NATIONAL PORTS AUTHORITY

DURBAN HARBOUR ENTRANCE WIDENING AND DEEPENING PROJECT

TIDAL ANALYSIS

REPORT NO. 385/25/001

MARCH 2003

Tidal Analysis Report No. 385/25/001					
Revision	**Date**	**Author**	**Checked**	**Status**	**Approved**
01	March 2003	FG	AHH/ARW	Draft	
Keywords: Tidal, Analysis					

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1. INTRODUCTION

The present report summarizes the analysis of sea level in the port of Durban. The data consists of hourly records from January 1972 to December 2001. These measurements are most affected by astronomical tides but also include stochastic variations due to meteorological phenomena. Variations from the astronomical tide are referred to as tidal residuals.

The scope of the study was to establish the deterministic astronomical tide parameters and to obtain a statistical description of tidal residuals. Together, these two components provide a complete description of sea level that can be used for design purposes.

Section 2 of the report provides a description of the methods used for analysing sea level data. The measured data and corrections are described in section 3. Astronomical tidal analysis is presented in section 4 with an analysis of tidal residuals in section 5. Conclusions are presented in section 6

2. METHODOLOGY

A number of quality checks were conducted on the data prior to analysis. These included plots of the measured data, description of bad or missing data and checking for any trends in the mean tidal level.

Once the data had been checked it was analysed with the *Tsoft* software package. The software allows decomposition of the data into astronomical tides and stochastic residuals. Once the data had been split into these two components maximum annual residuals were extracted and summarised by fitting an extreme value probability distribution.

3. SEA LEVEL DATA AND CORRECTIONS

Sea level data were provided as hourly elevations in centimetres relative to chart datum (CD), covering the period from January 1972 to December 2001. During the measurement period the absolute level of CD was changed three times. Table 3.1 provides a list of CD levels relative to land leveling datum (MSL).

TABLE 3.1

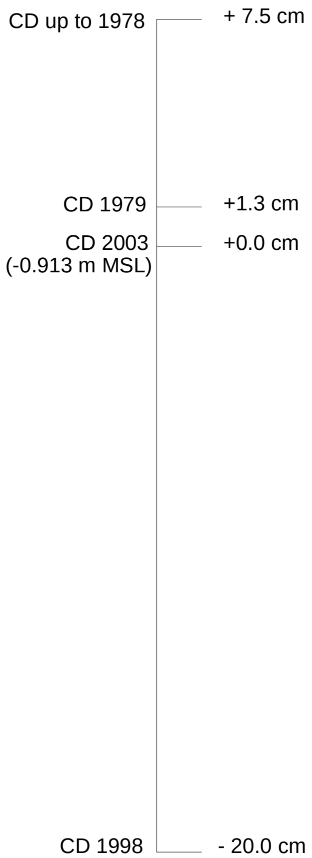
RELATIONSHIP BETWEEN CHART DATUM AND LAND LEVELING DATUM

Period	Height of chart datum relative to land leveling datum (m)
Up to 31 Dec 1978	-0.838
1 Jan 1979 to 31 Dec 1997	-0.900
1 Jan 1998 to 31 Dec 2002	-1.113
1 Jan 2003 onwards	-0.913

All levels were converted to correspond with the 2003 Chart Datum value (-0.913 m MSL). The raw data contained some spikes which were corrected. These corrected data are summarized in Table 3.2 indicating the number of valid hourly records for each year of measurement. The historic levels of CD relative to CD for 2003 are also shown graphically in this table.

TABLE 3.2

SUMMARY OF VALID HOURLY DATA AND RELATIVE CD 2003 LEVEL

Year	Total Hourly Data in Year	Valid Hourly Data	Graphical Presentation of CD Levels relative to CD 2003
1972	8784	8760	
1973	8760	8277	
1974	8760	6347	
1975	8760	7422	
1976	8784	7552	
1977	8760	8184	
1978	8760	8760	
1979	8760	7991	
1980	8784	8764	
1981	8760	4385	
1982	-	-	
1983	8760	8587	
1984	8784	7559	
1985	-	-	
1986	8760	6795	
1987	8760	7262	
1988	8784	5087	
1989	8760	7466	
1990	-	-	
1991	8760	6732	
1992	-	-	
1993	-	-	
1994	8760	5124	
1995	8760	6666	
1996	8784	7474	
1997	8760	4584	
1998	-	-	
1999	-	-	
2000	-	-	
2001	8760	7738	

It can be observed that there are no records for 1982, 1985, 1990, 1992, 1993, 1998, 1999 and 2000. For some years the data coverage was low (almost as low as 50 percent in 1981 and 1994). The overall number of available hourly records was 157 516 which represents 60 percent coverage over the 30 year period.

