CHAPTER 97

MEASURING OF SQUAT IN THE FAIRWAY TO THE PORT OF LULEÅ, NORTH SWEDEN

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ABSTRACT

The importance of knowledge of squat and expected underkeel clearance for ships passing a fairway is essential to the navigational safety and the economy of a harbour.

In order to check the squat of ships in the fairway to the port of Luleå a photographic measuring method has been evolved and used in measurements on three different ships. Determining of squat is made by levelling the position of vessels in relation to water level at the berth before sailing and en route at measuring points along the fairway.

The accuracy of measurements was determined by observations on reference staffs. The order of standard deviation is 1/2 inch. at 2,400 feet distance. Observations indicate squat ranging from 1 foot 5 inches at speeds of 9 knots to 2 inches at $3\frac{1}{2}$ knots.

The measured squat corresponds rather good to theoretically calculated values according to Woltiger and Shell/Sogreah.

The measuring method used has reduced the field work. The greatest advantage is that adequate values of squat will be directly recorded with only a few corrections including irregular factors such as turbulent flow, hull deformations and variable channel sections.

A condition is however sheltered water and possibilities of solid foundation for instrument arrangement.

INTRODUCTION

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THE FAIRWAY

A new ore loading terminal and a new fairway were built in 1962-65 at Luleå, North Sweden, by the Swedish mining company LKAB and taken into full operation in the summer of 1965. Shipping season is normally 7 months from May to December.

The total length of the fairway is 7 nautical miles, 5½ miles of which have been dredged; removed volumes totalling 7½ mill. cu.yds. consist of clay, gravel, sand (Fig. 1). Some 100,000 cu yds. was blasted rocks. The minimum depth at mean water level is mainly 40 feet. The blasted sections hold 45 feet and an excavated part with full channel cross section has 42 feet minimum depth. (Fig. 2).

The min. bottom width on one nautical mile stretch is 250 feet, in the remaining parts 330 feet.

There is no tide, but irregular variations in water level by currents and winds occur. Normal deviations from mean water are ± 1 foot (93 % duration). Lowest recorded water is about 3 feet below mean water level

Size of ships

At present the underkeel clearance recommended is 3 feet permitting a draught of 37 feet which corresponds to vessels of about 40,000 tons dw fully laden at mean water level The reckord load of about 45,300 tons in a 50,000 tons dw ship was shipped in August 1968 The curret draught was 36′ - 5″ at abt. 8″ low water.

NEED OF INFORMATION ON SQUAT

It is a well- known fact that a ship in motion changes the margin between the keel and the bed compared to the value when the ship is at rest. The change of this underkeel margin resulting from change of the ship′s trim and sinkage of the water level due to motion is usually combined under the term squat

Ships′officers and pilots have in general only their own experience to make themselves an idea of the required underkeel clearance. This often leads to overrating of the safety factor by adding considerable margins for squat. Seen from the point of safety this is inviolable but from the freight economy less satisfactorily. It is quite clear, that without underrating the safety, one should not base decisions of underkeel margin on thumb-rules but on real knowledge for an optimal utilization of investments made in harbours and approach channels

In 1960-1961, when the period of planning was in progress, much discussion occured about the dimensions of the channel and the order of underkeel clearance to be stipulated. Differences of opinion particularly among the pilots has forced to measurements in order to determine squat and evaluate underkeel clearance with ships in motion.

MEASURING METHODS

Already in 1904 observations on squat were made by US Army Engineers in the Ambrose Channel at the entrance to New York. These observations showed that big vessels needed large margins at high speeds. A few years ago model scale tests were made by Shell with experimented work executed by the Sogreah Laboratory, Grenoble A continuation of these investigations in full scale have been carried out by Shell in the deep channel to Maracaibo in Venezuela with echo sounding The method has given interesting results and has led to a pratical method for determining of squat.

Photographic measuring method

At the request of LKAB the Swedish consulting firm Skandiaconsult has evolved a method which seems to give rather thorough statements of vessels′ squat. A condition is however that there is sheltered water and possibilities for solid positioning of the levelling instruments near the fairway. The method is suitable for inland waterways in semi-open water.

Principally the sinkage of ships is photographically registered by means of levelling instrument combined with camera equipment. (Fig. 3). This method has the advantage of making the levelling operation possible after the field work, thus eliminating misreadings on the levelling staffs and preserving the basic measurement material. The measuring distance with equipment now used can under good visibility conditions reach up to about $\frac{1}{2}$ nautical mile with an accuracy of about $\pm \frac{1}{2}$ inch. (12.7 mm).

