平成11年度研究調査報告書

台湾地震交通調査

報告書

平成12年3月

財団法人　国際交通安全学会

International Association of Traffic and Safety Sciences

研 究 組 織

プロジェクトリーダー	飯田　恭敬（京都大学大学院工学系研究科土木工学専攻教授）
プロジェクトメンバー	宇野　伸宏（京都大学大学院工学系研究科土木工学専攻助手）
	小谷　通泰（神戸商船大学商船学部教授）
	塚口　博司（立命館大学理工学部教授）
	Cheng-Min Feng（Professor, National Chiao Tung University）
	S. K. Jason Chang（Professor, National Taiwan University）
	Tien-Pen Hsu (Associate Professor, National Taiwan University)
	Tang-Hsien Chang（Professor, Tamkang University）
	Chi-Kang Lee（Professor, National Cheng Kung University）
	Kuang-Yih Yeh（Professor, National Cheng Kung University）
事務局	本田　潔（(財)国際交通安全学会）
	関　敬子（(財)国際交通安全学会）

はじめに

1999 年 9 月 21 日深夜に台湾中部で発生した集集大地震は、マグニチュード 7.3 の規模であり、台中県ならびに南投県を中心に、犠牲者 2,400 名以上、負傷者 10,000 名以上、全壊建物 30,000 棟以上の甚大な被害を及ぼした。交通分野においても台湾島西部の南北の移動を担う国道 3 号をはじめ、幹線道路や街路網が寸断され、市民生活や復旧・復興活動などに少なからず影響をもたらしている。

国際交通安全学会においては、5 年前に発生した阪神・淡路大震災において、発災直後から震災が交通にもたらした影響や、交通マネジメントの方法について、極めて精力的に調査研究を実施し、学術上及び実務上大きな成果を挙げてきた。その中で判明したことは、地震などの災害が発生した際に、適切な交通管理のための交通状況の調査について、何を対象に、どのような方法・時点で実施すればよいのか、すなわち、災害発生時などの緊急時における交通調査の体系的方法論が今まで整理されていなかったことである。そのため、阪神・淡路大震災における調査研究においても、アンケート調査、踏査、交通写真による調査、ビデオ調査等で試行錯誤的に調査を実施し、計画分析に必要なデータを収集した。集集大震災においても状況は同じであり、復旧・復興のあり方および将来に備えたよりよい震災対策を確立するためには、現地において速やかに調査研究活動を行うことが必要と考えられる。

これらのことから、阪神・淡路大震災における我々の研究成果に基づき、災害時における交通調査および交通管理について台湾研究者と知識を交換し、相互の災害時交通管理に関する理解を深めることは極めて有益と思われる。なお、集集大震災は、山間部で発生しており、なおかつ平常時における交通データ収集についても日台で大きな隔たりがあるため、阪神・淡路大震災時の我々の経験が全てそのまま通用するわけではない。そのため、台湾研究者と議論を重ね、我々の経験をベースに調査を展開することは、今後我が国においても発生しうる、山間部での地震災害における交通管理のあり方に対して、有用な知見をもたらすものと考えている。

本プロジェクトは、上記のような認識のもとで、昨年度 11 月に緊急プロジェクトとして発足したものである。本年度の主な研究活動は以下の通りである。

1) 日本から阪神・淡路大震災において調査研究に携わった研究者 2 名（神戸商船大学小谷通泰教授、京都大学宇野伸宏助手）が台湾に赴き、阪神・淡路大震災時の交通調査について、台湾側研究者に知識提供を行った。
2) 阪神・淡路大震災時の交通調査を参考に、台湾側研究者が震災時における交通状況の調査を実施した。

現地調査については、日本側研究者の知識をベースとしているものの、実際の調査は現地で行うこととなるため、台湾側の研究者がレポートとしてまとめたものとなっている。プロジェクト発足は 11 月であり、調査解析のための期間は実質 3 ヶ月もなかった。今年度は、震災における実態調査が中心となっているが、災害時の交通状況は一過性のものであるため、郊外部で発生した地震災害における交通調査を行ったという点で非常に貴重なデータを収集したといえる。これらの交通データやデータ収集方法を、阪神・淡路大震災における状況と比較分析することにより、今後おこりうる地震災害における交通調査のマニュアル化、および非常時における交通管理の策定方法について、体系化が進むものと期待される。

Executive Summary

この報告書の目的は以下の3点である。

1. 地域交通ネットワークの被害状況の調査分析、
2. 南投市および草屯町の2都市を対象とした、メソレベルでの交通状況の調査および分析、
3. 集集町を対象にした地区道路の道路閉鎖状況の調査分析。

これらの目的を達成するために、マクロ・メソ・マイクロの3つのレベルでの task を、それぞれ Cheng-Min Feng 教授、Tien-Pen Hsu 助教授、Kuang-Yih Yeh 教授が担当し、Chi-Kang Lee 教授、Shyue-Koong Chang 教授、T.H. Chang 教授の協力と共に Cheng-Min Feng 教授によってとりまとめたものである。これら3つの task の概要を以下に示しておく。

Task 1　マクロレベル：地域交通ネットワークの被害状況調査

1) 集集大地震は、台湾中部の郊外部でおこった。地震動に加えて断層、地すべり、液状化が、地域交通ネットワークが破綻を起こした最大の原因であった。集集地震の被害は、日本のものやその他の世界のものとは異なるかもしれない。ゆえに、その被害原因や結果は他国において参考となりうる。
2) 地域交通ネットワークの被害情報をどのように敏速かつ正しく得るかは、第一に人命救助に、そして第二に被害地の人々に救援物資を供給するうえで、非常に重要である。それに加えて、地震発生後の交通状況データをどのように収集するかも交通計画者にとってもう1つの問題である。本研究では、お互いを補完しあうために、フィールド調査とインタビュー調査を一緒に行うことを提案している。
3) 集集地震におけるほとんどの大きな被害をうけた高速橋は車籠埔断層に隣接していた。すなわち、交通計画者や技術者は、橋の建設場所選定の際に注意することと、橋梁構造を強化することが必要である。
4) 山岳地帯での地すべりが多かったため、山岳地帯の地域高速道路の建設が必要か否かが、交通と環境の政策決定者、計画者、技術者の重要な議題となっている。

Task 2　メソレベル：2都市を対象とした都市レベルでの交通状況調査

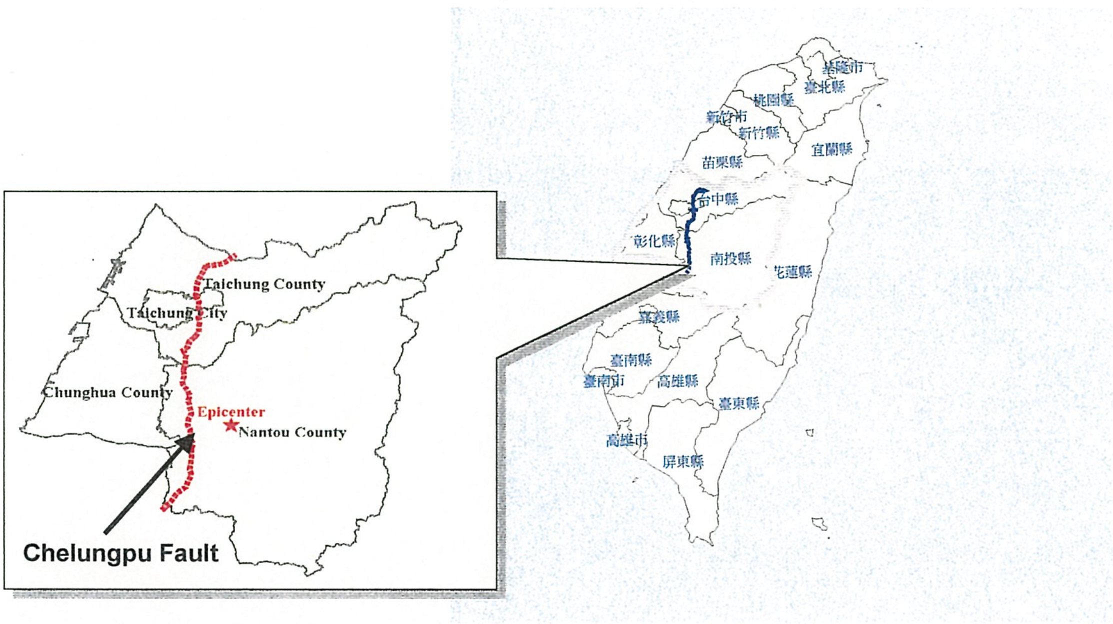
1) 交通状況に連帯的に影響をおよぼす要因は多く存在する。それらは、交通量の増大、レーン幅の縮小、倒壊建物による道路損壊、信号の故障、運転行動の変化などがあげられる。要するに、交通の需要と供給のパターンは、地震による土地利用、道路表面、ランドスケープの変化の結果、大きく変化する。
2) 調査した接続高速において、一般市民は県レベルの高速道路にもっと親しみがあり、より高い収容レベルやよりわかりやすい道路標識のようなよりよいサービスの点でこれらの高速道路を利用する傾向にあることが明らかとなった。それゆえに、近い将来それ以外のリンクの道路標識を改善することを提案する。
3) 居住者は自宅で被害を片づけることを目的に、公的にその期間が休日に設定されたため、地震後の3日間の交通状況はほとんど同じだった。しかし、被災地に救済物資を運搬するために大量に訪れた車両が原因で、交通量は増加した。この状況が普通の状態（地震前の）に戻ったのは地震から3週間後であった。

4) その他の研究と比較して、研究の主な重要性・違いは、“期間”と“瞬間”の考え方の違いである。レーン閉鎖コントロールは、非常に頻繁に変更されるため、この研究は地震後2週間の現実的な交通状況を把握することをねらいとした。そのため、本研究の成果は、具体的な“ある瞬間”を対象とした調査とは非常に異なっている。すなわち、その結果は、(高速道路もしくは街路が、) 閉鎖されているか否かで表されている。
5) 都市の道幅は非常に限られているため、路上駐車や路側での活動が日常的に交通渋滞をまねく。しかし、アンケート調査において、“道路スペースがそれら (不法駐車やその他の物) によって占有され、移動が困難であった”という選択肢が準備されているにもかかわらず、その選択肢を選んだ回答はなかった。これは、人々は交通渋滞に慣れ、路上駐車を当然のように思ってしまっているためである。
6) 草屯町と南投市の交通状況の比較によって、草屯町はあまり被害がなかったので、震災前後の交通状況はあまり変化していないことがわかった。一方で、南投市の交通モビリティは、地震でひどい損害があったために大きく減少している。したがって、地震による道路容量の減少の影響は、交通需要パターンの変化よりも影響を及ぼすといえる。

Task 3　マイクロレベル：街路の道路閉鎖状況調査

1) 集集町の12メートル以上の幅がある幹線道路は、災害に強い交通機能を供給可能であった。2メートル幅のほとんどの道路は、地震時には閉鎖された。
2) 8メートル以上の幅の道路は、その被害状況はランク1かランク2に位置づけされる。それはこれらの道路が緊急車両によって利用可能であることを示す。
3) 航空写真データと現地での聞き取り調査の比較では、20%(=27/140)の違いがある。理論的には、航空写真は正確に読みとることが可能であるが、9リンクが判読不可能で、確認が必要であった。住居者がアンケート調査に回答するとき、ほとんどの人々が控えめに答える。
4) 6～8メートルの幅での道路被害が一番多かった。一般的に集集市での被災街路の70%は、基本的な交通機能に対しても深刻な交通問題を及ぼした。
5) 木造家屋の倒壊によって閉鎖された道路はほとんどない。大部分の道路はRCや煉瓦造りの家屋の倒壊によって閉鎖されている。
6) 11の街路が緊急車両でも利用できなかったが、道路ネットワーク全体としては問題なく機能していた。
7) 調査の結果、集集市においては、孤立地域は発生しなかった。

The Survey and Analysis of Road Damage and Traffic Condition for Transportation Networks
— Case Study of Chi-Chi Great Earthquake



Prepared by Chinese Institute of Transportation

Sponsored by the IATSS (International Association of Traffic and Safety Sciences)

April 5, 2000

The Survey and Analysis of Road Damage and Traffic Condition for Transportation Networks
— Case Study of Chi-Chi Great Earthquake

The Study Group

Total Task: **Chaired and coordinated by Prof. Cheng-Min Feng**
National Chiao Tung University

Task 1. **Chaired by Prof. Cheng-Min Feng**
National Chiao Tung University
Research Assistant: Hsin-Yu Chen, Vincent Chang, Yu-Fong Ho

Task 2. **Chaired by Associate Prof. Tien-Pen Hsu**
National Taiwan University
Research Assistant: G. H. Lu

Task 3. **Chaired by Prof. Kuang-Yih Yeh**
National Cheng Kung University
Researcher: Yung-Lung Lee, Associate Prof., Dept. of Land Management, Chang Jung Christian University
Young-Long Wu, Assistant Prof., Dept. of Land Management, Chang Jung Christian University
Research Assistant: Ming-Hsien Hung, Undergraduate Student, Dept. of Land Management, Chang Jung Christian University

Advisors: Prof. Chi-Kang Lee, Prof. Shyue-Koong Chang,
Prof. T. H. Chang

Prepared by Chinese Institute of Transportation

Sponsored by the IATSS (International Association of Traffic and Safety Sciences)

April 5, 2000

Contents

Executive Summary

This research report was prepared by the Chinese Institute of Transportation (CIT) and funded by the International Association of Traffic and Safety Sciences (IATSS), Japan. The goal of this report has three:

1. **to survey and analyze the damaged conditions for regional transport network,**
2. **to survey and analyze the traffic condition in selected towns, Nantou City and Tsaotung Town,**
3. **to survey and analyze the street closure condition of local roads in Chi-Chi Town.**

In addition to acknowledging the funding from IATSS, we would like to give a special appreciation to Prof. Odani, Prof. Tsukaguchi, Dr. Uno and etc. who gave us some Japan's experiences in survey methods and results analysis for the earthquake.

To meet these goals, three tasks of macro, meso and micro level, were respectively assigned to Prof. Cheng-Min Feng, Associate Prof. Tien-Pen Hsu, and Prof. Kuang-Yih, Yeh, and coordinated by Prof. Cheng-Min Feng with the advice from Prof. Chi-Kang Lee, Prof. Shyue-Koong Chang, and Prof. T. H. Chang. The results of these three tasks were summarized as follows:

Macro level: the damaged conditions for regional transport network

1. The Chi-Chi great earthquake occurred at the suburban areas in the Central Taiwan. In addition to the ground shaking, the fault rupture, landslides and liquefaction were the main reasons to cause the failure of regional transportation systems. The damages in the Chi-Chi quake may be different from those in Japan and elsewhere in the world. Therefore, the damage reasons and results could be used as references for other countries.
2. How to obtain the immediate and correct damage information of regional transportation networks is very important to the work of rescuing people at the first time and distributing relief goods to the people in the disaster areas at the second time. In addition, how to collect data of post-quake traffic conditions is also another issue for transportation planners. It was suggested in this study that the methods of field survey and interview survey should be conducted together to complement each other.

3. Most of the seriously damaged highway bridges in Chi-Chi earthquake were adjacent to the Chelungpu fault, which reminded transportation planners and engineers in Taiwan to carefully choose bridge location and to strengthen bridge structure in the future.
4. Since there were many landslides in the mountainous areas, whether we need to construct more regional highways in the mountainous areas is now a critical issue to transportation and environmental policy makers, planners, and engineers for discussion.

Meso level: the traffic condition in selected towns

1. There are various factors that jointly influence the prevailing traffic conditions, such as traffic volume increase, lane width decrease, road damage caused by collapsed buildings, malfunction of traffic signals, and change of drivers' behaviors, etc. In short, the patterns of traffic demand and supply have been significantly changed due to the great quake, which results in the changes of land use, road surface, and landscape.
2. For the connecting highways being investigated, the general public are more familiar with provincial-level highways and they are more willing to use these highways in view of better service due to higher capacity levels, and clearer instruction of the signage systems. Thus, it is suggested to improve the signage systems for the rest of the links in the near future.
3. The traffic conditions in the following 3 days of the quake are much the same, since it is officially off during that specific period of time, and the residents are usually staying at home to take care of the damage. However, traffic volume is increased due to the increase of rescue resources flooding into the damaged areas. This situation returns to normal traffic conditions (before the quake) after 3 weeks of the quake.
4. The major significance / difference of the research as opposed to other research is the "time period" vs. "time spot" survey concept. Since lane closure control is periodically changed with a very high frequency, this research aims to find out realistic traffic conditions during 2 weeks of the quake. This outcome is significantly different from those surveys at a specific "time spot", in which the

results are represented by (highway or street) "in service" and "blocked".

5. Since the street width in the urban area is very limited, therefore street parking and roadside activities usually cause severe traffic congestion. However, even though there is choice option being designed in the questionnaire stating "road space is occupied (by street parking or other objects), which results in difficult traffic movement", there is no response to this specific option. This is due to people get used to the traffic conditions, and take street parking for granted.
6. By the comparison of the traffic conditions in both Tsaotun Town and Nantau City, it is found that the traffic conditions in Tsaotun Town are less changed before and after the quake since it is not severely damaged. On the other hand, the traffic mobility in Nantau City is significantly decreased due to serious damage by the quake. Therefore, it is reasonably to infer that the influence of the decrease of roadway capacity caused by the quake is much serious than the change of traffic demand patterns.

Micro level: the street closure condition of local roads

1. The arterial roads whose width are 12 meters and above in Chi-Chi town could provide traffic functions of disaster relief. Most of the streets with widths of 2 meters are blocked during the earthquake.
2. For those streets with widths greater and equal to 8 meters, the damage conditions are located at rank1 and rank2. It means that these streets are accessible by emergency vehicles.
3. There are 20% (=27/140) difference in comparison the on-site survey with the air photographic data. Theoretically, air photos provide accurate reference, but 9 links remain unreadable and are required reconfirmation. When residents answer the questionnaires, most of them provided their answers conservatively.
4. There is a significant amount of damage links shown in wider streets, the percentage of streets damage with the width between 6 and 8 meters is the highest. Generally 70% of damaged streets in Chi-Chi town caused serious traffic problems in providing fundamental transportation functions.
5. Very few streets are blocked by collapse of wooden houses. Most of the streets are closed due to collapse of R.C or brick houses.

6. 11 streets could not be accessible by emergency vehicles, but the street network still functions well.
7. The study finds no isolation area in Chi-Chi town.

Task I: Macro Level: Damaged Conditions for Regional Transportation Network

Introduction

Location and Time

Most people in Taiwan were at home asleep at 1:47 a.m. of September 21 when the island of Taiwan was rocked by a magnitude 7.3 earthquake. The epicenter of the earthquake was located in the mountainous central region of the island near the town of Chi-Chi in Nantou County (figure 1-1). The earthquake was named locally as “921” great earthquake or “Chi-Chi” great earthquake in attempt to document the time or place of the disaster.

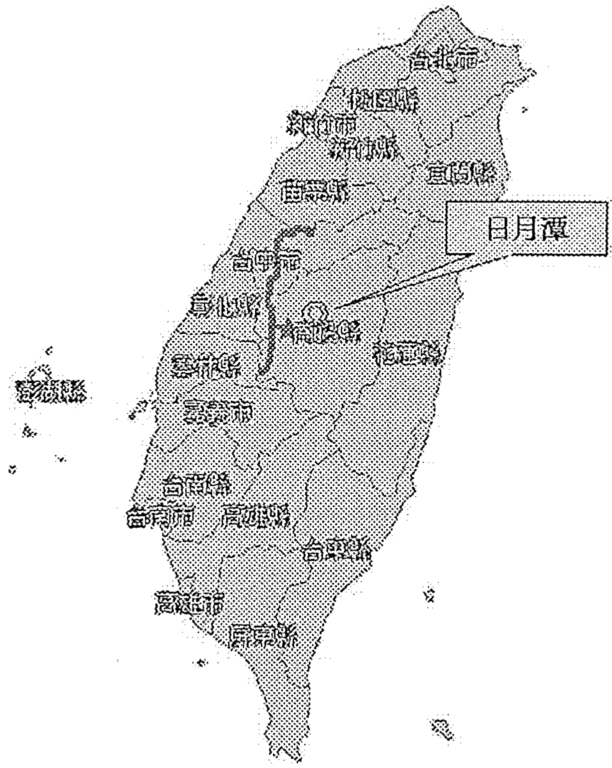


Figure 1-1 Epicenter of Chi-Chi Quake

The Chi-Chi great earthquake was caused by the rupture of the Chelungpu fault. Because Central Taiwan is the area seriously hit by the earthquake, this study will choose Taichung City, Taichung County, Changhua County and Nantou County in the central Taiwan as our study area (figure 1-2).

