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Relationships between joint density and P-wave velocity in rock units of the Cantabrian Zone (NW Spain)

Relations entre la densité des diaclases et la vitesse des ondes P dans des massifs rocheux de la Zone Cantabrique (NW d'Espagne)

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ABSTRACT: Determination of the joint density index of different Paleozoic formations has been possible through the study of jointing in these lithostratigraphic units. This has been accomplished for different rocks and the relation between joint density and P-wave velocity has been determined by realisation of seismic profiles.

From the relationships between seismic parameters and fracture density different particularities may be inferred. Two groups are distinguished in the limestone depending on the velocity of primary waves, but both of them show an inverse relationship between propagation velocity and joint density index -when the index decreases the velocity increases-. The siliciclastic rocks show less slope and correlation than carbonated rocks.

RÉSUMÉ: Il s´agit d´une analyse de la fracturation qui affecte diverses formations paléozoïques et du calcul d´un index de densité de diaclases qui présente un grand intérêt pour la caractérisation géomécanique de ces massifs. De plus, plusieurs profils séismiques ont été tracés a fin de caractériser les materiaux rocheux, en analysant le rapport entre la fracturation et la vitesse de propagation des ondes P.

En ce qui concerne la relation entre la vitesse des ondes P et le index de densité de fracturation, plusieurs particularités sont relevées. Parmi les roches calcaires l´on remarque l´existence de deux familles distinctes suivant les hautes ou basses vitesses de propagation des ondes, mais dans chacune d´elles la relation avec le taux de fracturation présente la même tendance inverse -plus la vitesse est grande, plus le taux est bas-. Dans le cas des roches détritiques, cette relation présente un écart moins prononcé et un degré de corrélation inférieur.

1 INTRODUCTION

The work has been carried out in the complete Paleozoic succession cropping out along the valley of the Bernesga river (N of León) from Cambrian to Carboniferous periods, about which only scarce bibliographical references, concerning mechanical properties can be found. The two aspects considered: joint density and primary seismic wave velocity, have been dealt with in articles by Rodríguez Bouzo et al. (1992) and by Sánchez Fernández et al. (1992), which analyse some of the materials studied here. From the same area comes the essay by Carbó Gorosabel (1984) in which geotechnical parameters are obtained by means of Down-Hole tests.

The analysis of rock mass jointing is frequently used to determine some of the indexes (RSR, RMR, IF and Q) on which geomechanical classifications are based, jointing orientation, spacing and degree of aperture playing the main role in them. The measured fracturation affects 16 lithostratigraphic formations, grouped in 27 measurement stations, the situation of which is shown in Fig. 1. The best studied lithology has been carbonates; due to its pelitic nature, no measurements were possible on the Formigoso, Fueyo and Vegamián Formations, and La Vid shales and Alba shales.

Field geophysical measurements were also made in order to determine, at rock mass scale, the variations in propagation velocity which longitudinal elastic waves (P-waves) present when moving across it. Analysis of these variations allows to determine features such as degree of weathering, lithological changes, fracturing degree, discontinuities, presence of fluids, etc., which facilitates a better knowledge of material behaviour as far as geotechnical effects are concerned. At the same time, wave propagation was also measured on some laboratory samples, in order to evaluate these formations at intact rock scale.

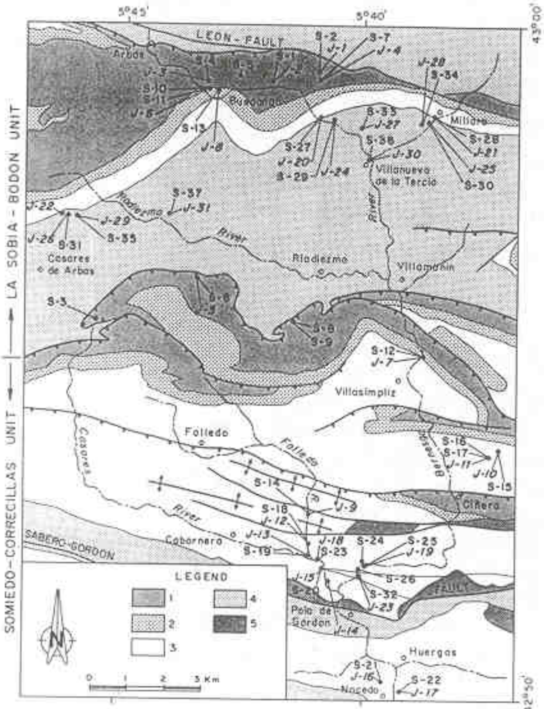

Fig. 1. Geological sketch-map and location of measuring stations. Legend: (1) Cambrian, (2) Ordovician, (3) Silurian y Devonian, (4) Carboniferous and (5) Stephanian.