4. ASTRONOMICAL TIDAL ANALYSIS

The time series from 1972 to 2001 was separated into astronomical and residual components. The resultant astronomical tide is composed of the following 17 harmonics: M_m, M_f, MTM, Q_1, O_1, NO_1, P_1, K_1, J_1, OO_1, μ_2, N_2, ν_2, M_2, L_2, S_2 and K_2. An example of the component separation is shown in Figure2 for selected events.

The new astronomical time series was analysed to obtain the typical elevation parameters. Results are presented and compared with those of SAN (2003) in Table 4.1.

TABLE 4.1

TIDE PARAMETERS FOR ASTRONOMICAL TIDE (1972-2001)

Tide	Analysed Tidal Levels (cm CD 2003)	Published SAN Tidal Levels (cm CD 2003)
HAT	226	230
MHWS	208	201
ML	112	111
MLWS	18	21
LAT	4	0

The analysed values compare well with those of SAN (2003) taking into account that only 17 harmonics are used in the present tidal analysis.

5. RESIDUAL COMPONENT ANALYSIS

The residual component was obtained by subtracting the hourly data of the astronomical tide time series from the measured time series. In general residuals have a magnitude of less than 20 cm with larger peaks of up to 40 and 60 cm.

Residuals are caused by winds, atmospheric gradients, density gradients, and other phenomena that all have a stochastic nature. To enable a description of extreme events Goda's (1990) approach was followed. All residuals exceeding 40 cm were extracted from the data. In order to avoid dependence between samples, the maximum residual per event was identified and are shown in Table 5.1.

TABLE 5.1

EXTREME RESIDUAL EVENTS EXCEEDING 40 cm

Rank	Start Date of Event	Maximum Residual of Event (cm)
1	24-Apr-1984 11:00	62.3
2	01-Jan-1991 08:00	59.1
3	29-Aug-1988 08:00	53.1
4	23-Sep-1976 12:00	52.2
5	22-Oct-1997 17:00	50.8
6	21-Nov-1997 05:00	50.3
7	04-Dec-1984 15:00	49.2
8	15-Jul-1976 23:00	47.3
9	05-Dec-1997 18:00	47.2
10	20-Jul-1975 11:00	45.3
11	09-Oct-1973 04:00	45.3
12	16-Dec-1997 17:00	44.9
13	04-May-1972 16:00	42.8
14	26-Oct-1997 09:00	42.4
15	04-Sep-1978 14:00	41.9
16	31-Dec-1997 05:00	41.9
17	05-Jul-1984 12:00	41.6
18	17-Feb-1996 15:00	40.9
19	13-Feb-1996 19:00	40.7
20	22-Feb-1976 06:00	40.3

The three parameter Weibull distribution defined by Equation 1 was fitted to the data set in accordance with Goda (1990).

$$H = \alpha + \beta \ (-Ln(1-p))^{(1/k)} \qquad (1)$$

where:

H = significant wave height

α = location parameter

β = scale parameter

k = shape parameter

p = probability of non-exceedence

The Petruaskas plotting formula defined by Equation 2 was used to determine the plotting probability (p_m) required to calculate the reduce variate (x_m) as defined by Equation 3.

$$p_m = 1 - [m - (0.30 + 0.18/k)]/[N+(0.21+0.32/k)] \qquad (2)$$

where:

m = data point number

N = total number of data points

$$x_m = (-Ln(1-p_m))^{(1/k)} \qquad (3)$$

The recorded data were assigned to variable y_m and a linear regression between x_m and y_m was performed using the method of least squares for a range of k-values. The highest regression coefficient (best fit) was obtained for a k-value of 1.2 and corresponding coefficient values of:

$\alpha = 39.255$
$\beta = 8.205$

This fit is indicated graphically in Figure 3 together with estimated return period residual values.