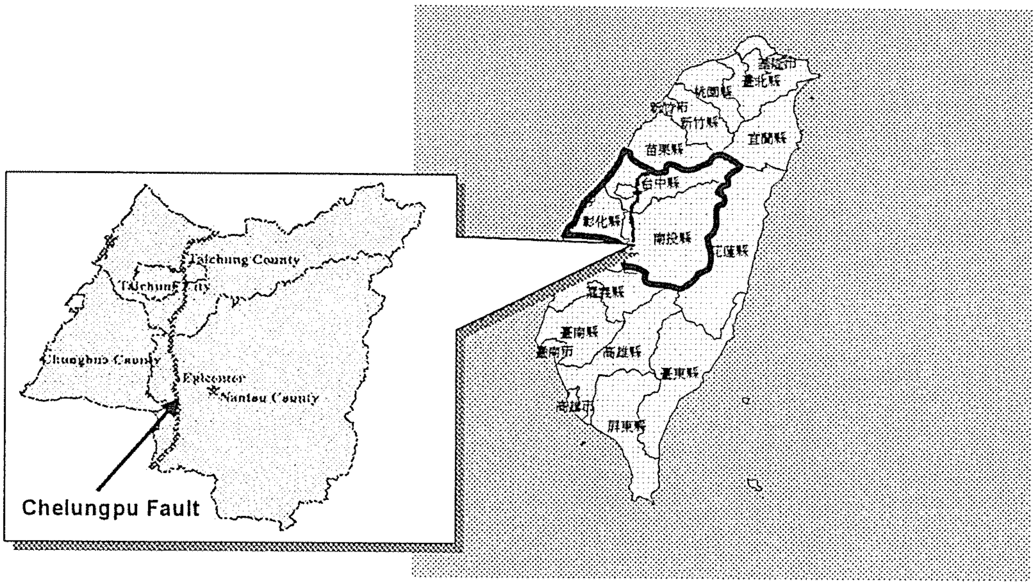


Figure 1-2 Location of Chelungpu Fault and Study Area

Characteristics of the Chi-Chi Earthquake

The Chi-Chi great earthquake had several characteristics: suburban disaster location, shallow earthquake, many aftershocks, and some special geotechnical effects such as fault rupture, landslides and liquefaction.

Suburban disaster location

The primary disaster area of the Chi-Chi great earthquake was in the suburban areas, while that of the 1995 Hanshin-Awaji earthquake in Kobe, Japan was in the urbanized areas.

Shallow earthquake

The Chi-Chi great earthquake was categorized as a shallow earthquake, which has a greater impact near the epicenter than deeper one does. This shallow earthquake caused greater vertical and lateral displacement than Taiwan had in the last century. The ground in some places was lifted more than five meters.

Many aftershocks

In the first few days (9/21~9/27) following the earthquake, there were about 8,000 aftershocks, with 13 of these measuring over 5.5 magnitude.

Geotechnical effects

The geotechnical effects of Chi-Chi great earthquake could be characterized by fault rupture, landslides, liquefaction, which were also the main causes of all kind of damages in addition to the ground shaking.

1. Fault rupture

The total length of the Chelungpu fault is about 80 km. The epicenter is located about 15 km from the south end of the fault. The Chelungpu fault thrust activity triggered a violent vertical offsets and surface ruptures, which caused the severe destruction in Tungshih, Fengyuan, Tali, Wufen in Taichung County, and in Puli, Chushan, Mingchien, Chungliao in Nantou County along the fault line.

2. Landslides

The Chi-Chi great quake changed the mountains shape, dammed a creek and formed an artificial lake. Examples of disfigured mountains in the central Taiwan are the Chiufen Mountain 2, Kuohsing township and on Chiuchiu Mountain in Tsaotun township in Nantou County. The once-verdant mountains have turned to barren escarpment. These landslides and rockfalls destroyed the highway transportation systems, damaged buildings, isolated the communities, and created the mudflows.

The six consecutive days of heavy rainfall in the end (2/20~2/25) of February, 2000 have unleashed more mudslides, stranded quake victims, and cut off water supplies in Nantou County. Many people in the affected villages needed to be relocated to safer areas. Jenai Township, a predominantly aboriginal area, had 35 houses crushed, seven roads blocked and more than 1,000 people trapped by these mudslides. The Council of Agriculture said total damages to the agricultural sector (2/20~2/25) amounts to more than NT 190 million, while Highway Bureau said the damages to the highway amounts to NT 200 million because of this mudslide (2/20~2/25).

3. Liquefaction

Liquefaction occurs primarily in saturated, loose, fine to medium-grained soils. When these sediments are shaken, a sudden increase in pore water pressure causes the soils to lose strength and behave as liquid. Liquefaction-related effects include loss of brearing strength, ground oscillations, lateral spreading, and flow failures or slumping.

Liquefaction induced damage was reported at some locations of riverbank, levee, port area and bridge area in the Chi-Chi great quake. Liquefaction led to settlement of building foundation, lateral spread of levees, and movements at bridge abutments at river crossings.

The major characteristics of Chi-chi earthquake could be summarized as follows:

(1) No. of Aftershock: 8,000 (9/21~9/27)

(2) Major Aftershocks (≥ 5.5 ML): 13 (figure 1-3)

(3) Shallow Earthquake: 1.1 Km

(4) Vertical and Lateral Displacement: 5M (Ground Lift)

(5) Affected Area: Most in Suburban Areas

(6) Geotechnical Effects:

- Landslide (山崩)
- Fault Rupture (斷層錯動)
- Liquefaction (液化)

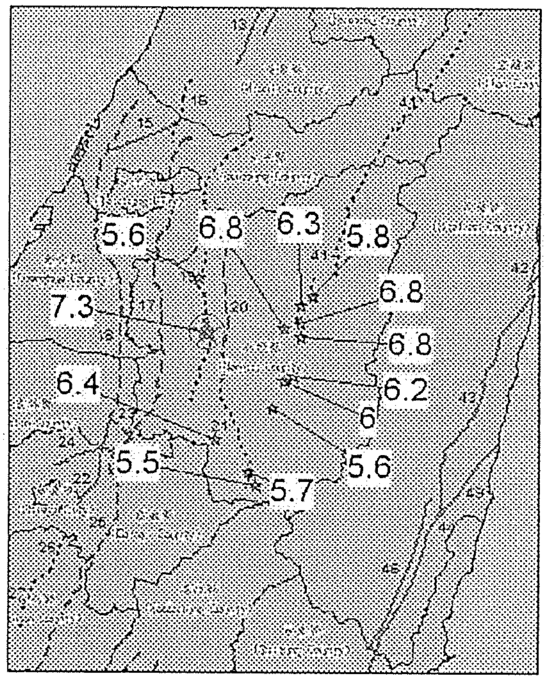


Figure 1-3 Location of Major Aftershocks of Chi-Chi Earthquake

Deaths and Injuries

The Chi-Chi great quake left 2,400 people dead, and more than 10,000 injured. More than 30,000 housing units were destroyed, 25,000 housing units were damaged, and 100,000 people were left homeless (figure 1-4). Many towns and villages in central Taiwan were destroyed. Industry and commercial activities were brought to a standstill because of power cuts or insufficient workfore. The conservative estimates of total losses were over US$ 9.2 billion.

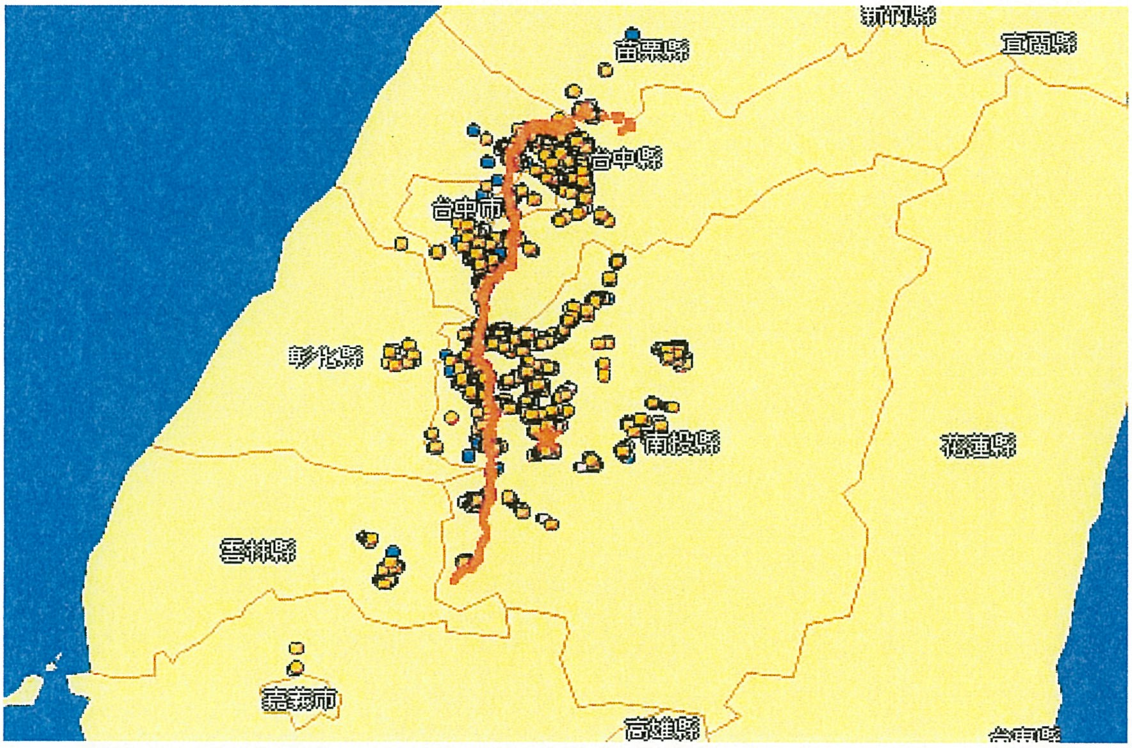


Figure 1-4 Distribution of Major Disaster Areas

Survey for Damaged Conditions of Regional Transportation Network

Survey Purpose

The survey of macro level is to understand the damaged conditions of highways, highway bridges, and bus transit systems for regional transportation in the damaged central region of Taiwan.

Survey Area

This survey area mainly focused on the damaged central Taiwan, including Taichung City, Taichung County, Changhua County and Nantou County. The survey areas were shown in figure 1-5.

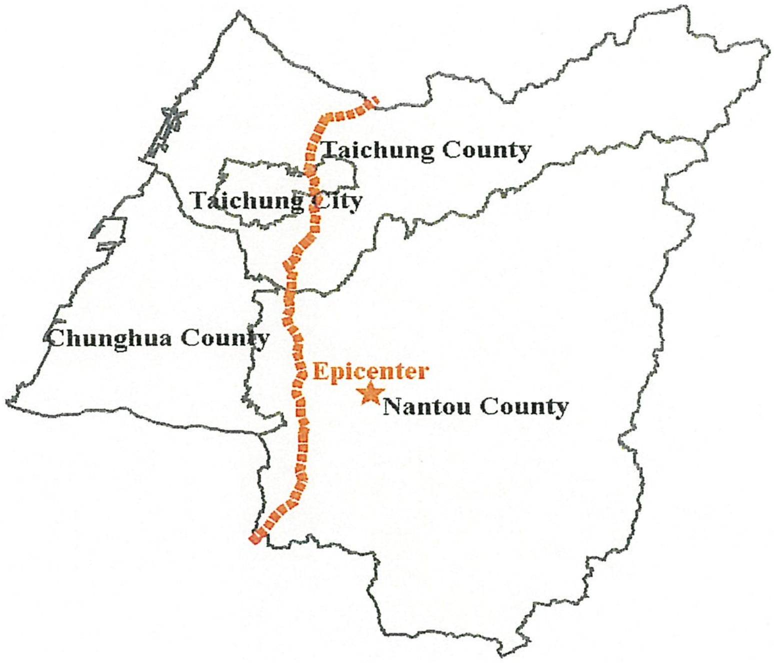


Figure 1-5 Survey Area

Survey Method

The survey of damage conditions of regional transportation networks were conducted through both field survey and interview survey. The field survey were conducted by sending students to the disaster areas to understand the real damaged conditions. However, some damaged conditions had been recovered when conducting our field survey. Therefore, interview survey were very helpful to obtain the damaged conditions at the immediate time after earthquake for the regional transportation networks. The interviewed agencies in this interview survey were Center of Earthquake Engineering Research, Highway Bureau, Architecture & Building Research Institute, Construction Planning Administration, and etc.

Survey Results

(1) Highways

Highway transportation failure not only impeded access to hospitals, evacuation areas, emergency relief centers, and fire departments during the rescuing period, but also affected the ability to get to or from work during the recovery period.

The highway transportation disruption in the Chi-Chi great quake resulted primarily from landslide, fault rupture and liquefaction. Highway traffic were closed on 156 sites for provincial road and on 112 sites for county road. There were 290 sites having the road surface displacements and landslides. The locations of these damaged sites could be seen in figure 1-6.

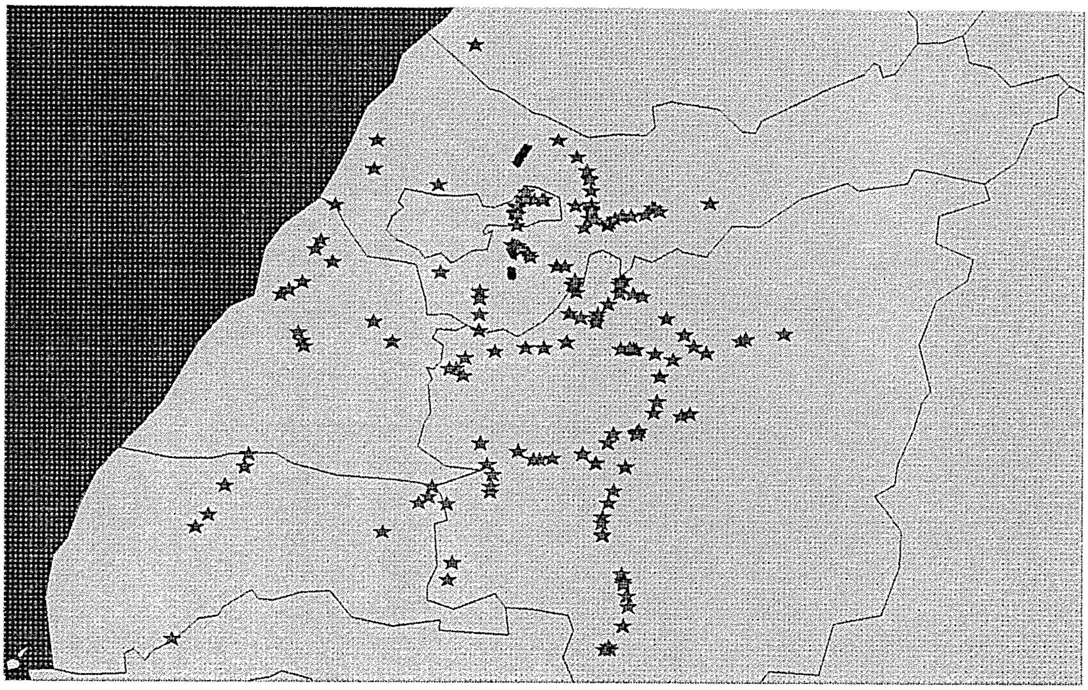


Figure 1-6 Distribution of Highway Damage Sites

From the topography of disaster areas (figure 1-7), it can be seen that the seriously damaged highway sites or highway routes are located at mountainous areas which caused the landslides, or adjacent areas of fault rupture. The highway routes of major damage were No. 3, No. 8, No. 8-1, No. 14, No. 16, No. 18, No. 21, and No. 21-1 at the provincial highway level, and No. 131, No. 136, No. 149, No. 149-1, No. 149-2, No. 151 at the county highway level (Table 1-1).

Table 1-1 Highways of Major Damage

1. No. 3	**Provincial Highway**
2. No. 8	
3. No. 8-1	
4. No. 14	
5. No. 16	
6. No. 18	
7. No. 21	
8. No. 21-1	
No. 131	**County Highway**
No. 136	
No. 149	
No. 149-1	
No. 149-2	
No. 151	

Among these, Provincial-3 is a very important north-south highway routes, which is unfortunately located adjacent to the Chelungpu fault. Provincial-8, -14, -16, and –21 were basically the mountainous highway routes, which were damaged because of the landslide, rockfall and surface displacement. The distribution of damaged highway routes can be seen in figure 1-8. The other reasons for damaged provincial-3 and –14-2 highway routes are liquefaction. The reasons and locations for highway damages can be summarized as in the figure 1-9.

