Chapter 19
Construction of an Urban Road Collapse Risk Assessment Model and Its Case Study in Guangzhou

Yizhao Wang, Yuming Qiao, Weijie Deng, Fei Wang, Wenfeng Bai, Juncai Jiang, Jianmei Liu, Shiyang Xu, Honghui Lin, and Zhi Wang

Abstract Road collapse has become one of the frequent geological disasters in large cities, and effective road collapse risk assessment is of great significance for the arrangement of urban road collapse prevention and control work. The current risk assessment models related to road collapse show a high dependence on the results of underground disasters (UD) detection, and lack risk assessment analysis for the case of undetected. In this paper, based on the actual geological conditions and urban construction characteristics of Guangzhou, P.R. China, the road collapse risk assessment model (RCRA) for detected and undetected underground disasters is established by integrating the elements of the risk occurrence possibility (ROP) and risk consequence (RC). Combining the analytic hierarchy process (AHP) and variable fuzzy sets (VFS) theory, a road collapse areal assessment method adapted to Guangzhou was proposed. Moreover, the analysis and calculation were carried out with Dongfeng Road in Guangzhou as a typical case, and the RCRA was synchronously applied to the road collapse risk assessment of Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue, which further verified the characteristics and scientific of RCRA. Compared with current risk assessment models, RCRA constructed in this study considers more comprehensive influence elements and exhibits higher adaptability to the actual road collapse risk situation in Guangzhou.

Keywords Road collapse · Risk assessment · Detection · Risk occurrence possibility · Risk consequences

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Y. Wang · W. Bai · J. Liu · S. Xu
Guangzhou Metro Design & Research Institute Co., Ltd., 204 Huanshi West Road, Guangzhou 510030, China

Y. Qiao · F. Wang (✉) · J. Jiang
Tsinghua Shenzhen International Graduate School, 2279 Lishui Road, Shenzhen 518055, China
e-mail: feiwang@tsinghua.edu.cn

W. Deng · H. Lin · Z. Wang
Foshan Urban Safety Research Center Co., Ltd., 13 Huabao South Road, Foshan 528051, China

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19.1 Introduction

As an important form of ground collapse disaster, road collapse refers to the rapid subsidence of the ground due to the movement of underground materials. It belongs to the local sudden ground subsidence and deformation with point distribution, and has the characteristics of unpredictable and strong suddenness [1]. Relevant research shows that water level changes such as pipe leakage or fracture, groundwater exploitation, vacuum suction, water level rise and fall will lead to underground cavities. In addition, open-cut tunnel construction, underground excavation, shield construction, pipe-jacking method underground engineering construction, vehicle vibration disturbance and karst influence will produce additional stress on the soil layer and induce the destruction of underground cavities [2]. Guangzhou is located in the south of Guangdong Province, with complex geological environment conditions and a wide range of groundwater types, and the soft ground layer is developed and widely distributed. Its complex and fragile geological conditions and hydrological conditions have laid a hidden danger for the occurrence of ground collapse accidents [3]. Moreover, due to the increasing intensity of underground space development and infrastructure construction, loose soil layer is extremely easy to induce geological disasters such as ground subsidence and ground collapse [4]. Therefore, since road collapse threatens the safe operation of urban infrastructure and endangers the lives and properties of citizens [5], there is an urgent need to conduct risk assessment of roads in Guangzhou to improve the ability to resist the risk of road collapse.

The current risk assessment models related to road collapse mainly include *Standard for Comprehensive Detection and Risk Evaluation of Underground Disasters in Urban Area* (*JGJ/T 437-2018*) [6], *Code for Assessment and Prevention and Cure of Surrounding Soil Disease of Underground Pipeline* (*DB11/T 1347-2016*) [7] and *Technical Standard for Detection of Underground Disasters on Urban Roads* (*DBJ41/T 233-2020*) [8]. In the above standards, *JGJ/T 437-2018* presents more comprehensive provisions on the indicator types of environments, facilities and underground disasters. *DB11/T 1347=2016* focuses on the influence of underground pipelines and soil diseases, while *DBJ41/T 233-2020* mainly calculates various risk factors related to underground disasters. However, the above-mentioned standards related to road collapse show a high dependence on the results of underground disasters detection, and lack risk assessment analysis for the case of undetected. In addition, *JGJ/T 437-2018* and *DB11/T 1347-2016* merely support point assessment with underground disasters as the assessment object, lacking the definition of risk assessment for the road dimension. Moreover, although *DBJ41/T 233-2020* specifies the road or road section as the object of areal assessment, it presents a single index system, which only considers the risk occurrence possibility without detailed explanation of risk consequences. Based on the limitations of the current risk assessment standards, it is particularly urgent to construct a risk assessment model suitable for urban road collapse disasters in Guangzhou.

Among the traditional risk assessment methods, decision tree algorithm, FN-curve, analytic hierarchy process (AHP) and variable fuzzy sets (VFS) theory appear to be more representative. Specifically, the structure of the decision tree is presented clearly and each node exhibits a clear basis for judgment, but such models are highly dependent on the quality and volume of the training samples [9]. The FN-curve is suitable for risk comparisons with sufficient data, but not for risk comparisons where data with different characteristics vary in both quantity and quality [10]. AHP regularizes the research object into a system, which is suitable for system evaluation with complex factors, multiple objectives, multiple criteria and multiple periods. Besides, coupling qualitative and quantitative methods, AHP enables the decomposition of complex systems, and mathematizes and systematizes the thinking process [11–14]. VFS theory can handle fuzzy evaluation objects by precise numerical means, so that information with fuzzy characteristics can implement scientific, reasonable and close to the actual quantitative evaluation [13, 14]. In summary, the selection of risk assessment methods should comprehensively consider the mechanism of road collapse, the characteristics of urban construction, and the applicable features of assessment methods. This study concluded that the AHP and VFS theory can refer to the characteristics of each assessment area, which is more suitable for assessing the complex urban road conditions in Guangzhou.