The relationship between return period and non-exceedence probability is given by Equation 4:

$$p = 1 - 1/(\lambda \ R_p) \qquad (4)$$

where λ denotes the average number of extreme events per year.

For the 20 extreme events selected over an effective 18 year period (157 516 hourly records), the value for λ equals 1.112. Table 5.2 indicates residual values corresponding to various return periods.

TABLE 5.2
RESIDUAL TIDES FOR GIVEN RETURN PERIODS

Return Period, T_r (years)	Probability of Non-exceedence	Residual (cm)
1	0.1009	41
5	0.8201	52
10	0.9100	56
50	0.9820	65
100	0.9910	69

6. CONCLUSIONS

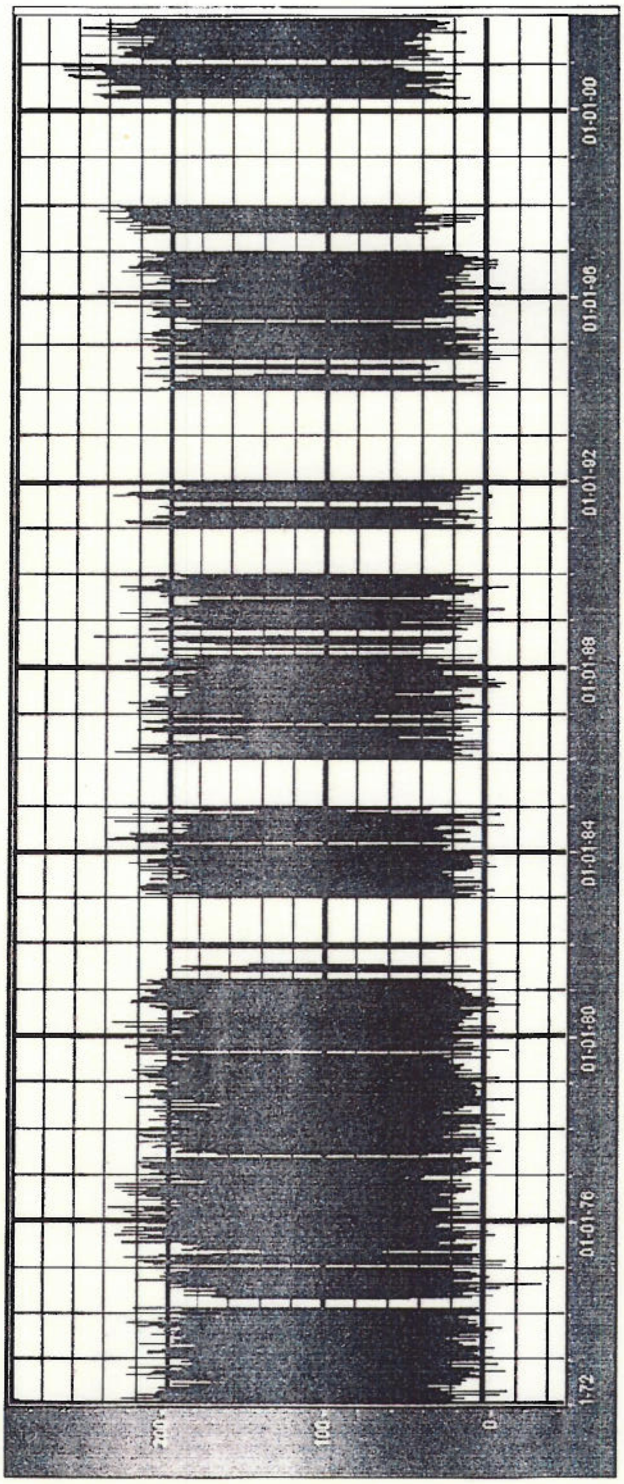
Durban tide records covering the period from 1972 to 2001 have been analysed and separated into a deterministic tidal component and a residual stochastic component. This enables a full description of the astronomical tide and probabilistic description of residuals. Extreme residuals are around 70 cm with the 1:100 return period estimated at 69 cm.

REFERENCES

SAN (2003) South African Tide Tables. Hydrographer, South African Navy, Tokai.