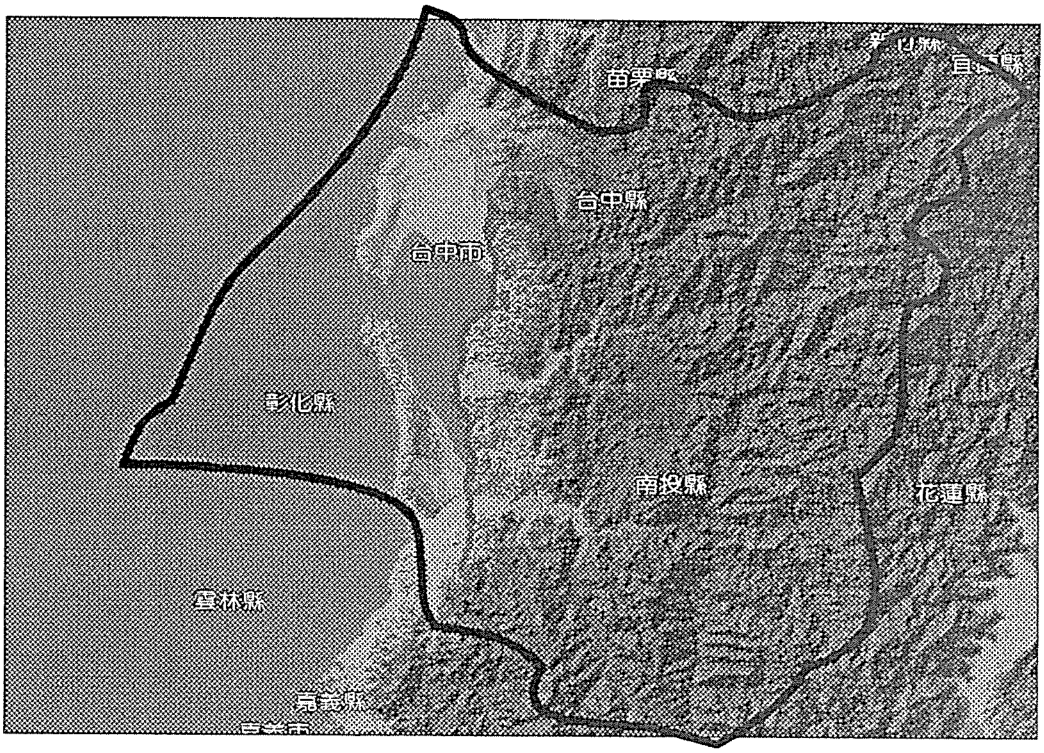


Figure 1-7 Topography of Disaster Areas

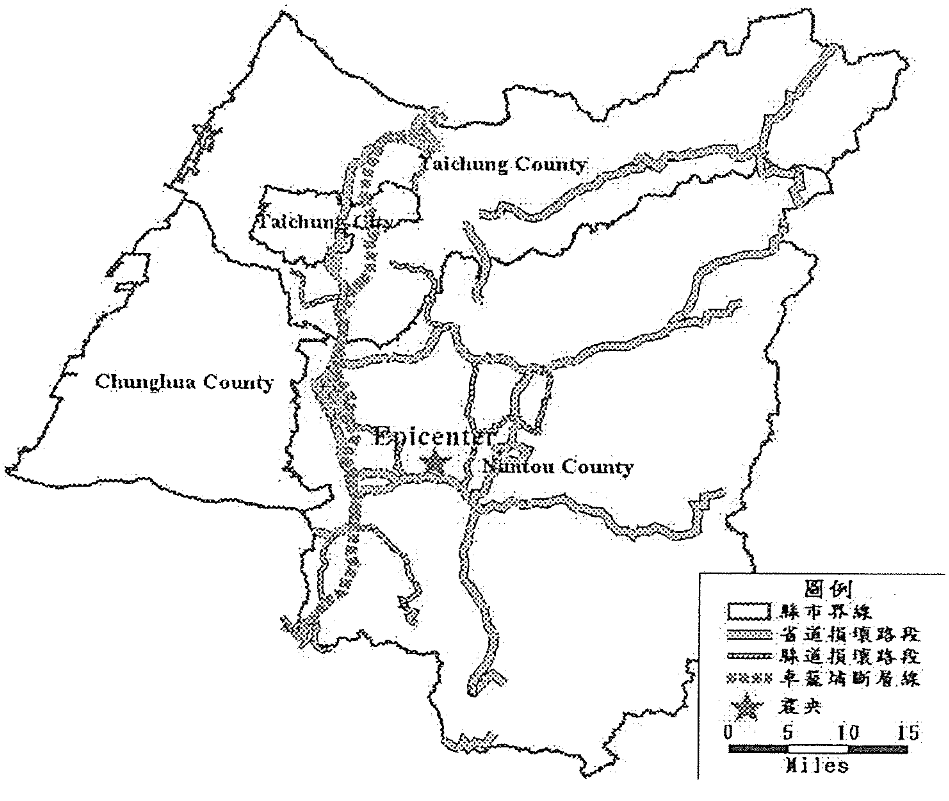


Figure 1-8 Distribution of Damaged Highway Routes

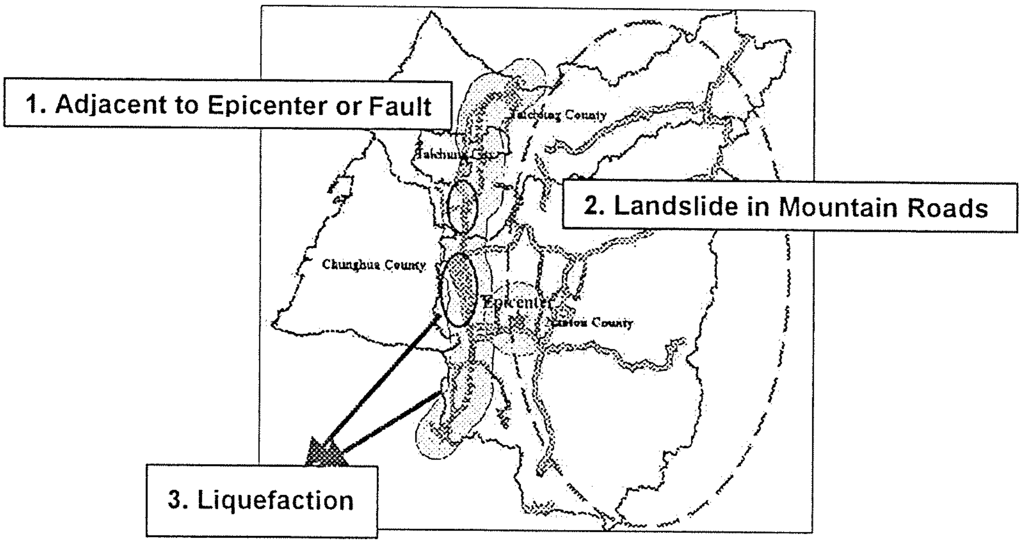
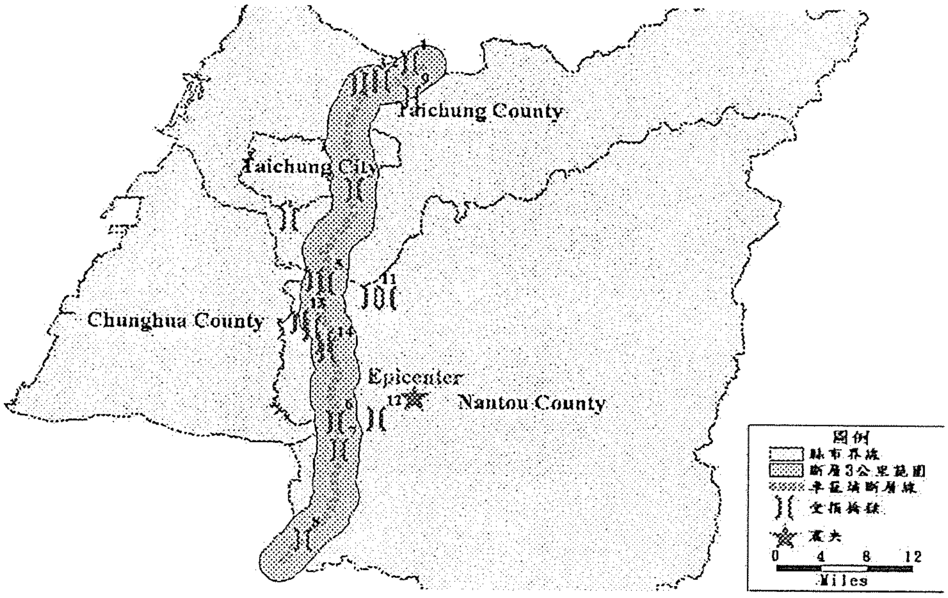


Figure 1-9 Major Reasons for Highway Damage

(2) Highway Bridges

Bridges are the most vulnerable component of the transportation system. Nearly every bridge along the Chelungpu Fault was seriously damaged or destroyed. Although Chi-Chi earthquake damaged more than 85 bridges, 13 of these belonged to the sites of major or medium damage identified by the Taiwan Highway Bureau. Some bridges failed due to fault rupture beneath or adjacent to them. Examples for fault rupture were Shi-We Bridge, U-Shi Bridge, Min-Chu Bridge, I-Chiang Bridge, Tung-Tou Bridge, and etc. Some bridges failed due to ground shaking. Examples for ground shaking included Dong-Fung Bridge, Yen-Fung Bridge, Chi-Lu Bridge, and etc. Some bridges failed due to liquefaction. Examples for liquefaction had Mao-Lou-Shi Bridge, Jiun Kung Bridge and etc. The distribution of some bridges of major damage were illustrated in Figure 1-10.



NO	Bridge Name	NO	Bridge Name	NO	Bridge Name
1	石圍橋	6	名竹大橋	11	炎峰橋
2	長庚大橋	7	延平橋	12	集鹿大橋
3	碑豐橋	8	桶頭橋	13	貓羅溪橋
4	一江橋	9	東豐橋	14	軍功橋
5	烏溪橋	10	南崗橋		

Figure 1-10 Relationship between Bridge and Fault

Fault rupture and ground shaking are two major reasons to cause the highway damages. Privincial-3 highway is a typical example. The other reason of highway damage is from landslide particularly in mountainous areas, and Princial-8, Princial-14, Princial-18 and princial-21 are these examples. Liquefaction is another reason to cause the highway damage.

The damage levels and damage reasons for major damaged highway bridges were summarized in the Table 1-2. It was found that most of seriously damaged bridges were adjacent to the fault rupture, which delivered a warning message to the transportation engineers who need to pay much attention on the location of fault and the structure of bridges in the future.

(2) Intercity Bus Operation

Some intercity bus operations stopped their services due to the transit routes, transit terminals and transit vehicles were damaged. The damaged conditions for these affected bus companies could be shown in Table 1-3. The failure of intercity bus transit routes can be shown in figure 1-11. Most of the failure of bus transit routes were located on the damaged mountainous highways such as Provincial-8, -14, -21, -16, and etc.

Table 1-2 Damage Level and Damage Reason for Bridges

NO	Bridge Name	Damage Level	Damage Reason
1	石圍橋	S	*Fault Rupture*
2	長庚大橋	M	
3	碑豐橋	M	
4	一江橋	S	
5	烏溪橋	S	
6	名竹大橋	S	
7	延平橋	M	
8	桶頭橋	S	
9	東豐橋	S	*Ground Shaking And Liquefaction*
10	南崗橋	M	
11	炎峰橋	S	
12	集鹿大橋	S	
13	貓羅溪橋	S	
14	軍功橋	M	

S: Serious, M: Moderate

Table 1-3 Intercity Bus Damage Conditions

Bus Company	Revenue Loss	Hardware Loss	Total
台中客運	1,191,842	1,191,842	2,383,684
南投客運	7,080,067	7,080,067	14,160,134
員林客運	20,064,094	20,064,094	40,128,188
豐原客運	25,033,387	25,033,387	50,066,774
彰化客運	11,476,522	11,476,522	22,953,044
豐榮客運	730,318	730,318	1,460,636
仁友客運	11,866,074	0	11,866,074

Summary

1. The Chi-Chi great earthquake occurred at the suburban areas in the Central Taiwan. In addition to the ground shaking, the fault rupture, landslides and liquefaction were the main reasons to cause the failure of regional transportation systems. The damages in the Chi-Chi quake may be different from those in Japan and elsewhere in the world. Therefore, the damage reasons and results could be used as references for other countries.
2. How to obtain the immediate and correct damage information of regional transportation networks is very important to the work of rescuing people at the first time and distributing relief goods to the people in the disaster areas at the second time. In addition, how to collect data of post-quake traffic conditions is also another issue for transportation planners. It was suggested in this study that the methods of field survey and interview survey should be conducted together to complement each other.
3. Most of the seriously damaged highway bridges in Chi-Chi earthquake were adjacent to the Chelungpu fault, which reminded transportation planners and engineers in Taiwan to carefully choose bridge location and to strengthen bridge structure in the future.
4. Since there were many landslides in the mountainous areas, whether we need to construct more regional highways in the mountainous areas is now a critical issue to transportation and environmental policy makers, planners, and engineers for discussion.

Task 2: The Study for Traffic Congestion Levels in the Chi-Chi Great Earthquake — The Case Study in Nantou City and Tsaotun Town

Introduction

This study aims to investigate the mobility and accessibility of local road network after the 921 Chi-Chi Earthquake. Traffic related data are collected and earthquake prone traffic characteristics are summarized for the road network in transporting goods / rescue resources through questionnaire survey.

Scope of the Study

The scope of the research is focusing on the core of the quake influence area. Nantou County, which is the most seriously affected prefecture, is the target area to be investigated. This study will choose Nantou City and Tsaotun Town as our survey area to explore the traffic congestion conditions before and after quake (figure 2-1).

Population Level and Distribution Status

In terms of population distribution, most of the people are resided in the following 5 local towns: Nantou City, Puli, Tsaotun, Jushan, and Mingjen, The total population of the above 5 towns accounts for 71.57% of the entire population of Nantou County. There are 102,990 people resided in Nantau City, and 94,8225 people in Tsaotun Town. Thus, this research takes the above two local towns for examples, and investigates the post quake situations in terms of the change of local traffic characteristics.

Basic Transportation Information

The most importation transportation mode in Nantou County is road transport due to its geographic characteristic (Nantou County is the only county in the main island of Taiwan without direct access to maritime and air transportation). Therefore, the most frequently used transportation modes are land transport related, such as passenger car (67.7%), motorcycle (48.7%), and public transit--bus (19.7%). The low usage of public transit is due to inappropriate routing / scheduling of bus systems and the high ownership of private cars.

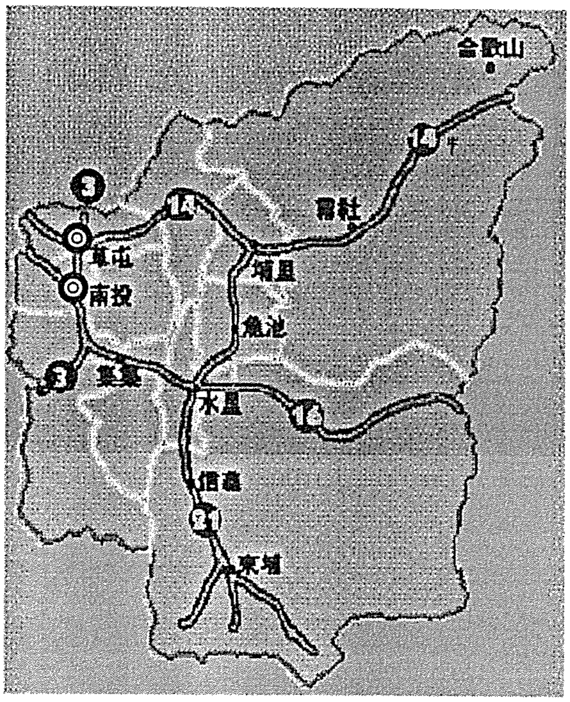


Figure 2-1: Locations of Tsaotun Town and Nantou City in Nantou County

Survey on Traffic Congestion Levels

Purpose of the Survey

The survey of meso level is to understand the traffic condition before and after quake is selected towns, Nantou City and Tsaotung Town in Nantou County.

Location of the Survey

Tsaotun Town is the north / west gateway of Nantou County. It is the unavoidable throughway that rescue resources are transported from Taichung in the north and from Changhua in the west. While the county's rescue command center is set in Nantou City, Nantou City is headquarter for distributing / dispatching rescue resources. As regard to city road / street network, Nantou City and Tsaotun Town are the local towns of highly urbanized and populated areas. In the quake, the houses / buildings in Nantou City are more seriously damaged than those in Tsaotun Town. Thus, it is appropriate to conduct before and after studies in obtaining traffic congestion levels via questionnaire survey for the above two local towns.

Time of the Survey

Speaking of issues of levels of traffic congestion, blockage on traffic flow, road closure, and traffic accessibility, Odani and Tsukaguchi have investigated road network damage as well as network links' / nodes' accessibility using air photographing approach. Due to the lack of air photographing data, this research conducts questionnaire survey to investigate the traffic conditions after the quake in the above mentioned research scope area. The duration of the survey is from December, 1999 to February of 2000.

Methodology of the Survey

Recognizing the purposes of the research, questionnaire is designed in the following parts: the first part is to obtain relevant traffic data from major highways connecting to adjacent counties; the second part is targeted to those urban road network at the street level in both Nantou City and Tsaotun Town.

The first stage of the survey is to obtain the general public's opinions toward the proposed research topics using open (options) questionnaire. The main problems surfaced at this stage are: 1) the general public have difficulty in memorizing the road / street names so that it is difficult to answer street-based questions; 2) the general public are not familiar with traffic specific terms, such as traffic volume and traffic delay, etc., therefore they are not able to easily respond to the questions in a professional way.

The second stage of the survey is to conquer the problems / difficulties raised in the first stage. Specifically, instead of using road / street names, we provide them with the objects of well-known site names, easily recognized landscape / building as the reference target. Meanwhile, to ensure the validity of the survey results, the respondents are selected for those who are familiar with local traffic conditions / geographic layout and highly cooperative in the questionnaire survey, such as traffic policeman, postman, cab driver, and bus driver. The Q/A formation is designed from a driver's perspective by defining driving smoothness as the indices for evaluating the level of service (LOS) of road network. It is supposed that the above indices have direct relationships with traffic speeds, therefore we are able to infer the accessibility of road network and the mobility of major highways.

Contents of the Survey

1. Major Connecting Highways

The capacity for inter-city highway is generally high and traffic condition is less complicated. The research specifies various traffic conditions into 5 levels of congestion in which level 1 represents "very smooth" and level 5 means "very congested", as shown in table 2-1. In the meantime, traffic speeds are also collected through the survey in order to provide the comparison basis. The collected speeds are divided into 6 levels ranging from 20 kph to 70 kph, since 20 kph is generally the lowest speed shown in a car's meter and 70 kph is the speed limit in the surveyed highways. The responses are collected by surveying cab drivers, bus drivers, and personnel of the fire department of Nantou County.

Table 2-1 Questionnaire for Traffic Condition and Speed of Intercity Highways

		traffic condition and speed before quake		traffic condition and speed two weeks after quake	
1	Tsaotung-Ushi Bridge	□Very Smooth □Smooth □fair □Congested □Very Congested	□20 □30 □40 □50 □60 □70 Unit: kph	□Very Smooth □Smooth □fair □Congested □Very congested	□ 20 □ 30 □ 40 □ 50 □ 60 □ 70 Unit: kph

2. Urban Streets

The questionnaire for the target urban street network is designed based on road / street names with the support of easily recognized landscape. In order to provide the respondents with clear ideas to capture the target questions, answering choices are designed from a driver's perception toward traffic conditions, as shown in table 2-2. In table 2-2, traffic conditions ranging from level 1 to 5 represent different traffic congestion levels. It needs to be pointed out that level 4 (congested with slower speed) means traffic moves slowly. However, level 5 (road space occupied with very slow speed) shows that the traffic almost stops due to lane width decrease and / or closure. It means not only the traffic moves very slowly, but also the LOS's or road service is even worse. Due to the lack of detailed data describing the influence of building collapse on lane width decrease and / or closure, we may roughly infer the potential bottleneck links from the responses to the choice of level 5. The respondents are local policemen and postmen who are regularly patrolling / travelling in the target street network.

Table 2-2 Questionnaire Form for Traffic Condition of Major Arterials

Minsheng Street	Highschool of Nantou◀▶Roundabout
Before Quake	☐Very Few Cars with Higher Speed ☐Many Cars with Moderate Speed ☐Slow Speed but Acceptable ☐Congested with Slower Speed ☐Roadspace Occupied with Very Slow Speed
Two Weeks After Quake	☐Very Few Cars with Higher Speed ☐Many Cars with Moderate Speed ☐Slow Speed but Acceptable ☐Congested with Slower Speed ☐Roadspace Occupied with Very Slow Speed

Methodology for Specifying LOS

The questionnaire describes traffic conditions using general terms / words, therefore this research specifies LOS in the light of the contents of the questionnaire. For example, ranging from the best to the worst traffic conditions, there are 5 choices. The best traffic condition scores 1 point, while the worst one scores 5 points, as shown in table 2-3. By averaging all the scores of a specific link, we may obtain the final score, N. If N is between 1 and 1.5, the LOS of the specific link is at level A, which represents traffic is "very smooth" and "very few cars with higher speed". If N sits between 1.5 and 2.5, then the LOS of the link is at level B, which means traffic is "smooth" and "many cars with moderate speed". These relationships can be further demonstrated in figure 2-2.

The change of LOS is identified by using the difference of the average scores before and after the great quake, that is N_1-N_0, where N_1 and N_0 represent the average scores after and before the great quake, respectively. If the difference is less than 0.5, then one can infer that the quake has no influence on traffic. If the difference is between 0.5 and 1.5, then the LOS is degraded one level, as shown in figure 2-3.

