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GEOLOGICAL ENGINEERING

An engineering geological appraisal of the Chamshir dam foundation using DMR classification and kinematic analysis, southwest of Iran

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ABSTRACT

This paper describes the results of engineering geological investigations and rock mechanics studies carried out at the proposed Chamshir dam site. It is proposed that a 155 m high solid concrete gravity-arc dam be built across the Zuhreh River to the southeast of the city of Gachsaran in south-western Iran. The dam and its associated structures are mainly located on the Mishan formation. Analysis consisted of rock mass classification and a kinematic analysis of the dam foundation's rock masses. The studies were carried out in the field and the laboratory. The field studies included geological mapping, intensive discontinuity surveying, core drilling and sampling for laboratory testing. Rock mass classifications were made in line with RMR and DMR classification for the dam foundation. Dam foundation analysis regarding stability using DMR classification and kinematic analysis indicated that the left abutment's rock foundation (area 2) was unstable for planar, wedge and toppling failure modes.

Keywords: Sochagota the Zuhreh river, Chamshir dam site, rock foundation, DMR classification, kinematic analysis.

RESUMEN

Este articulo describe los resultados de una investigación de ingeniería geológica y estudios de mecánica de roca que se llevo a cabo en el lugar propuesto para le represa Chamshir. Se propone una presa de 155m de altura, de arco gravitacional en concreto de solido, la cua debe ser construida a través del rio Zuhreh al sureste de la ciudad de Gachsaran en el suroeste de Irán. La presa y su estructura asociada son localizadas principalmente sobre la formación Mishan. El análisis consistió en la clasificación del macizo rocoso y un análisis cinemático de la fundación de la masa rocosa de la presa. Los estudios se llevaron a cabo en campo y laboratorio. Los estudios de campo incluyeron cartografía geológica, un estudio intensivo de discontinuidad, perforación de núcleo y toma de muestras para pruebas de laboratorio. La clasificación de la masa rocosa se realizo de acuerdo con la clasificación RMR y DMR para la fundación de la presa. El análisis de basamento rocoso de la presa en relación a la estabilidad usando la clasificación DMR y el análisis cinemático indico que el estribo izquierdo del basamento (área 2) es inestable para tipos de fallo planares y de cuña.

Palabras claves: El rio Zuhreh, sitio presa Chamshir, fundación rocosa, clasificación DMR, análisis cinemático.

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Introduction

The most important advantage of a favourable rock mass classification is that it has parameters describing most of a rock mass's engineering characteristics for providing base input data for engineering design purposes. Rock quality designation (RQD, Deere 1964) and rock mass rating (RMR, Bieniawski 1989) are two of the most commonly used numerically-expressed rock mass classification systems. Several researchers have referred to RMR as being a useful tool for describing rock mass foundations (Di Salvo, 1982; Van Schalkwyk, 1982; Marcello *et al.*, 1991; Hemmen, 2002; Ramamurthy, 2004).

Some difficulties are involved in using RMR for dam foundation studies, such as very doubtful water pressure consideration, there are no good rules for quantifying the adjusting factor for joint orientation and watering changes introduce changes in properties concerning the rock mass and the joints. Guidelines have only been offered regarding general stability against horizontal sliding, which is important but is not a very common problem.

Dam mass rating (DMR, Romana, 2004) has been proposed as an adaptation of RMR, giving tentative guidelines for several practical aspects of dam engineering and for dam foundation appraisal in preliminary studies taking account of the effects of rock mass anisotropy and water saturation.

The Chamshir dam site on the Zuhreh river is located in south-western Iran, about 20 km southeast of the city of Gachsaran (50° 52' 36" E and 30° 10' 59" N, Figure 1). The dam is now being studied and has been designed as a 155 meter high concrete gravity-arc dam; its useful reservoir volume is 1.8 milliard cubic meters (Figures 1 and 2). Exceptional topographical, hydrological and geological circumstances regarding the river in the Chamshir gorge has led to the site being proposed as a suitable option for dam construction, concerning available national resources use (i.e. water storage for irrigation projects). So far some researchers have studied the rock mass conditions of the Chamshir dam site (e.g., Gharouni-Nik, 2008; Torabi-Kaveh *et al*., 2010).

