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DESCRIPTION OF FAILURES AND RISKS THAT ARE EMERGED FROM LANDSLIDE MEASUREMENT ACTIVITIES IN INFRASTRUCTURE DEFORMATIONS

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Original scientific paper
The occurrence of frequency of landslides that are considered parts of natural hazards continues to increase and their negative consequences affect human life, environment and urban infrastructures. In consideration of landslides that have remarkable destructive effects among the natural hazards, the importance of the engineering measurements and calculations in the geodetic network that is constructed in the landslide area plays an important role. A lot of factors affect the accuracy of the engineering measurements and calculations. Failure Mode Effect Analysis (FMEA) and Pareto Analysis methods are the effective tools in revealing these factors and alleviating their risks by taking relevant precautions. It may be possible to alleviate the risks to a minimum in the engineering measurements and calculations relevant to landslide parameters by these methods.We have attempted to alleviate failures and to take relevant precautions with FMEA and Pareto Analyses for the failures resulted in engineering measurements.

Keywords: *FMEA analysis; infrastructure deformations; geodetic and topographic measurements; landslide monitoring; Pareto analysis*

Opis promašaja i rizika nastalih zbog aktivnosti mjerenja odrona zemlje u deformacijama infrastrukture

Izvorni znanstveni članak
Učestalost pojave odrona zemlje koji se smatraju prirodnim opasnostima i dalje se povećava i njihove negativne posljedice utječu na ljudski život, okoliš i gradsku infrastrukturu. S obzirom na odrone zemlje koji među prirodnim nesrećama završavaju značajnim destruktivnim posljedicama, važnost tehničkih mjerenja i izračuna u geodetskoj mreži koja se izrađuje u područjima s odronima od velikog je značaja. Među velikim brojem čimbenika koji djeluju na točnost tehničkih mjerenja i proračuna, metode Failure Mode Effect Analize (FMEA) i Pareto Analize su učinkoviti alati u otkrivanju tih čimbenika i ublažavanju njihovih rizika poduzimanjem odgovarajućih mjera predostrožnosti. Tim je metodama moguće gotovo potpuno smanjiti rizike u tehničkim mjerenjima i proračunima relevantnim za parametre odrona. Pokušali smo ublažiti propuste nastale tehničkim mjerenjima i poduzeti odgovarajuće mjere predostrožnosti primjenom FMEA i Pareto analize.

Ključne riječi: *deformacije infrastrukture; FMEA analiza; geodetska i topografska mjerenja; nadziranje odrona zemlje; Pareto analiza*

1 Introduction

Human beings, in some cases are prone to a lot of natural hazards such as earthquake, flooding, landslide, tsunami, overflows, avalanches, etc. that are resulted from meteorological events that are realized in the atmosphere as well as in the active faults in the internal structure of the earth from the formation of the earth to the present time. While looking at the existing data relevant to natural hazards, we realize that there has been considerable increase in the amount of natural hazards, however, number of affected people and substantial losses have also been increased [1÷7]. Among one of the prime reasons of the increases in natural hazards is growth in population, expansion in industrialization, and the development of settlement and urbanization in the areas in which natural hazards occur frequently or there is the potential for natural hazards [8].

The landslides that make a substantial part among the natural hazards, may be defined as downward movement of rocks, debris and earth materials or mixture of those masses with effect of the attraction of gravity [9] (Fig. 1). The landslides may be propagated with geomorphologic, geologic, atmospheric and climatic effects and in addition to this fact may be triggered with various activities of human-beings [10]. The landslides that take an important part among natural hazards with regard to their devastating negative effects, cause substantial losses of human life and properties in the stricken areas as well as cause considerable destructions in the infrastructure of the urbans, in railways, highways and agricultural fields [1, 5, 11, 12]. The studies of expert researchers and engineers in landslide issues play an important role in defining the incurred losses and potential losses in the landslide stricken areas, or in the landslide potential areas as well as avoiding the damages in advance of their occurrence. In order to define the area geometry and the borders by engineering geodetic measurement studies in the landslide area or in the potential landslide area, as well as monitoring the landslide indications and movements by sensitive GPS systems have significant importance.