Determining of squat is made by levelling the position of the vessel in relation to the water level in the trimming position at the berth before the sailing and en route at measuring points along the channel. The difference between the values of ship in motion and at rest makes the sinkage demanded, which practically includes squat and hull deformations, appearing with ships in motion.

Equipment and arrangements

For determining the position of the vessel in relation to the water level, graded levelling staffs are put up midship and near the bow and stern. (Fig. 4) Listing of the ship is found with a pendulum 30 - 50 feet in length attached to the sky-light of the engine room. The positions are determined by observations of the light buoys passed and the speed by timing between the buoys.

Water table fluctuations are observed by means of a water level indicator. The current stationary water level on the actual occassion of measuring is used as reference level. The heights over the water level of the instrument are decided with stationary levelling staffs put up at the measuring stations along the fairway. The collimation errors of the instruments can easily be corrected by a number of measurements between the stationary staffs.

The measuring equipment consists of a combination of a standard model self-aligning level instrument (Zeiss, Ni2, 30 X Magn.) and reflex cameras with a picture size of 24 x 36 mm of good optical quality, (type Cannon 1:2 and Minolta 1:1.2. Film: Kodak Plus X, exposure 1/30 - 1/60 sec.).

Registration of the height positions of the vessel related to the stationary water level is made by photographing the levelling staffs, when the vessel is passing the observation lines from the measuring stations. (Fig. 5).

Assessment of the registrations is made from the photos by means of a micrometer with a reading accuracy of 0,01 mm. The ship's sinkage can be determined in relation to the reproduced cross hairs which represents the stationary water level in the observation line. On calculation of the reference water level and the squat, corrections for earth curvature, refraction and the listing of ship must be made. Corrections for variations in water density were unnecessary.

OBSERVATIONS

Measurements on ships' sinkage and determinations of squat have been carried out for three different vessels carrying 23,300, 37,200 and 35,700 tons of load respectively.

Dimensions of the ships:

No.	DW	Length, PP	Breadth moulded	Depth moulded	Draught, SFB
1.	23,420 tons	560′- 0"	74′- 6"	44′- 3"	32′- 11½"
2.	38,270 tons	abt. 700′	88′- 2"		35′- 3½"
3.	36,200 tons	630′- 2"	88′- 6"	52′- 0"	35′- 11½"

The 36,200 tons ships traversed the fairway three times under similar conditions at different speeds. Observations were made from stations positioned on two light-houses and one point on the canal embankment. Distances ranged from 300 metres (1,000 feet) to 900 metres (3,000 feet) in three or four lines from each station to the centre line of the fairway. (Fig. 1).

Accuracy of measurements was determined by a great number of observations on the reference staffs. The order of the standard deviation ranges from ± 4.2 mm (± 0.065 inches) to ± 13 4 mm (± 0.53 inches) at a distance of 800 metres (2,600 feet). The values stated indicate the accuracy of the measurements, including the error in reading the photos. A previous series of 20 measurements in a known precision levelling net has showed a mean deviation of 11- 14 mm (0.43 - 0.55 inches) at a distance of 740 metres (2,400 feet).

Results of observations indicate that speed of the ship has great influence on the squat. The order of squat measured was maximum 370 - 430 mm (1′- 2½" to 1′- 5") for the 4 knots for the 36,200 tons ship.

Squat diagram for the 36,200 tons ship (Fig. 6) inward bound show moderate squat values of 3½ - 4½ inches at a speed of 4 - 4½ knots and 5 - 7 inches at 5 - 5½ knots. (Corrections are made for counter-current of 0,2 - 0.4 knots).

The listing due to trimming or sheering is at most 60 mm (2½ inches) converted to required extra margin at a speed of 8 knots, negligible at 4 - 5 knots Change of listing was observed at the curves.

All the ships was changing the trim slightly by the bow, maximum about 2 inches at speed of 7 - 9 knots, when passing the constricted cross section of the channel In the other parts of the fairway with incomplete cross sections and semi-open water, no observable change of trim could be stated. In the trimming position at the berth, all the ships had a trimming to the stern between 8 inches and 1 foot. The change of trim when they passed the channel was less than 2 inches.