In this paper, an areal road collapse risk assessment methodology based on AHP, VFS theory and risk matrix method is proposed with the dimension of road sections, as shown in Fig. 19.1. According to the practical geological conditions and urban construction characteristics of Guangzhou, the risk occurrence possibility (ROP) and risk consequence (RC) factors are summarized, and the effects of the hazard of the causative factors, the vulnerability of the disaster-bearing carriers, and the emergency management capability are comprehensively considered as well. Moreover, the risk in the case of undetected underground disasters was innovatively analyzed, and the road collapse risk assessment system of detected underground disasters (RCRA-DUD) and undetected (RCRA-UUD) were established respectively. This paper is organized as follows. Section 19.2 describes the construction of RCRA. Section 19.3 introduces the risk assessment model based on AHP-VFS. Section 19.4 summarizes the application and case study of RCRA. Section 19.5 concludes the paper.

19.2 Construction of RCRA

19.2.1 Risk Assessment Indexes

In this paper, the road is divided into several risk assessment units according to the granularity of 20–300 m based on the principle of the location of traffic intersections along the road alignment. Combining the current standards and previous research achievements, the road collapse risk assessment index systems were formulated by sufficiently considering the mechanism of road collapse and the characteristics of urban construction in Guangzhou, which focus on the analysis of geological environment, hydrological conditions, meteorological conditions, underground disasters,

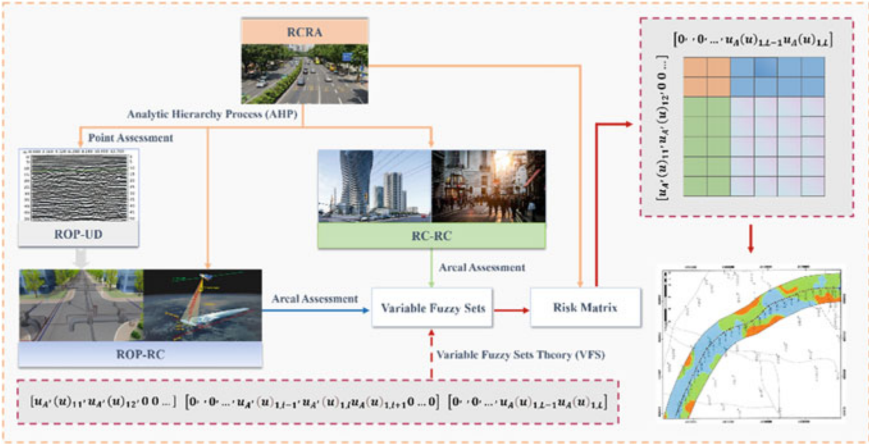

Fig. 19.1 Schematic of road collapse risk assessment (RCRA indicates the road collapse risk assessment model; ROP-UD indicates the risk occurrence possibility of underground disasters; ROP-RC indicates the risk occurrence possibility of road collapse; RC-RC indicates the risk consequences of road collapse)

anthropogenic geological activities, road conditions, underground pipeline conditions, and historical disasters information [15–17]. In particular, it is pointed out that the impact of whether the detection of underground disasters on road collapse has been explored in depth, and the risk assessment models of road collapse for detected underground disasters (RCRA-DUD) and undetected underground disasters (RCRA-UUD) have been established respectively.

Assessment Indexes of RCRA-DUD. Based on the results of the underground disasters detection, RCRA-DUD firstly evaluated the impact of risk occurrence possibility of single underground disasters (ROP-UD), involving the first-level indexes including the scale of underground disaster (P_{A}), geological conditions (P_{B}) and adjacent facilities (P_{C}), as detailed in Fig. 19.2. Subsequently, based on the assessment results of ROP-UD, the critical factors affecting road collapse were considered comprehensively, and the risk occurrence possibility of road collapse (ROP-RC) evaluation index system and risk consequence of road collapse (RC-RC) evaluation index system were constructed. Among them, the first-level indexes of ROP-RC include the conditions of underground disasters in the assessment unit (P_{A1}), the potential risk of underground disaster in assessment unit (P_{B1}), the facility disturbance (P_{B2}), the self-factors of risk assessment unit (P_{C1}), the geological and geomorphological features (P_{D}), the historical disaster information (P_{E}), the meteorological condition (P_{F}) and the human or natural geological activities (P_{G}) [18–21]. In addition, RC-RC integrates the distribution of buildings and structures (P_{R1}), the population density (P_{R2}), the distribution of property and hazardous chemicals facilities (P_{R3}), the social influence (P_{R4}), the foundation of surrounding buildings (P_{R5}) and the structure of surrounding buildings (P_{R6}) [22]. The second-level indexes and corresponding weights are summarized in Table 19.1.

