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Evaluating analytical and statistical models in order to estimate effective grouting pressure

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Abstract. Grouting is an operation often carried out to consolidate and seal the rock mass in dam sites and tunnels. One of the important parameters in this operation is grouting pressure. In this paper, analytical models used to estimate pressure are investigated. To validate these models, grouting data obtained from Seymareh and Aghbolagh dams were used. Calculations showed that P-3 model from Groundy and P-25 model obtained from the results of grouting in Iran yield the most accurate predictions of the pressure and measurement errors compared to the real values in P-25 model in this dams are 12 and 14.33 Percent and in p-3 model are 12.25 and 16.66 respectively. Also, SPSS software was applied to define the optimum relation for pressure estimation. The results showed a high correlation between the pressure with the depth of the section, the amount of water take, rock quality degree and grout volume, so that the square of the multiple correlation coefficient among the parameters in this dams were 0.932 and 0.864, respectively. This indicates that regression results can be used to predict the amount of pressure. Eventually, the relationship between the parameters was obtained with the correlation coefficient equal to 0.916 based on the data from both dams generally and shows that there is a desirable correlation between the parameters. The outputs of the program led to the multiple linear regression equation of P=0.403 Depth+0.013 RQD+0.011 LU–0.109 V+0.31 that can be used in estimating the pressure.

Keywords: grouting; analytical and statistical modeling; pressure

1. Introduction

Generally, cement grouting operation, is one of the ways to reduce water leakage, increase strength and consolidate jointed rock on the site. In this process, the cement grout permeates into sections with pressure and fills the joints. Different parameters affect the grouting operation procedure and the most important of which include the characteristics and geometry of the rock mass, properties of the joints and cracks, operational parameters governing the grouting process. An important parameter that plays an essential role in the grouting operation and in determining the grout penetration distance and increasing operation efficiency is grout pressure (Wang 2009).

By definition, grouting pressure is the maximum permitted pressure applied at each step of grouting.Grouting pressure usually starts with a minimum value that is required to permeate into the crack and reaches to its maximum permitted amount at the end of the operation. In order to increase the permeability of the grout and reduce grouting expenses, it is logical to use high pressures as far as it is possible (Bencardino 2014).

On the other hand, excessive pressure can cause deformation or other irreparable damages. Therefore, the parameter of grout pressure is a key quantity and it is highly important to determine the permitted range which it can be applied (Jafarian 2016).

After hydrogeological, topographical, geological and geotechnical examinations, grouting pressure is determined for different depths in the ground. The applied pressure is proportionate to the depth of grouting, the grout properties, the grouting technique, the rock's penetrability, jointed rock properties, the status of local stresses, the structure dimensions and the physical and mechanical properties of the rock mass. The pressure in this operations can be controlled by the grout volume. Thus, the properties of the grout and the cracks are effective in selecting a suitable pressure for grouting.

For a Bingham material, density, composition, grain size, viscosity, cohesion and hardening time must be considered in determining the grouting pressure. When the pressure and the grout density are constant, the velocity and pressure of the grout in time decrease by getting away from the grouting site. And when the kinetic energy decreases and reaches the critical point, cement particles start to sediment. However, when the grouting pressure is variable and the grout density is constant, the pressure must increase with time to prevent from early sediment of the cement particles (El Tani 2012).

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Grout pressure plays an essential role in overcoming the resistance parameters such as friction, yield stress and viscosity. In relation to the rock failure, it must be specified whether different kinds of separation planes have similar behavior in rock fracture process. In these cases, the orientation of the boreholes can be influential. By studying the drilling cores, it becomes clear that separation planes do not work in the same manner and it seems that bedding planes have more potential for fracturing. Studies confirm that bedding indicates a change in the sediments.

In sedimentary rocks, bedding planes have the required potential for fracturing. In Fig. 1, some of the main parameters that affect the grouting pressure in a borehole are shown. In this study, the most important analytical relations proposed by different researchers in association with grouting pressure are presented. The results of grouting in Seymareh and Aghbolagh dams were used to validate those models. Moreover, in addition to analytical models, statistical analyses by SPSS software and the data obtained from dam’s site were presented to introduce an optimal relation to calculate the pressure (Garagash 2003).

