



EVALUATION OF BUILDING RECONSTRUCTION PROCESS IN CHI-CHI AREA BASED ON A GIS- DATABASE AFTER THE 1999 CHI-CHI EARTHQUAKE, TAIWAN

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SUMMARY

The authors have investigated the damaged Chi-Chi area several times since the 1999 Chi-Chi Earthquake in Taiwan and conducted design surveys to grasp location and dimensions of all of the buildings on purpose to make a GIS database in the area. In this paper, some recent condition and process of reconstruction are reported based on the obtained data sets, materials, and information as follows: 1) Overview of Chi-Chi and damage due to the 1999 Chi-Chi Earthquake, 2) Introduction of the essential city planning and policy for reconstruction by the governments, 3) Process of recovery and reconstruction in Chi-Chi area using the GIS database, which has constructed by the author based on IKONOS, 4) Proposal of "Spatial Reconstruction Model" to represent condition of physical environment of an area after the Earthquakes, and 5) Applying of the Spatial Reconstruction Model to public space and buildings in Chi-Chi area and considerations. The most remarkable portion of the contents is the proposal of "Spatial Reconstruction Model". It is difficult to quantitatively perceive reconstruction process of a damaged city and to compare the reconstructive condition with the previous one before the earthquake. This proposed Spatial Reconstruction Model is applied to the public space and buildings in Chi-Chi area and makes the reconstructive condition visualized. This method can be useful in future research to compare recovery process of damaged areas due to natural disasters in the World which have different social background.

INTRODUCTION

Since the 1999 Chi-Chi Earthquake damaged to more than one hundred thousand buildings in Taiwan on September 21, 1999, four years have passed. The authors investigated the damaged Chi-Chi area in Nantou County several times. Recovery conditions of some damaged areas in Taiwan were reported to Architectural Institute of Japan [1] and Research Committee on Urban Planning and Community Development for Disaster Reduction in the City Planning Institute of Japan [2]. Ichiko and Nakabayashi [3] suggested differences of post-earthquake responses among Hanshin (Japan), Kocaeli (Turkey), and

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Chi-Chi (Taiwan). Maki [4] reported possibilities to use CCD camera for getting information of recovery condition of a damaged area through Internet.

Through these investigations concerned with recovery and reconstruction process after the earthquakes, the authors have recognized some difficulties to compare seismic resilience of one damaged area with other areas or countries. Part of the reason is because countermeasures of the damaged areas are influenced by their own context, such as economic conditions, culture, mentality, politics, history, religion, etc. Bruneau et al [5] proposed a conceptual framework to define seismic resilience of communities and quantitative measures. In this paper, "Spatial Reconstruction Model" as a tool to quantitatively represent condition of physical environment of an area after the Earthquakes is proposed and is applied to Chi-Chi area using dataset of public space and buildings. It also deals with making Chi-Chi GIS database based on IKONOS image.

OVERVIEW OF CHI-CHI AND DAMAGE DUE TO THE 1999 CHI-CHI EARTHQUAKE

History of Chi-Chi Town [6]

Chi-Chi is located in Nantou County in the central part of Taiwan as in Figure 1 and is 230 meters above the sea. Total area of Chi-Chi is 12.43 square kilometers and it has a population of about 12,000 in 11 villages. In the mid-eighteenth century, part of the Chinese race immigrated into the area and some undeveloped wasteland were exploited as a town in 1780. Thereafter, the town had become very prosperous as farmland or trading place for daily necessities and had become called Chi-Chi that means "gathering" in Chinese. In the end of nineteenth centuries, camphor industry was developed and rich people immigrated, so that Chi-Chi became the most prosperous town in Nantou County. Although the town was destroyed and the population decreased at the beginning of the Japanese reign, it prospered again as the center of traffic, commerce, and politics. This is because of Chi-Chi railroad starting, construction of the city hall, and success of banana industry, early in the twentieth century under Japanese rule. After one village of Chi-Chi declared independent in 1950, the power of Chi-Chi as the center gradually became to decline. In 1970s, when main industry of Taiwan was changing from primary to secondary, economic conditions of Chi-Chi that depended on agriculture became worse. However, Chi-Chi has been known as a sightseeing area which has lots of cultural resources like Japanese styled Chi-Chi station and beautiful natural environment.



