CHAPTER 52

'STABIT' - A NEW ARMOUR BLOCK

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ABSTRACT

There are a number of specially shaped concrete armour units in use today. The Stabit is one of them and was first developed in 1961 for use on the reconstruction of breakwaters at Benghazi Harbour, Libya. This paper describes the development of Stabits and gives the technical details relating to their use. The subjects covered include full scale and model tests, stability coefficients, wave run-up, coverage, placing patterns, moulds, casting, handling and placing.

INTRODUCTION

The first Stabits were experimental and 7 ton in weight of Mark I variety used at Benghazi Harbour, Libya, early in 1961. These were placed at the end of one of the existing protective moles where they were exposed to open sea waves. This experiment proved that Stabits had excellent wave energy dissipation properties and were worthy of development. However, load testing to destruction indicated that Mark 1 Stabits did not possess an adequate reserve of structural strength and Mark II Stabits of increased strength were introduced.

In order to decide whether Stabits would be satisfactory for full scale breakwater armouring, hydraulic model tests were instituted at the National Hydraulics Research Laboratory in 1961. These tests were carried out using models of Mark II Stabits and demonstrated that Stabits offered a satisfactory solution. In consequence it was decided to use 29 ton Stabits in the reconstruction and extension of existing moles at Benghazi Harbour.

During the course of construction when some 2,000 Mark II Stabits had been cast and placed on the Outer Mole it became increasingly evident that undue care had to be exercised to prevent breakages during placing. In consequence a still more robust Mark III unit was devised.

The Mark III design supersedes all the previous designs and is currently in use. A 29 ton Mark III Stabit is illustrated in Fig. 1.

The number of 29 ton Stabits which have been used on the reconstructed moles at Benghazi is about 10,000 and about 900 of the smaller 7 ton units are being used as absorbent facing to reduce wave effects in certain parts of the harbour. An aerial view of the harbour with the completed moles is given in Fig.2.

In England, about 600 of the 7 ton units were used to stabilise the beach at the root of the East Breakwater at Shoreham in 1962. Fig.3 illustrates these Stabits in position.

Fig.1 - 29 ton Mark III Stabit

Fig.2 - Aerial view of Stabits at Benghazi

Construction commenced in 1968 on Port Rashid, Dubai, Arabian Gulf, where 13,000 of 15 ton and 12,000 of 7 ton Stabits will be used as armouring for breakwaters. In addition about 2000 of 7 ton Stabits may have to be used at the root of breakwaters to stabilise the beach if further investigations and observations show that erosion is likely to occur in these areas.

TESTS

Hydraulic Models

The first hydraulic model tests were carried out in 1961 by the National Hydraulic Research Station, Wallingford, England. The purpose of these tests has been explained in the previous section.

Model Stabits were made representing prototype 29 ton Stabits to a linear scale of 1/47 and tested in a flume. Prototype wave periods of 10 and 12 secs. with a tidal range of 3 ft. and a storm duration of 7 and 12 hours simulating 32 feet maximum waves were used. The breakwater armouring of Stabits was found to be stable for waves of this height and the tests confirmed that for stability under such wave attack, Stabits of 29 ton weight with concrete density of 145lb/cu.ft. were a satisfactory alternative to any other form of artificial armour.

Stabits of Mark II variety were used in these tests.

In September, 1963 further hydraulic model tests were undertaken from which formulae were derived for use in the preparation of preliminary designs and estimates.

Models of Mark III Stabits made from concrete of 145lb/cu.ft. density were used. Design coefficients were established and wave run-up, porosity and the thickness of armour layer were measured for various breakwater slopes and wave periods. The data obtained from these tests are reproduced in the following pages.

It should be noted that in the original tests a conventional method of placing known as the "double layer" method was used whereas in the subsequent tests a new method called the "brickwall pattern" was adopted.

The brickwall pattern was evolved during the course of construction of the breakwaters at Benghazi and confirmed by model tests as providing maximum efficiency and economy on slopes of 1 in 2 and steeper.

The two methods of placing have been described in detail in the section dealing with design.

Full Scale

As mentioned in a previous section, full scale tests were carried out using the experimental 7 ton Mark I Stabits at Benghazi Harbour, structurally expected to resist waves 8-10 feet in height.

The armoured test face received open sea waves of 11 to 12 ft. in height over a period of about four months and sustained very little damage.

