SPATIAL MITIGATION TREATMENTS: WENCHUAN EARTHQUAKE CASE STUDY

By

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ABSTRACT

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Planners, designers, government officials and citizens are interested in creating safe environments, such as in mitigating the effects of earthquakes. In this investigation, various landscapes associated with the Wenchuan earthquake in China are examined to assess environmental safety. Six landscape treatments (k=6) were examined with seven variables (b=7). The study employed the Freidman Analysis of Variance Statistics to test the treatments, resulting in the confirmation that some treatments were significantly better and safer than other designs (p≤0.05).

The designs that were significantly more safe include spaces where the buildings are less tall, there is more space between the building, the buildings are neither in the floodplain nor in landslide zones, there are many escape routes for people experiencing and earthquake and there are large open environments for refugees and transportation provided by helicopters. If such principles were in common practice during the 20^{th} century, approximately 421,250 earthquake related deaths could have been avoided.

Key word: Landscape Environmental Design, Disaster Planning, Landscape Hazards, Urban Planning.

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Chapter 1: Introduction

I choose this topic of study before I enterted graduate school. Back in 2008, there was a tremendous earthquake which occurred in my homeland province --the Wenchuan earthquake. The earthquake killed many people. So, after the earthquake I ask myself what can I do and what can a landscape designer do to help reduce the damage of earthquake? So, I thought often about the Wenchuan earthquake and what can I do? I expereiened the earthquake first hand. During the earthquake I paniced and had no idea where to go and what to do, so my first reaction was to escape from where I was.

When people panic, they often quickly choose to escape from the potential danger. However, a quick and correct decision could save a person's life. Conversely, one wrong turn in direction, could also cause one's death. Since we can never predict the moment of a natural event, we do not know what movement maybe correct. To avoid the poor decision, society can take precautions against natural disasters such as good spatial management and city designs that could mitigate the damage, provide safe escape routes, protect people and provide safe shelter parks to give people a temporary home. It is apparent that proper planning and design of a town is very important for safety issues. Good design could save peoples' lifes. There is no hundred percent guaranteed approach to resolve the problem completely, but preparation can help. Earthquakes are classified as a primary disaster (Coburn and Spence, 2002). However, following by the earthquake, secondary disasters also threatened cities (Coburn and Spence, 2002). Secondary disasters are include: landslides, landslide daming water, flooding, fire, building collapses, and diseases. The primary disaster and the secondary disaster destroy many families and kill many of people, such as in the 2008 Wenchuan earthquake (Dong and Dong, 2009).

At 14:28:04 on May 12, 2008, Sichuan province suffered an earthquake of a magnitude 8.0 and this earthquake is named as Wenchuan earthquake (Tian, Zhao, Fan & Gou, 2011). The Wenchuan earthquake was the most devastating earthquake since the founding of New China (Dong and Dong, 2009). Rescue after the earthquake was difficult. During the earthquake, within 50 km radius of epicenter the earth shock violently. Even within a 100km radius of epicenter one can also strongly feel the shaking (Tian, Zhao, Fan & Gou, 2011). The Wenchuan earthquake affected 417 counties (cities, districts) of 10 provinces such as Sichuan, Gansu, Shanxi, Chongqing and Yunnan Provinces. There were 10 extremely afflicted disaster areas (Town/City) and 40 moderately afflicted disaster areas (Town/City) (Wang, 2010). There were 29 million people affected by this earthquake, 68.8 thousand people died, 17.9 thousand people missing and 370.5 thousand people injured (Wang, 2010). After the earthquake happened on 11 June 2008 the Provincial Council issued "Wenchuan earthquake restoration and reconstruction counterpart support program". This program was for post-disaster restoration and reconstruction of those affected sites (Wang, 2010). There are 18 counties /cities of Sichuan province choosen to participate in this program. Eighteen provinces and municipalities signed a three-year term to support affected sites. The support program in each province assisted both counties and cities. The following table (Table 1) shows the support in one province (city) help one county (city) (Wang, 2010).



Figure 1: Destroyed Yingxiu electric substation, notice the landslide area in the background. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis. (copyright ©2008 Feng Mengwen all right reserved used by permission).

	Help Province	Helped Counties and Cities (recipients)
1	Shandong Province	Beichuan County
2	Zhejiang Province	Qingchuan County
3	Beijing City	Shifang City
4	Hebei Province	Pingwu county
5	Henan Province	Jiangyou City
6	Shanxi Province	Mao County
7	Jilin Province	Heishui county
8	Jiangxi Province	Xiaojin county
9	Chongqing Province	Congzhou City
10	Guangdong Province	Wenchuan county
11	Jiangsu Province	Mianzu City
12	Shanghai City	Dujiangyan City
13	Liaoling Province	An County
14	Fujian Province	Pengzhou City
15	Hunan Province	Li County
16	Anhui Province	Songpan County
17	Hubei Province	Hanyuan County
18	Heilongjiang Province	Jiange County

 Table 1: Collaborative support by provinces/cities help one counties/cities



Figure 2: Destroyed Duwen highway Baihua bridge, notice the temoporary highway adjacent to the bridge (copyright ©2008 Feng Mengwen all right reserved used by permission).

Chapter 2: Literature Review

The essential function for landscape architecture is to improve cities' aesthetics (Motloch, 2001). But, landscape architecture could also contribute to its environment, physical geography, ecology and human culture (Wang, Liu and Shi, 2009). One of important process for landscape planning and design is to analyze the land and solve the potential problems of the land and reduce the risk of natural hazard (Wang, Liu and Shi, 2009).

According to Corburn and Spence (2002) preparing for disasters includes a wide range of disciplines such as architecture, engineering, geography, psychology, physics, landscape architecture and public health. In the book "Earthquake Protection", Corburn and Spence (2002) note that 75% of the deaths attributed to earthquakes were caused by building collapses, and other 25% of the deaths were caused by fire, landslides and others causes. Since buildings contain most human activities, therefore, building's safety is the most important element to be considered for earthquake safety. In the twentieth century, there were at least 1,248 deadly earthquakes that happened worldwide and 1,685,000 people who died in those earthquakes (Coburn and Spence, 2002). 40% of these deaths were occurred in China (Coburn and Spence, 2002). So, China is one of the countries over the world suffering the most seminude from earthquake disasters. There is 79% of land affected by earthquakes; however, only 2% of earthquakes happen in the city and 98% of earthquakes happened in rural area (Zhou, Guo and

Deng, 2005). Due to China's current uneven economic status, most rural areas are underdeveloped. The lack of economic support, lack of education, and local traditional culture cause the majority of rural buildings to be built without earthquake resistance standards. Those buildings are under serious threat (Zhou, Guo and Deng, 2005). Therefore, decreasing the height of the buildings would better achieve the seismatic functions in undeveloped areas (Meng, Miao and Pan, 2005).

The huge amount of fatalities caused by building collapses over the world was primarily due to the weak structure of the buildings (Coburn and Spence, 2002). Vatsa (2002) notes that the weak structure was due to inappropriate materials and poor structural form. However, a building's collapse is not always related to the quality of building. Structures can also be affected by external factors from secondary defects following the earthquake such as landslide, fire and tsunamis (Coburn and Spence 2002). Those factors are all affiliated with issues in landscape architecture. Since architecture is about everything inside the building and landscape architecture is about everything outside the building, the outside needs consideration too.

