
A Study of Human Response in the Blind Zone of Earthquake Early Warning

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Abstract: The potential for seismic hazard in Taiwan is quite high. In addition to the comprehensive reinforcement of the earthquake resistance of old construction, a short period of time can be immediately is the implementation of earthquake prevention and rescue education. Because of the blind zone of the existing strong earthquake real-time alarm system, the response time is limited, so the application of the message will have better efficiency in an automated way. As regards the emergency response of schoolchildren and the population in the blind zone of strong earthquake early warning, it is suggested that people should be using methods in line with local circumstances. In order to understand and make good use of the vibration characteristics of seismic waves, this study analyzes and illustrates them with several practical examples, including (1) 20100304 Jiasian earthquake with local magnitude (M_L) of 6.4, (2) 20130327 Nantou earthquake with local magnitude (M_L) of 6.2, as well as (3) 19990921 Chi-Chi earthquake with moment magnitude (M_w) of 7.6. The results of this study show that the human body's feelings are one of the most direct, real-time strong earthquake warning messages, especially in the blind zone of earthquake early warning where it is too late to provide seismic information. Judging by the obvious vibrations up and down by the P wave, it is advisable for the people on the first floor of the old low earthquake-resistant premises to seize the opportunity and suggest a time take an immediate approach to outdoor escape response. While fear and panic may be an obstacle to escape, reflex movements can overcome fear, and reflex movements can be developed through regular drills. Accordingly, people will make a correct seismic response immediately within the earthquake, in a short period of time without panic of the emergency evacuation to reach a safe location.

Keywords: Earthquake Early Warning System, Blind Zone, Earthquake Response, Seismic Wave Vibration Characteristics, Drop Cover and Hold on (DCH)

1. Introduction

Taiwan is located on the boundary of the Eurasian continental plate and the Philippine Sea plate, so seismic activity is very frequent. Historically, there were several damaging earthquakes had occurred in Taiwan. Some of these earthquakes had resulted in heavy loss of human lives, such as a 1906 Meishan earthquake, 1935 Taichung-Hsinchu earthquake, 1999 Chi-Chi earthquake, 2016 Meinong earthquake and 2018 Hualien earthquake. In the event of an earthquake, the body's proper protection will help the people to reduce their casualties. Generally speaking, two response methods are more commonly proposed, the first is the Triangle of Life, the other is Drop Cover and Hold on (DCH).

The "Triangle of Life" is an advocate for Doug Copp, the captain of the American International Rescue Team, that when a building collapses, a roof or slab can hit an object or furniture due to gravity, leaving a space near those objects. This space is called the "triangle of life" [1]. On the other hand, the United States, Japan and Taiwan advocate indoors to squat, hide and hold under a table in the event of an earthquake response, namely, Drop, Cover and Hold on (DCH) [2-3]. However, the roof or slab will be crushed table when the building collapsed due to strong earthquake. The escape space under the table will be compressed if people hide under the table. Especially, it is really worrying the student that the school desk could be not afforded the weight of the falling floor in the classroom [4].

In addition, in the development of seismic technology to reduce casualties, the Earthquake Early Warning System can estimate the shaking amplitude of the S wave by the faster and first arrival P wave and alert with seeking a second to tens of seconds of warning time before the arrival of S-wave which had a higher destructive potential to the structure of the house [5-6]. Due to the limited response time for strong earthquake real-time alarm system, and the closer to the epicenter, the shorter the warning time, furthermore, it takes time to acquire the P wave data of seismic station near the epicenter, and data processing, communication system transmission, so close to the epicenter area to receive the alarm, the more destructive S waves may have arrived and no warning can be made, and these areas, which lack response time, are called early warning blind Zones, and are the limits of earthquake warning [7]. Taking the earthquake occurring in the island of Taiwan as an example, the early warning blind zone of the regional strong earthquake real-time alarm system is within 50-70 kilometers of the epicenter [8]. The early warning blind zone of the

on-site P-alert strong earthquake real-time alarm system is within 20 kilometers of the epicenter [9] and the early warning blind zone of the strong earthquake real-time alarm system of the National Center for Research on Earthquake Engineering (NCREE) is 30 kilometers within the epicenter [10]. It is worth noting that the closer the area to the epicenter, the shorter the early warning response time. Figure 1 shows the travel time difference between the P-wave and the S-wave from the different epicenter distances of a 921 earthquake can be considered as an early warning response time [11]. For example, the response time is about 5.4 seconds in Taichung.

