J Hous and the Built Environ
https://doi.org/10.1007/s10901-018-9602-9

ARTICLE

A measurement framework of community recovery to earthquake: a Wenchuan Earthquake case study

Jie Liu[1] · Di Lu[2] · Yong-liang Wang[3] · Zhen-wu Shi[1]

Received: 27 April 2017 / Accepted: 23 February 2018

Abstract This paper builds a measurement framework of community recovery to earthquake as a way to measure the recovery capacity and performance of local government. First, the paper examines and documents the concept of community recovery to summarize the evidence on dimensions and indicators of community recovery. And four dimensions of community recovery—population, economy, building, and infrastructure, are established on the basis of interviewing the organizational specialists on post-disaster recovery and reconstruction. Second, this paper extents the concept of the resilience triangle to propose a two-stage stochastic program for building a measurement framework of community recovery. Third, this measurement framework is demonstrated for Wenchuan Community, China, in the context of earthquake. The results illustrate that the four dimensions of Wenchuan Community achieve vastly different recovery levels, and the economy has the lowest recovery level, which provides a robust basis to prioritize dimensions of community recovery, and reinforces the vital role and position of local governments in improving the community recovery.

Keywords Community · Recovery indicator · Measurement framework · Earthquake · China

1 Introduction

The damaging earthquake risk of communities as the most devastating in terms of impact, but not in terms of likelihood, has specifically increased over the years due to the increasing complexities in built environments and a high concentrated urbanization in seismic

✉ Zhen-wu Shi
shizhenwu@126.com

[1] School of Civil Engineering, Northeast Forestry University, Harbin, China

[2] Corporate Financing Department, GuoDu Securities Co., Ltd, Beijing, China

[3] Harbin Power System Engineering & Research Institute Co., Ltd, Harbin, China

Published online: 09 March 2018

risk-prone areas (Peacock et al. 2008; Olshansky and Chang 2009). The growing large-scale devastating effects caused by recent catastrophic earthquakes (e.g., August 15, 2007, Peru; May 12, 2008, Wenchuan, China; January 12, 2010, Haiti; March 11, 2011, Honshu Island, Japan) have attracted the attention of the policy makers to formulate effective risk prevention policies. Some researchers assert that a disaster-resilient community has the ability to cope with the earthquake disasters. And the recovery, which is a fundamental dimension of resilience, can improve the inherent genetic or behavioral characteristics of the communities to better adapt to earthquake disasters (Mooney 2009). The National Disaster Recovery Framework, which is developed by FEMA (2011), defines the recovery as "those capabilities to assist the affected communities to recover effectively, including, but not limited to, rebuilding infrastructure systems, providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources". And community recovery has traditionally taken on a more outcome-oriented conceptualization "the outcome of several sets of activities, such as restoring basic services to acceptable levels, replacing infrastructure capacity that is damaged or destroyed, rebuilding or replacing critical social or economic elements of the communities that are damaged or lost, and establishing or reestablishing relationships and linkages among critical elements of the communities" (Alesch et al. 2009). There is currently much of the research literature proposed to measure the community recovery, which has provided two major aspects: (1) returning to pre-disaster conditions and (2) obtaining new normal situations (Chang et al. 2011). The first aspect emphasizes the comparison of the community condition before and after the earthquake disasters, which recovers to the pre-disaster conditions (Sherrieb et al. 2010). In this sense, the pre-disaster condition of the community is used as the normal status. The rapid recovery process is designed to minimize the recovery time (Alesch et al. 2001). The second aspect highlights the community should recover to a new normal status after an earthquake disaster. The idea of "build back better" (Lyons et al. 2010) or "recover better" is more applicable, indicating the evolution of the development of communities, which is especially indeed possible in the case of developing countries (Mulligan and Nadarajah 2012), because recovery is a multi-dimensional process, encompassing post-disaster activities to rebuild, restore, and reshape those negative physical, social, economic, political, and natural environments, which provides an opportunity for local government to justify the implementation of proactive mitigation strategies and to learn from the previous experience to increase future resilience (Reddy 2000; Birkland 2006).

In the recovery process of Wenchuan Community, Chinese Central Government has invested and implemented many recovery programs. The local government was the concrete implementer of these recovery programs, which has played a significant role in the reconstruction and recovery of Wenchuan Community. How to compare these recovery programs? How to quantify the efficiency of these recovery programs? How to determine whether communities are becoming more resilient after these recovery programs? The development of standards and metrics for Chinese Central Government to measure the recovery capacity and performance of the local government remains a challenge. To address these questions, our paper aims to (1) produce a measurement framework for developing four dimensions of community recovery through summarizing a diverse range of related literature and interviewing the organizational specialists, and (2) measure the recovery level and analyze the recovery process of four dimensions of community in application of the resilience triangle theory. This measurement framework is demonstrated to measure the recovery of Wenchuan Community (China) to Wenchuan Earthquake. Wenchuan Community is a typical rural community of the most developing countries, such as China, which is prone to earthquakes due to its poor quality and ill-maintained infrastructure, high-density and low-income individuals, particularly low-quality building stock without seismic design. So many other earthquake-prone rural communities in developing countries will face with the similar challenges, and the recovery process of Wenchuan Community provides an important opportunity to learn how it can be influenced by the decisions of the local governments to deal with post-disaster scenarios. So the intended outcome of this paper is to build a measurement framework of community recovery to earthquake in four dimensions, which is a prerequisite for helping and directing planning and mitigation initiatives to reduce the destruction and disruption effects in the event of earthquakes.

