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Et BegrensSkade prosjekt

BegrensSkade/REMEDY

Risk Reduction of Groundwork Damage

Deliverable D5.1

A literature review of risk matrices applied for risk assessment in geotechnical engineering

Work Package 5 – Risk assessment and management

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Summary

Risk matrices are frequently used for risk assessment in all kinds of areas. This study makes a simple literature review on their applications in different fields of geotechnical engineering with focus on their size and risk classifications. It is found that the 5×5 risk matrices with 3 or 4 risk levels are most commonly used. For risk assessment on tunnels, the 5×5 risk matrices with 4 risk levels are recommended, and the risk matrix given by the International Tunnelling Association (ITA) can be used as a typical example. For risk assessment on other fields, the 5×5 risk matrices with 3 or 4 risk levels are recommended. However, no typical example is available regarding to their detailed patterns.

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1 Introduction

A risk matrix is a table that has several categories of "consequences" for its rows and several categories of "probability" for its columns. It delivers a recommended level of risk for each row-column pair, that is, for each cell (Ball & Watt, 2013; Cox, 2008). Risk matrices are commonly utilized devices for rating hazards in numerous areas of risk management, such as terrorism risk analysis, highway construction project management, office building risk analysis, climate change risk management, and enterprise risk management. This literature review focuses merely on their applications in geotechnical engineering, with main attention on their size and classification of risk levels.

Ball & Watt (2013) pointed out that the risk matrices generally range in size from 2×2 to 10×10. In addition, it is stated in IEC/ISO 31010 (IEC, 2009) that the scale of probability and consequences may have any number of points. However, 3, 4, or 5 points are most common. After a critical overview of the use of risk matrices in different fields, Elmontsri (2014) found that the 4×4 or 5×5 risk matrices are most typical.

The Norwegian Standard NS 5815 (2006) provides guidelines for risk assessment of various construction work and recommends a 5×5 risk matrix with 3 risk levels. However, it is also stated that both consequences and probability can have more or less categories.

The NORSOK Standard Z-013 (2001) was drawn up by the Norwegian Technology Centre (NTC) to guide risk analysis and emergency preparedness associated with offshore work related to oil exploitation. In this standard, a 4×4 risk matrix with 3 risk levels is recommended.

DET NORSKE VERITAS (DNV) issued a recommended practice for assessing pipeline protection against accidental external loads (DNV, 2010). In this recommended practice, both consequences and probability are ranked into 5 different categories, and damage to pipelines is divided into 3 categories. Thus, a 5×5 risk matrix with 3 risk levels is recommended.

The Working Group No. 2 of the International Tunnelling Association (ITA) has given guidelines for tunnelling risk management (Eskesen et al., 2004). It is recommended that both probability and consequences be classified into five classes. Moradi & Farsangi (2014) also pointed out that a five-level rating for both the probability and consequences is commonly used in the field of tunneling.

2 Applications of risk matrices in geotechnical engineering

Nowadays, risk matrices have been widely applied for risk assessment in almost every field of geotechnical engineering, for example, tunnels, dams, excavations, and landslides. To make a comprehensive comparison, their applications in other disciplines are also investigated, such as environmental hazards and health services. Table 1 summarizes their applications in these different fields, and the corresponding risk matrices are illustrated in Figures 1 to 23, respectively.

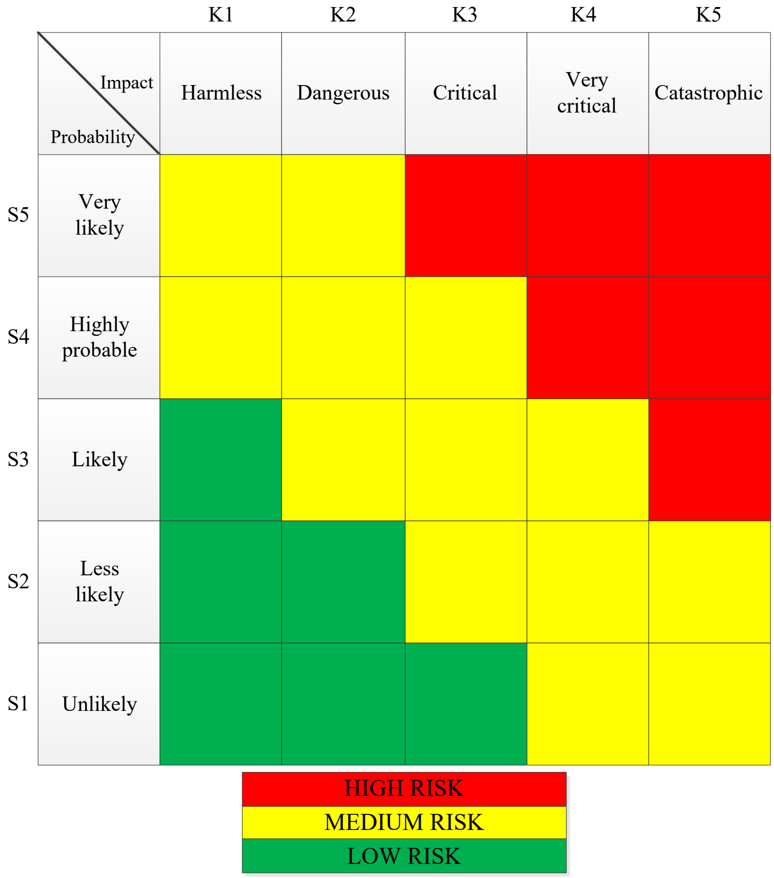

Figure 1 An example risk matrix recommended in NS 5815.

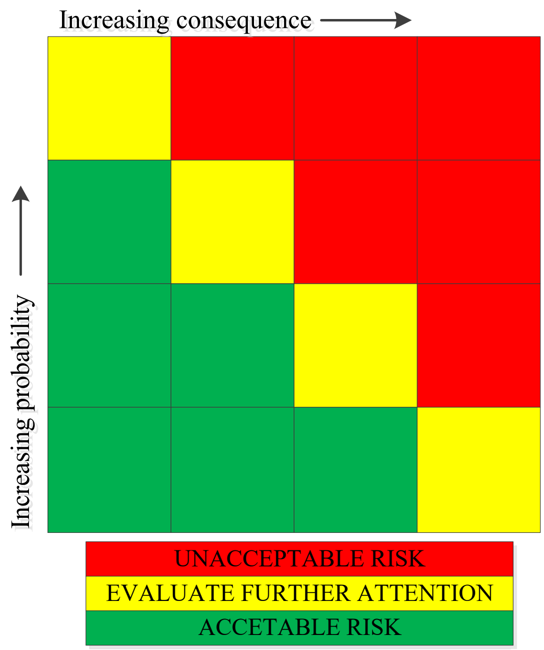

Figure 2 An example risk matrix recommended in NORSOK Standard Z-013.

