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NON-DESTRUCTIVE TESTING OF SHAFT LINING

Summary. The function of ultrasonic testing is to obtain the acoustic velocity in a studied medium. High frequency electrical signals from the ultrasonic transmitter are converted into mechanical vibrations by the transducer in the transmitter, and then transmitted to the concrete and the surrounding medium, by turns the elastic waves are again converted into electrical signals by the transducer in the receiver, the wave form is shown by a oscilloscope. Owing to the difference of acoustic velocities in concrete and surrounding rock, and in loose and unloose rock, the thickness and strength of concretes lining and the extant of loosen rock can be detected. The results of ultrasonic testing for the shaft lining in Jiulongkou ventilation shaft of Handan and Xingtai coal mines are as the following records:

The average thickness of shaft lining 256.9 mm the average strength of concrete 28.57 MPa, 96% of the lining has reached or exceeded the design strength and the average extent of loosen rock is 543.7 mm.

1. Principle of ultrasonic testing

The ultrasonic testing is to obtain the acoustic velocity of the medium. High frequency electrical pulse issued from the ultrasonic transmitter are converted into mechanical vibrations by transducer in the transmitter which are transmitted to concrete and the surrounding medium, and then the elastic waves are again converted into electrical signals by the transducer in the receiver, and the wave form is shown by a oscilloscope after exaggeration. Owing to the difference of acoustic velocity in concrete and surrounding rock and in loosen or unloosen rock, the thickness and strength of concrete lining and the extent of loosen rock may be detected.

It is assumed that concrete is a kind of homogeneous isotropic and elastical medium. Although concrete is built up of materials of different elastic parameters, when the dimension of concretes is big enough, the opportunity of the arrangement and distribution of its ingredients to all directions are equal, so it can be assumed to be homogeneous, isotropic and elastic at a macroscopic point of view. The travel of ultrasonic through the concrete body will follow the equations of motion for an elas-

stic solid i.e. wave equations. If we neglect body forces in the static equilibrium equation of the space problem of elastic theory and put in force of inertia, then by Newton's first law of force we can get wave equations in terms of strain as follows:

$$\left. \begin{aligned} (\lambda + G) \frac{\partial \epsilon}{\partial x} + GV^2 u - P \frac{\partial^2 u}{\partial t^2} &= 0 \\ (\lambda + G) \frac{\partial \epsilon}{\partial y} + GV^2 v - P \frac{\partial^2 v}{\partial t^2} &= 0 \\ (\lambda + G) \frac{\partial \epsilon}{\partial z} + GV^2 w - P \frac{\partial^2 w}{\partial t^2} &= 0 \end{aligned} \right\} \quad (1)$$

Where

ϵ = Volumetric strain,

$$\epsilon = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = \epsilon_x + \epsilon_y + \epsilon_z;$$

∇^2 = Laplacian,

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2};$$

u, v, w = displacements of particle in the direction of coordinates
X, Y, Z;

P = density;

λ = Lame's constant;

G = modulus of rigidity.

The equation of motion of longitudinal wave derived from (1):

$$\frac{\partial^2 \epsilon}{\partial t^2} = \left(\frac{\lambda + 2G}{P} \right) \nabla^2 \epsilon \quad (2)$$

The equation of motion of shear wave:

$$\frac{\partial^2 u}{\partial t^2} = \frac{G}{P} \nabla^2 u \quad (3)$$

By integral equation of motion, wave velocity can be proved:
Longitudinal wave velocity

$$v_p = \sqrt{\frac{\lambda + 2G}{P}} = \sqrt{\frac{E(1-\mu)}{P(1+\mu)(1-2\mu)}} \quad (4)$$

Shear wave velocity

$$V_s = \sqrt{\frac{G}{P}} = \sqrt{\frac{E}{2P(1+\mu)}} \quad (5)$$

Where

 μ - Poisson's ratio,

E - Dynamic modulus of elasticity

and

$$\lambda = \frac{E\mu}{(1+\mu)(1-2\mu)}; \quad G = \frac{E}{2(1+\mu)}$$

From (4) and (5) we can see travelling of longitudinal and transversal waves depends upon elastic parameter and density of the elastic medium, therefore, if travelling behaviours of wave have been measured, the corresponding evaluation for its elastic parameters can be worked out, and elastic parameters of a medium beared relationship with strength, porosity etc of a medium so it makes physical foundation for ultrasonic detection.

