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ANALYSIS OF SEA WAVE RECORDS

A comparison of simple methods to obtain significant waveheight

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NATURAL ENVIRONMENT RESEARCH COUNCIL
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SUMMARY

This comparison was carried out to test the feasibility of using IOS Frequency Modulated cassette loggers (Hardcastle, 1978) in place of the chart recorder for IOS Shipborne Wave Recorders (Haine, 1980). The FM cassette system has proved satisfactory for use with pressure transducer wave recorders and some work has been done to extend the frequency response to the higher frequencies measured by Shipborne and Waverider transducers. The cassette system replays into an automatic analysis system, and there are considerable cost savings over manual analysis of chart records.

The Significant Waveheight, Hs, derived from the root mean square ordinate of the digital record was used as the reference, and relative to this the simple semi-automatic system used to replay and analyse the FM cassettes, gave the same waveheight to better than 1% on average, with an rms error of 1.9%.

Using the Tucker-Draper method applied automatically to the digital records again gave negligible bias, but with an rms error of 8.7%. One would expect more random error in this comparison.

RECORDING

Wave data was simultaneously recorded for 1024 seconds every 3 hours on a Microdata logger, and a FM cassette logger, using a Waverider moored in 30 m of water as the sensor. 107 records were taken, with Significant Waveheight, Hs, ranging from ~0.6 m to ~6 m, and Zero Crossing Period, Tz, ranging from ~4 seconds to ~10 seconds.

The Waverider signal was processed as follows. The signal was demodulated giving a normal 259 Hz tone which varied by 1.86 Hz per metre of vertical displacement. This signal was applied to a phase locked loop, and the frequency multiplied by 128 in the loop, and then mixed with a fixed frequency of (290 x 129) Hz. The difference between the two frequencies was taken, ie 128 (290-259) Hz, and used as the input to the Microdata logger for frequency logging. The Microdata counted this frequency over 0.5 second intervals, giving a logged count of 1984 for zero waveheight, and a deviation of -1.86 x 64 counts per metre of upward motion. The frequency response of this logging system is of the form $\frac{\sin x}{x}$ where x is (frequency x π)/sampling frequency, and will be modified slightly at higher frequencies by the phase locked loop. The modified response curve is shown in Fig 1. The resolution of this sytem of 0.0084 m per count:

The same output frequency of 128 (290-259) Hz was used for the FM cassette logger. The frequency was divided by 256, giving a frequency of 15.5 Hz, which was directly recorded on one track of the cassette tape, at a tape speed of 0.07 cm sec^{-1}. A clock frequency was also recorded on another track of the tape. Recording at this speed gives a total tape capacity of 50 hours recording time on a C-90 cassette.

REPLAY

The Microdata tape was replayed through IOS computing facilities. Each record consisted of 2048 data points recorded at 0.5 second intervals. The following parameters were computed from the records.

H_{RMS}	the root mean square waveheight
$H_{MEAN\ RECT}$	the mean rectified waveheight
A	the highest crest in the record
B	the second highest crest in the record
C	the lowest trough in the record
D	the second lowest trough in the record

$H_1 = A + C$, $H_2 = B + D$

N_Z	the number of upward zero crossings in the record

These parameters were computed from the actual digital data, with no interpolation between data points, and are referred to subsequently as being derived from the digital data. This leads to the systematic under-estimate of A, B, C, D and for waves of 5 seconds period is about 2%. No correction has been made for the frequency response of the buoy, or of the recording system.

The FM cassette tape was replayed through the IOS FM replay system. This converts the frequencies recorded on the tape to voltages, using the clock track to correct for any speed variations in the tape transport. The data track output voltage is filtered, and then treated as an analogue wave record. The response curve of the filters is shown in Fig 2. The record is automatically analysed (a) by counting the upward zero crossings to give Nz, and (b) by full wave rectifying the record and integrating over the record length to give the Mean Rectified Waveheight. Normally this is measured over 600 seconds, but for these comparisons, a time of 980 seconds was also used, to correspond with the 1024 seconds of the digital record. Measurements from the cassette system will be referred to as analogue records.

Significant waveheight, Hs, was derived from the various measured waveheight parameters using the relationships

$Hs = 4\ H_{RMS}$

$Hs = 5.01\ H_{MEAN\ RECT}$

$Hs = \frac{1}{2}\ H_1\ (2\ \log_e Nz)^{-\frac{1}{2}}\ \{1 + 0.289\ (\log_e Nz)^{-1} - 0.247\ (\log_e Nz)^{-2}\}^{-1}$

$Hs = \frac{1}{2}\ H_2\ (2\ \log_e Nz)^{-\frac{1}{2}}\ \{1 - 0.211\ (\log_e Nz)^{-1} - 0.103\ (\log_e Nz)^{-2}\}^{-1}$

These latter equations are the derivation of Hs from A, B, C, D and Nz using the Tucker-Draper method (Draper, 1966; Tucker, 1963). The factors used in modifying H_1 and H_2 are available as a look up table, varying with Nz. This is the normal system used with chart analysis, and it is assumed in this note that the digital record can be treated as a chart record. Normally the derivations of Hs from H_1 and H_2 are averaged to improve the accuracy of estimation of Hs, and this method has been followed here.

RESULTS

107 records were analysed. It was assumed that the best estimate of Hs was that derived from H_{RMS} (digital). All measurements of Hs are in metres.

Figure 3 shows a plot of Hs derived from H_{RMS} (digital) (Y coordinate), against Hs derived from Tucker-Draper analysis of the digital record (X coordinate).

The regression line of the plot has the equation

$Y = 0.919X + 0.224$

with a rms error of 8.04%. However, if a line from coordinates (0, 0) through $(\bar{X}, \bar{Y})$ is used to predict Y from X, then the rms error rises to 8.74%. The gradient of this line is 0.9988.