2 Study area

Wenchuan Earthquake was occurred in Wenchuan Community, Sichuan Province of China, at 14:28 on May 12, 2008, which was a magnitude of 8.0 Ms (the surface-wave magnitude) and 7.9 Mw (the moment magnitude from U.S. Geological Survey). As of June 12, 2008, this earthquake had killed 69,159 people, injured 374,141, and missed 17,469 people, which is the most destructive earthquake since the founding of the People's Republic of China. And Wenchuan Community was the epicenter of this earthquake, which was one of 18 worst-hit communities (e.g., Beichuan, Shifang, Mianzhu, Qingchuan, Mao, An, Dujiangyan, Mingwu, Pengzhou). But Chinese Central Government invested 1 trillion yuan ($157.7 billion) to implement a large number of reconstruction and recovery programs. Just for Wenchuan Community, the reconstruction and recovery programs of the national plan are more than 4000 with the total investment of 40 billion yuan ($ 6.3 billion), which were constructed from May 12, 2008, to May 12, 2011. The recovery process of Wenchuan Community is shown in Fig. 1.

3 Data and methods

3.1 Data sources

The detail data of the recovery processes of Wenchuan Community were mainly obtained from our discussion paper (Jie et al. 2017). Beside that, we conducted a detailed

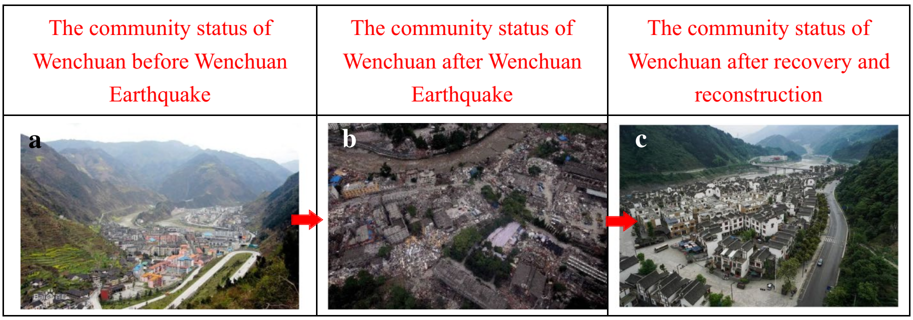

Fig. 1 Recovery process of Wenchuan Community between May 12, 2008, and May 12, 2011

questionnaire survey with 1000 affected families from 10 resettlement sites in order to collect the data to describe the recovery process and measure the recovery score of the population (in the case of the affected people). The remote sensing image of the settlements was the multispectral fusion image of Fuwei, TerraSAR, and AS7ER satellites, which are shown in Fig. 2. These settlements were on the Minjiang River coast and located around Wenchuan Community. And most affected families were concentrated in there. During the questionnaire and interview, the investigators only selected one person from each affected family. Using the data collected from 1000 persons of 1000 affected families, we identified the recovery characteristics of the population of Wenchuan Community, and the analysis results are further carried out in Sect. 4.1 and shown in Fig. 7.

The detailed data of the reconstruction processes of buildings and infrastructure of Wenchuan Community were also obtained from our discussion paper (Jie et al. 2017). Beside that, we performed mail surveys then follow-up in-person interviews with representatives of national and local governments and nongovernmental organizations who participated in the reconstruction programs to gather more detailed information. For example, the critical infrastructure of the interviewed settlements such as the emergency water supply, telecommunications, electricity, and roads was recovered, respectively, on May 13, May 15, May 17, and August 12, 2008. And the earthquake-affected buildings which were repaired and rebuilt by 501 reconstruction programs with the total investment of 22.177 billion yuan ($ 3.5 billion) were implemented after the Wenchuan Earthquake. Between 2008 and 2011, these reconstruction programs had been completed by 19, 53, and 94.7% in each year. In 2012, all of these 501 reconstruction programs were completed. We evaluated the effect of these reconstruction programs in terms of buildings and infrastructure recovery. And other information and data were gathered by combining different sources, and the data sources are shown in ‘“Table 1 in Appendix.” This information and data were first standardized by dividing the value of each core dimension and indicator in each neighborhood by maximum block value, and then the standardized values were integrated into a coherent database.

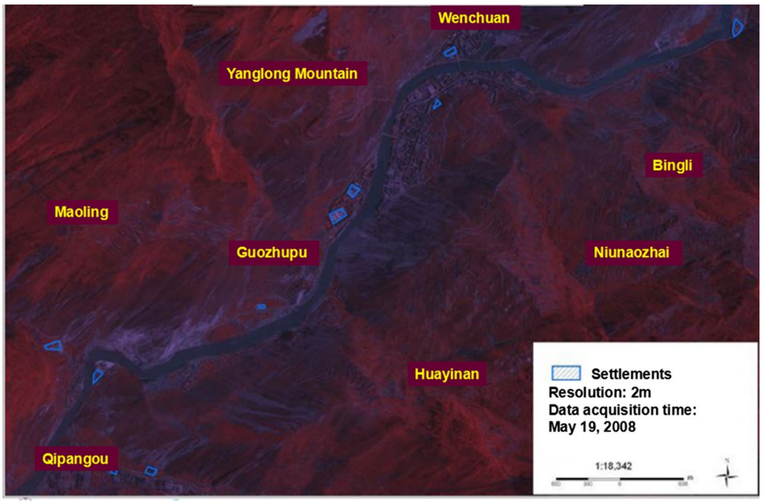

Fig. 2 Geographic location of the interviewed settlements of Wenchuan Community (Source: Digital Library of National Geological Archives of China)

3.2 Building a measurement framework of community recovery to earthquake

In the initial research, the indicator of recovery time has been widespread applied in the literature as a means of understanding how and by what means communities to respond to and recover from catastrophic events. For example, in the "resilience triangle" (Tierney and Bruneau 2007), the term of R (loss of resilience) can be used to measure the resilience by loss of functionality (or quality), which is characterized by the extent of disruption and recovery time. From t_0 to t_1, as indicated in Fig. 3, the recovery curve, which is represented by the recovery time, can illustrate the dynamic recovery process of the community. Mathematically, it is defined by

$$R = \int_{t_0}^{t_1} (100 - Q(t))\mathrm{d}t \tag{1}$$

where R is the resilience score which presents the loss of the functionality of the community, t_0 is the time point when the earthquake occurs, t_1 is the time point when the functionality of community is fully recovered, $Q(t)$ is the functionality function of the community which is a non-stationary stochastic process and each ensemble is a piecewise continuous function, and t is time.