This paper explains the engineering geological assessment involved in the safe design of the proposed Chamshir dam site. Such geotechnical investigation has been carried out at the project site and in the laboratory. Various laboratory tests and detailed discontinuity surveying were performed to assess rock mass characteristics.

The Chamshir dam site rock mass was studied using RQD, RMR and DMR classification and kinematic analysis more accurately assessed the dam foundation.

Geological setting

Geological factors play a major role in designing and constructing a dam (Ichikawa, 1999) as they control the nature of geological formations and also provide the needed materials for construction.

Many cases have occurred throughout the world where dam foundation rock mass conditions were not sufficiently known and the cost of construction and treatment greatly exceeded the original budget.

According to the 1:100,000 geological map of Ghachsaran (Setodehnia and O.B. Perry, 1966) (Figure 1), the geological formations in the study area, from oldest to youngest, are Gachsaran (early Miocene), Mishan (early-Middle Miocene), Aghajari (Miocene-late Pliocene), Bakhtiari (late Pliocene-Pleistocene) and alluvial sediments. The Mishan formation (an isocline) along with the Gachsaran formation cover the western part of the dam reservoir and dam site. This formation has two different facies; the first consists of biohermy limestone and forms a great lens within a second facies which consists of alternating marl and limestone layers. The Zuhreh river has created the long and narrow Chamshir gorge by erosion of biohermy limestone, thereby making it a suitable location for dam construction (Figure 2). The Chamshir dam reservoir is located on the Gachsaran, Mishan and Aghajari formations; the Gachsaran formation's stratigraphy sequence in the study area is similar to that of the Khuzestan area (Tehran-Sahab and Parab-Fars Consulting Engineering Companies, 1997). This formation has 7 members: the oldest member is 40m thick consisting of alternating thick anhydrite, limestone and shale layers. The second member is a 115m thick salt layer, with anhydrite alternating with thin limestone layers. The third member is a 347m thick anhydrite layer with salt. The fourth member consists of a 290m thick salt layer with marl, gray limestone and anhydrite. The fifth member is 342m thick red and gray marl with alternating layers of gypsum. The sixth member is