Figure 4 shows a plot of Hs derived from H_{RMS} (digital) against Hs derived from $H_{MEAN\ RECT}$ (analogue - 980 second record length).

The equation for the regression line is

$Y = 0.992X + 0.019$

with a rms error of 1.9%. If the line is constrained to pass through (0, 0) and $(\bar{X}, \bar{Y})$ the gradient becomes 0.9983, and the rms error rises to 1.906%.

Estimating Hs from a record of finite length is subject to a random sampling error. The rms value of this error depends on parameters of the wave spectrum which differ with different methods of estimation. For 1000 second records of oceanic waves, typical rms errors are

Hs from H_{RMS}: 4%

Hs by the Tucker-Draper method: 7%

The theory for the random error in Hs calculated from the mean rectified waveheight is not available, but Tucker (1966) thinks that it may be smaller than that for Hs derived from H_{RMS}.

When considering the theoretical rms error in the ratio of estimates of Hs, it is necessary to know to what extent the errors in each estimate are correlated, and the theory of this is not known to us. However, what is clear from the empirical results in Fig 4 is that

(a) There is negligible bias in Hs derived from $H_{MEAN\ RECT}$

(b) That if we make the least favourable assumptions about the correlation between the errors in $Hs_{MEAN\ RECT}$ and those in Hs (rms digital), then $Hs_{MEAN\ RECT}$ is still a more accurate estimate of the true Hs than Hs Tucker-Draper.

Figure 5 shows a plot of Tz derived from the digital data against Tz derived from the analogue records.

The equation for the regression line is

$Y = 0.9924X - 0.165$ and the rms error is 3.33%.

In general the period derived from the analogue record is longer than that from the digital data, due to the high frequency cut off from the filters on the analogue record. The data from the analogue record would compare better with that from a chart record, as this too is subject to a high frequency cut off. The zero crossing counter in the analogue processor has a hysteresis equivalent to 0.01 m, so waves smaller than this height will not be counted.

Figures 6 and 9 are included for interest.

Figure 6 is Hs derived from H_{RMS} (digital) plotted against Hs derived from $H_{MEAN\ RECT}$ (digital).

The regression line is

$Y = 1.003X + 0.022$ and the rms error is 1.24%.

Figure 7 is HS derived from H_{RMS} (digital) plotted against Hs derived from $H_{MEAN\ RECT}$ (analogue 600 seconds).

The regression line is

$Y = 0.991X + 0.027$ and the rms error is 4.22%.

Figure 8 is Hs derived from $H_{MEAN\ RECT}$ (digital) plotted against Hs derived from $H_{MEAN\ RECT}$ (analogue - 980 seconds).

The regression line is

$Y = 0.988X - 0.002$ and the rms error is 1.75%.

Figure 9 is Hs derived from $H_{MEAN\ RECT}$ (analogue - 980 seconds).

The regression line is

$Y = 0.992X + 0.015$ and the rms error is 3.77%.

CASSETTE SYSTEM vs CHART RECORDS - SALIENT POINTS

The maximum waveheight, Hmax, that can be recorded on the cassette with the frequency deviations used here, is 30 m, and for a typical wavetrain this would give a significant waveheight, Hs, of about 21 m. A noise level of Hs equal to 0.1 m would be given by replaying a recording of zero waveheight through the analogue system.

At present, the chart recorders used on the Shipborne Wave Recorders have a maximum waveheight of 30 m, and the waves are noted as 'Calm' if H_1 is less than 0.5 m.

It thus appears to be feasible to replace chart recorders on Shipborne Wave Recorders by the FM cassette system. The voltage that drives the chart recorder pen would have to be converted to a frequency using a good quality voltage to frequency converter.

There should be no degradation in the quality of data recorded, and considerable cost savings in analysis can be made.

However it still remains to be shown that the FM cassette recorders can operate satisfactorily in the shipborne environment. Trials are currently in progress to check this.

REFERENCES

Draper L, 1966. The analysis and presentation of wave data - a plea for uniformity. Proc 10th Conference on Coastal Engineering, September 1966 Vol 1, pp 1-11. American Society of Civil Engineers 1967.

Haine R A, 1980. Second generation shipborne wave recorder. Transducer Technology Vol 2, Issue 2, pp 25-28, February 1980.

Hardcastle P J, 1978. A sea wave recording system using magnetic tape cassettes. IOS Report No 61.

Tucker M J, 1963. Analysis of records of sea waves. Proc Instn Civ Engrs, 26 pp 305-316.