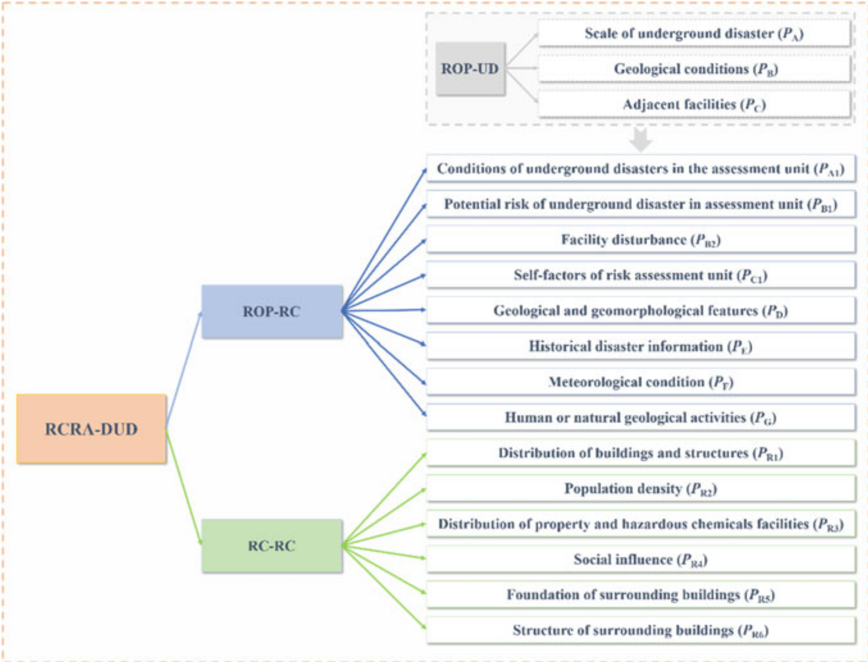

Fig. 19.2 Schematic of risk assessment indexes of RCRA-DUD

Assessment Indexes of RCRA-UUD. RCRA-UUD takes into account the key factors influencing road collapse in addition to the underground disasters, and similarly includes the risk occurrence possibility of road collapse (ROP-RC) evaluation index system and risk consequence of road collapse (RC-RC) evaluation index system, as shown in Fig. 19.3. Among them, the first-level indexes of ROP-RC include the geological conditions (P_B), the adjacent facilities (P_C), the facility disturbance (P_{B2}), the self-factors of risk assessment unit (P_{C1}), the geological and geomorphological features (P_D), the historical disaster information (P_E), the meteorological condition (P_F) and the human or natural geological activities (P_G). Specifically, the indexes for RC-RC are consistent with the risk assessment system RCRA-UUD, which integrates the distribution of buildings and structures (P_{R1}), the population density (P_{R2}), the distribution of property and hazardous chemicals facilities (P_{R3}), the social influence (P_{R4}), the foundation of surrounding buildings (P_{R5}) and the structure of surrounding buildings (P_{R6}). The second-level indexes and corresponding weights are summarized in Table 19.2**.**

Table 19.1 Risk assessment indexes of RCRA-DUD

Type	First-level indexes	Second-level indexes	Weight of second-level indexes	Weight of first-level indexes
Assessment indexes of ROP-UD	Scale of underground disaster (P_A)	Area of underground disaster (P_{A1})	0.35	0.35
		Height of underground disaster (P_{A2})	0.2225	
		Disposal of underground disaster (P_{A3})	0.4275	
	Geological conditions (P_B)	The stratum where the underground disaster is located (P_{B1})	0.2	0.3
		Permeability of the underground disaster in stratum (P_{B2})	0.2	
		Disadvantageous geologic condition (Karst geology) (P_{B3})	0.2	
		Disadvantageous geologic condition (Compressible stratum) (P_{B4})	0.05	
		Disadvantageous geologic condition (Vulnerable stratum) (P_{B5})	0.3	
		Disadvantageous geologic condition (Fault zone) (P_{B6})	0.05	
	Adjacent facilities (P_C)	Service life of underground pipeline (P_{C1})	0.2	0.35
		Pipe diameter of underground pipeline (P_{C2})	0.1	
		Material of underground pipeline (P_{C3})	0.3	
		Type of underground pipeline (P_{C4})	0.25	
		Burial depth of underground pipeline (P_{C5})	0.15	

(continued)

Table 19.1 (continued)

Type	First-level indexes	Second-level indexes	Weight of second-level indexes	Weight of first-level indexes
Assessment indexes of ROP-RC	Conditions of underground disasters in the assessment unit (P_{A1})	Risk level of underground disaster in assessment unit (P_{A11})	0.5	0.3
		Scope of underground disaster in assessment unit (P_{A12})	0.3	
		Location of assessment unit (P_{A13})	0.2	
	Potential risk of underground disaster in assessment unit (P_{B1})	Risk coefficient of thickness span (P_{B11})	0.65	0.1
		Risk of development trend of underground disaster (P_{B12})	0.35	
	Facility disturbance (P_{B2})	Construction interference (P_{B21})	0.35	0.15
		Surface construction (P_{B22})	0.15	
		Underground works (P_{B23})	0.5	
	Self-factors of risk assessment unit (P_{C1})	Situation of road (P_{C11})	0.25	0.15
		Environmental risk of assessment unit (P_{C12})	0.4	
		Average subsidence rate of subgrade (P_{C13})	0.1	
		Average load of road (P_{C14})	0.25	
	Geological and geomorphological features (P_D)	Development degree of karst (P_{D1})	0.2	0.1
		Groundwater level fluctuation in karst terrains (P_{D2})	0.3	
		Thickness of quaternary system (P_{D3})	0.35	
		Thickness of overburden layer (P_{D4})	0.15	

(continued)

Table 19.1 (continued)

Type	First-level indexes	Second-level indexes	Weight of second-level indexes	Weight of first-level indexes
	Historical disaster information (P_E)	Disaster frequency ratio (P_{E1})	0.35	0.05
		Disaster area modulus ratio (P_{E2})	0.65	
	Meteorological condition (P_F)	Surface water system (P_{F1})	0.35	0.05
		Rainfall conditions (P_{F2})	0.65	
	Human or natural geological activities (P_G)	Defects of underground pipelines (P_{G1})	0.8	0.1
		Geological structure (P_{G2})	0.2	
Assessment indexes of RC-RC	Distribution of buildings and structures (P_{R1})	–	–	0.35
	Population density (P_{R2})	–	–	0.3
	Distribution of property and hazardous chemicals facilities (P_{R3})	–	–	0.15
	Social influence (P_{R4})	–	–	0.1
	Foundation of surrounding buildings (P_{R5})	–	–	0.05
	Structure of surrounding buildings (P_{R6})	–	–	0.05