Water pressure test is used before the grouting operation to determine the rate of penetrability, the necessity of grouting and estimations related to it and the amount of sealing caused by grouting. In this test, the rate of hydraulic conductivity of the rock mass is specified by the penetration of water into the borehole. On some sites, there are rock masses in which the recorded water take in the pressure test is low but in contrast the amount of recorded cement grout in the grouting operation is high. This is while the joints in which the rate of penetration is low must naturally be inclined to absorb little grout. It is because the hydraulic fracturing phenomenon occurs as a result of too much grouting pressure. Hydraulic fracturing causes joints with little opening to widely open or creates new fractures. Therefore, understanding hydraulic fracturing can be helpful in determining why there is difference in the rate of water take and cement grout in these two operations. In water pressure test, the amount of water that enters the pit under certain pressure is recorded. Absorption of one liter of water per minute for each meter of the borehole at the pressure of one mega Pascal is equal to lugeon.

Lugeon number is always between one and 100 and if this value is higher than 100, it is considered to be 100:

LU=10Q/Pe. Where Q is the quantity of the water absorbed in liters per meter per minute, Pe is the highest effective pressure in the test and LU is the lugeon value (El Tani 2012).

2. Analytical models for the estimation of grouting pressure

Mathematical models are used to simulate the grouting process in joints and calculate the permitted grout pressure. With the development of human knowledge, these models can be applied to improve our understanding of the geometrical and hydraulic properties of the channels that are effective in the permeation of the grout into the rock mass. By simulating the rock mass according to simple hypotheses, we can obtain an acceptable prediction and at the same time practical prediction of the site conditions and, in fact, we can take a step forward in the optimization of the grouting operation. In the following lines, the most important analytical relationships proposed by scholars for the estimation of pressure are discussed.

2.1 Kutzner relation

Kutzner proposed Eq. (1) about the grouting pressure

$$p = \gamma_0 H + \Delta P \tag{1}$$

In this relation, P is the allowable pressure in mega Pascal, γo is the specific weight of the rock in mega Newton per cubic meter, H, is the depth of the section in meters, ΔP is the excess pressure in mega Pascal, which is applied for better permeation of the grout in the section. The value of ΔP can be increased by increasing the depth. However, this value is assumed to be equal to zero near the ground surface in order to prevent heave or failure of the rock mass.

2.2 Groundy relation

Grundy proposed Eq. (2) about the grouting pressure

$$p = 44 \times H \tag{2}$$

In this relation, P is the pressure without dimensions. In order to modify and make it practical, it is turned into Eq. (3) in which pressure is in mega Pascal and depth is in meter.

$$p = 0.044 \times H \tag{3}$$

2.3 Zaruba relation

Zaruba proposed two Eqs. (4) and (5) about rocks with horizontal and steep joints:

The relation proposed for rocks with steep joints

$$p = 30 + 2h^2 \tag{4}$$

The relation proposed for rocks with horizontal joints

$$p = 24h + 0.5h^2 \tag{5}$$

In the relations above, pressure is given without a unit. In order to modify these relations and make them practical, Eqs. (6) and (7) are proposed in which pressure is presented in mega Pascal and the depth of the section in meter:

The relation used for steep joints

$$p = 0.03 \times H_L + 0.002 H_L{}^2 \tag{6}$$

The relation applied for horizontal joints

$$p = 0.024 \times H_L + 0.0005 H_L{}^2 \tag{7}$$

2.4 Verfel relation

Verfel proposed Eqs. (8) and (9) for the conditions where the slag is almost homogenous