The indicator of recovery time, which can be used to measure the community recovery simply, directly, and quickly, is strictly connected to the functionality of community (the vertical axis). Therefore, in order to exclude this influence, our paper uses the indicator of recovery speed which refers to the rapidity as the capacity to meet priorities and achieve goals in a timely manner after earthquake, to measure the community recovery. This is based on the concept of community recovery which has been proposed by us in a discussion paper (Jie et al. 2017). Figure 4 shows the measurement framework of community recovery to earthquake. In Fig. 4, the impact of the earthquake can be represented by the comparison between "with-earthquake" and "without-earthquake" scenarios. And the recovery process can be interpreted by the comparison between "pre-disaster" and "post-disaster" status of community, which always assumes that the pre-disaster status is 'normal' and static. Therefore, in the without-earthquake scenarios, $Q(t)_0$ (the functionality function of community) is plotted as the horizontal straight line over time. In the

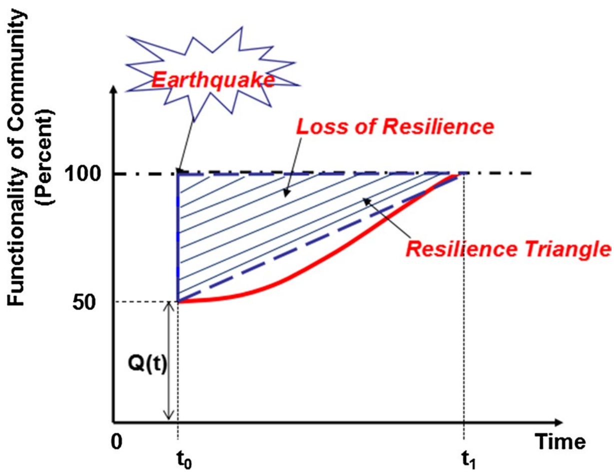

Fig. 3 Concept of resilience triangle

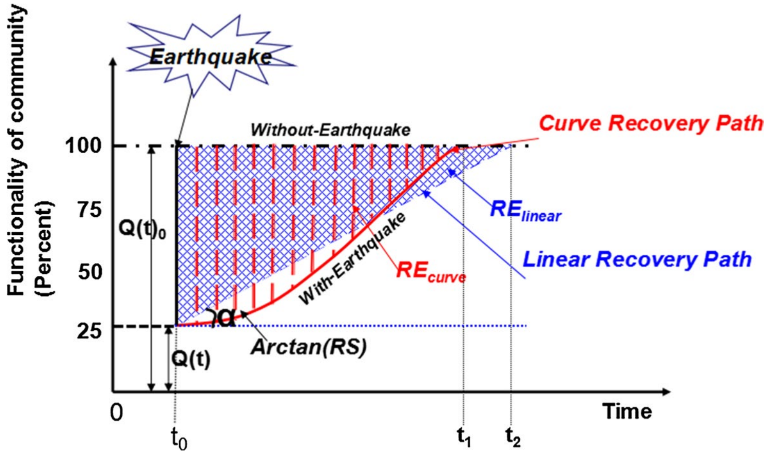

Fig. 4 Measurement framework of the community recovery to earthquake

with-earthquake, $Q(t)$ (the functionality function of community) is plotted as the fluctuation curve over time. The earthquake occurs at the time point of t_0, and the total functionality of community is restored at time t_1. The slope of the recovery curve illustrates the speed of the recovery process. Finally, the resilience triangle is the normalized shaded area above the curve recovery path.

However, measuring the community recovery by quantifying the slope of the recovery curve is very difficult, because in practice, the recovery process is always evolving due to the unstable change of the recovery speed. In order to facilitate the calculation, in this paper, we assume a static recovery analysis that the performance of the community recovery is a constant line and it is measured by a static quantity. So the linear recovery path can be approximately equivalent to the curve recovery path. The three key variables of the resilience triangle are particularly meaningful for measuring the community recovery. The first is the functionality function of community [$Q(t)_{\text{curve}}$, $Q(t)_{\text{linear}}$], which presents the loss of the functionality of community after the earthquake. The second is the length of the recovery time (t_1–t_0, t_2–t_0). The third is the recovery score (presented by the value of recovery speed), which is approximately equal to the slope of the linear recovery path. Based on the notation, the measurement framework of community recovery is formulated by two stages:

First stage:

$$R_{\text{curve}} = \int_{t_0}^{t_1} \left[100 - Q(t)_{\text{curve}}\right] \mathrm{d}t \tag{2}$$

$$R_{\text{linear}} = \int_{t_0}^{t_2} \left[100 - Q(t)_{\text{linear}}\right] \mathrm{d}t \tag{3}$$

where R_{curve} and R_{linear} are resilience score which presents the loss of the functionality function of the community in the curve and linear recovery path, respectively; $Q(t)_{\text{curve}}$ and $Q(t)_{\text{linear}}$ are the functionality function of the community in the curve and linear recovery path, respectively; t_0 is the time point when the earthquake occurs; t_1 and t_2 are the time points when the functionality of community is fully recovered in the curve and linear recovery path, respectively.

Second stage:

$$R_{\text{curve}} = R_{\text{linear}} \tag{4}$$

$$t_2 = \frac{2 \times \int_{t_0}^{t_1} \left[100 - Q(t)_{\text{curve}}\right] \mathrm{d}t}{100 - Q(t_0)_{\text{linear}}} \tag{5}$$

$$\text{RS} = \tan \alpha = \frac{100 - Q(t_0)_{\text{linear}}}{t_2} = \frac{\left(100 - Q(t_0)_{\text{linear}}\right)^2}{2 \times \int_{t_0}^{t_1} \left(100 - Q(t)_{\text{curve}}\right) \mathrm{d}t} \tag{6}$$

where RS is the recovery score; α is the tangent angle of the linear recovery path; $Q(t_0)_{\text{linear}}$ is the functionality function of the community in the linear recovery path.