Fig.3 - 7 ton Stabits at Shoreham

Fig.10 - Stripping Moulds from 29 ton Stabit

The performance of the experimental Stabits in disrupting and destroying the assaulting waves was particularly striking when compared to that of the adjacent pell mell blockwork. Waves collapsed almost completely and run-up was small by comparison.

Static and dynamic load tests were also carried out on Stabits from time to time. In the final tests a Mark III unit was dropped through a height of 15 feet onto rock armour without destruction.

DESIGN DATA

Dimensions

The Stabit is basically a hollow tetrahedron. Its proportions are related to the basic dimension 'T' and are shown in Fig.4. Once the required weight of a unit and thus its volume are known the basic dimension 'T' can be calculated from the following simple formula:-

$$V(\text{volume}) = 11.34\ T^3$$

Stability

The results of hydraulic model tests were used in the evaluation of the experimental coefficient K_Δ in the stability formula developed by Mr. R. Y. Hudson[1] of Waterways Experiment Station, Vicksburg, Mississipi, U.S.A. The Research work of Mr. R. Y. Hudson which led to the evolution of his stability formula has been published in various technical articles and will not be described here.

This formula is generally stated as follows:-

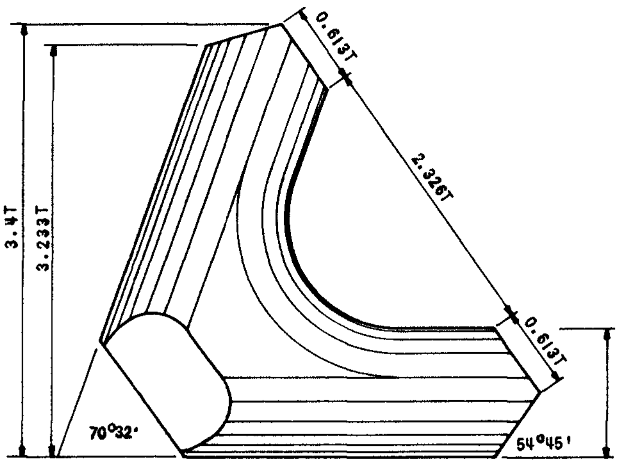
$$W_r = \frac{\gamma_r H^3}{K_\Delta (s_r - 1)^3 \cot \alpha}$$

where W_r = Weight of armour unit (lbs)
H = Wave Height (feet) (significant)
γ_r = Specific weight of armour unit (lbs/cu.ft.)
S_r = Specific gravity of armour unit (should be related to the density of water in which the structure is located).
α = Angle of slope of the armour layer.
K_Δ = Experimentally derived coefficient.

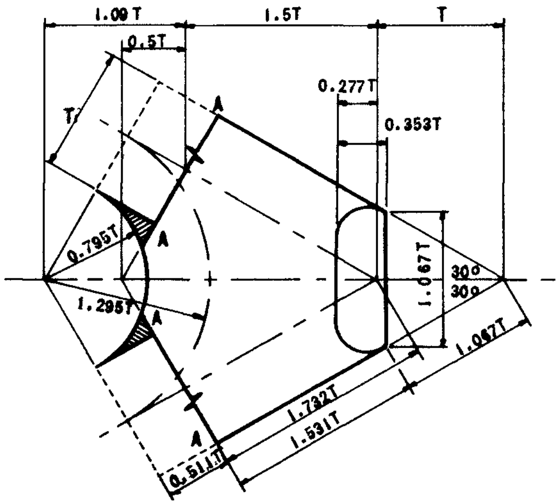
The experimentally derived K_Δ values of Stabit armouring for no damage condition are as follows:-

K_Δ = 25.4 - Use with discretion and only where good supervision and control over placing available.
K_Δ = 19.04- Normal usage and where average supervision and control over placing available.

The wave flume used for this investigation was 78 ft. long, 4 ft. wide and 4 ft. deep. The depth of water was kept constant at 17 inches at the breakwater test section and therefore the effect of tidal variation was excluded. Three breakwater slopes of 1 in 2, 1 in 1.5 and 1 in 1.3 were used. Four wave periods of 1.2, 1.4, 1.6 and 1.8 sec. were used for each



SIDE ELEVATION OF STABIT SITTING ON TWO LIMBS



PART PLAN OF STABIT SHOWING CORNER

FIG 4 - STABIT PROPORTIONAL DIMENSIONS

NOTE.

