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Submarine cable voltage measurements between Pusan and Hamada

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Abstract: The voltage difference between the ends of telephone cable across the Korea Strait is measured for one year beginning March 1990. Spectral analysis and tidal analysis show that the voltage variations have most energies in low frequencies and some peaks at the tidal frequencies, which are highly correlated to the variation of tidal stream in the Korea Strait. Using the M_2 amplitude the transport per one volt is simply estimated as 35.95 Sv/volt.

1. Introduction

By the Faraday's law, an electromagnetic force induces electric potential difference in water flowing in a channel as it works as a moving conductor in the earth's magnetic field. If the potential difference is measured at the both ends of a submarine telephone cable laid at the bottom of a channel, the total volume transport of water flowing through the channel at any instant can be estimated.

LONGUET-HIGGINS (1949) first introduced the theoretical application of the Faraday's law for the purpose of estimating the transport for a shallow channel whose depth is small compared with its width. Since then this technique has been applied very successfully in the Dover Strait. BOWDEN (1956) indentified the main tidal constituents of the cable voltage and showed that they vary seasonally with sea conductivity. He also estimated residual flows using a calibration factor derived from the tidal signal and correlated them with local winds and sea-level gradients. Since BOWDEN's experiment CARTWRIGHT and CREASE (1963), PRANDLE and HARRISON (1975) also used this method to study water movements in the Dover Strait while HUGHES (1969) and PRANDLE (1980) applied this method in the Irish Sea and Pentland Firth respectively. ALOCK and CARTWRIGHT (1977) analyzed 10-year's voltage records in Dover Strait for tidal and non-tidal effects.

The theoretical work of LONGUET-HIGGINS (1949) had been advanced by SANFORD and FLICK (1975) and ROBINSON (1976). ROBINSON (1977) described a theoretical model which was capable of predicting the potential difference across the Dover-Sangatte cable.

LARSEN and SANFORD (1985) described the Florida Current volume transport from voltage measurements and recently LARSEN (1991) used in-service undersea telephone cable with repeaters to estimate the Florida Current transport.

In the Korea Strait KAWATATE *et al.* (1991) obtained a time series of the electric voltage records at the Japanese side of the submarine cable buried between Pusan and Hamada for the period of July 1987 to February 1988 together with a set of the current records measured southeast of the Tsushima Island. A cross-spectral analysis showed a strong correlation between the voltage and current variations.

There have been earlier efforts to estimate the transport passing through the Korea Strait and flowing into the East Sea (HIDAKA and SUZUKI, 1950; YI, 1966). However, because of shal-

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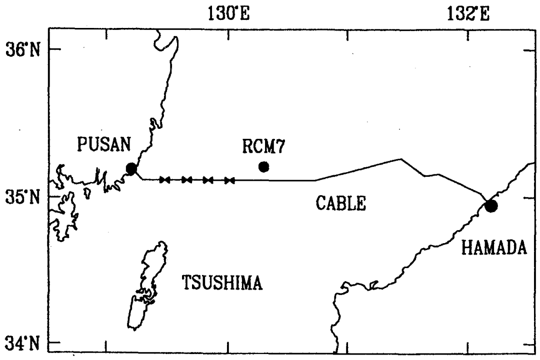

Fig. 1. Location map of submarine telephone cable and RCM current meters.

lowness of this region, dynamic calculation of geostrophic flow has a limitation of determining the reference level. One of our objectives is to apply the voltage measurement technique in the Korea Strait for a long-term monitoring of the transport variation of the Tsushima Current. As a follow-up of the measurements at Hamada Station, we took data of voltage variation at Pusan Station of the underwater cable across the Korea Strait beginning March 1990. This paper describes the preliminary results of data analysis to investigate the usefulness of the voltage records. We analyze one year data focusing at fluctuations at tidal frequencies mainly.

2. Data

The submarine cable between Pusan and Hamada is 281 km long, oriented mainly in the east-west direction and contains 50 repeaters (Fig. 1). The essential elements are shown in Fig. 2. We installed the data logger at the Pusan Submarine Cable Relay Station and have recorded the voltage fluctuations since March 29, 1990. The power supply voltage (Vs) is about −550 at Pusan and about +550 at Hamada, which compensate each other maintaining 1100 volts between two stations. This power voltage is measured from a pair of test points divided

