

Case Report

Investigation of Collapsed Building Incidents on Soft Marine Deposit: Both from Social and Technical Perspectives

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Abstract: A collapsed incident occurred on 10 October 2016 in Wenzhou City, China, which resulted in 22 casualties and 6 injuries. Most of victims were migrant laborers (rural dwellers who move to urban for a temporary work), who rented apartments in these residential buildings, which were originally constructed by local rural residents. This case report investigates the collapsed incident as well as other similar previous incidents. From the perspectives of both social and technical aspects, this report analyzed the Chinese rural land use policy with relevant technical factors. These incidents reveal social problems of the existing dual structure land-use policy in China. Chinese dual structure land-use policy caused deficiencies in the supervision of the construction market in rural area so that the following technical factors were not well supervised by the various quality control departments: (1) poorly quality of residential buildings, (2) unauthorized rooftop additions, and (3) differential settlement caused by the uneven distribution of underlying Wenzhou clay under creep conditions. Mandatory regulation by the government for any construction in China, particularly for the construction of self-constructed house building sites in rural areas, was recommended to minimize the resettlement issue of migrant workers.

Keywords: building collapse incident; rooftop addition; dual structure land-use policy; social problems; Wenzhou; China

1. Introduction

China is experiencing massive land use changes due to an unprecedented period of economic growth, which has catapulted it from one of the world's poorest countries 30 years ago to the world's second largest economy today. Since the 1950s, the Chinese social system enacted a dual structure land-use policy for urban and rural areas, which was initially aimed at the ease of land management [1,2]. This dual structure land-use policy resulted in a dichotomy between the residents of urban and rural areas [1,2]. The dual structure is beneficial for rapid initial industrialization of China, however, these discrepancies between urban and rural land use induced many social problems in recent years [3,4]. According to the Land Management Law of China [5], in rural areas, land is owned by the collective group, e.g., the village group and individual rural residents, who had the right of land use, which was separated from land ownership. Thus, rural lands are banned from land transfers unless the urban government has acquired the rural land. Urban land was owned by the state and became scarce with

the expansion of cities. To comply with the demands for urban land, an urban-rural unified land system was established in the 1980s [1,2]. The government in some provinces launched a new-round of land-policy reform to reduce the dichotomy between urban and rural areas. Social problems occurred frequently in this land-policy reform process.

With rapid urbanization, more and more people migrated from rural to urban areas, which led to the subsequent shortage of urban land in China. Figure 1 shows the urbanization rate of China [6]. As seen from Figure 1, the urbanization rate varied from 18% to 46% within the past three decades (from 1978 to 2008), during the period from 1978 to 2008. In 2013, the urbanization rate rose to 58%, and it is expected that this rate will reach 80% in the near future. At present, more than 50% cities are exhibiting the phenomenon of urbanization, as more and more people move to urban areas, particularly in the coastal cities of China. Rapid urbanization increases the construction of infrastructures, such as, roads, bridges, highway, and metro system [7–9] as well as development of residential areas. During the urbanization process, a rural village gradually develops into an urban village. The urban village in fact stands for “the village surrounded by urban, where the land has already changed its function as urban”. Urban villages are a phenomenon in the process of urbanization of Chinese cities [10,11]. Residential buildings in urban villages are built with poor quality control, often resulting in structurally unsound structures. In addition, migrant people from rural areas often have no place to live, and seek low rental accommodations in urban villages. Therefore, a large numbers of migrant laborers live in damaged buildings with illegal rooftop additions.

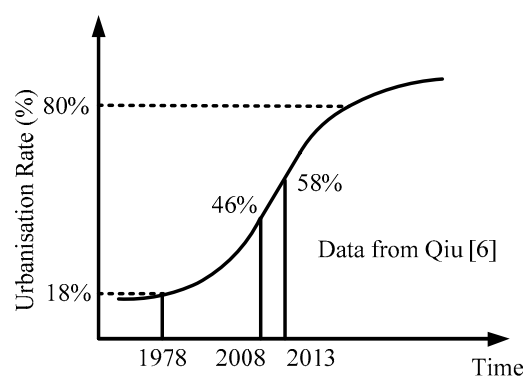


Figure 1. Variation of the urbanization rate for China.