Owing to the fact that concrete strength are influenced by a number of factors, it is difficult to establish common analysis formula between sonic velocity and compressive strength, but empiric formula may be established between velocity and strength through a large number of test of that medium, empiric formula had been worked out by the institute of building research of Poland Warsaw as follows:

$$R_c = 24.34 V_p^2 - 71.954 V_p + 42.726 \quad (6)$$

Where

 R_c - compressive strength of concrete, 0,1 MPa, V_p - velocity of longitudinal wave, km/s.

But in the calculation during measurement, on the basis of above empirical formula, we add in a coeficient of adaptation K_R to meet the condition of the test. Let $R_S = K_R \cdot R_c$ be the compressive strength of concrete.

Formula for thickness of shotcrete H is:

$$H = t_h \cdot V_d / 2 \quad (7)$$

Where

H - thickness of shotcrete, mm,

t_h - time of wave reflection, s,

V_d - equivalent velocity, km/s.

2. Instrument and Equipment

Apparatus used is model SYC-2 sonic testing instrument of rock parameter with a cathode-ray oscilloscope, selected accessories are: 50 KHz ordinary transducers 2 pcs/set, model FSS (38 KHz) transducers of single hole 1 pcs/set, 35 KHz transducers of double hole 2 pcs/set.

Drilling is done in the shaft, using air drill model 7655, sealing is proceeded by home-made sealer. Plane grinding on the surface of shaft lining is finished by using grinder model SR-60, Telephone model XC76^A is used for communication between surface and underground.

3. Test in situ

The diameter of this shaft is 5.5 m, depth of shaft 487 m passing through 26 layers of cleavage water bearing strata in sandstone; from shaft collar down to the depth of 325 m, it had been pregrouted, in shaft sinking, smooth blasting with borehole 4 m long was used.

Design requirements: grade of concrete 200# spray thickness 200 mm, proportion of concrete 1 (cement): 2 (sand): 2 (crushed rocks); Grade of cement 425#.

Measuring system: Power source 220 V AC on surface → coaxial cable down shaft → instrument → H-type cable → transducers. Put instrument into main hoist bucket, operations of transducers were done in the assistant bucket, operate the two bucket simultaneously. Testing were made at intervals of 4 meters apart. 46 stations were arranged from a depth of 74.75 m to 252.25 m of shaft at random.

4. Analyses of results

Concrete samples were taken from shaft lining in situ. standard size of specimen: 100 × 100 × 100 mm calculated parameters had been gotten as follow:

Average velocity of longitudinal wave $V_p = 4.26$ km/s;

Average velocity tested when position of transducer in parallel $V_{b10} = 3.725$ km/s;

Average equivalent velocity $V_{ds} = 4.098$ km/s, (distance of transducer 5 cm);

Dynamic modulus of elasticity $E_d = 35.5 \times 10^3$; MPa

Static modulus of elasticity $E = 30 \times 10^3$; MPa

Average compressive strength of specimen: $\bar{R} = R \times 0.9 = 26,63$ MPa;

Calculated compressive strength $R_c = 177.8$ kg/cm²;

Adapted coefficient of strength $K_R = \bar{R}/R_c = 1.498$;

Rate coefficient of wave velocity: $K_p = V_p/V_{b10} = 1.444$; $K_{fs} = V_{ds}/V_{b10} = 1.100$.

Analyses of results

1) Strength of shaft lining

Results from 45 stations in 178.5 meters of shaft are given in table 1.