Due to the strong earthquake real-time alarm system has the limitation of blind zone, so the application of the message will have better benefit in an automated way. In different time and space background there are different response behavior, this paper analyze the human response located in the blind zone of earthquake early warning, especially for the people and schoolchildren on the first floor of the old buildings in these high seismic hazard potential areas.

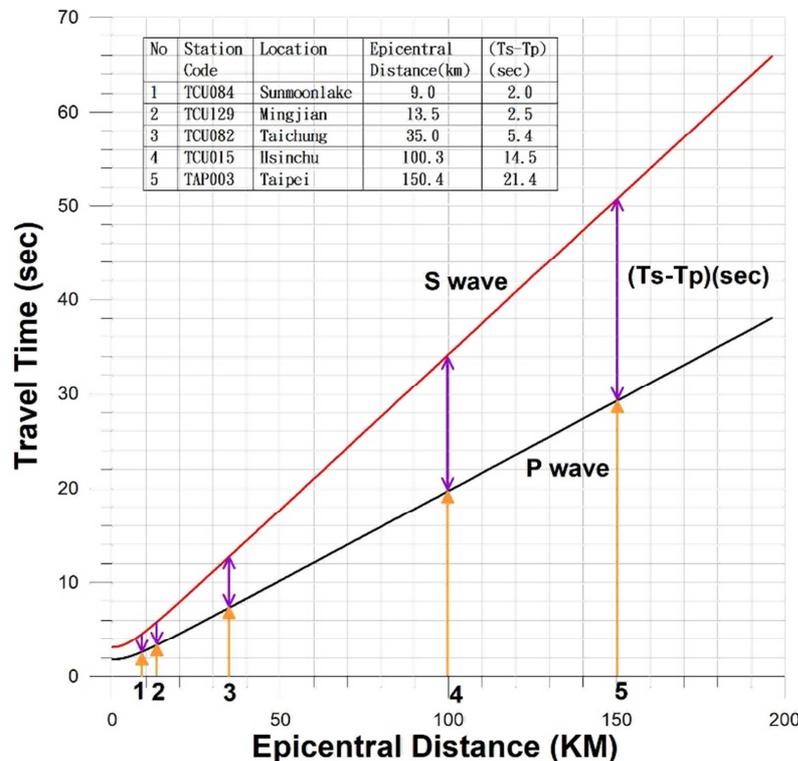


Figure 1. The travel time difference between P and S wave versus epicentral distance. The travel time's differences between P and S wave for 5 stations are also shown for Chi-Chi earthquake. (Liu, 2000).

2. The Judgement and Response in the Blind Zone of Earthquake Early Warning

2.1. The Characteristics of Vibration for Seismic Wave

Next, let's explain how seismic waves vibrate to understand the sequence in which the entire seismic wave arrives and how the body feels the vibration, so as to make timely emergency measures. When an earthquake occurs, the types of the

vibration of the seismic wave depending on the propagation medium can be divided into longitudinal and transverse waves. The longitudinal wave is in the propagation, the direction of the particle motion is the same direction as the direction of the longitudinal wave propagation. It means the particle of the transmitted wave alternately produces compression and extensibility changes along the direction of transmission. P wave belongs to the longitudinal wave. Another type is a transverse wave. The transverse wave is in the propagation, the direction of particle motion and the direction of the transverse wave propagation are perpendicular to each other. S