2 GEOLOGICAL ENVIRONMENT OF THE STUDIED AREA

The area of study is located in the Variscan Belt of the Iberian Peninsula, and within it, in the so-called Cantabrian Zone. More specifically, it includes two geological units: Sobia-Bodón and Somiedo-Correcilla (Fig. 1). Paleozoic stratigraphic succession is complete, formed by alternating carbonate and sandstone formations, representative of the Cambrian (Herrería, Láncara and Oville Formations), Ordovician (Barrios Fm.), Silurian (Formigoso and San Pedro Fms.), Devonian (La Vid, Santa Lucía, Huergas, Portilla, Nocedo, Fueyo and La Ermita Fms.) and Carboniferous (Baleas, Vegamián, Alba, Barcaliente, Valdeteja and San Emiliano Fms.). The dominant formations are those of carbonated character: Láncara, La Vid (in part), Santa Lucía, Portilla, Nocedo (in part), Baleas, Alba, Barcaliente, Valdeteja and, partially, San Emiliano.

In the northern sector of the La Sobia-Bodón unit, there is an important stratigraphical break, which covers the greater part of the Middle and Upper Devonian (absence of the Huergas, Portilla, Nocedo and Fueyo Fms). The structures present a quite generalised E-W orientation, locally modified (for example in the Busdongo area) by N-S folds formed by lateral ramps.

The Somiedo-Correcilla unit, constitutes the allochton of a higher unit, the basal nappe just S of Villamanín, where it is overlain by synorogenic materials of the San Emiliano-Villamanín basin (Lower Bashkirian-Moscovian). The stratigraphic sequence becomes more complete towards the south.

It is worth mentioning the existence of the León Fault to the N and the Sabero-Gordón Fault to the S which laterally makes up the southern limit of the Ciñera-Matallana Stephanian basin. Transversal faults are also present, with a general NE-SW trend, despite a much lesser importance.

The Stephanian is found unconformably overlying the nappe surfaces, and appears folded along E-W axes. Alonso et al. (1990) concluded that the folds related with the nappes were produced in the Stephanian during this period, reorienting their course and acquiring the present S vergent.

3 METHODOLOGY

The study of joint density was made applying a method proposed by Davis (1984) and recently modified by Gutiérrez Claverol et al. (1991). Basically, consists in measuring all joins, independently of their size or any other features, included in the circle of reference of the pre-established area (circle-inventory method) being later computer processed, in order to obtain rose and density diagrams (Fig. 2), together with joint density index.

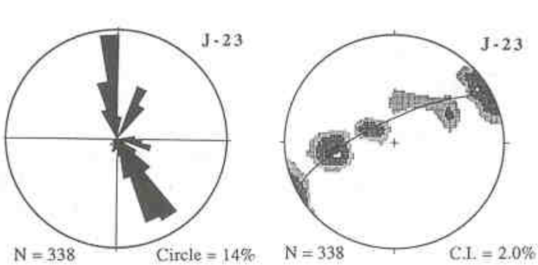

Fig. 2. Representative examples of rose diagram and density diagram of the measuring stations.

Once all data from one station have been collected, the fracture density is quantified, using the relationship: $\rho_j = L/\pi r^2$, where ρ_j represents joint density, L the accumulated length of all joints, and r the radius of the inventory circle. The length of joints is normally measured in cms, and consequently, as joint density is a rate length/area, the density index is expressed in cm/cm^2 (cm^{-1}). In the density diagram, concentration maxima can be observed in characteristic points of the sets of sub parallel joints, which define the different existing families, and on these maxima direction an average dip of bedding can be measured.

For the study of P-wave propagation velocity, seismic refraction method was chosen, as it was considered the most interesting and practicable one for the determination of the aforementioned feature, this being one of the parameters which is involved in numerous correlations with geomechanical factors. The knowledge of seismic waves velocity, when they travel across rock materials, allows the evaluation of their degree of weathering and fracturing.