The Stabit comprises, in effect, four identical corners joined along section AA The area shown shaded overlaps the adjoining corner An overlap (not shown) also occurs where the inner radius of the adjacent corner extends a corresponding distance beyond this section breakwater slope. For any particular wave period, every cross-section was tested with waves, the height of which was decreased from test to test until a wave height was found which would result in less than 1% damage. Tests using higher waves causing over 1% damage were terminated after about 30 minutes continuous running. Tests using lesser wave heights to establish the no damage condition were continued for up to two hours. If the applicability of these general tests can be considered to hold good for Stabits ranging between 5 to 30 tons, then two hours in the tests would represent prototype storm conditions over a period of 12 to 14 hours.

The Stability Number, $N_s = \dfrac{\gamma_r^{1/3} H}{W_r^{1/3}(S_r-1)}$, was

calculated using a Stabit weight of 0.638lbs., a specific weight of the armour unit of $145 lbs/ft^3$, a specific weight of fresh water of $62.4 lbs/ft^3$ and the significant wave height causing damage of 1% or less. The calculated values of the Stability Number were plotted as the ordinate with the reciprocal of the breakwater slope ($\cot\alpha$) as the abscissa as illustrated in Fig.5. It can be seen that there is a wide scatter of results the cause of which can be attributed primarily to the difficulty of repeating exactly the way in which the Stabits were placed on the breakwater face between tests. It should be noted that every effort was made to simulate prototype placing and no attempt was made to force Stabits to interlock one with another. It was felt that variations in standards of control over placing might also occur in practice and therefore it was decided to draw two lines representing two standards. Line AB represents good standard of supervision and control whereas line CD represents average to poor standard.

It can be shown that $N_s = a(\cot\alpha)^{\frac{1}{3}}$

For line AB, $a = 2.94$

& For line CD, $a = 2.67$

It can also be shown that $K_\Delta = a^3$

$\therefore$ For line AB, $K_\Delta = (2.94)^3 = 25.4$

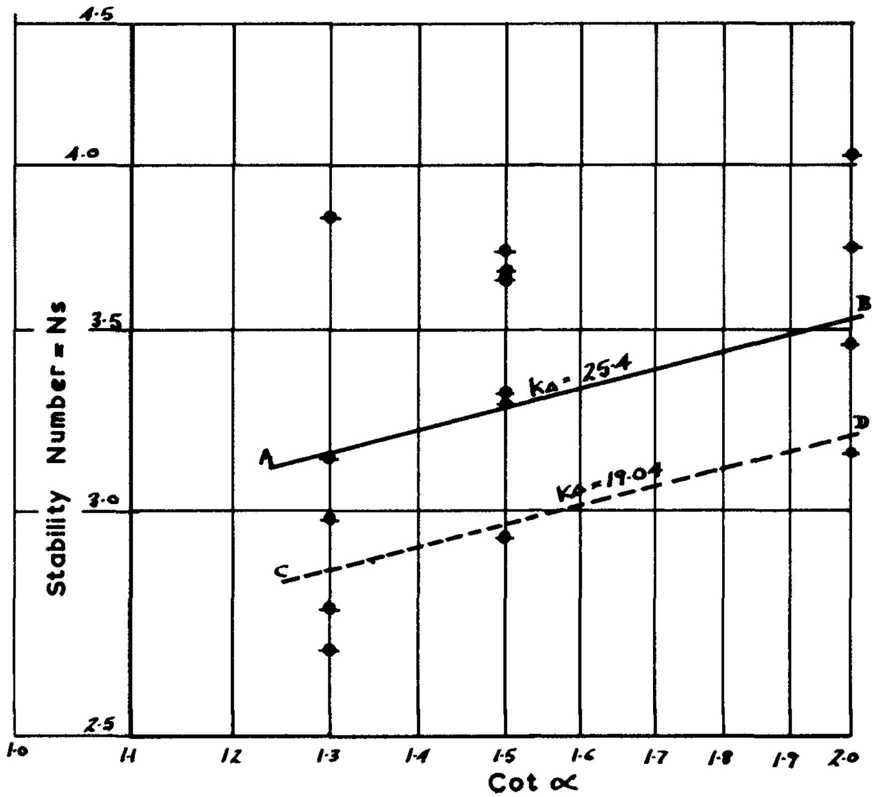
& For line CD, $K_\Delta = (2.67)^3 = 19.04$

It should be noted that the "no damage" condition was defined as the removal and/or excessive oscillation of Stabits of up to 1% of the total number of units on the test face.