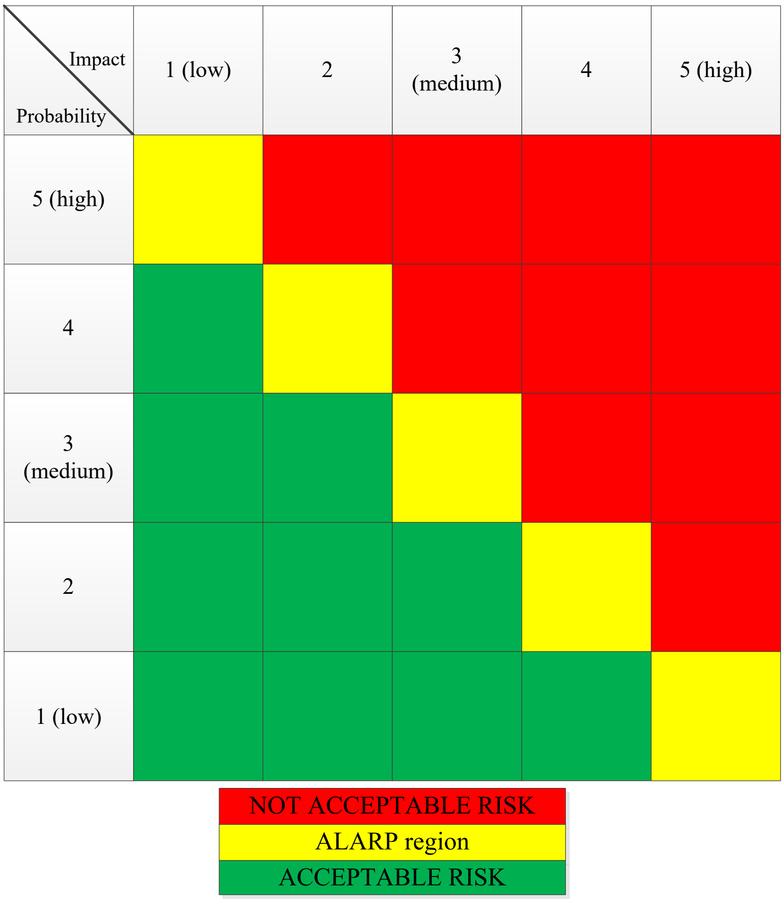

Figure 3 The risk matrix recommended in DNV-RP-F107. The ALARP (As-low-as-reasonably-practicable) region identifies an area where the risk is acceptable, however further reduction of the risk should be pursued with cost-benefit evaluation.

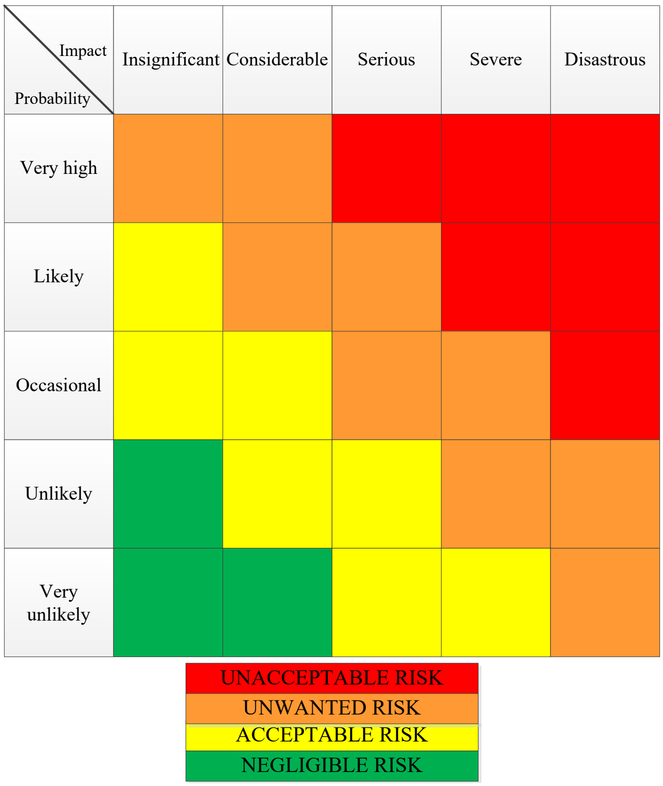

Figure 4 An example of a risk matrix used in tunnelling given by the ITA.

	Impact / Probability	1 Negligible	2 Moderate	3 Serious	4 Critical	5 Catastrophic
5	Frequent	5	10	15	20	25
4	Probable	4	8	12	16	20
3	Occasional	3	6	9	12	15
2	Remote	2	4	6	8	10
1	Improbable	1	2	3	4	5

VERY HIGH RISK
HIGH RISK
MEDIUM RISK
LOW RISK

Figure 5 The risk matrix used for risk assessment in rock TBM tunneling.

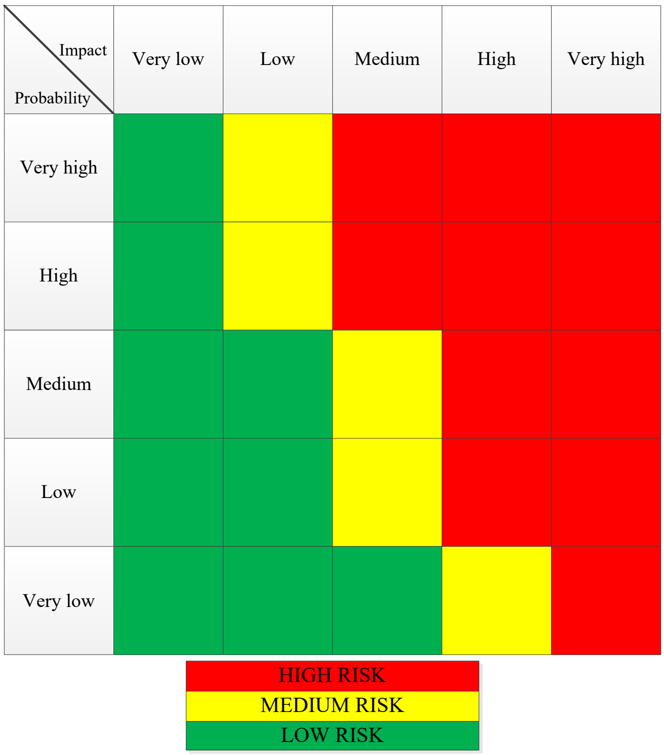

Figure 6 Risk matrices proposed by the Federal Highway Administration of the U.S.A.