Table 2-3 Scores of Traffic Condition

Traffic Condition		Score
□Very Smooth	□Very Few Cars with Higher Speed	1
□Smooth	□Many Cars with Moderate Speed	2
□Fair	□Slow Speed but Acceptable	3
□Congested	□Congested with Slower Speed	4
□Very Congested	□Roadspace Occupied with Very Slow Speed	5

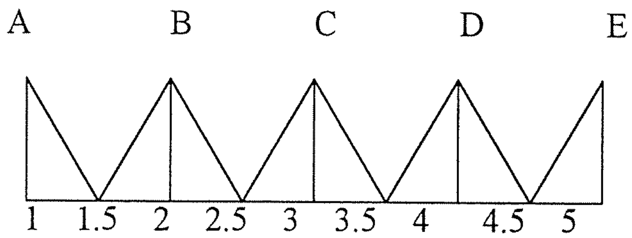


Figure 2-2: Rank of Scoring Before Quake

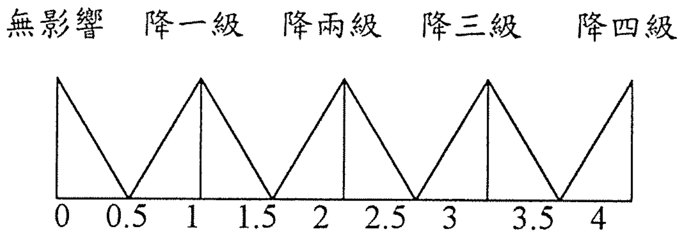


Figure 2-3: Rank of Scoring After Quake

Results of the Survey

Connecting Highways

In the part of connecting highways, there are totally 9 County-level highways located in Tsaotun Town and Nantau City being investigated. They are Provincial-3, Provincial-3A, Provincial-14, Provincial-14B, Provincial-14D, Provincial-63, County-139, County-148, and County-150. The scope of the survey area is shown in figure 2-4. The adjacent cities / counties are Taichung, Wufeng, Fenyen, Yenlin, Sirtau, Tenjong, Mingjen, and Chungliao. The specific links and segments being surveyed are demonstrated in table 2-4.

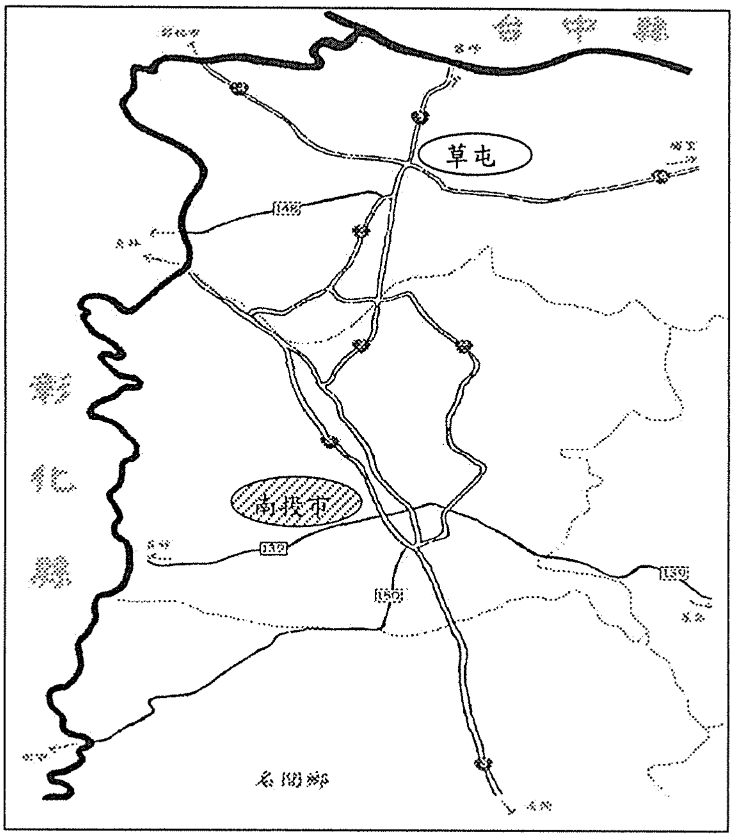


Figure 2-4: Connecting Highways

Table 2-4 Scores Change B/A Quake

Road Section		Road Name
A	草屯~烏溪橋	(No. 3)
B	中投公路	
C	草屯~芬園	(No. 14)
D	草屯~員林	(No. 148, 碧山路)
E	草屯~南投	(No. 3, 草溪路)
F	草屯~南投	(No. 3-1, 東閔路)
G	草屯~南投	(No. 14-2, 經中興新村)
H	草屯~埔里	(No. 14)
I	南投~碧山巖	(No. 14-4, 南崗路)
J	南投~社頭	(No. 139, 民族路)
K	南投~田中	(No. 150, 中興路)
L	南投~名間	(No. 3, 南崗路)
M	南投~中寮	(No. 139, 南鄉路)
N	南投~員林	(No. 14-2, 彰南路)

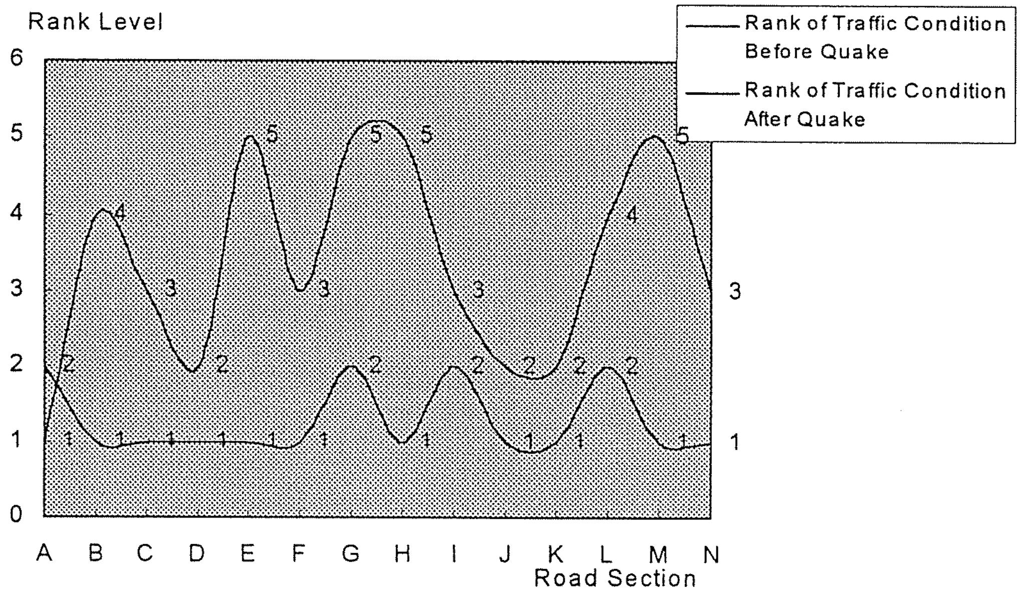
1. Levels of Traffic Congestion

This research specifies levels of traffic congestion into 5 levels: level 1 to 5 represent very smooth, smooth, fair, congested, and very congested, respectively. The results are obtained by analyzing the before and after questionnaire surveys, as shown in Table 2-5. The results show that the LOS's of the highways connected Nantau and Tsaotun are ranging from levels A to B before the quake, which means traffic conditions are generally well. However, after the quake, the results indicate that the LOS's of the same highways become worse. The LOS's are distributed from level A to level E. Only 4 highways remain the same LOS's, and 4 highways degrade the LOS's to level E. It is found, in general, that traffic conditions become worse after the great quake. The change of the traffic congestion levels is shown in figure 2-5.

Table 2-5 Traffic Conditions for Intercity Highways B/A Quake

Level	Road Name(Before Quake)	Road Name(After Quake)
A	中投公路(63) 草屯至芬園(14) 草屯至員林(148)碧山路 草屯至南投(3)草溪路 草屯至南投(3 甲)東閔路 草屯至埔里(14) 南投至社頭(139) 南投至田中(150) 南投至中寮(139)南鄉路 南投至芬園(14 乙)彰南路	草屯至烏溪橋(3)**
B	草屯至烏溪橋(3) 草屯至南投(14乙)經中興 南投至員林(14丁)南崗路 南投至名間(3)南崗路	草屯至員林(148)碧山路 南投至社頭(139) 南投至田中(150)
C		草屯至芬園(14) 草屯至南投(3 甲)東閔路 南投至員林(14 丁)南崗路** 南投至芬園(14 乙)彰南路
D		中投公路(63) 南投至名間(3)南崗路
E		草屯至南投(3)草溪路 草屯至南投(14 乙)經中興** 草屯至埔里(14)** 南投至中寮(139)南鄉路**

**: represents seriously damaged road



Note: A, B, C, …,N represent the road name

Figure 2-5: Rank Level Before and After Quake

2. Change of Traffic Speeds

This research also conducts survey on the change of traffic speeds before and after the quake. As demonstrated in table 2-6, before the disaster, the traffic speeds are relatively high, usually at the level of 50-kph with the highest speed at 67.8 kph. However, all the traffic speeds are decreased after the quake, with the largest decrease rate at 65%, as shown in figure 2-6.

3. Change of LOS's

In the light of the LOS evaluation methodology mentioned previously, in terms of the change of LOS, for the 14 connecting highways being investigated, there are 6 highways without significant influence by the quake, 4 highways degrade 1 level, 2 highways degrade 2 levels, and 2 highways degrade 3 levels. The details of the analysis are shown in table 2-7.

Table 2-6 Travel Speed B/A Quake

Road Name	Travel Speed (Kph)	
	Before Quake (B)	After Quake (A)
草屯至烏溪橋(3)**	50.0	51.7
中投公路	67.8	42.2
草屯至芬園(14)	61.4	46.7
草屯至員林(148)碧山路	53.3	43.3
草屯至南投(3)草溪路	56.0	26.0
草屯至南投(3甲)東閔路	58.0	38.0
草屯至南投(14乙)經中興**	54.0	28.0
草屯至埔里(14)**	61.7	21.7
南投至員林(14丁)南崗路**	60.0	27.5
南投至社頭(139)	60.0	50.0
南投至田中(150)	60.0	46.0
南投至名間(3)南崗路	51.7	33.3
南投至中寮(139)南鄉路**	58.3	25.0
南投至員林(14乙)彰南路	56.0	40.0

Note: A, B, C, ...,N represent the road name

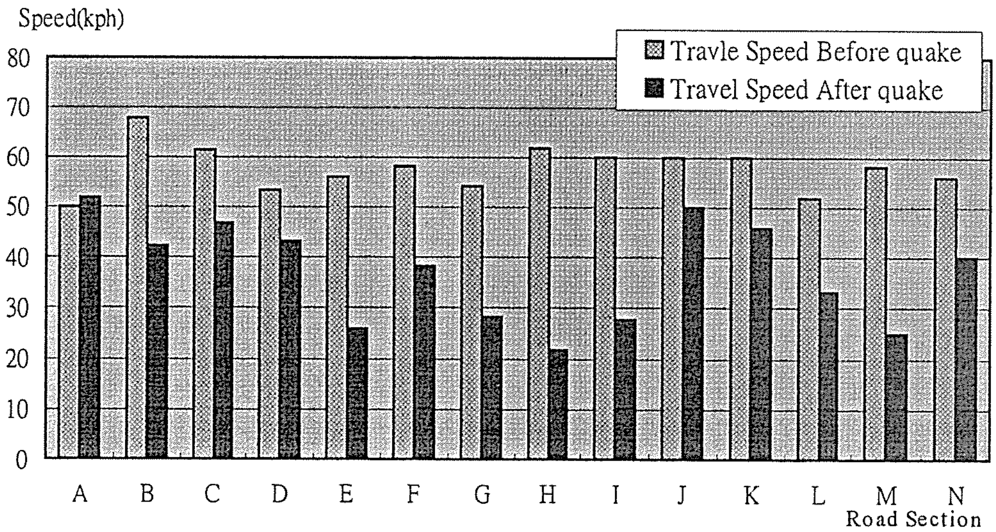


Figure 2-6: Travel Speed Change B/A Quake

Urban Streets

1. Characteristics of Urban Streets

The traffic patterns in both Tsaotun Town and Nantau City are much the same before the quake. Generally speaking, the traffic volumes are relatively low in urban streets except at rush hours. Even though traffic is not heavy, traffic speed is not high due to limited street width and serious street parking problems. During the 921 great quake's influenced time period, since there were very few buildings collapsed, the traffic in Tsaotun Town was not seriously influenced. In addition, the following 3 days after the quake were officially off, the change of traffic flow patterns is not significant, the traffic volume for connecting highways of first day after the quake is slightly decreased, and it is increased a little in the following two days. On the other hand, traffic volume for urban streets is slightly decreased.

As regard to the traffic after the quake in Nantau City, due to serious road / street damage and lane width decrease caused by collapsed buildings, the traffic volume is significantly decreased, and traffic speed is also decreased.

2. Traffic Congestion Levels in Tsaotun Town

Traffic congestion levels in terms of LOS after 2 weeks of the quake in Tsaotun Town are shown in figure 2-7, and the change of LOS is shown in figure 2-8.

(1) Description of the LOS's (figure 2-7)

A. The links with trunk lines are provincial-level highways, in which Pui-I Road, Chengkung Road and ChungShin Road are 4-lane highways. The rest of the links are 2-lane urban streets.

B. In the survey, there are totally 104 link segments being investigated, in which 15 segments with LOS of A, 18 segments with B, 51 segments with C, 17 segments with D, and 3 segments with E.

(2) Description of the change of LOS's after the quake (figure 2-8)

A. The segment marked with an "X" represents that the LOS of the segment degrades one level, two "X" means degrading 2 levels, etc.

Table 2-7 Level of Service Change B/A Quake

Road Name	Congestion Level		Change of Rank
	Before	After	
No. 3 (草屯-霧峰)	B	A	+1
Chang-Tou Road (台中-南投)	A	D	-3
No. 14（草屯-芬園）	A	C	-2
No. 148（草屯-員林）	A	B	-1
No. 3（草屯-南投）	A	E	-4
No. 3-1（草屯-南投）	A	C	-2
No. 14-2（草屯-南投）	B	E	-3
No. 14（草屯-埔里）	A	E	-4
No. 14-4（南投-員林）	B	C	-1
No. 139（南投-社頭）	A	B	-1
No. 150（南投-田中）	A	B	-1
No. 3 (南投-名間)	B	D	-2
No. 139（南投-中寮）	A	E	-4
No. 14-2（南投-芬園）	A	C	-2

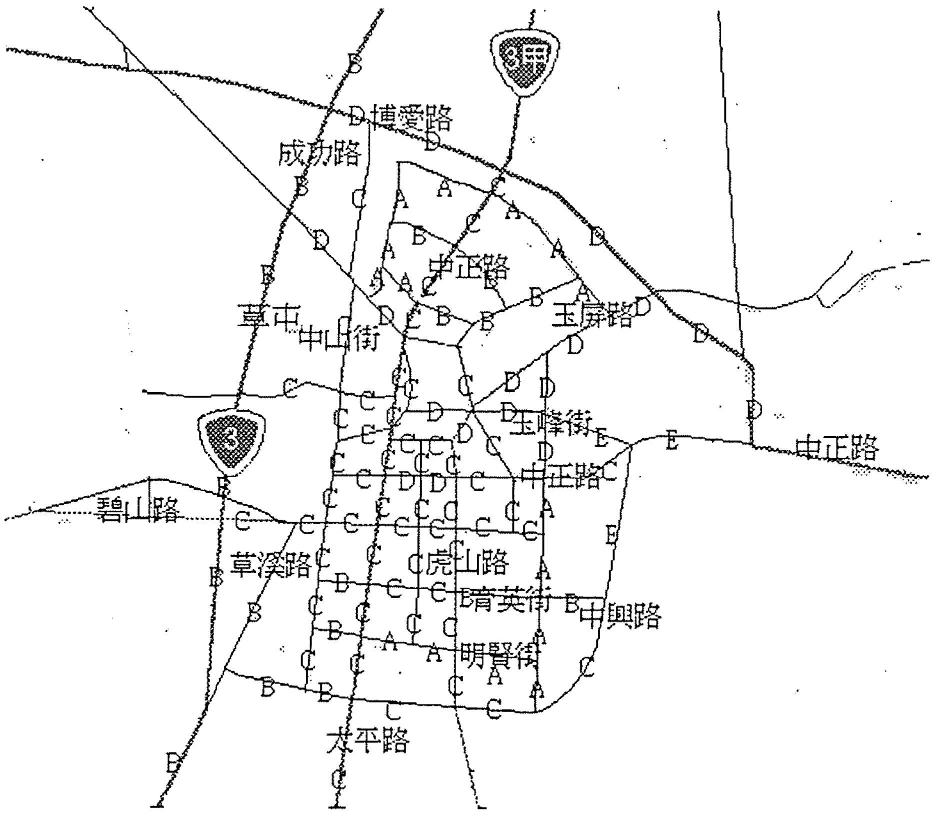


Figure 2-7 Level of Service Change B/A Quake in Tsaotung Town

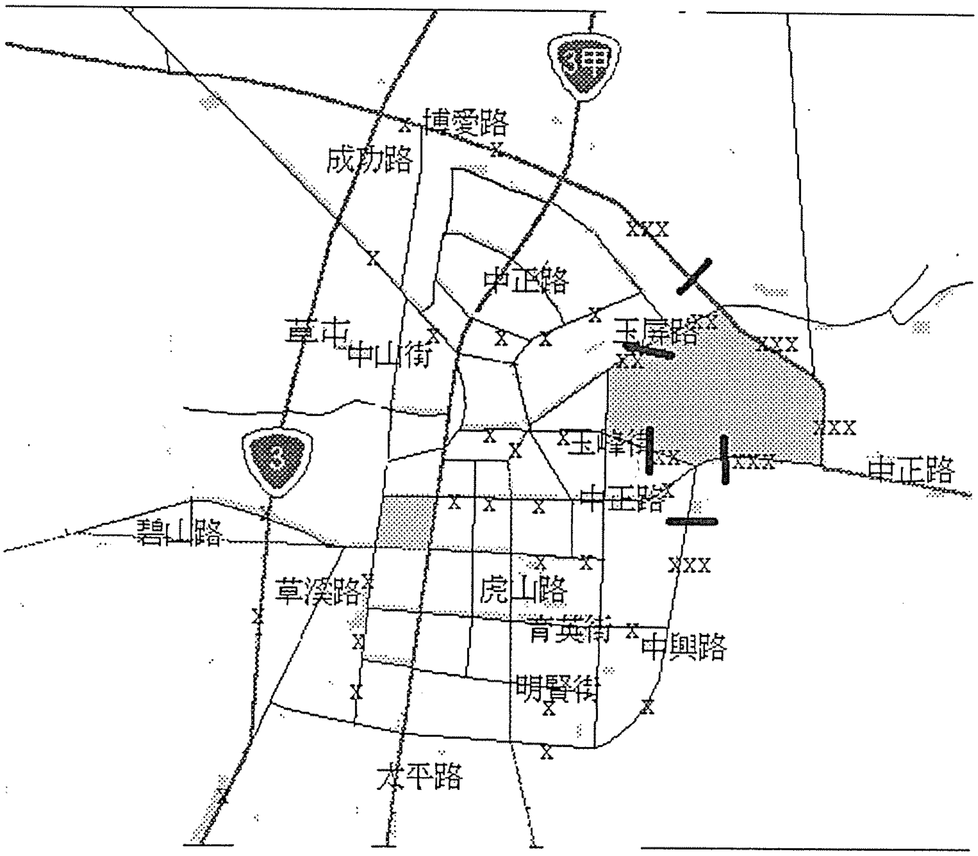


Figure 2-8 Level of Service Change B/A Quake in Tsaotung Town

B. For those segments with a thick block line, it means that the link segments were damaged by fault rupture. Thus, the significant degrade of LOS are due to fault rupture.

C. The area with shadow means that there are collapsed buildings in that specific area. Since the earthquake damage is not serious, the urban street network remains much the same as before. Therefore, the traffic conditions are similar to those before the quake. The only degrade of LOS is due to fault rupture, which causes backup queue in some street segments. The other one is on the way west to Puli due to increasing traffic demands.

3. Traffic Congestion Levels in Nantau City

The traffic conditions in terms of levels of traffic congestion after two weeks of the quake are shown in figure 2-9, and the change of traffic conditions is demonstrated in figure 2-10.