3.3 Core dimensions and indicators of community recovery

The core dimensions and indicators of community recovery were selected by individual interviews. The purpose of our paper is to help Chinese Central Government measure the recovery capacity and performance of local government of Wenchuan. So we attempted to conduct a total of 15 face-to-face interviews with 20 experts who were the organizational specialists on post-disaster recovery and reconstruction of National Workplace Emergency Management Center. Appropriate experts were identified on the basis of their professional roles, and they were the experts with the knowledge and experience to provide the expert judgments sought. They all clearly understood which aspects of the community recovery were most concerned by Chinese Central Government, and they can choose the most representative dimensions and indicators to significantly reflect the recovery capacity and performance of local government. Core dimensions and indicators of community recovery were broadly captured in three main stages: First, the dimensions were developed from a systematic analysis of much theoretical framework of community recovery in the literature, which gathered the potential dimensions and indicators for measuring community recovery; second, the experts judged all the potential dimensions and indicators to select the most important core indicators of each dimension; and last, four core indicators are summarized and identified by the experts in defining four core dimensions of community recovery. The four core indicators which were selected to constitute the measurement framework of community recovery to earthquake were included: (a) population recovery as a form of the recovery speed of the interviewed affected families; (b) economic recovery as a form of the recovery speed of gross domestic product (GDP); (c) building recovery as a form of the recovery speed of damaged or destroyed buildings; and (d) infrastructure recovery as a form of the recovery speed of critical infrastructure system (e.g., electricity, roads, telecommunications, and water supply).

4 Results

In the result of our study, by using the measurement framework of community recovery proposed in Sect. 3.2, we calculated the scores of population recovery, economic recovery,

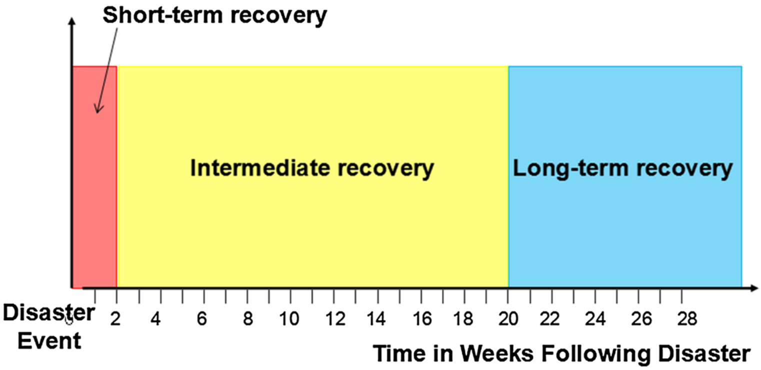

Fig. 5 Three interrelated phases of recovery process

building recovery, and infrastructure recovery of Wenchuan Community, respectively. The recovery scores of these four dimensions were then ranked and divided into three levels: When the recovery score RS was in the internal (0–0.577) and the tangent angle α was in the internal (0°–30°), it belonged to the low-recovery level; when the recovery score RS was in the internal (0.577–1.732) and the tangent angle α was in the internal (30°–60°), it belonged to the medium-recovery level; when the recovery score RS was in the internal (1.732– $+\infty$) and the tangent angle α was in the internal (60°–90°), it belonged to the high recovery level. Among the four dimensions, the economic recovery with the recovery score $RS_{economy} = 1.15$ reached the minimum value, which belonged to the medium-recovery level. But the infrastructure recovery with the recovery score $RS_{infrastructure} = 135.19$ reached the maximum value, which belonged to the high recovery level. The population recovery and the infrastructure recovery were relatively high as well. And the recovery and reconstruction processes of four dimensions were often described as having three interrelated phases (shown in Fig. 5) due to the time phases of community recovery proposed by NRC (National Research Council) (2006): (1) Short-term recovery (< 2 weeks), it "addressed the health and safety needs beyond rescue, measured the scope of damages and needs, restored the basic infrastructure, and mobiled the recovery organizations." (2) Intermediate recovery (2–20 weeks), it involved "taking temporary activities to return individuals, families, critical infrastructure, and essential government or commercial services to a functional, if not pre-disaster, state." (3) Long-term recovery (> 20 weeks) was the phase "that may continue for months or years to complete redevelopment and revitalization of the impacted area, rebuild or relocate damaged or destroyed social, economic, natural, and built environments."

4.1 Analysis of the population recovery of Wenchuan Community

Damaging earthquakes occurs more in highly populated and vulnerable areas, which have a major effect on the nation as a whole. It emphasizes the need to understand the detailed knowledge of the natural and the built environments, as well as the earthquakes and human behaviors. The trend of rapid urbanization induces the exponential rise in the urban exposure to seismic hazards, but it also increase the capacity to reduce such negative effects to increase our population recovery to earthquake. Figure 6 plots the recovery process and score of population of Wenchuan Community. After Wenchuan Earthquake, the percent