It is interesting to mention that completely independent model tests were carried out in New Zealand where a value of 19.9 was obtained for K_Δ. However, it should be noted that these tests were for a particular design and a particular site and damage of 2.5 to 3% was accepted. The details of these tests have been published by Mr. P. D. L. Holmes[2] in New Zealand Engineering of November, 1965 and reproduced in the Dock & Harbour Authority[3] of June, 1966.

It must be emphasized that the above formula and the experimentally derived values of K_Δ should be used with discretion and preferably only for the purpose of preliminary designs and estimates for the following reasons:-

1) Only a limited number of variables could be taken into account in the model tests and, in particular, wind was not produced. It is believed that wind waves have a different shape and are generally steeper than



Stability Number (Ns) = $\frac{\gamma_r^{1/3} H}{W_r^{1/3}(S_r - 1)}$

Fig. 5.

STABILITY NUMBER AS A FUNCTION OF BREAKWATER SLOPE FOR NO DAMAGE CRITERIA those generated by the normal paddle type mechanism.

2) Waves attacking the breakwater obliquely were not reproduced in the test nor was the special case of a roundhead tested.

3) In nature, storm-waves contain a large proportion of waves which are higher than the significant whereas in the model tests it was not possible to reproduce a similar proportion, nor the same ratio of maximum to significant wave height. Therefore, some doubt remains as to which of the various wave heights present in storm-waves occurring in nature should be selected as the "design" wave.

It is strongly recommended that for final design, specific conditions pertaining to the particular site in question should be examined and, if necessary, hydraulic model tests should be undertaken to confirm the adopted design.

Prototype Results

The breakwaters at Benghazi, a typical cross-section of which is illustrated in Fig.6, were completed in 1962. Wave records for the period 1961 to 1965 were analysed and have been presented in another paper[4] to this conference. A careful record of damage has also been kept and which has been found to be about $\frac{1}{4}$% per annum taken as an average over the period of 5 years up to January, 1968. From an examination of the wave records it has been confirmed that the breakwaters have been subjected to the "design wave" several times. The experimentally derived stability coefficients have, therefore, been amply verified in practice.

Placing Patterns

There are two methods of placing Stabits; the "double layer" and the "brickwall". Both the methods were tried at Benghazi where it was found that the latter method resulted in good interlocking on slopes steeper than 1 in 2. Thus, on breakwaters, Stabits would be placed using the "double layer" method on the soleplate on the sea bed at the toe of the slope whilst the "brickwall" method would be adopted for armouring the side slopes of the breakwater itself.

Double Layer In this method Stabits are placed to a predetermined grid in two layers; the top layer being displaced from the bottom layer by half the grid spacing in both the directions. The upper Stabits thus sit in cradles formed by lower Stabits. The grid dimension is approximately equal to 3T.

Brickwall This method closely follows the principle of bonded brickwork construction and hence the name. Stabits in the first row are placed side by side. In the next row up the slope, Stabits are placed staggered from those in the first row. Each succeeding row partly overlaps the lower row so that every Stabit penetrates into it but at the same time rests against the slope. The brickwall method was developed during the course of construction at Benghazi where a trial length of breakwater was constructed using this method and was found to be very successful. For work above water and also for under-water where visibility is good, placing is carried out by eye but where under-water visibility is poor a predetermined grid for placing can be defined. Placing by eye and by means of a grid have been tried and both result in equally well interlocked armour layers. Fig.7 shows a photograph of 29 ton Stabits placed with this method.

