FORMATION MECHANISM OF DEBRIS FLOWS IN ROODBARAK SUB-BASIN, MAZANDARAN, IRAN

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Abstract: In this study through field observations, 9 debris flows were investigated and their morphometric characteristics were determined in Roodbarak sub-basin. The most important morphometric characteristics of debris flows in this region are dip of debris flow's head, dip of debris flow's slope, length of crossing part, debris flow's height and size of debris flow's base. In order to analyze is these morphometric parameters acquired from debris flows of Roodbarak sub-basin, linear regression has been used for a meaningful analysis between parameters. According to the results of linear regression, maximum coefficient of determination of the size of debris flow's base is computed with the independent variable of debris flow's height (0.89) and after that with the length of crossing part (0.55) that shows more justification and determination of variation in the size of debris flow's base with these two parameters. After these two parameters, the coefficient of determination for slope's dip is 0.37 and the weakest coefficient of determination for dip is the one between head and slope of the debris flow having the current base. The results of quantitative analyses between the volume of debris and other independent variables also show that with a coefficient of determination of 0.95, the variable related to the length of crossing part has the most correlation with dependent variable (the volume of debris). Afterwards, the coefficient of determination for the crossing part was determined 0.82. Using the factor analysis, the most important factors in variation of the size of debris flow's base and debris volume were determined as the respond variables. Regarding to the results of factor analysis by rotation of varimax, 3 effective components on variation of the base size of debris flows in Roodbarak sub-basin were determined that the first component has a dip of 0.95 for debris flow's base, justifying 45.5 percent of changes of variance and is the most effective component on the respond variable. In this component, the height of debris flow and the length of crossing part with coefficient of 0.97 and 0.88, respectively, have a strong positive relation with the respond variable (the size of debris flow's base) and are the most important parameters of variability of this dependent variable. In the first component, slope's dip has a strong negative relation with dependent variable (the size of base); in other words, the size of debris flow' base gets smaller when slope's dip gets increased. For the dependent variable of the volume of debris, two effective variables on this variable were acquired by application of factor analysis; these two components justify 75.2 percent of changes of variance. First component with a coefficient of 0.96 is the principle effective component on variation of debris volume that justifies 54.7 percent of variance changes.

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1. Introduction

According to most of geomorphologists, debris flows are consisting of disparate alluviums and rock bodies that are deposited on slopes and Galleys route. Impact of sands to each other and the pressure put by water flow from melting the snow and abrupt rains in mountainous regions can easily lead to the movement of these rock bodies; because they have a very weak and irregular maturity (May and Gresswell, 2004). Debris flows are regarded to the massive movement of angular materials with locked up air and water that the characteristics of their movement are completely different from flows of water and wet clays or flat stones on inclined surfaces (Khatibi, 2000). Debris flows are fast movement of massive clastic materials in mountainous regions. To create such a flow, steep slope, loose rock materials and abundant water flow are needed that rarely occur and are unpredictable

(Sidle and Ochiai, 2006). Debris flows have very variable characteristics depend on factors like: the start mechanisms, available materials and the amount of entering water.

Some scientists believe that debris flow is a mass of materials or destructive tiny or large angular elements with water and air that its characteristics are different in various amounts of water, clays, maturity and slope's dip (Dorren, 2004; Davies, 1986). Occurrence and importance of debris flows in any region are depended to climate condition, lithology, tectonic setting, and human activities that active debris flows create problems for agriculture, industry and communication networks (Liu and Li, 2003; Passuto and Soldat, 2004; Boelhouwers, 2000; Xilin and Junzhong, 2003). Debris flows are massive movements of clastic materials towards downstream by the gravity that in terms of flow characteristics have an intermediate properties between sliding events and flooding flows and their maturity is very weak and irregular (May and Gresswell, 2004). Xiling (2003) has used the debris expression for fast movements for clastic rocks and any kind of angular sands on slopes. Economical-social effects and damages of these flows can be catastrophic for human and agriculture; even small mud flows can create serious damages, especially in mountainous regions. Deposited masses of these flows can also indirectly create damages and hazards through closure of rivers, and increase the deposited load of rivers.

Northern watersheds of Alborz Mountains, Mazandaran Province, have the proper condition for the occurrence of any kind of massive movements. Vazrood basin (Roodbarak sub-basin) in northern parts of the Central Alborz Mountains is potentially capable for hazards of slope movements and has encountered many damages. One of common massive movements in this basin is slope debris that has intensely damaged gardens, roads, machines, animals and humans. Natural disasters in the region, like June 1954, killed 30 domestic animals. Another event in July 1989 killed several animals and in May 2005 closed 100 meters of the Roodbarak road. Several factors with complex mechanisms are involved in formation of slope debris in the region. The most important factors are:

Geologic and tectonic factors
Climate factors (effects of rain and melting of snow – Temperature)
Topographic factors (height – dip)
Physical, chemical and mechanical properties of rocks
Human activities

Movement of angular rock clasts (debris) on slopes by the gravity force is one of the most important and predominant processes on slopes of mountains in Vazrood basin. Considering the predominance of mechanical weathering in some parts of basin and formation amplification of debris flow, formation of active debris flows in heights of more than 1600 m due to anthropogenic activities, effects of land use changes on the processes of debris flow and the effects of these slope hazards on valleys morphology and rivers dynamics in the study area, investigation of mechanisms of debris flow formation in Vaz basin need to be done. Detection of these mechanisms can help us to properly investigate the spatial range of occurrence and to analyze their systems relation to human activities in the region.

2. Study area

Vaz basin with an area of 143.93 km^2 is located in northern slopes of Alborz Mountains in southern Chamestan, Nour City, and Mazandaran Province, Iran. This basin is inclined N-S that its runoff flows to the Mazandaran Sea. Southern part of Vazrood basin (Sarab) is wider than its northern part (runoff of basin) and is located between longitudes of 59 52 1 and 52 12 56. The more it goes towards the east, the narrower gets the basin. Basin's latitude is also between 36 25 17 and 37 14 17. Vazrood in north ends to Jorband village, in east to Basins of NaplarRood and AlashRood, in south to the basin of NoorRood (of Haraz's sub-basins), and in west to the basin of LavichRood. Vazrood steam is the main branch of Vaz basin that has a length of more than 23 km flowing in the main valley of the basin. Two main branches of Vazrood are Xenasara stream (eastern branch) and DovlehSara stream (western branch) that in Vazbala village meet each other and form Vazrood. This study deals with the formation mechanisms of slope debris in Roodbarak basin that has an area of 15 km^2 and located at western south of Vazrood basin (Figure 1). The length of elevation slope of Roodbarak sub-basin is varying from 2074 to 3567 m.