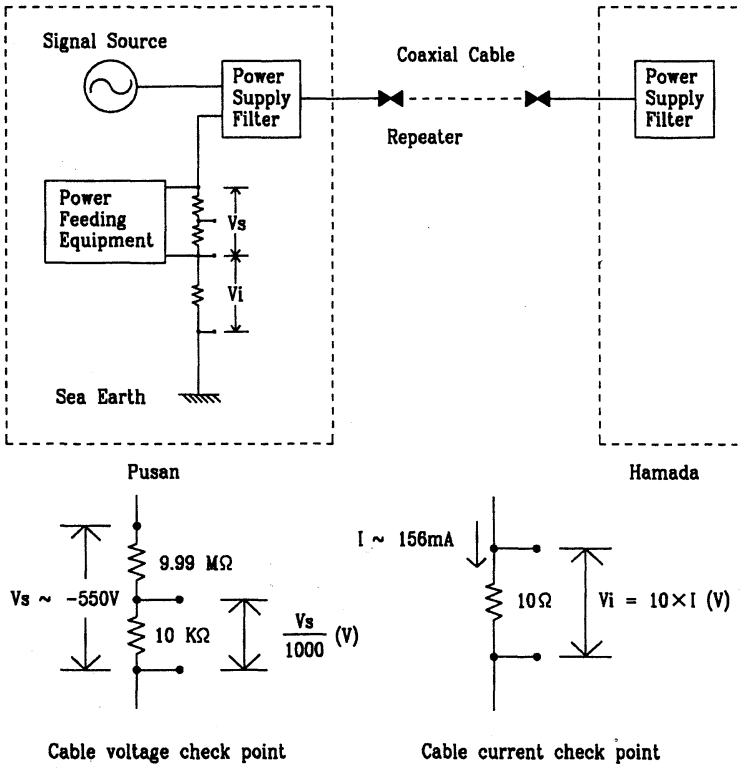

Fig. 2. Essential elements of submarine telephone cable for monitoring motion-induced voltages.

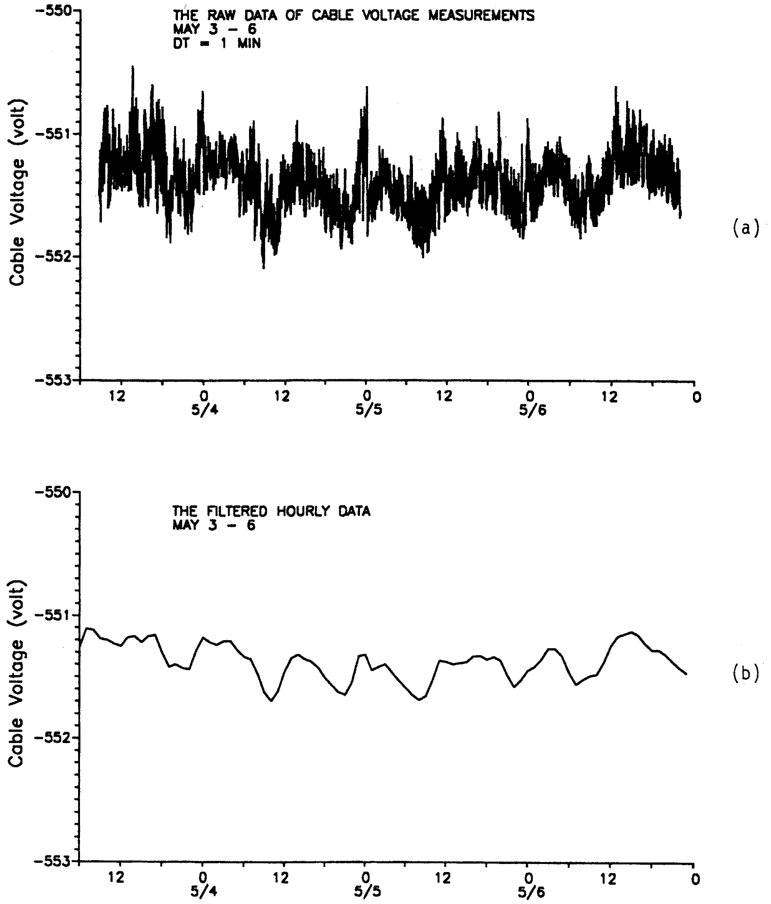

Fig. 3. Examples of (a) raw data and (b) filtered hourly data of voltage variations from May 3 to 6.

by 1000 at Pusan. The power supply current (I) is about 156 mA and determined from the voltage Vi measured from a pair of test points connected across a 10 ohm resistor. This power current flows through the power supply filter, the submarine cable and the repeaters and returns to the sea-earth ground through the ocean. Data acquisition system is further described by BAHK (1991) separately.

The logger samples the voltage every minute, which is an average over 8 seconds. About every 10 days, the data are retrieved through a dial up modem system. The retrieved raw data are filtered and subsampled to obtain hourly data for final analysis.

These cable voltages previously have been measured at Hamada Station from 1987 to 1988 (KAWATATE, 1991), and have continued to record at the same time as our recording. In this study we used one year data to March 20, 1991 at the Pusan and analyzed these data with RCM7 current meter data moored from May 11 to June 29, 1990 approximately at the mid-point of cable (Fig. 1).

3. High frequency response

An example of the raw data from May 3 through 6 is shown in Fig. 3(a). The voltage fluctuates between about −552 and −551 volts with a conspicuous semidiurnal periods.

In order to check the quality of our data and the significance of high frequency response, we selected sample data during 3 days in May, August, November and February, and calculated