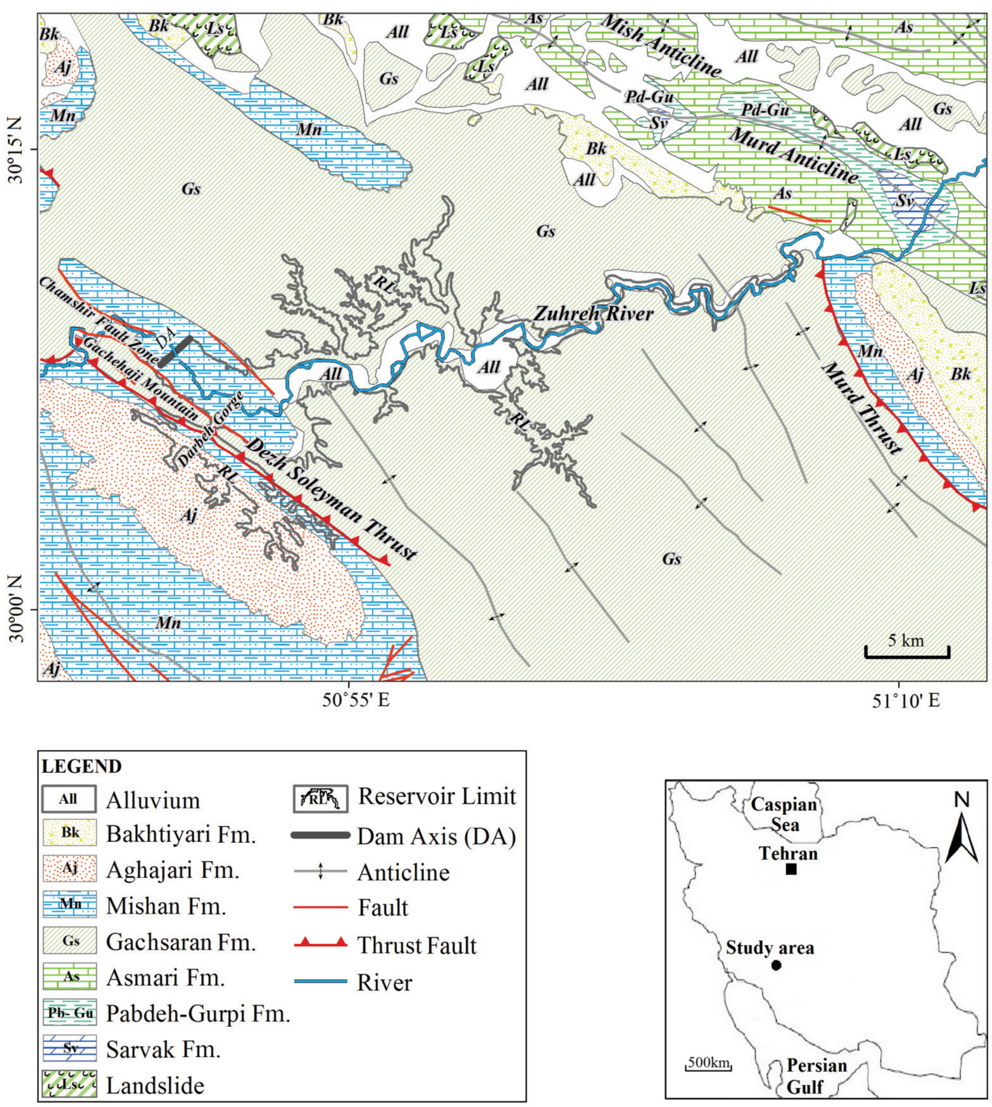
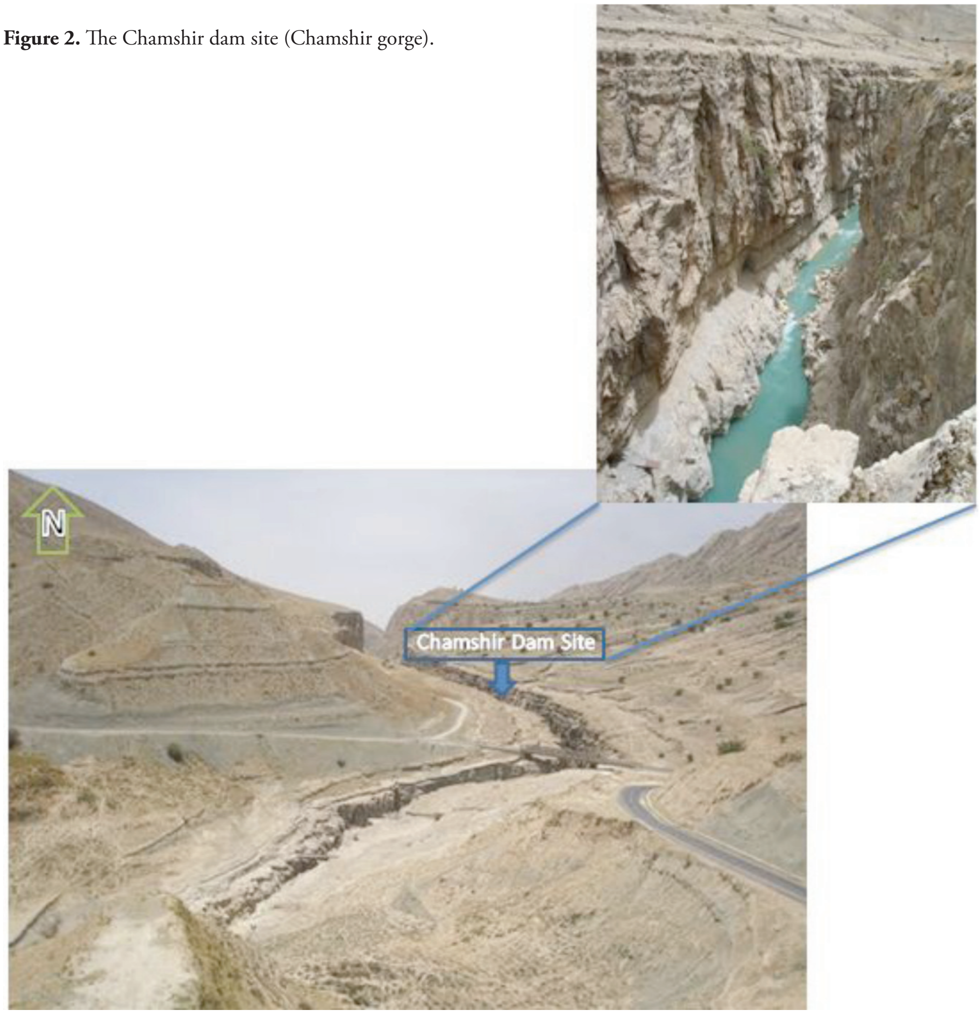