Figure 1: Location of Chi-Chi Town and the epicenter

Damage in Chi-Chi Town due to the 1999 Chi-Chi Earthquake [7]

The Chi-Chi Earthquake that occurred at the epicenter (see Figure 1) on September 21 in 1999 damaged to more than 106,000 buildings and about 2,500 people died in Taiwan [8]. In Chi-Chi town, 1,736 buildings were seriously, 792 buildings were moderately damaged, and 42 people were died due to the earthquake as shown in Table 1. It was one of the most serious disasters in the history of Chi-Chi, so that lots of tourist attractions were lost such as Japanese traditional Chi-Chi station, historical temples, potteries, and other public facilities. Those cultural resources together with the historical unique background have been significant elements for the economical and industrial recovery of Chi-Chi.

Table 1: Number of damaged buildings and casualties in Chi-Chi Town due to the 1999 Chi-Chi Earthquake

Villages	Severely Damaged Buildings	Moderately Damaged Buildings	the Dead	Severely Injured Person	Ratio of Severely and Moderately Damaged Buildings
Chi-Chi	143	64	4	2	60.88%
He-Ping	235	71	3	2	80.95%
Lin-Wei	163	45	2	4	94.97%
Tian-Liao	318	56	8	1	70.96%
Ai-Liao	100	42	0	1	65.74%
Yu-Ying	118	20	4	2	71.87%
Wu-Li	151	107	1	2	68.61%
Ba-Jhang	225	210	8	3	85.62%
Yong-Jhang	120	71	3	0	54.57%
Guang-Ming	132	67	6	1	60.12%
Fu-Shan	31	39	3	1	28.11%
Total	1,736	792	42	19	68.58%

ESSENTIAL CITY PLANNING AND POLICY FOR RECONSTRUCTION

Essential City Planning for Reconstruction in Taiwan

In November 1999, the Economy and Construction Committee in Ministry of Interior promulgated "*Platform for the Recovery and Reconstruction after the 921 Earthquake* [9]" as a guideline of the reconstruction planning of the damaged areas in Taiwan. Each damaged town or Village was requested to make a reconstruction plan according to their own situation, which was named as "Essential City Planning and Policy for Reconstruction" (Figure 2). This reconstruction scheme was constituted by public construction plan, industry reconstruction plan, life recovery plan, and community reconstruction plan.

Outline of the Essential City Planning for Reconstruction for Chi-Chi

In February, 2000 in which 5 months passed from the earthquake occurrence, Chi-Chi Government Office released "Master Plan for Sightseeing and Cultural Development in Chi-Chi [10]". The plan aimed to improve Chi-Chi's tourist industry which is one of the significant elements for the future of Chi-Chi after the earthquake and to develop the area systematically (Figure 3). "*Essential City Planning and Policy for Reconstruction of Chi-Chi Town, Nantou*

County [11]" was passed the examination by an examining committee of the town on January 5th, and was completed on December 21st, 2000.

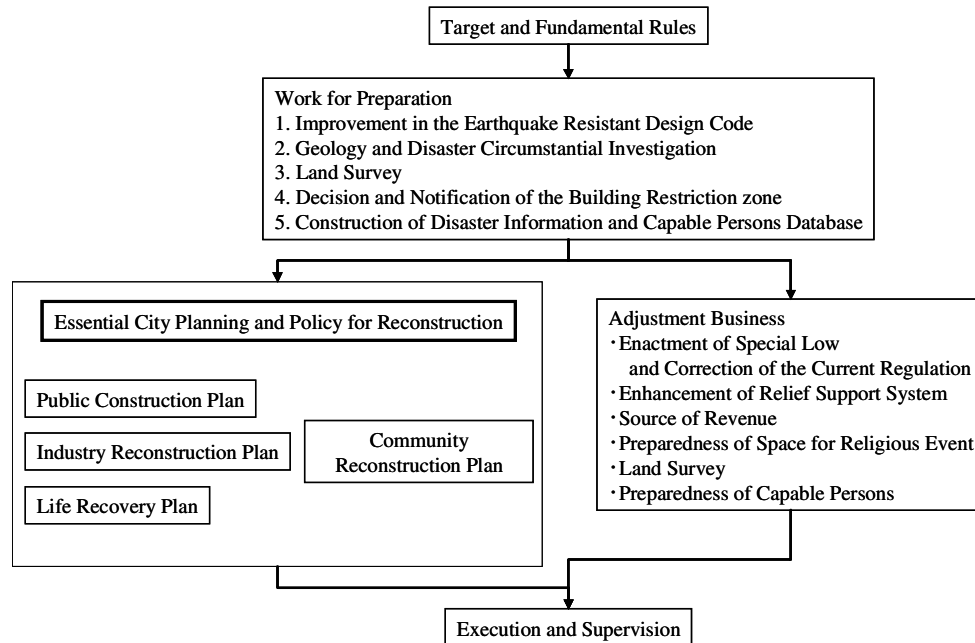


Figure 2: Scheme of the recovery and reconstruction policy and planning for the damaged areas requested by the Taiwan government