(1) Description of the LOS's (figure 2-9)

A. The links with trunk lines are 4-lane, provincial-level highways, including Nankang 1st Road, Nankang 2nd Road, and Chunshing Road. The rest of the links are 2-lane urban streets.

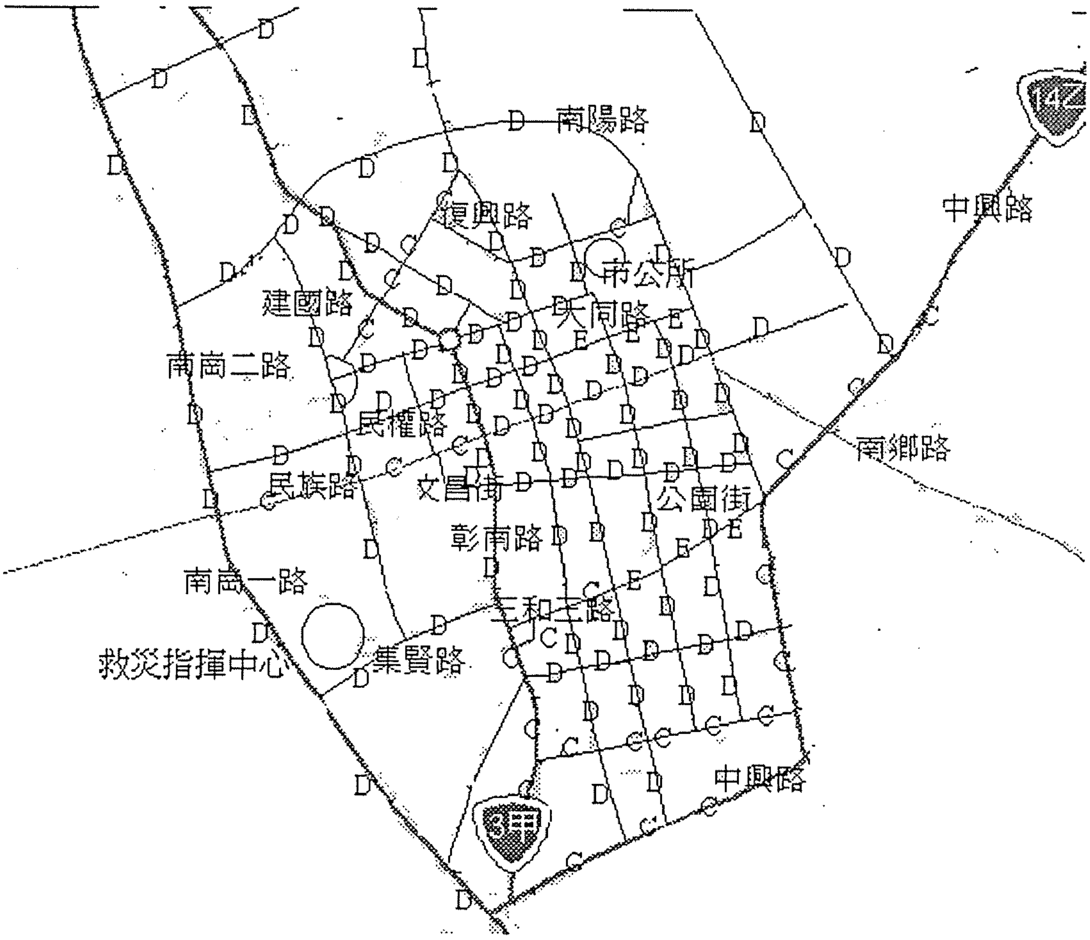


Figure 2-9 Level of Service Change B/A Quake in Nantou City

B. In the survey, there are totally 127 link segments being investigated, in which 25 segments with LOS of C, 96 segments with D, and 6 segments with E.

C. The LOS's for most of the links in the study area are at D level.

D. The main rescue center is located at Nankang Road. The center is the temporary administration office of Nantau County Government. It also acts the dispatching, rescue, and resource collection / distribution headquarter. The city government office is located at the corner of Tatung Street and Nanyang Road. This office is for general administration business and rescue resource collection / distribution center.

(2) Description of the change of LOS's after the quake (figure 2-10)

A. The segment marked with an "X" represents that the LOS of the segment degrades one level, two "X" means degrading 2 levels, etc.

B. Unlike the road damage caused by the quake in Tsaotun Town, for the segments being investigated in Nantau City, there are no such links caused by fault rupture.

C. The areas with shadow mean that there are collapsed buildings in those specific disaster areas. The damage situations in Nantau City are more serious. Almost all the links west to Provincial-3 highway is influenced by collapsed buildings. After two weeks of the quake, most of the lanes are closed in view of the potential danger of collapsed buildings, which results in significant degrade of LOS's.

D. In spite of the serious traffic conditions caused by lane closure, the responses collected from the survey in terms of LOS's are general at level D, with some responses of level E. This is due to lane closure control is periodically conducted in case it is necessary based on actual needs, and the survey was conducted two weeks after the quake, therefore the traffic pattern becomes stable. This outcome is significantly different from that of air photographing data in which highway condition is generally classified into two types: "in service" and "blocked".

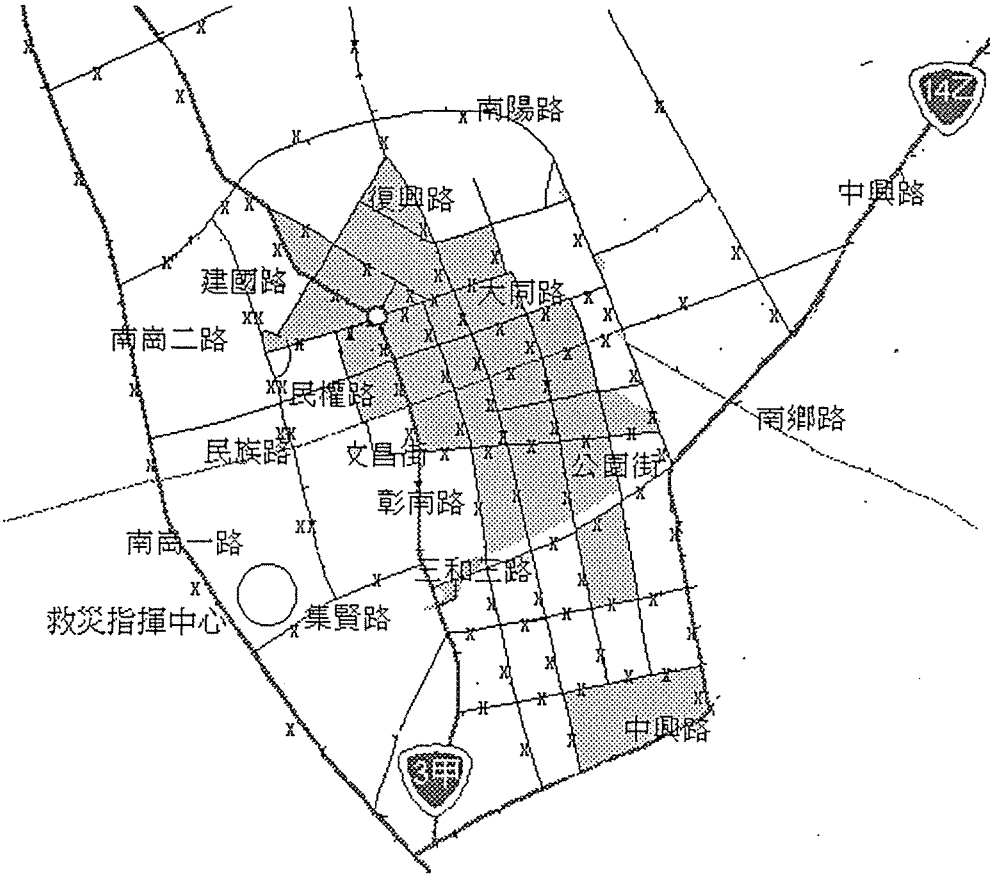


Figure 2-10 Level of Service Change After Quake in Nantou City

E. In the neighboring areas of the rescue center, which are newly developed space; the buildings are slightly damaged. However, the LOS's of connecting highways, such as Nankang Road and Changnan Road are degraded. This is due to increased demands of rescue vehicles. Similar situation is found in Nanyang Road, which connects the rescue center and the city government office.

Summary

In conclusion, there are several findings surfaced from the proposed research. They are summarized as follows:

1. There are various factors that jointly influence the prevailing traffic conditions, such as traffic volume increase, lane width decrease, road damage caused by collapsed buildings, malfunction of traffic signals, and change of drivers' behaviors, etc. In short, the patterns of traffic demand and supply have been significantly changed due to the great quake, which results in the changes of land use, road surface, and landscape.
2. For the connecting highways being investigated, the general public are more familiar with provincial-level highways and they are more willing to use these highways in view of better service due to higher capacity levels, and clearer instruction of the signage systems. Thus, it is suggested to improve the signage systems for the rest of the links in the near future.
3. The traffic conditions in the following 3 days of the quake are much the same, since it is officially off during that specific period of time, and the residents are usually staying at home to take care of the damage. However, traffic volume is increased due to the increase of rescue resources flooding into the damaged areas. This situation returns to normal traffic conditions (before the quake) after 3 weeks of the quake.
4. The major significance / difference of the research as opposed to other research is the "time period" vs. "time spot" survey concept. Since lane closure control is periodically changed with a very high frequency, this research aims to find out realistic traffic conditions during 2 weeks of the quake. This outcome is significantly different from those surveys at a specific "time spot", in which the results are represented by (highway or street) "in service" and "blocked".
5. Since the street width in the urban area is very limited, therefore street parking and roadside activities usually cause severe traffic congestion. However, even though there is choice option being designed in the questionnaire stating "road space is occupied (by street parking or other objects), which results in difficult traffic movement", there is no response to this specific option. This is due to people get

used to the traffic conditions, and take street parking for granted.

6. By the comparison of the traffic conditions in both Tsaotun Town and Nantau City, it is found that the traffic conditions in Tsaotun Town are less changed before and after the quake since it is not severely damaged. On the other hand, the traffic mobility in Nantau City is significantly decreased due to serious damage by the quake. Therefore, it is reasonably to infer that the influence of the decrease of roadway capacity caused by the quake is much serious than the change of traffic demand patterns.

Task 3. Micro Level: The Street Closure Condition of Local Roads – The Case Study in Chi-Chi Town

Introduction

A large number of inter-city highways and urban roads / streets were blocked due to the collapse of adjacent buildings and facilities during the Great Chi-Chi Earthquake in September 1999. The earthquake caused significant damages to a large portion of Chi-Chi town, especially for the local street network. It is important to ensure disaster-resilient urban planning by the provision of efficient goods and people movements during the disaster.

The purpose of this study is to investigate the levels and conditions of street damage during a large disaster. Data were collected by conducting on-site surveys (including field and questionnaire surveys) and were compared to those of air photographic data taken by the government on September 22, 1999. The data of street damage were further analyzed to find out the factors that affect street closure. The results of this study are targeted to provide a district street network plan with minimum functional requirements during a large disaster in a future research.

Scope and Contents of the Study

The scope of this study focuses on urban network systems, including local streets in the urban area of Chi-Chi town. The major contents of this study are as follows：

1. **Closure or isolation of streets is identified by on-site survey and air photographic results.**
2. **The factors affecting street closures are analyzed based on the comparison result.**
3. **The air photographic and on-site surveys are used for the comparison analysis.**
4. **The disaster-prevent functions of street network are proposed for future study.**

Data Collection

Area of survey

The case study area of this study is focused on Chi-Chi town.

Date of survey

Data was collected from September 1999 to February 2000. The first on-site survey was conducted on September 24, 1999. Disaster photos were taken and demonstrated in Appendix A. The supplementary survey was further conducted in November 1999. The questionnaire (interview) surveys were conducted from December 1999 to February 2000.

Method of survey

The on-site survey consists of the field survey and the questionnaire (interview) survey. The air photographic data taken by the satellite center at National Cheng Kung University on September 22, 1999 were used to identify the levels of street damage. The analysis of street closure was based on the comparison of on-site survey and air photographic data.

Data collected

The data collected in the survey are as follows：

1. **street width**
2. **street length**
3. **damage position (one end, both ends, or middle)**
4. **partial closure (width and length)**
5. **length of complete closure**
6. **limit of height by passing vehicles**
7. **passable by emergency vehicles**
8. **facilities nearby streets (including road trees, sidewalks, walls, and wire poles)**
9. **damage levels of collapsed building structure**

Process of survey

Chi-Chi town was divided into three survey areas and network links were numbered. One survey group conducted street width / length measuring and video camera and photos taking. The questionnaire survey interviewed local residents who recalled the situation of street damage back to the Great Chi-Chi Earthquake on September 21, 1999. Each questionnaire was answered by 1~3 groups of people, with each group containing five local residents. Each group of people could clearly state and reach the same conclusion, while asking about the damage of street length, some respondents provided ambiguous responses.

The Analysis of Street Closure

Factors affecting street closure and levels of street damage

The factors that affect street closure are: 1) street width, 2) structure and stories of buildings nearby street frontage, 3) existence of wire poles, 4) existence of walls, 5) existence of street trees, 6) existence of sidewalks. In this survey, it was found that there were few collapses of wire poles, walls, street trees, and closure of sidewalks. The major factors resulted in street closure are street width and collapse of buildings.

Levels of street damage are classified into four ranks in this study：

Rank1：almost no damage
Rank2：little damage but accessible by emergency vehicles
Rank3：accessible only by pedestrians
Rank4：closed to both emergency vehicles and pedestrians

The comparison between on-site survey and air photographic data

All the data of this study were collected from the field surveys. The field and questionnaire survey results are compared to each other and presented in Table A (which was processed from Appendices 1 and 2). 140 links of streets are surveyed on site, but 9 links could not be read in the air photographic data.

Comparison of the data between on-site survey and the air photographic data is presented in Table 3-1. 23 links are different in length and width of streets(denoted by "*" in Table 1, 23/140=16%), 4 links are different in width (denoted by "( )" in Table 1, 4/140=3%). That is, totally 27 links were found different in length or width (27/140=19%).

Tablel 3-1 Comparison between on-site survey and air photographic data

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	Width (m)		
B1	12	122	—	—	O*	24.4* 61*	2.4* 4.8*	—	O
B2-1	8.6	68	—	O	—	—	—	—	Unreadable
B3	12	72	—	O	—	24*	2.4*	—	O
B3-1	2.6	148	—	O	—	—	—	—	Unreadable
B4	12	44	O	—	—	11*	7.2*	—	O
B5	12	128	—	—	O	12.8* 25.6* 16*	2.4* 4.8* 7.2*	—	O
B7	12	66	—	O	O	22*	6*	—	O
B7-2	7.2	56	O	—	O	18	2 (6)	—	X
B8-1	8	32	O	—	—	24*	4*	—	O
C2	13	92	—	O	O	23*	5.2*	—	O
C7	13	126	O	—	O	16 20* 16*	3 7* 3*	—	O
C8-1	13	74	O	—	O	24*	3*	44	O
C15-1	5.6	34	—	O	O	24*	3*	—	X
C15-5	5.6	74	—	O	O	9*	3*	—	X
C16-2	13	70	O	—	O	21	3 (7)	—	O
C16-4	8.4	162	—	—	O	—	—	—	Unreadable
D4	12	44	—	O	O	25	1.5 (2.5)	—	O
D5	12	102	—	O	O	25	1.5 (4)	—	O
D7	12	64	—	—	O	18*	2*	—	O
D8	12	74	O	—	O	10*	2*	—	O
D9	14.6	96	—	—	O*	7*	3*	—	O
F5	7.5	140	—	—	O	60*	2*	—	O
F8	7.5	112	O	—	O	32*	2*	—	O
G1	10.5	71	O	—	—	8*	2*	—	O
G3	10.5	101	—	O	O	15*	2*	—	O
G6	10.4	126.6	O	—	O	8*	3*	—	O
G7	10.5	280.5	O	—	O	12*	3*	—	O
G11	5.6	126	O	—	—	—	—	—	Unreadable
I4	12.4	52	—	—	O*	14.9*	6.2*	—	O
I5	12.4	58	O	—	—	19.33*	6.2*	—	O
K4	8.5	32	O*	—	—	—	—	—	Unreadable
K5	8.5	60	—	O*	—	—	—	—	Unreadable
K6	8.5	94	O	—	—	97*	2.8*	—	O
M5	2	138	—	—	—	—	—	—	Unreadable

Tablel 3-1 Comparison between on-site survey and air photographic data (1)

No.of links	street width (m)	length (m)	damage position			partial closure		length of complete closure (m)	Accessible by emergency vehicles (air photo)
			one end	both ends	middle	length(m)	length(m)		
M8	4.2	72	O＊	—	O＊	—	—	—	Unreadable
S3	4.2	74	—	O	—	—	—	—	Unreadable

Note：" ＊"represents available only in air photographic data, "( )"represents available in both surveys, but the data are different. The others (without any symbol) represent that data from both surveys are the same.

The air photographic data is greater than those of on-site survey area; it is due to the conservative answers provided by local residents. The accessible width of an emergency vehicle is assumed to 3.5 meters in this study. There are 3 sections that could not be accessible by emergency vehicles from the air photographic data but accessible from the on-site survey (B7-2, C15-1, and C15-5 in Table 3-1). The difference between the on-site survey and the air photographic data is shown in Table 3-2. Both ends damage of streets is different (9-7=2%) because some residents living nearby longer links in length could not recall exactly based on limited information.

Table 3-2 Differences in closure links between on-site survey and air photographic data

Survey methods	Damage only on one end of streets	Damage only on both ends of streets	Damage only on middle of streets	Damage on one end and middle of streets	Damage on both ends and middle of streets
Air photos	22 (17%)	9 (7%)	26 (20%)	21 (16%)	10 (8%)
On-site survey	23 (16%)	12 (9%)	27 (19%)	22 (16%)	10 (7%)

3. The conditions of street damage

The relationship between position of street damage and street width is shown in Table 3-3 and Figure 3-1. There is little difference between on-site survey and the air photographic data. The number of street damage is positively related to width of streets. 6~8 meters streets have highest percentage of damage. Damage only in the middle section of streets has the highest percentage of street damage. Because damage only in "both ends" or "both ends and middle" has the lowest percentage, disaster relief could provide smooth traffic service.