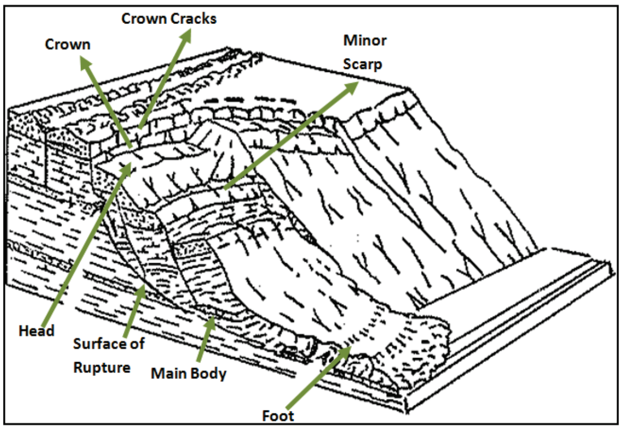

Figure 1 Natural landslide formation and its components [13]

However, after these monitoring studies the calculations of the vertical and horizontal axis parameters (curvature, unit deformation, etc.) of landslides by engineering calculations also becomes very important in description of landslide mechanism [11]. In addition, definition of geologic, geophysical, geomorphologic structure of the concerned settlement area also becomes very essential with regard to protection of the infrastructures in the area.

Specially in the dense settlement urban areas, landslide relevant risk analysis along side with these research studies play an important role in mitigating the landslide damages and providing life safety of the infrastructures and super structures in the concerned area. Among the major reasons for the landslide emergence in an area: geologic and tectonic features of the area, aggradations of the earth, physical and chemical features of the earth, distribution of rock and earth units in the area, topographic features of the field, beveled structure of the field, climatic and rainfall features of the area, etc. natural causes play an important role. In addition to this fact, humanitarian originated effects such as urbanization and engineering structures, agricultural activities, over ground and underground mining effects , irrigation, etc. in the area play important roles in landslide generation [8].

Fall down and breakage type landslides may be encountered frequently in the nature. In the case of soil or rock fall down incidents, the mass might do the free fall, bouncing, leaping or rolling movement in the air and mutual effects among the moving units during this type of fall down are rather very low [9]. On the other hand, gliding type landslide types are emerged due to reduction in the shearing strength along with the few gliding sections. Moreover, these sections have the detectability and predictability features as well [9]. Landslide types in the form of creeping emerge due to the moving or replacement of hillside spillages and loose materials over the wet or dry earth.

Basic reason of these movement types is the water, hence they are encountered frequently in the high rainfall areas. [9]. The landslides in the nature may be generated mostly in those three basic groups, however they also could be encountered in the combination form of those three groups due to the factors such as materials diversity that form the geologic and geomorphologic earth in the different periods of the landslide propagation process [9].

2 The importance of topographic measurement studies in landslide analysis

The share and place of topographic measurement activities is quite important in landslide analysis and other studies that are made towards landslides. In realization of landslide analysis, finding out topographic elevation values, calculations of hill side slope, calculation of horizontal and vertical axis curvature radius and finding the unit deformation amount in the area, the distances of the hillside crests are the important parameters that have to be included in definition of landslide geometry and carried out landslide risk analysis for urban infrastructures in the concerned area.

In the post review of the landslide potential areas or landslide stricken areas, it is also understood that the landslides are the kind of natural hazards that might occur also due to geologic, geophysical, geomorphologic and environmental features of the field as well as topographic features. Among those topographic features, specially field slope values, unit extension deformation and topographic hillside curvature (concave, convex, etc.) are the critical parameters that expert scientists studying in this field take primarily care of [8, 11]. A well designed and well optimized geodetic network is first and foremost needed in the area in order to calculate and define those parameters in a sensitive manner in the landslide analysis in which those topographic parameters have important value. In a durable geodetic network that is to be carried out in the landslide area in that manner and equipped with the bent bars, the periodical observations made by the static measurement technique and by GPS technique will provide sensitive definition of those parameters. Furthermore, it might be appropriate to use sensitive leveling technique in the geodetic network that is to be constructed in the landslide zone in order to define the vertical axis topographic parameters in the geodetic measurement points. Specially, in the urban settlement areas that are constructed in the landslide potential zones, advance precautions might be taken against the probable damages and hazards on the infrastructure units such as highways, railways, sewerage lines, utility pipelines, electrical installation lines, etc. with the aid of those type observations. Conducting some control stages and risk analysis will be inevitable in advance and during the topographic measurements in order to make the geodetic topographic measurement and observations in a controlled manner and serve the intended objectives coherently. As we point out hereby one of the important analysis techniques that will make the basis of this study is Failure Mode Effect Analysis (FMEA) and following step implementation technique of the Pareto Analysis.