There are those general topics related to landscape architecture and secondary disasters including: landslide, flooding, fire. And there are also primary earthquake disaster related elements: shelter and escape route. These topics form the body of the literature review.

2.1. Landslide:

Landslides are described in several ways: debris flows, earth failures, slope failures, and mass wasting (Schwab, Gori and Jeer, 2005, p.2). Landslides often threaten communities located in mountainous areas. There may be no completely effective way to stop a landslide. Instead humans can position facilities to avoid landslides.

According to Schwab, Gori and Jeer (2005) "The obvious driving force behind a landslide is gravity, but a landslide occurs only when the force of gravity overcomes the inertial forces of friction that hold a slope together" (p.2). Landslides are affected by many variables, especially geographical and human factors. Geographical variables include high moisture levels in the soil, soil composition, freezing of ice in jointed soil or rock and earthquake activity (Schwab, Gori and Jeer, 2005). Human variables include removing vegetation, grading, landscaping, paving, mining, and digging (Anderson and Holcombe, 2013). Due to the geographical environment that causes landslides, landslides occur in a variety of ways: rotational landslide, translational landslide, block slide, rock fall, topple, debris flow, debris avalanche and earth flow creep (Anderson and Holcombe, 2013). Landslide typology for planning and design has been divided into five types of movements: falls, topples, slides, spreads, and flows (Schwab, Gori and Jeer, 2005, p.5).

Landslides can be classified, but one cannot often stop landslides from happening, because it is a natural earth process. So, the approach to avoiding landslides is to not build a community in those susceptible landslide areas. Since, there is no ideal way to stop a landslide from occurring, the only way to keep the community away from the danger is not building the community in a landslide susceptible zone. Therefore the community has a reduced chance to suffer from a landslide. Fell, Corominas, Bonnard, Cascini, Leroi and Savage, (2008) defines the susceptibility zone as it "involves the spatial distribution and rating of the terrain units according to their propensity to produce landslides. This is dependent on the topography, geology, geotechnical properties, climate, vegetation and anthropogenic factors such as development and clearing of vegetation" (p.100). Even though, one might realize that some areas are in a susceptible zone, one may not avoid those areas due to the limited land availability and high-density populations in some countries. Therefore, creating a development plan is very important for each landslide susceptible zone. In 2005, Schwab, Gori and Jeer (2005) noted that "development regulations for landslide hazard could contain wide variety of plan policies affecting land-use and development practices" (P.39).

Schwab, Gori and Jeer (2005) have listed 11 regulations. Among those 11 regulations, there are two regulations that are directly related to the landscape architecture discipline: one is use restrictions and the other one is a site grading ordinance. Use restrictions refer to typical ordinal land use for landslide susceptible zone. It restricts use of the land in susceptible areas. For example, Schwab, Gori and Jeer (2005) mentioned "heavily irrigated or watered agricultural uses or landscaping can raise legitimate concerns" (p.44). This restriction could control area uses for parks, botanical gardens, agriculture, horticulture and tree farm, because all those land use are often irrigated. Irrigation might affect slope stability (Cascini, Bonnard, Corominas, Jibson and Montero-Olarte, 2005).

Schwab, Gori and Jeer (2005) stated site grading ordinances are landscape related rules that regulate the grading of projects to meet the requirement for slope stability, safety and aesthetics for the community. The grading ordinances could be defined as following:

- Utilization of land form or contour measures to produce cut-and fill slopes compatible with existing land character. Continuous unbroken slope surfaces that are visible from offsite are discouraged.
- Graded slopes contoured by varying slope increments and undulating banks vertically and horizontally.
- Varied cut-and-fill banks and drainage terrace spacing to alleviate monotony and allow random landscaping.
- Berms at top of slopes and other locations used to screen, vary profile, and insure drainage away from slopes.
- A drainage plan devised to direct flow to streets or approved collector systems that will be maintained by a public agency or maintenance district.
- Varied pad elevations above street level to avoid appearance of monotonous, flat, level pads.

- Creation of view from hillside sites.
- Slopes less steep than 2-to-1 are encouraged and may not require drainage systems, if approved by the Department of Public Works.
- Cuts and fills in excess of 50-feet depth are discouraged .(p.54)

China is a typical example of high density population with limited buildable land. In China, about 75 % the land is mountainous (Li, 1994). Therefore, China is facing more landslide damages than many other nations (Li, 1994). Other than an ordinance for development planning, China is facing the problem of landslides within an existing community. Li (1994) categorize seven categories for landslide control in China:

-Avoid Problem: Relocation of bridging tunnel (or open-out tunnel)

-Surface Drainage: Channel or ditch, prevention of water leakage.

-Subsurface drainage: Tunnel, blind trench, stabilization trench, vertical-drill drainage holes, horizontal bore holes, slope-seepage, ditch, drainage well of ferro-concrete, drainage well with liner plates.

- Support structures: Retaining wall, anchored retaining wall, cribwork, gabion, stabilization trench and pilling works.

- Excavation: Removal, flattening, and benching.

-River structure work: Erosion control dam, consolidated dam, revetment, groin, spur and dikes.

-Other methods: Planting vegetation, blasting, and hardening (P. 345).

In 2008, the Wenchuan earthquake resulted in 69,226 deaths and more than 2,506 people died by landslides (Chinese research academy of environmental sciences, 2010). According to the record of the department of Land and Resources of Sichuan province, this earthquake triggered landslides over 10,000 spots (Liu, Xia and Xu, 2008). This earthquake occurred in a densely populated area and due to the mountainous geographical location and geological environment, the site contains both heavy rainfall and earthquakes to trigger landslides frequently (Liu, Xia and Xu, 2008). However, heavy rainfall and earthquakes are not the only cause of landslides. "The operations like road, building and mining often contribute to the severity of the event when it occurs" (Schwab, Gori and Jeer, 2005, p. 2).

2.2 Flooding:

Landslide could be a secondary effect after an earthquake. It could also cause another secondary disaster by landsliding into a dam and impoundment causing this secondary disaster – flooding. For example on June 1, 1785 in Sichuan, China, an earthquake triggered a huge landslide flowing into the Dadu River and causeing a landslide dam blocking the river. Ten days later, the sudden breaching of the dam resulted in catastrophic downstream flooding (Dai, Lee, Deng and Tham, 2004, p. 205). As a result of this disaster, there were over 100,000 deaths caused by this landslide dam flooding (Dai, *et al.*, 2004).

Floods often result in a disaster when a community is built upon a flood susceptible area (Watson and Adams, 2010). Floods could happen in several manners: heavy rainfall, ice melting in the mountain or a landslide behind a dam (Watson and Adams, 2010). The floods happened after an earthquake is caused by landsliding into a dam, and impoundment, this type of flood called Landslide dam-break floods (Becker, Johnston, Paton, Hancox, Davies, McSaveney and Manville, 2007). Landslide dam-break floods peak discharge usually much greater than the normal rainfall triggered flood, potentially placing "normally safe" infrastructure and lives at risk (Becker, *et al*, 2007, p.35).