The field tests consisted in the elaboration of 22 geophysical profiles. The waves were created artificially, either by means of the impact of a 10 kg thumper with free fall from a 3 meters height, generating an energy of 30 kpm, or with a sledge hammer. Two equipments were used. The first one was the ABEM TRIO, type 5352, which works with a maximum of 12 seismic traces. Recording velocity varied between 50, 100 y 200 cm/s, with a separation across the time lines of 2 milliseconds. The other equipment used was a Geometrics digital seismograph, model ES-2401, with vertical geophones, which offers simplicity and reliability, both in wave generation, and in record logging, together with a greater measurement accuracy, with 9 to 12 geophones.

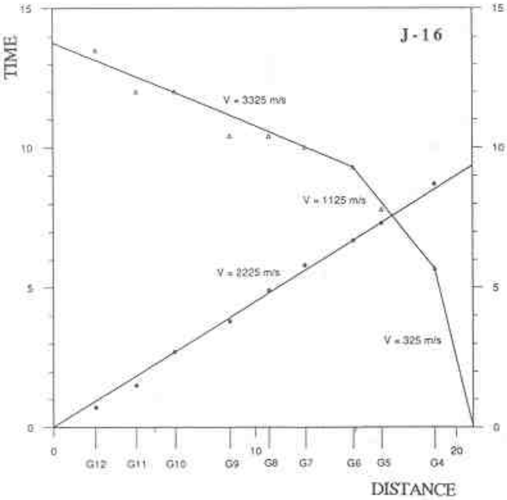

Fig. 3. Dromochrones corresponding to one of the seismic profiles.

For the interpretation of data obtained in these tests, and as the rock masses present a subvertical bedding, it was chosen to mesure the propagation velocity of surface and shallow-travelling waves, measuring the time it takes the wave to travel along the outcrop surface from the shooting point to the first geophone and from this to the second one and so on. Knowing the time and the distances -determined during the realisation of each test-, the velocity at which the direct wave crosses each different lithological medium is calculated. In order to be able to relate the velocity to given domains within the same formation, the geophones were placed in the inter-phases or contacts between different levels.

Normally, for each of the studied profiles, several shots were carried out from the opposite ends, and the corresponding dromochrones were set up (Fig. 3). It was observed that when one of the slices presents surface weathering, occasionally, the velocities obtained for each of the opposing shots are not identical, offering very different values, due to the interference of surface waves close to the source of vibrations. This seems to be due to the surface weathering that exists in the rock masses, in such a way that the area with greater velocity corresponds to the deepest ones in the rock mass, which are fresher, and consequently, the ones which present a smaller degree of weathering.

In the laboratory tests, the P-wave propagation velocity was measured in dry samples from carbonate Carboniferous rocks. The method used was the "ultrasonic impulse" with an Oyo Corporation equipment, model 5217A New Sonicviewer, which consists of a 63 kHz transmitter, and a P.A.C. receiver, with a band jump from 20 to 100 kHz. The pulse frequency was 128 Hz, sampling interval 400 nanoseconds, and transmitter excitation voltage 400 volts. The test consisted in applying the sample (cylindrical or cubic test-tubes) a vibration, and measuring the time the wave needed to propagate across it between two parallel faces, one in contact with the transmitter, and the other with the receiver.

4 JOINTING GEOMECHANICAL FEATURES

Jointing shows a dominant trend between NW-SE and NNE-SSW with bedding dipping variably, generally accompanied -locally- by another the E-W set, with S dipping bedding. The detected sets, together with their jointing index are shown in Tables I and II, where besides the orientation and the percentage of the different families present in each measurement

TABLE I. Joint orientation and joint density index of the Cambrian, Ordovician, Silurian and Devonian formations.