wave belongs to the transverse wave. During an earthquake, the types of seismic waves include the first arrive P wave, followed by the S wave that arrive later, followed by the arrival of the main vibration wave of the potentially destructive surface wave. In terms of the particle motion, the P wave is the up and down vibration, the S wave is the horizontal vibration, and the surface wave is the horizontal vibration and the slow up-and-down rock vibration. Because earthquakes occur below the ground level, seismic waves travel up to the ground, so the way the human body feels the vibration caused by the P wave is the short-period high-frequency up-and-down vibration. The way the body feels the vibration caused by the S wave is the short-period high-frequency horizontal vibration.

2.2. The Intensity of the Blind Zone of Strong Earthquake Early Warning and the Inspection of the Building's Earthquake Resistance

Estimates of the seismic intensity of the blind zone of strong earthquake early warning can be calculated by the

attenuation model. Figure 2 shown the horizontal peak ground acceleration (PGA) versus hypocentral distance for 19990921 Chi-Chi earthquake with a magnitude of Mw7.6, 20160206 Meinong earthquake with a magnitude of Mw 6.6 and 20100304 Jiasian earthquake with a magnitude of Mw6.4 by the attenuation model of Liu and Tsai (2005) [12]. The corresponding intensity of the PGA is given in Table 1. Central Weather Bureau Intensity Scale (CWBI) of Taiwan [13]. For example, the Chi-Chi earthquake with a depth of 8 km, the PGA are 682gal (CWBI VII), 425gal (CWBI VII) and 294gal (CWBI VI) at the epicentral distances of 10km, 20 km and 30 km, respectively. The above-mentioned PGA are all more than 0.23G that corresponding to the seismic force of earthquake-resistant design of the building Code in Nantou area in 1997. Obviously, from the estimates of the seismic intensity by the attenuation model, can be calculated show that the blind zone of strong earthquake early warning is a high-seismic earthquake disaster area where buildings are seriously damaged or even collapsed.