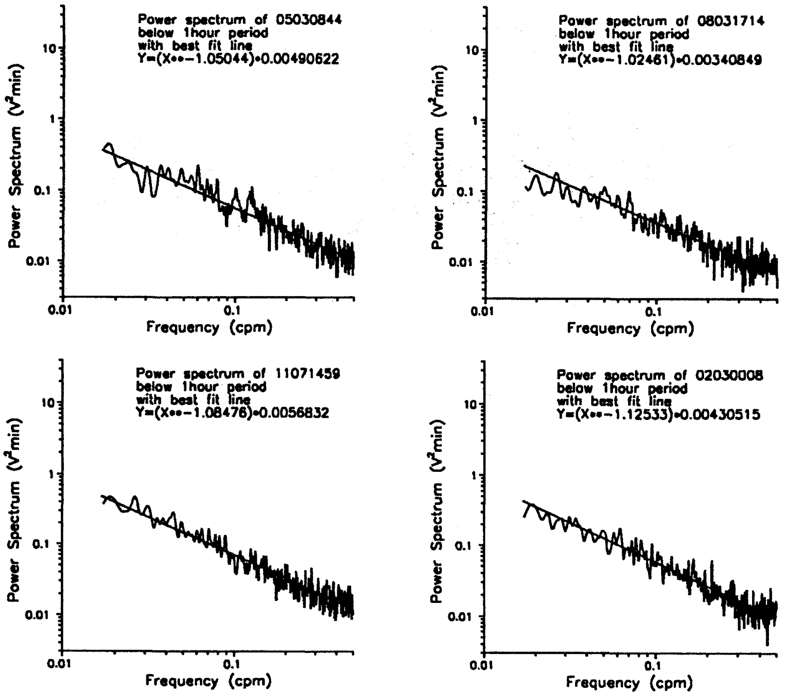

Fig. 4. Power spectra of about 3 days in each month.

the spectrum for each data (Fig. 4). These spectra are very similar to each other, linearly decreasing with frequency in logarithmic scale for frequencies corresponding to the period shorter than one hour. The decreasing slopes are −1.05, −1.03, −1.08 and −1.12 respectively, same in each month with the mean of −1.08. WUNSCH (1972) showed that the logarithmic slope was −3.5 above 2 cph in the ocean. The nearly constant slopes suggest that voltage response is systematic but may not be oceanic for high frequencies. BAHK (1991) suggested that the fast random change of less than 60 minutes was most likely caused by noises occurred from the cable system.

4. Voltage variation of hourly data

Because of our interest in the long-term variation, we applied a lowpass filter as follows.

$$x_0(t)=(1.5/N)x(t)+\sum_{r=1}^{N} F_r[x(t+r)+x(t-r)]$$

$$F_r=\cos^2 \tfrac{1}{2}\Omega r \sin(1+\tfrac{1}{2})\,\Omega r/2N \sin \tfrac{1}{2}\Omega r, \quad (\Omega=\pi/N)$$

where N=18. The cut-off period of this filter is 2 hours with a half-power point at 4 hours. Fig. 5 shows the amplitude response and cut-off

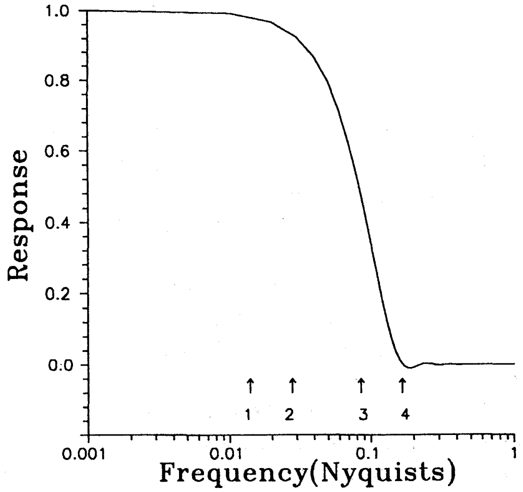

Fig. 5. Frequency response of filter used in analysis : 1. 0.00069 cpm (24 hours), 2. 0.00139 cpm (12hours), 3. half-power point 0.00417cm (4hours), 4. cut-off point 0.00833 cpm (2hours).

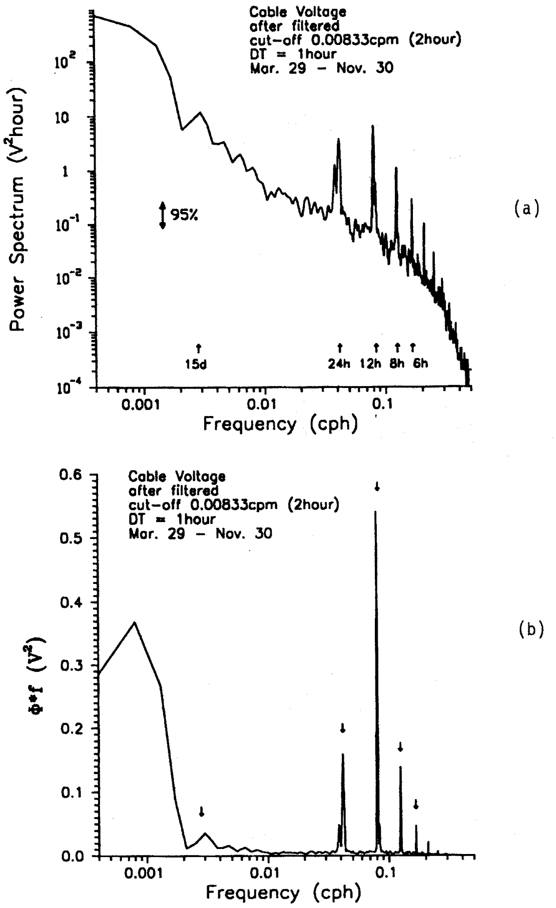

Fig. 6. (a) Spectrum of the hourly low pass cable voltage data, (b) energy conserving spectrum of same data.

frequency. The filtered series are subsampled every hour for final analysis. The example of the subsampled data is shown in Fig. 3 (b).