19.2.2 Weight of Assessment Indexes

This study composes the reference ranges of *JGJ/T 437-2018*, *DB11/T 1347-2016* and *DBJ41/T 233-2020* on indexes weights. And based on the analysis results of historical road collapse in Guangzhou, the causes and formation mechanism of road collapse are summarized, and the weight range of the RCRA is initially formed. Further, after several review meetings, the importance scores of each index were determined by industry experts, and the importance scores were checked for consistency by AHP, and then the risk assessment index weights were formed, as summarized in Tables 19.1 and 19.2. In particular, this study allows the parameters and

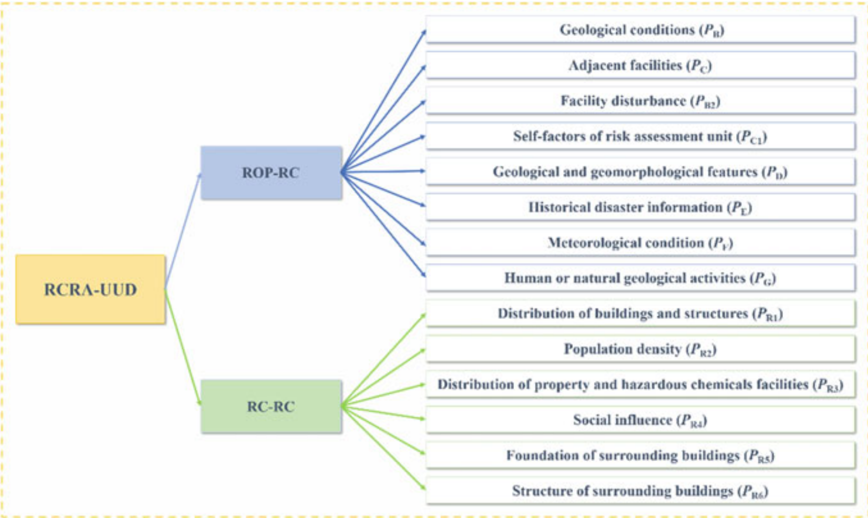

Fig. 19.3 Schematic of risk assessment indexes of RCRA-UUD

hyperparameters of the model to be adjusted in the iterative validation of the model, so as to enhance the practicability of RCRA in urban road collapse risk assessment in Guangzhou, making the model risk assessment results more consistent with the road characteristics.

19.2.3 Levels of Risk Assessment

The risk levels are determined with reference to the classification principle of *JGJ/T 437-2018*, *DB11/T 1347-2016* and *DBJ41/T 233-2020*, and adjusted according to the geological conditions and urban construction characteristics, in order to adapt to the actual road conditions in Guangzhou. Specifically, the risk levels of ROP-UD and ROP-RC are uniformly classified as Level A (extremely likely to occur in the near future), Level B (more likely to occur in the near future), Level C (less likely to occur in the near future and more likely to occur in the far future), Level D (less likely to occur in the near future and likely to occur in the far future), and Level E (unlikely to occur in the near future and extremely unlikely to occur in the far future), as described in Fig. 19.4a. In addition, the risk level of RC-RC is implemented according to the classification principle shown in Fig. 19.4b and defined as five levels: Level 1 (extremely serious consequential impact), Level 2 (more serious consequential impact), Level 3 (general consequential impact), Level 4 (less consequential impact), and Level 5 (negligible consequential impact). Finally, coupled with the levels of ROP

Table 19.2 Risk assessment indexes of RCRA-UUD

Type	First-level indexes	Second-level indexes	Weight of second-level indexes	Weight of first-level indexes
Assessment indexes of ROP-RC	Geological conditions (P_B)	Geotechnical conditions (P_{B1})	0.2	0.1
		Formation permeability (P_{B2})	0.2	
		Disadvantageous geologic condition (Karst geology) (P_{B3})	0.2	
		Disadvantageous geologic condition (Compressible stratum) (P_{B4})	0.05	
		Disadvantageous geologic condition (Vulnerable stratum) (P_{B5})	0.3	
		Disadvantageous geologic condition (Fault zone) (P_{B6})	0.05	
	Adjacent facilities (P_C)	Service life of underground pipeline (P_{C1})	0.2	0.15
		Pipe diameter of underground pipeline (P_{C2})	0.1	
		Material of underground pipeline (P_{C3})	0.3	
		Type of underground pipeline (P_{C4})	0.25	
		Burial depth of underground pipeline (P_{C5})	0.15	
	Facility disturbance (P_{B2})	Construction interference (P_{B21})	1	0.2
	Self-factors of risk assessment unit (P_{C1})	Situation of road (P_{C11})	0.25	0.05
		Environmental risk of assessment unit (P_{C12})	0.4	
		Average subsidence rate of subgrade (P_{C13})	0.1	

(continued)

Table 19.2 (continued)