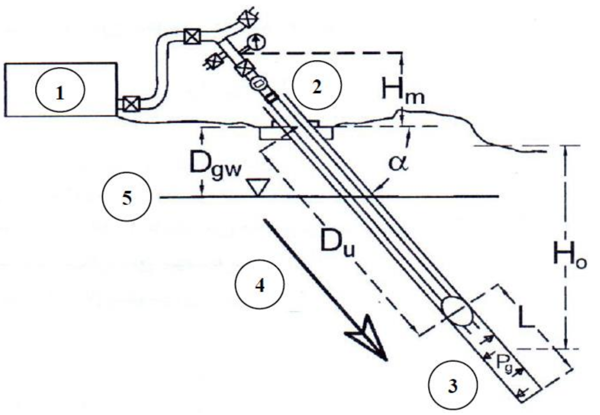

Fig. 1 Some of the main parameters that affect grouting pressure in a borehole (8): 1-Grouting pump, 2-pipe equipment from the top to the bottom are the backflow control valve, input flow control valve for the grout that gets out of the pump, excess grout discharge valve after the completion of the operation, manometer or pressure gauge, input flow control valve for the grout that gets into the borehole, flow meter. H_m is the vertical distance of the manometer from the baseline; α is the borehole slope, 3-L is the length of the section, 4-D_u is the borehole depth to the top of the section in a borehole, 5- D_{gw} is the depth of groundwater level, H_{gw} is the groundwater level height compared to the baseline level in a borehole and H_0 is Thickness of the rock at the top of the section

$$p = C_p \times \rho_0 H_0 + \Delta P \tag{8}$$

$$C_p = \frac{P_c}{\rho_0 H_0} \tag{9}$$

If the slag consists of two types of stratification with significant density differences such as alluvium and stones, Eqs. (10) and (11) are obtained

$$p = C_p \times \rho_{02} H_{01-2} + \rho_{01} H_{01} \Delta P \tag{10}$$

$$C_p = \frac{P_c - \rho_{01} H_{01}}{\rho_{02} H_{01-2}} \tag{11}$$

In these relations, ρ_o, is the specific weight of the slag with the density of H_0 in mega Newton per cubic meter in a state that it can be assumed homogenous, ρ_{o1} is the specific weight of the upper layer of the slag with the density of H_{o1} in mega Newton per cubic meter, ρ_{o2} is the specific weight of the lower layer of the slag with the density of H_{o1-2} meter in mega Newton per cubic meter. The value of C_p according to the critical pressure of P_c in mega Pascal is determined through Lugeon test and the weight of the slag is calculated in the section that is fractured during the Lugeon test.

2.5 Milatovich relation

Milatowich also proposed some other experimental Eqs. (12)-(18) for the estimation of grout pressure in the year 2000

$$p = K.h_w \tag{12}$$

$$p = h + (0.35 - 0.7)m \tag{13}$$

$$p = 2h + (0.7 - 3.5)m \tag{14}$$

$$p = (0.25 - 0.45)H \tag{15}$$

$$p = p_0 + mh \tag{16}$$

$$p = (\gamma H / 10) + mH \tag{17}$$

$$p = \gamma H / 10n \tag{18}$$

In these relations:

P: grout pressure (in bar)

h: static coefficient (in meter) from the section

h_w: water depth (the distance between the final level of the lake and the section under experimentation)

K: coefficient of depth (0.15 to 0.3)

H: depth of the grouting section

P: grouting pressure in shallow depth

n: coefficient of grout pressure that is distributed inside the crack (0.2 to 0.3)

γ: special weight (in grams per cubic centimeter)

m: coefficient proportional to pressure

2.6 Lippold relation

According to Lippold's idea that the value of the allowable safe pressure for every meter of the slag increases around 16.97×10-3 to 56.56×10-3 mega Pascal, the mean of these two values, i.e., 36.765×10-3 can be taken into consideration. Thus, Eq. (19) is obtained for the calculation of pressure

$$p = 36.765 \times 10^{-3} \times H \tag{19}$$

The value of H in this relation and in all the relations used is the mean value of the upper and lower limits of the grouting section in borehole.

2.7 Indian practical standard relation

According to the practical standard of India, the initial pressure must be at a low level, i.e. 9.8×10-3 to 24.52×10-3 mega Pascal for each meter of the slag. The mean of these two values, i.e., 17.17×10-3 is taken into consideration and Eq. (20) is obtained

$$p = 17.17 \times 10^{-3} \times H \tag{20}$$

2.8 Jager relation

According to Jager, American scholars proposed 0.025 mega Pascal and European scholars proposed 0.1 mega

Table 1 Experimental relations based on the conditions that govern grouting in Iran

The relation proposed for grouting pressure		Grouting place	Number of relation
maximum	average		
10	$P=2+0.3D$	Borehole drilling on the rock surface without concrete cover	(25)
15-20	$P=6+0.3D$	Borehole drilling on the concrete cover or the shotcrete before the concrete cover D: The distance between the grouted section and the mouth of the borehole	(26)