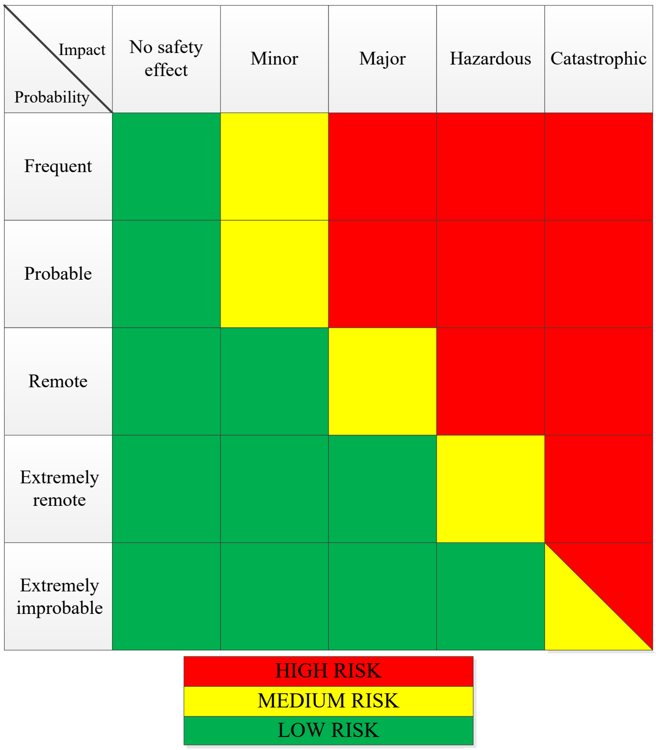

Figure 7 Risk matrices proposed by the Federal Aviation Administration of the U.S.A.

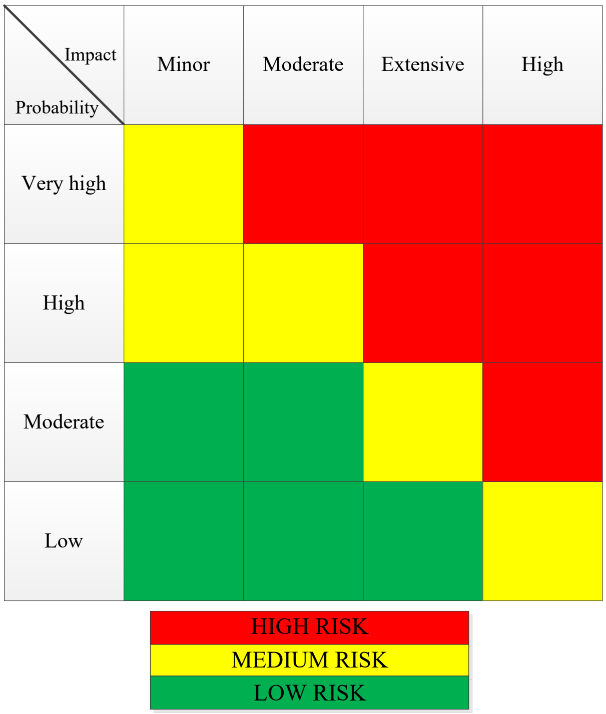

Figure 8 The risk matrix used by the Bureau of Reclamation.

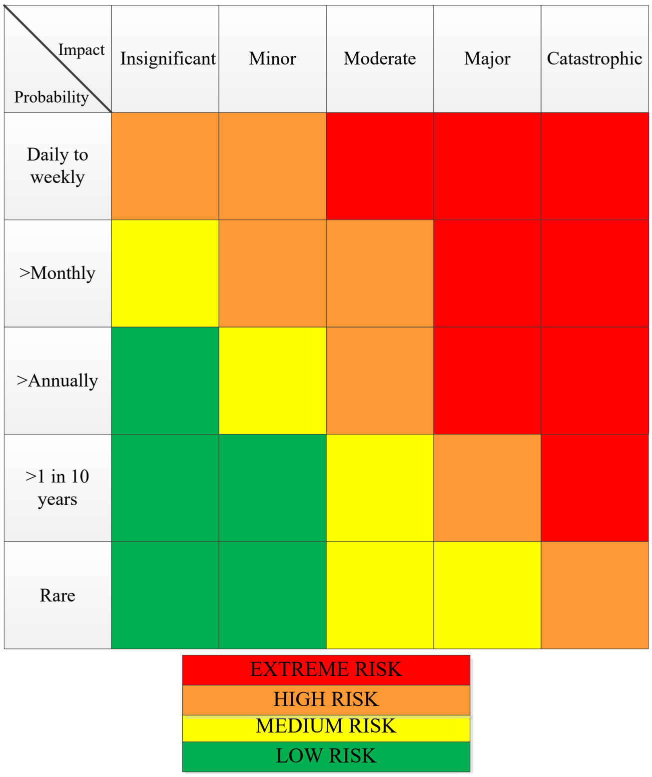

Figure 9 The risk matrix proposed by SRK Consulting Ltd for risk assessment of mining.

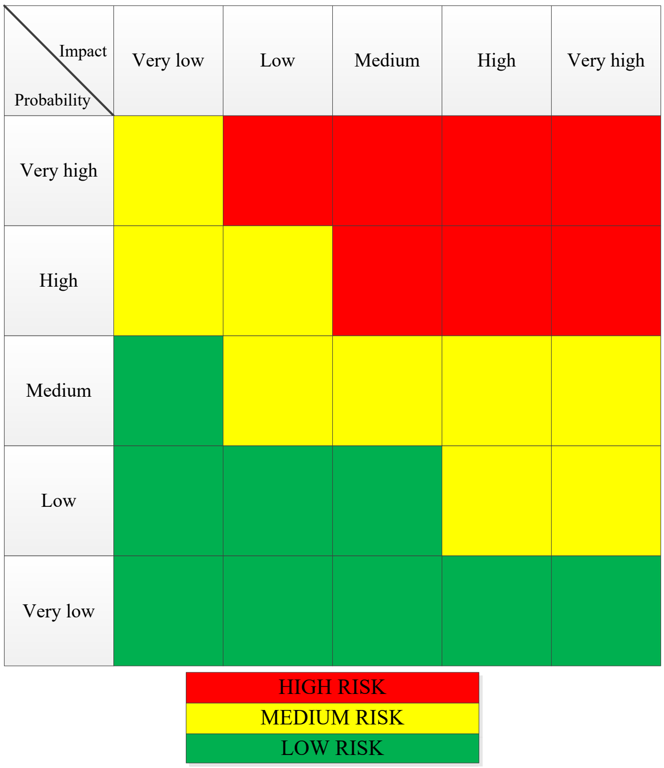

Figure 10 The risk matrix used by SGI to assess landslide risks in the Göta River Valley.