Evaluation of the underkeel clearance

The minimum depth stated is regularly being controlled by bar-sweeping along the total bottom area of the fairway with help of a measuring frame suspended on a catamaran driven by two out-board motors and operated by 2 - 3 men. (Fig. 7). According to the observations and calculations on squat, there was a minimum underkeel clearance of fully 3 feet at the current high water level of 6 to 8 inches on the occasion of measurements.

SQUAT CALCULATIONS

Measured squat based on the photographic levelling method have given some results which might be of interest especially in comparison with calculated squat based on theoretical methods.

Two methods of calculation have been tested against the measured squat values. The calculations, referring to the three passages of the 36,200 tons ship at different speeds, have been carried out for observation line No. 2 (semi-open water, incomplete cross section) and line No. 9 (full cross section, calculated area 3640 sq.metres). The speed of the ship ranged from 3½ to 5 knots in line No. 2 and 4 to 6 knots in line No. 9.

The graphs show that in this particular case the measured squat corresponds rather good to a somewhat modified method according to Wöltiger at low speeds and in semi-open water, while a method developed by Shell and Sogreah is nearer to the measured values at full cross section and higher speeds. (Fig. 8 and Table 1). The graphs even indicate the well-known fact, that the speed of the ship has great influence on the order of squat.

CONCLUSIONS

Though the measurements of squat at present should be regarded as preliminary, some conclusions for practical purpose can be drawn on the results. One is that the ships observed seemed to be trimmed to the stern ½ to 1 foot more than necessary for the passage of the fairway. A trimming to an even keel could probably help to improve the underkeel margin or alternatively increase the load, in case of underkeel clearance sufficient to the navigational safety.

Another conclusion is that the ships were changing the trim slightly by the bow, when they passed the full cross sectional area of the channel. The change of trim was max. 2 inches at speeds of 7-9 knots. In other parts of the fairway with incomplete cross sections and semi-open water minor change of trim could be observed.

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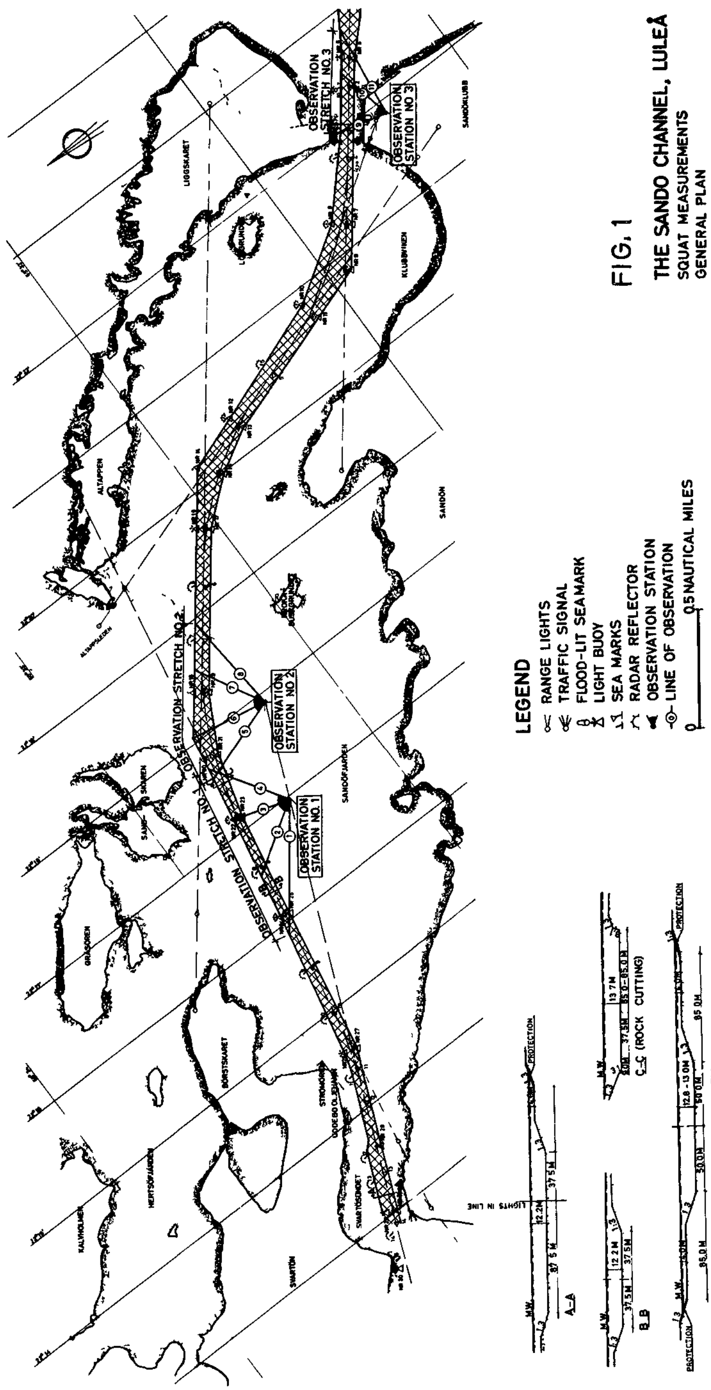