Landslide dam does not frequently happen but has occurred as a secondary disaster right after an earthquake (Dong and Dong, 2009). In 2008, the Wenchuan earthquake formed 34 landslides dam and 2 of them were extremely dangerous for the local residents (Li and Zhao, 2008). Flooding often occurs when a mountain slope has instability. Landslide debris blocks river channels causing the upstream lake to overflow the community boundaries and also threaten the downstream communities (Evans, Delaney, Hermanns, Strom and Mugnozza., 2011).

Many landslides triggered by the 2008 M8.0 Wenchuan earthquake formed landslide dams on rivers draining the Tibet Plateau, this created numerous landslide-dammed lakes, known as "barrier lakes" in Sichuan (Evans, *et al.*, 2011, p. 18). During this Wenchuan earthquake there were about 257 landslide dams forming 24 lakes over 1 Mm³ in volume (Chen, Cui, Li and Zhao 2010). Among those 257 earthquakes-triggered landslides, there was a huge landslide dam named Tangjia shan, located 4 km upstream of Beichuan and 80 km downstream of Mianyang city (Qinghua University, 2009). Tangjia Shan landslide dam (see figure 1) was blocking the lake for 29 days and stored a maximum of 247 Mm³ (Evans, *et al.*, 2011). This landslide dam posed a significant danger to the downstream Mianyang resulting in the evacuation of downstream residents (Evans, *et al.*, 2011). Partial drainage of the lake was achieved by the excavation of a spillway across the rockslide debris prior to overtopping, thus reducing the magnitude of the outburst flood (Evans, *et al.*, 2011, p. 19).



Figure 3: An aerial view of the location for the Tangjia shan landslide dam (Copyright ©2013 Google, all rights reserved, used by permission. Copyright ©2013 Cnes/Spot Image, DigitalGlobe, Landsat, all rights reserved, used by permission. Copyright, © 2013 AutoNavi, all rights reserved, used by permission.).

An earthquake-generated landslide dam may possibly be less dangerous than the landslide dam caused by heavy rain, since a large earthquake itself can be interpreted as a warning to all of the likelihood of a landslide, and provides the earliest possible warning (Evans, *et al.*, 2011,p.41). Due to its haphazard character it is very difficult to control a landslide dam flooding from occuring. So, for the reconstruction sites, they should apply the basic flood-resistant design. According to Watson and Adams (2010) flood-resistant design should include:

- Prevention by relocation buildings and community infrastructure out of harm's way and enhancing natural flood dissipation features of the land and coast.
- Mitigation by raising buildings above anticipated peak flood levels, engineering building structures and envelopes for severe wind and wave impacts, and using building materials that are waterproofed of otherwise impermeable to water damage.
- Other than using engineering methods to control flooding, the most important issues of flood protection are the ecological issue, the environmental resource planning and natural geomorphic processes can do a better job to control flooding (p.135).

However, landslide dams are not always negative. If we could examine them and there are no further tremendous dangerous to that areas, then we could use them properly to benefit us (Dong and Dong, 2009). According to Wang, Cui, Yu and Zhang, (2010, p.1078) landslide dams should be preserved rather than be removed if the risk of dam failure is not so high because preserved landslide dams act as a primary control of river bed incision, and, thus, reduce the potential of new landslide. It could also provide a hydropower station after examining its topography and evaluating the landslide (Dong and Dong, 2009). The lakes could be preserved on a long-term basis and become beautiful landscapes. Streams with long-term unfilled lakes have good aquatic ecology (Wang, *et al.*, 2012, p.1079).

2.3 Shelter:

City emergency shelter, such as in urban parks, green spaces, squares, school playgrounds and other large gathering spaces, to provide a safe refuge, basic life support and rescue command sites (Yang and Yin, 2008). Shelters should be widely spread in the community, with easy access and easy approach (Yang and Yin, 2008). During the post-disaster period, the people's living environments have been destroyed. This means their homes are unable to meet the basic living requirements. Therefore, emergency shelter is necessary. The shelters provide the basic living space for people live during the disaster recovery transition (Coburn and Spence, 2002).

In Beijing, China, there are 29 public shelters and among those 29 shelters there are 21 public shelters are parks, also in Chengdu, China among 26 shelters there are 13 shelters are parks (Yue and Shu, 2009). However, public shelter parks are different than a regular park, it is a functional park. It should contain a variety of facilities to meet the basic requirements for large groups of people for daily use, such as water supply, electronic supply, medical supply,

shelter, restroom, shower room and airfield (Urban planning land and resources commission of Shenzhen municipality, 2009).

Location of shelters should be selected according to the local conditions; shelter planning process is list below:

-Analysis of the regional environment and urban development, determine the major types of disasters affecting urban development.

- Analysis local land resources and land use for emergency shelters

-Analysis local population distribution for comprehensive disaster zoning division

- Classification and grading for emergency shelters.

- Choice of site for emergency shelters and responsibility distribution.

- Disaster prevention and organize evacuation routes

- Related facilities preparations which support the operation of urban disaster prevention system, such as water supplied, electricity, emergency airfield and emergency medical care system (Yang and Yin, 2010, p.134).

Specialized disaster park facilities usually cover a large area. This large area is designed for the primary use of providing shelter (Li, Ma, Su & Wang, 2006). The park should be able to accommodated large amount of local residents and provide basic living conditions, as well as the ability to participate in the city's restoration and reconstruction work after natural disasters. Parks generally have specially designed emergency water, electricity and health facilities. They could work individually for long periods and could meet the needs for large group of people without external assistance (Su & Chu, 2007). When designing a disaster shelter park it should be integrated to its surrounding environment and facilities, such as hospital, school, food market, city's main road, other types of green areas, to form a green network system in the city for evacuation purpose (Li, Ma, Su & Wang, 2006). A buffer zone is set at the interface between inside and outside park area for disaster prevention, such as green belt to prevent the spread of fire or windstorms. Rivers and lakes could act as barriers, as they can slow down and prevent the spread of fire and other disasters (Su & Chu, 2007).

Due to the different circumstances for scattered mountainous and rural areas, emergency shelters should be positioned in a centralized location. Furthermore, in China most of the villagers' houses are self-built (Liu, Ruan and Wu, 2010). Those houses usually have a weak structure and cannot resist most seismic disruptions (Liu, Ruan and Wu, 2010). For the regional characteristics of the mountainous rural areas, schools are planned for use as shelters. This approach assures schools are built to resist high seismic levels to reduce victims in school (Liu, Ruan and Wu, 2010). Therefore, schools need to have emergency lighting, use of electricity, emergency broadcast abilities, and able to store large amounts of relief supplies, food, water, tents and emergency medicine (Liu, Ruan and Wu, 2010).