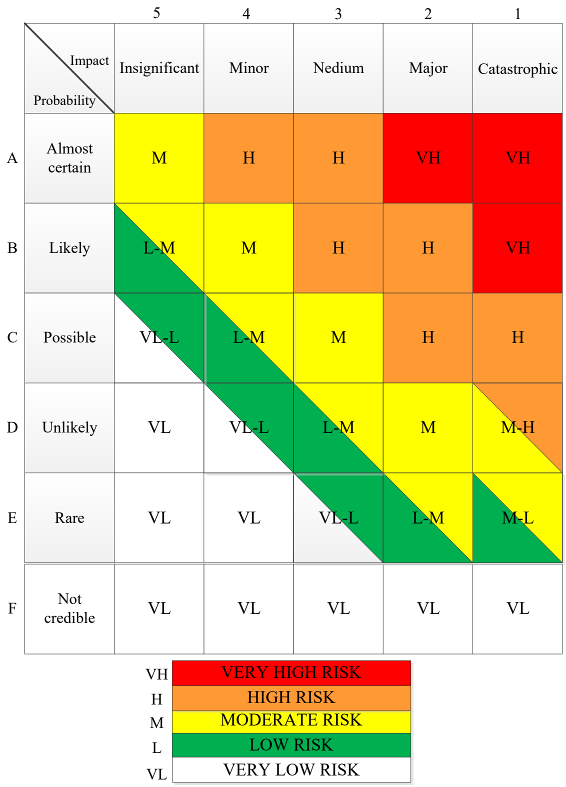

Figure 11 An example matrix given by AGS for landslide risk assessment.

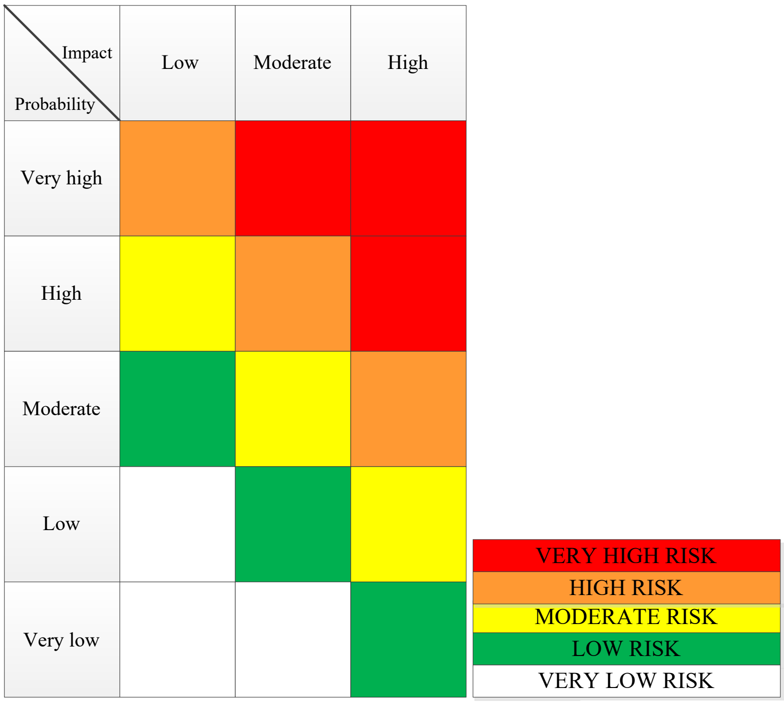

Figure 12 An example risk matrix given by MFBC for landslide risk analysis.

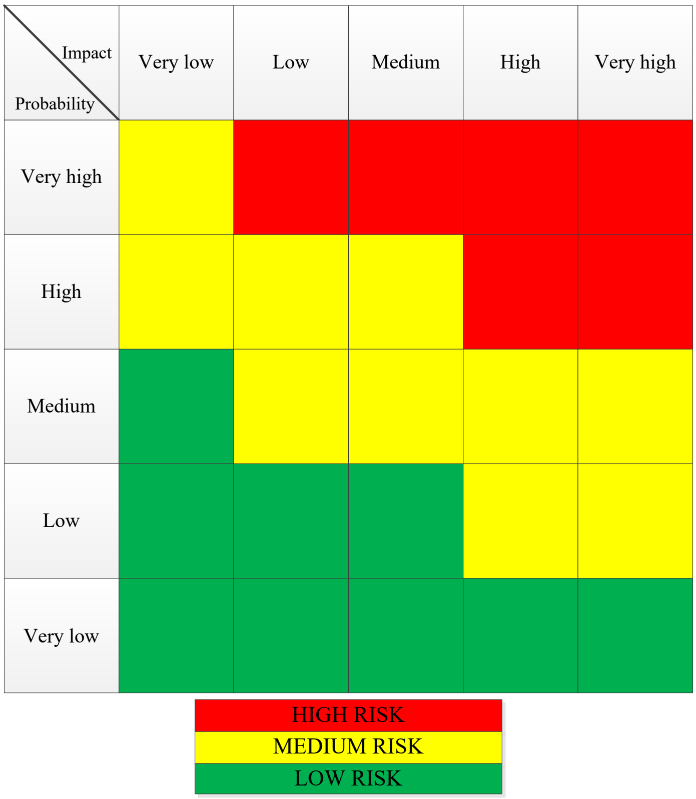

Figure 13 An example risk matrix resulting from the Göta River Commission.

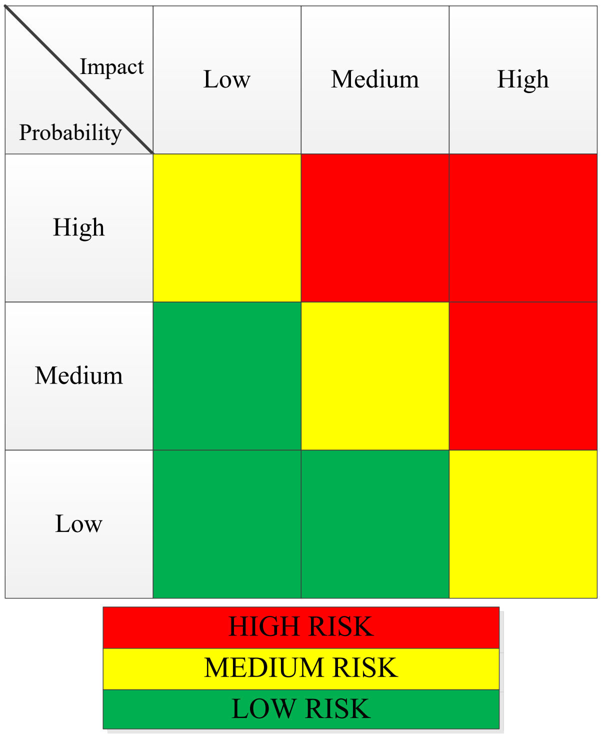

Figure 14 The risk matrix adapted for landslide risk management.