3 Failure Mode Effect Analysis (FMEA) and Pareto analysis

This risk analysis method provides the means for detecting the potential failures before their transformation into harms and eliminating and controlling the risks in an order starting from the major ones in the implemented systems and planning [14÷16]. Furthermore, apart from the other risk analysis methods, it will also provide the means for assessment of detectability of the risks in advance. On the other hand Failure Mode Effect Analysis (FMEA) as having a wide utilization area, is also a firm analysis technique in order to estimate the risks in advance and to prevent the potential harms before they occur [16÷18]. The implementation of this technique will be more appropriate during the design and development stage of the projects. The cost of the consumption resources will be lowest in the design and development stage compared to other system implementation stages. It is realized due to the corrective and preventive actions that are initiated after detected non-conformities during the overall system operation. The benefits of the system can be cited as follows:

- To develop the quality, reliability and safety of the formed system.
- To define priorities of the activities in the system.
- To reveal the potential failure modes and their similarities that will provide the means to assess their effects
- To enable the definition of potential critical and important characteristics.
- To enable a suitable platform for failure prevention.

- To enable the definition of corrective and preventive actions.
- To monitor the risk mitigating activities.

Definition of a competent study team will be necessary in the FMEA studies as per the selected system because the definition of the potential problems and ascertaining of the Risk Priority Numbers (RPN) require knowledge and experience. During the design of the systems, the failures that the FMEA analysis comprises are handled in a certain system sequence and formula. However, there are 3 main elements in this analysis to define the priorities of the risks and failures. Those are defined as follows: Occurrence, Severity and Detection [14, 15, 17, 19, 20]. Among these elements, occurrence indicates the existence probability, defect frequency, (gradation system from 1 to 10 is used); severity or weight indicates the seriousness (effect) of the failure-defect, (gradation system from 1 to 10 is used), detectability means the level of difficulty in detecting the failure (gradation system of from 1 to 10 is used). However , the detectability element is also important due to its advantage of representing the failure's definition before happening. There are many alternative methods for defining the values of these elements.

Besides, the most customary way is to use numerical calculation tables (risk value tables). When the above mentioned three risk factor elements are assessed all together, it represents the risk priority level (RPL) for each failure-defect type. And this value defines the numerical level of critical risk [16, 19]. In calculation of risk priority level (RPL), the assigned values of risk factors are taken, that remain in a certain numerical range. Whilst the risks are defined for each failure type, starting from the biggest risk priority level (RPL), it is intended to reduce this risk level to an acceptable lowest level in a short term. On the other hand in the long term for eliminating these risks to initiate, the relevant and suitable corrective actions are intended. Risk priority levels (RPL) for FMEA is calculated by multiplying the Occurrence (*O*), Severity (*A*), and Detectability (*S*) levels [14, 17, 19÷22]. In Tab. 1 Risk Priority Levels (*RPL*) assessment table is given.

$$RPL = O\ (Occurrence) * A\ (Severity) * S\ (Detectability) \quad (1)$$

Table 1 Risk priority levels (*RPL*) [8]

Risk priority levels (*RPL*)	Precaution
$RPL < 40$	No need to take action
$40 \leq RPL \leq 100$	Medium risk measures can be taken
$RPL > 100$	Caution needs to be taken, high-risk

Risk priority levels (*RPL*) provide the definition of failures to be given priority in failure improvement studies by making priority rating. Risk priority levels (*RPL*), while enabling the priority rating of failures, on the other hand provide a useful guidance to the relevant people who take part in the post assessment FMEA analysis, RPL values improvement studies.