GEOLOGICAL TIME	FORMATION	STATION	BEDDING	STRIKE AND DIP OF JOINTING (%)									ρ_j
				WNW	NW	NNW	NS	NNE	NE	ENE	EW	HORIZONTAL	
DEVONIAN	La Ermita	J-18	352/87	194/20 (6)		77/75 (15)		285/80 (29) 291/58 (19) 98/20 (10)				0/0 (21)	0.13
	Nocedo	J-17	187/74		40/42 (4)	82/72 (11)		106/79 (31)	314/31 (47)			0/0 (7)	0.33
		J-16	277/40		38/69 (44)					164/79 (56)			0.27
	Portilla	J-15	345/85		234/53 (49)	72/60 (11) 250/83 (5) 72/22 (5)						0/0 (30)	0.22
	Huergas	J-14	260/60	23/85 (29)					125/37 (18)		180/76 (53)		0.06
		J-13	0/72			82/98 (63)					182/19 (37)		0.16
	Santa Lucía	J-12	20/70				265/53 (6)	116/72 (55) 282/21 (23)	137/14 (16)				0.13
	La Vid	J-11	13/67			246/24 (58)	275/65 (3)	112/83 (32) 99/64 (7)					0.29
SILURIAN	San Pedro	J-10	34/67		230/14 (47)			298/74 (22)	129/87 (31)				0.17
		J-9	0/72	200/31 (45)			270/87 (55)					332/9 (2)	0.07
ORDOVICIAN	Barrios	J-8	330/64			74/80 (59) 250/45 (15) 83/41 (10)					180/20 (16)		0.26
		J-7	30/70				274/65 (12)	119/67 (18)	132/60 (26)		180/20 (44)		0.34
CAMBRIAN	Oville	J-6	342/87			244/72 (59) 69/56 (14)				156/21 (27)			0.26
	Láncara	J-5	194/43		39/52 (35)	71/68 (38)				349/55 (27)			0.12
		J-4	341/83		237/79 (11)		89/41 (23) 271/42 (21)					0/0 (35)	0.41
		J-3	166/88		45/29 (45)		93/52 (45) 279/53 (30)						0.28
	Herrería	J-2	142/90			77/78 (10)		103/89 (29) 101/53 (6) 288/15 (6)				0/0 (49)	0.20
		J-1	149/90		60/49 (34) 236/88 (3)	62/75 (2)	270/40 (51)					0/0 (10)	0.39

TABLE II.-Joint orientation and joint density index of the Carboniferous formations.

GEOLOGICAL TIME	FORMATION	STATION	BEDDING	STRIKE AND DIP OF JOINTING (%)									ρ_J
				WNW	NW	NNW	NS	NNE	NE	ENE	EW	HORIZONTAL	
CARBONIFEROUS	San Emiliano	J-31	312/68	17/81 (8)	210/61 (19) 33/79 (8)	65/25 (14)			138/27 (22)		182/40 (13)		0.35
		J-30	329/81	204/21 (7)	238/60 (11) 231/86 (9)	257/43 (16) 70/32 (12) 71/62 (10)						0/0 (15)	0.45
	Valdeteja	J-29	338/89	187/48 (20) 193/65 (8)	50/87 (25) 39/87 (10)				135/28 (10)			85/5 (14)	0.24
		J-28	17/90				88/31 (14) 275/31 (10)	293/86 (21) 282/53 (11)	315/76 (7)		181/41 (12)	0/0 (7)	0.21
		J-27	307/58	200/32 (24) 204/56 (13)	230/87 (11)	84/54 (9)		289/33 (9) 113/23 (7)	140/89 (5)			188/9 (15)	0.57
	Barcaliente	J-26	328/76	206/46 (13)	215/79 (13) 54/79 (10)		90/75 (11)				179/31 (17)	135/8 (15)	0.43
		J-25	197/84				270/70 (30)	277/26 (17)	136/42 (16) 121/61 (16)	333/24 (10)		0/0 (6)	0.46
		J-24	333/73		237/79 (30)	76/43 (24) 242/47 (11)		116/21 (12) 290/76 (6)			182/22 (11)		0.37
		J-23	179/87		226/43 (26)		271/19 (2)	280/79 (21)	133/19 (51)				0.12
	Alba	J-22	328/78	195/40 (19)	45/60 (14)	250/50 (13) 262/75 (13)		116/22 (12)		164/20 (9)		0/0 (10)	0.56
		J-21	18/85			63/74 (4)		113/84 (23) 97/36 (21) 290/45 (16) 119/12 (14) 286/25 (8)					0.28
		J-20	308/65	189/31 (11)	213/70 (7)	78/54 (13) 244/72 (7) 254/80 (7)	88/32 (16)	290/32 (7)		332/49 (7)			0.31
	Baleas	J-19	4/76			74/80 (31)	271/32 (58)		135/43 (11)				0.23

station, the density index (ρ_j) which varies from 0,06 to 0,57 cm^{-1} is represented.