Table 1

Strength of shotcrete shaft lining

Test Point	V_p (km/s)	R (0.1 MPa)	Test Point	V_p (km/s)	R (0.1 MPa)
1	4.40	295	25	4.77	379
2	-		26	4.40	295
3	4.08	231	27	4.13	241
4	4.19	253	28	4.28	270
5	4.02	220	29	4.02	220
6	3.96	205	30	3.70	165
7	4.19	255	31	4.12	239
8	4.09	233	32	3.93	203
9	3.98	213	33	4.29	272
10	4.77	279	34	4.52	323
11	4.77	379	35	4.77	379
12	4.71	365	36	4.77	379
13	4.77	379	37	4.77	379
14	4.09	233	38	4.31	270
15	4.45	307	39	4.26	266
16	4.40	295	40	4.58	336
17	3.98	213	41	4.45	307
18	4.35	285	42	4.56	336
19	4.19	254	43	4.71	365
20	4.52	323	44	3.07	134
21	4.52	323	45	4.02	224
22	4.77	379	46	4.19	254
23	4.58	336			
24	4.23	261			

Analysis of data in table 1:

Average strength

$$\bar{R}_c = \frac{1}{n} \sum_{i=1}^n R_i = 28,57 \text{ MPa}$$

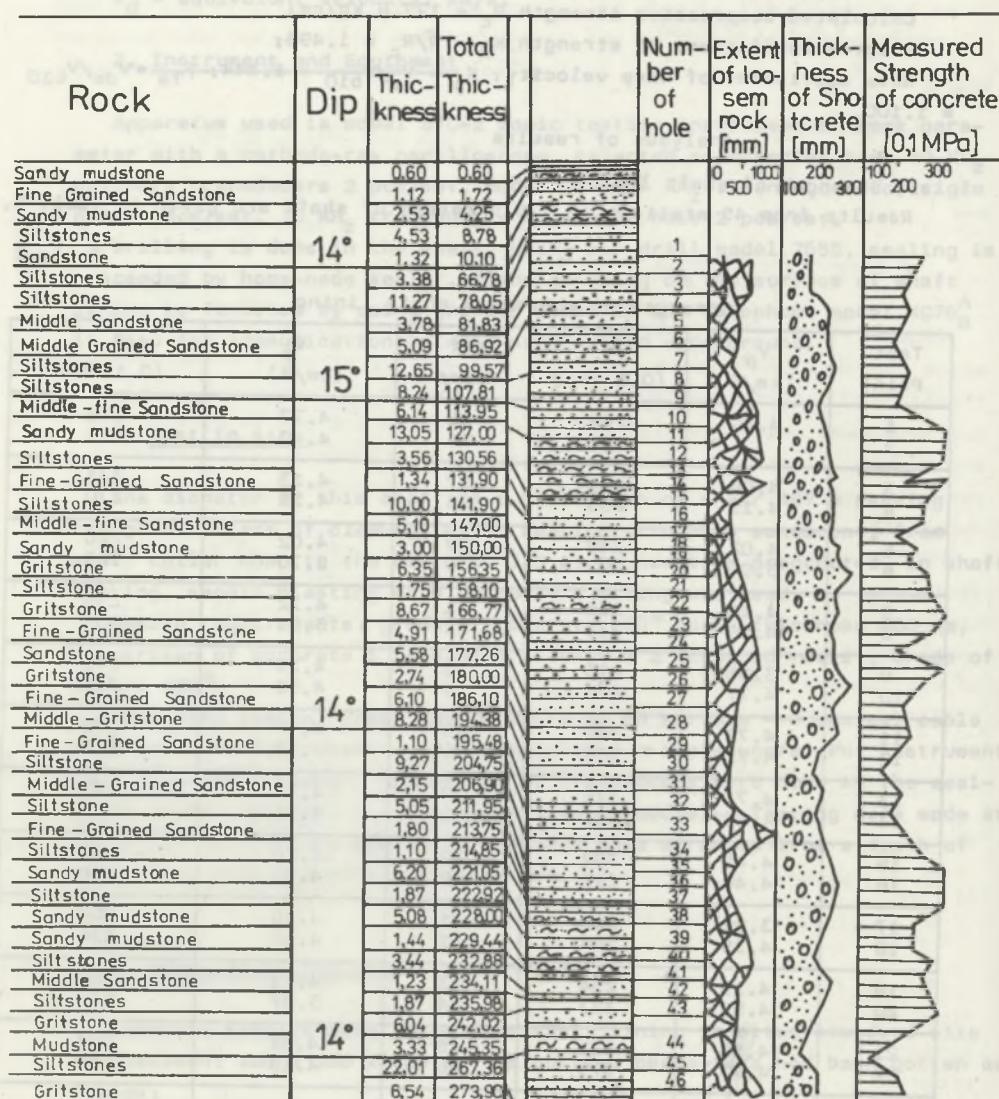


Fig. 1. The thickness and strength of shotcrete lining and the extent of loosen rock vary with depth of shaft

Standard deviation

$$\sigma_n = \sqrt{\frac{1}{n} \sum_{i=1}^n (R_i - \bar{R}_c)^2} = 6.453 \text{ MPa}$$

Coefficient of variation

$$V = \sigma_n / R_c \times 100\% = 23\%$$

Here we can see the average actual strength of shotcrete is higher than the designed strength. 96% of the lining has reached or exceeded the designed and only 4% of it is below.

The variation of actual strength along with the depth of shaft is shown in fig. 1.