Type	First-level indexes	Second-level indexes	Weight of second-level indexes	Weight of first-level indexes
		Average load of road (P_{C14})	0.25	
	Geological and geomorphological features (P_D)	Development degree of karst (P_{D1})	0.2	0.2
		Groundwater level fluctuation in karst terrains (P_{D2})	0.3	
		Thickness of quaternary system (P_{D3})	0.35	
		Thickness of overburden layer (P_{D4})	0.15	
	Historical disaster information (P_E)	Disaster frequency ratio (P_{E1})	0.35	0.05
		Disaster area modulus ratio (P_{E2})	0.65	
	Meteorological condition (P_F)	Surface water system (P_{F1})	0.35	0.1
		Rainfall conditions (P_{F2})	0.65	
	Human or natural geological activities (P_G)	Defects of underground pipelines (P_{G1})	0.8	0.15
		Geological structure (P_{G2})	0.2	
Assessment indexes of RC-RC	Distribution of buildings and structures (P_{R1})	–	–	0.35
	Population density (P_{R2})	–	–	0.3
	Distribution of property and hazardous chemicals facilities (P_{R3})	–	–	0.15
	Social influence (P_{R4})	–	–	0.1
	Foundation of surrounding buildings (P_{R5})	–	–	0.05
	Structure of surrounding buildings (P_{R6})	–	–	0.05

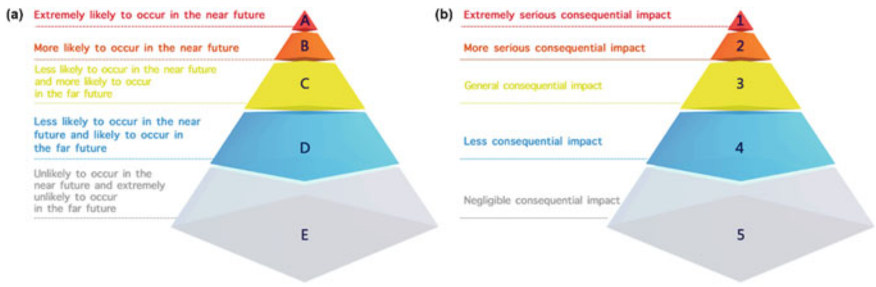

Fig. 19.4 Schematic of risk assessment levels. **a** ROP; **b** RC

and RC, the assessment unit road collapse comprehensive risk levels are divided into Level I (extremely high risk), Level II (high risk), Level III (general risk), Level IV (low risk) and Level V (extremely low risk), and detailed descriptions are shown in Table 19.3.

Table 19.3 The levels of RCRA

Risk level	Example
Level I	This level is an extremely high risk, which means that there is a high probability of road collapse accident occurring within a short period of time or occurring in areas with a high density of people (such as commercial streets, etc.) or the presence of important buildings (such as schools and shopping malls). The degree of damage to people, economy and environment is extremely high, and once it happens, the consequences of the accident cannot be sustained
Level II	This level is a high risk, which means that there is a greater probability of a road collapse accident in the near future or occurring in an area with a high density of people, dense buildings or the presence of important buildings (such as schools and shopping malls), which may cause greater damage to people, economy and environment
Level III	This level is general risk, which means that there is a certain probability of road collapse accidents or occurring in areas with lower population density, lower building density without important buildings (such as schools and shopping malls), but may cause some degree of damage to people, economy and environment
Level IV	This level is low risk, which means that it is basically impossible to cause road collapse accidents or accidents happen in sparsely populated areas. There are basically no casualties and minimal economic and environmental damage after an accident
Level V	This level is extremely low risk, which means that it is basically impossible to cause road collapse accidents or accidents occurring in sparsely populated areas. There are basically no casualties and no economic or environmental losses after the accident

19.3 Proposed Methodology Based on AHP-VFS

After a comparative analysis of the current risk assessment methods, it was concluded that the proposed methodology based on AHP-VFS are capable of focusing on the characteristics of each assessment area, which are more suitable for assessing the complex urban road conditions in Guangzhou. In order to classify risks more scientifically and to reasonably measure the correlation between risk elements and risk levels, RCRA simultaneously considers the combined impact of the risk occurrence possibility and risk consequences. Explicitly, the risk occurrence possibility assessment level and risk consequence assessment level are calculated by AHP and VFS theory respectively, and then the level of RCRA is determined according to the risk matrix comparison.

19.3.1 Assessment of ROP-UD

The weight of each index is derived from the AHP combined with the importance score given by experts, and can be reasonably adjusted according to the actual situation of the assessment region. Equations (19.1) and (19.2) show the calculation process of index weights [13, 14].

$$W = \begin{bmatrix} W_{1,1} & \cdots & W_{i,1} \\ \vdots & \ddots & \vdots \\ W_{1,j} & \cdots & W_{i,j} \end{bmatrix} \tag{19.1}$$

$$W_{i,j} = \frac{\sum_{n=1}^{i} W_{n,m}}{\sum_{m=1}^{j} \sum_{n=1}^{i} W_{n,m}} \tag{19.2}$$

where $W_{i,j}$ stands for the weight value of second-level index in first-level index.

The weights involved in the calculation of the risk assessment score of ROP-UD are appropriate to vary according to the assessment region, and the risk occurrence possibility assessment score is calculated by Eqs. (19.3), (19.4) and (19.5) [11].

$$Score_T = \sum_{i=1}^{k} W_i * P_i \tag{19.3}$$

$$\sum_{i=1}^{k} W_i = 1 \tag{19.4}$$

$$P_i = \sum_{j=1}^{m} W_{i,j} * P_{i,j} \tag{19.5}$$

where $Score_T$ stands for the risk assessment score of ROP-UD. W_i is the weight value of the first-level index. P_i represents the calculated score of the first-level index. $P_{i,j}$ stands for the calculated score of second-level index in first-level index.

The risk levels of ROP-UD are determined based on the VFS theory calculation. Precisely, the results of the qualitative dynamic assessment in the hierarchical analysis are transformed into the results of the quantitative dynamic assessment, from which the probability of each risk level is output, and the specific calculation process is based on Eq. (19.6) [13].

$$RMD_p = FUZZY\_Function\left(Score_T, Level_p\right) \tag{19.6}$$

where RMD_p represents the result of the affiliation calculation of ROP assessment level. $FUZZY\_Function$ is the fuzzy sets calculation function. $Level_p$ stands for the division interval of ROP.