Table 3-3 Cross tabulation of damage position and street width

Street width (m)	Damage only on one end of street ①	Damage only on both ends of street ②	Damage only in middle section of street ③	Damage on one end and middle of street ④	Damage on both ends and middle of street ⑤	No. of damage links ⑥	No. of links ⑦
Below 4m (on-site)	1(17%)	3(49%)	1(17%)	1(17%)	0(0%)	6【67%】	9
Below 4m (air photo)	1(20%)	2(40%)	1(20%)	1(20%)	0(0%)	5【71%】	7
4~6m (on-site)	3(27%)	1(9%)	1(9%)	3(27%)	3(27%)	11【65%】	17
4~6m (air photo)	3(30%)	1(10%)	1(10%)	2(20%)	3(30%)	10【67%】	15
6~8m (on- site)	2(13%)	0(0%)	8(50%)	5(31%)	1(6%)	16【70%】	23
6~8m (air photo)	2(18%)	0(0%)	7(47%)	5(29%)	1(6%)	15【77%】	22
Above 8m(on-site)	16(27%)	8(13%)	16(27%)	13(22%)	6(11%)	59【65%】	91
Above 8m (air photo)	16(29%)	6(11%)	16(28%)	12(21%)	6(11%)	56【64%】	87
Total (on-site)	23(24%)	12(13%)	27(29%)	22(23%)	10(11%)	94【67%】	140
Total (air photo)	22(25%)	9(10%)	26(30%)	21(24%)	10(11%)	88【67%】	131

Note： 1.⑥=①+②+③+④+⑤

2.⑦=⑥+ number of damage streets

3.（ ）：①/⑥,……⑤/⑥

4.【】：⑥/⑦

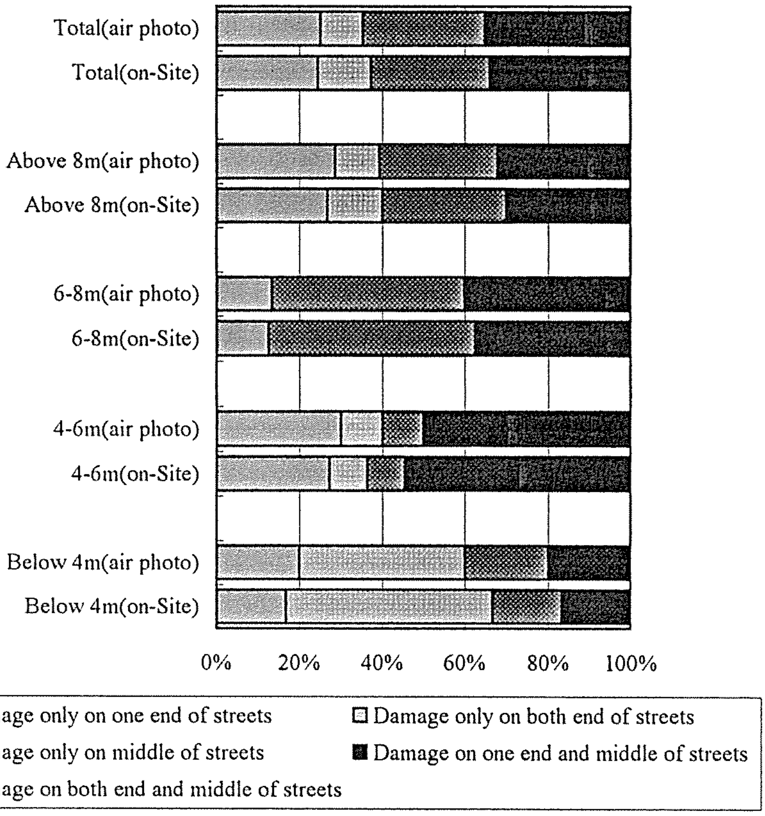


Figure 3-1 Damage position by street width

The relationship between street width and street damage is shown in Table 3-4 and Figure 3-2. Most of the levels of street damage are at rank1 and rank2. There are 4 links at rank4. Regarding the emergency vehicles, there are 11 (=7+4) links readable from the air photographic data and 12 (=8+4) links from the on-site survey. Street width of 4 meters locates in rank 3 and rank 4, and closed to emergency vehicles. Street width of 8 meters and above locates in rank1 and rank2, and all accessible by emergency vehicles. It is found that streets width between 6 and 8 meters can offer disaster-prevented function. Please also refer to Figure 3-3 and Figure 3-4.

Table 3-4 Cross tabulation of street width and street damage

Street width	Rank1 ①	Rank2 ②	Rank3 ③	Rank4 ④	No. of sections ⑤
Below 4m(on-site)	0(0%)	0(0%)	6(67%)	3(33%)	9
Below 4m(air photo)	0(0%)	1(14%)	3(43%)	3(43%)	7
4~6m (on-site)	6(35%)	9(53%)	2(12%)	0(0%)	17
4~6m (air photo)	6(43%)	5(36%)	3(21%)	0(0%)	14
6~8m (on-site)	7(31%)	15(65%)	0(0%)	1(4%)	23
6~8m (air photo)	7(31%)	14(61%)	1(4%)	1(4%)	23
Above 8m(on-site)	30(33%)	61(67%)	0(0%)	0(0%)	91
Above 8m(air photo)	27(31%)	60(69%)	0(0%)	0(0%)	87
Total (on-site)	43(31%)	85(60%)	8(6%)	4(3%)	140
Total (air photo)	40(31%)	80(61%)	7(5%)	4(3%)	131

Note: ⑤=①+②+③+④

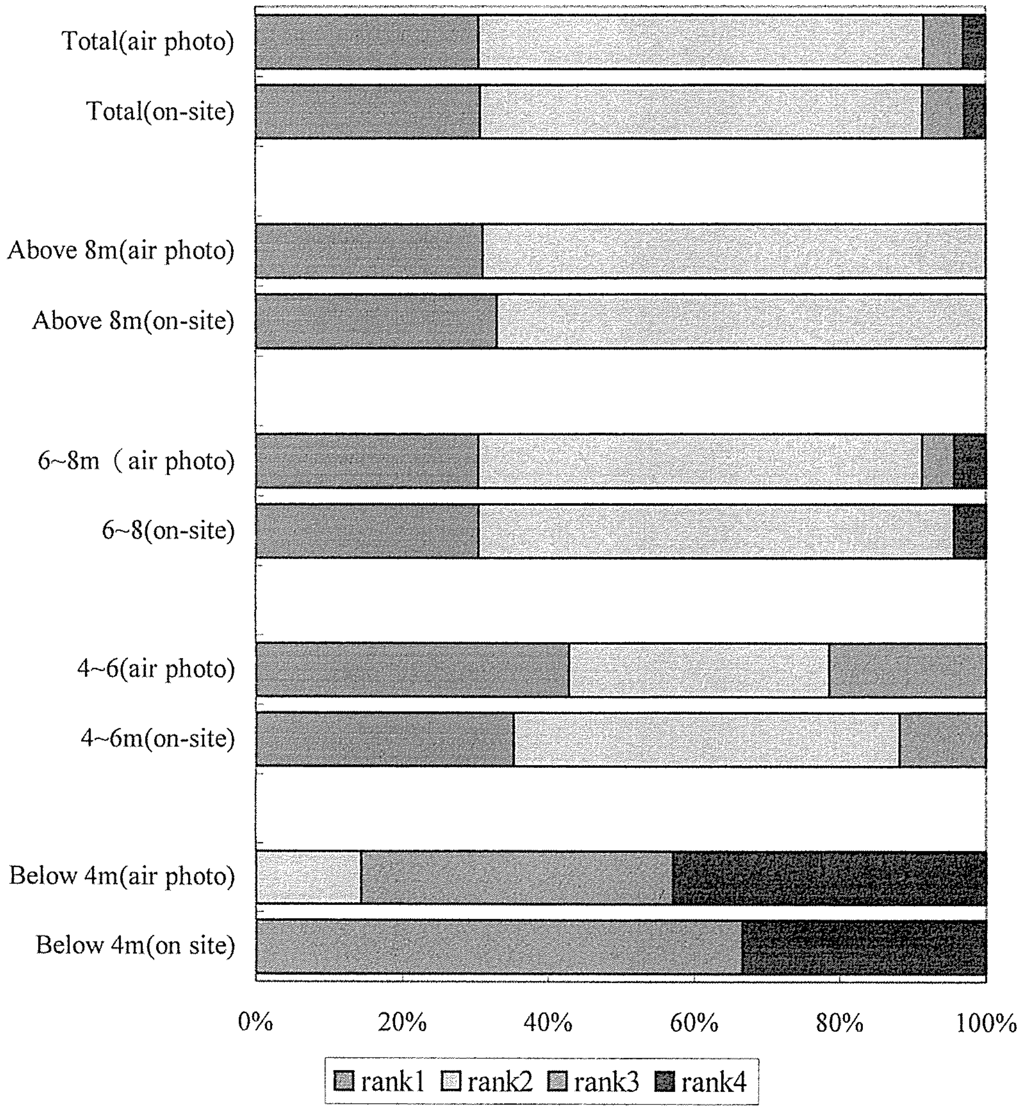


Figure 3-2 Street closures by street width

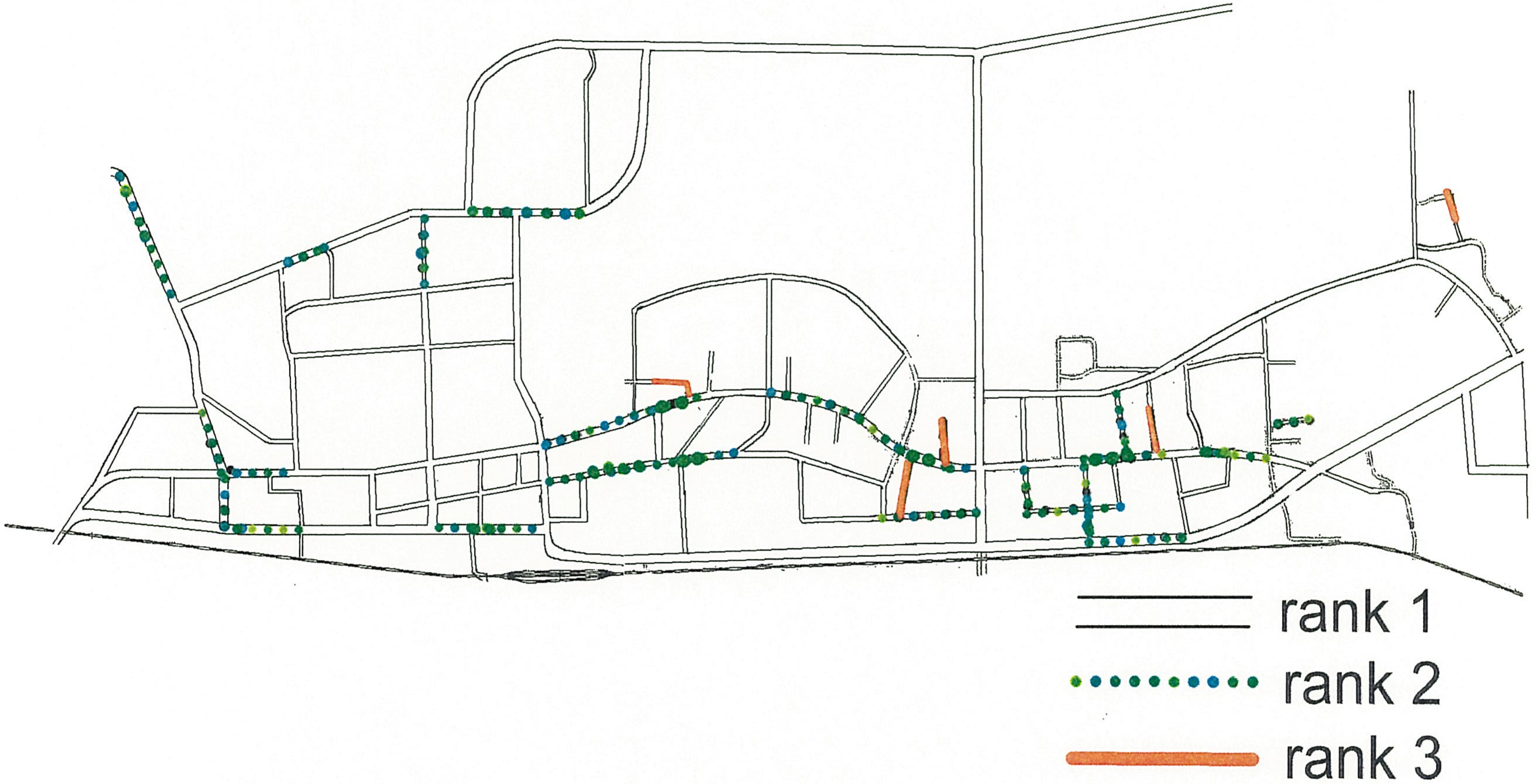


Figure 3-3 Street damage based on on-site surveys in Chi-Chi

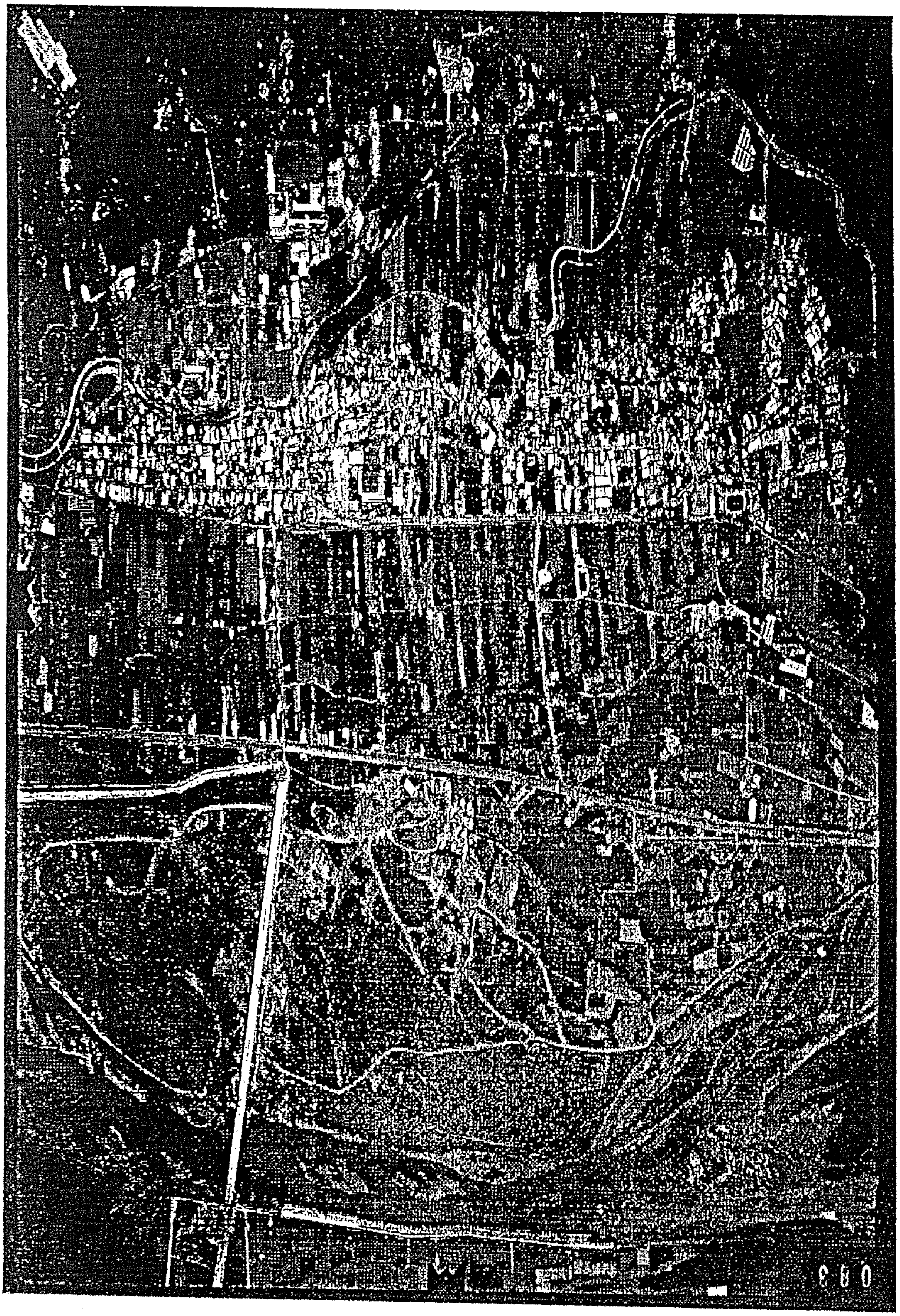


Figure 3-4 Street damage based on air photographic data in Chi-Chi

The damage conditions of collapsed buildings and public facilities could not be read directly from the air photographic data, we have to reconfirm the conditions via on-site survey. The relationship between street width and collapsed building structure / public facilities is shown in Table 3-5 and Figure 3-5. There were a lot of brick houses collapsed, but wooden houses were relatively less. It was also found that many collapses of wire poles and walls in the streets whose width are between 6 and 8 meters.

The earthquake has caused significant number of collapsed buildings, which result in street closure. However, from the analysis results shown in Table 3-5, it is difficult to identify the effects of building structure to street closure under different street width. It is necessary to collect more data on street building types and land uses for further research.

Table 3-5 Cross tabulation of street width and collapsed building structure / public facilities

Street width	Wooden houses	R.C houses	Brick houses	Wire pole	Wall
Below 4m	1	8	13	4	0
4~6m	0	6	15	9	0
6~8m	0	3	54	34	4
Above 8m	0	86	108	22	0
Total	1	103	190	69	4

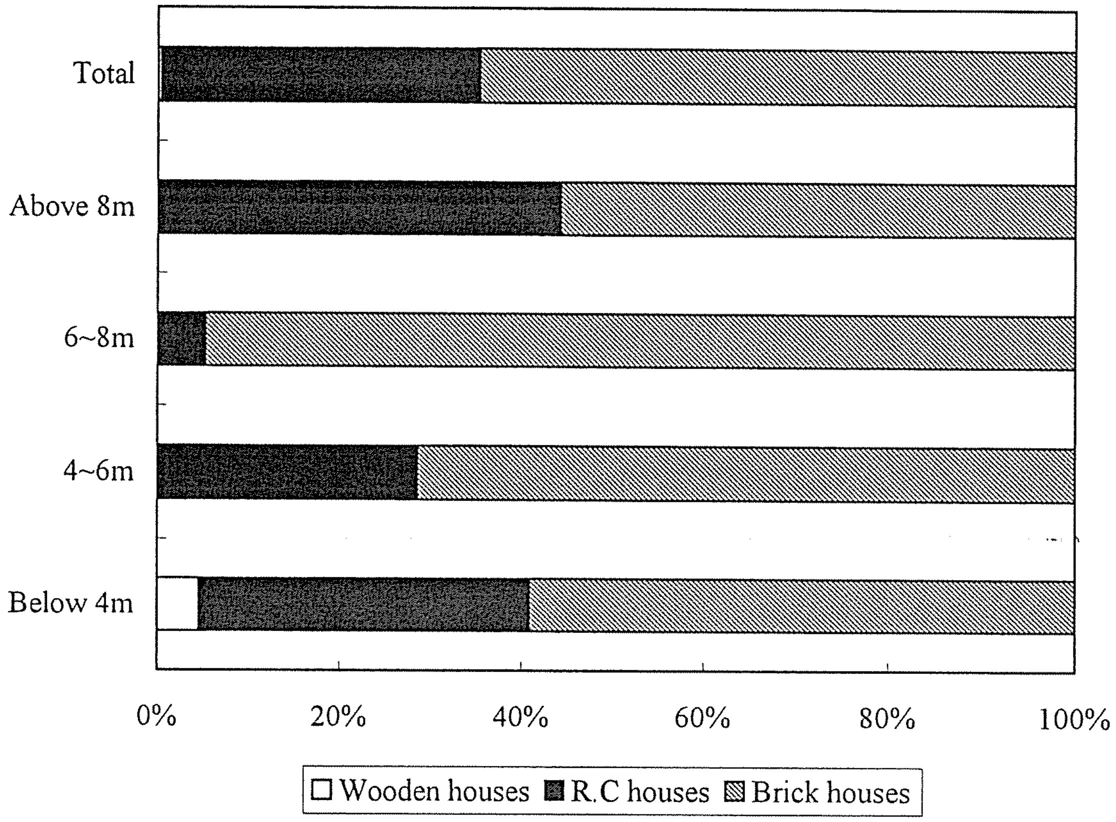


Figure 3-5 Street closure classified by collapsed building structure

Summary

This study focuses on street closure survey during the Great Chi-Chi Earthquake. Some preliminary concluding comments are summarized as follows：

1. The arterial roads whose width are 12 meters and above in Chi-Chi town could provide traffic functions of disaster relief. Most of the streets with widths of 2 meters are blocked during the earthquake.
2. For those streets with widths greater and equal to 8 meters, the damage conditions are located at rank1 and rank2. It means that these streets are accessible by emergency vehicles.
3. There are 20% (=27/140) difference in comparison the on-site survey with the air photographic data. Theoretically, air photos provide accurate reference, but 9 links remain unreadable and are required reconfirmation. When residents answer the questionnaires, most of them provided their answers conservatively.
4. There is a significant amount of damage links shown in wider streets, the percentage of streets damage with the width between 6 and 8 meters is the highest. Generally 70% of damaged streets in Chi-Chi town caused serious traffic problems in providing fundamental transportation functions.
5. Very few streets are blocked by collapse of wooden houses. Most of the streets are closed due to collapse of R.C or brick houses.
6. 11 streets could not be accessible by emergency vehicles, but the street network still functions well.
7. The study finds no isolation area in Chi-Chi town.