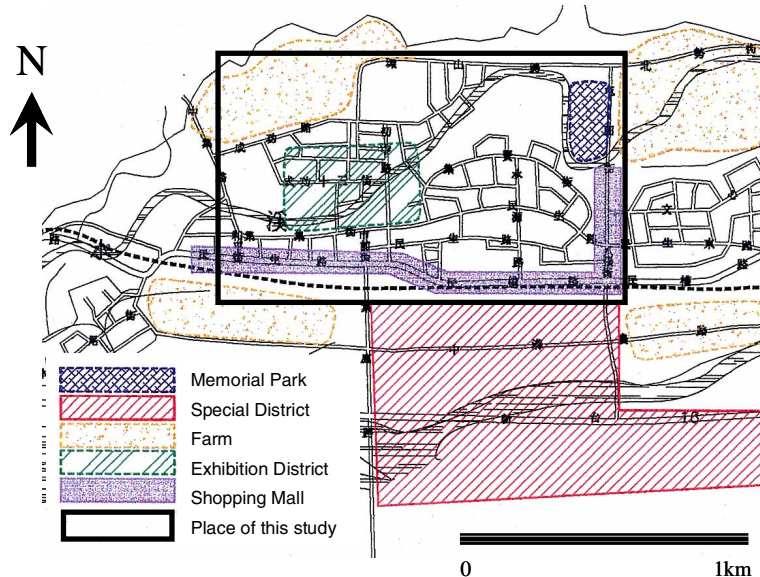


Figure 3: Master plan for the reconstruction of Chi-Chi

In the report, 14 items were mentioned as basic concepts of the reconstruction plan. These are as follows; (1) Preservation of the Rural Landscape, (2) Emphasis on the Local Color, (3) Preservation of the Natural Resources and the Ecosystem, (4) Living Environment with the Humanity, (5) Preservation of the Historical, Cultural, and Artistic Resources, (6) Resident Participation, (7) Development of the Tourism and Agriculture, (8) Improvement of the Traffic Network, (9) Development of the Parks and Open space,

(10) Harmonious Architecture and Townscape, (11) Support of the Cultural Activities by the Inhabitant, (12) Urban Disaster Mitigation, (13) Promotion of Urban Activities in which Various Culture Coexists, and (14) Synthetic Development with the Nearby Region.

CONSTRUCTION OF CHI-CHI GIS DATABASE AND PROCESS OF RECOVERY AND RECONSTRUCTION IN CHI-CHI AREA

Conducted Field Surveys by the authors after the Earthquake

In order to grasp the reconstruction process of the central area in Chi-Chi after the earthquake, the authors conducted investigations and field surveys as follows.

1) October 1st, 1999:

Damage investigation due to the earthquake

2) April 1st and 2nd, 2000:

Investigation of reconstructive condition including hearing to Chi-Chi Government Office, Nantou County Government Office, and residents in the area

3) January 7th and 9th, 2002:

Investigation of reconstructive condition including hearing to Chi-Chi Government Office, Nantou County Government Office, and residents in the area

4) August 8th to 15th, 2002:

Field Design Survey including hearing to Chi-Chi Government Office, and residents in the area

5) September 15th to 19th, 2003:

Field Design Survey including hearing to Chi-Chi Government Office, and residents in the area

Construction of Chi-Chi GIS database to Grasp Recovery and Reconstruction Process

It is essential to describe reconstruction process of physical environment of a damaged area. However, there were no helpful accurate maps of Chi-Chi for the purpose of this study, so that the author had to make an original GIS database (Chi-Chi GIS database) as following process.

Getting Image

The authors [12] got the satellite image of the whole area of Chi-Chi Town that had been taken on September 28th, 2000 by IKONOS and made it the base map.