According to Chinese government statistics, a total of 269 million rural migrants have migrated to urban cities since 2013 [12]. Residential buildings are in increasing demand to provide accommodation for rural migrants; therefore, many older residential buildings were constructed with unauthorized rooftop additions. Urbanization and economic migration of workers from rural to urban areas have altered the residential conditions, thus leading to increases in the number of man-made hazards [13,14]. These hazards include building collapses, urban waterlogging, land subsidence, water and soil pollution, and slope failures [15–18]. When the factors causing hazards due to human activity are not carefully controlled, catastrophic failures may occur. This case study report provides an investigation of collapsed buildings from the perspectives of social and technical problems and also provides guidelines for future urban planning in China.

Recently, three six-storey, and one two-storey, residential buildings occupied by migrant labourers in the city of Wenzhou in Zhejiang Province, China, collapsed suddenly at 3:25 a.m. on 10 October 2016 [19,20]. Figure 2 shows the site of the collapsed residential buildings located in the city’s industrial Lucheng District. A massive search and rescue operation was immediately initiated with over 600 people involved. Dozens of rescuers sifted through the rubble after the four residential buildings collapsed early on the morning of 10 October. Authorities dispatched heavy machinery to the site to remove the debris and search for survivors. At least 17 ambulances responded to take

the injured to local medical facilities. On 11 October, 22 people were confirmed dead and 6 were rescued including a three-year-old girl who was pulled from the wreckage on the evening of 10 October. A further 20 people were believed to be trapped under the rubble of the four collapsed residential buildings. Since Wenzhou is a major manufacturing hub for shoes and purses, its factories attract thousands of migrant workers from across the country. Thus, most of the victims were migrant workers. According to the government press conference on the preliminary investigation into the residential buildings collapse incident [19,20], the four residential buildings, which were located next to each other, had been constructed by rural workers during the 1970s.