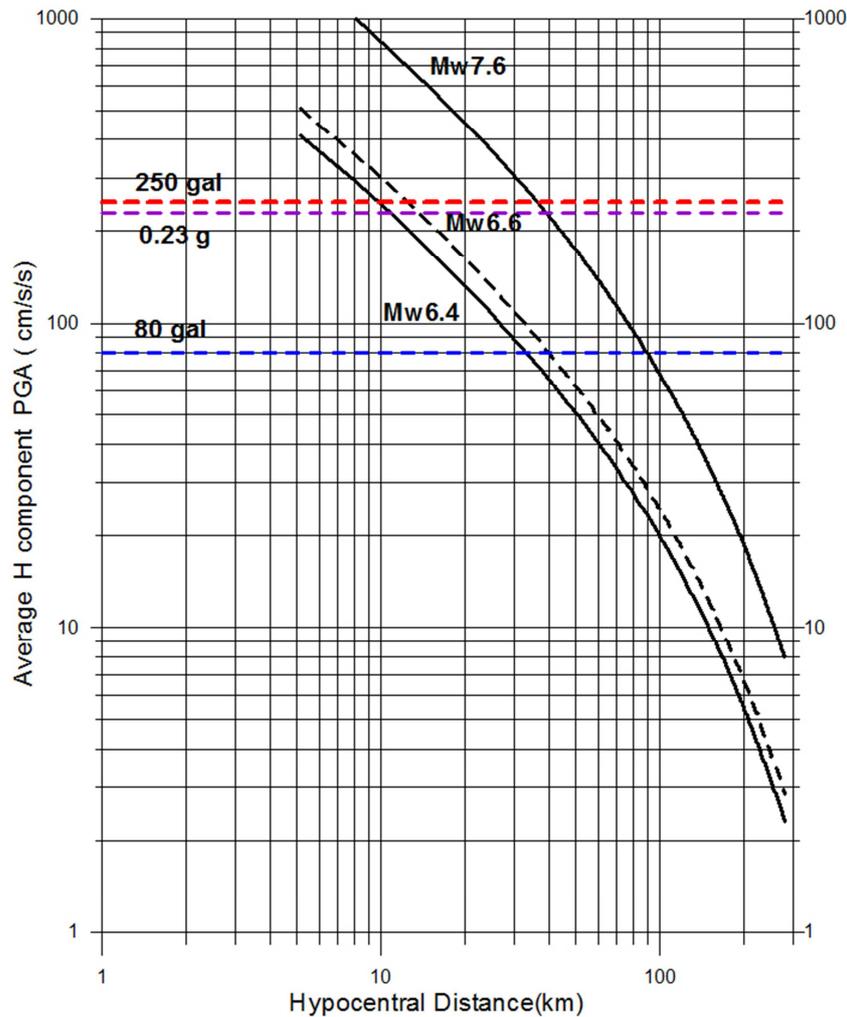


Figure 2. Horizontal PGA versus hypocentral distance displays for Chi-Chi earthquake and Meinong and Jiasian earthquakes based on the proposed attenuation relationship of Liu and Tsai (2005).

Table 1. Central Weather Bureau Intensity Scale (CWBI) of Taiwan.

Intensity Scale		Ground Acceleration (cm/s ² , gal)	Effects on People	Effects Indoors	Effects Outdoors
0	Micro	Below 0.8	Not felt.		
1	Very minor	0.8~2.5	Felt only by a few people at rest, vibrates slightly.		
2	Minor	2.5~8.0	Felt by the majority of people. Some awakened from sleeping.	Hanging lamps and objects vibrate slightly.	Standing vehicles vibrate slightly, similar to being passed by a truck, but only lasts for a short time.
3	Light	8~25	Felt by nearly everyone, a few frightened.	Buildings shake; dishes, windows, and doors shake making sounds; hanging objects shake visibly.	Standing vehicles vibrate obviously; electric wires sway gently.
4	Moderate	25~80	Many people are quite frightened, looking for safe shelter. Most people are awakened from sleep.	Buildings rock noticeably; unstable objects topple over; heavy furniture moves; may cause slight damage.	Felt by drivers; electric wires sway obviously, felt by people walking.
5	Strong	80~250	Most people are considerably frightened.	Walls crack; heavy furniture may overturn.	Noticeably felt by drivers; some chimneys and large archways topple over.
6	Very Strong	250~400	People have trouble walking due to violent rocking.	Damage to some buildings; heavy furniture overturns; doors and windows bend.	Drivers have trouble steering; sand and clay blasts occur.
7	Great	400 and above	People move with difficulty due to severe rocking.	Severe damage to or collapse of some buildings; almost all furniture moves or falls down.	Landslides and faults rupture occur; railway bend; underground lines break.

The peak ground acceleration (PGA) estimate in the earthquake early warning blind zones will cause damage to buildings in these areas, the following three conditions need to be further examined: (1): what is the seismic zone of Building Code in the earthquake early warning blind zones: buildings are required to construct according to the seismic zone of building Code. Taiwan area conducted several different seismic zones from the results of seismic hazard analysis of data such as disasters earthquakes in Taiwan in the past. (2) The seismic force of earthquake-resistant design of the building Code in the past is insufficient: the seismic zone of Nantou area, for example, belongs to the medium seismic zone in 1982. The updated seismic zone II with a seismic coefficient of 0.23 in 1997. After the 921 earthquake, the seismic zone in the Nantou area was changed to seismic zone A, and the corresponding seismic coefficient was increased to 0.33. This is due to the strong ground motion recording in the Nantou area from the 921 earthquake exceeds the original regulations design, seismic force 0.23g, showing that the seismic design of building code in the past can withstand the earthquake force is insufficient. (3) Earthquake resistance was insufficient in old building: The number of housing residences on June 2017 was 8,539,849 in whole Taiwan. The number and percentage of housing age of more than 40 years with high risks facing the strong earthquakes was 1,793,001 and 21.0%. The whole residential structure mainly has reinforced concrete accounting for 67.4%, while the less seismically resistant confined masonry and brick, wood and stone building account for 19.9% and 8.1%, respectively [14]. Unfortunately, the local government in the face of the strong earthquake warning, almost no perfect prevention or more planning. Accordingly, the people's property and security are not guaranteed [15].