2.4 Fire:

Fire is one of the secondary disasters that could possibly happen following by an earthquake. In San Francisco, in 1906, the huge fires occurred after an earthquake, almost destroying the entire central city (Saul and Denevi, 1981). Fire can happen due to the built environmental characteristics such as building vulnerability, urban density, utility network, preparedness, and mitigation efforts (Zolfaghari, Peyghaleh and Nasirzadeh, 2009, p.46). These are all important factors in controlling ignitions as well as fire spread and effectiveness of suppression measures (Zolfaghari, Peyghaleh and Nasirzadeh, 2009, p.46). Post-earthquake fires in urban areas are very likely, caused by flammable items, such as gas, heating and cooking appliances inside a building that have been destroyed by the earthquake (Nishino, Tanaka and Hokugo, 2012). Damage to utility systems could cause outdoor ignition. The fire could be caused by the overhead electricity and leaking gas networks (Zolfaghari, Peyghaleh and Nasirzadeh, 2009). Large fires result because of inability of fire departments to put out fires due to the road destruction, communication impairments, and lack of water for firefighting (Wai-Fah and Scawthorn, 2003). Water is an essential element during firefighting. In 1871 Chicago and 1906 San Francisco earthquake, there were large urban fires due to lack of reliable water supplies (Zolfaghari, Peyghaleh and Nasirzadeh, 2009). Therefore post-earthquake reliability of water supply is a necessary element of post-earthquake fire mitigation (Zolfaghari, Peyghaleh and Nasirzadeh, 2009). To decrease the damage, a number of proactive steps can be

taken to reduce post-earthquake fire risk which are awareness, assessment, and mitigation of the risk of fire following earthquakes are crucial if catastrophe is to be avoided (Wai-Fah and Scawthorn, 2003,p.29-61).

In Japan, they created "disaster-proof living zones". The zone has firebreaks, consisting of roads, railways, waterways and green ways at least 16 meters wide that would prevent many fires from spreading to adjacent blocks (Fluchter, 2003, p.223). The importance of regulating the distance between buildings to reduce the risk of fire spreading from one to another building is recognized (McGuire, 1965). A minimum requirement of distance between buildings is necessary (Wai-Fah and Scawthorn , 2003). Building separation distance for fire safety could be calculated by using the height and wide of the fa çade (Williams-Leir, 1970). Distance between buildings could reduce the risk of fire spread, In Japan, they created "disaster-proof living zones", it has firebreaks, consisting of roads, railways, water ways and green ways at least 16 meters wide that would prevent a fire from spreading to adjacent blocks (Fluchter, 2003, P.223). However, different cities have different requirements on the minimum distance between buildings. In general the distance between buildings should be apart farther to better avoid fire spread.

However, when a building collapses or is damaged by an earthquake, it changes spatial characteristics. The damage level and debris will change the burning behavior (Nishino, Tanaka and Hokugo, 2012). Even though an earthquake could change the original structures, there

still needs to be fire safety design. The following factors should be considered in the structural fire safety design phase: (i) damage limits for structural elements, (ii) provisions for preventing local collapse, (iii) limits on the deformation of structural components to minimize the negative impact on nonstructural components and fire protection systems, and (iv) measures taken to prevent progressive collapse of buildings (Mousavi, Bagchi and Kodur, 2008, P.691).

Building separation distance, downwind direction, building material are all important components during fire spreading (Wai-Fah and Scawthorn, 2003). However, other than those elements, there is another important element for spreading fire which is vegetation. When a community is developed, vegetation selection should be fire resistant. The vegetation around buildings should be more widely space, since the threat of the spreading of fire is only present when vegetation is at close distance (Cohen and Saveland, 1997). According to Jensen and McPherson (2008, p.107) the removal of understory shrubs and branches to prevent the accumulation of ladder fuels or the removal of needle litter from around the bases of trees or structures to prevent their ignition is one of mechanical fuel reduction. This method is less useful for public lands. It is an efficient tool with very specific parameters. This treatment should be used directly around homes and other structures in the wild land-urban interface (Jensen and McPherson, 2008, p.109). Jensen and McPherson (2008) mentioned the most effective ways to prevent these building from burning is to clearing vegetation within 65 to 130 feet of structures (p.109). The other effective way to prevent fire is to make the structures themselves as flame resistant as possible (Jensen and McPherson, 2008, p.109).

2.5 Escape Route:

An escape route is one of the most important elements to ensure the life safety during disasters and should be coordinated with city planning. It needs to be designed at several scales which include city escape route, local escape route and building escape route (Yang and Yin, 2008). Different scales are associated with different problems. Multi alternative escape routes are important in all the scales of design. Local escape routes and building escape routes are very important for immediate evacuation. According to Zhao and Arup (2003) building escape routes could be define as "escape routes sufficiently separated by either direction and space, or by fire resisting construction, to ensure that one is still available should the other be affected by fire" (p.134).

A local escape route usually is associated with local shelters. It is a very important system that can be divided into three main levels: region at risk, routes, and destination (Dixit & Radwan, 2009). Properly arranging the route from region at risk to shelter is the biggest issue to resolve. This system involves several factors such as human behavior, escape route, and radius distance from shelters (Fluchter, 2003). There are two aspects of evacuation behavior, the first is the rate at which people evacuate and the second are the driving behavior during evacuation, drivers tend to be more aggressive during an evacuation (Dixit & Radwan, 2009).

When people panic, the evacuation behavior is erratic, people act irrationally during evacuation and their decisions to evacuate depends on factors such as direct perception of threats (Dixit & Radwan, 2009). To guarantee safety and quick movement of people from harms way, it is important to spread out the capacity of the escape route, and it requires the creation of muli-access routes (Dixit & Radwan, 2009).

In the mountainous area, city escape routes are very limited based on the geographical environment. Most roads connect to other regions are build on mountains. Roads built on mountains affect the slope stability and could trigger a landslide (Cascini, *et al.*, 2005). A landslide will block a primary road and isolating the region at risk, it affects city evacuation and outside rescue.

When a catastrophe affects a community, the major damage of the earthquake is not only caused by the primary affect of the seismic force, but the surrounding area is affected by the secondary disaster. Most of the secondary disasters and primary disaster could minimize the damage before the catastrophe happened (Coburn and Spence, 2002). All above disasters preventing the secondary effects of earthquakes are related to planning and design issues in landscape architecture. However, there are relatively few studies that focused upon landscape planning and design elements that could reduce the damage from an earthquake and the secondary disasters. This investigation examines the relationship between landscape planning and designs elements with the primary earthquake disaster and secondary earthquake effects. I

will study the landscape design elements that help to prevent and reduce the suffering from primary and secondary disasters.

Chapter 3: Methodology

3.1 Purpose of Study:

Landslide, shelter, flooding, fire and escape route are five very important elements to consider for primary earthquake and secondary disaster safety. They are individual problems, but if we look at them as a whole, they are all connected. Those issues could be used as mitigation features in landscape planning and design elements.

The purpose of study is to assess landscape features as a factor that would reduce the damage by an earthquake and reduce secondary disaster damage. My study areas are defined by Old Beichuan, New Beichuan, Shuimo, Fengyi, Yingxiu and Linda's Town. This study attempts to compare different towns by looking at seven landscap e architecture design related elements and determine the effect landscape architecture upon in town's safety when facing earthquake and its secondary disasters.

3.2 Study area

3.2.1 Old Beichuan County:

Old Beichuan County is located at the north west of the Sichuan basin with latitude of 31 °50' 05" N and longitude 104 °27' 42" E (Dong and Dong, 2009). The entire county is surrounded by mountains (Figure 4) . The area is about 20,249 million km² with population of one hundred sixty thousands. In May 12, 2008, when the 8 magnitude earthquake hit southwest

China, Beichuan County was one of most seriously damage area (Li and Zhao, 2008). Downtown Beichuan had about twenty thousand people living there. Only four thousand people survived.