Field Design Survey

Field design surveys based on the IKONOS image were conducted in twice in order to understand the exact shape of about 2,300 buildings in the object area to make vector data for the GIS map. Several characteristics of each building were also investigated.

Digitalizing the Spatial Information

The spatial information of the buildings obtained by the design surveys was digitalized into shape files on Arc/View GIS software. In addition to the polygonal vector dataset of buildings, other spatial information in the area (e.g.: railroad, street, river, administrative district, park, etc.) was incorporated for the Chi-Chi GIS database.

Making of the Chi-Chi GIS database

These spatial vector files should be combined with the characteristics investigated in the surveys for the Chi-Chi GIS database. The author designed the database to grasp the reconstructional process, in which attributes of a building are building ID, type of structure, number of stories, type of use, village, address, resident ID, possessive condition, block ID, damaged rank, and reconstructive condition (1999/09, 2000/04, 2002/01, 2002/08, 2003/09). The GIS database was shown in Figure 4 and Figure 5.

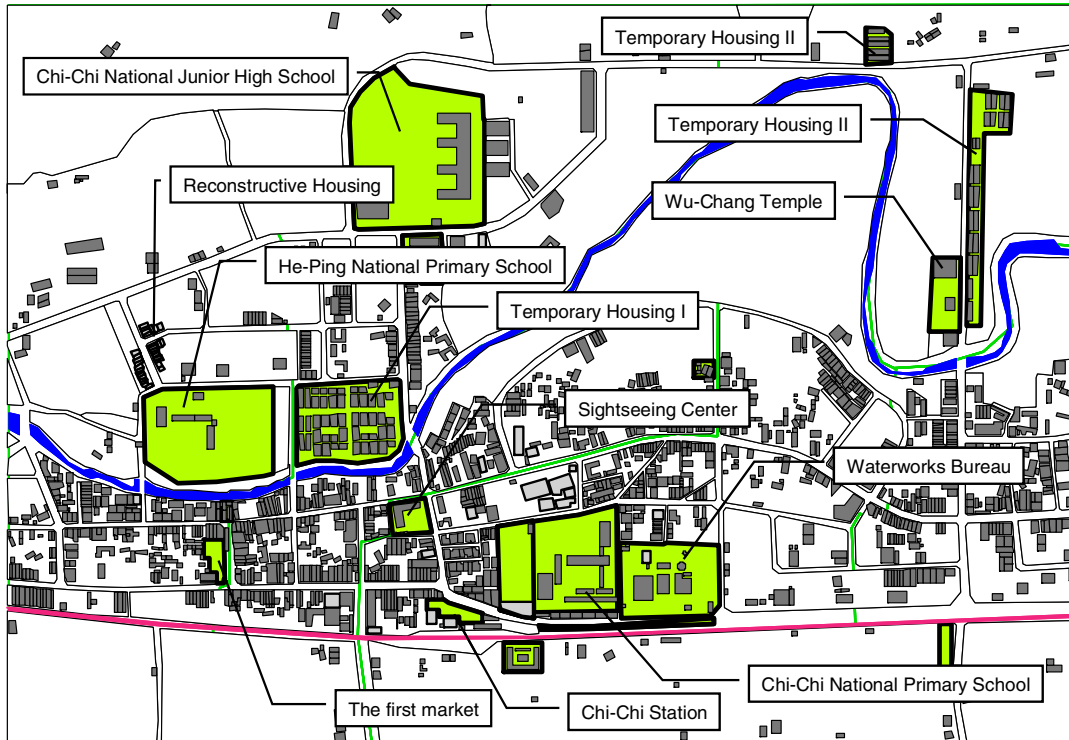


Figure 4: Chi-Chi GIS database



Figure 5: Reconstructional Condition of Chi-Chi in September, 2003, expressed by 3D analyst on Chi-Chi GIS database

Recovery and Reconstruction Process with regards to Public Space

Various kinds of organizations or individuals are related in the social phenomenon of the reconstruction. The author thinks that the most significant subjects we should consider are the regional government office and the households. This study deals with the reconstructive conditions of public space (including public facilities) which belongs to the Chi-Chi government. The list of the objective public space and damage rank due to the 1999 Chi-Chi Earthquake is shown in Table 2. Period to demolish and to (re)construct for each facility was also investigated but it is omitted in the list. These 41 facilities were classified into four categories according to the damage rank and that reconstructional process indicated different tendency. It will be described later.