19.3.2 Assessment of ROP-RC

In the calculation of the risk assessment score of ROP-RC, it is necessary to select the index items to be calculated according to the assessment unit (covering detected and undetected underground disasters). The weights involved are appropriate to vary according to the region, and the calculation process refers to Eqs. (19.3), (19.4) and (19.5). The process of calculating the risk level of ROP-RC is similar to that of ROP-UD, which is determined based on the VFS theory, as shown in Eq. (19.6).

19.3.3 Assessment of RC-RC

The weights involved in the calculation of the risk assessment score of RC-RC are appropriate to vary according to the assessment region, and the risk consequences assessment score is calculated by referring to Eqs. (19.3) and (19.4). The process of calculating the risk level of RC-RC is similar to that of ROP-UD and ROP-RC, as shown in Eq. (19.7).

$$RMD_c = FUZZY\_Function(Score_G, Level_C) \tag{19.7}$$

where $Score_G$ stands for the risk assessment score of RC-RC. RMD_C represents the result of the affiliation calculation of RC assessment level. $Level_C$ is the division interval of RC.

19.3.4 Assessment of RCRA

The assessment results of road collapse risk occurrence possibility and risk consequences are calculated based on the AHP. Moreover, the fuzzy affiliation algorithm is pioneered to further subdivide the assessment results based on the AHP into more reasonable risk levels, and the dynamic results of the affiliation of each risk level are calculated. Finally, the risk matrix method is used to generate the road collapse risk assessment levels by organically combining the two dynamic risk levels, and the principles of determination are shown in Table 19.4.

19.4 Application and Case Study of RCRA

In this paper, Dongfeng Road, which spans the two old urban areas of Yuexiu District and Liwan District of Guangzhou, is designated as the typical cases of road collapse. Specifically, a total of 5.5 km from the intersection of Dongfeng West Road and Panfu Road in the west to Zhongshan Interchange of Dongfeng East Road in the east was selected for road collapse risk assessment. Dongfeng Road is the first east–west trunk road without traffic lights in Guangzhou, and it is mainly composed of high-rise buildings, large shopping malls, schools and government departments. Moreover, during the rush hour, it is one of the major sections of traffic jam in the city. There are Memorial Hall Station of Metro Line 2 and Xichang Station of Metro Line 5 along Dongfeng Road, and some construction sites of Phase II of Metro Line 13 are located on both sides of it. In general, Dongfeng Road is of typical representative significance for studying the mechanism, inducement and risk assessment of road collapse. Dongfeng Road is divided into 82 evaluation units. Through the detection of underground disasters in the above units, a total of 16 underground disasters were detected, as shown in Fig. 19.5. Precisely, there are 11 road assessment units associated with underground disasters, while 71 units are not detected.

In addition, RCRA was further applied to the road collapse risk assessment analysis of Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue. Among them, a total of 8.0 km of roads including Huanshi Dong Road, Huanshi Zhong

Table 19.4 The principles of risk assessment level classification

Level of ROP	Level of RC				
	1	2	3	4	5
A	I	I	I	II	II
B	I	I	II	II	III
C	I	II	III	III	IV
D	II	III	IV	IV	V
E	III	IV	IV	V	V

Fig. 19.5 Distribution of underground disasters in Dongfeng Road

Road and Huanshi West Road were selected for collapse risk assessment analysis. Huanshi Road was divided into 39 assessment units, with 6 road sections of underground disasters detected and 33 road sections of undetected. A total of 9.0 km of Zhongshan Avenue West was selected for collapse risk assessment and analysis, which was divided into 52 assessment units, with 5 road sections of underground disasters detected and 47 road sections undetected. Guangzhou Avenue was selected to include a total of 17.1 km of roads around Guangzhou Avenue Central, Guangzhou Avenue North and Guangzhou Avenue South for collapse risk assessment and analysis. Guangzhou Avenue is divided into 98 road sections, with 12 sections of underground disasters detected and 86 sections undetected.

19.4.1 Application of RCRA-DUD

Firstly, the assessment scores of road collapse risk occurrence possibility and risk consequences of Dongfeng Road, Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue were calculated based on AHP. Then, the fuzzy affiliation algorithm is used to further subdivide the assessment results calculated based on AHP into more reasonable risk levels, and the dynamic results of the affiliation of each risk level are calculated. Finally, the risk matrix method was used to organically combine the two dynamic risk levels to generate the road collapse risk assessment levels of Dongfeng Road, Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue, and the calculation results are summarized in Table 19.5 and Fig. 19.6.

As shown in Table 19.5 and Fig. 19.6a, the results of the road collapse risk assessment of Dongfeng Road calculated based on RCRA-DUD can be summarized as follows. There is 1 unit with assessment Level II, accounting for 9%. There are 5 road sections with assessment Levels III and IV, with a cumulative percentage of 91%, and there are no risk assessment units of Level I and Level V. In particular, the ROP-RC level of the road section with Level II is assessed as Level C, indicating a less likely to occur in the near future and more likely to occur in the far future, while the RC-RC level is assessed as Level 2, reflecting a more serious consequential impact. The higher assessment level of ROP-RC is mainly attributed to the fact that the road section is associated with 2 underground disasters, resulting in a higher potential

Table 19.5 Risk assessment results based on RCRA-DUD

Risk level	Dongfeng Road		Huanshi Road		Zhongshan Avenue West		Guangzhou Avenue	
	Quantities	Ratio (%)	Quantities	Ratio	Quantities	Ratio	Quantities	Ratio
I	0	0.0	0	0.0	0	0.0	0	0.0
II	1	9.0	0	0.0	1	20.0	0	0.0
III	5	45.5	5	83.3	1	20.0	5	41.7
IV	5	45.5	1	16.7	3	60.0	7	58.3
V	0	0.0	0	0.0	0	0.0	0	0.0