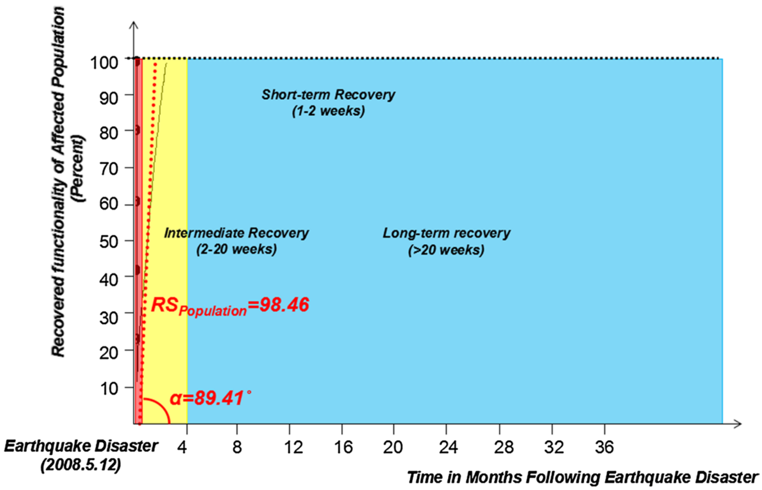

Fig. 6 Process and score of population recovery of Wenchuan Community

of dead, injured homeless, and missing people is more than 80%. But the affected population displayed a rapid recovery, it only took less than 3 months to regain their normal life. The analysis of the interviewed data is conducted to examine the recovered patterns of the affected population after Wenchuan Earthquake. In Fig. 6, the red dotted line shows the approximate recovery process of affected population, and the black curve shows the actual recovery process of the affected population, which is calculated by the measurement framework we proposed in Sect. 3.2. The recovery score of the population $RS_{population}$ is 98.46, and the tangent angle α is 89.41°, which belongs to the high recovery level. So in the intermediate recovery period, the affected population has been completely recovered, which is mainly due to the most aggressive recovery activities conducted by the Chinese Central Government. About 1.2 million relief tents were built, and more than 800 tons of military food and supplies, 6380 tons of fuel were transported to the damaged area. The built of many settlements encouraged relocation of population from areas where earthquake is likely and retreat from damaged areas.

4.2 Analysis of the economic recovery of Wenchuan Community

Economic recovery refers to the capacity to make full use of the internal and external resources to accelerate the recovery of the economic function to a desired state. The local economic status works indirectly on how rapidly a community can recover from earthquakes by affecting the availability of economic resources for post-disaster response and recovery (Lee 2014; Anne and Adam 2011). Figure 7 provides a summary view of the process and score of economic recovery of Wenchuan Community. And gross domestic product (GDP) is used as a basic flow indicator of economic production or output. After Wenchuan Earthquake, the devastating loss of GDP of Wenchuan Community has been up to 77.47% of the pre-disaster status. The main reason of the significantly economic damage is the increased economic complexity and interdependency. Black curve shows the actual GDP of Wenchuan in 10 years after Wenchuan Earthquake. Statistical analysis here shows that GDP of Wenchuan Community has experienced an accelerated decrease within

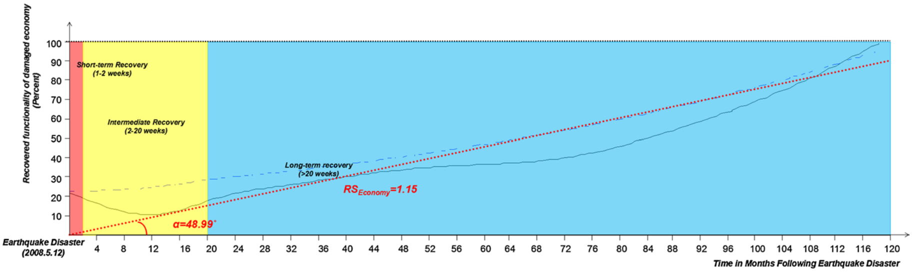

Fig. 7 Process and score of economic recovery of Wenchuan Community

the first year after Wenchuan Earthquake, which can be considered as the impact of the earthquake. Because after Wenchuan Earthquake, production activities in many sectors remained considerably lower than pre-disaster levels, including manufacturing, industry, and small businesses. Moreover, GDP of Wenchuan Community has increased quickly in the second and third years after Wenchuan Earthquake, which was due to the direct influence of the reconstruction. The reconstruction activities lasted for 3–4 years after Wenchuan Earthquake, which has brought a lot of capital investments. During this period, GDP of Wenchuan Community has experienced a temporary boost, but it was still not return to the pre-disaster economic status. However, when the temporary reconstruction activities have almost completed, GDP of Wenchuan Community has stabilized, even reduced again from the forth to sixth years after Wenchuan Earthquake. Then the highly influence of the earthquake on economy has gradually dissipated, and GDP of Wenchuan Community has received an extraordinary boost due to the steady increase in market demand and post-disaster improvement effort. But statistical data show that GDP of Wenchuan Community has only recovered to 60% of the pre-disaster level until 2016. So we assume that GDP of Wenchuan Community increased with an average rate of 25.2% per year which was the average growth rate of GDP between 2008 and 2016, and it will finally recover to the pre-disaster level in 2018. In Fig. 7, the red dotted line shows the approximate recovery process of the economy, and the black curve shows the actual recovery process of the economy, which is calculated by the measurement framework we proposed in Sect. 3.2. The recovery score of the economy $RS_{economy}$ is 1.15, and the tangent angle α is 48.99°, which belongs to the medium-recovery level, and its recovery level is lowest among the four dimensions. Some economic characteristics (lack of investment and finance, fragile industrial production chains, human resource deficiencies, low income per capita, limited access to economic resources) of Wenchuan has induced to such a long process of economic recovery. The economic recovery can be improved both in terms of the properties of local economies and in terms of their capacity for post-disaster improvisation and innovation. It is an important opportunity to integrate post-disaster recovery activities with economic development to affect the broader structural changes of economy, achieving the multiple objectives needed for a strong and diverse regional economy. The resilient economy does not only to return to the pre-disaster level of functionality by the 'pulling' effects of upward general economic forces or the fluctuations in macroeconomic and structural conditions, but also to increase the capacity of the economic support mechanisms, which is often defined by the level of a community's economic resources, the degree of equality in the distribution of a community's economic resources, and the scale of the diversity of a community's economic resources (Sherrieb et al. 2010).