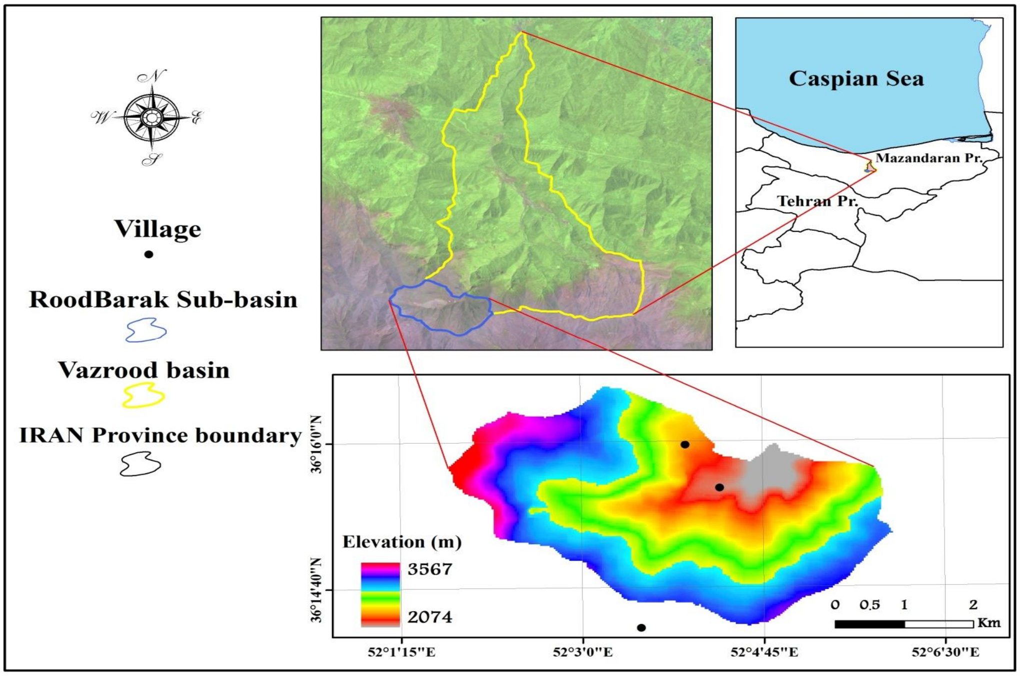

Fig 1. Geographic location of Roodbarak basin

3. Methodology

To analyze the behavior of debris flows, first of all should separately describe general features of debris flows. In all of debris flows, three certain parts are detectable (Figure 2).

A) Deep part which is located on top of the debris flow and has the most shares in supplying debris for the debris flow part, especially in first stages of debris flow formation. Usually, this part in cold seasons of year, covered by snow bodies, has an important role in weathering and formation of debris (Figure 2, A).

B) Crossing part of debris which is a crossing channel excavated by repetitive movements of debris on rocky slopes, and gradually turns into the main supplier of debris (Figure 2, B).

C) Deposition part or the debris flow part that is located at the end of crossing part, and has different length and width (Figure 2, C).

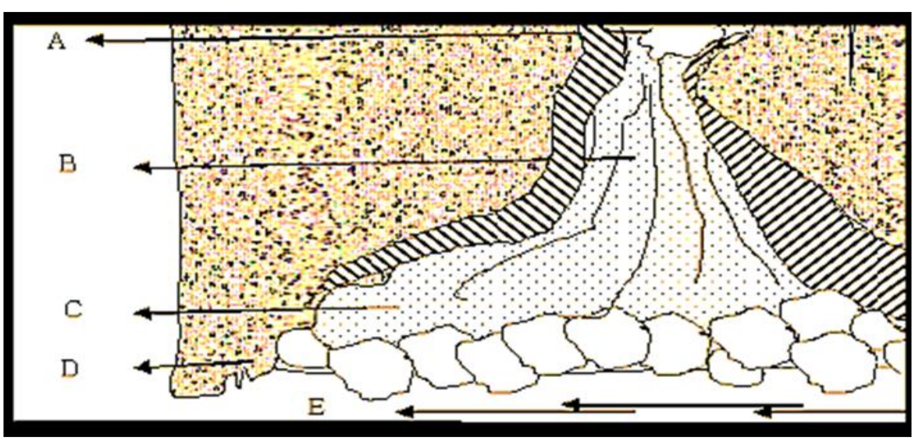

Fig 2. Schematic illustration of a debris flow; A is the deposition part of snow masses supplying the debris; B the crossing part of debris; C debris flow; D rocky wall; E the river rout (after Khatibi, 2000)

3.1 Morphometric debris

In this study, 9 debris Flows have been examined in Roodbarak basin and their morphometric parameters are presented in table 1. Table shows that the most important morphometric characteristics of debris flows in the region are dip of debris flow's head, dip of debris flow's slope, length of crossing part, debris flow's height and size of debris flow's base. A brief description of each debris flow and their schematic illustration are as follows (Figures 3 - 11).