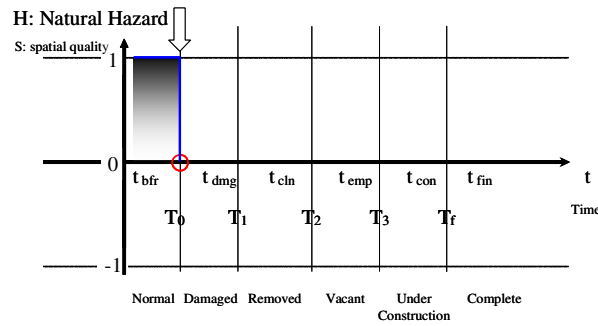
Table 2: List of the objective public space in the area

Classification	ID	Facilities	Structure (Num of Stories)	Ttl Flr (m ²)	Damage Level
The Other	01	Chi-Chi Fire Station	RC (3F)	303	Non
	02	Chi-Chi Post Office	RC (2F)	218	Non
	03	Water Works (Office)	RC (2F)	229	Non
	04	Chi-Chi Sightseeing Center	Parking Lot	1,527	Non
	05	Chi-Chi Legal Affairs Bureau	RC (3F)	572	Slightly
	06	Chi-Chi Telecommunication Office	RC (3F)	927	Slightly
	07	He-Ping National Primary School	RC (2F)	25,142	Slightly
Moderately Damaged	08	Chi-Chi Government Office	RC (4F)	1,472	Moderately
	09	Chi-Chi Library	RC (4F)	732	Moderately
	10	Chi-Chi Nursery School	RC (3F)	1,430	Moderately
	11	Chang-Cing Hall/He-Ping Community Center	RC (3F)	806	Moderately
	12	Wu-Li Community Center	RC/BR (2F)	232	Moderately
	13	Yu-Ying Community Center	RC/BR (2F)	249	Moderately
	14	Fresh Produce Mart	S (1F)	232	Moderately
	15	Agricultural Cooperative Association	RC (2F)	100	Moderately
	16	Waterworks Bureau	RC (2F)	8,005	Moderately
	17	Cycling Road	-	1,564	Moderately
Severely Damaged	18	Representatives Hall	RC (3F)	182	Moderately
	19	Chi-Chi Health Center	RC (2F)	162	Non (Rebuilt)
	20	Ba-Jhang Community Center	BR (1F)	110	Severely
	21	Chi-Chi Assembly Hall	RC (1F)	144	Severely
		Chi-Chi Community Center	RC (3F)	93	Severely
	22	The First Market	RC (3F)	1,019	Severely
	23	Chi-Chi Station	Wooden (1F)	133	Severely
	24	Railroad Museum	Wooden (1F)	148	Severely
	25	Chi-Chi Resort Center	RC (5F)	2,205	Severely
	26	Chi-Chi Public Swimming Pool	-	2,468	Severely
	27	Parking Lot	RC (B2F)	7,744	Severely
	28	Chi-Chi Police Station	RC (3F)	1,455	Severely
		Chi-Chi Police Station (Temporary)	-	767	Private
	29	Chi-Chi National Junior High School	RC (2F)	42,032	Severely
	30	Chi-Chi National Primary School	RC (2F)	17,322	Severely
	31	Farmer Bank	RC (3F)	1,076	Collapsed
	32	Chi-Chi Water Service Station	RC (3F)	588	Collapsed
	33	Wu-Chang Temple	RC (3F)	2,628	Collapsed
	34	Chang-An Temple	Adobe (1F)	361	Collapsed
	35	Guang-Sheng Temple	Wooden (1F)	225	Collapsed
Facilities for Reconstruction	36	Temporary Housing (I) (138+20)	-	16,824	Private
	37	Temporary Housing (II) (72)	-	3,328	Private
	38	Temporary Housing (III) (23)	-	1,090	Private
	39	Reconstructive Housing	-	4,072	Private
	40	Bamboo Park	-	830	Private
	41	Chi-Chi Exhibiton Center	-	1,388	Private

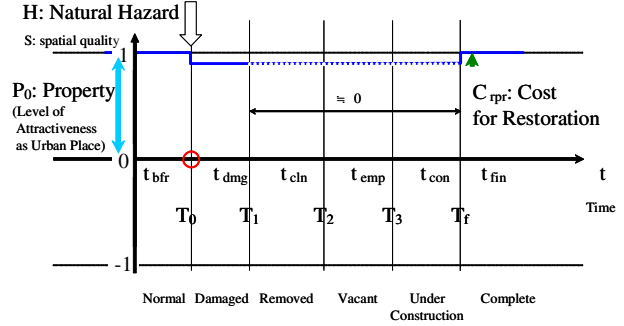
SPATIAL RECONSTRUCTION MODEL TO VISUALIZE OF RECOVERY AND RECONSTRUCTION PROCESS