Pascal for each meter of the slag. Therefore, Eqs. (21) and (22) are used for each of these two propositions

$$p = 0.025 \times H \quad \text{American} \tag{21}$$

$$p = 0.1 \times H \quad \text{European} \tag{22}$$

2.9 Weaver relation

According to Waiver's view, in the process of increasing the pressure applied in grouting jointed rocks or rocks with horizontal bedding in shallow sections, the grout pressure must not exceed 22.62×10-3 mega Pascal per meter. Paying a little attention to the initial grout pressure in the existing boreholes and the practical standard of India, the initial grout pressure is selected somewhere between 0.1 to 0.2 mega Pascal. The mean of these two values is 0.15 mega Pascal. Therefore, the value of the calculated pressure is added to 0.15 and Eq. (23) is obtained

$$p = 22.62 \times 10^{-3} \times H \tag{23}$$

2.10 Lombardi relation

Lombardi presents the relationship between the permeation radius and the grouting pressure in the form of Eq. (24)

$$R_{\max} = \frac{P_{\max}.t}{C} \tag{24}$$

R_{max}=maximum grouting range, P_{max}=maximum pressure, t: half of the crack's thickness, C: grout cohesion

2.11 Experimental relations proposed based on the conditions that govern grouting operations in Iran

Eqs. (25) and (26) in Table 1 are presented according to the general conditions governing grouting operations in Iran, which is provided by Mahabghodss company. It must be noted that the pressure values presented are for the beginning of the operation and in the process of carrying out the operations, they can be changed by the supervisor or become more precise. Moreover, the grouting pressure must remain stable until the grout gets hard. The time that the pressure is removed or reduced must be confirmed by the supervisor engineer.

3. Case study

3.1 Seymareh dam

Seymareh dam and its power plant are located in Iran, 40 km northwest of Dareshahr city and 7.5 km away from Cheshme Shirin village in Ilam province. Its purpose is to use the potential power in Seymareh river. Seymareh is a thin double-arched concrete dam with the height of 130 m from the present river bed (and about 180 m from the bedrock). Dam crest elevation is 730 m and at the normal elevation, water level is at the 720 m height above high sea level. The length of the dam crest at the elevated part of the dam crest is 202 m. The capacity of the dam reservoir is 3.215 billion cubic meters.

3.2 Aghbolagh dam

Aghbolagh earth dam is located at the distance of 32 km in the south of Borujen city in Chahar Mahal-o-Bakhtiari province in Iran. The geographical coordinates of the dam axis in the UTM system are x=520363 and y=3512353. Considering the geological map, the area under study is located in the Zagros zone and under the Overthrust zone.

From the stratigraphic perspective, Mesozoic and Cenozoic rocks, especially the Cretaceous rocks are dominant in this zone and from the structural point of view, large faults such as the main Zagros fault and Dena fault play a major role in the zone.

4. Calculating the grout pressure according to analytical models

In this section, the grout pressure is calculated based on the analytical models proposed in this article. The input parameters of these models were obtained from geological, engineering, geotechnical and grouting information in Seymareh and Aghbolagh dams. In Tables 2 and 3, a sample of this information is shown. It must be mentioned that some parameters that affect some of the analytical relations, are not exist in the information obtained from the dams and it is not possible to determine their value. Thus, some of the analytical relations have not been used in grouting pressure calculations.

According to the results of grouting pressure, In order to validate the modeling, relative error of the measured pressure (Pm) was compared to the real recorded pressure (Preal) obtained from the E=[(Preal-Pm)/Preal]*100. The results are shown in Tables 4, 5.

According to the results obtained from different analytical models in these tables, it can be seen that among all the models, P-3 model proposed by Groundy and model p-25 obtained from the general conditions governing grouting operations in Iran are more precise and pressure measurement errors in P-25 model are 12 and 14.33 Percent compared to the real values in Seymareh and Aghbolagh

Table 2 the results of water pressure test and grouting in boreholes of the Seymareh dam