On the other hand Pareto Analysis, is a kind of analysis method that facilitates the definition of risk priorities and it is used for estimating the percentage sequence and importance rate of any certain risks or problems among the other risks in the project [23]. Furthermore, it is also a kind of risk analysis that enables the formation of cumulative risk values with regard to the pre-defined risk threshold value (between70 % and 80 %) and hence it enables us to find out which type of risks are under the threshold value or above the threshold value and helps us to take relevant precautionary measures.

4 Landslide monitoring and risk definition studies towards measurements of urban infrastructure deformations

In the landslide incurred areas or landslide potential areas in urban settlements, the measurement processes for the landslides in ultimately accurate manner are very important as well as in order to make calculations of landslide topographic parameters in horizontal and vertical axis in precise manner. However, the above defined measures present importance as well in order to take precautionary measures in the infrastructures and superstructures of the urban settlements.

Definition and assessment of the failures and risks that might emerge from the topographic measurements and calculations in the landslide regions by systematic analysis methods such as FMEA Analysis and Pareto Analysis consist of the major part of the analysis. With the intended measurement processes and precautionary measures as a result of the risks and failures that are found here, horizontal parameters (horizontal gliding curvatures, horizontal gliding unit deformation) and vertical parameters (slope changes, vertical slope calculations, etc.) could be calculated in a more precise manner. If we come across the abnormal values in those calculated parameters, it will specially ease to take precautionary measures in urban settlement construction areas with landslide potential. In our study, as an implementation by utilizing the experiences and researches in scientific and vocational studies, due care is given to the three numbers of probable main risk and failure elements that the numbers of the risks could be increased in further studies, as shown in Tab. 1.

FMEA analysis, and main concentration is given to 11 numbers of the sub-parts of those risks In addition, in order to eliminate or mitigate those risks, vocational experiences are utilized and relevant solutions are attempted to offer. With the proposed solutions it is attempted to lower the Risk Priority Numbers (*RPN*). The studied risk and failures as per the process sequence numbers are given below:

- The risks and failures arising from the realized measurements for the definition of landslide geometry and borders that are the part of landslide monitoring and measurement studies toward infrastructure protection in the landslide potential settlement areas (E10)
- The risks and failures arising from the measurement devices that are used in landslide monitoring and measurement studies toward infrastructure protection. (R10)

Table 2 FMEA Table that is prepared for the landslide monitoring and risk definition activities towards infrastructure deformations in the urban settlements

FMEA Table for the Landslide Monitoring and Risk Definition Activities Towards Infrastructure Deformations in the Urban Settlements. Year 2016

RPL=OCCURRENCExSEVERITYxDETECTABILITY

OCCURRANCE	SEVERITY	DETECTIBILITY	RPL VALUE (Risk Priority Level)
1-2 Very Low	1-2 No effect or slightly	1. Sure 2.Very High	RPL<40 No need to take precaution LOW RISK
3-4 Low	3-4 Slightly	3. High 4. Above Average	40≤ RPL ≤100 Caution can be taken MEDIUM RISK
5-6 medium	5-6 Medium	5. Medium 6.Low Level	RPL >100 Caution must be taken. HIGH RISK
7-8 High	7-8 Serious	7. Very Low 8. Little	
9-10 Very High	9-10 Very serious	9.Very Little 10. Undetectible	