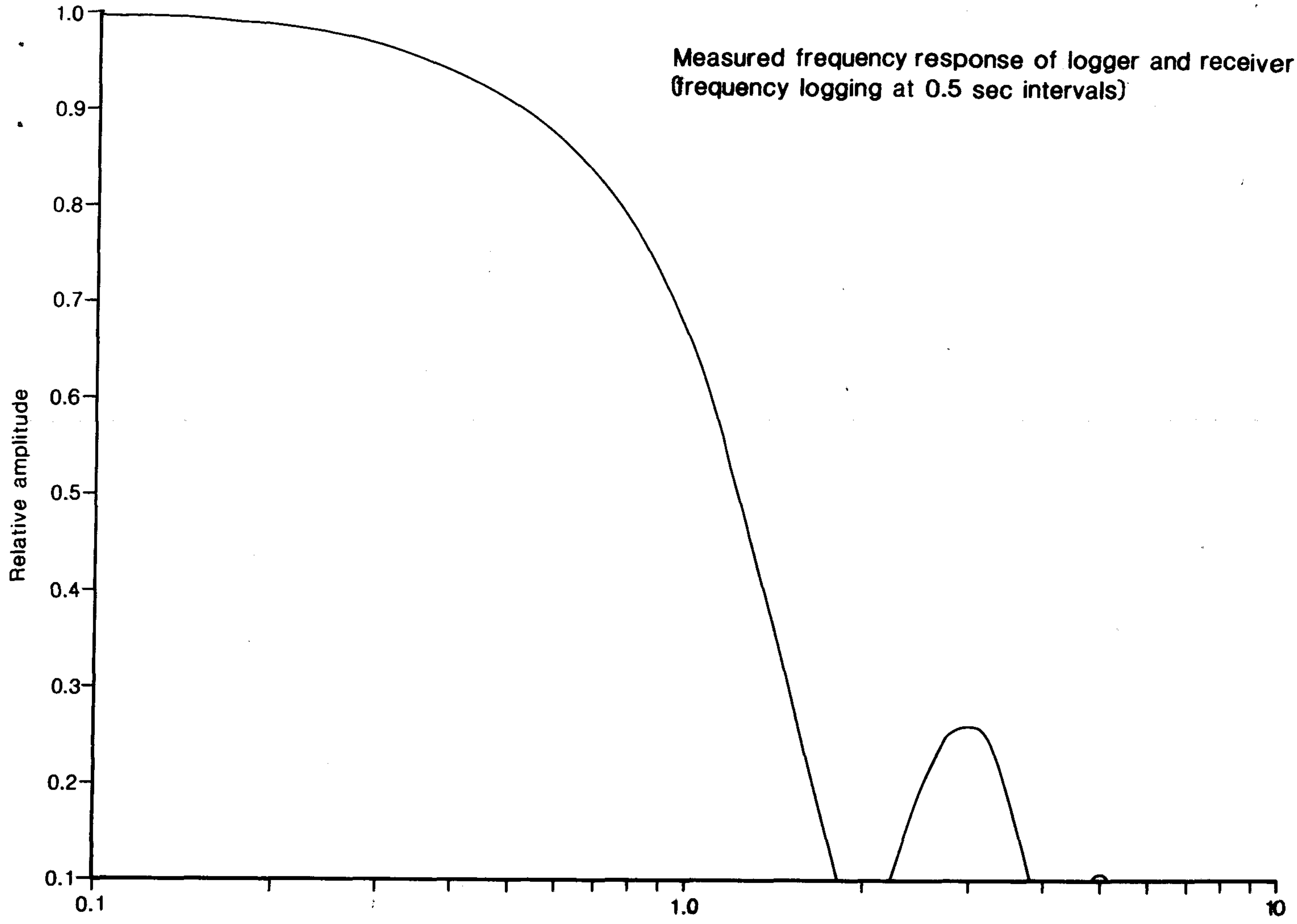

Measured frequency response of logger and receiver (frequency logging at 0.5 sec intervals)
Relative amplitude
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.1
1.0
10
Wave frequency Hz