Figure 1. Geological map of the study area (modified from the Gachsaran geological map, 1:100,000, Iranian Oil Operating Companies (IOOC), 1966).

Figure 2. The Chamshir dam site (Chamshir gorge).



258m thick, having alternating layers of anhydrite (or gypsum), salt, red marl and limestone. The seventh member is the youngest member, being 139m thick and having alternating gypsum, gray marl and limestone layers. It should be mentioned that sulphate layers outcrop as gypsum on the surface and as anhydrite at deeper levels. The Gachsaran formation covers most parts of the projected dam reservoir (Figure 1). According to field observations, members 5, 6 and 7 of the Gachsaran formation would be in contact with the dam reservoir in this area and only member 7 outcrops downstream of the dam. The Aghajari formation would form a small part of the reservoir at its south-western corner and consists of sandstone, siltstone, conglomerate, gypsum and marl. Young and old terraces are also present along the banks of the Zuhreh river (Figure 1), consisting of coarse grained gypsum particles and fine grained silt and sand sediment.

The study area is in the Zagros folded area or external Zagros (Stocklin, 1968) and simply folded belt (Berberian, 1995). Zagros folding compressional tectonic forces have created some faults and thrust faults having a NW-SE trend in the study area; the Dezh Soleyman thrust (DST), Murd thrust and Chamshir fault area are the most important ones (Figure 1).

The role of the DST in the study area is important according to field observations. The Gachsaran formation is uplifted along this fault from deeper parts to the surface. It has dissected some parts of the Mishan formation in the north-eastern branch of the Chamshir syncline and has consequently thrust the Gachsaran formation over the Mishan formation. The extensive tectonic pressure of the DST created the important Chamshir fault area, this being the source of several springs throughout this area and the DST. The Zuhreh river's deviation from its direct pathway into the Chamshir fault area could also provide reasonable evidence of tectonic activity in the study area.

Materials and Methods

Engineering geological investigations and rock mechanics studies include discontinuity surveying, core drilling, *in situ* and laboratory testing. Quantitative description of discontinuity (i.e. orientation, spacing, persistence, roughness, aperture and filling materials) were determined *in situ* by exposure logging according to the International Society for Rock Mechanics' (ISRM) standards (1981). Laboratory tests were carried out on the core samples to quantify the physical and geomechanical properties of intact rocks at the dam site.