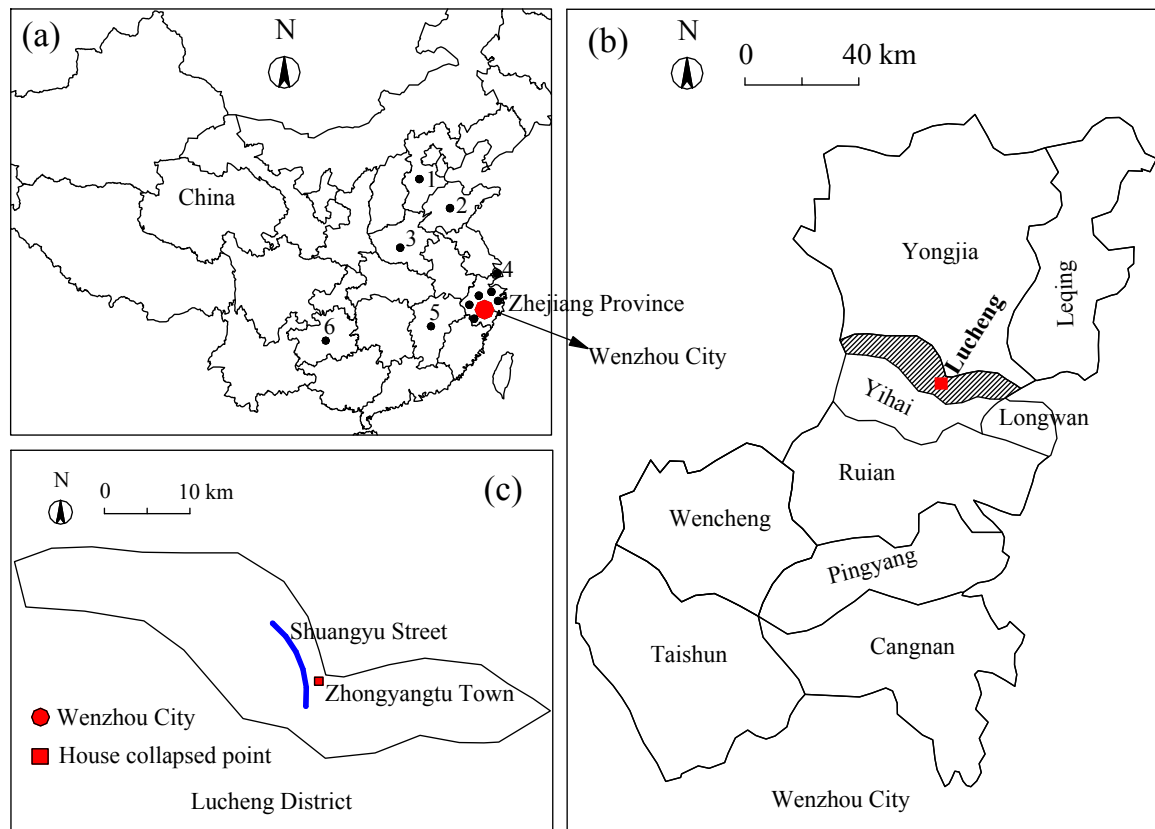


Figure 2. Location of the collapsed site on 10 October 2016: (a) collapsed sites (1: Hebei Province; 2: Shandong Province; 3: Henan Province; 4: Shanghai municipality; 5: Jiangxi Province; 6: Guizhou Province); (b) administrative zonation map of Wenzhou City; (c) detailed location of the site in Zhongyangtu Town, Lucheng District.

2. Methodology

2.1. Analytical Procedure

In order to analyze why this collapse incident, this case study summarizes previous collapsed incidents from 2009 to 2016 in China. According to the statistics of collapse incidents, the reason that induced this collapsed incident was analyzed both from the social and technical perspectives. Figure 3 shows the procedure for the analysis of the collapsed incident. To investigate the reason for these collapsed incidents, the Chinese rural land-use policy with relevant technical factors in Wenzhou City were analyzed. Based on the analysis, recommendations were made for future sustainable urban planning to minimize the resettlement of migrant workers.

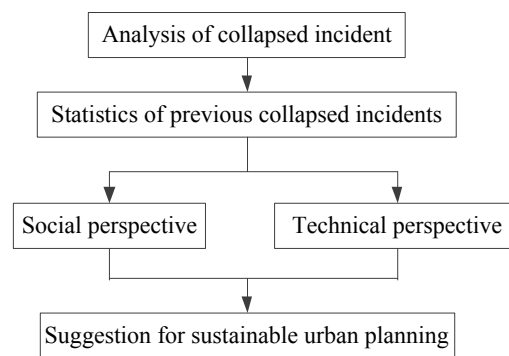


Figure 3. Procedure for the analysis of the collapsed incident.

2.2. Investigation of Collapsed Incidents

In recent years, there have been many collapsed building incidents in China. In 2009, a 13-story residential building founded on lightly reinforced prestressed high-strength concrete pipe piles in Shanghai collapsed completely during the excavation of an adjacent underground garage [21,22]. Table 1 lists collapsed building incidents from 2009 to 2016 (the provinces of the collapsed sites can be found in Figure 2) [19–23]. As shown in Figure 2, there are six collapsed incidents in Zhejiang Province from 2009 to 2016. As tabulated in Table 1, the construction dates of these collapsed buildings are mostly concentrated in the 1980s. The poor construction in that period is the primary reason that induced these collapsed incidents. In addition, these collapses mostly have unauthorized rooftop additions. For example, on 9 June 2015, a seven-storey residential building with a four-storey rooftop addition collapsed in Zunyi City, Guizhou Province, which caused four deaths and three injured [23]. There were also collapse incidents, one of which occurred on 27 August 2014 in Xinzhen City, Henan Province. The collapsed building was a seven-storey building with a three-storey rooftop addition, which was originally built in the 1970s according to website news [23].