Fig. 6 (a) is the spectrum of the low pass data and Fig. 6 (b) is energy conserving spectrum of the same data. Most energies are contained in the low frequency with the period longer than about 20 days, with peaks at periods of half a month (0.003 cph), diurnal (0.0416 cph), semi-diurnal (0.0806 cph) and 8 hours (0.1248 cph). All these peaks correspond to tidal frequencies and semi-diurnal component has the highest peak among them. We compare the cable voltage with the north-south component of current measured by RCM7 and sea level changes at Pusan during the same period (May 11 to June 26). Fig. 7 indicates higher frequency voltage fluctuations superposed on a steadily increasing mean value. The fluctuating ranges of the speed and sea level change have a periodicity of about half a month. The spectra (Fig. 8) show that the north-south speed and sea level change also have large energies in the low frequencies and peaks at the same periods as the cable data. It should be noticed that the diurnal peak is higher than semi-diurnal one in the spectrum of the north-south speed unlike those of cable voltage and sea level change. It is speculated that low energy of the current is related to the closeness of the amphidromic point of the semi-diurnal tide to the location of the current meter mooring (Fig. 9; ODAMAKI, 1989).

5. Tidally induced voltage variations

As shown by spectral analysis the tidal components are dominant in the cable voltages as well as the current speed and the sea level changes. Thus we further analyzed the relationship by the harmonic analysis. The hourly values of cable voltage were analyzed in 9 discrete blocks of 29 day duration. The blocks started on the first day of each month from April 1990 to January 1991. The hourly values of the current speed and the sea level change were analyzed in block of 29 days from beginning of the current meter mooring. The analysis was performed using "TIRA" program from Bidston Observatory, IOS (Korea Ocean Research and Development Institute, 1979) which is based on a least squares harmonic method. The close frequency constituents were separated by reference to the values of the constituents of the vertical tides in Pusan.

(a) *Harmonic analysis of cable voltages*

The variation in each month's analysis of cable voltages is shown in Table 1. Table 1(a) represents the amplitude and (b) the phase.

For diurnal constituents while O_1 is consistent from month to month, but the other constituents Q_1, M_1, P_1, K_1 vary markedly. Following PRANDLE and HARRISON (1975), we think that this variation can be attributed to both the difficulty in separating these constituents from 29 day data set and to the electromagnetic tide of solar diurnal periodicity. Amplitudes show that K_1 is the largest and O_1 is the second. Among

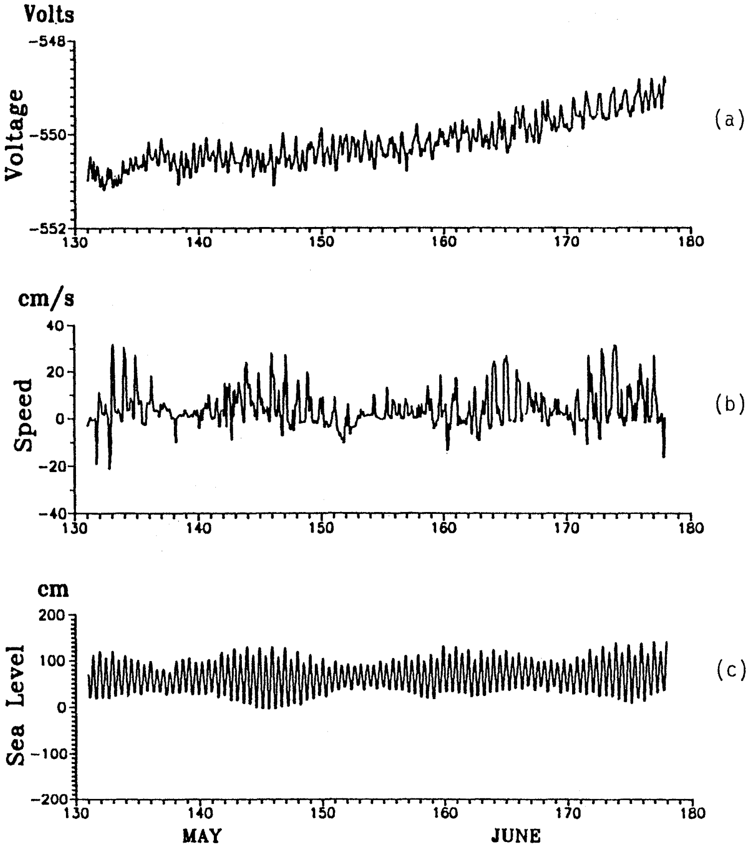

Fig. 7. Time series of (a) the filtered voltage, (b) north-south speed measured by RCM7 and (c) sea level change at Pusan during May 11 to June 26

the semi-diurnal constituents M_2 is the most dominant and consistent in amplitude and phase. The semi-annual fluctuation of the amplitudes of S_2 and K_2 constituents can be interpreted as interference between the two constituents which appears when the analyzed time series is not enough (RIKIISHI, 1982). The ter-diurnal constituents are smaller than semi-diurnal ones and MK_3 is the largest. The quarter-diurnal constituents are relatively small.

A spectral analysis of both hourly voltages and residual voltages was made. Desipite removal of tidal constituents considerable variations remain in the residual. The variations have the energies of about 45 percent of hourly data.

(*b*) *Harmonic analysis of the current speed and sea level change*

Table 2 shows the results of the analysis of current speed, sea level change and cable voltages during the same period.