Beichuan located on the Wenchuan earthquake fault zone. Since it was 99 miles away from the epicenter, Beichuan suffered both horizontal and perpendicular directional of vibrations (Li and Zhao, 2008). After the Wenchuan earthquake, Beichuan contained heavy secondary disasters destruction. Due to its geographical location, Beichuan experienced many of the features of earthquakes and secondary disasters, including landslides, debris flows and collapse of buildings (Li and Zhao, 2008). According to the public statistics information of land and resources department of Sichuan province (2008), Beichuan County had a total of about 581 of landslides, the event basically destroyed the entire Beichuan. However, the disaster did not stop when earthquake ended. Beichuan continued suffering from secondary damages. From the geographical perspective, the geological environment of Beichuan is very complex with many high mountains, steep slopes, plus heavy rainfall during the summer time. Beichuan was under great threat from secondary disasters.



Figure 4: An aerial view of Old Beichuan (Copyright ©2006 Google, all rights reserved, used by permission. Copyright ©2006 Cnes/Spot Image, Digital Globe, Landsat, all rights reserved, used by permission. Copyright ©2006 AutoNavi, all rights reserved, used by permission. Copyright ©2013 Google, all rights reserved, used by permission. Copyright ©2013 Cnes/Spot Image, Digital Globe, Landsat, all rights reserved, used by permission. Copyright ©2013 AutoNavi, all rights reserved, used by permission.

3.2.2 New Beichuan County:

The old Beichuan County is no longer suitable for people to inhabit because of recurring earthquakes and secondary disasters. So, the entire town was relocated to another site. New Beichuan County's altitude is between 546 meters to 640 meters. The center part of this town is flat and surrounded by many low hills (China academy of urban planning and design, 2011). The new county of Beichuan was built 15 miles south of the old Beichuan County. New Beichuan County is located about 2 kilometers east of Anchang town. It is 23 kilometers away from the old Beichuan County (Dong and Dong, 2009). New Beichuan Cunty is next to Anchang River (Figure 5). The location has a suitable environment for living. There are about eight square kilometers for the town settlement. New Beichuan County is located in flat terrain with excellent natural conditions and very suitable for urban construction. This location is conducive for the reconstruction of Beichuan and also adequate for future development. According to local conditions, the sustainable garden city is the concept for entire town. There are about 1.2 million square meters of green space (China academy of urban planning and design, 2011). The average is 16 square meters per person. A public green space can be reached within five minutes by the inhabitants (China academy of urban planning and design, 2011).


Figure 5: An aerial view of New Beichuan (Copyright ©2010 Google, all rights reserved, used by permission. Copyright ©2010 Cnes/Spot Image, Digital Globe, Landsat, all rights reserved, used by permission. Copyright ©2010 AutoNavi, all rights reserved, used by permission, copyright).

3.2.3 Shuimo Town:

Shuimo town is located in a mountain and canyon area with a mild climate, abundant rainfall, and suitable for a variety of crop growth (Chen and Yin, 2010). The tributaries of Minjiang River called Shouxi River flow from west to northeast flow through the entire territory.

During the Wenchuan earthquake, Shuimo town experienced severe earthquake damage, landslides and substantial house destruction, the village was demolished. The entire town and its 15,000 people all suffered in the catastrophe. A large number of residential houses were destroyed. The financial loss in this earthquake is 5.8 billion RMB (Chinese money) (The Aba government information office, 2010). Shuimo Town is located in the south of Wenchuan County. Shuimo (mean Water mill in Chinese) Town was once also called Longevity town. It is an ancient town with a history of thousands of years (Chen and Yin, 2010). Before the earthquake, Shuimo town was a busy industrial estate. The town was founded along a scenic riverside, but full of industrial smoke and dust. The Qiang ethnic minority lives in this area. All the residents lived in their traditional housing (Figure 7, 8). But after this earthquake, 97 percent of their housing was destroyed (Chen and Yin, 2010). After the earthquake, there are not many historical building left for preservation (Chen and Yin, 2010). However, after Shuimo town had been reconstructed as the educational, cultural, and tourist center of Aba (Figure 6). Poetic and picturesque visions generated a new Wenchuan ecological city and the new

construction in the town provided heritage for the Qiang's (Figure 9, 10). After the earthquake the town became a very popular tourism site. The site is receiving between 10,000 and 20,000 visitors every day (The Aba government information office, 2010).



Figure 6: The reconstruction design of Shuimo Town. (Copyright ©2013 Kaishi Chen, all right reserved used by permission).



Figure 7: Qiang's house(copyright ©1998 Feng Mengwen all right reserved used by permission).



Figure 8: Qiang's house (copyright ©1998 Feng Mengwen all right reserved used by permission).



Figure 9: New residential and commercial area in new reconstruct Shuimo Town (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 10: New residential and commercial area in new reconstruct Shuimo Town (copyright ©2012 Feng Mengwen all right reserved used by permission).

3.2.4:Yingxiu Town



Figure 11: The reconstruction design of Yingxiu town. (Copyright ©2013 Shanghai Tongji Urban Planning & Design Institute all right reserved used by permission).



Figure 12: Memorial site in Yingxiu, the memorial site keep the original look of collapse buildings after Wenchuan earthquake (Build on former address). (copyright ©2012 Feng Mengwen all right reserved used by permission).

Yinxiu town located in the southeast of Wenchuan County, an area of total 115 square kilometers, with an average altitude of 900 meters. The territory around the Yingxiu town is rich with vegetation, beautiful scenery, convenient transportation and developed business (Yu and Guan, 2009). After the Wenchuan earthquake, everything changed. The town area was razed to the ground 5,462 people died and 2,096 acres of farm land was destroyed (Yu and Guan, 2009). After the earthquake, the entire town added 440 new potential dangers spots to the site such as potential dangers of landslide and landslide dam. During the earthquake the water line, electricity line, roads, communication facilities and other infrastructure had been

completely destroyed. Industry, agriculture, and the tourism industry suffered heavy losses, with a direct economic loss of 45 billion RMB (The Aba government information office, 2010).

The reconstruction of Yinxiu town included 7 villages (Figure 11). The total new town planning area is about 115.12 square kilometers, for 0.6 million people and a total investment is 1.719 billion yuan (The Aba government information office, 2010). The total construction area is about 280,000 square meter with 200,000 square meters of housing in urban areas and 80,000 square meters for public service facilities which including schools, hospitals, farmers market, youth activity center earthquake memorial and other public buildings like water plants, sewage treatment and other municipal infrastructure (The Aba government information office, 2010). (Figures 12, 13, 14, 15, 16, 17).



Figure 13: River bank of new reconstruct Yingxiu Town (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 14: New gate at new reconstruct Yingxiu town. (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 15: New build residential area in Yingxiu town. (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 16: A new reinforced bridege in Yingxiu town. (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 17: A small plaza in front an office building in new reconstruct Yinxiu Town. (copyright ©2012 Feng Mengwen all right reserved used by permission).