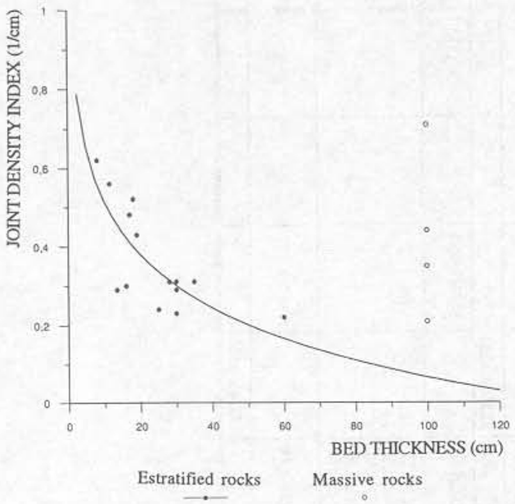

Fig. 4. Joint density index vs bed thickness of carbonate rocks. Note: A thickness of 100 cm has been asigned to all massive carbonated rocks because there are no thickness values of stratum available.

Plotting the jointing index against the thickness of the strata on which the measurements were made, a certain lineal relationship appears. In the case of stratified carbonate rocks, and alternanting sandstones and shales, the relationship between both parameters is of the inverse logarithmic type (Figs. 4 y 5).

Fig. 5. Joint density index vs bed thickness of alternating sandstones and shales.

On the contrary, quartzitic rocks present a direct relationship (Fig. 6). No dependence has been found between both variables in the massive carbonated rocks, concluding thus that after a certain bed thickness (normally above 40 cm) ρ_j is independent of thickness, which agrees with the conclusions of Ladeira y Price (1981).

There seems to be an anomalous behaviour in the formations characterised by alternating competent and incompetent beds, and in those that present a great heterogeneity in the bed thickness (i.e., Oville, San Pedro, Huergas and Nocedo Fms.).

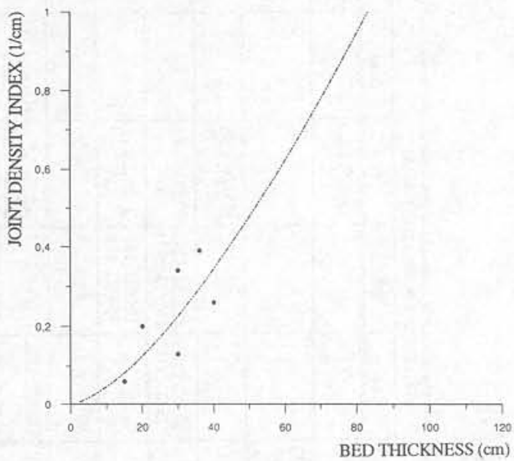

Fig. 6. Joint density index vs bed thickness of quarztitic rocks.

5 MEASUREMENT OF SEISMIC VELOCITIES

Starting from the dromochrones, before calculating the slopes of the different resulting slices, the velocities for each material were obtained, and the slices with different velocities and its value being deducted. In some profiles, the existence of several zones was detected. These were mainly two, which presented different values for the velocity parameter. The ones with a greater slope, belonging to a smaller velocity, corresponds to the surface zone, and therefore, to the one with greater weathering.

Table III presents the data obtained for the Paleozoic formations of the Cambrian and Devonian periods, whereas Table IV synthesises the velocity values for P-waves measured, in the rock masses and in the laboratory, for rocks of the Carboniferous period.

The fact that the surface zone gives lower velocity values is due principally to weathering processes, decompression of the rock mass, fracturing, etc. which diminish as we go deeper. The results obtained in the laboratory are in general, higher than the field ones, as they were carried out on the rock matrix, and therefore, free of the discontinuities which affect rock mass.

TABLE III. P-wave propagation velocity in Cambrian, Ordovician, Silurian and Devonian formations.

GEOLOGICAL TIME	FORMATION	STATION	VELOCITY OF "P" WAVES	
			Depth >3m	Depth <3m
DEVONIAN	La Ermita	S-24	4100	–
		S-23	4200	800
	Nocedo	S-22	2850 (4500) 5650	850
		S-21	2750	1100
	Portilla	S-20	7550 1700 (1)	3250 1200 (1)
	Huergas	S-19	3300	1250
	Santa Lucía	S-18	4300	1550
	La Vid	S-17	3200	1080
		S-16	3850	1200
SILURIAN	San Pedro	S-15	2500 6000	1300
		S-14	5300 2900	800
ORDOVICIAN	Barrios	S-13	3750	1050
		S-12	2450 5100	550
CAMBRIAN	Oville	S-11	7000 (4350) 3000	1550
		S-10	3550	1150
	Láncara	S-9	4850	3000
		S-8	3350	700
		S-7	4500 5500	2000
		S-6	2300	600
		S-5	2900 4600	850
		S-4	6700 (2) 4000 (3)	1000 (2) 600 (3)
		S-3	3600	1650 600
	Herrería	S-2	3950	950
		S-1	3750	550

NOTES: (1) Oolitic intercalated zone. (2) Thick beds zone. (3) Stratified zone.