FIG.1

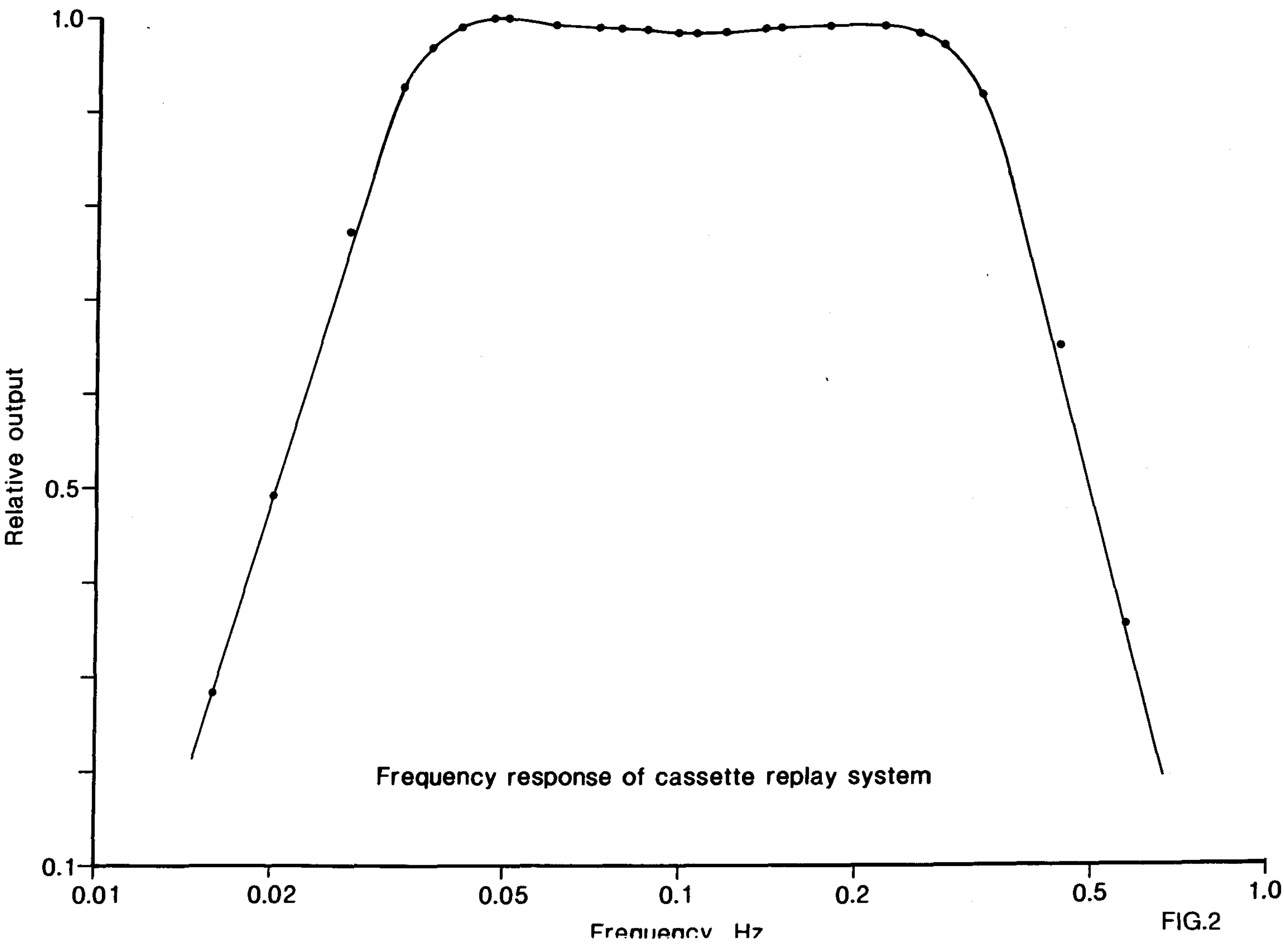