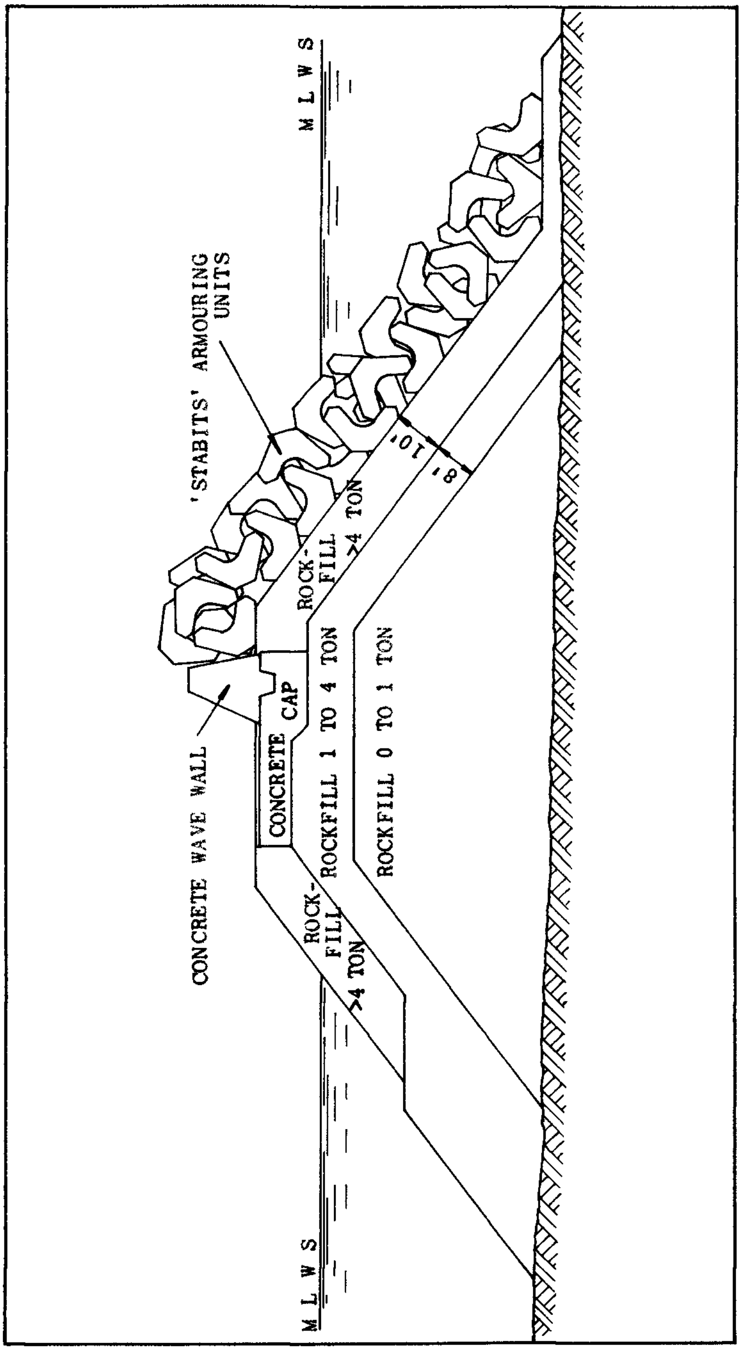


FIG 6 - TYPICAL BREAKWATER CROSS-SECTION AT BENGHAZI

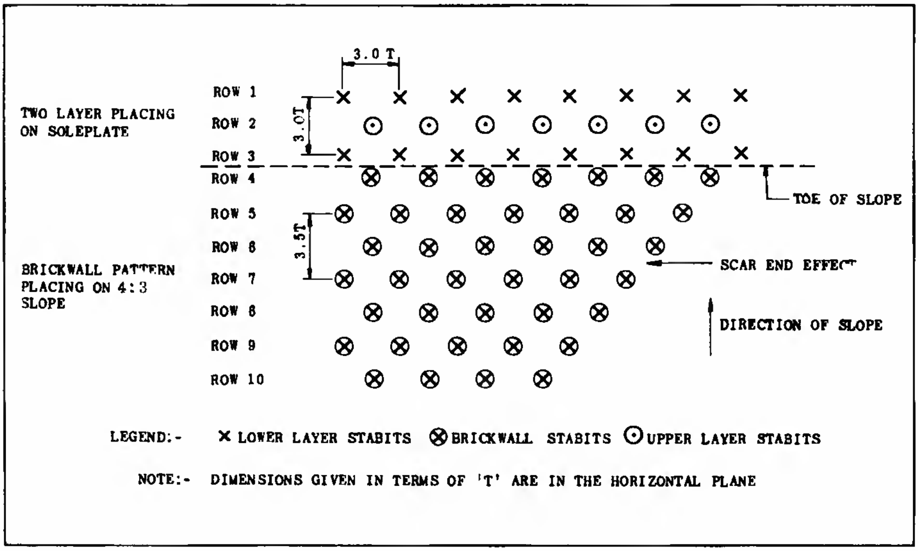


FIG 8 - DIAGRAMMATIC PATTERN FOR BRICKWALL PLACING

Fig.7 - Stabits placed "brickwall" method

Fig.8 shows a diagrammatic illustration of the sequence of placing operations on a typical breakwater.