Proposal of Spatial Reconstruction Model to Represent Condition of Physical Environment of an area after the Earthquakes

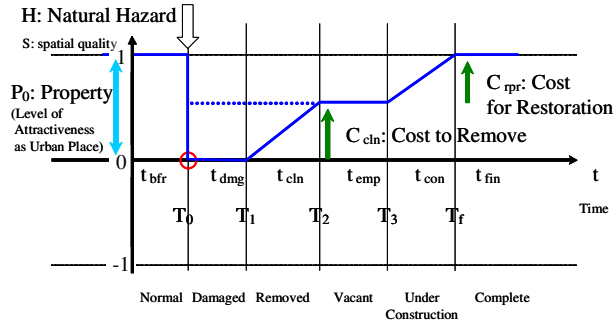
In order to describe visually and to understand the reconstructional conditions, "Spatial Reconstruction Model" is proposed in this section. The basic concept of the model and three types in connection with damage rank are shown in Figure 6.



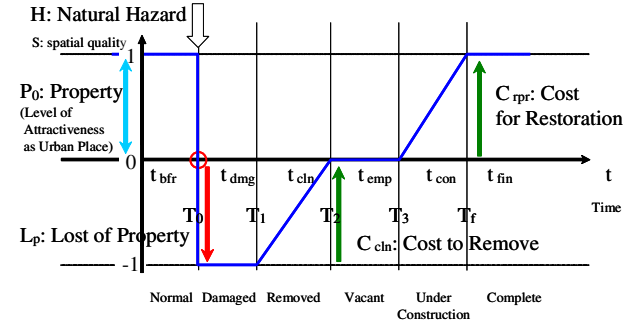
(a) Basic concept



(b) for a slightly (or no) damaged building



(c) for a moderately damaged building



(d) for a severely damaged building

Figure 6: Spatial Reconstruction Model

The author would like to mention the basic concept at the beginning. There are plural public place and facilities as regional spatial resources in one area. Although each public facility actually has own properties (e.g.: use, function, materials, etc.), it is not discussed here and this study deals with "Spatial Quantity Unit (as spatial quality)" as a measure for the reconstructional conditions. The "Spatial Quantity Unit" is defined as follows.

- 1) "Spatial Quantity Unit" is 1 in case of the building completed (before the earthquake or after the completion of the construction).
- 2) "Spatial Quantity Unit" is 0 in case of vacant lot after complete the removal of the debris.
- 3) "Spatial Quantity Unit" is -1 when the debris should be removed to be used.
- 4) "Spatial Quantity Unit" ranges from -1 to 1.

In the Figure 6, the value of the "Spatial Quantity Unit" is taken in the vertical axis. The time in the horizontal axis is indicated as follows; T_0 is the point of the event, T_1 is the starting point for the removal of the debris, T_2 is the point when the removal is completed and it begins to be the vacant lot, T_3 is the beginning point of the reconstruction or the repair, and T_f is the point of the building construction completed. Thus, it becomes possible to describe the situation of the reconstruction of each public space.

Concept of Spatial Reconstruction Model for a slightly (or no) damaged building

"Slightly damage" in this study is defined less than 20% damage according to "Japanese standard for the damage authorization". Figure 6 (b) shows that a building, which have had "Spatial Quantity Unit" 1, was damaged slightly due to a hazard at the point T_0 in time and was repaired to the state 1 in the short time. In the case of "No damaged building", it keeps "Spatial quantity unit" 1 all the time.

Concept of Spatial Reconstruction Model for a moderately damaged building

"Moderate damage" means less than 50% damage. This 50% damaged building cannot be used as a facility with 50% function until the end of removal debris. At the point of T_3 the construction for repair begins from the spatial quantity unit value of 0.5 as in Figure 6 (c).

Concept of Spatial Reconstruction Model for a severely damaged building

Except the traditionally valuable buildings such as Chi-Chi station, the severely damaged buildings basically need to be destroyed and to be reconstructed. Hence "severely damage" means 100% loss of the function. However, the spatial quantity unit value of those buildings just after the event is not 0, which means "vacant", but -1. Because it is necessary to spend money and time in order to make it "vacant" in Figure 6 (d).