Data obtained from P-22 borehole					Data obtained from P-20 borehole				
Depth(m)	RQD	LU	P(pa)	V(m^3)	Depth(m)	RQD	LU	P(pa)	V(m^3)
0-5	63.8	11.4	233000	0.021625	0-5	64.4	3.8	230000	0.012667
5-10	92.2	41.5	376000	0.032417	5-10	89.4	2.7	377000	0.012667
10-15	91	20.5	523000	0.068458	10-15	94.4	22.4	523000	0.0095
15-20	73	39.4	764000	7.291667	15-20	91.4	69.9	552000	5.216667
20-25	95.4	<1	964000	0.154208	20-25	83.8	<1	974000	0.015833
25-30	94	3.1	1162000	0.106833	25-30	75.8	22.8	1029000	7.654167
30-35	94.2	7	1299000	0.097375	30-35	51.4	1.34	1247000	0.025333
35-40	90.6	<1	1587000	0.005375	35-40	98.4	<1	1456000	0.022167
40-45	96.2	<1	1794000	0.010792	40-45	98	<1	1639000	0.019
45-50	88.6	6.4	2230000	0.022167	45-50	92	<1	2064000	0.015833
50-53	45.3	18.5	2082000	0.256125	50-53	95	19.54	1886000	2.6665
Data obtained from P-19 borehole					Data obtained from P-23 borehole				
Depth(m)	RQD	LU	P(pa)	V(m^3)	Depth(m)	RQD	LU	P(pa)	V(m^3)
0-5	74.75	54.3	130000	0.012667	0-5	44.8	51.3	225000	0.172625
5-10	81.6	29.8	377000	0.012667	5-10	54	72.2	343000	0.123333
10-15	80.4	10.9	521000	5.291667	10-15	83.4	10.3	522000	0.026667
15-20	97.6	6.7	695000	8.691667	15-20	84.6	5	767000	0.019458
20-25	97.8	11.54	1015000	0.006333	20-25	91	4.1	795000	0.049417
25-30	94.4	26.9	1066000	0.012667	25-30	87.6	95	1037000	3.110833
30-35	91	2.2	1291000	0.038	30-35	72.4	6.1	1207000	0.074667
35-40	90.6	4.5	1682000	0.022167	35-40	92.4	1.82	1445000	0.127667
40-45	91.8	<1	1743000	0.022167	40-45	94	<1	1663000	0.004833
45-50	100	3.6	3980000	0.019	45-50	62.2	3.8	2074000	0.021083
50-53	99	11.2	2381000	0.025325	50-53	54.6	18.2	2232000	3.98665

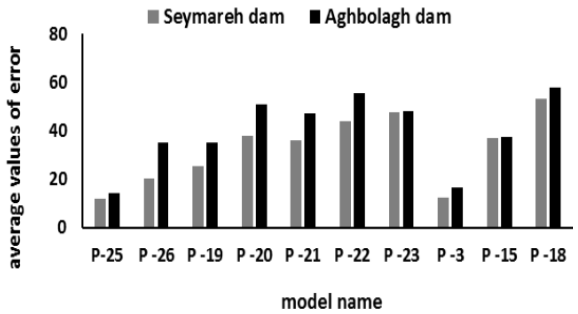

Fig. 2 average values of the measured pressure error in Seymareh and Aghbolagh dams

dams and in p-3 model are 12.25 and 16.66 respectively.

Number 12 is equal to the average values of relative error for P-25 model in Seymareh dam in Table 4 and number 14.33 is equal to the average values of relative error for P-25 model in Aghbolagh dam in Table 5. And values of 12.25, 16.66 also obtained for p-3 model as the same way.

These models present a more accurate estimation of the grouting pressure and the values of the measured pressures by them are closer to the real pressures. Average values of the measured pressure error in Seymareh and Aghbolagh dams is shown in Fig. 2.

Table 3 some results of the water pressure test and grouting in boreholes of the Aghbolagh dam

TG-1 Borehole				
Depth(m)	RQD	LU	P(pa)	V(m^3)
4-6	20	100	5	311
6-10	61	100	5	30
10-15	67.8	14	7.5	350
15-20	83	25	10	1057
20-25	53.5	1	13	378
25-30	22	2	12	2380
30-35	51.8	2	12	2474
35-40	30	1	15	1589
40-45	94.5	26	20	5921
TG-2 Borehole				
4-7.3	58.8	100	5	756
7.3-12	50	12	9	812
12-17	93.5	49	14	243
17-22	94.6	100	13	3052
22-27	45.5	1	10	147
27-32	76.3	1	15	126
32-45	90	2	24	4471
TG-3 Borehole				
4.2-5.8	9	100	5	609
5.8-8.3	83	100	5	266
8.3-13	41.5	37	5	189
13-18	58.8	1	7.5	126
18-23	15.3	1	7	112

5. Estimation of the grouting pressure through statistical analysis

In the analytical models that estimate pressure, all the parameters obtained from grouting boreholes are not effective. Also, some of these models include parameters whose values cannot be determined by drilling cores, grouting and geotechnical information in dam sites. Thus, determining a real model that can show a complete relationship among all the existing and effective parameters in the grouting operation is highly important. Considering the above points, in addition to estimate pressure according to analytical models, in order to achieve a realistic and practical model, the statistical modeling and analysis by SPSS software also was used.