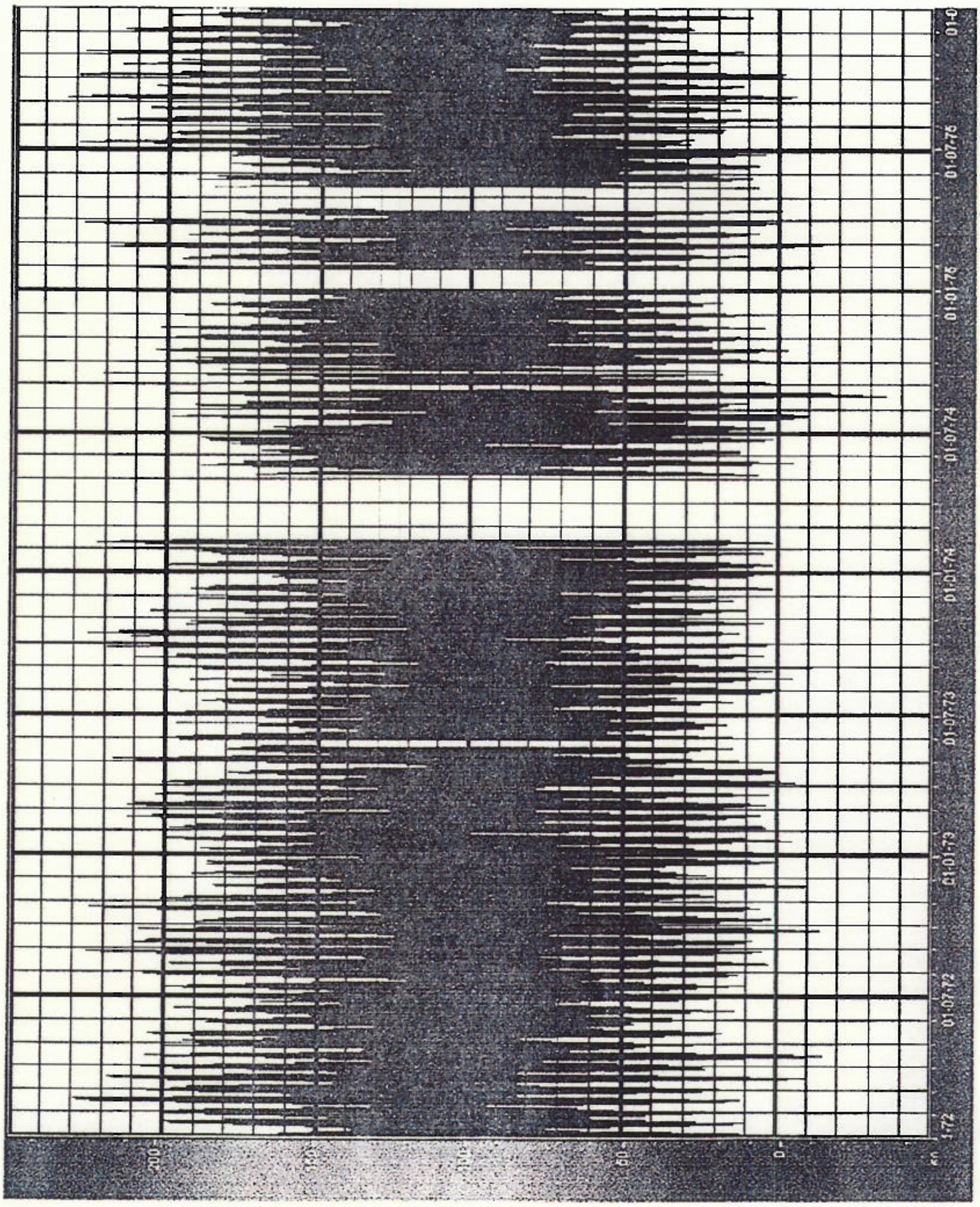
Goda Y (1990) Distribution of Sea State Parameters and Data Fitting. Handbook of Coastal and Ocean Engineering, Volume I. John B. Herbich, Editor. Gulf Publishing. ISBN 0-87201-461-4