Table 1. Incidents of residential collapse building from 2009 to 2016.

Incident Date	Location	Type of Collapsed Building	Casualties	Constructed Date
24 Oct. 2016	Heze City, Shandong Province	Self-constructed residential building	6 deaths, 7 injured	Under construction
10 Oct. 2016	Wenzhou City, Zhejiang Province	One two-storey and three six-storey residential buildings	22 deaths, 6 injured	1970s (two-storey rooftop addition)
26 Feb. 2016	Pingxiang City, Jiangxi Province	Six-storey residential building	1 death, 1 injured	1980s
27 Jul. 2015	Hangzhou City, Zhejiang Province	Four-storey residential building	2 injured	/
14 Jun. 2015	Zunyi City, Guizhou Province	Seven-storey residential building	4 deaths, 3 injured	1995 (Four-storey rooftop addition)
27 Aug. 2014	Xinzheng City, Henan Province	Seven-storey residential building	2 deaths, 1 injured	1970s (Three-storey rooftop addition)
4 Apr. 2014	Ningbo City, Zhejiang Province	Five-storey residential building	1 death, 6 injured	1994
29 Aug. 2013	Wenzhou City, Zhejiang Province	Two-storey residential building	1 death, 3 injured	1990s
27 Mar. 2013	Shaoxing City, Zhejiang Province	Four-storey residential building	3 deaths, 1 injured	/
16 Dec. 2012	Ningbo City, Zhejiang Province	Two residential building	1 death, 1 injured	/
4 Aug. 2009	Shijiazhuang City, Hebei Province	Two-storey residential building	17 deaths	1990s
27 June. 2009	Shanghai municipality	13-storey high-rise building	1 death	Under construction

The collapsed residential buildings mentioned in the reported incidents were constructed by residents in the period of 1970–1990. Residents seldom consider safety design for their building structure during construction. Thus, these older residential buildings have a lower safety factor after the construction of their rooftop additions. This situation also arose during construction of newly self-constructed residential buildings, e.g., on 24 October 2016, a self-constructed residential building collapsed while under construction in Heze City, Shandong Province, which caused six deaths and seven injuries. According to a later investigation, this collapse was attributed to non-improved foundations and unreasonable construction procedures. A collapse that occurred on 10 October 2016 in Wenzhou City, Zhejiang Province also aroused wide attention from society. Figure 4 shows the scene of the collapsed incident in Wenzhou City. As shown in these photos, the collapsed building has an illegal rooftop addition (Figure 4a), which damaged the structure of the building. It is also evident that the collapsed building was surrounded by high buildings (Figure 4b), which induced the differential settlement of the foundation. These two factors have significant impacts that induced this collapsed incident.



Figure 4. Scene of collapsed incident on 10 October 2016: (a) rooftop addition of collapsed building; (b) surrounding high building at collapsed site.

3. Analysis of Collapsed Incident

3.1. Social Perspective

3.1.1. Transactions Involving Rural Land

Great demands of urban land due to the rapid urbanization lead to the transaction of rural land [24]. The trend for rural land transactions was significant particularly in coastal areas, e.g., in Kunshan Industrial Park in Jiangsu Province where 25% of industrial and commercial land was directly transferred from farmers [25,26]. These actions associated with rural land transactions have played an important role in easing urban land shortages, although these efforts were often in conflict with current land use laws and thus deemed illegal [27,28]. Since there is no mandatory regulation governing the use of rural land, illegal transactions over rural land have become frequent, a situation compounded by some local governments turning a blind eye to these illegal land use transactions [29,30]. The dual land system eventually produced a black market in rural land transactions.