3.2.5: Fengyi Town:



Figure 18: An aerial view of Fengyi Town (copyright ©2013 Google, all rights reserved, used by permission. Copyright ©2013 Cnes/Spot Image, DigitalGlobe, Landsat, all rights reserved, used by permission. Copyright ©2013 AutoNavi, all rights reserved, used by permission, copyright.)

Fengyi town is located in Mao County, with Miao Mountain in the east and Ming River to the west (Figure 18). The climate in this area is dry, windy and cold in winter and cool in summer (The Aba government information office, 2010). The temperature between day and night is substantial. The county 's average annual temperature is 11.2 °C. In May, 12, 2008, the earthquake had affected 140 counties. The Aba Tibetan and Qiang Autonomous Prefecture was one of the most severely affected areas (The Aba government information office, 2010). Mao county is only 100 kilometers from the epicenter (The Aba government information office, 2010). Most of houses in town had been damaged by the earthquake. Some of them can no longer be in use. After the earthquake, the entire site has been evaluated by its geological conditions, topography, earthquake fault zones, and other factors. The town was relocated to a location with good geological conditions, a gentle slope, far from the earthquake fault zone, suitable site for construction. The total area of Fengyi town is about 7.43 square kilometers (The Aba government information office, 2010).

3.2.6. Linda's Town:

Linda's town (Figure 20) is an ideal hypothetical town. I imagined the site to be surrounded by mountains. A river flows through the site and separates the site into two parts. The climate in this region is assured to be a humid sub-tropical monsoonal climate, with mild winter, hot summers, long frost-free period, plentiful rainfall and mist, heaving high humidity and less sunshine. The temperature in July is the hottest month around 25-29 degrees: January is the coldest month where the temperature is around 3-8 degrees. I designed the site located on the fault line: the fault is the biggest threat to the town, because once the fault line moves, the town is facing several secondary disasters. The geographical character of this region presents secondary disasters that could ruin the entire town. The secondary disasters could happen in this area include: landslides, fire and flooding. On site, there is a frequent landslide area. The infrastructures on the site meet the requirement for all human needs. For the new construction of this town, I considered all the potential secondary disasters. For example, I designed one large public shelter on site, the location of this public shelter, so people can reach it quickly (Figure 19). The open space is in the centre of the town and along the river. It is the best location which works for the residents on both sides of the river. The schools' stadiums and playgrounds can also be use as public shelter. The public shelter needs to create with full facilities for homeless people who can live there at least a week. For each residential hall I designed at least one temporary shelter. The temporary shelters were located around residents' living and work spaces (Figure 21). They are much smaller than the public shelters, and support people to live there for one or two days. In my design the escape route system needed to be well organized for people's daily use and emergency use. Multiple escape routes were developed to reduce the escape time and reduce the traffic time. In the design there were only three escape routes. Two emergency airfields were place on site for air rescue. School and hospitals were placed in a great distance away from the downhill slopes.



Figure 19: The city's shelter park in Linda's Town. (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 20: The new development of Linda's Town. (copyright ©2012 Feng Mengwen all right reserved used by permission).



Figure 21: The residential community design in Linda's Town. (copyright ©2012 Feng Mengwen all right reserved used by permission).

3.3 Variables:

3.3.1 Average Height of building:

This variable will be measuring by the height of buildings in each disaster area. To generate the number, the buildings are summed and divided by the number of buildings that are measured to derive the number of final average height of buildings in each disaster area. Destroyed areas will be measured through old photos. The lower the height of buildings, the better the score, as a measure to indicate ability to exit the structure.

3.3.2 Average distance between building:

To measure the average distance between buildings, aerial maps of each disaster area will be used. To make the calculation, the sums of the numbers for distance between each building are divided by the number of times the measurement is taken to determine the average distance between buildings.

3.3.3 How many escape routes:

An escape route is one of the most important elements to ensure the life safety during disasters. More escape routes could enhance the speed and safety of the evacuation (Dixit & Radwan, 2009). This study will focus on city escape routes, the more the better.

3.3.4 Shelter (long term):

The long term shelter is defined as the use of urban parks, school, playgrounds and other large gathering spaces. It should contains variety facilities meet the basic requirement for large group of people's daily use, such as water supply, electronic supply, medical supply, shelter, restroom, shower room and airfield. Some of the data will be collected through government issued documents and some of them will be measuring the space by using aerial maps.

3.3.5 Public green area per capita

Public green area only contains small parks and public green space around buildings. So, the public green area per capita could reflect the size of open space and size of temporal shelters.

Some data about public green area per capita is collected though government issued documents and some of the data is collected by measuring the area through aerial maps.

3.3.6 Space for helicopter area

Large open flat space is requiring for airfield and it is designated in most public shelter parks. To determine how many spaces are for helicopters aerial maps and government issued documents will be used.

3.3.7 Zoning landslide susceptible area:

To collect how many zoning landslide susceptible areas are in the study sites, government issued documents will be used.

3.4 The Friedman Analysis of Variance Statistic:

Because my observational data has an unknown distribution, I need to use a non-parametric test to evaluate my data. Therefore, my data will be evaluated by using the Friedman analysis of variance statistic. This method is applicable when the observation data come from three or more independent samples (Daniel, 1978, p223).

3.4.1 The Friedman Test:

To assess the treatments, I utilize the Friedman test. The Friedman test (Daniel, 1978) allows multiple variables to be compared. The test measures the different ranking between groups (in this case cities/towns). Collected observation (k) data of each subject (n), and

placing them into a table, comparing the numbers in the rows across treatments. If the results are not significant ($p \le 0.05$), then for each column, the rank for each treatment is very similar. However, if the outcome is significant, the mean of rank will show a difference in at least one column.

To conduct the test, the sum of ranks for the six earthquake related towns are calculated and computed with the Friedman Test statistic. The first step I did is to convert the data into rankings. However, to covert those data into ranks, I have to relate the ranking with the circumstance of each variable. For example, to compare the average height of building, in this situation a lower value is better. However, to compare the variable of escape routes, the standard for escape route is larger the better. So, to get the final rankings I need to compare the data by looking at the condition for each variable with different standard to convert observation data into ranking.

The two hypotheses in Friedman test:

 H_0 : The six treatment yield identical results.

 H_I : At least one treatment tends to yield larger values than at least one other treatment. To calculate the difference of the sum for each rank, I utilized the following formula (equation 1):

$$x_{\rm r}^2 = \left(\frac{12}{bk(k+1)}\sum_{j=1}^k R_j^2\right) - 3b(k+1)$$

Where:

- x_{r}^{2} =Friedman two-way analysis of variance by ranks k = number of columns (also called "treatments") b = number of rows (also called "blocks") R_{j} = Sum of ranks in each column

Equation 1: The formula of Friedman two-way analysis of variance by ranks.

After applying the Friedman test statistic formula, to find out if the result is significant or not, when b and k are small, the X_r^2 value needs to compare with critical values. If the result of the sums of the ranks is not showing significant difference between each treatment, then X_r^2 value will be a smaller number than the critical value. However, if the computed X_r^2 is greater than or equal to the tabulated X_r^2 for *b*, *k*, and $\alpha = p$, we can reject null hypothesis at the α level of significance (Daniel, 1978, p226).