FIGURES

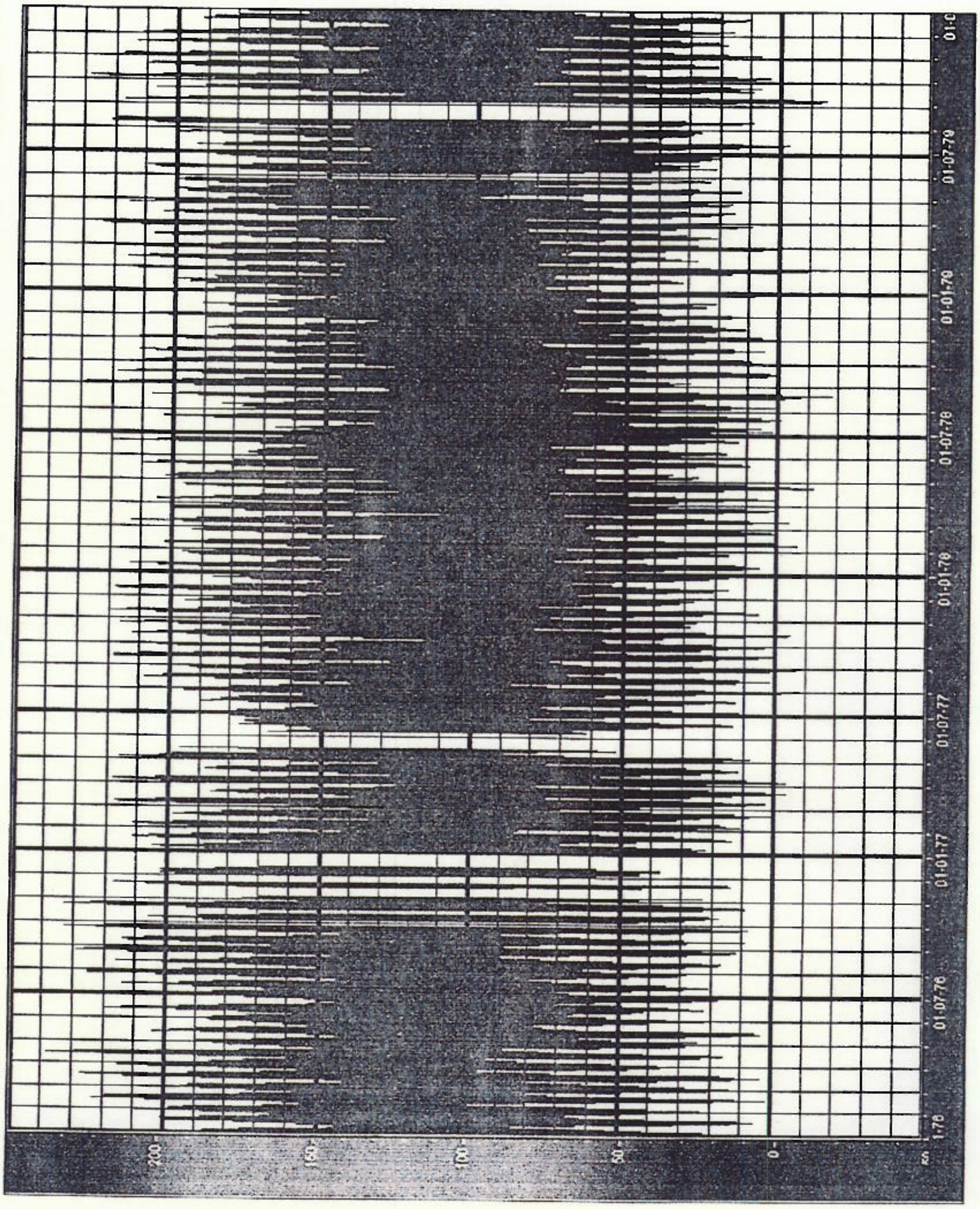


DURBAN TIDAL RAW DATA (cm)
Jan01-1972 – Dec31-2001

Figure No.
1



	DURBAN TIDAL RAW DATA (cm) **Jan01-72 – Dec31-75**	**Figure No.** **2**



DURBAN TIDAL RAW DATA (cm)
Jan01-76 – Dec31-79

Figure No.
3