Process No	POTENTIAL CAUSES OF FAILURE: Failure	Limit	RISK EVALUATION: Reference	Occurrence	Severity	Detectability	R.P.L	Importance	PRECAUTION ACTIVITY	RESPONSIBILITY	RISK EVALUATION: Reference	Occurrence	Severity	Detectability	R.P.L
The risks and failures, arising from the realized measurements for the definition of landslide geometry and borders that are the part of landslide monitoring and measurement studies toward infrastructure protection in the landslide potential settlement areas (E10)	The risks and failures, arising from the measurement devices that are used in landslide monitoring and measurement studies toward infrastructure protection. (R10)	International Measurement standards, legal requirements and laws		5	7	3	105	UNACCEPTABLE HIGH RISK	Measurement, calibration and usage controls have to be made for the devices (GPS, Total station,..etc) that are used in Monitoring and Measurement studies in high risk potential land slide areas and sensitive results have to be obtained and assessed.	Surveying Engineers	3	2	2	12	LOW RISK
	The errors and failures, arising from the geodetic network geometry in the landslide monitoring and measurement studies toward infrastructure protection. (R20)	International Measurement standards, legal requirements and laws		5	7	5	175	UNACCEPTABLE HIGH RISK	Network geometry has to be improved and sensitive results has to be obtained in order to make optimization studies for the geodetic network that is constructed in landslide monitoring studies. Hence the zones of having land slide potential has to be defined and infra structures to be protected in dwelling areas.	Surveying Engineers	2	2	2	8	LOW RISK
	The errors and failures, arising from the definition of landslide potential areas and landslide mapping studies toward infrastructure protection. (R30)	International Measurement standards, legal requirements and laws		5	5	5	125	UNACCEPTABLE HIGH RISK	If the failures and mistakes that are relevant to surveying studies, exceed the the failure limit, they have to be renewed as per the mapping legal requirements in the the zones of having landslide potential	Surveying Engineers	2	2	2	8	LOW RISK
	The risks and failures, arising from the faulty displacement and deformation measurements that take place in the field among the monitoring points. (R40)	International Measurement standards, legal requirements and laws		6	8	4	192	UNACCEPTABLE HIGH RISK	The measurements that are made by extensometer has to be repeated in the the urban and outskirt constructed zones of having landslide potential toward protecting infrastructures.	Civil Engineers, Geology Engineers, Geophysic Engineers,Surveying Engineers	3	2	2	12	LOW RISK
	The errors and failures, arising from the angular rotation measurements of monitoring points that are set in the landslide area. (R50)	International Measurement standards, legal requirements and laws		6	6	3	108	UNACCEPTABLE HIGH RISK	The measurements that are made by inclinometer has to be repeated in the urban and outskirt constructed zones of having landslide potential toward protecting infrastructures.	Civil Engineers, Geology Engineers, Geophysic Engineers,	2	3	2	12	LOW RISK
	The errors and failures, arising from the human originated rough measurement mistakes in the landslide parameter definition measurements. (R 60)	International measurement standards, legal requirements and laws		4	8	3	96	MEDIUM RISK	The measurements that are made in piezometric ways has to be repeated as per measurement rules in the urban and outskirt constructed zones of having landslide potential toward protecting infrastructures.	Civil Engineers, Geology Engineers, Geophysic Engineers,	2	2	2	8	LOW RISK
The errors and failures, arising from the landslide parameter calculations toward infrastructure protection in urban and rural areas having landslide potential. (E20)	The errors and failures, arising from the miscalculation of landslide vertical axis parameters (slope, curvature calculations,..etc) in the land-slide potential area. (R70)	International Measurement standards, legal requirements and laws		5	6	5	150	UNACCEPTABLE HIGH RISK	The failures that are emerged in the calculation of vertical parameters (slope, curvature,..etc) in landslide zones has to be reviewed, the mistakes has to be corrected and relevant measurements have to be repeated.	Civil Engineers, Geology Engineers, Geophysic Engineers,	2	2	2	8	LOW RISK
	The errors and failures, arising from the miscalculation of landslide horizontal axis parameters (horizontal gliding curvature, horizontal gliding unit deformation ,…etc) in the landslide potential area. (R80)	International Measurement standards, legal requirements and laws		5	8	4	160	UNACCEPTABLE HIGH RISK	The failures that are emerged in the calculation of horizontal parameters (horizontal sliding curve, horizontal sliding unit deformation..etc) in landslide zones has to be reviewed, the mistakes has to be corrected and relevant measurements have to be repeated.	Civil Engineers, Geology Engineers, Geophysic Engineers,	2	3	2	12	LOW RISK
The errors and failures, arising from the project originate miscalculations in the landslide potential area toward infrastructure protection.(E30)	The risks and failures, arising from the property and field usage projects in the landslide areas. (R90)	International Measurement standards, legal requirements and laws		5	5	3	75	MEDIUM RISK	In these zones, the cadastral measurements for property and land usage that are made after the landslide has to be repeated as per the mapping legal requirements and the legal rights has to be restored.	Surveying Engineers	2	2	1	4	LOW RISK
	The errors and failures arising from the super structure design activities in the landslide potential areas. (R100)	International Measurement standards, legal requirements and laws		5	6	3	90	MEDIUM RISK	In these regions,while the buildings are constructed, the positioning of buildings, dimensioning of the building, floor and wall coating,slopes in the installation systems, has to be designed and measured properly.	Civil Engineers, Geology Engineers, Geophysic Surveying Engineers.Architects, City and Area Planners.	2	1	2	4	LOW RISK
	The errors and failures arising from the infrastructure units design activities (highways, railways , facility pipe lines, bridge, culvert,…etc) in the land-slide potential areas (R 110).	International Measurement standards, legal requirements and laws		4	5	4	80	MEDIUM RISK	In design studies in these zones, if any zone with landslide potential is detected either the route change has to be made, or necessary measurements are made and relevant precautions have to be taken as per the legal requirements.	Civil Engineers, Geology Engineers, Geophysic Engineers,Surveying Engineers	2	2	2	8	LOW RISK