For the values of b and k, one can determine the significance by comparing X_r^2 with table of Chi-squared distribution with *k*-1 degrees of freedom. One can reject, the null hypotheses at

the α level of significance if the X_r^2 computed from the data is greater than or equal to the tabulated value of $X^2(1-\alpha)$ for k-1 degree of freedom (Daniel, 1978).

If the null hypothesis had been rejected, one needs to use Friedman Multiple Comparisons Test to find out which two treatments have most differential value, to get this result one needs to compare all the possible pairs of treatments by the sum of the rank (Daniel, 1978). The formula is showing below:

$$|R_j-R_{j'}| \gg Z \sqrt{\frac{bk(k+1)}{6}}$$

Where:

 R_j = Sum of *j*th rank R_j = Sum of *j* th rank z = A value corresponding to $\alpha / k (k - 1)$ b =Ranking k = Objects

Equation 2: The Multiple-comparison procedure for use with Friedman test.

Then, z is the standard normal critical value, it is equal to the value of $(\alpha / k (k - 1))$. The value is calculated by comparing the difference between sums of rank of each treatment. If any

difference between sum of rank is greater than the critical value, then one can confirm that two treatments are showing significant differences.

Chapter 4: Results

In the study I desired to know which town designs have the best landscape architectural design solution to prevent and reduce the damage from earthquake and from secondary disasters. From the literature review and methodology, I had listed seven criteria about reconstruction after earthquake which related to the landscape architecture design. Those seven criteria are average height building in each town, average of distance between buildings, the number of escape route in the town, number of spaces for helicopter, number of zoning of landslide susceptible area, numbers of shelters, public green area per capita. The study employed the Freidman Analysis of Variance Statistics to determine the results of my research. Each criterion has different standard of ranking.

Standard of Ranking:

- Average Height of Buildings in town: The lower the better.
- Average of distance between buildings: The farther the better.
- Number of escape route in the town: The more the better.
- Spaces for helicopter: The more the better.
- Zoning of landslide susceptible area: The less the better.

- Numbers of shelters: The more the better.

- Area of green area per person: The larger the better.

Table 2: The Table Treatments For Six Areas:

Cities	ShuiMo	Yingxiu	Fengyi	New	Linda	Old
Variables				Beichuan		Beichuan
Average Height of	6.912	8.532	11.88	15.417	6.42	14.553
Building (m)						
Average Distance	10.982	9.39	5.27	7.45	8.34	4.247
between						
buildings(m)						
How many escape	7	10	15	11	9	3
route						
Number of Space	2	2	0	6	2	0
for helicopter area						
Number of zoning	11	7	2	0	1	23
landslide						
susceptible area						
Number of Shelters	20	15	19	16	11	5
(long term &						
temporal)						
Public green area	15.7	18.65	25.7	16.51	17.1	0.51
per capita(m ²)						

Six towns are tested by the seven variables. The towns include: Shuimo town, Yingxiu town, Fengyi town, Old Beichuan County, New Beichuan County and Linda town. Among those six sites, there are four reconstruction sites (after the Wenchuan earthquake), one ideal site (which I had design as a hypothetical site), and Old Beichuan county (a site existing before the Wenchuan earthquake). To start the analysis, I compared all six sites, and the result of sum of ranking of those six sites is extremely close (See Table2).

The results in Table 2 suggest that Shuimo, Fengyi and New Beichuan have similar properties (they have a similar sum of ranking -21). Yingxiu, and Linda town also had a similar score-- 20. Thus the values of those five towns have very similar numbers, this result was not expected when I choose to study those sites. So, for the further analysis I chose three towns to study which contained three different sum of rankings. The final analysis included the towns are Old Beichuan, New Beichuan and Linda (See Table3).

Cities	ShuiMo	Yingxiu	Fengyi	New	Linda	Old
Variables				Beichuan		Beichuan
Average Height of Building (m)	2	3	4	6	1	5
Average Distance between buildings(m)	1	2	5	4	3	6
How many escape route	5	3	1	2	4	6
Number of Space for helicopter area	2	2	5	1	2	5
Number of zoning landslide susceptible area	5	4	3	1	2	6
Number of Shelters (long term & temporal)	1	4	2	3	5	6
Public green area per capita(m ²)	5	2	1	4	3	6
Sum of ranking	21	20	21	21	20	40

Table 3: The Table of Ranking For Six Areas:

Cities	Old Beichuan	New Beichuan	Linda
Variables		Defendan	
Average Height of Building (m)	14.553	15.417	6.42
Average Distance between buildings(m)	4.247	7.45	8.34
How many escape route	3	11	9
Number of Space for helicopter area	0	6	2
Number of zoning landslide susceptible area	23	0	1
Number of Shelters (long term & temporal)	5	16	11
Public green area per capita (m ²)	0.51	16.51	17.1

Table 4: The Table of Treatments For Three Areas:

And follow the same ranking standard, the new ranking is showing in Table 5.

Then, I utilized the Friedman statistic to calculate as

$$x_{\rm r}^2 = \left(\frac{12}{bk(k+1)} \sum_{j=1}^k R_j^2\right) - 3b(k+1)$$

Where:

 $X_{\rm r}^2$ = Friedman two-way analysis of variance by ranks

k = number of columns (also called "treatments")

b = number of rows (also called "blocks")

 R_j = Sum of ranks in each column

Equation 1: The formula of Friedman two-way analysis of variance by ranks.

 H_0 : The six treatment yield identical results.

 H_1 : At least one treatment tends to yield larger values than at least one other treatment.

Then, substitute the number of k, b, R_j into the formula to show as following:

$$k=3$$
 $b=7$
 $R_1=20, R_2=11, R_3=11$

$$x_{r}^{2} = \left(\frac{12}{bk(k+1)}\sum_{j=1}^{k} R_{j}^{2}\right) - 3b(k+1)$$
$$= \frac{12}{7*3*(3+1)} * (20^{2} + 11^{2} + 11^{2}) - 3*7*(3+1)$$

=0.14285714 * 642-84

=7.71428571

Since 7.714 is not the final result, computed of X_r^2 is not included. So, I still need to find the chi-square with *k*-1 degree of freedom to find out the final value.

When k=3 k-1=3-1 =2

Cities	Old	New	Linda
Variables	Beichuan	Beichuan	
Average Height of Building(m)	2	3	1
Average Distance between buildings(m)	3	2	1
How many escape route	3	1	2
Number of Space for helicopter area	3	1	2
Number of zoning landslide susceptible area	3	1	2
Number of Shelters (long term & temporal)	3	1	2
Public green area per capita (m ²)	3	2	1
Sum of Ranking (<i>R_j</i>)	20	11	11

Table 5: The Table of Ranking For Three Areas:

So, from the above equation I receive the number 2, then it is 2 degrees of freedom and alpha is equal to 0.025. Find the 2 degree of freedom value in Daniel (1978, p. 452). The number of 2 degree of freedom is 7.378, the value of X_r^2 is 7.714, the X_r^2 value is greater than the value of 2 degree of freedom 7.378. Those three treatments do not all yield identical results. Therefore the null hypotheses is rejected, and among the three towns, there is at least one town has larger number than the rest of towns.