Concept of Spatial Reconstruction Model for facilities related to regional reconstructional activities

Facilities described above are existed before the event and take a course from damage to reconstruction. However in the process of recovery and reconstruction, another kind of public space related to regional reconstructional activities is constructed. This study also deals with those facilities apart from the existed facilities. For example, a temporary housing area appears with the spatial quantity unit value of 0 when the government office gets the site, and it acquires 1 at the point of construction completed in time.

Applying of the Spatial Reconstruction Model to Public Space and Buildings in Chi-Chi

In this section "Spatial Reconstruction Model" is applied to the public space and buildings in Chi-Chi listed in Table 2 and the reconstructional process are discussed. The 41 facilities in Table 2 are classified into four categories. The author made each "Spatial Reconstruction Model" for the period of 1,493 days from one month before the earthquake in 1999 to September 21st of 2003 according to the damage type. The average of "Spatial Quantity Unit" for each damage type was also taken as well as the average of all of the public space. The changing of the reconstructive conditions in the objective area are displayed with some noteworthy events in Figure 7.

"The other" (slightly damaged and no damaged) became restored to the value of 1 within a few months after the earthquake, and when "the moderately damaged" became 1 is 1230 days later (February, 2003). Restored condition of "the severely damaged" is only 80% at the point of September 21, 2003. The curve of "the facilities for reconstruction" frequently changes. A part of the reason is because it includes the temporary housings which were constructed at first, demolished, and constructed again for new parks. It also includes the reconstructive housings and the other important places for the tourist industry of Chi-Chi. The bold line indicates the comprehensive reconstructional condition of all of the public space in Chi-Chi. It can be seen that the restored condition of Chi-Chi is 40% at the point of 2 months later, 50% at the point of 1 year later, 75% at the point of 2 years later, and 80% when the 4 years passed. This result corresponds to mentions by officers of Chi-Chi the author met in the hearing investigations.

The above description is about the reconstructional condition for the view point of "Spatial Quantity Unit" which means qualitative changes. On the other hand each facility has substantial space and it can be expressed using the measurement of floor space. Considering the floor space of all of the facilities in Table 2, "Spatial Reconstruction Model" from the view point of substantial spatial quantity was also made as shown in Figure 8.

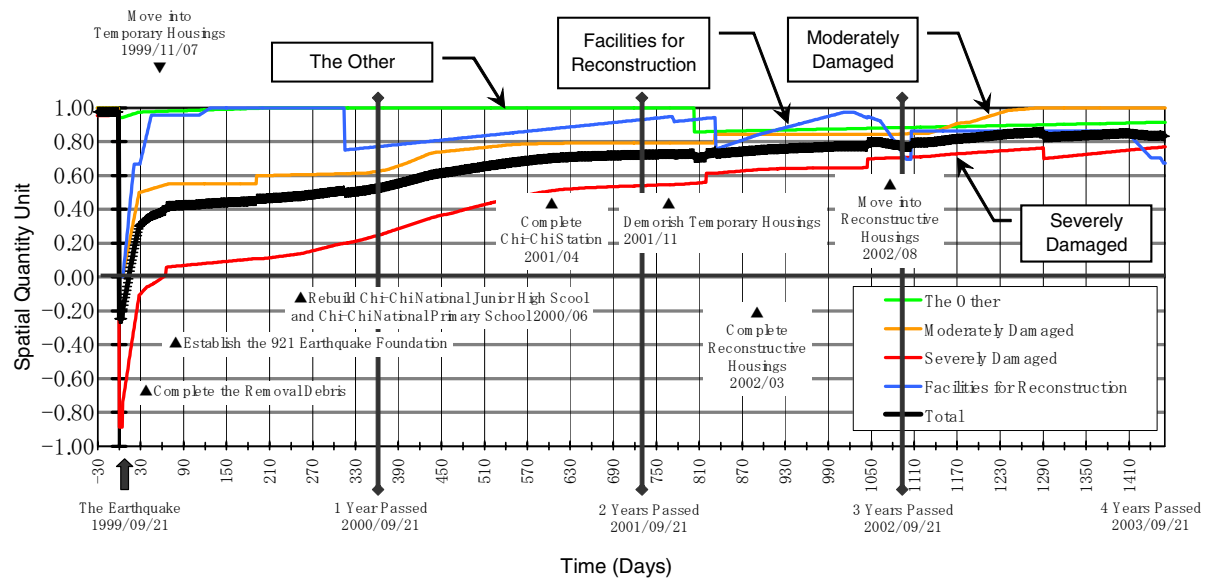


Figure 7: Spatial Reconstruction Model of public space in Chi-Chi area from the view point of spatial quantity unit