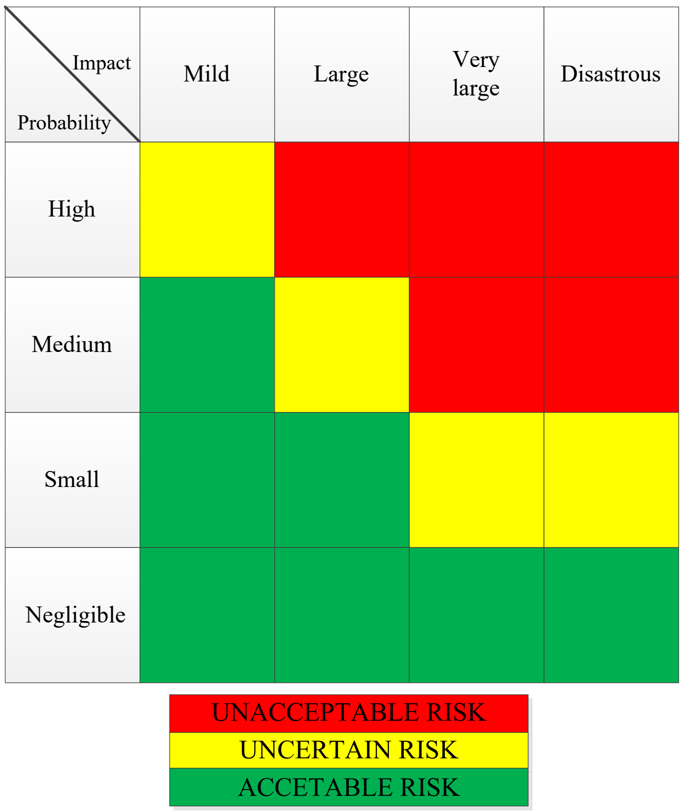

Figure 15 The risk matrix given by SGI for landslide risk assessment.

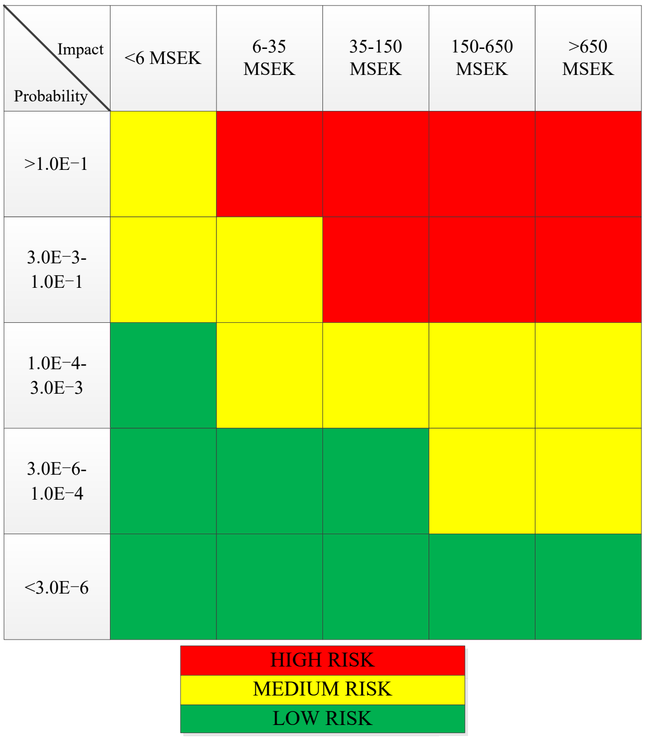

Figure 16 The risk matrix used by SGI for landslide risk assessment in the Göta River Valley.

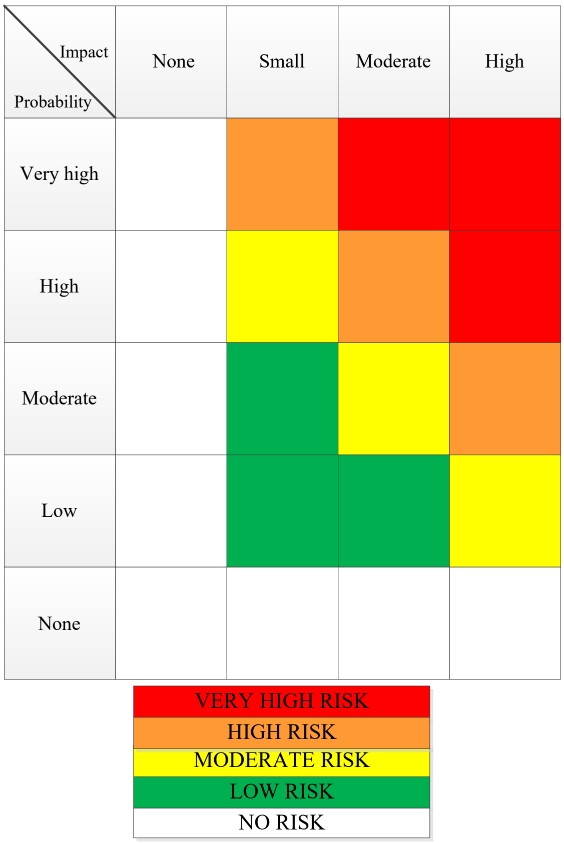

Figure 17 An example risk matrix used for risk assessment of environmental hazards.

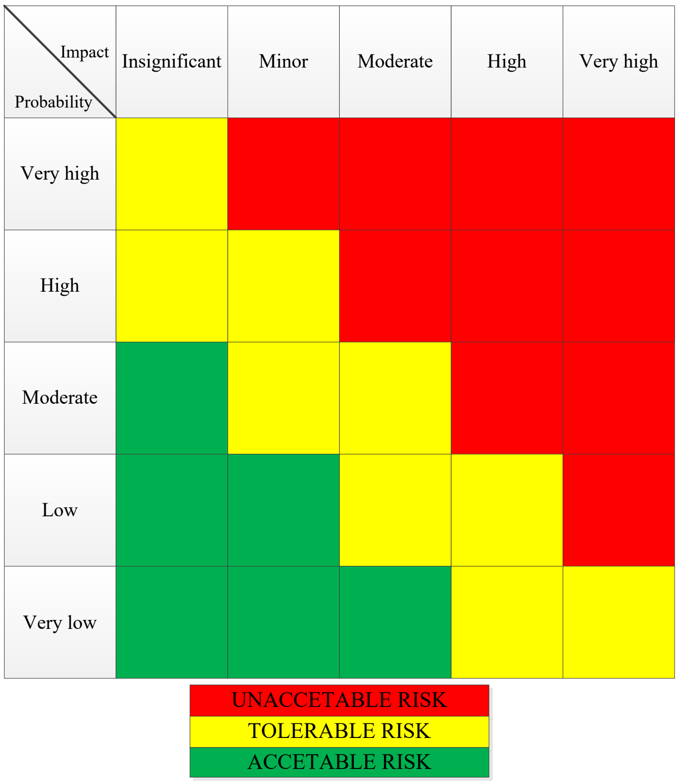

Figure 18 An example matrix used for risk assessment in a high hazard area.