Table 1. Computed morphometric parameters of debris flows in Roodbarak sub-basin

Sample	Range slope (%)	Debris top slope (%)	Debris surface slope (%)	Pathway length (m)	Debris elevation (m)	Debris base (m)
1	90	60	70	11.2	32.3	66
2	75	65	60	21.1	36.2	73.8
3	100	90	63	1.8	9.7	20.4
4	85	51	65	2.2	8.6	25.8
5	100	45	67	4.6	10	26.7
6	110	85	60	2.4	13.5	34.3
7	120	45	46	1.99	7.8	30.3
8	83	67	55	5.6	29.5	81
9	90	70	60	2.04	8.4	33.4

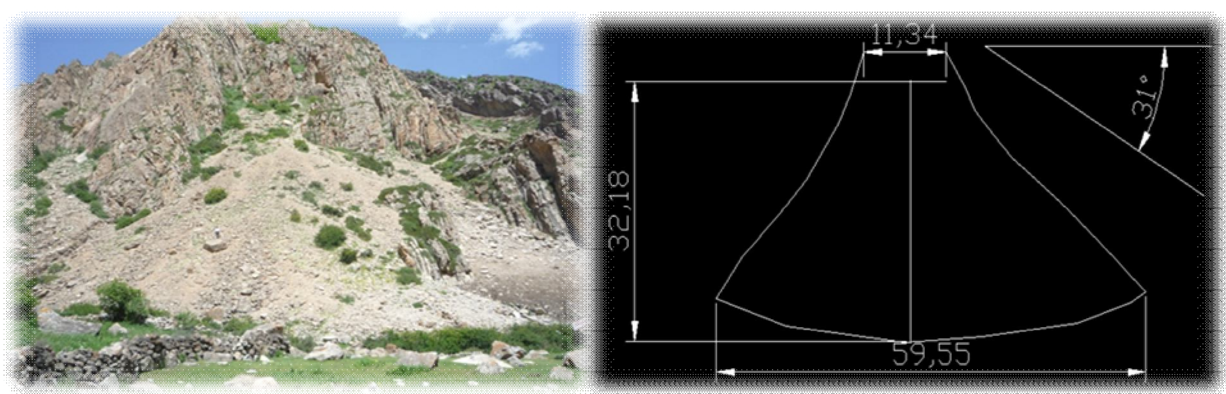

Fig 3. Debris flow 1 (left) and schematic of its (Right)

Regarding to the taken sample, debris flow's height is 32 m, the size of debris flow's base is 66 m, the length of crossing part is 11 m, and the dip of debris flow's slope is 31 degree.

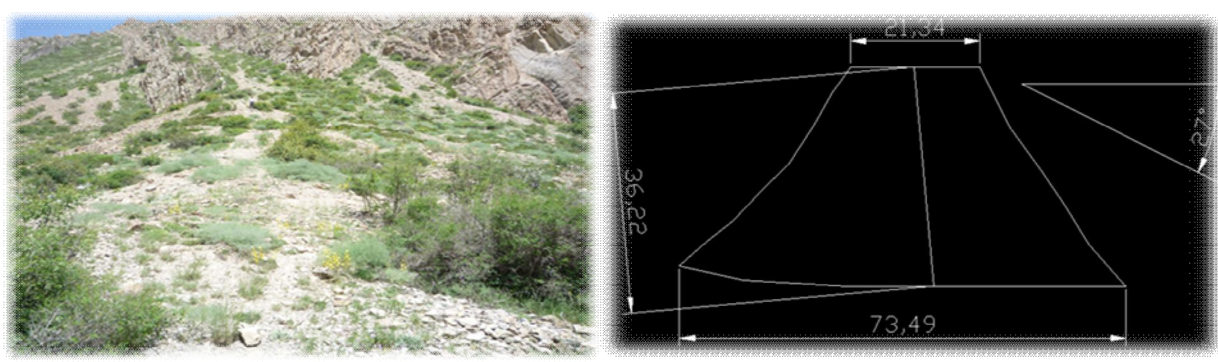

Fig 4. Debris flow 2 (left) and schematic of its (Right)

Regarding to the sample taken form debris flow No.2, debris flow's height is 36 m, the length of debris flow's base is 73 m, the length of crossing part is 21 m, and dip of debris flow's slope is 27 degree.

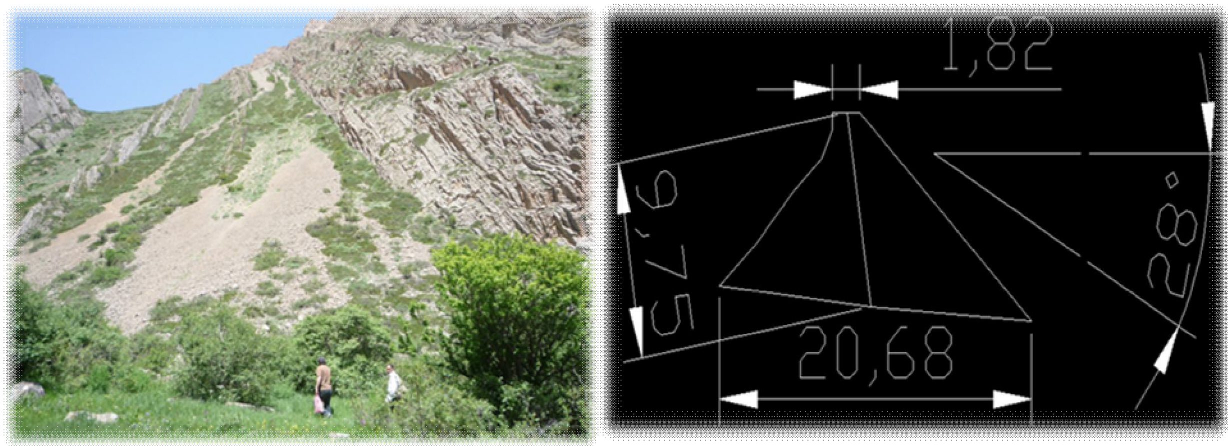

Fig 5. Debris flow 3 (left) and schematic of its (Right)

In debris flow No. 3, the height of debris flow is 9.7 m, the size of base is 20.6 m, the length of crossing part is 1.8 m, and dip of debris flow's slope is 28 degree.