After the null hypothesis had been rejected, I use Friedman Multiple Comparisons Test to find out the difference between pairs of treatments. I need to find out which pairs of treatments are different from which others. Then, I need to compare all three pairs of treatments by the sum of the rank. The formula is showing below:

$$|R_j-R_{j'}| \gg Z\sqrt{\frac{bk(k+1)}{6}}$$

Where:

 $R_{j} = \text{Sum of } j \text{th rank}$ $R_{j'} = \text{Sum of } j \text{'th rank}$ k = number of columns (also called "treatments") b = number of rows (also called "blocks") z = standard normal critical value (a / k (k - 1))

Equation 2: The Multiple-comparison procedure for use with Friedman test.

The experimentiwise error rate of α =0.10, with *k*=3 and α =0.10 (0.10/6=0.0167 \approx 0.02). And we can find z in the Daniel (1978, p. 397), which z =2.05.

Then, substitute the number of k, b, z into the formula to show as following:

$$k = 3$$
 $b = 7$ $z = 2.05$

$$|R_j - R_{j'}| \gg 3.623$$

The sum of rank for each treatment is $R_a=20$, $R_b=11$ and $R_{c=11}$.

The three pairs of difference are:

$$|R_a - R_b| = |20 - 11| = 9,$$

 $|R_a - R_c/=/20 - 11/= 9,$
 $/R_b - R_c/=/9 - 9/= 0.$

I have tie in my treatment, the difference between R_a , R_b and R_a , R_c are the same which is value 9. But R_b and R_c do not. Since I have the same value for R_a , R_b and R_a , R_c , so I choose R_a and R_b to do further comparison. After computed the value of $|R_j - R_{j'}|$ is 3.623, I compared it with the value of $|R_a - R_b|$. $|R_a - R_b|$ has the value 9 which is greater than 3.623, so does $|R_a - R_c|$. Therefore treatment a and b and, treatment a and c yield different results, but treatment b and c do not.

This study confirms that the new reconstruction site new Beichuan and the ideal site Linda have the same value of sum of ranking. The significant difference is between those two towns with the old Beichuan.

Chapter 5: Discussion

In the study, people may have neglected the important role of landscape architecture which could mitigation disasters. However, landscape planning and design elements could reduce the damage of natural disasters. Well developed town/cities must consider landscape planning and design elements into their planning consideration.

The study employed the Freidman Analysis of Variance Statistics to test three sites which is Old Beichuan, New Beichuan and Linda's town. The results show significant differences. It presents the new reconstruction sites new Beichuan county and the ideal site Linda's town as having the same value of sum of ranking. The significant differences occur between those new construction sites with the old Beichuan county (see Table 4). The differences are due to Old Beichuan having a very low ranking on all those seven variables. This reflects Old Beichuan experiencing disasters when earthquake arrives.

From Table 4, the high ranking score means the site achieve better variable requirement than others. The old Beichuan County has much lower ranking score than other new construction sites, this is due to its geographic location and inappropriate city's planning. The old Beichuan is locate in a mountainous area, the slope of some mountains are around 60 degree (Li and Zhao, 2008). According to Wang and Kong (2008) if slope is larger than 35 degree, it will most likely occurring Debris flow and landslide. Also, in old Beichuan the altitudes of nearby

mountains' are around 500 to 1000 meters. According to Wang and Kong (2008) if the attitude is more than 500 meter, the mountain could cause tremendous landslide. During the 2008 Wenchuan earthquake, landslide buried 80% of old Beichuan County and caused more than 8000 people to die (Chinese research academy of environmental sciences, 2010). However, geographical location is not the only cause aggravated the earthquake damage, the inappropriate city's planning was another reason. The county lacked an escape route. There was only one secondary road to connect with outside world. After the earthquake, the road was twisted and braided. There was no airfield for a helicopter, so a rescue was not immediate. For those reasons old Beichuan was isolated for very long time after earthquake happened.

Old Beichuan is no longer suitable for people live there, due to its geographical location, the entire population was relocated 15 miles away from the Old Beichuan (Dong and Dong, 2009). The New Beichuan County area altitude is between 546 meters to 640 meters, the center part of this town is flat and surrounded by low hills (China academy of urban planning and design, 2011). The New Beichuan County has been designed with 11 escape routes, 6 airfield spaces, 16 shelters and 0 landslide susceptible areas. Compare the data (see Table 2) between Old Beichuan and New Beichuan we can see the big difference between them. Those differences reflect the importance of those design elements to an earthquake susceptible area.

Linda's town is a hypothetic site, it considered majority of natural disasters which could happen especially secondary disaster. And in view of those disasters, I designed landscape architecture related solutions for each disaster to achieve the community's safety. So, Linda's town is a model for earthquake resistant community. From the result, it present New Beichuan county and Linda's town has same ranking and has better landscape architecture design solution for preventing and reducing the damage from earthquake and secondary disaster than Old Beichuan county. On other hand, the results shows the seven variables are playing a role in reduce the damage of earthquake and secondary disaster and provide safer community for residents live there.

In the twentieth century, if all the communities considered those seven variables, the death caused by earthquakes could be reduced by 421,250 people (See Figure 20). Since there are total about 1,685,000 people who died in earthquakes and 25% of those death are cause by secondary disasters (Coburn and Spence, 2002) one fourth of the deaths could be avoided by employing those seven variables. A large proportion of the deaths often happen in rural areas of China, because the majority of rural areas in China is similar to Old Wenchuan County which has no earthquake and secondary disaster protection.



Figure 22: Twentieth Century Death cause by Earthquake.

5.1 Limitation and Future Research

Due to the limitation of access to the data, I could not find complete satellite maps and photos in Old Beichuan. Because of Old Beichuan was entirely destroyed, some important documents were missing or buried under collapse buildings. I can only find estimates by combining two satellite maps which were taken before the Wenchuan earthquake, but those two maps were not taken in the same date, due to this issue, the data may be occur inaccurate. Beside the limitation of access into the data, since the research areas are taking place in China but, I am in US, so most of the data are measured through satellite maps, the satellite maps have a large scale. It is very hard to measure my variables such as the distance between each building accurately. Also, by reason of most of the data are collect online, some are through Government Issue documents and some found by collecting photos, such as height of building. So, I need to go thought the online photo of the town to estimate the average of height of buildings. Therefore, without being able to study on site, the data may not be accurate.

The future research should consider study more sites before the earthquake happened, so the data could better show the difference between sites which is missing those landscape design variables and sites including those variables. More variables should be examined such as flooding, distance between residential and mountains, species for fire resistance plants and shelter design.

A good spatial management could reduce the damage when disasters occur, however, if people do not know where shelters and escape routes are, those facilities are useless for save people's live, so a clear sign direction and guidance book is very important for residents to learn where to go and what to do when disasters arrive. Future study should also study about the cost which could maintain those spatial management elements.

5.2 Conclusion

In the study, I use Freidman Analysis of Variance Statistics to assess various design treatments to reduce the impact of an earthquake. The difference between reconstruction site and the original site has significant difference. The result is showing by management of those seven variables in the village/town/cities people will live in a safer environment.
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