Site investigation

The dam site was investigated in two stages; the site was geologically studied and mapped in detail. Thirty-four boreholes were drilled (1,578 m), 8 of them pertaining to the dam site. Six boreholes were drilled (565m total depth) during the first stage (1999 to 2000); the second stage was carried out between 2008 and 2009 when 2 boreholes were drilled (246 m total depth). Two locations have been have been considered for field studies regarding the proposed areas for constructing a dam in the Chamshir gorge (Figure 3). Five hundred discontinuities were measured (250 on both the left and right abutments). Four dominant discontinuity sets were identified on the left (area 1) and right (area 1 and 2) abutments of the proposed dam site (Tables 1 and 2). Five dominant discontinuity sets were

Table 1. The left and right abutments' discontinuity characteristics (area 1).

Location	Type of discontinuity	Average dip direction (°)	Average dip (°)	Trend	Plunge
Right abutment	Bedding	177	13	357	77
	J_1	323	78	143	14
	J_2	147	79	327	10
	Fault set	118	76	298	14
Left abutment	Bedding	126	11	306	79
	J_1	316	78	136	12
	J_2	146	76	326	12
	Fault set	125	73	305	17

Table 2. The left and right abutments' discontinuity characteristics (area 2).

Location	Type of discontinuity	Average dip direction (°)	Average dip (°)	Trend	Plunge
Right abutment	Bedding	170	13	350	77
	J1	324	78	144	12
	J2	140	79	320	11
	Fault set	125	76	305	14
Left abutment	Bedding	99	11	279	78
	J_1	328	78	148	14
	J_2	146	76	326	13
	Fault set 1	300	73	120	13
	Fault set 2	118	81	298	9

Figure 3. Satellite image of Chamshir dam site (http://www.google.com/earth/index.html).

Table 3. The right and left abutments' RQD values.

Place	RQD value	
	Obtained from cores	Obtained from joint frequency
Right abundant	90-100	100
Left abundant	90-100	100

Table 4. The Chamshir dam foundation's RMR classification

Situation	Right abutment rock mass		Left abutment rock mass	
Description	conditions	rate	conditions	rate
Compressive strength (MPA)	25-50	4.0	25-50	4.0
RQD (%)	90-100	20.0	90-100	20.0
Joint spacing (m)	>2	20.0	>2	20.0
Discontinuity condition	Sum of five parameters	25.0	Sum of five parameters	25.0
Water flow	dry	15.0	dry	15.0
RMR_{BD} rate	84.0		84.0	
Joint orientation rate	Favourable	0	Favourable	0
RMR	Very good	84.0	Very good	84.0

identified (Table 2) for the left abutment (area 2). A quantitative description of discontinuity in two areas included type and orientation in the left and right abutments (Tables 1 and 2).

Results and Discussion

Rock mass quality

RQD and RMR were also used for obtaining the exposed rocks' engineering properties within the dam foundation. The data were collected from the dam site. The RQD values were determined by examining drill cores and joint frequency (Table 3). The Table shows that the left and right abutments' RQD values were excellent for the projected dam construction.

Table 4 gives the RMR values, rock unit quality being classified as very good.

DMR classification

DMR_{STA} (related to dam stability against sliding) value was:

$$DMR_{STA} = RMR_{BD} + CF \times R_{STA} \quad (1)$$

where RMR_{BD} (basic dry RMR) resulted from adding the RMR's first four parameters plus a water rating of 15 and R_{STA} was the dam stability adjustment factor.

Regarding Hoek-Brown criteria, Hoek has advocated the use of a "dry RMR" obtained with the maximum rating for water, simultaneously introducing real pore pressures into the computations (Hoek *et al*., 2002).

RMR_{BD} was obtained by adding the first four parameters of RMR plus 15:

1) Compressive strength, tested in water conditions similar to future ones, i.e. saturated when the rock is going to be saturated and having the same pH as that water;

2) Rock mass RQD;

3) Significant governing joints' spacing (s);

4) Significant governing joints' conditions (s); and

5) Water rating (WR), always 15 (as if dry).

The R_{STA} (adjustment factor for dam stability) was obtained (Table 5).

The danger of sliding became reduced when the significant joint's dip direction was not almost parallel to the dam's downstream-upstream axis due to the geometrical difficulties involved in sliding. Such effect could be taken into account by multiplying dam stability adjusting factor rating R_{STA} by a geometric correction factor (CF):

Table 5. Dam stability RSTA adjustment factors, according to joint orientation; DS dip downstream/US dip upstream/A any dip (Romana, 2003a).