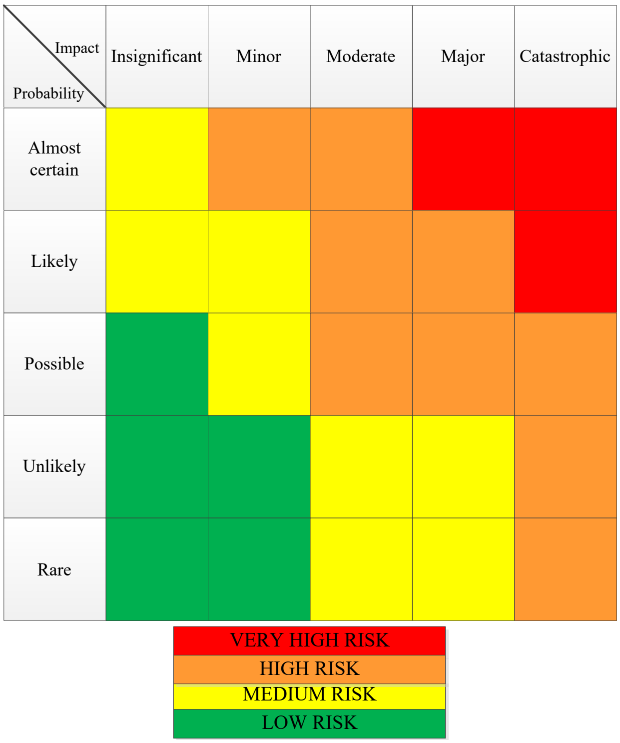

Figure 19 The risk matrix in the AS/NZS.

		1	2	3	4	5
	Impact / Probability	Insignificant	Minor	Moderate	Major	Severe
5	Almost certain	5	10	15	20	25
4	Likely	4	8	12	16	20
3	Possible	3	6	9	12	15
2	Unlikely	2	4	6	9	10
1	Rare	1	2	3	4	5

Figure 20 The risk matrix used for survey of fall from height. The number in each cell represents in the conventional way the product of scores (1-5) assigned to the individual probability and impact ratings.

Impact / Probability	1	2	3	4	5	6
E	IV	III	II	I	I	I
D	IV	III	III	II	I	I
C	V	IV	III	II	II	I
B	V	IV	III	III	II	I
A	V	V	IV	III	II	II

Figure 21 Part example of a risk matrix in IEC/ISO 31010.

	Impact / Probability	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5	Almost certain	MODERATE	HIGH	EXTREME	EXTREME	EXTREME
4	Likely	MODERATE	MODERATE	HIGH	EXTREME	EXTREME
3	Possible	MODERATE	MODERATE	HIGH	EXTREME	EXTREME
2	Unlikely	LOW	LOW	MODERATE	HIGH	EXTREME
1	Rare	LOW	LOW	MODERATE	HIGH	HIGH

Figure 22 The risk matrix used by the NHS.

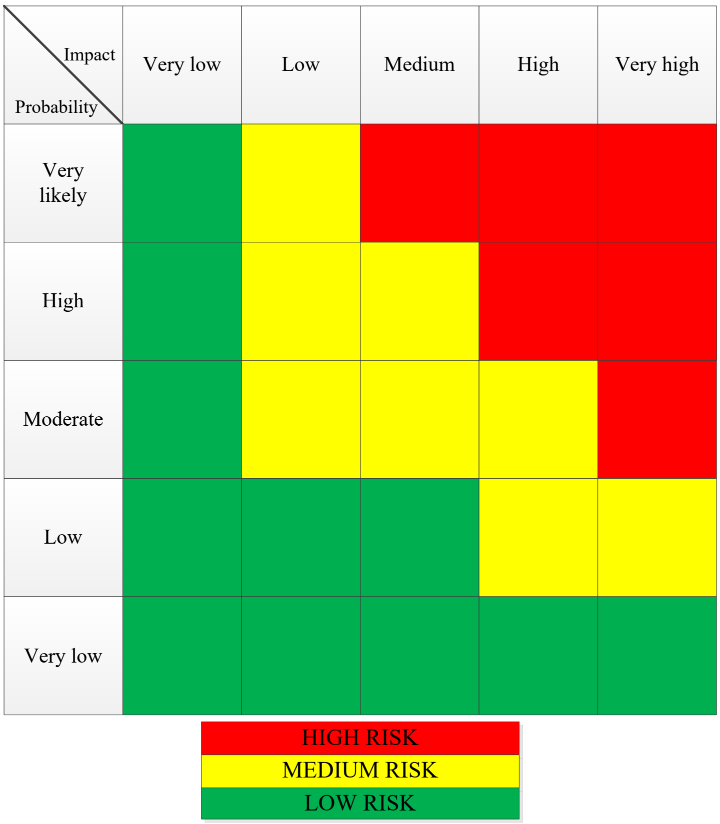

Figure 23 The risk matrix used by NESC.

The 23 risk matrices as illustrated in Table 1 and Figures 1 to 23 were randomly selected from the literatures via "Google scholar", 16 of which were applied for risk assessment in geotechnical engineering, while the rest for problems in other disciplines. As these risk matrices were randomly selected, the information they deliver is expected to be typical and universal to some extent. Figures 24 to 26 show the statistics of these risk matrices in terms of the size, the risk levels and their combination, respectively.

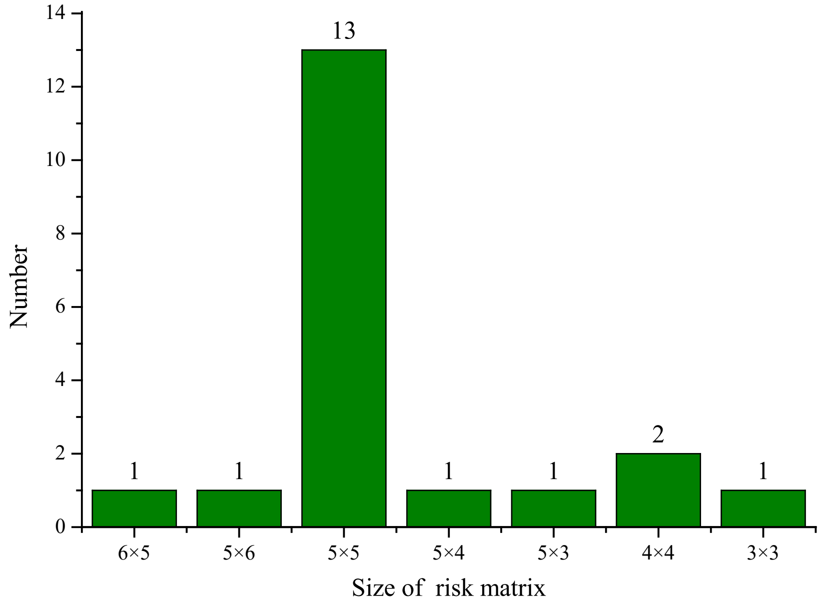

Figure 24 The statistic of the risk matrices in terms of the size.