References

1. Hiroshi Tsukaguchi and Yan Li, 1999, "District and Local Distributor Network to Ensure Disaster-resilient Urban Planning", Shangri International Symposium on Urban Transportation Proceeding.
2. Hiroshi Tsukaguchi, Upali Vandebona and Yan Li, 1999, "Planning of Residential Street Network for Disaster Prone Urban Area" Proceedings of WCTR.

Appendix

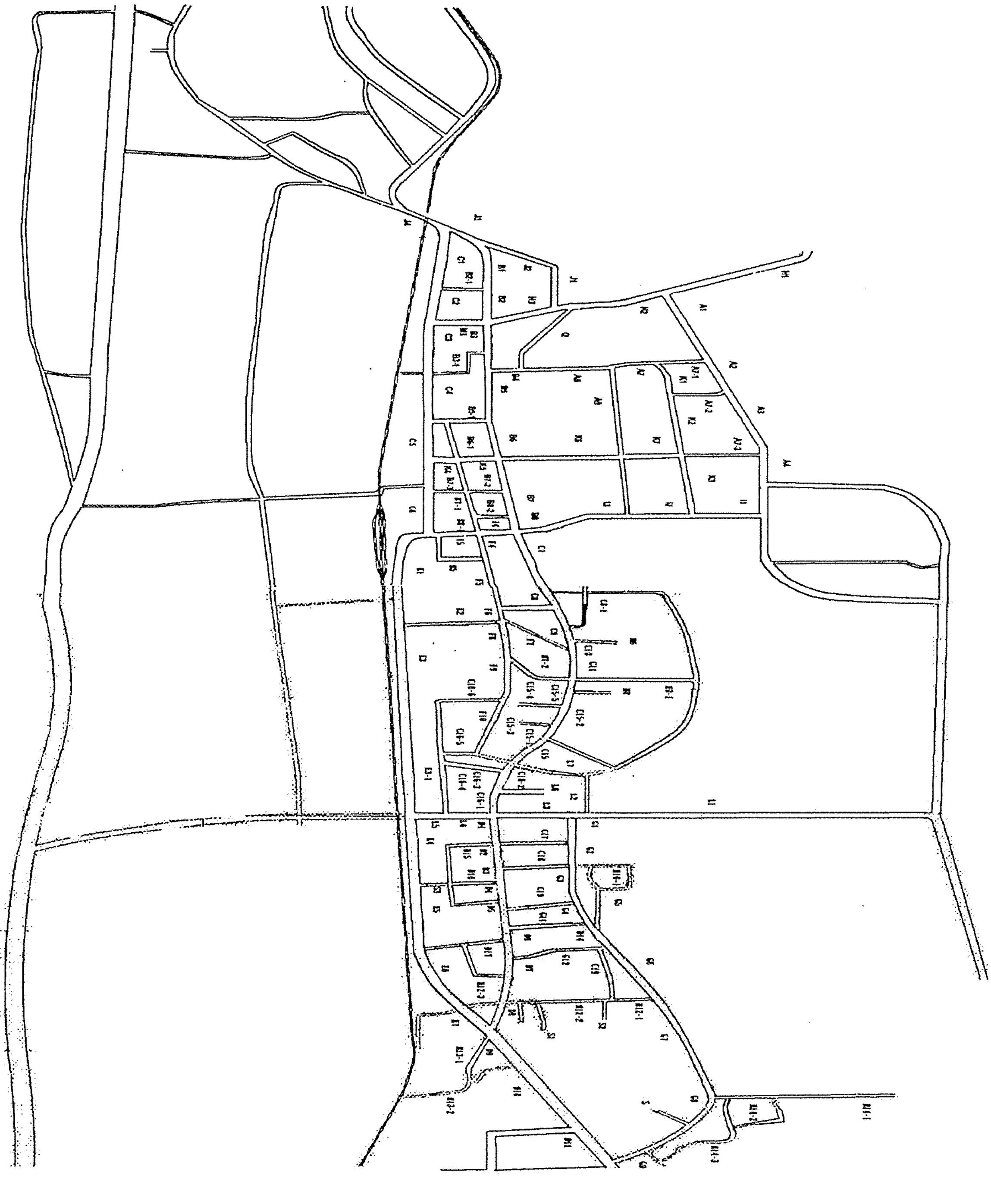


Figure A No. In Chi-Chi

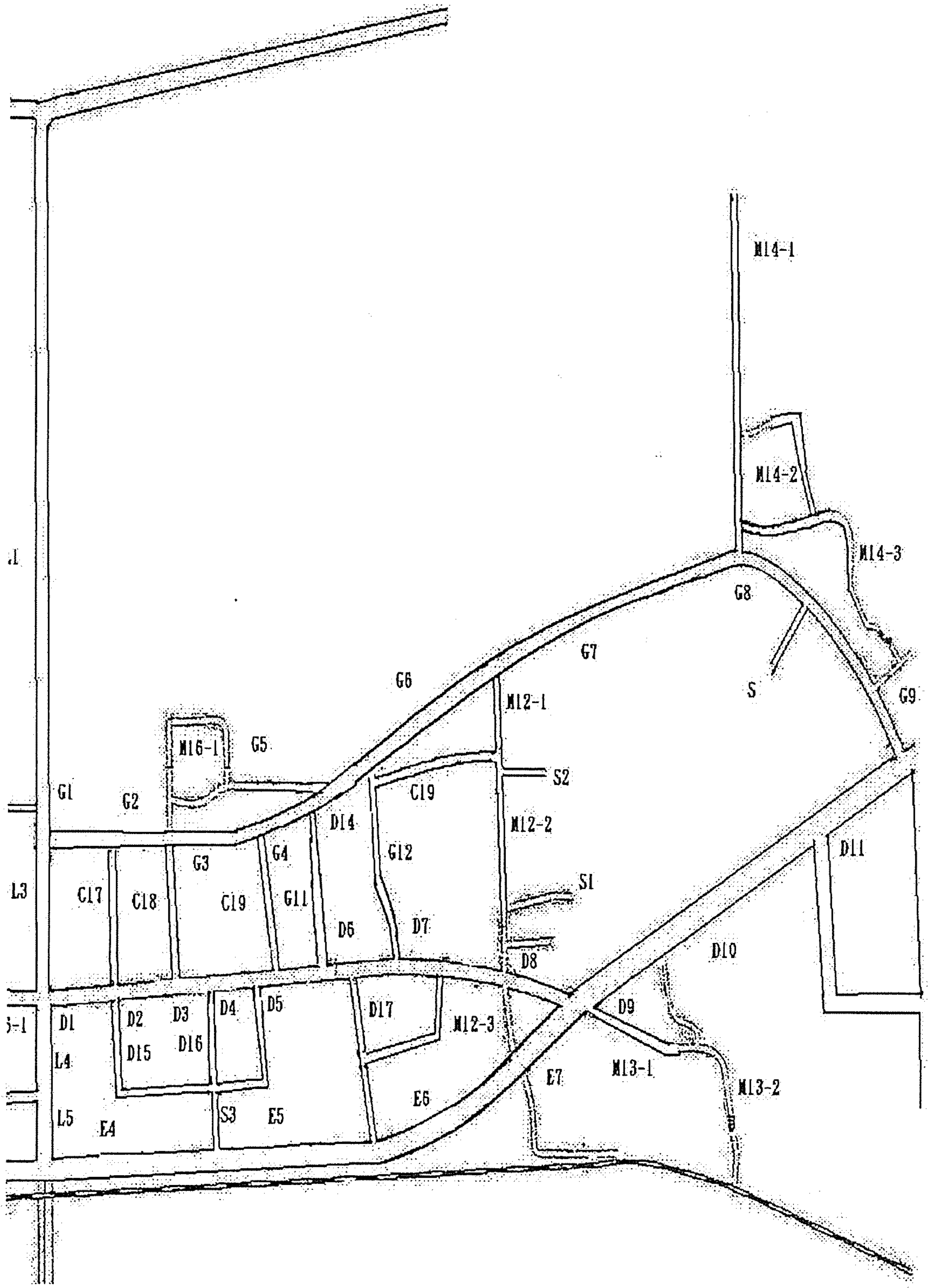

M14-1
M14-2
M14-3
G8
G7
G6
S
G9
M12-1
M16-1
G5
S2
G1
G2
C19
D14
M12-2
D11
G4
G3
G12
L3
C17
C18
C19
G11
S1
D6
D7
D8
D10
D1
D2
D3
D4
D5
D17
M12-3
D9
L4
D15
D16
M13-1
E7
M13-2
E6
L5
E4
S3
E5

Figure A-1

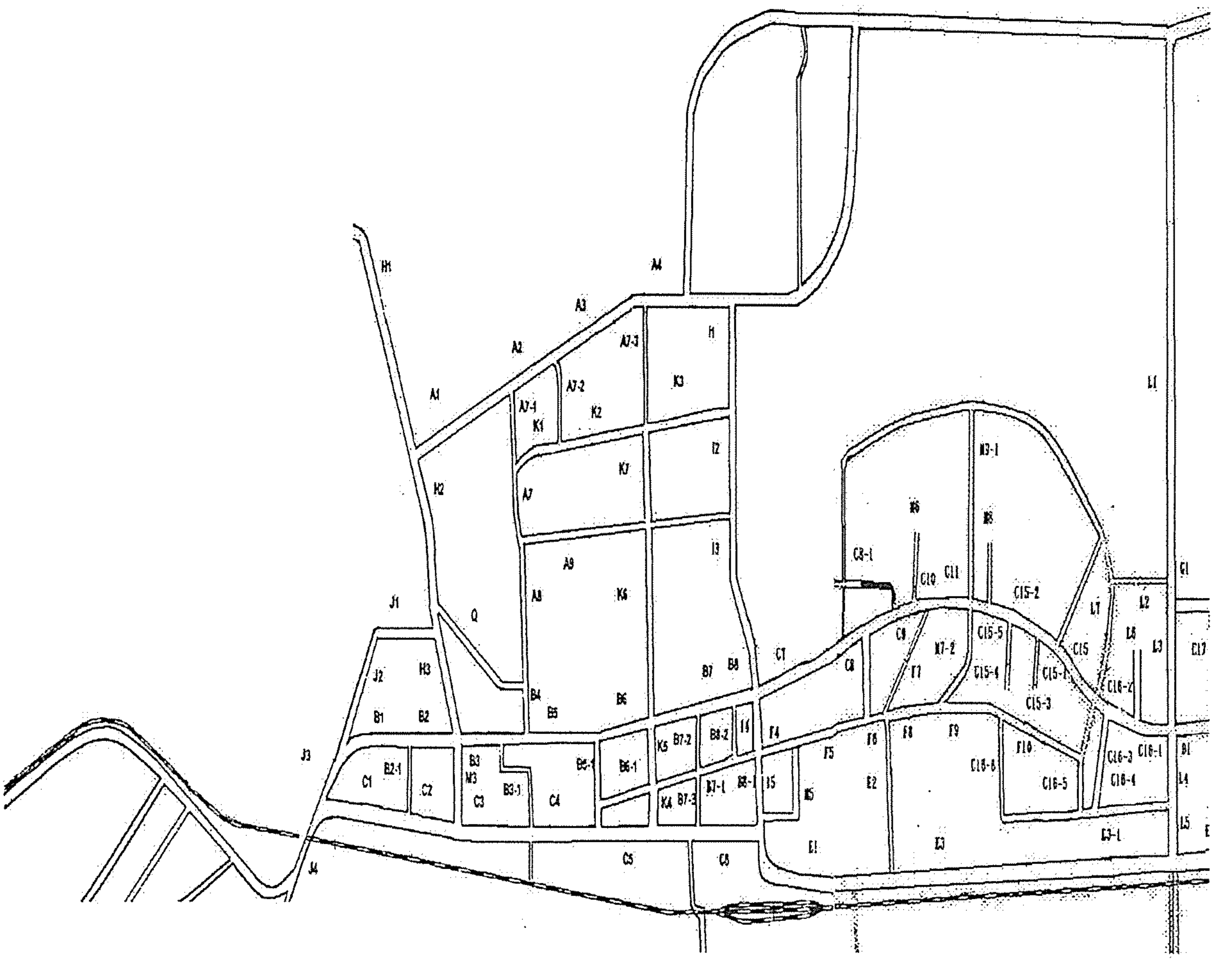


Figure A-2

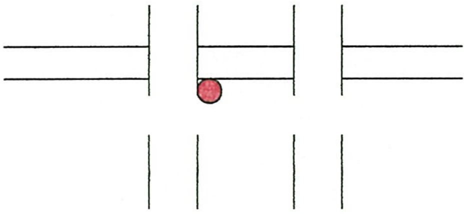
Table1 Data collected in Chi-Chi town from on-site survey

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	width (m)		
A1	7	194	—	—	O	—	—	—	O
A2	7	88	—	—	O	30	3	—	O
A3	7	112	O	—	—	—	—	—	O
A4	7	78	—	—	—	—	—	—	O
A5	7	194	—	—	O	30	3	—	O
A7	8.5	74	—	—	—	—	—	—	O
A7-1	6.4	78	—	—	—	—	—	—	O
A7-2	6.4	84	—	—	O	20	1.5	—	O
A7-3	6.4	125	O	—	—	—	—	—	O
A8	8.5	198	—	—	O	—	—	—	O
A9	8.5	404	O	—	—	—	—	—	O
B1	12	122	—	—	—	—	—	—	O
B2	12	84	O	—	—	—	—	—	O
B2-1	8.6	68	—	O	—	—	—	—	O
B3	12	72	—	O	—	—	—	—	O
B3-1	2.6	148	—	O	—	—	—	—	X
B4	12	44	O	—	—	—	—	—	O
B5	12	128	—	—	O	—	—	—	O
B5-1	5.6	90	O	—	—	—	—	—	O
B6	12	192	O	—	O	—	—	—	O
B6-1	9.5	198	O	—	O	—	—	—	O
B7	12	66	—	O	O	—	—	—	O
B7-1	8	74	—	—	O	—	—	—	O
B7-2	7.2	56	O	—	O	18	2	—	O
B7-3	7.2	48	—	—	—	—	—	—	O
B8	12	34	—	—	—	—	—	—	O
B8-1	8	32	O	—	—	—	—	—	O
B8-2	7.2	52	—	—	O	—	—	—	O
C1	13	166	O	—	O	—	—	—	O
C2	13	92	—	O	O	—	—	—	O
C3	13	136	—	O	O	—	—	—	O
C4	13	128	—	O	—	—	—	—	O
C5	13	188	—	O	—	—	—	—	O
C6	13	144	—	O	—	—	—	—	O
C7	13	126	O	—	O	16	3	—	O
C8	13	34	—	—	—	—	—	—	O
C8-1	2	112	—	—	—	—	—	44	X
C9	13	74	O	—	O	—	—	—	X

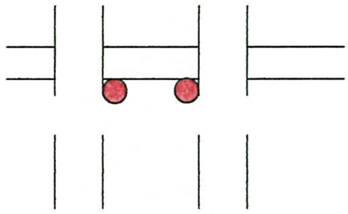
No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	width (m)		
C10	13	38	—	—	—	—	—	—	O
C11	13	108	O	—	O	—	—	—	O
C15	13	100	—	—	—	—	—	—	O
C15-1	5.6	34	—	O	O	—	—	—	O
C15-2	5.6	44	O	—	O	—	—	—	O
C15-3	5.6	48	O	—	O	—	—	—	O
C15-4	3.2	72	O	—	—	—	—	—	X
C15-5	5.6	74	—	O	O	—	—	—	O
C16-1	13	68	O	—	O	—	—	—	O
C16-2	13	70	O	—	O	21	3	—	O
C16-3	5	108	—	O	O	16	3	—	X
C16-4	8.4	162	—	—	O	—	—	—	O
C16-5	8.4	62	—	—	—	—	—	—	O
C16-6	8.4	258	—	—	—	—	—	—	O
C17	3.2	104.8	—	—	O	—	—	—	X
C18	3.2	116	—	—	—	—	—	—	X
C19	10.4	142	O	—	O	—	—	—	O
D1	12	66	O	—	—	—	—	—	O
D2	12	74	—	—	—	—	—	—	O
D3	12	32	—	—	—	—	—	—	O
D4	12	44	—	O	O	25	1.5	—	O
D5	12	102	—	O	O	25	1.5	—	O
D6	12	76	—	—	O	31.2	1.6	—	O
D7	12	64	—	—	O	—	—	—	O
D8	12	74	O	—	O	—	—	—	O
D9	14.6	96	—	—	—	—	—	—	O
D10	14.6	176	—	—	O	—	—	—	O
D11	14.6	114	—	—	O	—	—	—	O
D14	2.7	120	O	—	O	—	—	31	X
D15	6.7	186	O	—	O	—	—	—	O
D16	6.7	128	—	O	O	—	—	—	O
D17	5.6	108	—	—	—	—	—	—	O
E1	14.6	216	—	—	O	—	—	—	O
E2	14.6	66	—	—	—	—	—	—	O
E3	14.6	210	—	—	O	—	—	—	O
E3-1	14.6	159	—	—	O	—	—	—	O
E4	14.6	162	—	—	O	—	—	—	O
E5	14.6	186	O	—	—	—	—	—	O
E6	14.6	154	—	—	—	—	—	—	O

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo))
			One end	Both ends	Middle	Length (m)	width (m)		
E7	14.6	84	—	—	—	—	—	—	O
F4	7.5	68	O	—	O	—	—	—	O
F5	7.5	140	—	—	O	—	—	—	O
F6	7.5	46	O	—	O	—	—	—	O
F7	2	144	—	O	—	—	—	—	X
F8	7.5	112	O	—	O	—	—	—	O
F9	7.5	112	—	—	—	—	—	—	O
F10	7.5	156	—	—	—	—	—	—	O
G1	10.5	71	O	—	—	—	—	—	O
G2	10.5	52.5	—	—	O	—	—	—	O
G3	10.5	101	—	O	O	—	—	—	O
G4	10.4	62.2	—	—	O	—	—	—	O
G5	10.4	53.3	—	—	—	—	—	—	O
G6	10.4	126.6	O	—	O	—	—	—	O
G7	10.5	280.5	O	—	O	—	—	—	O
G8	10.5	182	—	—	O	—	—	—	O
G9	10.5	60	—	—	—	—	—	—	O
G11	5.6	126	O	—	—	—	—	—	O
G12	5.6	140	—	—	O	5	0.5	—	O
H1	12	240	—	—	O	92	4	—	O
H2	12	182	—	—	—	—	—	—	O
H3	12	108	O	—	—	24	2	—	O
I1	12.4	110	—	—	—	—	—	—	O
I2	12.4	109	O	—	—	—	—	—	O
I3	12.4	184	—	—	—	—	—	—	O
I4	12.4	52	—	—	—	—	—	—	O
I5	12.4	58	O	—	—	—	—	—	O
J1	12	112	—	—	—	—	—	—	O
J2	12	136	—	—	—	—	—	—	O
J3	12	64	—	—	—	—	—	—	O
K1	8.5	94	—	—	—	—	—	—	O
K2	8.5	166	—	—	—	—	—	—	O
K3	8.5	164	—	—	—	—	—	—	O
K4	8.5	32	O	—	—	—	—	—	O
K5	8.5	60	—	O	—	—	—	—	O
K6	8.5	194	O	—	—	—	—	—	O
K7	8.5	92	—	—	—	—	—	—	O