FIG. 1

THE SANDO CHANNEL, LULEÅ
SQUAT MEASUREMENTS
GENERAL PLAN

Section No	Speed over ground	Direction	Current velocity	Relative speed	Measured squat			Calculated squat according to	
					F	M	S	Shell	Wöltiger
1	4.4 4.5 3.8	O I O	0.2 0.2 0.2	4.2 4.7 3.6	5 12 5	6 7 5	5 8 1	17.0 21.1 13.6	8.4 10.2 5.9
2	4.4 4.5 3.6	O I O	0.2 0.2 0.2	4.2 4.7 3.4	6 8 2	6 8 2	3 8 3	14.4 17.2 11.3	6.4 7.9 3.9
3	4.6 4.5 3.6	O I O	0.2 0.2 0.2	4.4 4.7 3.4	6 9 5	6 8 3	3 7 2	16.0 17.8 10.6	9.2 10.8 5.3
4	4.8 4.6 3.8	O I O	0.2 0.2 0.2	4.6 4.8 3.6	4 8 5	5 8 5	6 7 5	13.7 14.3 9.5	8.0 9.2 5.1
5	4.8 4.5 3.9	O I O	0.2 0.2 0.2	4.6 4.7 3.7	6 11 4	3 8 3	4 8 3	13.7 13.7 10.1	8.0 8.3 5.1
6	4.8 4.5 3.8	O I O	0.2 0.2 0.2	4.6 4.7 3.6	5 9 4	2 12 6	4 11 4	15.2 15.7 1.0	6.8 7.3 4.5
7	4.8 4.4 3.8	O I O	0.2 0.2 0.2	4.6 4.6 3.6	6 9 6	5 10 5	5 9 5	18.6 18.6 13.4	7.7 7.7 5.0
9	4.5 5.0 6.0	O I O	0.4 0.4 0.4	4.1 5.4 5.6	7 17 21	5 13 14	4.5 12 14	13.4 21.2 22.4	6.1 11.7 12.6
10	4.5 5.1 6.7	O I O	0.3 0.3 0.3	4.2 5.4 6.4	5 15 22	1 10 17	1 12 12	11.8 17.5 24.4	7.1 12.8 18.8
11	4.6 5.3 7.0	O I O	0.2 0.2 0.2	4.4 5.5 6.8	6 13 20	6 9 21	4 12 18	12.7 18.8 27.1	7.3 11.7 18.6

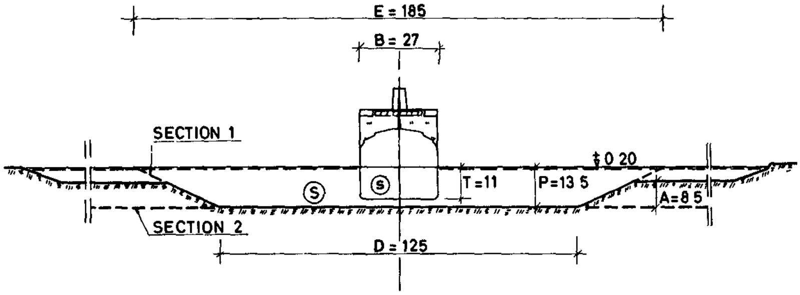
TABLE 1: SUMMARY OF MEASURED AND CALCULATED SQUAT

NOTATIONS

Speed over ground)
Current velocity) expressed in knots
Relative speed)