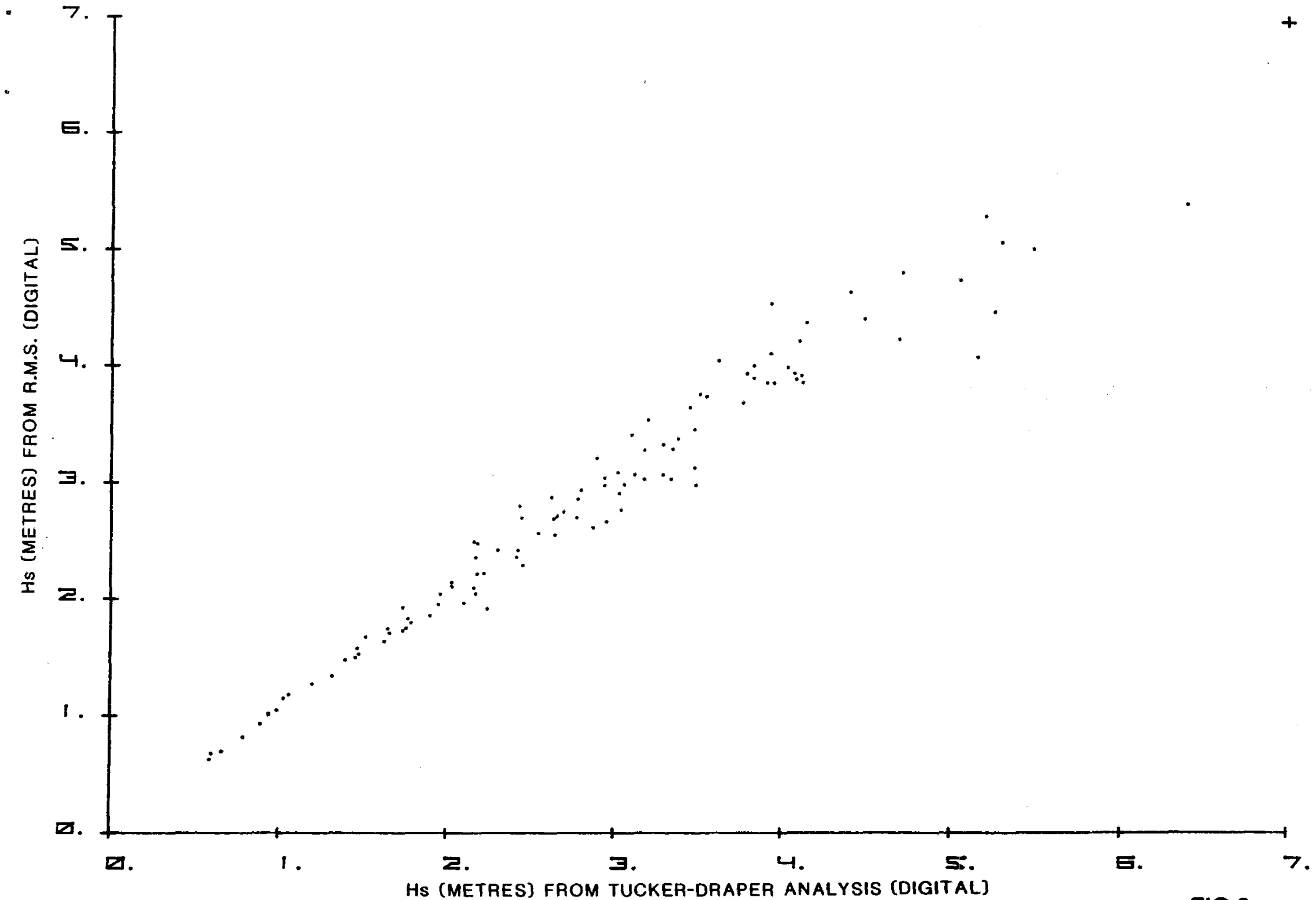
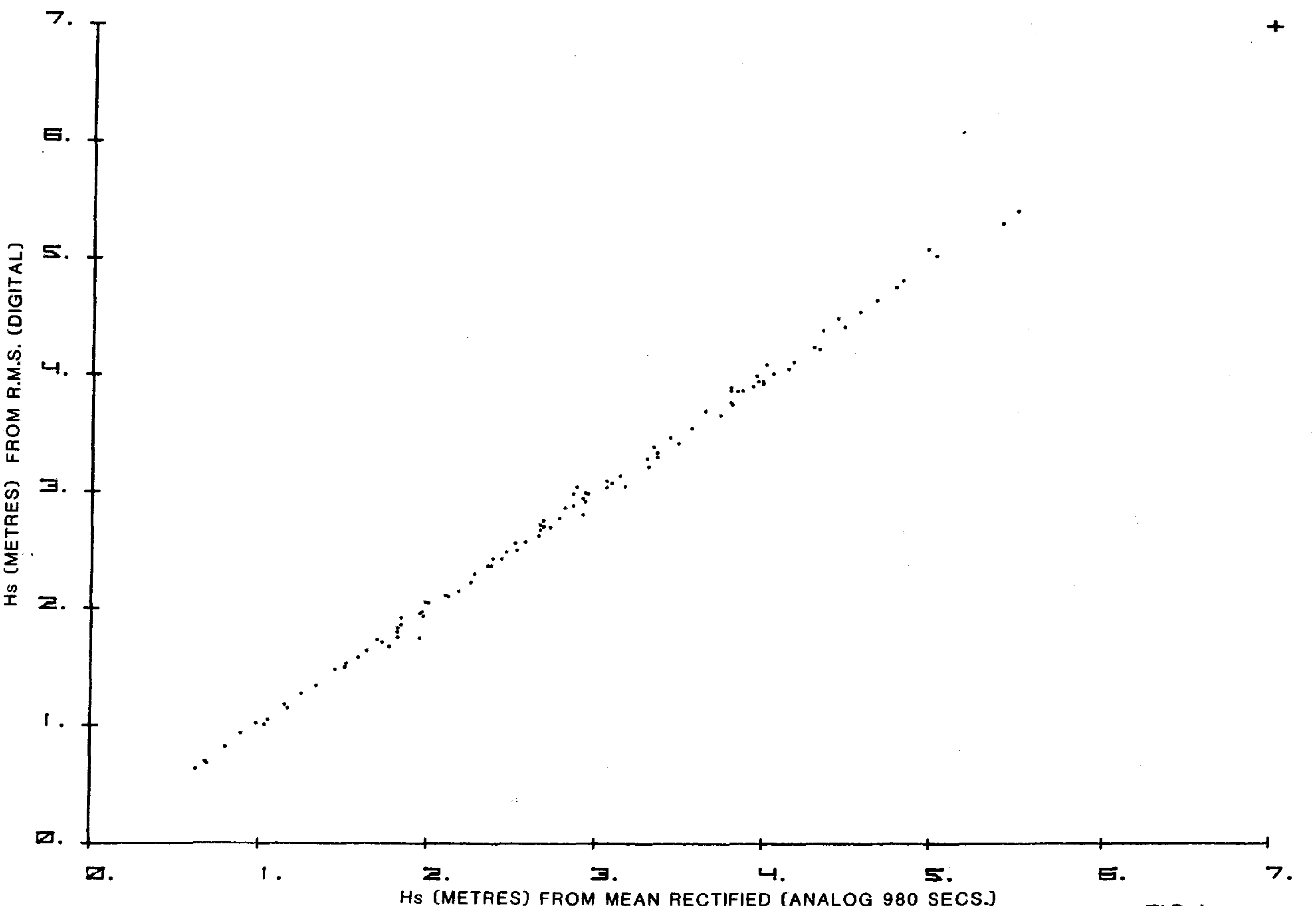