Rural land includes homestead land and agricultural land. At present, according to existing land use regulations, homestead land is prohibited from being subject to any market transactions [24]. Local governments also prohibit urban “Hukou” residents from purchasing rural homesteads or from building residential buildings on such land [31]. Moreover, farmers independently constructed factory and residential buildings on their land, which are lax with regards to meeting safety design requirements. In the transaction process, these residential buildings were banned from being transferred into the market, so these self-constructed houses were termed as property-limited houses. To gain more benefit, many unauthorized and unapproved rooftop additions were constructed on

these original buildings, thus leading to structural inadequacy and significant loss of geotechnical capacity for these modified buildings.

3.1.2. Land-Policy Reform in Wenzhou

As a typical coastal city, Wenzhou has experienced rapid urbanization over the past three decades [32]. Population migration from rural to urban areas was significant, while many factories were also established there during this period [32]. This rapid urbanization resulted in an urgent demand for construction land [31]. Since the central government realized the challenges were actually linked to the dual land system, a series of regulations were announced to stipulate the entitled use of rural land [33]. More specifically, the rural land could not be used for purposes other than public welfare projects. The goal of announcing the rural land use regulation was to integrate rural residents into urban life through establishment of a unified urban-rural land market. Governments also encouraged rural residents to transfer or mortgage their rural land in the market [34,35]. On 1 March 2013, Wenzhou Municipal Government made a decision enabling the acquisition of collective-owned rural land parcels in Lucheng District [36]. This document focused on the demolition and acquisition of damaged buildings on collective-land in Zhongyangtu, Lucheng District. The region of this collapsed incident was exactly within the extent of demolition. However, this document did not clearly state the collapsed buildings whether or not were classified as damaged buildings.

According to investigations of the incident happened on 10 October 2016, the collapsed buildings subjected to the combined effect of unauthorised rooftop addition, differential settlement, and long-term deformation, which can hence be classified as dangerous buildings [19,20]. Since the slow reform process, these old heritage buildings were not preserved with appropriate strengthening measures. As mentioned, these collapsed buildings were constructed by farmers in the 1970s. Additionally, to obtain more rental income, unauthorized rooftop additions were constructed without consideration of the design of the original structure and its foundations. Moreover, a geotechnical investigation of the foundation before rooftop additions were built was not conducted. These inappropriate human activities exacerbated this fatal building collapse incident. Cities have furthermore mushroomed in the past few decades as hundreds of millions of rural residents migrated to cities in search of employment. Shoddy construction due to the “dual structure” policy was prevalent in many cities. Poorly built structures have been blamed for exacerbating the death toll during the 2008 Sichuan earthquake which took more than 69,000 lives [37]. This fact, along with the prevalence of unauthorized rooftop additions, has exacerbated the situation.

3.2. Chinese Land Use Policy

Accelerating economic development in rural areas of China has raised the demands for residential housing for the economic migration of workers to the developing suburbs of cities [38,39]. These residential demands increase the low-rental market of apartments; however, the market cannot provide enough low-rental apartments [40]. Therefore, unauthorized rooftop additions are increasing in these city suburbs. The combined effects of the poorly built structures or locally termed “tofu buildings” with their unauthorized rooftop additions, and differential settlements have resulted in these collapses. The collapse incident in the Lucheng District of Wenzhou City was a painful lesson for China’s construction industry. Following this collapse, questions about how to cope with problems associated with endangered houses became an urgent matter for official consideration. The required supervision by government authorities for the prevention of unauthorized rooftop addition was deemed to be inadequate. Additionally, the dichotomy between rural and city areas in China appeared to have been reduced after enacting rural economic reforms, but this process occurred at a pace too slow to have prevented this incident [41,42]. During the land-policy reform process, the government must strengthen management systems and ensure the effective implementation of policies and construction regulations.