Measured squat)
Calculated squat) expressed in centimetres

F - Fore
M - Midship
S - Stern
O - Outgoing
I - Incoming



NOTE

THE DATA OF THE BOTTOM PROFILE ARE AFTER FINAL DREDGING AND DO NOT CORRESPOND TO THE DATA ON THE GENERAL PLAN

S = CROSS SECTIONAL AREA

s = MIDSHIP AREA ≈ 0.98 x BxT

FIG. 2

CROSS SECTION AT LINE 9 (OBSERVATION STATION NO 3, SEE GENERAL PLAN,

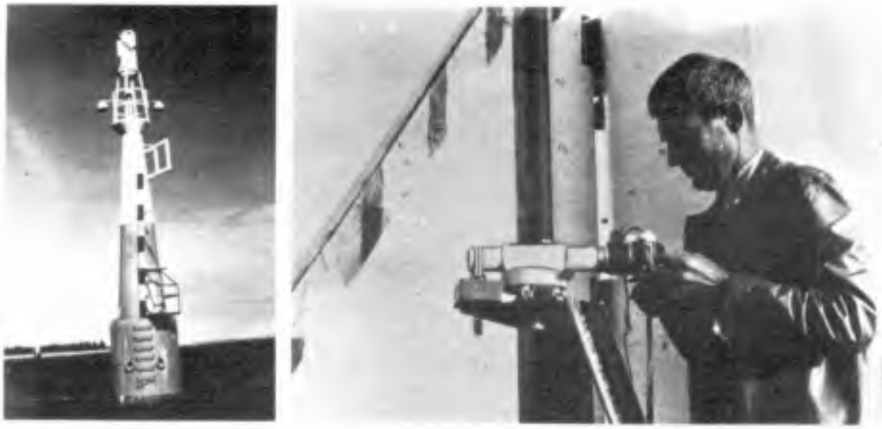


FIG. 3 OBSERVATION STATION AT LIGHTHOUSE