Frequency response of cassette replay system
Relative output
1.0
0.5
0.1
0.01
0.02
0.05
0.1
0.2
0.5
1.0
Frequency Hz

FIG.2



Hs (METRES) FROM R.M.S. (DIGITAL)
Hs (METRES) FROM TUCKER-DRAPER ANALYSIS (DIGITAL)

FIG.3



Hs (METRES) FROM R.M.S. (DIGITAL)
Hs (METRES) FROM MEAN RECTIFIED (ANALOG 980 SECS.)

FIG.4

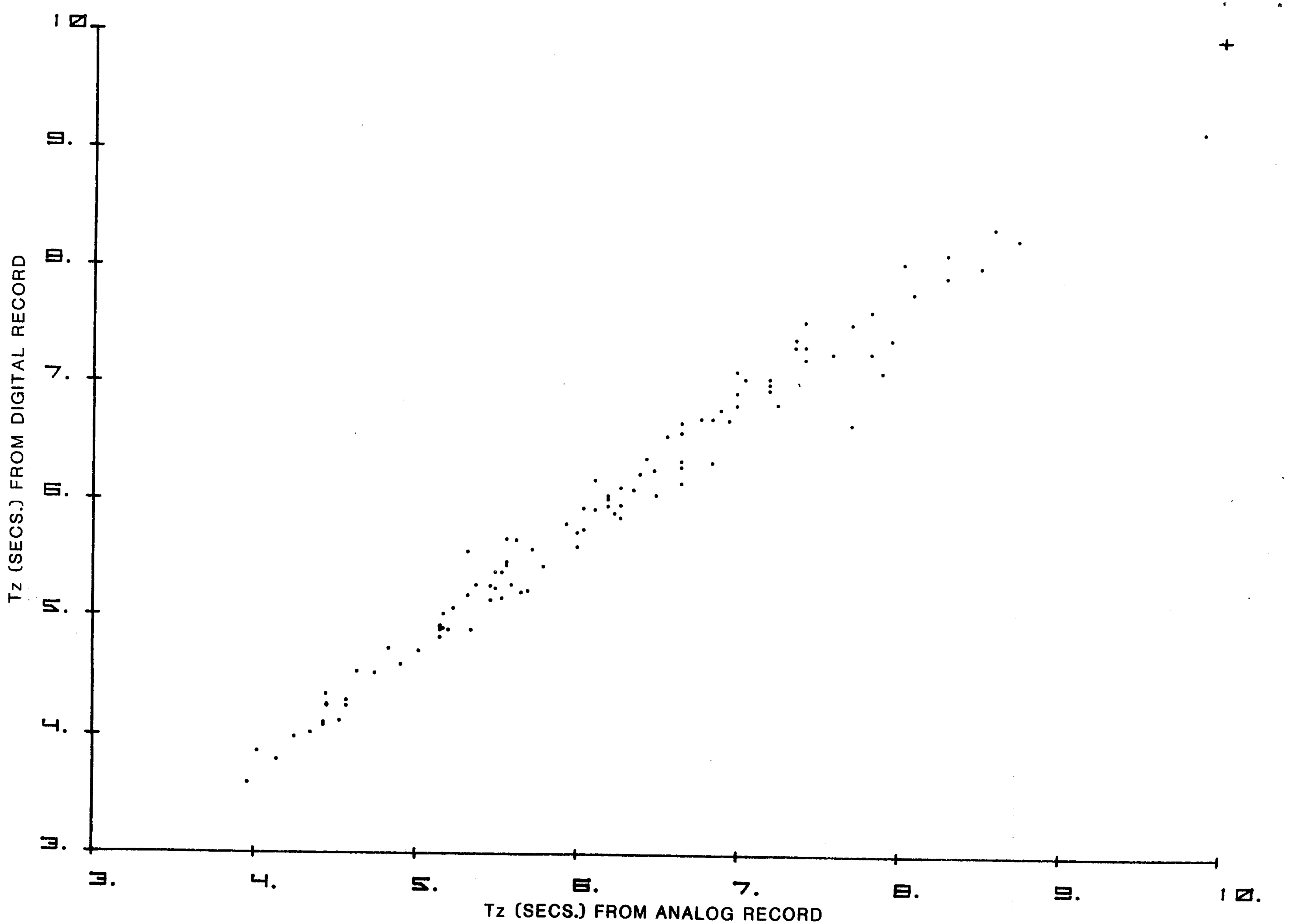

Tz (SECS.) FROM DIGITAL RECORD
Tz (SECS.) FROM ANALOG RECORD
3.
4.
5.
6.
7.
8.
9.
10.

FIG.5

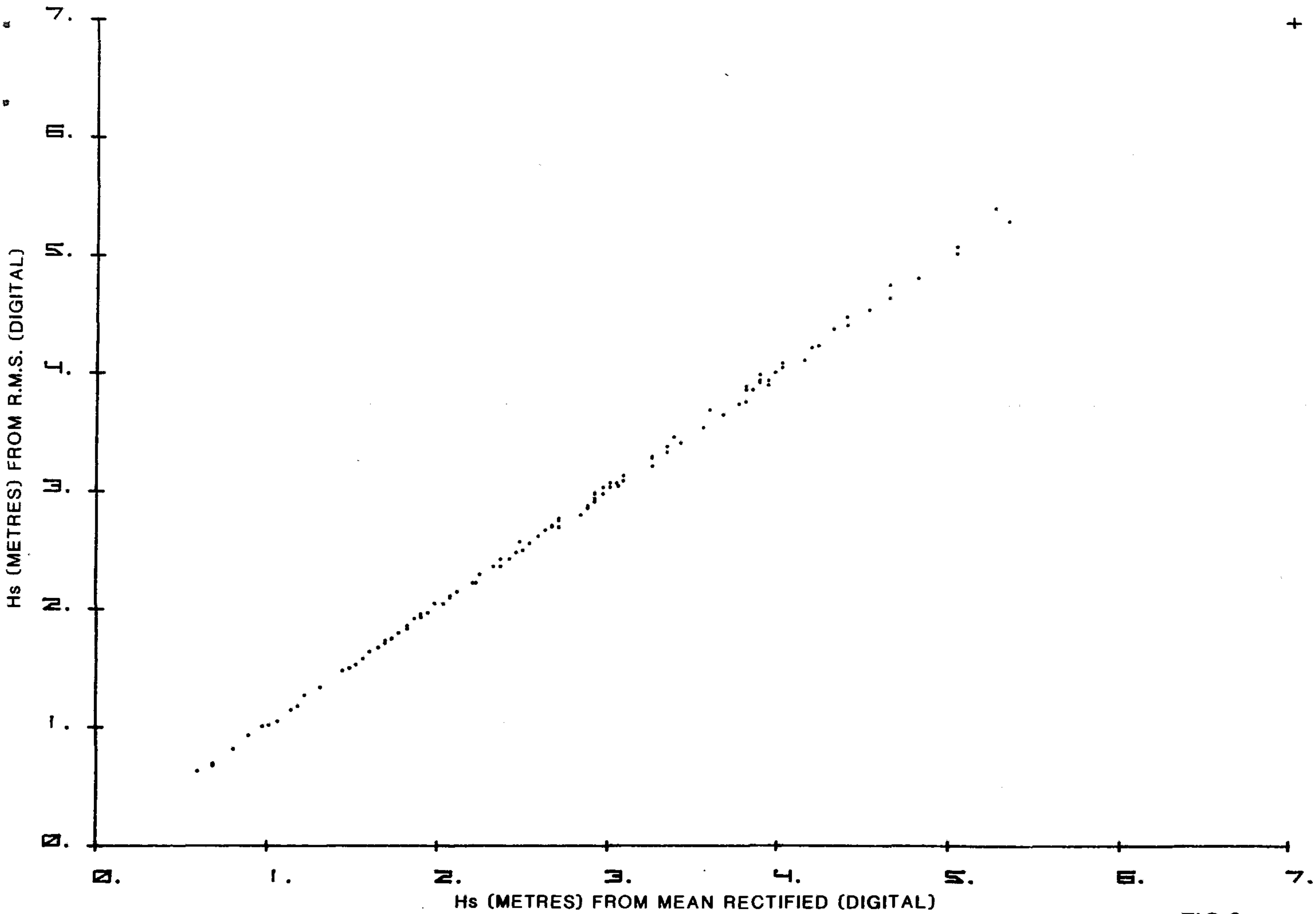

Hs (METRES) FROM R.M.S. (DIGITAL)
Hs (METRES) FROM MEAN RECTIFIED (DIGITAL)