However, there is a certain dispersion of results due to the texture heterogeneity typical of sedimentary rocks. In the cubic samples, the velocity measured perpendicularly to stratification is significantly smaller than parallel to it, which can be accounted for by, apart from the very effect of bedding, the existence of thin sedimentary laminations.

6 CONCLUSIONS

6.1 *Jointing*

* Jointing orientation allows to distinguish several families trending from NW-SE to NE-SW, with predominant WNW and NW directions. Occasionally, and specially related to longitudinal folds, E-W trending sets appear.

* In general, dominant join families are suborthogonal to stratification, being evident certain differences related with folds (limb and hinge).

* Joint density index varies depending on:

- Space location. It is greater in the La Sobia-Bodón unit.
- Lithology. Carbonate rocks generally have a somewhat greater than siliciclastic ones.
- Bed thickness. Bedded carbonate rocks and alternating sandstones and shales have an inverse logarithmic relationship between the bed thickness and fracturation index, in such a way that the smaller values for the latter parameter appear in greater bed thickness. In the case of quartzitic rocks the tendency is opposite, presenting a direct thickness relationship. Massive carbonate rocks do not show any kind of correlation.

* The geometrical figure resulting from the join intersections is generally of the rhomboidal or trapezoidal shape.

* The lithostratigraphic units in which jointing presents a greater geomechanical importance are Herrería, Láncara, Barrios and Nocedo Fms. and above all, the Carboniferous limestones.

6.2 *P-waves velocity*

* The P-wave velocity data separates two zones in the rock masses, a shallow one, with low velocity values, which indicates a high degree of weathering, and includes, approximately, the first three metres and a deeper one, not weathered, with higher velocity.

* Discontinuities in the rock mass, derived both from bedding surfaces (the greater velocities are associated to massive outcrops) and fracturation ones, greatly reduce wave propagation velocity.

* Velocities obtained in the laboratory show a clear relationship with the structures present in the test-tubes. Smaller velocities are associated to samples that show a greater number of structures (predominantly sedimentary laminations, porosity, small fractures), and especially when these are perpendicularly to wave propagation.

TABLE IV. P-wave propagation velocity in Carboniferous formations.

GEOLOGICAL TIME	FORMATION		STATION	VELOCITY OF "P" WAVES			DINAMIC YOUNG'S MODULUS (GPa)					
				LABORATORY	IN SITU		LABORATORY				FIELD	
					Depth >3m	Depth <3m	Maximum	Minimum	Average	Deviation	Depth >3m	Depth <3m
CARBONIFEROUS	San Emiliano		S-37	–	6500	4400	–	–	–	–	114.9	52.7
	San Emiliano		S-36	5150	6900 4600 (4) 3600 (1)(3)	6900 1200 (2) 3600 (1)(3)	84.7	56.4	71.5	9.39	127.9 56.8 34.8	127.9 3.9 34.8
	Valdeteja		S-35	–	5100	3100	–	–	–	–	71.8	26.5
	Valdeteja		S-34	5200	4000	700 (2)	83.2	58.0	72.7	10.47	43.1	1.3
	Valdeteja		S-33	4550	5700	3100	–	–	54.6	–	85.8	25.4
	Barcaliente		S-32	–	6000 4350	–	–	–	–	–	–	–
	Barcaliente		S-31	–	2700	800 (2)	–	–	–	–	19.4	1.7
	Barcaliente		S-30	3800	4800	800 (2)	48.8	31.6	37.6	6.02	59.3	1.6
	Barcaliente		S-29	5450	5300	1200	105.7	61.8	80.5	15.63	75.7	3.9
	Alba	Limestones	S-28	5800	3800	2100	100.7	73.2	90.0	10.00	38.5	11.8
	Alba	Shales		–	2100	–	–	–	–	–	–	–
	Alba	Limestones	S-27	5800 5700-4650 (5)	3000 2600 (1)	1200 2600 (1)	111.2	70.3	88.7	13.90	23.6 17.76	3.8 17.76
	Alba	Shales		–	2100	1200	–	–	–	–	–	–
	Alba	Limestones	S-26	–	2500	–	–	–	–	–	–	–
	Alba	Shales		–	2200	1100	–	–	–	–	–	–
	Baleas		S-25	–	8400	1300	–	–	–	–	–	–