While the semi-diurnal constituents are larger than diurnal ones in the cable voltages and sea level changes, the semi-diurnal constituents are not larger in the current speed. For diurnal constituents K_1 is the largest, O_1 is the second and P_1 is the third in three records However, for the semi-diurnal constituents S_2 is larger than M_2 in the current speed, while M_2 is larger in cable voltages and sea level changes.

The results of the phase show that in the speed and sea level S_2 tides are about one hour later than M_2, which corresponds to ODAMAKI (1989), but S_2 tide in cable voltage is about 7 hour later. The phase differences between the voltage measurements and speed may occur because the cable

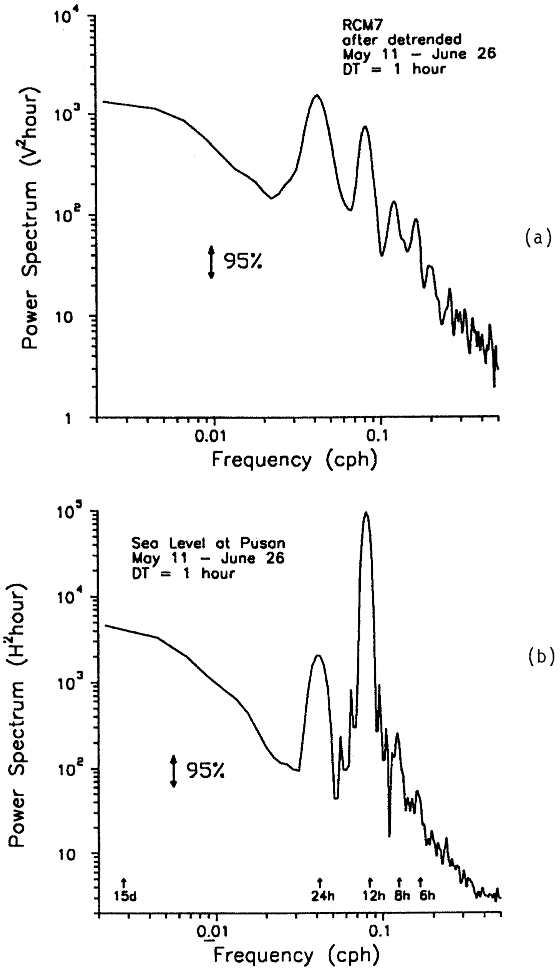

Fig. 8. Spectra of (a) north-south speed and (b) sea level change

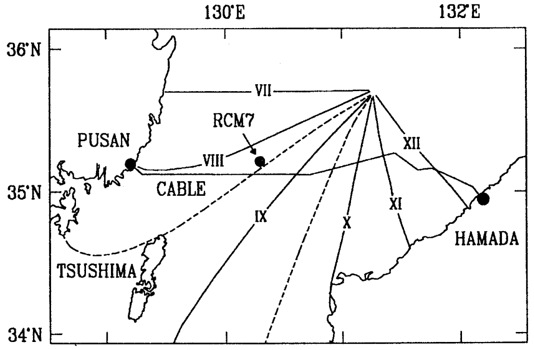

Fig. 9. M_2 tidal chart by ODAMAKI (1989)

voltage represents the integrated transport through the channel while the speed was measured at one point.

(c) *Estimation of the tidal transport*

The amplitude of M_2 transport is about 5.5 Sv according to ODAMAKI (1989) and KANG *et al.* (1991) and the harmonic constant of the cable voltage is 0.154 volts. Therefore the estimation of transport per one volt is 35.95 Sv/volt, which is equal to 105 cm/sec/volt.

According to LONGUET-HIGGINS (1949)

$$e = \delta VZL \times 10^{-8},$$

where $\delta = (1 + (\kappa_0/\kappa_1)(L/2D))^{-1}$, κ_0 and κ_1 are the specific conductivities of the channel bed and water and V is depth mean velocity of water along the channel, which is assumed uniform across section. In the Korea Strait region, κ_0

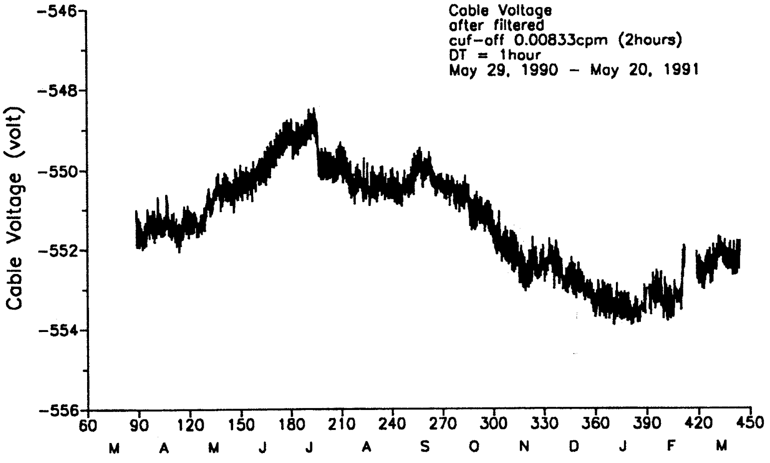

Fig. 10. A time series of the low pass data from Mar. 29, 1990 to Mar. 20, 1991.

Table 1.(a) Harmonic constants of the cable voltages in each month (amplitude).