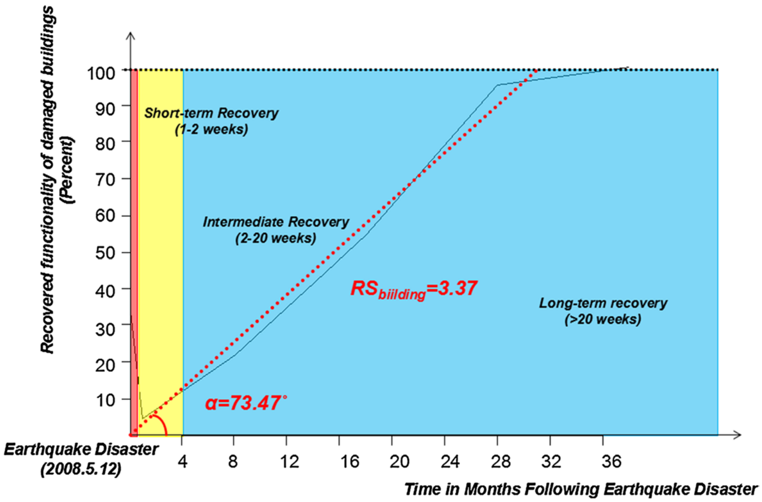

Fig. 8 Process and score of building recovery of Wenchuan Community

4.3 Analysis of the building recovery of Wenchuan Community

Buildings built without adequate consideration of the earthquake effects weaken the community recovery to earthquake. Figure 8 shows 3-year building recovery process of Wenchuan Community. More than 90% of the buildings were damaged, even destroyed in Wenchuan Community. These buildings may be seismically vulnerable because of the nonexistent or poorly regulated building codes, which were largely anthropogenic. The black curve plotted in Fig. 8 shows the actual repaired and reconstructed process of the buildings. It considers the repaired and reconstructed speed of the buildings is not a constant line. During the first 2 years, the recovery speed has increased, while it has decreased after that. And after 3 years, the destroyed buildings were all repaired and reconstructed. With the financial support and planning guidelines from the Chinese Central Government, the local government was almost equivalent to build a "new" Wenchuan Community just over 3 years. In Fig. 8, the red dotted line shows the approximate recovery process of the building, which is calculated by the measurement framework we proposed in Sect. 3.2. The recovery score of the building $RS_{building}$ is 3.37, and the tangent angle α is 73.47°, which belongs to the high recovery level. Building recovery indicates the capacity of a community to take on board resilient technologies to rebuild and retrofit these earthquake-resistant buildings, which can provide a safer built environment for the communities. So the replacement reconstruction period was the time in directing new development away from hazardous locations and strengthening buildings through seismic standards and building codes. Based on utilizing construction practices and technology, it may be better for some architectural practices to specialize in earthquake-proofing existing and new structures of building codes and engineering design.

4.4 Analysis of the infrastructure recovery of Wenchuan Community

Critical infrastructure system refers to those infrastructure elements in dependent systems or organizations, which not only responds to the needs of society for the smooth daily

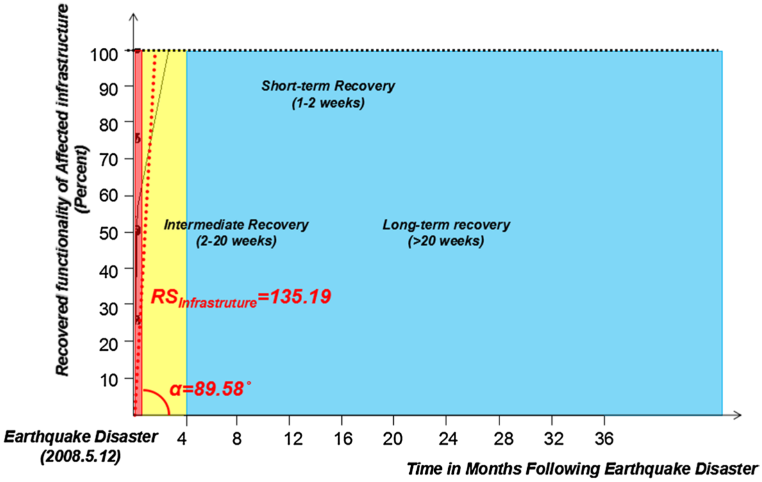

Fig. 9 Process and score of infrastructure recovery of Wenchuan Community

continuation of activities, but also provides the basis on which society exists and relies. It is therefore critical for sustaining and maintaining a community's economy and security and must be recovered as rapidly as possible from disruption of service in post-disaster time. Figure 9 shows the recovery process and score of infrastructure of Wenchuan Community. All of the critical infrastructure elements were disrupted and destroyed in the immediate aftermath of Wenchuan Earthquake. Their functionality is continually challenged by the aging process, the poor quality, and constrained resources. Focusing on the reconstruction and mitigation post-disaster phases, the improvement in critical infrastructure system recovery is not simply on the temporary fix that usually takes place immediately after the earthquake, but also involves restoration and hardening of the infrastructure in the intermediate recovery and long-term recovery (Kathleen et al. 2010; Whitman et al. 2013). After Wenchuan Earthquake, the critical infrastructure took 3 months to regain its pre-disaster levels. The water supply and telecommunications were recovered in short-term recovery period, and the electricity and roads were recovered in the intermediate recovery time period. It illustrates that the recover trend of the infrastructure is considered to be the fastest among the four dimensions, shown in black curve of Fig. 9. The red dotted line shows the approximate recovery process of the infrastructure, which is calculated by the measurement framework we proposed in Sect. 3.2. The recovery score of the building $RS_{\text{infrastructure}}$ is 135.19, and the tangent angle α is 89.58°, which has the highest recovery score of the four dimensions. And it belongs to the high recovery level. The critical infrastructure system is a complex system in that the dynamic is the metric to reveal a high degree of interconnectedness and interdependency in system. These challenges and the desire to improve infrastructure recovery can be addressed by the type, condition, and performance of infrastructure, the geographic features, and the capacity for flexibility and adaptability after earthquakes, which is a priority goal for earthquake-resilient communities (Tierney and Bruneau 2007). And enhancing the defense design of infrastructure design played a vital role in optimizing mitigation, disaster planning, response, and recovery efforts of the communities to earthquake disasters (National Infrastructure Advisory Council 2010).