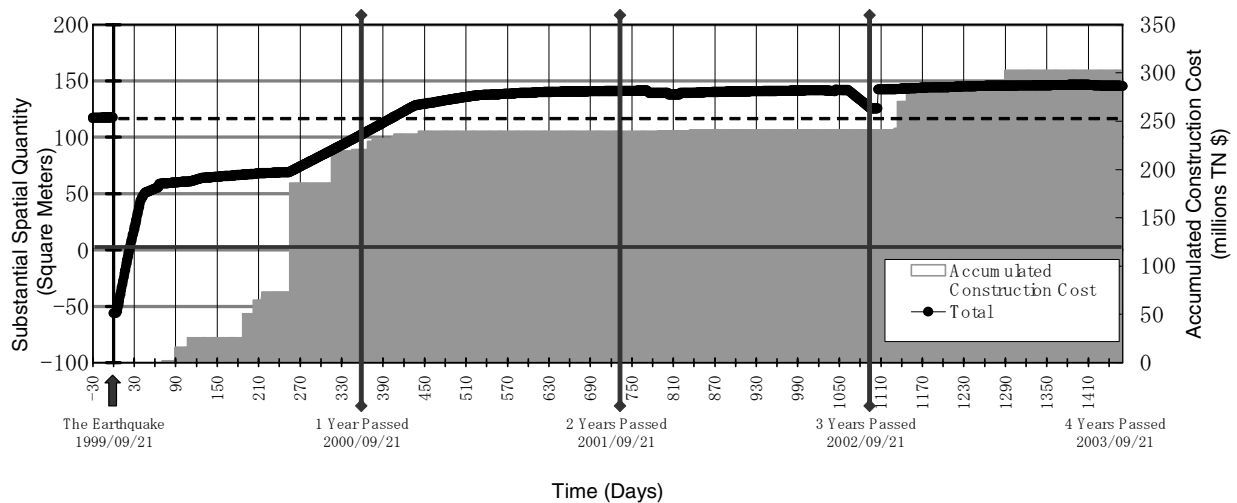


Figure 8: Spatial Reconstruction Model of public space in Chi-Chi area from the view point of substantial spatial quantity

It describes that the total area of space which was formerly 117,000 m² increased to 145,000 m² after the earthquake. This is because the government acquired some land properties for the regional significant facilities like space for the temporary housings. Accumulated construction cost the government spent is also shown in Figure 8. This cost rapidly increased about nine months later after the earthquake and contributed to the recovery of Chi-Chi.

As above we were able to make the complicated reconstructional conditions of Chi-Chi visualized using the proposed "Spatial Reconstruction Model".

CONCLUSIONS

The authors conducted design surveys to grasp location and dimensions of all of the buildings on purpose to make a GIS database in Chi-Chi. This paper contains some recent condition and the reconstructional process based on the obtained data sets, materials, and information as follows:

- 1) Overview of Chi-Chi and damage due to the 1999 Chi-Chi Earthquake were reported based on the obtained materials.
- 2) "Essential City Planning and Policy for Reconstruction" by the Chi-Chi governments were introduced.
- 3) Using "Chi-Chi GIS database", which has been constructed by the author based on IKONOS, the recent condition of recovery and reconstruction in Chi-Chi area was reported.
- 4) "Spatial Reconstruction Model" to represent condition of physical environment of an area after the Earthquakes was proposed
- 5) "Spatial Reconstruction Model" was applied to public space and buildings in Chi-Chi area.

The most remarkable portion of the contents was the proposal of "Spatial Reconstruction Model". It is difficult to quantitatively perceive reconstruction process of a damaged city and to compare the reconstructive condition with the previous one before the earthquake. As the result of the study the author was able to make the complicated reconstructional conditions of Chi-Chi visualized using the proposed "Spatial Reconstruction Model". This method can be useful in future research to compare recovery process of damaged areas due to natural disasters in the World which have different social background.

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