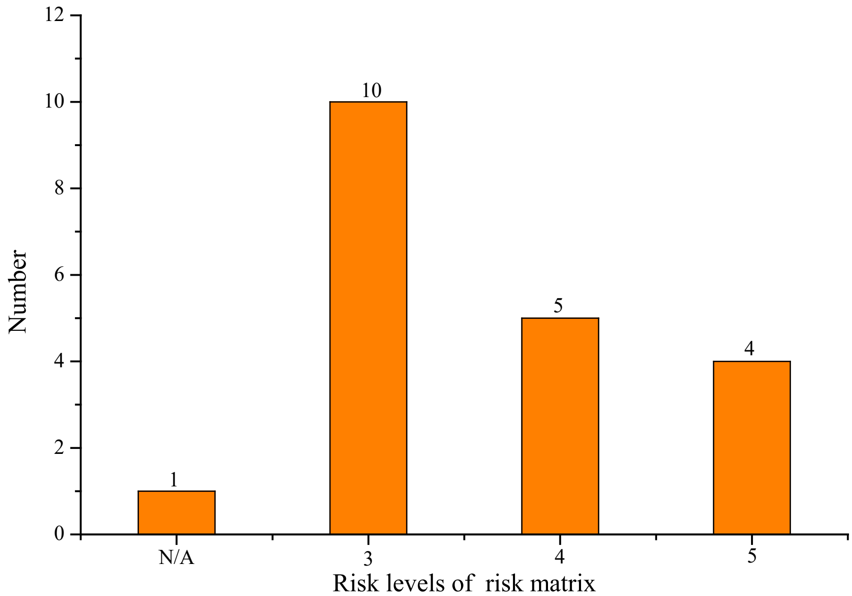

Figure 25 The statistic of the risk matrices in terms of risk levels.

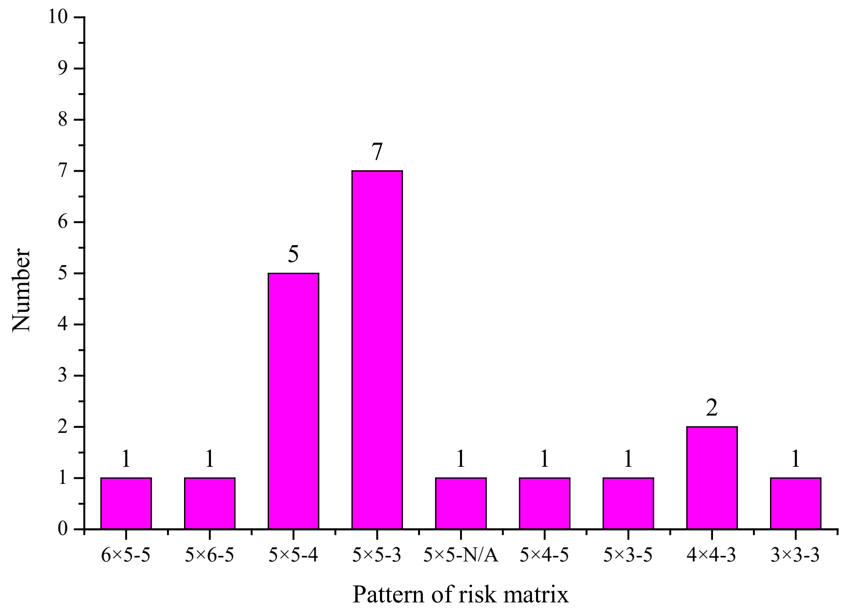

Figure 26 The statistic of the risk matrices in terms of the detailed pattern.

As can be seen from Figure 24, the selected risk matrices all range in size from 3×3 to 6×6, and the 5×5 risk matrices, which take a percentage of 65% of the total matrices, are most commonly used. This finding is consistent with the previous studies (Ball & Watt, 2013; DNV, 2010; Eskesen et al., 2004; Elmontsri, 2014; IEC, 2009; Moradi & Farsangi, 2014; NORSOK Standard Z-013, 2001; Norwegian Standard NS 5815, 2006).

As can be seen from Figure 25, the risks are generally classified into 3, 4 or 5 levels, of which the three-level rating is most common. Combined with Figure 26, it can be concluded that the 5×5 risk matrices with 3 and 4 risk ratings are most and second-most commonly utilized in practice, respectively.

However, when it comes to the details, except of the risk matrices shown in Figures 10 and 16, which are both used by Swedish Geotechnical Institute (SGI) for landslide risk assessment in the Göta river valley, no two risk matrices are exactly the same. Even the matrices given by the same institute for the same purpose in the same district have some differences. For instance, the risk matrices shown in Figures 10 and 13 are both provided by SGI for landslide risk assessment in the Göta river valley. Although they are the same in size and are both classified into three risk levels, there still exists some discrepancies with respect to risk rating of every cell. Thus, concerning the details of a risk matrix, including its size, number of risk levels and risk rating for each cell, neither a general rule nor a typical example is available.

Table 1 Risk matrices used in different fields of geotechnical engineering.

No.	Disciplines	Applied fields	Characteristics		Project details	Makers	Intended users	References	Notes
			Size	Risk levels					
1	Geotechnical engineering	Construction work	5×5	3	An example matrix	Norwegian Standard NS 5815, Norway	The builder and contractor	Norwegian Standard NS 5815, 2006	See Fig. 1
2		Offshore oil exploitation	4×4	3	An example matrix	Norwegian Technology Centre (NTC), Norway	Decision makers on offshore work related to oil exploitation	NORSOK Standard Z-013, 2001	See Fig. 2
3		Offshore risers, pipelines and umbilicals	5×5	3	A recommended matrix	DET NORSKE VERITAS (DNV), Norway	Operator of risk assessment related to offshore pipelines	DNV, 2010	See Fig. 3
4		Tunnels	5×5	4	An example matrix	Working Group 2 of the International Tunnelling Association (ITA)	Desion makers, owners and consultants	Eskesen et al., 2004	See Fig. 4
5		Tunnels	5×5	4	Rock TBM tunnelling	Shahid Bahonar University of Kerman, Iran	Decision makers for geotechnical risks	Moradi & Farsangi, 2014	See Fig. 5
6		Highways	5×5	3	N/A	The Federal Highway Administration, the U. S.	Highway operators	Cox, 2008	See Fig. 6
7		Airports	5×5	3	N/A	The Federal Aviation Administration, the U. S	Airport operators	Cox, 2008	See Fig. 7
8		Dams	4×4	3	N/A	The Bureau of Reclamation, the U. S.	Decision makers for dam safety	Scott, 2011	See Fig. 8
9		Excavations	5×5	4	Deep and high stress mining excavations	SRK Consulting Ltd, South Africa	Decision makers in mining companies	Joughin, 2017	See Fig. 9