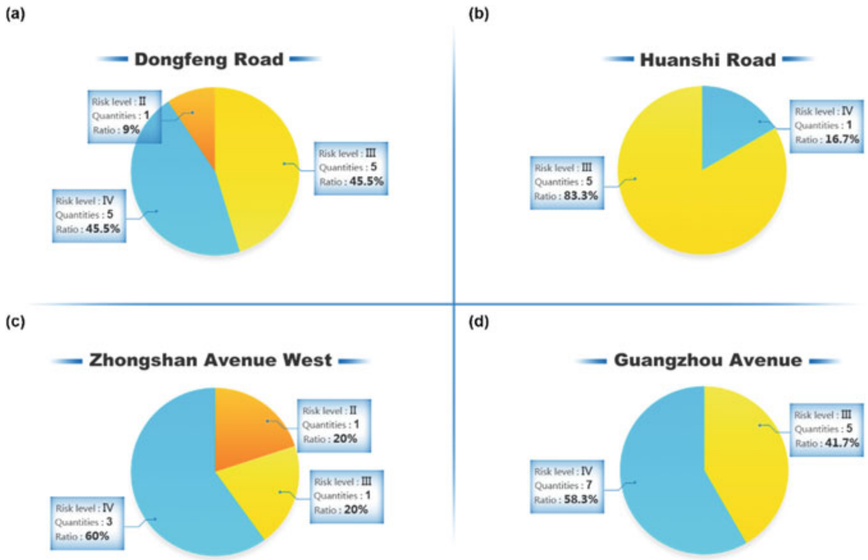

Fig. 19.6 Statistics of risk assessment results based on RCRA-DUD. **a** Dongfeng Road; **b** Huanshi Road; **c** Zhongshan Avenue West; **d** Guangzhou Avenue

risk of underground disasters within the assessment unit. Moreover, the road section is located near the subway construction site, and the disturbance of facilities such as underground construction may cause the occurrence of road collapse accidents. In addition, the results of the risk consequence assessment indicate that there are important places such as government departments, famous attractions and historical buildings within 200 m around the assessment unit, which will have present serious consequences in case of a road collapse accident. In general, the road sections that have been detected with underground disasters are mainly at Level III (general risk) and Level IV (low risk) risk, which is generally in line with the actual situation of Guangzhou Dongfeng Road.

The results of the road collapse risk assessment based on RCRA-DUD for the Huanshi Road can be summarized in Table 19.5 and Fig. 19.6b. There are 5 and 1 risk assessment units of Level III and Level IV, accounting for 83.3% and 16.7%, respectively, and there are no risk assessment units of Level I, Level II and Level V. In general, the sections of Huanshi Road that have been detected with underground disasters are mainly at Level III (general risk) risk. Comparing with the actual data conditions for sorting and analysis, it can be concluded that the above assessment results are generally consistent with the actual situation of the Huanshi Road in Guangzhou.

The results of the road collapse risk assessment based on RCRA-DUD for Zhongshan Avenue West are shown in Table 19.5 and Fig. 19.6c. There are a total of two Level II and Level III risk sections in Zhongshan Avenue West with a cumulative percentage of 40%, while there are three Level IV risk assessment units with a percentage of 60%, and there are no Level I and Level V risk assessment units. In particular, Zhongshan Avenue West contains a Level II (high risk) risk assessment unit, with a higher risk consequence assessment level. This is mainly attributed to the assessment unit contains a number of densely populated large shopping malls and schools nearby, which are vulnerable to the threat of road collapse accidents. In general, the road sections of Zhongshan Avenue West that have been detected with underground disasters are generally dominated by Level IV (low risk) risk, which is in line with the actual situation of the data.

As shown in Table 19.5 and Fig. 19.6d, the results of road collapse risk assessment of Guangzhou Avenue based on RCRA-DUD calculation can be summarized as follows. There are 5 and 7 risk assessment units of Level III and Level IV respectively, accounting for 41.7 and 58.3%, and there are no risk assessment units of Level I, Level II and Level V. Overall, the assessed Guangzhou Avenue are all Level III (general risk) and Level IV (low risk) risk sections. Comparing with the actual data conditions for sorting and analysis, it can be concluded that the above assessment results are generally consistent with the actual situation of the Guangzhou Avenue in Guangzhou. Thus, the scientific validity of RCRA-DUD is verified by the above cases, which proves that RCRA-DUD is suitable to be applied to road collapse risk assessment in Guangzhou.

19.4.2 Application of RCRA-UUD

The results of road collapse risk assessment of Dongfeng Road based on RCRA-UUD can be summarized in Table 19.6 and Fig. 19.7a. There are 3 and 4 assessment units with Level III and Level IV respectively, accounting for 4.2 and 5.6%. Moreover, there are even 64 units of Level V, accounting for 90.1%, and there are no risk assessment units of Level I and Level II. In particular, the overall risk of the road sections without detecting underground disasters is reduced due to the lack of influence of underground disasters on road collapse compared with the road sections with detected. Therefore, it can be considered that the undetected sections of Dongfeng Road are mainly at Level V (extremely low risk), which is generally in line with the actual situation.

As shown in Table 19.6 and Fig. 19.7b, the results of the road collapse risk assessment based on RCRA-UUD for the Huanshi Road can be summarized as follows. There are 28 risk assessment units of Level III, accounting for 84.8%, while there are 5 risk assessment units of Level IV, accounting for 15.2%, and no risk assessment units of Level I, Level II and Level V. In general, the road sections of Huanshi Road without detecting underground disasters are dominated by Level III (general risk) risk, and the assessment results are basically consistent with those of the road sections with detected. Comparing with the actual data conditions, it can be concluded that the assessment results are generally consistent with the actual situation of the Huanshi Road.