A series of regulations for rural construction was begun by the Chinese Government in 2003 [43–45]. A publication [5] has shown that “this regulation is not applicable for the construction activity for rural people’s self-construction of one story residence”. The collapsed residential buildings in this incident were self-constructed by rural workers, who were not well versed in engineering principles, such as the nature of the load path and the loss of geotechnical bearing capacity due to extra vertical loads resulting from rooftop additions. Generally, these workers have no basic construction qualification [46–49].

3.3. Technological Perspective

The collapsed site is located on the floodplain, which is abundant with much Wenzhou clay. Based on the code for building foundation design [50], the physical properties of soils have critical influence for the safety of building foundation. Figure 5 shows the topography of Wenzhou city. As shown in Figure 5, the collapsed site is close to river. It indicates that the strata in the collapsed site are mainly about soft deposits. Geotechnical investigation shows that the Wenzhou clay has a strong tendency to deform as the tertiary creep takes place [51,52]. Wenzhou clay deposit is typical Chinese marine clay characterized as slightly organic and highly plastic. Figure 6 depicts the physical properties of Wenzhou clay. Zhu et al. (2013, 2016) [53,54] carried out a series of laboratory tests on the three clays (Shanghai clay, Zhoushan clay, and Wenzhou clay) and reported that the plasticity index (I_p) for Shanghai and Zhoushan clays is approximately 20, while the I_p value for Wenzhou clay could be as high as 35. Based on the aforementioned results, Shanghai clay and Zhoushan clay have low plasticity; while Wenzhou clay is high plasticity, which has the capacity of creep combined with destructuration (see Figure 6). On the other hand, the initial void ratio (e_0) for Wenzhou clay could also reach 1.98 which is significantly higher than the e_0 value of around 1.10 in Shanghai and Zhoushan clays (see Figure 6). Moreover, Wenzhou clay with a low shear stress ranged from 3~6 kPa (see Figure 6), indicating that the foundations residential buildings have less capacity to bear vertical load. Therefore, due to the occurrence of creep, the decrease in the pore volume for Wenzhou clay could be more pronounced, thus promoting the development of differential settlement (δ). According to Yin [55,56], the tertiary creep of a soil contributes significantly to the long-term deformation of foundations of the highly sensitive clays [57–59]. Thus, this creep behavior becomes one of the significant factors contributing to this incident. If a geotechnical investigation had been conducted before construction, this collapse should have been avoided.

Additionally, the poor condition of the residential buildings can be considered as one of the prime factors that triggered the building collapse incidents. According to preliminary investigation, the collapsed residential buildings were constructed with brick structures, which leads to an inability of withstanding natural hazards (e.g., earthquakes, floods, landslides) and illegal man-made hazards (e.g., rooftop addition) [60]. According to Xu et al., 2017 [60], reinforced concrete may be used to provide an increasing collapse resistance of building.

Since Wenzhou clay is of high plasticity and possesses a high potential of creep. This leads to an inability for the foundation soil to withstand the weight of upper structures and/or buildings. Additionally, the unauthorised rooftop additions were constructed without introducing appropriate structural and geotechnical designs. Moreover, based upon the preliminary investigation, the collapsed residential buildings were brick structures which in fact possess a low shearing resistance. The above facts have been considered as the main factors triggering the building collapse incident.