Table 3 Components of high risk error by 75 % threshold value of the risks in the generated Pareto chart (high and medium risks)

Components of High Risk Error by 75 % Threshold Value of the Risks in the generated Pareto Chart (High and Medium Risks)						
SEQUENCE NO	FAILURE MODE-	PROCESS NO	RPL* VALUE	RISK(%)	CUMULATIVE RISK %	RISK STATE
1	The risks and failures, arising from the faulty displacement and deformation measurements that take place in the field among the monitoring points. (R40)	80	192	14.2	14.2	UNACCEPTABLE HIGH RISK
2	The errors and failures, arising from the geodetic network geometry in the landslide monitoring and measurement studies toward infrastructure protection. (R20)	40	175	12.9	27.1	UNACCEPTABLE HIGH RISK
3	The errors and failures, arising from the miscalculation of landslide horizontal axis parameters (horizontal gliding curvature, horizontal gliding unit deformation ,…etc) in the landslide potential area. (R80)	20	160	11.80	38.9	UNACCEPTABLE HIGH RISK
4	The errors and failures, arising from the miscalculation of landslide vertical axis parameters (slope, curvature calculations,..etc) in the land-slide potential area. (R70)	30	150	11.1	50.0	UNACCEPTABLE HIGH RISK
5	The errors and failures, arising from the definition of landslide potential areas and landslide mapping studies toward infrastructure protection. (R30)	70	125	9.2	59.2	UNACCEPTABLE HIGH RISK
6	The errors and failures, arising from the angular rotation measurements of monitoring points that are set in the landslide area. (R50)	50	108	8.0	67.1	UNACCEPTAB LE HIGH RISK
7	The risks and failures, arising from the measurement devices that are used in landslide monitoring and measurement studies toward infrastructure protection. (R10)	10	105	7.7	74.9	UNACCEPTABLE HIGH RISK
8	The errors and failures, arising from the human originated rough measurement mistakes in the land-slide parameter definition measurements. (R 60)	60	96	7.1	82.0	MEDIUM RISK
9	The errors and failures arising from the super structure design activities in the landslide potential areas. (R100)	100	90	6.6	88.6	MEDIUM RISK
10	The errors and failures arising from the infrastructure units design activities (highways, railways , facility pipe lines, bridge, culvert,…etc) in the landslide potential areas (R 110).	110	80	5.9	94.5	MEDIUM RISK
11	The risks and failures, arising from the property and field usage projects in the landslide areas. (R90)	90	75	5.5	100.0	MEDIUM RISK