LEVELLING INSTRUMENT AND ATTACHED CAMERA

FIG. 4 LEVELLING STAFFS ATTACHED TO SHIP

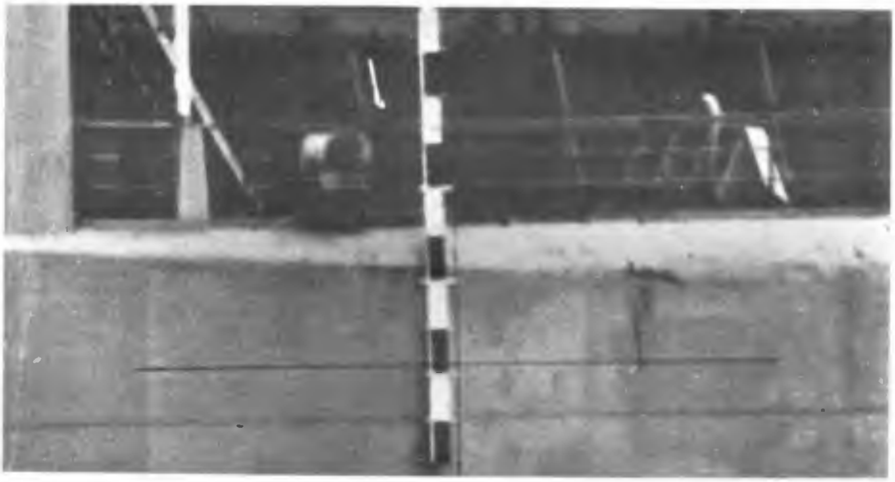


FIG. 5 OBSERVATION PHOTO OF LEVELLING STAFF AND CROSS-HAIRS

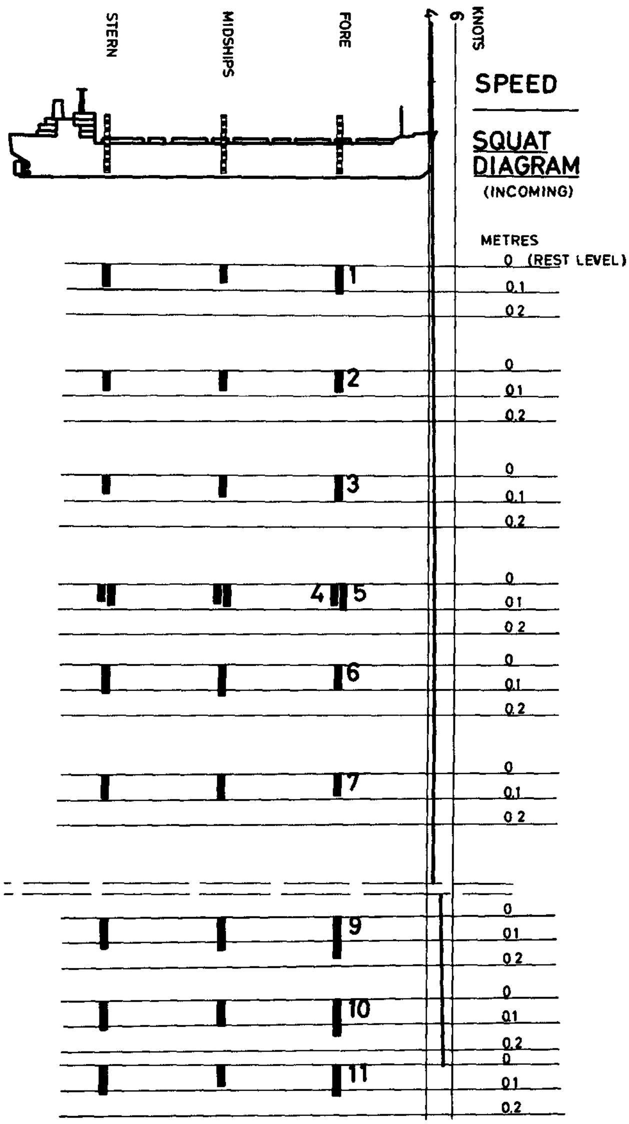


FIG. 6 SQUAT MEASUREMENTS, AUGUST 20, 1967
SQUAT DIAGRAM FOR MS "LAPONIA"

FIG. 7 BAR-SWEEPING CONTROL EQUIPMENT

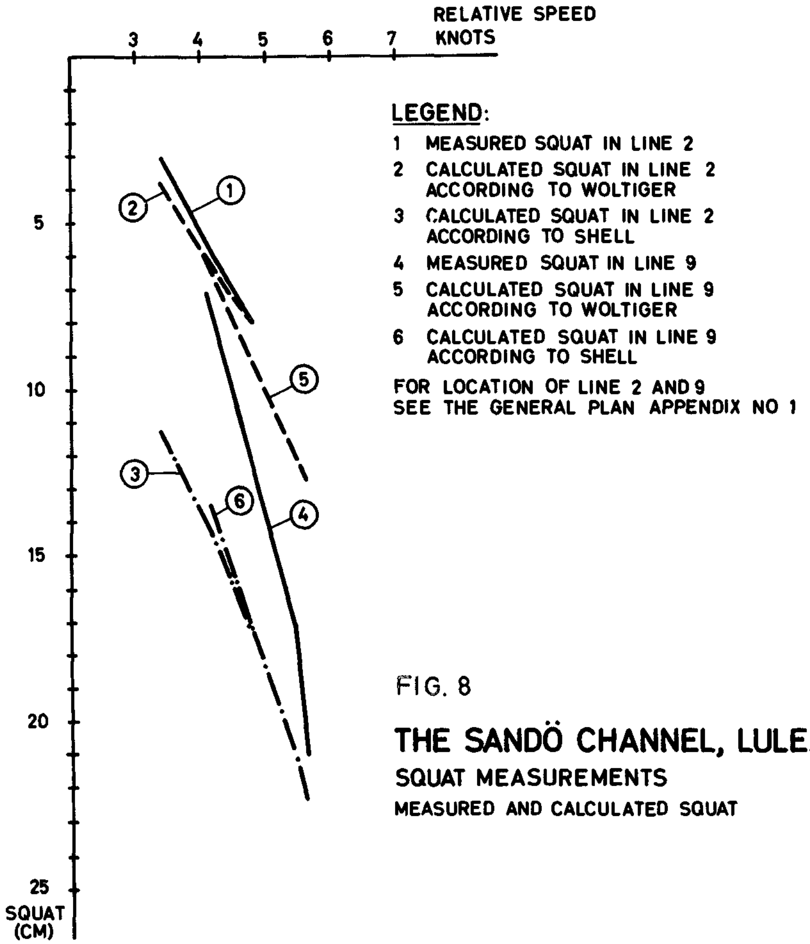


FIG. 8

THE SANDÖ CHANNEL, LULEÅ
SQUAT MEASUREMENTS
MEASURED AND CALCULATED SQUAT