FIG.6

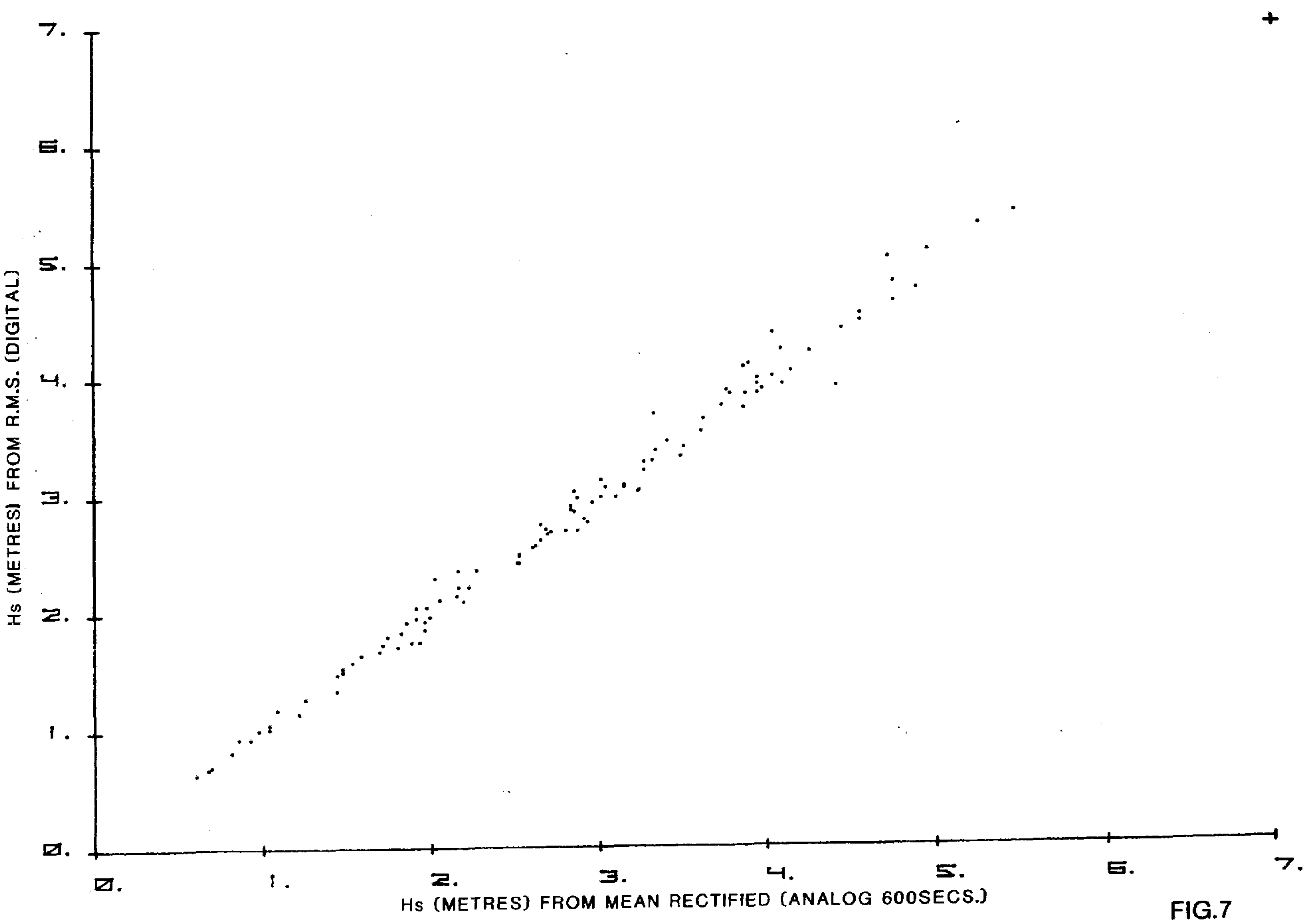

Hs (METRES) FROM R.M.S. (DIGITAL)
Hs (METRES) FROM MEAN RECTIFIED (ANALOG 600SECS.)