In fact, those models are practical and valuable that enable us to estimate grouting pressure in dam sites based on the present data. The most important parameters that are obtained from cores and grouting boreholes in dam-sites include the depth of the grouting sections, the amount of water take in the rock masses in the lugeon test (LU) before grouting, rock quality degree (RQD), grout intake volume and the grout pressure recorded at the time of grouting. Considering the above points, in order to obtain a real and practical model in the estimation of the grout pressure, SPSS was also used for modeling and statistical analyses

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	V, LU, RQD, Depth[a]	.	Enter

a. All requested variables entered

b. Dependent Variable: P

Fig. 3 SPSS input parameters: Independent parameters V, LU, Depth, RQD and dependent parameter P

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.966[a]	.932	.928	2.57508437

a. Predictors: (Constant), V, Depth, RQD, LU

(a)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.929[a]	.864	.830	2.17634829

a. Predictors: (Constant), V, LU, RQD, Depth

(b)

Fig. 4 The results in SPSS output: The multiple correlation coefficient R and the square of the multiple correlation coefficient R^2 and Adjusted R Square and std. Error of the Estimate in (a)-Seymareh dam and (b)-Aghbolagh dam

besides analytical models.

5.1 Statistical analysis details

The statistical analysis presented here is based on logical relationships among the parameters mentioned above. Generally, if a relationship between the variables is significant, the relationship can be presented with mathematical models. This model can be linear or non-linear. An equation that shows the relationship between the dependent and the independent variables is called a regression equation. If the correlation pattern can be written as a line equation, it is called a linear regression model whose aim is to predict the behavior of the dependent variable based on the values of the independent variables. Based on the proposed analytical models and the linear relationship observed among the parameters, SPSS software is used in this section to analyze the relationship between the dependent and the independent variables according to linear regression and based on the data obtained from Seymarh and Aghbolagh dams.

In general, if x is the independent and y is the dependent variable, the linear regression equation y=ax+b holds true. If there are several independent variables, the multiple linear regression equation $y=ax_1+bx_2+cx_3+dx_4+e$ is true about the relationship between the dependent and the independent variables. In this article, multiple linear regression equation is used since there are several independent variables where y is the dependent variable of grout pressure, x_1 to x_4 are independent parameters and e is a constant value.

Table 4 the values of relative error between calculated pressure by analytical models and real Pressure in term of percentage in Seymareh dam

p-19 Borehole		p-20 Borehole		p-22 Borehole		.p-23 Borehole	
Model name	Error rate	Model name	Error rate	Model name	Error rate	Model name	Error rate
P-25	10	P-25	12	P-25	9	P-25	17
P -26	22	P -26	18	P -26	14	P -26	27
P -19	24	P -19	19	P -19	27	P -19	31
P -20	43	P -20	33	P -20	38	P -20	37
P -21	30	P -21	35	P -21	40	P -21	40
P -22	34	P -22	42	P -22	52	P -22	48
P -23	33	P -23	45	P -23	57	P -23	55
P -3	13	P -3	10	P -3	8	P -3	18
P -15	32	P -15	38	P -15	46	P -15	32
P -18	54	P -18	49	P -18	57	P -18	53

Table 5 the values of relative error between calculated pressure by analytical models and real pressure in term of percentage in Aghbolagh dam

TG-1 Borehole		TG-2 Borehole		TG-3 Borehole	
model name	Error rate	model name	Error rate	model name	Error rate
P-25	16	P-25	14	P-25	13
P -26	28	P -26	26	P -26	52
P -19	32	P -19	42	P -19	32
P -20	43	P -20	53	P -20	56
P -21	40	P -21	50	P -21	51
P -22	52	P -22	58	P -22	57
P -23	55	P -23	44	P -23	46
P -3	21	P -3	17	P -3	12
P -15	32	P -15	46	P -15	34
P -18	65	P -18	55	P -18	54

5.2 Results of statistical analysis

According to the information obtained from Seymareh and Aghbolagh dams shown in Tables 4 and 5 and the multiple linear regression equation, statistical analysis was conducted using SPSS 15 software. A sample of the output data from the software about Seymareh and Aghbolagh dams is illustrated in Figs. 3 and 4.

