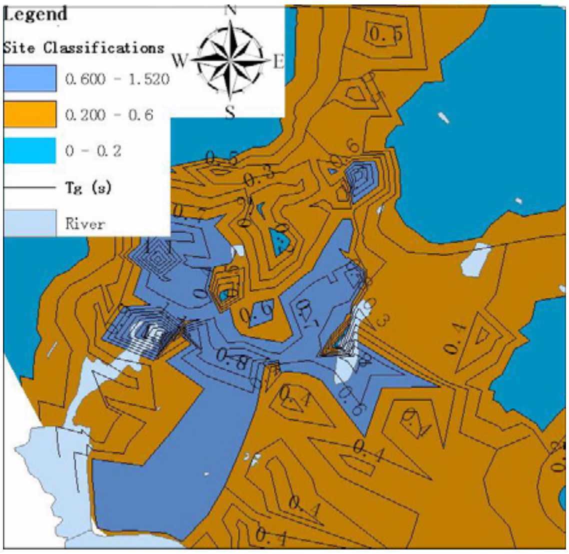

Fig.4 The characteristic period Tg and site classifications of Kunming Basin.

Given that the epicentral distance $\triangle$ is 25 km, the magnitudes of A_{max} of models described by Equations 1,4,5,6 were calculated respectively in case of different earthquake magnitude. The results have been compared in Table5. Generally, at the same epicentral distance and the same earthquake magnitude, the Japan Model (Eq.1) gives the largest value of A_{max}, whereas A_{max} calculated by Model3(Eq.4) increases rapidly when M>5.0, and reach a abnormal value as 3787.4 cm/s^2 when M is equal to 7.0, which means that the model might not be suitable for evaluating A_{max} when M is large than 6.0.

The spatial distribution of the site classifications and the Tg values of Kunming basin are shown in Fig.4, where the model in Eq. (1) are used. The ranges of Tg values corresponding to site classifications of I, II. III are 0～0.2, 0.2～0.6 and 0.6～1.52, respectively. The Tg of the quaternary soft ground of the basin varies from 0.2s to 1.25s as shown in Fig.5. The spatial distribution of the peak horizontal acceleration *Amax* of the basin is shown in Fig.5, where the model in Eq. (1) are used. The *Amax* of the study region of the basin *varies from 300gal to 540gal* as shown in Fig. 5.

Table 5. Comparison of A_{max} calculated from different attenuation models (Δ=25 km)

Attenuation models	Japan (Eq.1)	China Model1 (Eq.6, r=5.0)	China Model2 (Eq.5)	China Model3 (Eq.4)
Magnitude	Amax (gal)	Amax (gal)	Amax (gal)	Amax (gal)
1	12.3	8.6	0.2	0
2	20.3	14.4	0.5	0.2
3	33.3	24.2	1.3	1.2
4	54.8	40.5	3.6	9.2
5	90.1	67.8	9.7	68.4
6	148.2	113.4	26	508.9
7	243.6	189.9	69.8	3787.4
8	400.6	317.9	187.5	28186.3

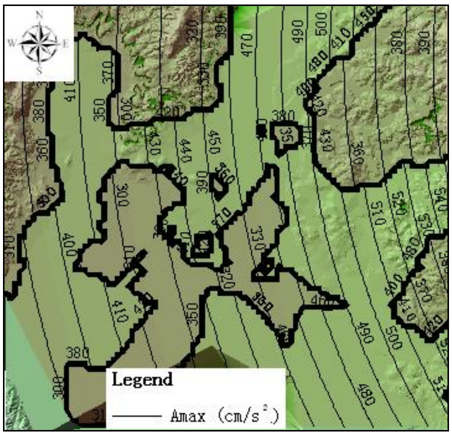

Figure 5. The peak horizontal acceleration corresponding to the seldom happen earthquake.

5. GROUND LIQUEFACTION PREDICTION

In China, since 1980s, ground liquefaction has been focused on in seismic design for buildings. Liquefaction prediction model suggested by current seismic design code for buildings [11] of China is an semi-empirical model, in which *STP-N* value *N* measured at the soil layer and a critical *N* value, N_{cr}, which is estimated from basic design acceleration of the region for the soil are used to calculate liquidity index I_{le}. In contrary to the semi-empirical model mentioned above, the model that is used in Japan has more clear geotechnical and mechanical meaning. To discriminate liquefaction soil layers, factors such as, soil type, buried depth, underground water, fine grain content, grain size distribution, shear stress of earthquake action and soil shear strength are taken into account in the model. The shear strength is estimated by STP-N value for sandy soil and by fine grain content for clayey soils in the model. The shear stress is calculated by horizontal peak acceleration factor k_{hc}, which is an equivalent of α (=A_{max}/980). In this model the horizontal peak acceleration equals to A_{max} at the ground surface and decreases linearly with ground depth.

In this paper a database has been built by SQL server 2000 data management system to store the data needed for liquefaction prediction. The database consist of data of boring, data of ground formation, data of soil properties, data of ground motion parameters, spatial data of geological structure, geographical information of Kunming basin. Based on the database, a GIS-based liquefaction prediction system has been developed using Delphi 7 development environment, and Map Object tool in this study. The tow models of liquefaction prediction have been adopted in the system (Fig. 6).