Type of dam	VF	F	FA	U	VU
	Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Fill	Others	10-30 DS	0-10 A	-	-
Gravity	10-60 DS	30-60 US 60-90 A	10-30 US	0-10 A	-
Arch	30-60 DS	10-30 DS	30-60 US 60-90 A	10-30 US	0-10 A
R_{STA}	0	-2	-2	-15	-25

Table 6. The degree of dam safety regarding sliding (Romana, 2004).

Rock mass rate	Degree of safety
$DMR_{STA} > 60$	No primary concern
$60>DMR_{STA}>30$	Concern
$30>DMR_{STA}$	Serious concern

$$CF = [1 - \sin(\alpha_d - \alpha_j)]^2 \, (\alpha_d > \alpha_j) \quad (2)$$

$$CF = [1 - \sin(\alpha_j - \alpha_d)]^2 \, (\alpha_d < \alpha_j) \quad (3)$$

where α_d was dam axis upstream-downstream direction and α_j was the dip direction of the significant governing joint. Dam foundation status DMR_{STA} was calculated (Table 6).

The Chamshir dam will built on Mishan limestone and marl rock units. The valley walls at the dam site are steep, having 80°– 90° slopes on the left abutment and 75°–90° on the right abutment. The valley runs NW-SE (310°). Dip direction is 40° NE for the left abundant and 220° SW for the right abundant. DMR classification for the Chamshir dam's foundation (for areas 1 and 2) is shown in Tables 4 and 5.

The results obtained from DMR classification (Tables 7 and 8) indicated that the left abutment (area 2) was instable; the results of this classification were compatible with field conditions.

Kinematic analysis

Kinematic refers to the motion of bodies without referring to the forces causing them to move (Goodman, 1989). Kinematic analysis is very useful for investigating possible rock mass failure modes and determining maximum safe slope angle (MSSA). Many studies have determined slope failure modes (Markland, 1972; Goodman, 1976; Goodman and Shi, 1985; Matherson, 1988) and evaluated slope stability (Özsan and Akin, 2002; Aksoy and Ercanoglu, 2007; Kulatilake *et al.*, 2011) using a stereographic projection technique. Kinematic analysis was used for the study area to estimate the MSSA regarding the three basic failure modes: plane sliding, wedge sliding and toppling.

The aforementioned kinematic analysis was performed for left abutment slopes (area 2) at the dam site using dominant discontinuity sets.

Kinematic analysis (Table 9 and Figure 4) results indicated that joint inclination was the most important parameter affecting rock mass instability. The analysis revealed possible wedge, planar and toppling failures in the left abutment (area 2).

Conclusions

The concrete Chamshir dam will be located on the limestone and marl rocks of the Mishan formation. Good rock mass quality was indicated for these rocks; however, according to DMR and kinematic analysis, most parts of the dam foundation (except the left abutment, area 2) were safe, being rated low-risk in terms of instability occurrence and magnitude. It is therefore recommended that slope failure should be constantly monitored.

Despite RQD and RMR values showing favourable condition for the dam abutments, the DMR classification provided more accurate assessment and was more reliable, i.e. considerable correlation between such classification and the kinematic analysis.

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Table 7. The DMR classification of the right abutment.

Situation	Right abutment							
	Area 1				Area 2			
Type of discontinuity	Bedding	J_1	J_2	Fault set	Bedding	J_1	J_2	Fault set
CF	1.7×10^{-2}	0.34	1.84	1.84	3.9×10^{-4}	8.82×10^{-4}	0.43	0.43
R_{STA}	-15	-7	-7	-7	-15	-7	-7	-7
RMR_{BD}	84							
DMR_{STA}	55.70				78.02			

Table 8. The DMR classification of the left abutment..