5 Discussion

What lessons do the case study of the recovery process of Wenchuan Community offer for planners and policy makers? Our findings emphasize that the local government plays a crucial role in fostering the community recovery. However, the recovery process of communities is mainly successful where local governments first have the knowledge and then grow the capacity to take actions. The overall results clearly highlight that the four dimensions of Wenchuan Community achieve vastly different recovery levels. To address this question, a recovery score was calculated for each dimension to determine whether or not a high level of recovery is achievable based upon the current post-disaster recovery strategies. Intuitively, the higher the recovery score, the higher the recovery level. The economic recovery had the lowest recovery score of the four dimensions at 1.15 (indicating the lowest recovery level) and the infrastructure recovery had the highest score at 135.19. The different recovery levels imply the pre-event inequality, exploitation, and vulnerability of the community. And the extent of damage, available recovery resources, social disparities, decision making, and organization capacity are also the decisive factors of the recovery levels. Therefore, the local government must learn how to balance the recovery rate of different dimensions in longer-term reconstruction. This inductive analysis of the community recovery can help the local government in building a comprehensive recovery prioritization system to effectively identify community priorities and allocate government resources. And this recovery process also needs to adapt to the broader environmental, social, and economic dynamics of the community. However, recovery is highlighted as best being achieved at the local level, and the design of recovery methods and strategies to be developed will depend on the community level of implementation. Our study also provides an in-depth understanding of the pivotal role of the national government. The high speed of recovery of Wenchuan Community suggests that the local government of Wenchuan Community has been successful in guiding, coordinating, and improving the recovery process. More importantly, the participation of national government can provide legislation, funding, and guidance for local government to deal with post-disaster recovery policy and program, which plays an important role in accelerating the recovery process at the local level (Satterthwaite 2011). In Wenchuan's long-term recovery process focused on the organizational aspect, Chinese Central Government provided a much number of financial (loans and gifts for property repair) and nonfinancial resources (post-disaster response efforts, emotional support, sheltering, information). And with the high-level support from the national government, the local government of Wenchuan Community incorporated long-term recovery goals into disaster response and pre-disaster planning, expanded the knowledge base by incorporating research into recovery and harnessing lessons learned from international experiences. These are all the key elements of successful recovery of Wenchuan Community.

6 Conclusion

Earthquakes induced high losses and extensive community disruption throughout China in the most recent years. The Wenchuan Earthquake (May 12, 2008), the Yushu Earthquake (April 14, 2010), and the Ya'an Earthquake (April 20, 2013) are only a few examples of recent devastating earthquakes, which is progressively giving high priority in efforts to enhance community recovery. The national and local government agencies have addressed their effects to attain deeper understanding of what makes the communities recover quickly from the earthquake damage. For purposes of this, the implementation of new concepts and methodologies of community recovery are aimed at facilitating and coordinating the effective post-earthquake recovery strategies; all contribute to abating the seismic risk and the potential for future losses. A measurement framework of community recovery to earthquake has been proposed and demonstrated in this paper, while implemented for a case of Wenchuan Earthquake. We defined community recovery as "the ability of communities to carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes." The objectives of enhancing community recovery are to minimize loss of life, injuries, economic losses, and other damages of building and infrastructure. So we addressed four dimensions (population, economy, building, and infrastructure) of the community recovery. By applying the measurement framework to Wenchuan Community, most dimensions represent the characteristics of a high recovery level that infrastructure has the highest recovery score, but the economy has the lowest recovery score. The results indicate that the recovery processes among different dimensions of Wenchuan Community are distributed unequally, which is a guiding planning for the local governments to improve response and recovery mechanisms to deal with future earthquake disasters. Our study can help Chinese Central Government measure the recovery capacity and performance of local government of Wenchuan Community, and some other similar communities. It also emphasizes that the determinants of community recovery are many, including earthquake impacts and disruptions, pre-disaster planning, post-disaster response efforts, socioeconomic status, and development trends, especially the formal external assistance of national governmental and the recovery capacity and performance of local government. While this paper has some contributions to advance the knowledge of measuring community recovery, it is clear that some limitations should be noted regarding the measurement framework developed here. First of all, since the conditions of each community vary as do the potential impacts of earthquake upon those localities, it is not discussed the application of this measurement framework at broader levels such as other potential earthquakes and other characteristics of communities. Second, measuring the recovery capacity and performance of local government could be the mainly purpose of this paper. The four core dimensions and indicators were selected by the organizational specialists to justify the community recovery (for example, using GDP to measure economic recovery). It is a dilemma to not consider other economic or social indicators, such as personal income, poverty, and unemployment. Third, time constraints and data limitation bring significant uncertainties into describing the recovery processes and measuring the recovery scores of four dimensions of Wenchuan Community. The measurement framework of community recovery is built based on mathematical statistical principles that require the input time series to be homogeneous and independent. But the data series collected by surveys, interviews, and other sources has significant approximations and uncertainties.

In our future research, it would be worthwhile to develop comparative insights on community-scale recovery. For example, quantitative indicators of community recovery should be used as a benchmark or reference for more in-depth study, which can be used systematically by local governments and researchers to monitor complex recovery processes. And validation may be possible in the future through expanded databases of the consequences of earthquakes for comparable regions, in order to give the operator a wider and deeper insight in the recovery patterns of different communities. Furthermore, the concept framework of community recovery should be evaluated and revised more efficiently and effectively by collecting and analyzing a large number of expert judgments. And considering long-term recovery and reconstruction, the framework should be extended in order to perform a dynamic measurement model of community recovery, where time-dependent indicators can be used to reflect post-disaster recovery capacity and performance of local government over time. Learning from the past recovery and rebuilding process, new research is needed to fully operationalize and realize the concept of recovery, and develop appropriate techniques of designing mathematical models to measure community recovery, which can help local government and policy makers develop the scientific and effective disaster recovery plan for the next devastating earthquake disaster.