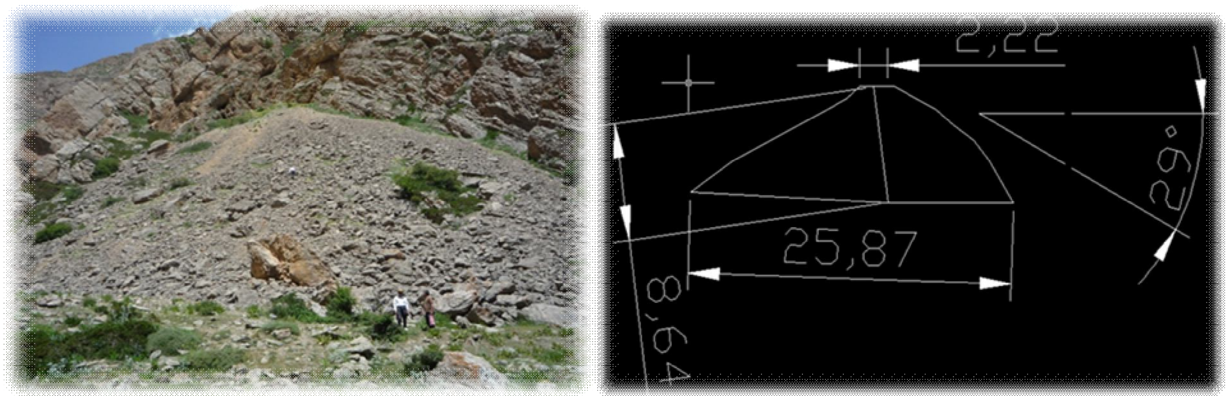

Fig 6. Debris flow 4 (left) and schematic of its (Right)

In this sample, debris flow's height, the length of crossing part and the size of base are 8.6, 2.2 and 25.8 m, respectively, and dip of debris flow's slope is 29 degree.

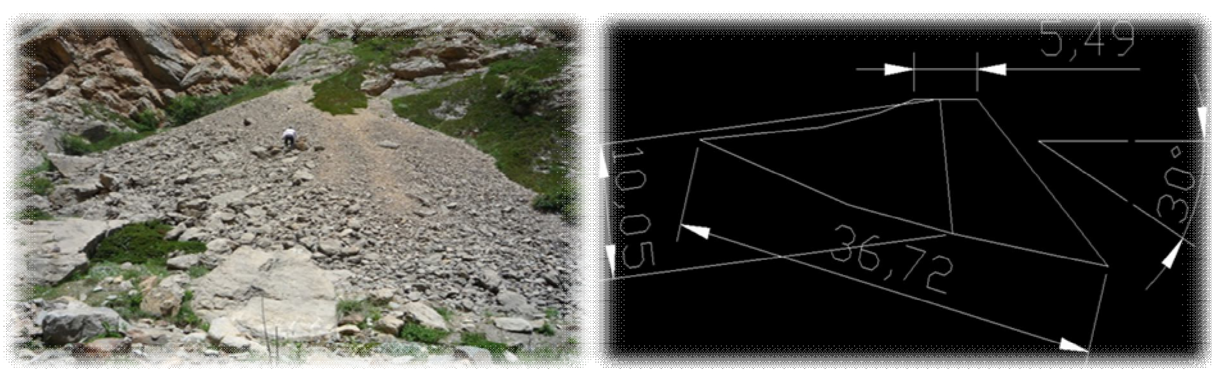

Fig 7. Debris flow 5 (left) and schematic of its (Right)

Regarding to the taken sample, debris flow's height is 10 m, the length of debris flow's base is 36.7 m, the length of crossing part is 5.4 m, and dip of debris flow's slope is 30 degree.

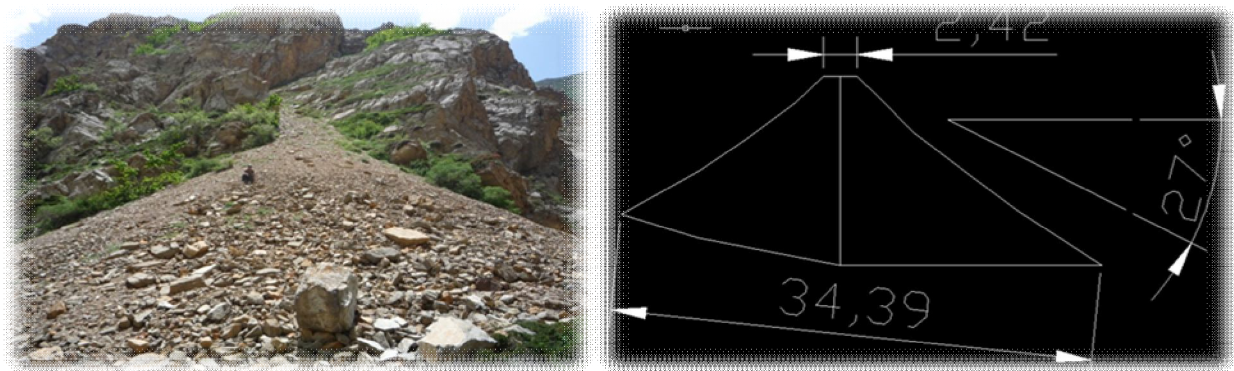

Fig 8. Debris flow 6 (left) and schematic of its (Right)

In sample No. 6, debris flow's height, the length of crossing part, and the length of debris flow's base are 13.5, 2.4 and 34.3 m, respectively, and dip of debris flow's slope is 27 degree.

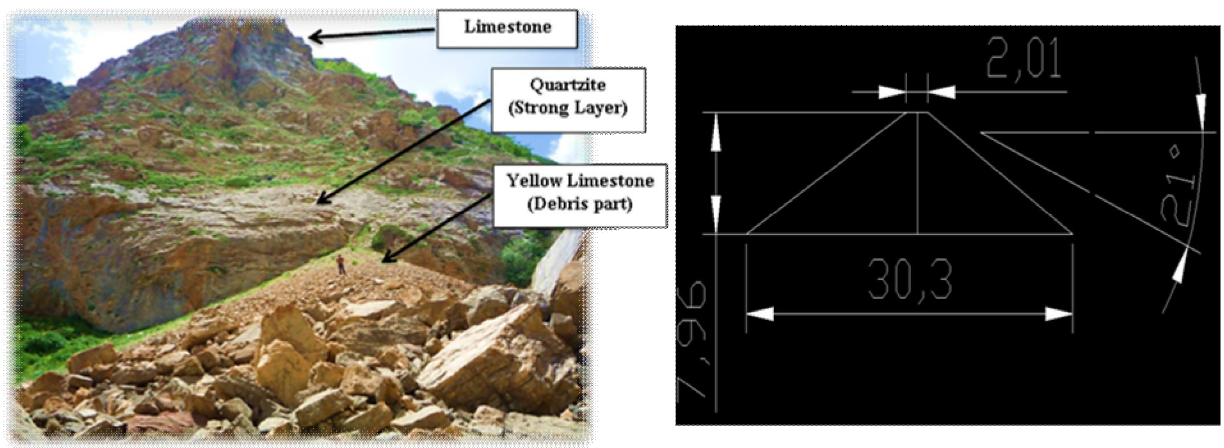

Fig 9. Debris flow 7 (left) and schematic of its (Right)

In sample No. 7, debris flow's height, the length of crossing part and the length of debris flow's base are 7.9, 2, 30.3 m, and dip of debris flow's slope is 21 degree. Three parts can be detected in formation place of this debris flow; the upper part is a yellow limestone, a resistant layer of quartzite is after that and at last a yellow limestone in debris part.