- The errors and failures, arising from the geodetic network geometry in the landslide monitoring and measurement studies toward infrastructure protection. (R20)
- The errors and failures, arising from the definition of landslide potential areas and landslide mapping studies toward infrastructure protection. (R30)
- The risks and failures, arising from the faulty displacement and deformation measurements that take place in the field among the monitoring points. (R40)
- The errors and failures, arising from the angular rotation measurements of monitoring points that are set in the landslide area. (R50)
- The errors and failures, arising from the human originated rough measurement mistakes in the landslide parameter definition measurements. (R 60)
- The errors and failures, arising from the landslide parameter calculations toward infrastructure protection in urban and rural areas having landslide potential. (E20)

- The errors and failures, arising from the miscalculation of landslide vertical axis parameters (slope, curvature calculations, etc.) in the landslide potential area. (R70)
- The errors and failures, arising from the miscalculation of landslide horizontal axis parameters (horizontal gliding curvature, horizontal gliding unit deformation, etc.) in the landslide potential area. (R80)
- The errors and failures, arising from the project originated miscalculations in the landslide potential area toward infrastructure protection. (E30)
- The risks and failures, arising from the property and field usage projects in the landslide areas. (R90)
- The errors and failures arising from the super structure design activities in the landslide potential areas. (R100)
- The errors and failures arising from the infrastructure units design activities (highways, railways, facility pipe lines, bridge, culvert, etc.) in the landslide potential areas (R 110).

Those indicated failures and risks have been listed as per the risk priority numbers (RPN) and risk importance ratings in Tab. 2 of Pareto analysis. In this study, while conducting Pareto Analysis, critical threshold value is accepted as 75 %, as the result of this analysis relevant graphic is depicted in Fig. 2.

Following the Pareto Analysis, the high risks are re-assessed among themselves again with Pareto Analysis of 75 % critical threshold value, the results are given in Tab. 3. The graphic that is obtained as the result of this analysis is depicted in Fig. 3.

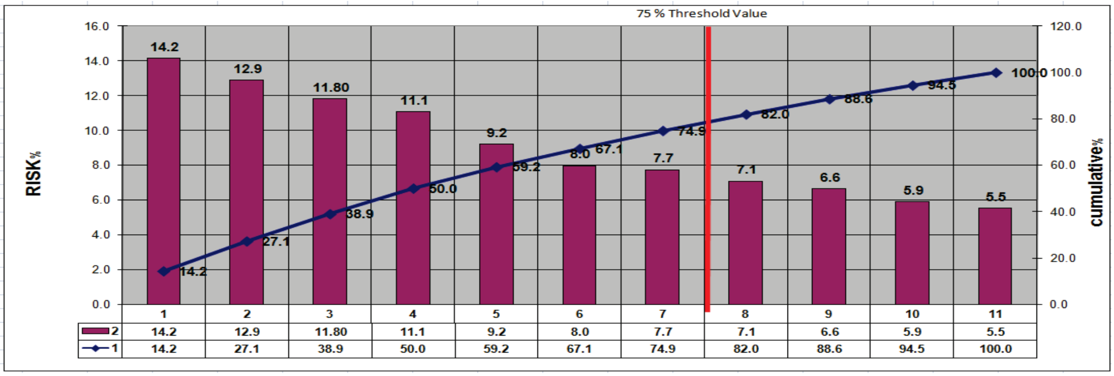

Figure 2 Pareto diagram resulting after Pareto analysis data evaluation (high and medium risks)