Constituents		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mean	SD
Z_0	0.00	551.445	550.809	549.789	549.516	550.382	550.229	550.998	552.321	552.860	553.410	551.176	1.248
M_M	0.54	0.106	0.482	0.539	0.617	0.066	0.315	0.383	0.284	0.321	0.209	0.332	0.170
M_{SF}	1.02	0.030	0.211	0.291	0.051	0.085	0.031	0.257	0.125	0.236	0.145	0.146	0.092
Q_1	13.40	0.031	0.003	0.038	0.005	0.020	0.013	0.022	0.019	0.023	0.009	0.018	0.011
O_1	13.94	0.045	0.050	0.057	0.058	0.050	0.059	0.064	0.070	0.060	0.046	0.056	0.008
M_1	14.49	0.008	0.012	0.020	0.011	0.002	0.021	0.040	0.020	0.012	0.042	0.019	0.012
P_1	14.96	0.011	0.017	0.033	0.040	0.043	0.040	0.030	0.029	0.015	0.015	0.027	0.011
PI_1	14.92	0.001	0.001	0.003	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.002	0.001
K_1	15.04	0.033	0.053	0.101	0.121	0.131	0.123	0.093	0.090	0.046	0.045	0.084	0.035
PSI_1	15.08	0.001	0.002	0.004	0.004	0.005	0.005	0.003	0.003	0.002	0.002	0.003	0.001
PHI_1	15.12	0.002	0.003	0.005	0.006	0.007	0.006	0.005	0.005	0.002	0.002	0.002	0.002
J_1	15.59	0.003	0.022	0.029	0.026	0.020	0.035	0.023	0.018	0.016	0.032	0.022	0.009
OO_1	16.14	0.018	0.017	0.007	0.007	0.007	0.009	0.010	0.023	0.011	0.011	0.012	0.005
MU_2	27.97	0.014	0.008	0.000	0.011	0.012	0.020	0.013	0.006	0.027	0.036	0.015	0.010
N_2	28.44	0.037	0.039	0.026	0.038	0.022	0.028	0.035	0.012	0.048	0.038	0.032	0.010
NU_2	28.51	0.006	0.006	0.004	0.006	0.004	0.005	0.006	0.002	0.008	0.006	0.005	0.002
M_2	28.98	0.168	0.140	0.148	0.163	0.140	0.145	0.182	0.175	0.184	0.138	0.158	0.017
L_2	29.53	0.013	0.016	0.007	0.007	0.011	0.022	0.013	0.024	0.014	0.026	0.015	0.006
T_2	29.96	0.004	0.001	0.011	0.006	0.002	0.001	0.002	0.004	0.008	0.001	0.004	0.003
S_2	30.00	0.044	0.011	0.128	0.073	0.019	0.010	0.028	0.049	0.094	0.016	0.047	0.038
K_2	30.08	0.012	0.003	0.035	0.020	0.005	0.003	0.008	0.013	0.026	0.004	0.013	0.010
$2SM_2$	31.02	0.013	0.008	0.013	0.024	0.018	0.015	0.005	0.002	0.008	0.015	0.012	0.006
MO_3	42.93	0.015	0.007	0.011	0.006	0.018	0.001	0.014	0.007	0.004	0.010	0.009	0.005
M_3	43.48	0.009	0.002	0.017	0.007	0.004	0.007	0.004	0.026	0.015	0.006	0.010	0.007
MK_3	44.03	0.017	0.019	0.015	0.012	0.020	0.014	0.014	0.011	0.029	0.010	0.016	0.005
MN_4	57.42	0.004	0.008	0.008	0.004	0.013	0.008	0.014	0.007	0.003	0.003	0.007	0.004
M_4	57.97	0.006	0.008	0.015	0.011	0.013	0.002	0.009	0.009	0.005	0.006	0.008	0.004
SN_4	58.44	0.000	0.012	0.010	0.012	0.003	0.011	0.002	0.009	0.015	0.015	0.009	0.005
MS_4	58.98	0.009	0.008	0.008	0.007	0.010	0.014	0.006	0.014	0.010	0.005	0.009	0.003
$2MN_6$	86.41	0.006	0.001	0.005	0.001	0.007	0.000	0.002	0.005	0.003	0.005	0.004	0.002
M_6	86.95	0.004	0.002	0.003	0.004	0.004	0.007	0.004	0.005	0.004	0.002	0.004	0.001
MSN_6	87.42	0.004	0.006	0.003	0.005	0.003	0.002	0.006	0.004	0.007	0.005	0.005	0.002
$2MS_6$	87.97	0.004	0.003	0.002	0.005	0.006	0.001	0.004	0.004	0.009	0.007	0.005	0.002
$2SM_6$	88.98	0.004	0.010	0.003	0.005	0.012	0.003	0.008	0.004	0.005	0.009	0.006	0.003

=0.1 ℧/m and κ_1=5 ℧/m(UTADA *et al.*, 1986), magnetic intensity Z=0.485 Gauss (Korea Institute of Energy and Resources, 1990), L=281 km and D=130 m. By the relationship from LONGUET-HIGGINS , mean speed per one volt is about 167 cm/sec/volt, which is equal to the transport 57.18 Sv/volt, while 141 cm/sec/volt in the Dover Strait. Thus above simple estimation is thought to be correct in the order of magnitude.