Table 19.6 and Fig. 19.7c summarizes the results of the road collapse risk assessment based on RCRA-UUD for Zhongshan Avenue West. There are 41 and 2 road sections with risk assessment Level III and Level IV, accounting for 87.2% and 4.3%, respectively, and no risk assessment units with Level I and Level V. In particular, there are 4 Level II (high risk) assessment units, accounting for 8.5%, mainly due to the higher risk consequence assessment level. This is mainly attributed to the above assessment units around large shopping malls, schools and subway stations, which are vulnerable to the threat of road collapse accidents. The risk of the road sections without detecting underground disasters is mainly Level III (general risk), which is generally in line with the actual situation of Zhongshan Avenue West data in Guangzhou.

As shown in Table 19.6 and Fig. 19.7d, the obtained results of road collapse risk assessment of Guangzhou Avenue based on RCRA-UUD can be summarized as follows. There are 34 and 52 units with risk levels of III and IV, accounting for 39.5 and 60.5%, respectively, and there are no risk assessment units with Level I, Level II and Level V. In general, the sections of Guangzhou Avenue without detecting underground disasters are all at risk of Level III (general risk) and Level IV (low risk), and the assessment results are basically consistent with those sections detected. After sorting and analyzing the actual data, it can be concluded that the above assessment results are generally consistent with the actual situation of Guangzhou Avenue in

Table 19.6 Risk assessment results based on RCRA-UUD

Risk level	Dongfeng Road		Huanshi Road		Zhongshan Avenue West		Guangzhou Avenue	
	Quantities	Ratio (%)	Quantities	Ratio (%)	Quantities	Ratio (%)	Quantities	Ratio (%)
I	0	0.0	0	0.0	0	0.0	0	0.0
II	0	0.0	0	0.0	4	8.5	0	0.0
III	3	4.2	28	84.8	41	87.2	34	39.5
IV	4	5.6	5	15.2	2	4.3	52	60.5
V	64	90.1	0	0.0	0	0.0	0	0.0

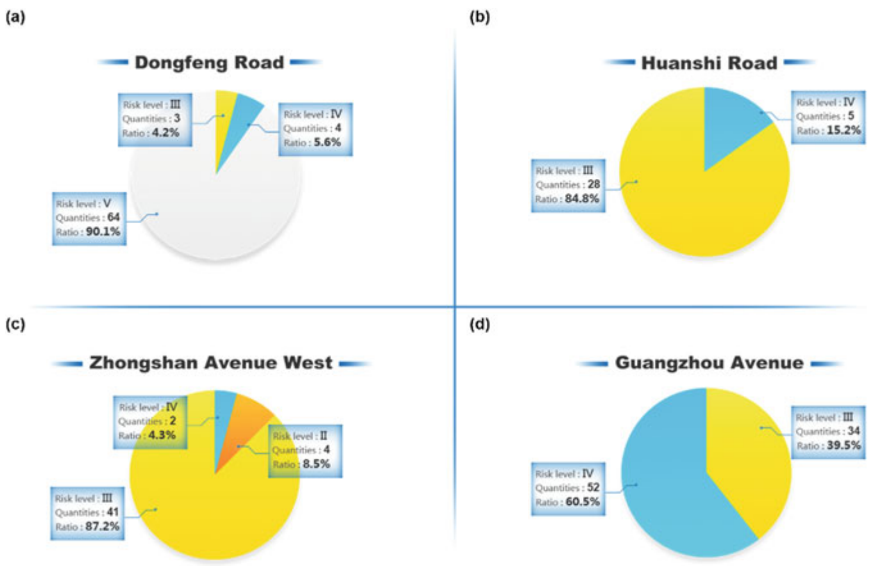

Fig. 19.7 Statistics of risk assessment results based on RCRA-UUD. **a** Dongfeng Road; **b** Huanshi Road; **c** Zhongshan Avenue West; **d** Guangzhou Avenue

Guangzhou. This demonstrates that RCRA-UUD focuses on the characteristics of roads and is suitable for application in road collapse risk assessment in Guangzhou.

19.5 Conclusion

In our work, based on the actual geological conditions and urban construction characteristics of Guangzhou, we comprehensively considered the risk occurrence possibility factors and risk consequence factors that may cause road collapse. Moreover, the risk in the case of undetected underground disasters was innovatively analyzed, and the road collapse risk assessment system of detected underground disasters (RCRA-DUD) and the road collapse risk assessment system of undetected underground disasters (RCRA-UUD) were established respectively. Subsequently, Dongfeng Road in Guangzhou was used as a typical application case for analysis and calculation, and the construction methodology of urban road collapse risk assessment model was proposed. In addition, RCRA was simultaneously applied to the road collapse risk assessment of Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue, which in turn verified the characteristics and scientific validity. The results showed that Dongfeng Road, Huanshi Road, Zhongshan Avenue West and Guangzhou Avenue are mainly at Level III (general risk), Level IV (low risk) and Level V (extremely low risk) risks, which are generally consistent with the actual roads conditions of Guangzhou. It is indicated that the RCRA based on AHP-VFS theory comprehensively considers the particularity and universality of various environmental conditions in Guangzhou. Compared with the current assessment standards, RCRA possesses a more comprehensive index system, which almost covers the direct and indirect causes of road collapse. Therefore, the urban road collapse risk assessment model constructed in this study can provide scientific support for the standardization and standardized implementation of urban road collapse risk prevention and control in Guangzhou.

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