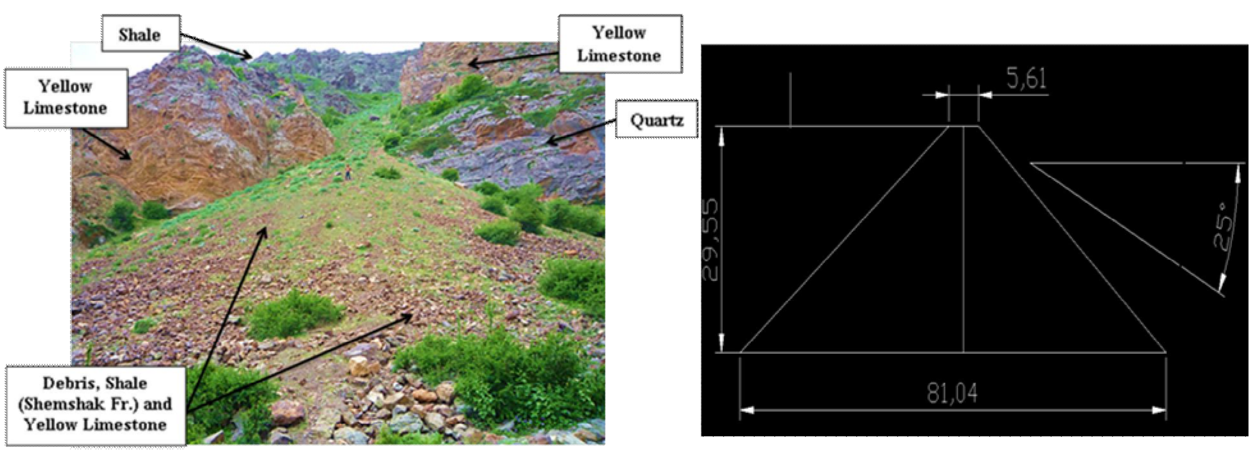

Fig 10. Debris flow 8 (left) and schematic of its (Right)

In debris flow No. 8, debris flow's height is 29.5 m, the length of debris flow's base is 81 m, the length of crossing part is 5.6 m, and dip of debris flow's slope is 25 degree. Regarding to the figure 10, stratigraphic units of the right part of debris flow is in upper part the yellow limestone and in lower part is the quartzite layer; in left side of the debris flow also, upper layer is shale and lower part is yellow limestone. Sedimentary rocks in this debris flow are mainly shale (belongs to the Shemshak formation) and the yellow limestone.

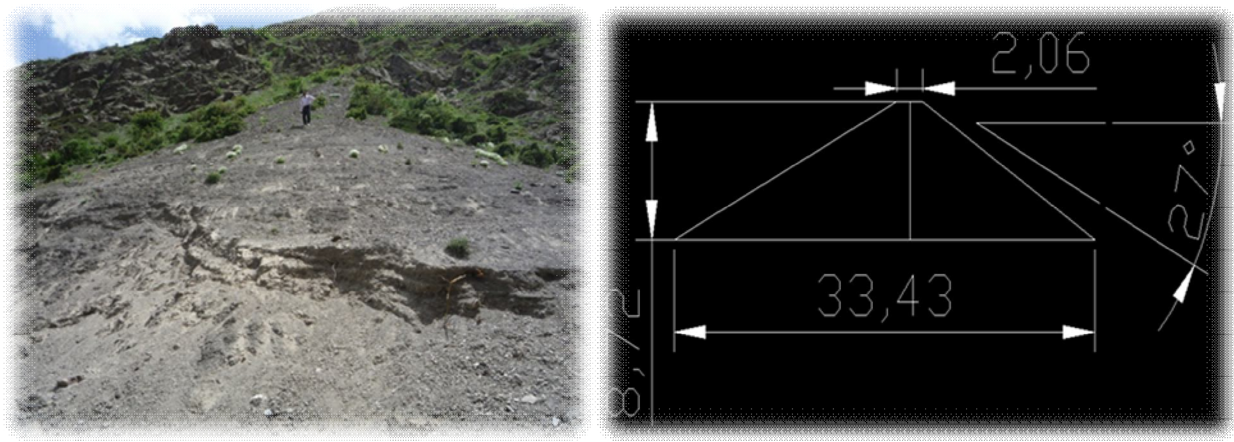

Fig 11. Debris flow 9 (left) and schematic of its (Right)

Considering the characteristics of morphometric parameters acquired from debris flow No. 9, the height of this debris flow is 8.4 m, the length of debris flow's base is 33.4 m, the length of crossing part is 2 m, and dip of debris flow's slope is 27 degree.

To analyze the morphometric parameters of the debris flows in Roodbarak sub-basin (dip of debris flow's head, dip of debris flow's slope, and length of crossing part, debris flow's height and length of debris flow's base), linear regression is used for a reasonable correlation between the parameters. Application of linear regression needs to determine dependant and independent variables; for this purpose, the length of debris flow's base and volume of debris have been selected as dependant variables, and dip of slope, dip of debris flow's head, dip of debris flow's slope, the length of crossing part, and debris flow's height as the independent variables. The lengths of debris flows are the most important part of debris flow and introduce many things related to the debris flows. Variation in their size is an independent variable. The volume of debris flow relates to the morphometric parameters of debris, and variation in any of parameters leads to the variation in volume of debris flow. To acquire the volume of debris flow, Rickman's equation is used: E = [(100 – 2.5 sf). L]. In this Equation, E is Debris flow volume (m^3), sf is debris flow slope (%) and L is length of debris flow pathway (m).