Include the depth of the grouting sections, the amount of water take in the rock masses in the lugeon test (LU) before grouting, rock quality degree (RQD), grout intake volume and the grout pressure recorded at the time of grouting. According to Fig. 4 it can be seen that in the case of both dam, There is a high correlation between the dependent and the independent variables, so that the square of the multiple correlation coefficient or determination coefficient (R^2) in the Seymareh and Aghbolagh dams is 0.932 and 0.864,

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.957[a]	.916	.912	2.65347177

a. Predictors: (Constant), V, RQD, Depth, LU

(a)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig
1	(Constant)	310	1.158		267	790
	Depth	.403	.014	.964	28.660	000
	RQD	.013	.014	.030	947	346
	LU	.011	.011	.035	1 008	.316
	V	-.109	.134	-.026	-.814	.418

a. Dependent Variable: P

(b)

Fig. 5 SPSS output considering the sum of input data from Seymareh and Aghbolagh dams: (a)-correlation coefficients, (b)-constant value, unstandardized coefficients for the independent variables (B), standard error (Std.Error), Beta standardized coefficients, t-test and level of significance (sig)

respectively and indicates that the regression results can be used in Prediction of grouting pressure according to depth of the grouting sections, the amount of water take in lugeon test, rock quality degree and grout intake volume. In the end, in order to determining a general relationship for calculation of the grouting pressure, the dependent and independent variables from both dams were given to the software in the form of a single input. The square of the multiple correlation coefficient R^2 in this status is equal to 0.916 and indicates that there is a high correlation between the dependent and the independent variables. According to Fig. 5 and output parameters, factors a, b, c, d and e in multiple linear regression equation y=ax1+bx2+cx3+dx4+e are determined. The model that estimates grout pressure is finally proposed as Eq. (27)

$$P=0.403\ \text{Depth} + 0.013\ \text{RQD} + 0.011\ \text{LU} - 0.109\ \text{V} + 0.31 \tag{27}$$

Variables x1 to x4 are Depth، RQD, LU and V respectively. This relation is a good model in order to estimate grouting pressure according to information obtained from grouting sites.

6. Conclusions

What is studied in this paper, Assessment analytical model to estimate the grouting pressure that is presented by various researchers. In order to validation this models geotechnical and grouting data from Seymareh and Aghbolagh dams is used. Considering the fact that in analytical models all grouting parameters are not effective and some of these models include parameters whose values cannot be determined by drilling cores, therefore determining a real model that can show a complete relationship among all effective parameters in the grouting operation is highly important. as a result, in addition to analytical models, the statistical analysis by SPSS software also was used and according to grouting data from Seymareh and Aghbolagh dams relationship between pressure with depth of the grouting sections, the amount of water take in lugeon test, rock quality degree and grout intake volume was evaluated.

- Results showed that P-3 analytical model proposed by Groundy and P-25 model obtained from the results of grouting in Iran yield the most accurate predictions of the grout pressure.
- Pressure measurement errors in analytical models according to P-25 model are 12 and 14.33 Percent compared to the real values in Seymareh and Aghbolagh dams and in p-3 model are 12.25 and 16.66 respectively.
- These analytical models present a more accurate estimation of the grouting pressure and the values of the measured pressures by them are closer to the real pressures.
- Results showed in statistical analysis there is a high correlation between parameters. As the square of the multiple correlation coefficient R^2 in Seymareh and Aghbolagh dams is 0.932 and 0.864, respectively.
- According to total data of the two dam, the high square of the correlation coefficient was obtained equal to 0.916.
- In statistical analysis, regression equation according to output was presented as: P=0.403 Depth+0.013 RQD+0.011 LU–0.109 V+0.31.
- This statistical analysis and the model obtained from it can be used to estimate grout pressure based on the data obtained from the grouting sites.

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