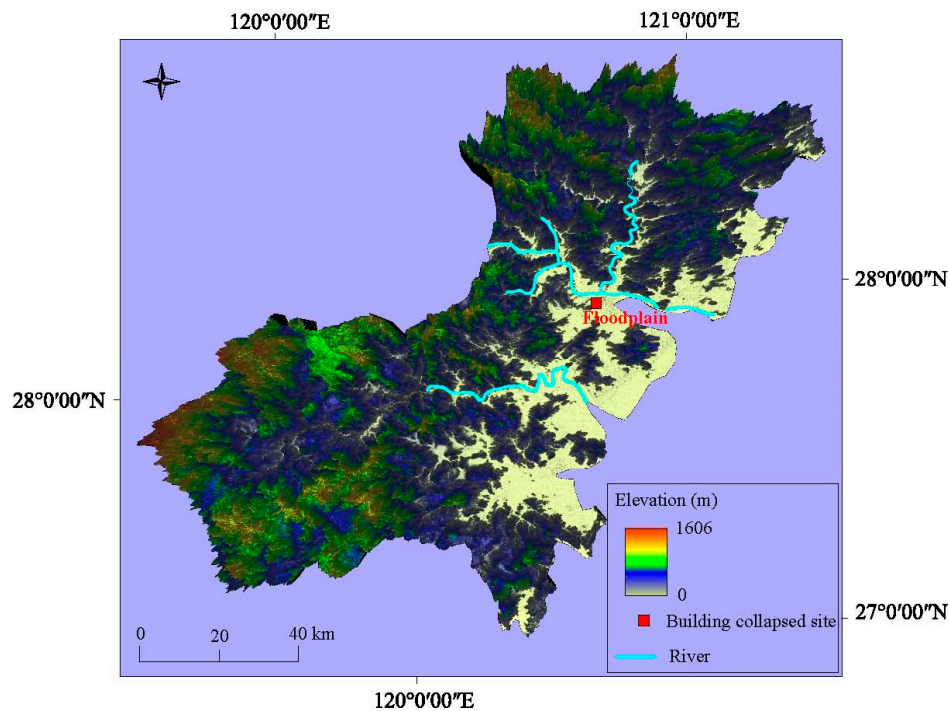


Figure 5. Topography of Wenzhou City.

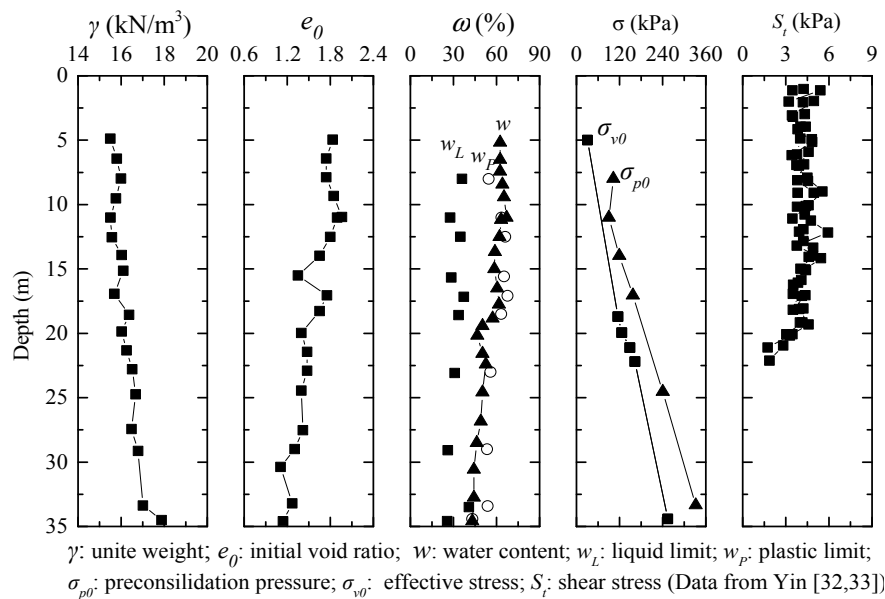


Figure 6. Physical properties of Wenzhou Clay.