2.3. The Judgement and Response in the Blind Zone

The way in which the earthquake occurred, on the website of the fire Department of the Ministry of the Interior and the Ministry of Education (MOE) Disaster prevention Education digital platform advocates earthquake saving 3 Step: Drop, Cover and holder on (DCH) [3] (The authors calls it the earthquake protection 1.0). Earthquake protection and response methods for the early warning blind zone where the information cannot be provided in real time. The author puts forward that the advanced version of the earthquake protection 2.0- it is suggested that people should be using methods in line with local circumstances.

How to decide where and how to take refuge, in short, is the consideration of time and space. The degree and type of vibration caused by an earthquake will behave differently depending on the arrival time of the seismic wave. In contrast, if you feel the obvious vibration of the P wave up and down, it represents two meanings: one is the earthquake is very large, the other is very close to the epicenter, then you can react to the time is very limited, often a few seconds later, by the S wave caused by the larger horizontal vibrations immediately arrived. At this time, such as the people live in the second and above floors can only shelter in situ to Drop, Cover and holder on (DCH). How should the people of the occupants who are on the first floor react? It is recommended to take an outdoor escape. Especially those people live on the first floor of old houses within 30 kilometers of the type I active fault, it is recommended to choose an immediate outdoor escape. The vibration time before the strong earthquake attack usually does not exceed a few seconds, by the 921 strong motion record, the horizontal to violent shaking before the up and down vibration time is only about five, six seconds, followed

by more than 30 seconds of violent vibration but caused a huge disaster, so when the earthquake came, the escapist action to be fast. In addition, a large part of the collapse of buildings occurred on the first floor, so it is advisable for people on the first floor to the escape outdoors in real time, but pay attention to arcade, because arcade is often the most vulnerable part of the building. Furthermore, be concerned about the danger of signboards, flowerpots, and glass falling. As for the occupants of the middle and high buildings, they should usually find suitable shelters in advance so as not to know what to do during the earthquake.

3. Examples and Discussion of Human Response in the Blind Zone of Earthquake Early Warning

3.1. 20100304 Jiasian Earthquake

For 20100304 Jiasian Earthquake with local magnitude (M_L) of 6.4, the early warning blind zone of the strong earthquake