3.2 Factor analysis of morphometric variation of debris

Accurate determination of the most important parameters affecting on variation of the length of debris flow's base can help us to properly know the morphometric sizes of debris, and to analyze the main factors of variation. To detect the main factors affecting on respond variables of debris, factor analysis is applied. Factor analysis is designed for conversion of main variables to one independent variable that is linear combination of main component. New axes (variables) are directed towards the maximum variance. The main component gives information about the most correlated components describing the whole of acquired data from the process of data reduction with a least lose in primary data (Helena et al., 2000).

$$z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \dots + a_{im}x_{mj}$$

In which Z is component's score, a component's weight, x is measured value of variable, i is component's number, j is sample's number, and m is total amount of variables.

Factor analysis follows Principle Component Analysis (PCA). The main aim of this analysis is to reduce the share of less correlated variables for further simplification of the structure of data acquired from principle component analysis. This goal can be achieved by rotation of defined axis (Varimax Rotation) through principle component analysis, and create new variables that are named variation factors (Varifactors or VF). Principle component is a linear combination of visible variables, whereas VF can be invisible, imaginary and hidden variables. In this study, factor analysis is applied for determination of the most effective factors in variation of debris flow's base and the volume of debris as the respond variables.

4. Results

In order to compute the volume of debris flow, Rickman's equation is used and the results are presented in table 2.

Table 2. Volume of materials in debris flows in sub-basin

Sample	Debris flow volume (m^3)	Sample	Debris flow volume (m^3)
1	238	6	78
2	685.8	7	96
3	52.4	8	213.5
4	59.1	9	66.3
5	113.3	-	-

The relation and correlation analyses between independent and dependent variables of debris flows in sub-basin are done by using the coefficient of determination (R2), correlation (R), and the level of significance (Sig) for linear regression results. Tables 3 and 4 show the results. According to the results of linear regression, maximum coefficient of determination of the debris flow's base is computed with the independent variable of debris flow's height (0.89) and after that with the length of crossing part (0.55) that shows more justification and determination of variation in the length of debris flow's base with these two parameters. After these two parameters, the coefficient of determination for slope's dip is 0.37 and the weakest coefficient of determination for dip is the one between head and slope of the debris flow.

The results of quantitative analyses between the volume of debris and other independent variables show that the variable related to the length of crossing part has the most correlation with dependent variable (the volume of debris), and entered into the regression model as the first variable. Considering that the coefficient of determination is computed 0.95, the most variation in volume of debris materials is being justified and determined by this variable. Explanation for the high correlation and coefficient of determination between the respond variable of the volume of debris materials, and also the debris flow's base with independent variable of the length of crossing part is that the higher gets the length of crossing part, the wider gets the area having the main share of snow masses. Furthermore, because this part acts as a leeside and creates a good situation for delaying in melt of snow, it plays an important role in amplification of weathering. In other hand, when the crossing part gets larger, the cross section that is potentially a weathering surface gets wider, thus the amount of debris entering into the debris flow gets increased.

After the length of crossing part, the variable debris flow's height that is a function of slopes length, with a coefficient of 0.82 has a better correlation with the volume of debris materials versus other variables (coefficient of determination of 0.67). Moreover, high correlation between debris flow's height and the length of base (the most correlation between all of variables) show that when debris flow's height increases, difference between temperatures, and also the vertical part of inclined surface increase. If the lithology type is suitable for weathering, the volume of collected debris in slopes increases.

Dip of slope has a coefficient of correlation of 0.6 and coefficient of determination of 0.36 with volume of debris materials. Weakest coefficient of correlation for volume of debris materials is with dip of head and surface of debris flow. Figures 12 and 13 show linear graph between respond and independent variables.

Table 3. Coefficients of correlation and determination between the variable base size of debris flow and independent variables

Independent Variable	R2	R	Sig
Range slope	0.37	0.61	0.01
Debris top slope	0.004	0.067	0.00
Debris surface slope	0.0002	0.008	0.00
Pathway length	0.55	0.74	0.00
Debris elevation	0.89	0.94	0.02

Table 4. Coefficients of correlation and determination between volume of debris materials and independent variables

Independent Variable	R2	R	Sig
Range slope	0.36	0.6	0.00
Debris top slope	0.03	0.51	0.00
Debris surface slope	0.00	0.013	0.01
Pathway length	0.95	0.96	0.02
Debris elevation	0.67	0.82	0.002