Situation	Left abutment								
	Area 1				Area 2				
Type of discontinuity	Bedding	J_1	J_2	Fault set	Bedding	J_1	J_2	Fault set 1	Fault set 2
CF	5.48×10^{-4}	1.64	0.16	0.43	2.22	3.07	0.16	2.38	1.84
R_{STA}	-15	-7	-7	-7	-15	-7	-7	-7	-7
RMR_{BD}	84								
DMR_{STA}	68.40				0.00				

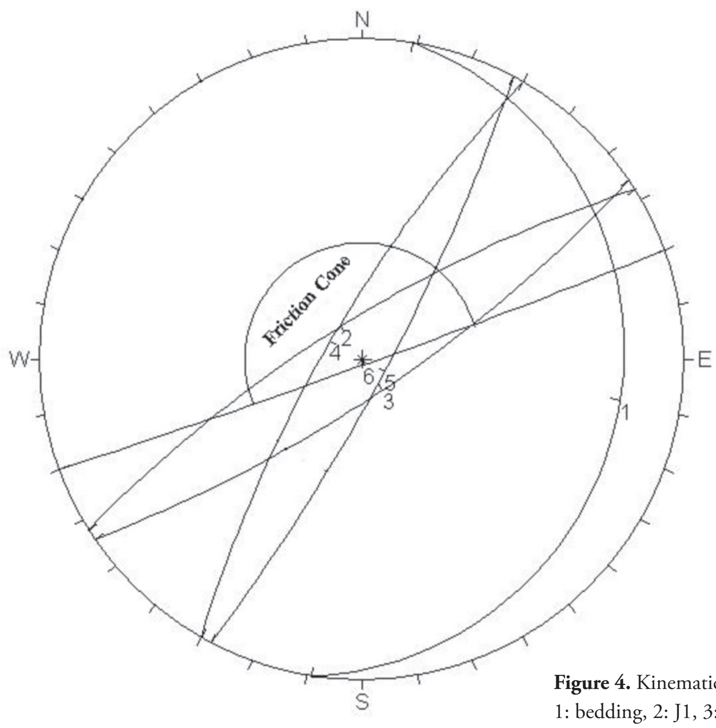

Figure 4. Kinematic conditions for the left abutment (area 2), 1: bedding, 2: J1, 3: J2, 4: fault set I, 5: fault set ∏, 6: slope face

Table 9. Kinematic analysis regarding sliding in the left abutment (area 2).

Wedge sliding results			Orientation of intersection lines		
Sliding along joint sets	Slope face dip direction	Maximum safe angle	Inters. line	Trend (deg.)	Plunge (deg.)
1-2	340.0	90	1-2	55.8	8.8
1-3	340.0	90	1-3	58.1	9.1
1-4	340.0	90	1-4	29.0	4.2
1-5	340.0	90	1-5	28.6	4.1
2-3	340.0	90	2-3	57.0	4.2
2-4	340.0	76*	2-4	322.8	75.9
2-5	340.0	68**	2-5	39.6	51.7
3-4	340.0	90	3-4	223.0	44.3
3-5	340.0	90	3-5	168.8	75.9
4-5	340.0	90	4-5	28.8	5.1
Planar failure			Toppling failure		
Slope face dip direction	Failure along joint set	Maximum safe angle (deg.)	Slope face dip direction	Failure along joint set	Maximum safe angle (deg.)
340.0	1	90	340.0	1	90
340.0	2	76***	340.0	2	90
340.0	3	90	340.0	3	53****
340.0	4	90	340.0	4	90
340.0	5	90	340.0	5	90

* Potential wedge failures along the intersection lines for joint set (1) with fault set 1 were possible if slope angle exceeded 76 degrees. ** Potential wedge failures along the intersection lines for joint set (1) with fault set 2 were possible if slope angle exceeded 68 degrees. *** Potential planar failure along faults was possible if slope angle exceeded 76 degree. **** Potential toppling failure due to the orientation of joint set 2 was possible if slope angle exceeded 53 degrees. Analysis must be carried out for faults sited close to the slope face in the vicinity of such faults.

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