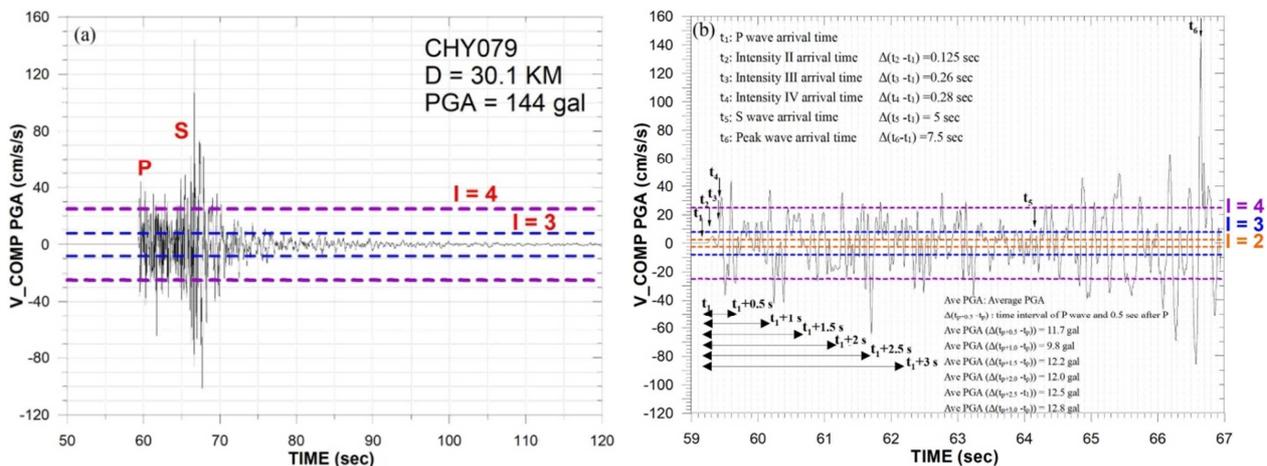


Figure 3. (a) The vertical-component acceleration seismogram of station CHY079 for Jiasian earthquake. (b) Enlarged version of (a) for time ranged from 59 to 67sec.

In addition, the average PGA of 0.5, 1.0, 1.5, 2.0, 2.5 and 3 seconds after the P wave arrival of the CHY079 station is 11.7 gal (CWBI III), 9.8 gal, 12.2 gal, 12.0 gal, 12.5 gal and 12.8gal, Meaning that the intensity of the within 0.5 seconds of the P wave arrival has reached three, almost all people feel the shaking up and down, can take immediate response. In other words, the human feeling is one of the direct real-time strong earthquake warning messages, especially in the blind zone of early warning that strong earthquake real-time alarm system cannot provide the information. According to the judgment of obvious vibration up and down of the P wave, the response of outdoor escape is taken immediately, and the reaction time is about 7 seconds for the time after 7.5 seconds of the P wave arrive, the maximum amplitude wave arrives.

Furthermore, from the disaster data of the 20100304 Jiasian earthquake, there were more than 10 old bungalows and mud-brick houses tilted in close proximity to the epicenter, and 3 collapsed in Shanglin District. It also includes Zhang Youmei, an 85-year-old woman in the Zhong-Zhuang village,

real-time alarm system of the NCREE is 30 kilometers within the epicenter, so we take the epicenter distance of 30 kilometers of the CHY079 station as an example. The seismic intensity of the station has reached CWBI VI, and its vertical, north-south and east-west components of the PGA are 144gal, 199gal and 320gal, respectively. Figure 3 (a) is the vertical component record of the CHY079 station, from Table 1 The human body's feelings are CWBI II for most people can feel shaking, CWBI III for almost all people feel rocking, and CWBI IV for a considerable degree of fear, sleep people will almost wake up. In Figure 3 (a), the range of 8 seconds after the P wave arrives is enlarged as shown in Figure 3 (b). The time shown in the figure that the acceleration amplitude of the CHY079 station is corresponding to CWBI II, III and IV is 0.125, 0.26 and 0.28 seconds, respectively after the arrival of the P wave. The peak ground acceleration (PGA) is 2.7 gal (CWBI II), 10.5 gal (CWBI III) and 27.9 gal (CWBI IV). The time after 5 seconds of the P wave arrive, the S wave arrives, and after 7.5 seconds of the P wave arrive, the maximum amplitude wave arrives.

about 14 kilometers from the epicenter, got up and fled in time, and finally climbed into the garden beside her house [16]. Unfortunately, the seismic station KAU068 in the neighborhood has no record and cannot be further analyzed. From the above example, it can be seen that the actual asylum behavior during the earthquake the people should be using methods in line with local circumstances. A single DCH approach in the old lower premises of the blind zone of strong earthquake warning is not suitable.