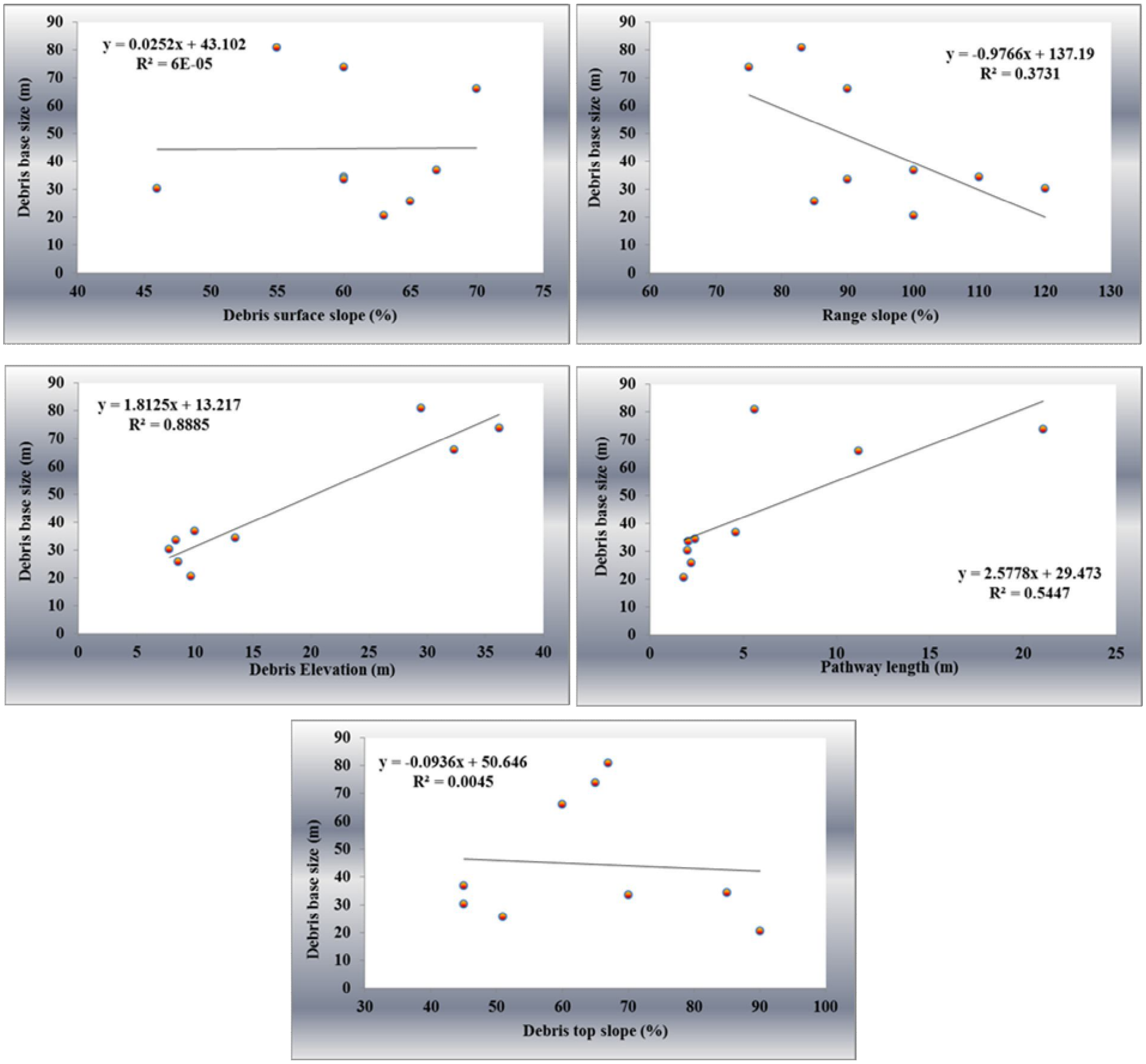

Fig 12. Graph of fitted line and curve of respond variable the length of debris flow's base and independent variables

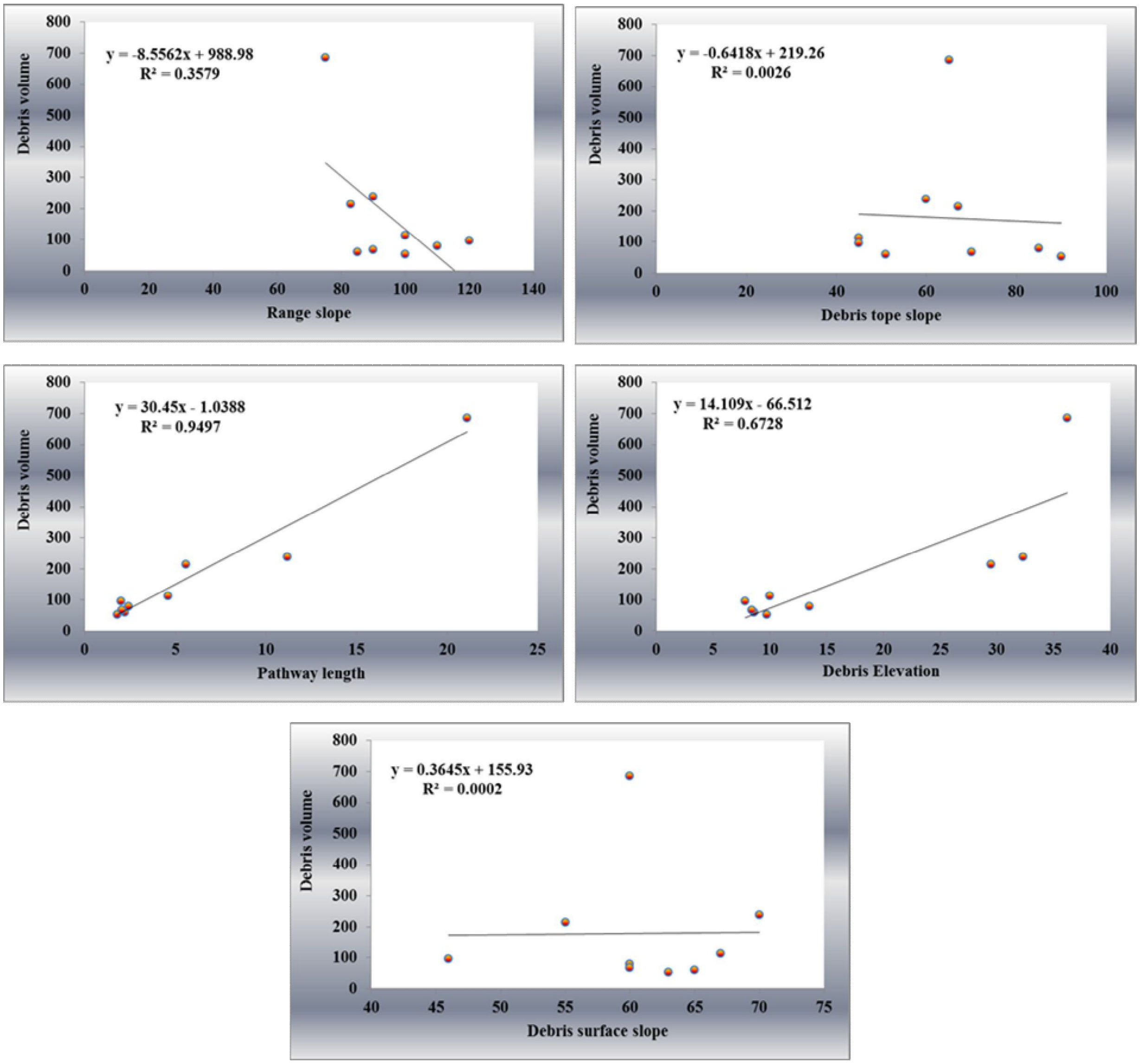

Fig 13. Graph of fitted line and the curve of respond variable the volume of debris materials and independent variables

In this study factor analysis is used for determination of the most important effective factors in variation of the length of debris flow's base and volume of debris as the respond factors, and the results are presented in tables 5 and 6. According to the results of factor analysis by rotation of varimax, three effective components in variation of the size of debris flow's base are acquired in Roodbarak sub-basin that the first component has a coefficient of 0.95 for the size of debris flow's base justifying 45.5 percent of variations of variance, and is the principle effective factor on respond variable. In this component, debris flow's height and the length of crossing part with coefficients of 0.97 and 0.88, respectively, have a strong positive relation with respond variable (size of debris flow's base) and the most important parameters of variation for this dependent variable. Moreover in component 1, slope's dip has a strong negative relation with dependent variable (size of base); the size of debris flow's base decreases with increase of slope's dip.