6. Seasonal variation

Fig. 10 is a time series of the low pass data from Mar. 29, 1990 to Mar. 20, 1991. From March the voltage increased and reached a maximum in July and then decreased to a minimum in January. A significant seasonal variation appears with a range of about 5 volts. Nevertheless the seasonal variation does not appear in the voltage records at Hamada during the same period (personal communication). LARSEN

Table 1.(b) Harmonic constants of the cable voltages in each month (phase).

Constituents	Frequency	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mean	SD
Z_0	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
M_M	0.54	7.328	141.405	215.794	63.302	51.011	239.938	190.761	175.845	264.163	205.672	10.748	126.827
M_{SF}	1.02	251.805	251.259	265.395	238.586	146.935	69.183	202.547	233.828	214.321	99.762	35.686	136.665
Q_1	13.40	256.734	141.907	263.699	282.718	283.226	248.052	178.647	279.514	279.937	140.565	66.222	139.246
O_1	13.94	263.050	269.610	256.234	272.107	249.132	300.869	285.522	297.978	293.598	245.767	273.364	19.193
M_1	14.49	171.114	249.354	144.817	12.767	334.968	262.555	17.760	196.436	340.891	76.373	316.426	97.280
P_1	14.96	293.481	266.674	251.797	258.463	239.712	300.691	339.655	349.791	260.475	320.487	287.019	36.704
PI_1	14.92	9.872	343.065	328.188	334.854	316.103	17.082	56.046	66.182	336.866	306.878	353.320	38.694
K_1	15.04	286.891	260.084	245.207	251.873	233.122	294.101	333.065	343.201	253.885	313.897	280.429	36.704
PSI_1	15.08	199.354	172.547	157.670	164.336	145.585	206.564	245.528	255.664	166.348	226.360	12.892	148.242
PHI_1	15.12	308.941	281.134	267.257	273.923	255.172	316.151	355.115	5.251	275.935	335.947	302.363	36.765
J_1	15.59	0.434	317.875	14.555	351.044	6.063	240.921	234.042	36.162	37.650	80.438	0.444	64.384
OO_1	16.14	24.545	240.302	340.888	207.183	225.154	333.156	85.410	80.388	233.239	327.258	303.114	85.290
MU_2	27.97	291.342	101.276	127.601	272.403	54.847	285.035	55.910	91.573	50.211	301.676	34.007	79.689
N_2	28.44	336.729	1.398	301.795	335.032	77.894	331.962	323.545	312.443	347.572	294.578	333.850	38.626
NU_2	28.51	332.053	356.722	297.119	330.356	73.218	327.286	318.869	307.767	342.896	289.902	329.174	38.626
M_2	28.98	2.046	348.851	355.929	359.475	359.640	6.034	10.450	355.720	353.190	4.136	359.546	6.090
L_2	29.53	32.112	117.830	157.555	255.064	84.207	180.607	339.321	274.750	324.020	340.555	336.989	100.893
T_2	29.96	310.931	250.655	147.609	120.896	252.382	15.709	311.439	329.271	284.486	255.562	285.323	77.836
S_2	30.00	314.006	253.730	150.684	123.971	255.382	18.784	314.514	332.346	287.561	258.637	282.417	77.860
K_2	30.08	306.353	246.077	143.031	116.318	255.457	11.131	306.861	324.693	279.908	250.984	284.370	78.258
$2SM_2$	31.02	353.084	175.820	242.359	46.776	247.804	194.174	227.628	98.036	211.729	345.330	13.867	123.839
MO_3	42.93	96.221	5.420	297.738	29.857	156.905	20.354	133.243	270.596	199.227	187.764	353.828	108.930
M_3	43.48	55.469	47.128	26.894	121.125	195.563	34.357	206.059	19.435	328.299	262.296	35.265	77.506
MK_3	44.03	211.279	94.676	137.251	196.655	57.469	232.130	298.747	122.867	315.338	271.474	33.456	129.811
MN_4	57.42	22.248	337.623	158.578	241.196	215.224	40.149	177.907	267.014	35.315	75.328	348.161	97.443
M_4	57.97	234.708	142.418	43.917	309.981	267.669	241.539	41.816	217.588	161.197	285.908	65.585	125.120
SN_4	58.44	100.234	214.400	158.086	343.095	267.698	173.803	304.420	78.307	173.696	150.726	352.464	129.828
MS_4	58.98	289.650	260.802	242.043	330.661	244.035	143.580	353.950	161.155	272.771	1.104	300.275	81.283
$2MN_6$	86.41	342.282	328.921	126.981	278.796	34.290	283.625	49.712	90.814	151.471	235.251	7.498	89.415
M_6	86.95	241.678	92.599	171.084	163.014	48.806	282.664	165.720	120.088	11.456	1.510	301.868	113.216
MSN_6	87.42	283.221	19.178	8.292	154.901	21.769	131.404	147.699	307.323	194.793	326.270	307.768	101.282
$2MS_6$	87.97	207.389	99.470	75.458	167.293	311.697	228.575	14.208	2.596	251.145	29.916	295.124	114.605
$2SM_6$	88.98	273.198	215.270	173.451	312.445	121.962	26.746	7.159	73.250	171.637	114.905	46.590	97.491

(1991) pointed out that the voltage variations observed at a telephone cable station are affected by temperature variations that cause variations in the resistance of the various components of the cable system. Actually, BAHK (1991) found that our voltage output was temperature-dependent. So we improved the recording system to also meaure ambient temperature to calibrate temperature drift.