Acknowledgements This work was supported by the National Natural Science Foundation of China under the Project Nos. 71601042 and 71603062, the Humanity and Social Science Youth Foundation of Ministry of Education of China under the Project Nos. 16YJC630071 and 16YJC630040, and China Postdoctoral Science Foundation Funded Project No. 2016M601401. We are thankful to editorial support (Editor Peter Boelhouwer, Queena Qian, and Naveen Parthiban) for their useful comments on the manuscript and three anonymous reviewers of Journal of Housing and Built Environment for their valuable advice.

Appendix

Table 1 Statistics and description data sources

Research report
Statistical report on the direct loss and quantity and the main hazard bearing body in Wenchuan Earthquake
Assessment report on the public health environment of the core area of Wenchuan in Wenchuan Earthquake
Investigation report on recovery of victims in Wenchuan Earthquake
Government report
Regulations on the reconstruction of Wenchuan Earthquake
Work plan for reconstruction of Wenchuan Earthquake
Main plan for reconstruction of Wenchuan Earthquake
Technical guide for reconstruction of highway of Wenchuan Earthquake
Support program on reconstruction of Wenchuan Earthquake
Action platform for twenty-year psychological assistance of Wenchuan Earthquake
Data collection from government agency
Earthquake relief leading group of Chinese Academy of Sciences
Working group on disaster reconstruction planning of Wenchuan Earthquake
Working group on remote sensing monitoring and disaster assessment of Wenchuan Earthquake Disaster
Data collection from website
Institute of Mountain Hazards and Environment, CAS
China Geological Survey
Institute of Geographic Sciences and Natural Resources, CAS
Institute of Geology and Geophysics, CAS

References

Alesch, D. J., Arendt, L. A., & Holly, J. N. (2009). *Managing for long-term community recovery in the aftermath of disaster*. Fairfax, VA: Public Entity Risk Institute.

Alesch, D. J., Holly, N., Mittler, E., & Nagy, R. (2001). *Organizations at risk: What happens when small businesses and not-for-profits encounter natural disasters*. Fairfax, VA: Public Entity Risk Institute Press.

Anne, W., & Adam, R. (2011). Economic resilience lessons from the ShakeOut earthquake scenario. *Earthquake Spectra, 27*(2), 559–573.

Birkland, T. A. (2006). *Lessons of disaster: Policy change after catastrophic events*. Washington, DC: Georgetown University Press.

Chang, Y., Wilkinson, S., Brunsdon, D., Seville, E., & Potangaroa, R. (2011). An integrated approach: Managing resources for post-disaster reconstruction. *Disasters, 35*(4), 739–765.

FEMA. (2011). *A whole community approach to emergency management: Principles, themes, and pathways for action*. Washington, DC: Federal Emergency Management Agency.

Jie, L., Zhenwu, S., Di, L., & Yongliang, W. (2017). *Measuring and characterizing community recovery to earthquake: The case of 2008 Wenchuan Earthquake, China*. Natural Hazards and Earth System Sciences, Discussion paper.

Kathleen, S., Fran, H. N., & Sandro, G. (2010). Measuring capacities for community resilience. *Social Indicators Research, 99,* 227–247.

Lee, B. (2014). Built-in resilience through disaster risk reduction: operational issues. *Building Research and Information, 42*(2), 240–254.

Lyons, M., Schilderman, T., & Boano, C. (2010). *Building back better: Delivering people-centred housing reconstruction at scale*. England: Practical Action Publishing.

Mooney, G. (2009). Problem populations, problem places. In J. Newman & N. Yeates (Eds.), *Social justice: Welfare, crime and society, Maidenhead* (pp. 97–128). London: Open University Press.

Mulligan, M., & Nadarajah, Y. (2012). Rebuilding community in the wake of disaster: Lessons from the recovery from the 2004 tsunami in Sri Lanka and India. *Community Development Journal, 47*(3), 353–368.

National Infrastructure Advisory Council. (2010). *A framework for establishing critical infrastructure resilience goals: Final report and recommendations by the council.*

NRC (National Research Council). (2006). *Facing hazards and disasters: Understanding human dimensions*. Washington, DC: The National Academies Press.

Olshansky, R., & Chang, S. (2009). Planning for disaster recovery: Emerging research needs and challenges. *Journal of Progress in Planning, 72,* 200–209.

Peacock, W. G., Kunreuther, H., Hooke, W. H., Cutter, S. L., Chang, S. E., & Berke, P. R. (2008). *Toward a resiliency and vulnerability observatory network: RAVON*. College Station, TX: Hazard Reduction and Recovery Center, Texas A&M University.

Reddy, S. D. (2000). Factors influencing the incorporation of hazard mitigation during recovery from disaster. *Natural Hazards, 22*(2), 185–201.

Satterthwaite, D. (2011). How urban societies can adapt to resource shortage and climate change. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369*(1942), 1762–1783.

Sherrieb, K., Norris, F. H., & Galea, S. (2010). Measuring capacities for community resilience. *Social Indicators Research, 99*(2), 227–247.

Tierney, K., & Bruneau, M. (2007). Conceptualizing and measuring resistance: A key to disaster loss reduction. *TR News, 250,* 14–17.

Whitman, Z. R., Wilson, T. M., Seville, E., Vargo, J., Stevenson, J. R., Kachali, H., et al. (2013). Rural organizational impacts, mitigation strategies, and resilience to the 2010 Darfield earthquake, New Zealand. *Natural Hazards, 69,* 1849–1875.