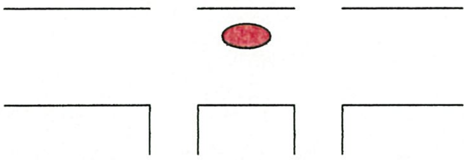
No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	width (m)		
L1	10.5	364	—	—	O	—	—	—	O
L2	10.5	28	O	—	—	—	—	—	O
L3	10.5	122	O	—	—	—	—	—	O
L4	10.5	92	—	—	—	—	—	—	O
L5	10.5	52	—	—	—	—	—	—	O
L6	2.4	146	—	O	—	—	—	12	X
L7	10.5	126	—	—	—	—	—	—	O
M3	12	78	O	—	—	—	—	—	O
M5	2	138	—	—	—	—	—	—	X
M7-2	8.5	144	O	—	—	—	—	—	O
M8	4.2	72	O	—	O	—	—	—	O
M9-1	8.5	200	O	—	O	—	—	—	O
M12-1	5.6	78	O	—	—	—	—	—	O
M12-2	5.6	120	—	—	—	—	—	—	O
M12-3	5.6	162	—	—	—	—	—	—	O
M13-1	5.6	84	—	—	—	—	—	—	O
M13-2	5.6	112	—	—	—	—	—	—	O
M14-1	6.4	174	—	—	O	—	—	—	O
M14-2	6.4	82	—	—	O	—	—	32	X
M14-3	6.4	182	—	—	—	—	—	—	O
M16-1	4.2	84	—	—	—	—	—	—	O
Q	7.7	192	—	—	—	—	—	—	O
S	8.5	62	O	—	—	—	—	—	O
S1	8.5	84	—	O	—	12	1.5	—	O
S2	8.5	49	—	O	—	12	0.5	—	O
S3	4.2	74	—	O	—	18	1	—	X



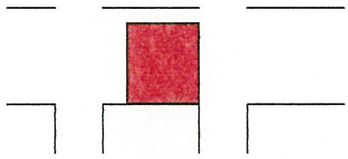
Damage on one end of the street



Damage on both ends of the street



Damage in the middle section of the street



complete closure

Table2 Data collected in Chi-Chi town from the air photos

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo))
			One end	Both ends	Middle	Length (m)	width (m		
A1	7	194	—	—	O	—	—	—	O
A2	7	88	—	—	O	30	3	—	O
A3	7	112	O	—	—	—	—	—	O
A4	7	78	—	—	—	—	—	—	O
A5	7	194	—	—	O	30	3	—	O
A7	8.5	74	—	—	—	—	—	—	O
A7-1	6.4	78	—	—	—	—	—	—	O
A7-2	6.4	84	—	—	O	20	1.5	—	O
A7-3	6.4	125	O	—	—	—	—	—	O
A8	8.5	198	—	—	O	—	—	—	O
A9	8.5	404	O	—	—	—	—	—	O
B1	12	122	—	—	O	24.4,61	2.4,4.8	—	O
B2	12	84	O	—	—	—	—	—	O
B2-1	8.6	68	—	—	—	—	—	—	Unreadable
B3	12	72	—	O	—	24	2.4	—	O
B3-1	2.6	148	—	—	—	—	—	—	Unreadable
B4	12	44	O	—	—	11	7.2	—	O
B5	12	128	—	—	O	12.8,25.6,16	2.4,4.8,7.2	—	O
B5-1	5.6	90	O	—	—	—	—	—	O
B6	12	192	O	—	O	—	—	—	O
B6-1	9.5	198	O	—	O	—	—	—	O
B7	12	66	—	O	O	22	6		O
B7-1	8	74	—	—	O	—	—	—	O
B7-2	7.2	56	O	—	O	18	6		X
B7-3	7.2	48	—	—	—	—	—	—	O
B8	12	34	—	—	—	—	—	—	O
B8-1	8	32	O	—	—	24	4	—	O
B8-2	7.2	52	—	—	O	—	—	—	O
C1	13	166	O	—	O	—	—	—	O
C2	13	92	—	O	O	23	5.2	—	O
C3	13	136	—	O	O	—	—	—	O
C4	13	128	—	O	—	—	—	—	O
C5	13	188	—	O	—	—	—	—	O
C6	13	144	—	O	—	—	—	—	O
C7	13	126	O	—	O	16,20,16	3,7,3	—	O
C8	13	34	—	—	—	—	—	—	O
C8-1	2	112	—	—	—	—	—	44	X
C9	13	74	O	—	O	—	—	—	O

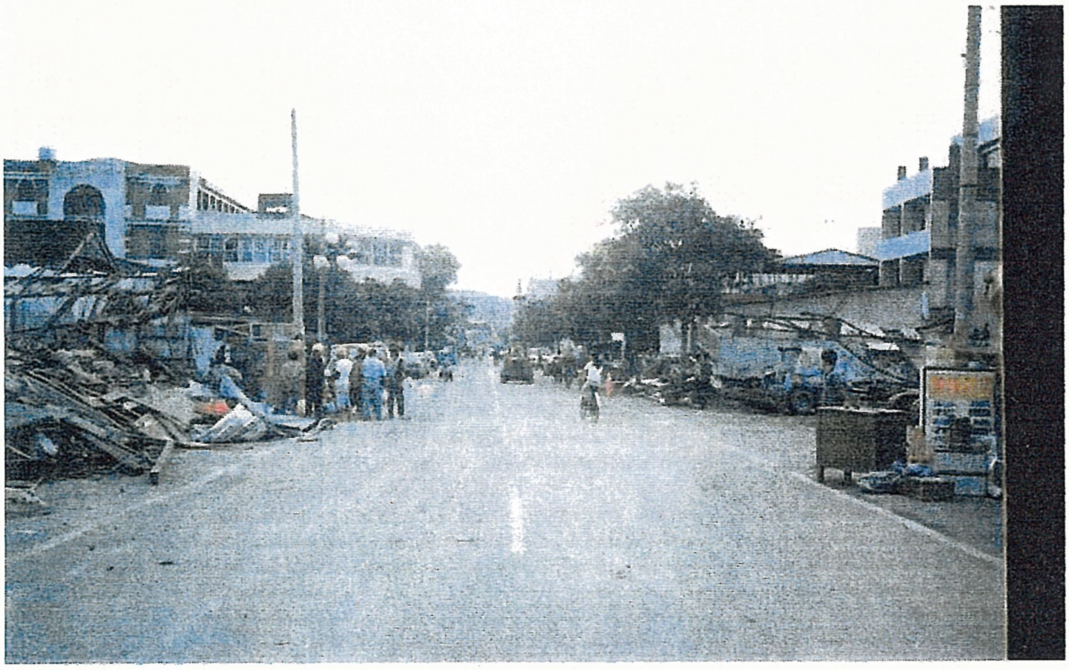
No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	width (m)		
C10	13	38	—	—	—	—	—	—	O
C11	13	108	O	—	O	—	—	—	O
C15	13	100	—	—	—	—	—	—	O
C15-1	5.6	34	—	O	O	24	3	—	X
C15-2	5.6	44	O	—	O	—	—	—	O
C15-3	5.6	48	O	—	O	—	—	—	O
C15-4	3.2	72	O	—	—	—	—	—	O
C15-5	5.6	74	—	O	O	9	3	—	X
C16-1	13	68	O	—	O	—	—	—	O
C16-2	13	70	O	—	O	21	7	—	O
C16-3	5	108	—	O	O	—	—	—	O
C16-4	8.4	162	—	—	—	—	—	—	Unreadable
C16-5	8.4	62	—	—	—	—	—	—	O
C16-6	8.4	258	—	—	—	—	—	—	O
C17	3.2	104.8	—	—	O	—	—	—	X
C18	3.2	116	—	—	—	—	—	—	X
C19	10.4	142	O	—	O	—	—	—	O
D1	12	66	O	—	—	—	—	—	O
D2	12	74	—	—	—	—	—	—	O
D3	12	32	—	—	—	—	—	—	O
D4	12	44	—	O	O	25	2.5	—	O
D5	12	102	—	O	O	25	4	—	O
D6	12	76	—	—	O	31.2	1.6	—	O
D7	12	64	—	—	O	18	2	—	O
D8	12	74	O	—	O	10	2	—	O
D9	14.6	96	—	—	—	7	3	—	O
D10	14.6	176	—	—	O	—	—	—	O
D11	14.6	114	—	—	O	—	—	—	O
D14	2.7	120	O	—	O	—	—	31	X
D15	6.7	186	O	—	O	—	—	—	O
D16	6.7	128	—	O	O	—	—	—	O
D17	5.6	108	—	—	—	—	—	—	O
E1	14.6	216	—	—	O	—	—	—	O
E2	14.6	66	—	—	—	—	—	—	O
E3	14.6	210	—	—	O	—	—	—	O
E3-1	14.6	159	—	—	O	—	—	—	O
E4	14.6	162	—	—	O	—	—	—	O
E5	14.6	186	O	—	—	60	2	—	O
E6	14.6	154	—	—	—	—	—	—	O

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo))
			One end	Both ends	Middle	Length (m)	width (m)		
E7	14.6	84	—	—	—	—	—	—	O
F4	7.5	68	O	—	O	—	—	—	O
F5	7.5	140	—	—	—	—	—	—	Unreadable
F6	7.5	46	O	—	O	—	—	—	O
F7	2	144	—	O	—	—	—	—	X
F8	7.5	112	O	—	O	32	2	—	O
F9	7.5	112	—	—	—	—	—	—	O
F10	7.5	156	—	—	—	—	—	—	O
G1	10.5	71	O	—	—	8	2	—	O
G2	10.5	52.5	—	—	O	—	—	—	O
G3	10.5	101	—	O	O	15	2	—	O
G4	10.4	62.2	—	—	O	—	—	—	O
G5	10.4	53.3	—	—	—	—	—	—	O
G6	10.4	126.6	O	—	O	8	3	—	O
G7	10.5	280.5	O	—	O	12	3	—	O
G8	10.5	182	—	—	O	—	—	—	O
G9	10.5	60	—	—	—	—	—	—	O
G11	5.6	126	O	—	—	—	—	—	Unreadable
G12	5.6	140	—	—	O	5	0.5	—	O
H1	12	240	—	—	O	92	4	—	O
H2	12	182	—	—	—	—	—	—	O
H3	12	108	O	—	—	24	2	—	O
I1	12.4	110	—	—	—	—	—	—	O
I2	12.4	109	O	—	—	—	—	—	O
I3	12.4	184	—	—	—	—	—	—	O
I4	12.4	52	—	—	—	—	—	—	O
I5	12.4	58	O	—	—	19.33	6.2	—	O
J1	12	112	—	—	—	—	—	—	O
J2	12	136	—	—	—	—	—	—	O
J3	12	64	—	—	—	—	—	—	O
K1	8.5	94	—	—	—	—	—	—	O
K2	8.5	166	—	—	—	—	—	—	O
K3	8.5	164	—	—	—	—	—	—	O
K4	8.5	32	—	—	—	—	—	—	Unreadable
K5	8.5	60	—	—	—	—	—	—	Unreadable
K6	8.5	194	O	—	—	97	2.8	—	O
K7	8.5	92	—	—	—	—	—	—	O
L1	10.5	364	—	—	O	—	—	—	O
L2	10.5	28	O	—	—	—	—	—	O

No. of links	Street width (m)	Length (m)	Damage position			Partial closure		Length of complete closure (m)	Accessible by emergency vehicles (air photo)
			One end	Both ends	Middle	Length (m)	width (m)		
L3	10.5	122	O	—	—	—	—	—	O
L4	10.5	92	—	—	—	—	—	—	O
L5	10.5	52	—	—	—	—	—	—	O
L6	2.4	146	—	O	—	—	—	12	X
L7	10.5	126	—	—	—	—	—	—	O
M3	12	78	O	—	—	—	—	—	O
M5	2	138	—	—	—	—	—	—	Unreadable
M7-2	8.5	144	O	—	—	—	—	—	O
M8	4.2	72	—	—	—	—	—	—	Unreadable
M9-1	8.5	200	O	—	O	21	4	—	O
M12-1	5.6	78	O	—	—	—	—	—	O
M12-2	5.6	120	—	—	—	—	—	—	O
M12-3	5.6	162	—	—	—	—	—	—	O
M13-1	5.6	84	—	—	—	—	—	—	O
M13-2	5.6	112	—	—	—	—	—	—	O
M14-1	6.4	174	—	—	O	—	—	—	O
M14-2	6.4	82	—	—	O	—	—	32	X
M14-3	6.4	182	—	—	—	—	—	—	O
M16-1	4.2	84	—	—	—	—	—	—	O
Q	7.7	192	—	—	—	—	—	—	O
S	8.5	62	O	—	—	—	—	—	O
S1	8.5	84	—	O	—	12	1.5	—	O
S2	8.5	49	—	O	—	12	0.5	—	O
S3	4.2	74	—	O	—	18	1	—	X

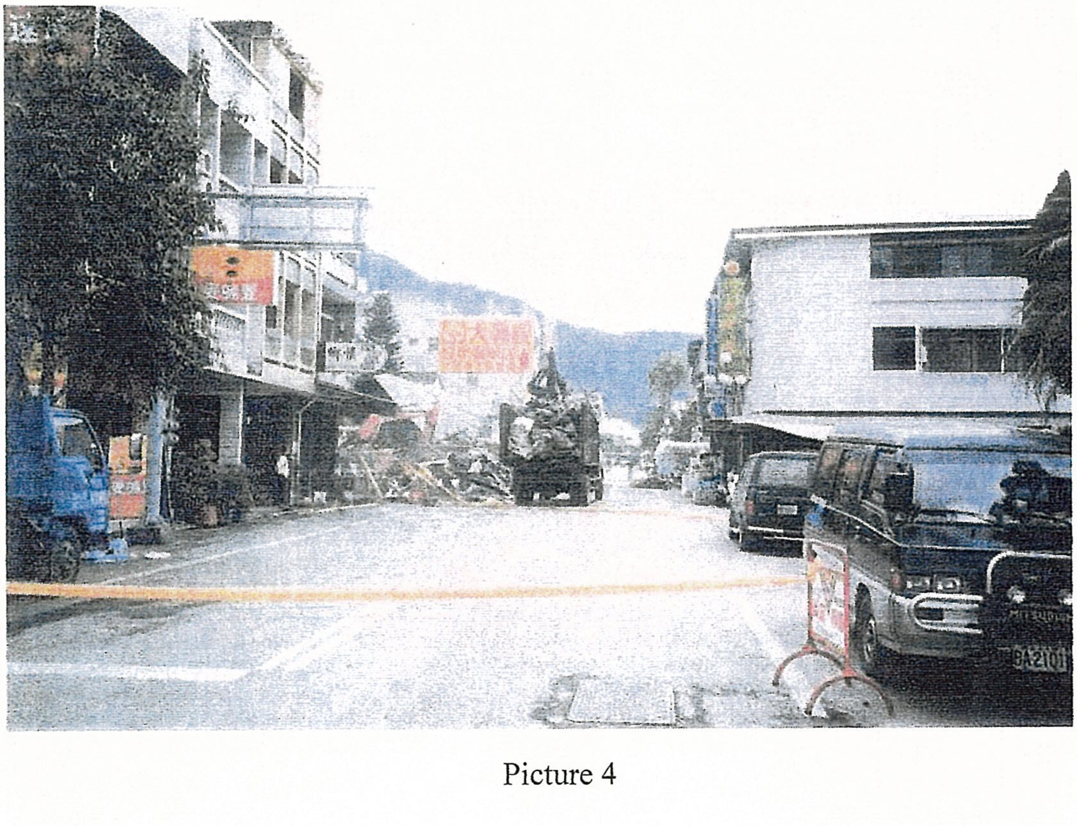
Appendix A

Picture 1



Picture 2

Picture 3



Picture 4

Picture 5

Picture 6

Picture 7

Picture 8

おわりに

本プロジェクトは、台湾で発生した集集大震災における交通状況を調査し、今後の大規模災害に備えた非常時の交通計画のための基礎的資料の収集を目的としたものである。我が国における阪神・淡路大震災の経験を参考にしつつ、地域レベル（マクロレベル）、都市レベル（メソレベル）、街路レベル（マイクロレベル）の3レベルに分類して調査分析を行った。各レベルにおいて得られた知見を以下に示す。

地域レベルでの分析により、交通ネットワークが断絶した原因は、地震動、断層、地滑り、液状化であったこと、フィールド調査のみならず、インタビュー調査も併せて実施することが重要であること、断層直近の道路や橋梁に被害が集中していたため、断層位置を考慮した構造物設計、道路計画の実施が重要であること、山間部における交通の途絶を防止するためのリダンダントな道路網構成の重要性などが明らかとなった。

都市レベルでの分析により、災害時においては、ドライバーは、より高い規格の道路を選好する傾向にあり、その理由として案内標識等が充実しているためであることが明らかとなった。そのため、今後その他の道路の道路誘導について検討を加える必要がある。さらに、救援物資運搬のための車両が被災地に集中したことによって、被災地内の交通量は増加し、深刻な交通渋滞が発生していたことも明らかとなった。阪神・淡路大震災においても、同様の問題が発生しており、救援物資等をいかに効率的に配送するか、緊急物資運搬用のロジスティクスセンターをどのように計画配置するかが非常に重要であるといえる。また、交通状況と被災状況、さらに交通需要の発生の面からみると、交通状況変化は、交通需要が変化した影響よりも、道路の被災による影響の方が大きいことが明らかとなった。なお、都市レベルでの分析においては、一定の期間の交通状況を定性的に質問し、それより一般的な交通状況を考察するという分析方法を行っており、この方法は、平常時より密に交通状況を観測していない地域においては有用な手法であるといえる。

街路レベルでの分析より、12メートル幅以上の幹線道路は、災害に強く、交通機能を失うことがなかったこと、航空写真データのみでは全てのリンクが判読可能ではなかったことなどが明らかとなった。さらに、街路閉塞の原因が倒壊家屋であったことは阪神・淡路大震災と同様であるが、台湾においてはRC構造あるいは煉瓦造りの家屋が多く、我が国のような木造住宅中心ではないため、閉塞原因の傾向が異なっていることがわかった。

本プロジェクトによって得られたデータと、阪神・淡路大震災において収集されたデータをもとに、今後は以下のような研究分析が必要であると考えられる。

(1) 災害時における交通調査に関するマニュアル作成に向けた調査分析

災害発生後に効果的な交通管理方策を考えるにあたって、まずどのような交通状況が発生しているかを迅速に把握することは非常に重要である。しかしながら、災害発生時という非常事態においては、交通状況の調査方法が平常時とは異なる可能性が高い。そのため、阪神・淡路大震災、集集大震災における両国の経験をベースに、災害発生時に調査目的に応じて適切な調査方法を示唆可能な、災害時交通調査マニュアルの作成が必要であるといえる。

(2) 災害時の緊急物資輸送とロジスティクスセンターの配置に関する研究

阪神・淡路大震災、集集大震災ともに、緊急物資を、必要な場所に必要な量だけを、いかに効率的に運搬するかが重要な課題となりうることが明らかとなった。災害発生時に緊急物資輸送の

ためのロジスティクスセンターとなりうる施設の配置、緊急輸送ルートの設定、配車配送計画の策定は、今後の災害発生時に備えて、非常に重要である。災害時における緊急物資流動に関する方法論的研究は、阪神・淡路大震災に関する調査研究でもそれほど詳細は実施されておらず、今後重点的に実施すべき課題であるといえる。

(3) 集集大震災における調査研究の深化

本プロジェクトは、実質的に 3 ヶ月間という短い期間で行ったものであり、より深い考察が求められているといえる。例えば、街路レベルでの調査分析においては、集集町のみを分析対象としたが、震央や断層からの距離によって、街路閉塞状況やその要因が異なること、さらには都市発展の歴史的経緯によっても異なることが考えられる。そのため、他地域で同様の調査を実施する等データの蓄積を図り、より普遍的な知見を得る必要があろう。

非売品

台湾地震交通調査

発行日　平成12年3月
発行所　(財)国際交通安全学会
東京都中央区八重洲 2-6-20　104-0028
tel : 03-3273-7884　fax : 03-3272-7054