7. Concluding remarks

An initial attempt to estimate the transport of the Tsushima Current through the Korea Strait using the cable voltage measurements have been performed.

Comparing the cable voltage with current meter observation and coastal sea level suggested that the voltage variation at the Pusan Station is closely related with the movements of the sea water in the Korea Strait, especially

Table 2. Harmonnic constants of the cable voltage, current speeds and sea levels at Pusan during 29 days from May 11, 1990.

Constituents	Frequency	Amplitude			Phase			Amplitude Ratio		Phase Diff.	
		Voltage (*e*)	Current (*V*)	Sea Lev (*H*)	Voltage (*e*)	Current (*V*)	Sea lev (*H*)	*V*/*e*	*H*/*e*	*V*-*e*	*H*-*e*
Z_0	0.00	550.480	3.630	64.020	0.000	0.000	0.000				
M_M	0.54	0.115	2.396	3.539	290.745	309.906	185.458	15.458	22.832	19.161	−105.287
M_{SF}	1.02	0.141	2.300	2.942	81.600	33.324	291.343	16.312	20.865	−48.276	−150.257
Q_1	13.40	0.008	0.955	0.275	320.497	265.673	79.136	119.375	34.375	−54.824	118.639
O_1	13.94	0.053	2.025	1.853	285.378	128.075	106.563	38.208	34.962	−157.303	−178.815
M_1	14.49	0.006	0.515	0.181	48.093	112.137	172.890	85.833	30.167	64.044	124.797
P_1	14.96	0.025	0.772	1.412	269.074	198.334	145.364	30.880	56.480	−70.740	−123.710
PI_1	14.92	0.002	0.062	0.114	345.465	274.725	221.755	31.000	57.000	−70.739	−123.710
K_1	15.04	0.076	2.370	4.334	262.484	191.744	138.774	31.184	57.026	−70.740	−123.710
PSI_1	15.08	0.003	0.086	0.157	174.947	104.207	51.237	28.667	52.333	−70.740	−123.710
PHI_1	15.12	0.004	0.122	0.222	284.534	213.794	160.824	30.550	55.500	−70.740	−123.710
J_1	15.59	0.032	0.375	0.812	14.728	210.228	219.519	11.719	25.375	195.500	−155.209
OO_1	16.14	0.021	1.356	0.248	265.947	29.292	223.595	64.571	11.810	−236.655	−42.352
MU_2	27.97	0.026	0.476	2.749	102.168	263.142	242.759	18.308	105.731	160.974	140.591
N_2	28.44	0.030	0.376	7.180	335.521	1.766	224.066	12.533	239.333	26.245	−111.455
NU_2	28.51	0.005	0.062	1.178	330.845	357.090	219.390	12.400	235.600	26.245	−111.455
M_2	28.98	0.154	2.095	40.559	348.690	332.211	234.549	13.604	263.370	−16.479	−114.141
L_2	29.53	0.020	0.086	1.175	171.254	347.269	287.264	4.300	58.750	170.015	116.010
T_2	29.96	0.003	0.206	1.508	181.928	3.760	270.078	68.667	502.667	−178.168	88.150
S_2	30.00	0.041	2.480	18.185	185.003	6.835	273.153	60.488	443.537	−178.168	88.150
K_2	30.08	0.011	0.672	4.930	177.350	359.182	265.500	61.091	448.182	−178.168	88.150
$2SM_2$	31.02	0.008	0.979	0.376	74.988	134.603	277.829	122.375	47.000	59.615	202.841
MO_3	42.93	0.003	0.788	0.856	241.969	115.938	54.463	262.667	285.333	−126.031	172.494
M_3	43.48	0.007	0.323	1.060	102.886	127.871	0.411	46.143	151.429	24.985	−102.475
MK_3	44.03	0.013	0.317	1.015	134.132	312.314	51.813	24.385	78.077	178.182	−82.319
MN_4	57.42	0.009	0.285	0.539	176.340	217.066	160.584	31.667	59.889	40.726	−15.756
M_4	57.97	0.009	0.213	0.505	317.104	336.201	171.478	23.667	56.111	19.097	−145.626
SN_4	58.44	0.009	0.479	0.180	179.810	107.670	56.028	53.222	20.000	−72.140	−123.782
MS_4	58.98	0.008	0.435	0.449	300.021	147.591	204.826	54.375	56.125	−152.430	−95.195
$2MN_6$	86.41	0.002	0.209	0.138	104.943	0.541	15.239	104.500	69.000	−104.402	−89.704
M_6	86.95	0.003	0.090	0.079	35.731	27.785	50.015	30.000	26.333	−7.946	14.284
MSN_6	87.42	0.005	0.031	0.227	86.441	21.389	189.139	60.200	45.400	−65.052	102.698
$2MS_6$	87.97	0.003	0.214	0.084	281.934	82.720	35.307	71.333	28.000	160.786	113.373
$2SM_6$	88.98	0.004	0.154	0.013	173.823	323.554	70.204	38.500	3.250	149.731	−103.619

tidal motions. However long-term variations shown in first year observation notably the seasonal variation are not yet to be concluded as oceanic. Therefore responses of data logger to the measuring environment including room temperature are presently being monitored carefully to have better quality of voltage signal for further analysis. The long-term signal also includes seasonal variation of the sea conductivity and geomagnetic flux (BOWDEN, 1956) and corresponding measurements are being planned.

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