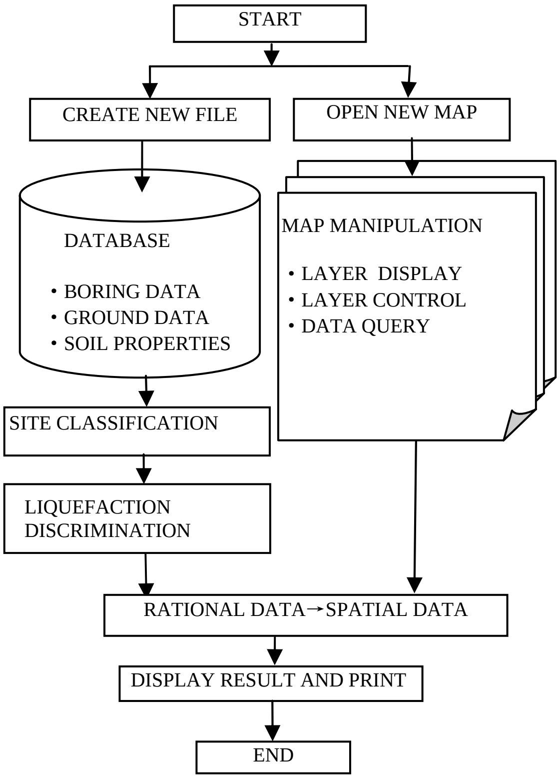

Figure 6. Flow chart of the GIS-based liquefaction prediction system developed in this paper.

The ground liquefaction risk is usually represented by the value of liquidity index. The larger the liquidity index, the higher the liquefaction risk. The spatial distributions of liquefaction risk of the ground are shown in Fig.7 and Fig.8. for the two models mentioned above, respectively. It is clear that the tow models give almost the same result.

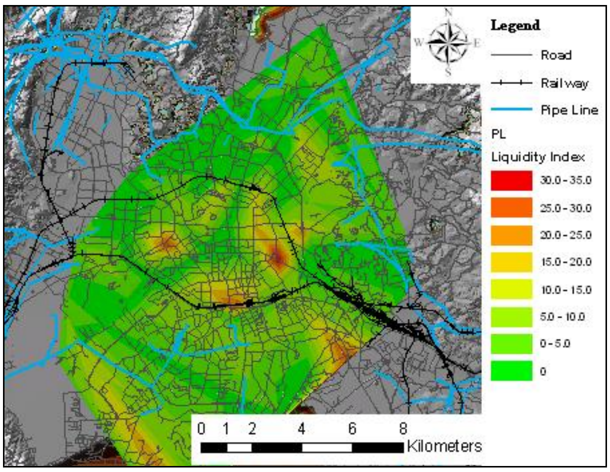

Figure 7. The ground liquefaction risk of Kunming basin in seldom happen earthquake (Japan Model)

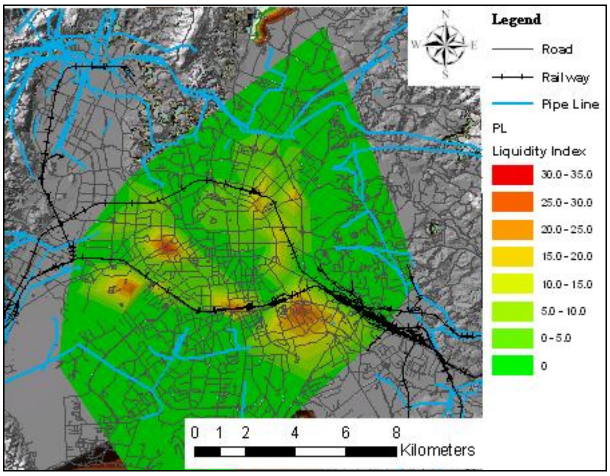

Figure 8. The ground liquefaction risk of Kunming basin in seldom happen earthquake (China Model)

6. CONCLUSIONS

1. The geological structure and earthquake activity nearby Kunming basin have been studied. It is suggested that the largest historical earthquake happen between Yiliang and Songming at Dongchuan- Songming earthquake zone in 1898 (M=8.0) should be used as the seldomly happened earthquake to estimate ground motion parameters of the basin.

2. Attenuation models of ground motion parameters in Japan and China have been introduced in this paper. It is clear that generally, at the same epicentral distance and the same earthquake magnitude, the Japan Model in Eq.(1) gives the largest value of A_{max}, whereas A_{max} calculated by Model3 in Eq.(4) increases rapidly when M>5.0, and reach a abnormal value as 3787.4 cm/m^2 when M is equal to 7.0, which means that the model might not be suitable for evaluating A_{max} when M is large than 6.0. It is suggest that model in Eq.(1) should be used to estimate ground motions of the basin in case of seldom happen earthquake.

3. The zonation of peak horizontal acceleration corresponding to the seldom happen earthquake and the zonation of the characteristic period of the seismic response spectrum of Kunming basin have been suggested in this paper. The *Amax* of the study region of the basin *varies from 300gal to 540gal*. The Tg of the quaternary soft ground of the basin varies from 0.2s to 1.25s.

4. Liquefaction prediction models used in China and Japan have been briefly introduced and compared. A GIS-based liquefaction prediction system has been developed. With the aid of the liquefaction prediction system developed by the authors the ground liquefaction risk of Kunming basin in seldom happen earthquake have been made clear. It is clear that the tow models give almost the same result of liquefaction risk of the basin.

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