For the dependent variable of the volume of debris materials, two effective components in variation of this variable are detected by factor analysis. These two components justify 75.2 percent of variation of variance. First component with a coefficient of 0.96 is the principle effective component on variation of the volume of debris flow and justifies 54.7 percent of variation of variance. In this component, two factors of the length of crossing part and debris flow's height with coefficients of 0.97 and 0.91 have a strong positive relation with volume variation of debris materials in the sub-basin. The factor of slope's dip also with a coefficient of -0.74 has a strong negative relation with respond variable (volume of debris flow).

Table 5. Results of factor analysis for effective variables in variation of size of debris flow's base

Variable	Component 1	Component 2	Component 3
Debris flow size	0.95	-0.14	-0.04
Range slope	-0.74	-0.36	-0.16
Debris top slope	-0.016	0.097	0.87
Debris surface slope	0.11	0.86	0.23
Pathway length	0.88	0.19	-0.16
Debris flow elevation	0.97	0.057	0.02
Engine Values	3.3	1.3	1.1
% of Variance	45.5	19.6	16.2
Cumulative %	45.5	65.2	81.4

Table 6. Results of factor analysis for effective variables in variation of the volume of debris materials

Variable	Component 1	Component 2
Debris flow volume	0.96	-0.14
Range slope	-0.74	-0.41
Debris top slope	-0.09	0.6
Debris surface slope	0.17	0.82
Pathway length	0.97	-0.02
Debris flow elevation	0.91	0.07
Engine Values	3.3	1.1
% of Variance	54.7	20.4
Cumulative %	54.7	75.2

5. Discussion and conclusion

Considering the formation of mountains is Roodbarak sub-basin from sedimentary formations (limestone, Shale …), mechanism of tectonic forces in resistant and brittle formations (limestone, sandstone …) create dense faulting, joints, etc., and consequently a suitable situation for occurrence of slope debris in sub-basin. High sensitivity of limestone and shale formations to the weathering factors in response to the neo-tectonics has led to expansion of rocky debris in different sizes on slope. Parallel to the effects of tectonic and predominance of Pre-glaciers system of weathering (especially in upper parts of sub-basin: 2074 to 3567 m), destruction and rollback of cliffs create many typical debris flows in region. Most of debris flows in the region have formed and are active in rivers undercutting places and predominant river processes. Although it should be noticed that in heights upper than 2800 m, debris flows decrease. The reason for this reduction is probably the destruction of rocks and formation of debris and also low occurrence of debris formations. In upper heights and near to the peaks, slope's dip increases, and therefore thickness and with the same proportion the retain duration of snow bodies decreases.

In steep scarp streams in limestone and shale formations, typical debris flows are completely active, and have very distinctive close crossing part, length, width and height, and cover a part of slopes in the regions with active river processes. The reason is penetration of water, especially water from melting the snow frozen and molten in tectonic and mechanic faults, joints and cracks (head of limestone and shale cliffs). Usually, debris of yellow limestone is coarse and size and volume of their materials increase from head of debris flows towards their end. Massive movement of debris in almost all of slopes, especially in slopes with steepness of more than 40 percent, are the morphogenic inhibitor factor of the evolution of plant and soil by intense movement of clastic detached materials with different sizes.

Because of temperature drop with increase of height (0.6 centigrade per 100 m) and increase of snow, the intensity of physical destruction of outcrops increase. Regarding to the expansion of Roodbarak sub-basin in heights between 2074 to 3567 m, favorable altitude conditions are present for occurrence of slope debris. However in mountainous region in shadow, temperature drop and its fluctuation are amplified. In such regions, altitude situation of the region and penetration of water produced from molten snows into the joints and diaclases are the most important active factors of rocks destruction and formation of rock debris in the sub-basin.

The amount and intensity of rainfall are the most other important and effective factors on the way of movement and volume of debris flows. Average annual amount of rainfall in the altitude of Roodbarak sub-basin is 339 mm per year. Occurrence of heavy flows, especially when abrupt rains related to the gravity force (active gravity processes), leads to fast movement of clastic materials from cliff's base to the lower parts of slope. The height factor plays an important role in the amount of rain, and consequently heavy stream flows, especially in heavy rains, important role in movement of debris flows (Laveige and Suwa, 2004). Therefore, the role of height in creation of distinct variation in climate elements (temperature, amount and type of rainfall, etc.) and amount (intensity) of roughness has a strong effect on destruction of rocks and formation of debris flows in the region.

Beside these effective factors on occurrence of debris flows and their morphometric sizes, occurrence of debris flows is also affecting on morphology of valleys and streams in its own path. During the time morphology of mountains valleys, is determined by the load of sediments, movement of materials in main rivers beds, and finally their deposition in a part of valleys. There are always feedbacks between the instability of the main bed and the amount of debris entry into the rivers that change the array of water flow along the valleys and the mode of rivers sinuosity in flows paths (Evans and Warburton, 2001). This situation is effective in small scales and short term periods. It should be mentioned that the effects of debris flows on rivers flows depends depend on hydrologic situation of running water (runoff and depth of flow and occurrence of abrupt flooding), morphometric properties of debris (e.g. space between them and the size of debris), and morphometric characteristics of flows beds (e.g. valleys depth, walls dip and width of valleys) (Levia and Page, 2000).

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