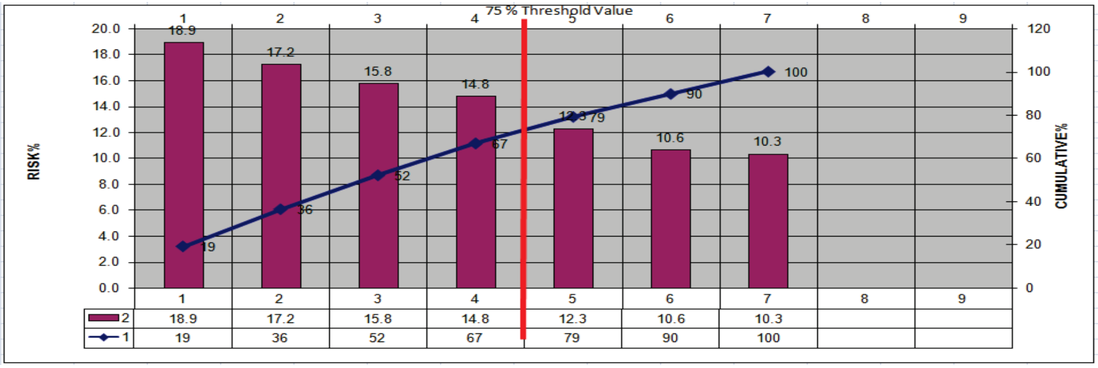

Figure 3 Pareto diagram resulting after Pareto analysis data evaluation for high risks

5 Conclusion

The landslides are among the natural disasters that play negative detrimental role in the society life with regard to life and property safety. Specially, in the urban areas where vital activities are sustained, the dimensions of these negative effects increase considerably.

Furthermore, these adverse incidents cause devastating effects in the infrastructure and superstructure of the urban areas as well as impose negative impacts on the economy of human society. For that reason, engineering measurements, calculations and design services become very important in order to take early precautions in the landslide potential areas.

Potential failures and risks that might emerge during the measurements, calculations and design services that are made in the landslide areas, are defined and analyzed with systematic FMEA and Pareto Analysis methods. Since these works will serve for mitigating the harms in the landslide stricken area, they are regarded very useful and important. In this study, it is shown that systematic FMEA and Pareto Analysis methods may be implemented successfully with the integration of engineering measurement and calculation services on the landslide cases that take part among the major natural disasters. As the result of the studies, and with utilizing the relevant vocational and expert knowledge, the relevant important conclusions are obtained and shown in Tabs. 2, 3 and 4. According to these results the following findings are set forward:

- The risks and failures, arising from the faulty displacement and deformation measurements that take place in the field among the monitoring points. (R40)

- The errors and failures, arising from the geodetic network geometry in the landslide monitoring and measurement studies toward infrastructure protection. (R20)
- The errors and failures, arising from the miscalculation of landslide horizontal axis parameters (horizontal gliding curvature, horizontal gliding unit deformation, etc.) in the landslide potential area. (R80)
- The errors and failures, arising from the miscalculation of landslide vertical axis parameters (slope, curvature calculations, etc.) in the landslide potential area. (R70)

Table 4 Components of high risk error by 75 % threshold value of the risks in the generated Pareto chart (high risk elements in their own error)

Components of High Risk Error by 75 % Threshold Value of the Risks in the generated Pareto Chart (High Risk Elements in Their Own Error)						
SEQUENCE NO	FAILURE MODE-	PROCESS NO	RPL* VALUE	RISK(%)	CUMULATIVE RISK %	RISK STATE
1	The risks and failures, arising from the faulty displacement and deformation measurements that take place in the field among the monitoring points. (R40)	80	192	18.9	19	UNACCEPTABLE HIGH RISK
2	The errors and failures, arising from the geodetic network geometry in the landslide monitoring and measurement studies toward infrastructure protection. (R20)	40	175	17.2	36	UNACCEPTABLE HIGH RISK
3	The errors and failures, arising from the miscalculation of landslide horizontal axis parameters (horizontal gliding curvature, horizontal gliding unit deformation ,…etc) in the landslide potential area. (R80)	20	160	15.8	52	UNACCEPTABLE HIGH RISK
4	The errors and failures, arising from the miscalculation of landslide vertical axis parameters (slope, curvature calculations,..etc) in the landslide potential area. (R70)	30	150	14.8	67	UNACCEPTABLE HIGH RISK
5	The errors and failures, arising from the definition of landslide potential areas and landslide mapping studies toward infrastructure protection. (R30)	70	125	12.3	79	UNACCEPTABLE HIGH RISK
6	The errors and failures, arising from the angular rotation measurements of monitoring points that are set in the landslide area. (R50)	50	108	10.6	90	UNACCEPTABLE HIGH RISK
7	The risks and failures, arising from the measurement devices that are used in landslide monitoring and measurement studies toward infrastructure protection. (R10)	10	105	10.3	100	UNACCEPTABLE HIGH RISK

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