10		Landslides	5×5	3	In the Göta River Valley	Swedish Geotechnical Institute (SGI), Sweden	The Swedish Government	Tremblay et al., 2013	See Fig. 10
11		Landslides	6×5	5	An example matrix	The Australian Geomechanics Society (AGS), Australia	Decision makers	AGS, 2000	See Fig. 11
12		Landslides	5×3	5	An example matrix	Ministry of Forests of British Columbia (MFBC), Canada	Forest road practitioners	Ministry of Forests of British Columbia, 2002	See Fig. 12
13		Landslides	5×5	3	An example matrix	Swedish Geotechnical Institute (SGI), Sweden	Decision makers for landslide risk management	Andersson-Sköld et al., 2013	See Fig. 13
14		Landslides	3×3	3	Used for buildings, land-use areas, roads and other linear elements	Academy of Sciences of the Czech Republic, Czech Republic	Decision makers for landslide risk management	Klimeš & Blahůt, 2012	See Fig. 14
15		Landslides	4×4	3	Landslides of contaminated soils into rivers	Swedish Geotechnical Institute (SGI), Sweden	Decision makers for landslide risk management	Göransson et al., 2009	See Fig. 15
16		Landslides	5×5	3	In the Göta river valley	Swedish Geotechnical Institute (SGI), Sweden	The municipalities in the Göta river valley	Andersson-Sköld et al., 2014	See Fig. 16
17	Others	Environmental hazards	5×4	5	An example matrix	University of Thessaly, Greece	Decision makers on environmental hazards	Dalezios, 2017	See Fig. 17
18		Environmental hazards	5×5	3	An example matrix	Institute of Earth Sciences, University of Lausanne, Switzerland	Decision makers	Jaboyedoff et al., 2014	See Fig. 18
19		Hydro-geomorphologic	5×5	4	N/A	The Standards Australia (AS)/Standards New Zealand	Decision makers	dos Santos et al., 2014	See Fig. 19

	disasters				(NZS)			
20	Fall from height	5×5	N/A	Surveys at three locations	Middlesex University, Centre for Decision Analysis and Risk Management, the U. K.	Postgraduate and undergraduate students	Ball & Watt, 2013	See Fig. 20
21	Electrical and electronic fields	5×6	5	An example matrix	The International Electrotechnical Commission	Decision makers	IEC, 2009	See Fig. 21
22	Health services	5×5	4	N/A	The National Health Service (NHS), the U. K.	Decision makers at NHS	Elmontsri, 2014	See Fig. 22
23	Safety concerns across the NASA agency	5×5	3	N/A	Futron Corporation, Safety & Mission Assurance Directorate of NASA Marshall Space Flight Center, the U. S.	NASA Engineering and Safety Center (NESC)	Malone Jr & Moses, 2004	See Fig. 23

3 Concluding remarks and recommendations

This study makes a literature review on risk matrices used in different fields of geotechnical engineering with respect to their patterns. The following conclusions and recommendations are made:

(1) The 5×5 risk matrices with 3 or 4 risk levels are most commonly used in different fields of geotechnical engineering.
(2) For risk assessment related to tunnels, a 5×5 risk matrix with 4 risk levels is recommended. The example matrix given by Working Group 2 of ITA (Eskesen et al., 2004) can be referenced for establishment of a risk matrix in detail.
(3) For risk assessment related to other fields of geotechnical engineering except of tunnels, no typical example matrix is available. However, a 5×5 risk matrix with 3 or 4 risk levels is recommended.
(4) The selection of risk matrix will vary according to the scope and nature of the project. It is important to note that classifications of probability, consequences and risk rating must be defined for each particular project in consideration of the specific risk policy, previous empiricism and information available.

References

Andersson-Sköld, Y., Bergman, R., Johansson, M., Persson, E., and Nyberg, L. 2013. Landslide risk management—A brief overview and example from Sweden of current situation and climate change. International Journal of Disaster Risk Reduction, 3: 44-61.

Andersson-Sköld, Y., Falemo, S., and Tremblay, M. 2014. Development of methodology for quantitative landslide risk assessment—Example Göta river valley. Natural Science, 6(03): 130-142.

Ball, D.J., and Watt, J. 2013. Further thoughts on the utility of risk matrices. Risk Analysis, 33(11): 2068-2078.

Cox, L.A. 2008. What's wrong with risk matrices? Risk Analysis, 28(2): 497-512.
dos Santos, P.P., Tavares, A.O., and Zêzere, J.L. 2014. Risk analysis for local management from hydro-geomorphologic disaster databases. Environmental Science & Policy, 40: 85-100.

DET NORSKE VERITAS (DNV). 2010. Risk assessment of pipeline protection. Recommended Practice DNV-RP-F107.

Dalezios, N.R. 2017. Environmental hazards methodologies for risk assessment and management. IWA Publishing.

Eskesen, S.D., Tengborg, P., Kampmann, J., and Veicherts, T.H. 2004. Guidelines for tunnelling risk management: International Tunnelling Association, Working Group No. 2. Tunnelling and Underground Space Technology, 19(3): 217-237.

Elmontsri, M. 2014. Review of the strengths and weaknesses of risk matrices. Journal of Risk Analysis and Crisis Response, 4(1): 49-57.

Göransson, G.I., Bendz, D., and Larson, P.M. 2009. Combining landslide and contaminant risk: a preliminary assessment. Journal of soils and sediments, 9(1): 33.

International Electrotechnical Commission. 2009. Risk Management-Risk Assessment Techniques. IEC/ISO 31010.

Jaboyedoff, M., Aye, Z., Derron, M., Nicolet, P., and Olyazadeh, R. 2014. Using the consequence-frequency matrix to reduce the risk: examples and teaching. In Proceedings of the International Conference on Analysis and Management of Changing Risks for Natural Hazards, Padua, Italy, pp. 18-19.

Joughin, W.C. Dealing with uncertainty and risk in the design of deep and high stress mining excavations. In Proceedings of the eighth international conference on deep and high stress mining 2017, pp. 28-30.

Klimeš, J., and Blahůt, J. 2012. Landslide risk analysis and its application in regional planning: an example from the highlands of the Outer Western Carpathians, Czech Republic. Natural Hazards, 64(2): 1779-1803.

Ministry of Forests of British Columbia. 2002. Forest road engineering guidebook. Forest Practices Code of British Columbia.

Malone Jr, R.W., and Moses, K. 2004. Development of risk assessment matrix for NASA Engineering and Safety Center.

Moradi, M.R., and Farsangi, M.A.E. 2014. Application of the risk matrix method for geotechnical risk analysis and prediction of the advance rate in rock TBM tunneling. Rock mechanics and rock engineering, 47(5): 1951-1960.

NORSOK Standard Z-013. 2001. Risk and emergency preparedness analysis. Rve. 2, 2001-09-01.

Norwegian Standard. NS5815. 2006. Risk assessment of construction work. 1st edition, ICS 93.010.

Sub-Committee on Landslide Risk Management, Australian Geomechanics Society. 2000. Landslide Risk Management Concepts and Guidelines. Australian Geomechanics Society, Technical Report, 3.

Scott, G.A. 2011. The practical application of risk assessment to dam safety. In Geo-Risk 2011: Risk Assessment and Management. pp. 129-168.

Tremblay, M., Svahn, V., and Lundström, K. 2013. Landslide risk assessment in the Göta River valley: effect of climate changes. In Proceedings of the 18th international conference on soil mechanics and geotechnical engineering, ICSMGE, Paris, pp. 2269-2272.

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