4. Suggestion for Sustainable Urban Planning

4.1. Land Policy Reform

The reform of land policy in China has brought significant success in improving land-use efficiency, increasing financial support for the supply of urban constructions [34,35]. It has also created job opportunities for many migrant laborers [38,39]. However, there are a number of challenges in the process of land policy reform [41,42]. For sustainable development, these challenges should be clarified for policy makers. The first challenge is how to balance the demand for urban land due to rapid

urbanization. It is difficult to control urban growth since land ownership and administrations are fragmented. The second challenge is related to the conflicts between land regulations and policies (e.g., conflicts between the land-use rights and farmland protection). The third challenge is how to deal with increasing social injustice arising from land policy reform. Spatially differential tax rates may help to increase the issue. The fourth challenge is how to improve land-use efficiency. The strategy of urban development requires changes in land-use regulations to promote urban development economically profitable. Finally, the increases in land prices can be attributed to private and public investments [43]. The absence of policy to capture land prices resulting from public investments creates social injustice. For sustainable urban development, government should strengthen their management systems and ensure the effective implementation during the implementation of land policy reform.

4.2. Reasonable Monitoring Measures

The residential buildings were founded on very poor ground (i.e., soft Wenzhou clay) and collapsed due to the lack of monitoring of unauthorized rooftop additions. The structural integrity of old residential buildings should be evaluated to see whether it is the right time for demolition. To sustainable urban development, geotechnical investigation, parameter selection, and structural design should be undertaken for such constructions. In future developments, before building construction, preventive measures such as geotechnical investigation and ground treatment, e.g., soil compaction, ground treatment, and piled foundation construction, may be necessary to improve the shearing resistance and stiffness of the existing ground [61,62]. Additionally, relevant regulations to prevent rooftop additions should be established to reduce potential damages to occupants in similar collapse events. All levels of the government and the Ministry of Construction should increase investment in resettling rural residents during the process of land acquisition. Moreover, mandatory regulations by the government for any construction in China, particularly for the construction of self-constructed house building sites in rural areas, was recommended to minimize the resettlement issue of migrant workers.

In addition, to sustainable urban planning, the area with a lowland topography should strengthen prevention measures to mitigate natural disasters (e.g., flooding hazards, debris flows, and landslides). To mitigate the damages caused by landslides and debris flows, residential buildings should be built far from the region with a steep topography. Finally, social problems associated with personal safety issues affecting migrant workers aroused public attention, as well as criticism from other quarters of the nation, and indeed the world. Most victims were migrant workers, and this remains a painful lesson for the Chinese Government when considering future reform of land policy.

5. Conclusions

This case study reports on catastrophic building collapse incidents that occurred in recent years in China. Particular attention was paid to a collapse incident that occurred on 10 October 2016, in Wenzhou City, China, where four residential buildings collapsed, resulting in 22 deaths and 6 people severely injured. The collapsed buildings were subjected to extra vertical load resulting from the unauthorised rooftop additions, differential settlement, and long-term deformation induced by the creep nature of Wenzhou soft clay. Based on the preliminary investigation and analysis of the building collapse incident, the following conclusions can be drawn:

1. From social perspective, one of the key reasons triggering the building collapse incident was ascribed to the dual land use policy structure, which distinguishes between the city and rural areas of China. From the technological perspective, the building collapse incident site lies on the floodplain of Wenzhou City. The self-constructed residential buildings were founded on weak Wenzhou clay, and collapsed due to the combined effects of the extra vertical load resulting from unauthorized rooftop additions, differential settlement, and long-term deformation.
2. The dichotomy between rural and urban areas in China appears to be reduced substantially after rural economic reform. The slow pace of land use reform progress promoted the frequency of

building collapse incident. In the dual land use system, there is less or no supervision, for such construction activities in rural areas, which results in frequent rural residential building collapse incidents. Strict supervision may be required to prevent similar incident from reoccurring.

3. For sustainable urban development, during the implementation of land-policy reform, the government should strengthen their management systems and ensure the effective implementation of land reform policies. The supervision capacity of government authorities to prevent unauthorized rooftop additions may need to be strengthened, reducing potential damage to occupants in similar collapse incidents. More attention should be paid to social problems associated with the personal safety issues affecting migrant workers. Mandatory regulations for any construction in China, especially for the private self-constructed work undertaken on house-building sites in rural areas should be on the “must-do” lists of government officials, thus minimizing the need for economic migration of workers.

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