2) Thickness of shaft lining

Analysis of measured results (table 2) of lining for 44 test point as follows:

Table 2

Thickness of shotcrete lining

Test Point	V_d (km/S)	t_n (μ s)	(-) (mm)	Test Point	V_d (km/S)	t_n (μ s)	H (mm)
1	4.24	94.7	201	25	4.59	119.7	275
2	-	-	-	26	4.24	143.0	303
3	3.93	98.0	193	27	3.10	173.0	268
4	4.03	127.3	257	28	3.22	184.3	297
5	3.86	130.0	251	29	3.01	155.7	234
6	3.80	131.0	249	30	2.77	149.0	206
7	4.03	133.3	269	31	2.86	170.0	243
8	3.93	128.3	252	32	2.86	154.0	220
9	2.99	145.7	218	33	4.13	120.7	249
10	3.58	134.0	240	34	4.35	122.7	267
11	3.58	144.0	258	35	4.59	120.3	276
12	3.53	135.7	261	36	4.59	126.0	289
13	3.58	158.7	283	37	4.59	120.0	275
14	3.06	165.0	252	38	4.15	130.3	270
15	4.28	128.7	275	39	3.19	148.0	236
16	4.24	129.3	274	40	3.44	126.0	217
17	3.83	130.7	250	41	3.34	159.0	266
18	4.18	133.0	273	42	3.43	149.0	256
19	4.03	136.0	274	43	3.53	133.3	235
20	4.35	156.3	340	44	2.30	152.3	175
21	4.35	127.3	277	45	3.03	150.0	227
22	4.59	126.0	289	46	3.14	145.7	229
23	4.40	121.7	268				
24	4.07	139.3	283				

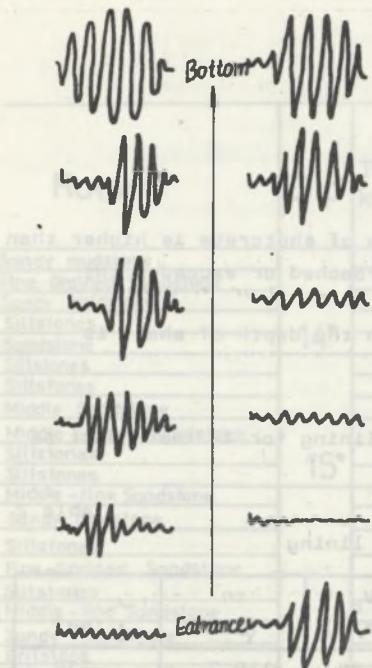


Fig. 2. Photo of wave from at hole 44 and 46

Average thickness

$$\bar{H} = \frac{1}{n} \sum_{i=1}^n H_i = 256.9 \text{ mm}$$

where

n - number of test point 44,

H_i - thickness of shaft lining at any point.