FIG.7

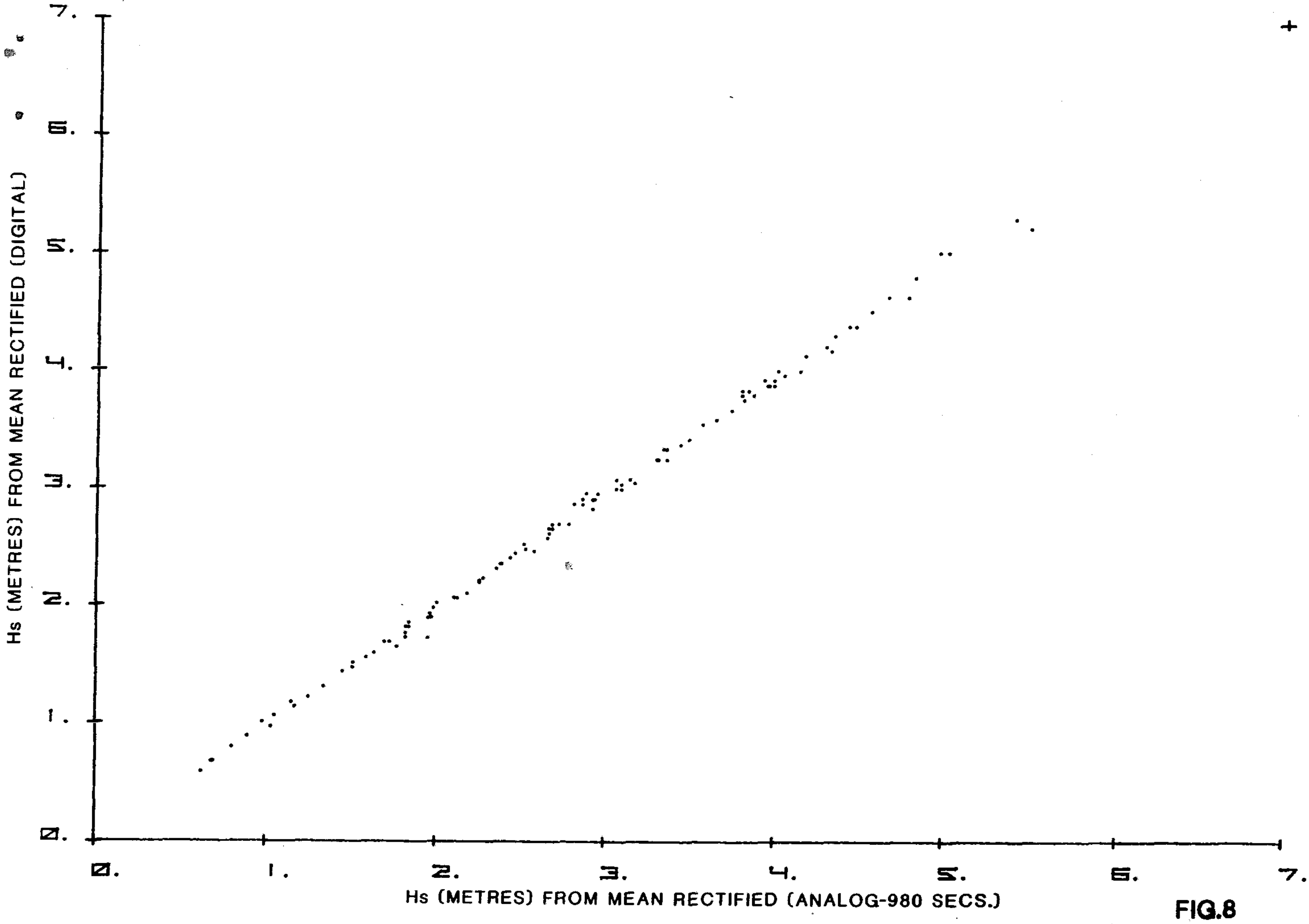

Hs (METRES) FROM MEAN RECTIFIED (DIGITAL)
Hs (METRES) FROM MEAN RECTIFIED (ANALOG-980 SECS.)

FIG.8

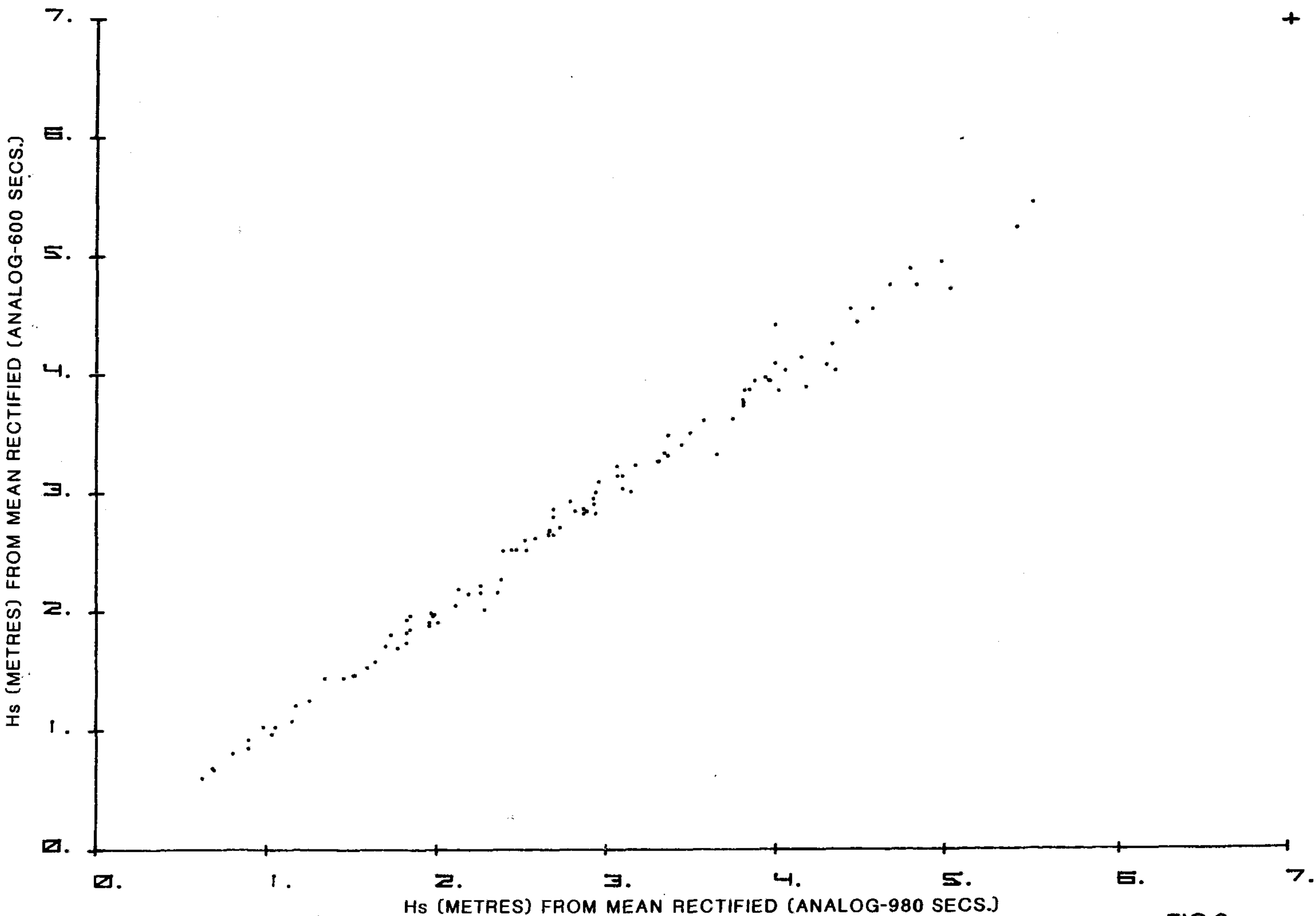

Hs (METRES) FROM MEAN RECTIFIED (ANALOG-600 SECS.)
Hs (METRES) FROM MEAN RECTIFIED (ANALOG-980 SECS.)

FIG.9