NOTES: (1) The measurement was parallel to the stratification. (2) Very surface measurement. (3) Stratified zone. (4) Zone with stratified intercalations. (5) Measurements on cubic samples, parallel and perpendicular to the structures.

* Velocity values for the seismic waves in deep zones, seem to be greater for carbonate rocks than siliciclastic.

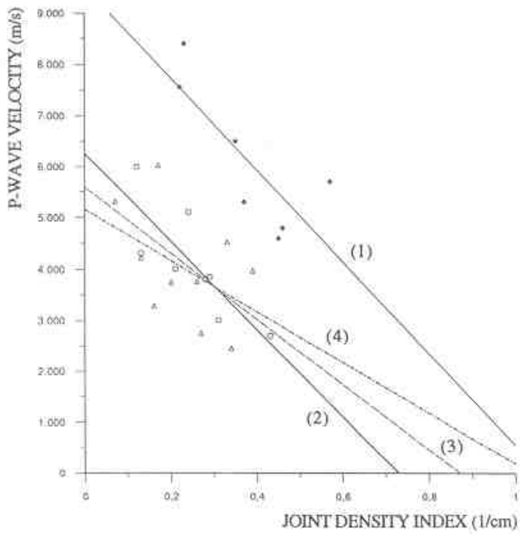

Fig. 7. Relationship between P-wave propagation velocities and the joint density index in different types of rocks. Legend: (1) Carbonate rocks with high P-wave velocity; (2) Carbonate rocks with low P-wave velocity; (3) Carbonate rocks with low P-wave velocity and sandstones; (4) Sandstones.

6.3 *Relationship between V_p and ρ_j*

* Several peculiarities appear as regards the relationship between P-waves and joint density (ρ_j) (Fig. 7):

- Within the carbonate rocks two different families can be found, one with high, and another with low wave propagation velocities; but in both, the relationship with the joint index shows the same inverse tendency (the greater the velocity the smaller the index). The relationship straight lines are parallel between themselves, and have similar correlation degrees (0,63 and 0,66 respectively).

- In the case of siliciclastic rocks, the relationship straighl line presents a lesser slope, with a lower correlation degree.

REFERENCES

Alonso, J.L., Suárez, A., Rodríguez Fernández, L.R., Farias, P. & Villegas, F. 1990. Mapa Geológico de España. Escala 1:50.000. Hoja nº 103 "La Pola de Gordón". *Inst. Tecnol. GeoMin. España*, Madrid.

Carbó Gorosabel, A. 1984. Obtención de parámetros geomecánicos por ensayos Down-Hole, en Pajares (León-Asturias). *VIII Simp. Ncnal. "Reconocimiento de macizos rocosos"* 1-2: 1-5, Madrid.

Davis, G.H. 1984. *Structural Geology of Rocks and Regions*. John Wiley & Sons, New York.

Gutiérrez Claverol, M., González Buelga, M. & Rodríguez Bouzo, L. 1991. Validación del método de Davis para el análisis de la diaclasación de macizos rocosos. *Ingeniería Civil (CEDEX)* 80: 31-36, Madrid.

Ladeira, F.L. & Price, N.J. 1981. Relationship between fracture spacing and bed thickness. *J. Struct. Geol.* 3: 179-184.

Rodríguez Bouzo, L., González Buelga, M., Gutiérrez Claverol, M. & Torres Alonso, M. 1992. Análisis geométrico de la diaclasación de materiales paleozoicos en la vertiente meridional de la Cordillera Cantábrica (N España). *III Congr. Geol. España*. 2: 388-392, Salamanca.

Sánchez Fernández, B., Calleja Escudero, L., González Buelga, L., Rodríguez Bouzo, L. & González Moradas, M.R. 1992. Parámetros sísmicos de materiales carbonatados del Paleozoico del valle del Bernesga (Zona Cantábrica). *III Congr. Geol. España*. 2: 230-234, Salamanca.