Standard deviation

$$\sigma_n = \sqrt{\frac{1}{n} \sum_{i=1}^n (H_i - \bar{H})^2} = 29.9 \text{ mm},$$

Coeffiecient of variation

$$V = \sigma_n / \bar{H} \times 100\% = 11.6\%$$

The results proved that the thickness of shaft lining agree with the designed thickness.

3) Extent of loosen rock

Table three shaws the measured extent of loosen rock, its variation with depth of shaft as shown fig. 1. As may be seem in fig. 2 the amplitude die-away with the increment of the extent of rock fracture from bottom of hole to its entrance.

Table 3

Extent of loosen rock

Number hole	Extent of loosen rock	Number hole	Extent of loosen rock	Number hole	Extent of loosen rock
1	699	15	335	32	380
3	617	16	306	33	1081
4	373	18	407	34	533
5	454	22	691	36	311
6	451	23	432	38	610
7	361	24	247	40	133
8	648	25	825	42	494
9	767	26	527	44	455
10	790	27	432	46	1001
11	832	28	453		
12	839	29	366		
13	517	30	344		
14	943	31	377		

Note: measured results of single-hole detection

Recenzent: Prof. dr hab. inż. Mirosław Chudęk

Wpłynęło do Redakcji w czerwcu 1988 r.

NIENISZCZĄCE TESTOWANIE OBUDOWY SZYBU

S t r e s z c z e n i e

Zadaniem testowania ultradźwiękowego jest uzyskanie prędkości akustycznej badanego ośrodka. Sygnały elektryczne o wysokiej częstotliwości z nadajnika ultradźwiękowego są przetwarzane na drgania mechaniczne przez przetwornik w nadajniku a następnie przekazywane do betonu i otaczającego ośrodka, z kolei fale elastyczne są ponownie przetwarzane w sygnały elektryczne przez przetwornik w odbiorniku, a postać fali ukazywana jest na oscyloskopie. Z uwagi na różnicę prędkości akustycznych w betonie i otaczającej skale oraz w odspojonej i zbitej skale można wykrywać grubość i wytrzymałość obudowy betonowej oraz zasięg odspojonej skały. Wyniki testowania ultradźwiękowego dla obudowy szybu w szybie wentylacyjnym Jiulongkou kopalni węgla Handau i Xingtai są następujące: przeciętna grubość obudowy szybu 256,9 mm, przeciętna wytrzymałość betonu 28,57 MPa; 96% obudowy osiągnęło lub przekroczyło zaprojektowaną wytrzymałość, a przeciętny zasięg odspojonej skały wynosi 543,7 m.

НЕРАЗРУШАЮЩИЕ ИСПЫТАНИЯ ШАХТНОЙ КРЕПИ

vibrating wire stress gauges and strain gauges are embedded for in-situ measurement of rein-forcing-rib stress and concrete strain. In this paper some results of in-situ measurement are described.

Р е з ю м е

Заданием ультразвукового испытания является получение акустической скорости исследуемого центра. Электрические высокочастотные сигналы ультразвукового передатчика преобразовываются в механические колебания в преобразователе передатчика, а затем направляются в бетон и окружающий центр, где упругие волны заново перерабатываются в электрические сигналы преобразователем приемника. Форма волны видна на осциллографе. Принимая во внимание разницу акустических скоростей в бетоне и окружающей горной породе, а также в отколотой и плотной горной породе – можно определять как толщину и прочность бетонной крепи, так и дальность отколотой горной породы. Результаты ультразвукового испытания для шахтной крепи в вентиляционном стволе Юлонгкую шахты Хандау и Сингтай, следующие: средняя толщина шахтной крепи 256,9 мм, средняя прочность бетона 28,57 мПа; 96% крепи достигло или превзошло запроектированную прочность, а средняя дальность отколотой горной породы составляет 543,7 м.