3.2. 20130327 Nantou Earthquake

Another example is the Nantou earthquake of local Magnitude (M_L) 6.2 on March 27, 2013, where the intensity of the TCU148 station is up to CWBI VII (PGA 483gal), the epicenter located in the Renai Township in Nantou County. The real-time escape response film of teachers and students of the Tamnan elementary school in the Xinyi Township of Nantou County, located about 15 km from the epicenter, have

aroused some discussion. Due to close to the epicenter, the blind zone of early warning where the strong earthquake real-time alarm system cannot provide the information. When the earthquake occurred, the third grade students were taking a nature class, and after feeling the vibrations up and down, they were able to flee the classroom spontaneously for 3 seconds, before seeing the lateral wobble of S wave arrival. Many netizens praised the children to react quickly, completely without the teacher shouted "Run". In this regard, the school said that there is usually earthquake prevention training, so students encounter earthquakes can be quick [17].

3.3. 19990921 Chi-Chi Earthquake

Looking at the buildings damage of 921 Chi-Chi earthquake, the main factor that the damage of the buildings on one to three floors is serious is the old buildings, especially the old buildings, such as the construction of mud-brick, wood and brick houses, which are less resistant to earthquakes and seriously damaged and collapsed. Another factor that causes the collapse of a building is the resonance effect, that is, when the fundamental period of vibration of the building and the significant periodic overlap of the main concentration of seismic energy, resulting in a resonant effect and serious damage. A survey of the 921 major earthquakes at the Institute of Architecture of the Ministry of the Interior revealed a serious damage to buildings of one to three floors within six km on both sides of the Chelungpu Fault, accounting for about 85% of all damaged buildings [18]. By the strong motion record of the seismic station of Central Weather Bureau, it is shown that the significant period of the earthquake is between 0.2 and 0.4 seconds after spectrum analysis, which is comparable to the fundamental period of vibration of the damaged building. Another study by Professor Yi-Ben Tsai points out that the total collapse houses more than 20% of all houses in the nearby epicenter [19].

For more example is the Nantou seismic station TCU129 with a epicenter distance of 13 km, also located in the blind zone of early warning where the real-time alarm system of strong earthquake cannot provide the information. The earthquake intensity can reach up to CWBI VII (PGA 983gal). The travel time of the P wave and S wave are 3.4 and 5.9 sec, respectively after the earthquake occurred. The travel time difference between P wave and S wave is 2.5 sec. The large amplitude of the main vibration wave arrived, followed by the P wave and S wave is 5.6 and 3.1 sec, respectively. As a result, people on the first floor of the low, old premises should seize the moment and immediately escape to the outdoors.

To sum up, in principle, people on the first floor of the low and old premises should seize the opportunity to immediately escape to the outdoors. However, in view of the suitability of emergency response for schoolchildren in classrooms on the first floor, the local refuge planned by the Ministry of Education's program is also different from the escape mode of immediate evacuation at the NCREE. Although the emergency response to consider the "human nature", in the event of disaster will be hesitant, dull,

panicked and so on, but by the teachers and students of Tamnan elementary school real-time escape reaction film in the above-mentioned Nantou earthquake, showing that students encounter earthquakes still have quick instinct, let us more confidence. Through teaching and exercise, it should be possible to evacuate outdoors more efficiently and quickly. While fear and panic may be an obstacle to escape, reflex movements can overcome fear, and reflex movements can be developed through regular drills.

4. Conclusion

This study analyzes the seismic protection, human response in the blind zone of earthquake early warning. Because the existing strong earthquake real-time alarm system has the limitation of early warning blind zone, the response time is limited, so the application of the message will be more effective in an automated way. As for the emergency escape or refuge of schoolchildren and people in the blind zone of strong earthquake warning, it is suggested that people should be using methods in line with local circumstances. Schools should field survey of earthquake refuge sites, meeting places and escape paths. Different location floors should have different response patterns, rather than a single seismic disaster prevention exercise standard operating procedure (SOP), should then plan a set of customized and suitable for individual campus earthquake disaster prevention drill plan. In addition, teachers and students or people on the first floor of the high seismic hazard potential area (for example, the occupants in the old construction of more than 40 years within 30km distance of the type I active fault), in the feeling of strong vibration up and down by the P wave, it is recommended to take immediate outdoor escape response.

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