Thickness and Porosity

The thickness of armour layer placed brickwall fashion is approximately equal to 4T, and the porosity is about 55%. The corresponding values for double layer armouring are 5T and 52%. These values were obtained in model tests and have been verified in practice.

Coverage

The breakwater surface area per Stabit in an armour layer placed brickwall fashion is given approximately by the following simple relationship which has been verified in practice:-

$$\text{Area/Stabit} = 6.3T^2 \text{sq.ft.}$$

Some typical brickwall coverages are given in the table below:-

SIZE Long tons	COVERAGE/100 sq.yd.
4	47 No.
5	40
7	32
12	22
15	19
18	17
23	14.5
29	12

The coverage for the double layer method can be calculated from the grid spacing which is approximately equal to 3T.

Wave Run-Up

Hydraulic model tests have indicated that the wave run-up on a Stabit armoured slope is governed by the following simple relationship:-

$$R = 1.3\ H$$

Where, R = Run-up measured vertically above S.W.L. (Feet)
H = Wave height (Feet)

The above formula should only be used as an approximate guide since it is not possible to generalise to cover an extensive variety of waves nor is it possible to measure accurately the run-up on a rough and porous sloping surface. Moreover, it should be noted that no wind was present in the tests, which is also believed to have an effect on the run-up.

The results of the wave run-up tests are given in Fig.9.

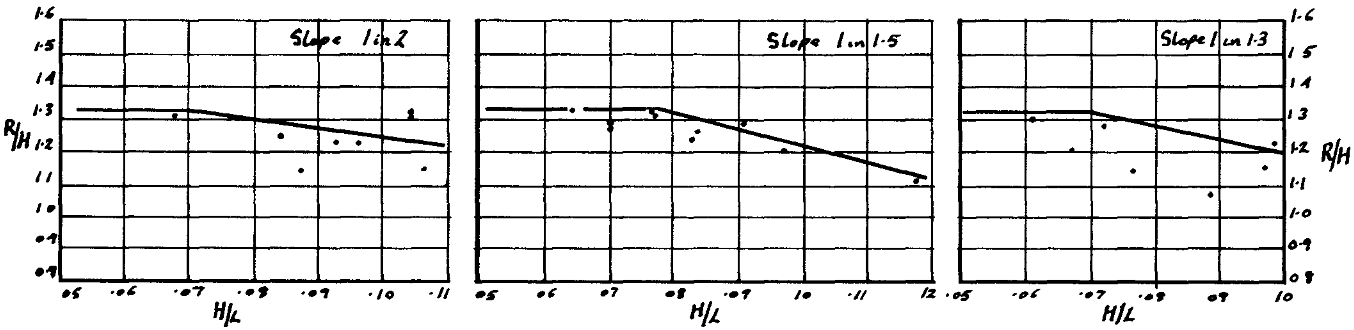


Fig 9. Results of Wave Run up Tests

	Tsecs	d/L	H	H/L	R	R/H
Slope 1 in 2	1 8	0 126	9 2"	0 067	12"	1 31
	1 8	0 123	7 75"	0 ·56	–	–
	1 8	0 126	9·00"	0 067	–	–
	1 8	0 125	9 25"	0 060	–	–
	1 6	0 139	10 75"	0 088	12"	1 12
	1 6	0 144	11 50"	0 097	14"	1 22
	1 6	0 149	9 75"	0 085	12"	1 23
	1 4	0 177	9 00"	0 093	11"	1 22
	1 4	0 171	10 50"	0 107	12"	1 14
	1 2	0 166	10 75"	0 106	14"	1 30
	1 2	0 20	9 00"	0 105	12"	1 33

	Tsecs	d/L	H	H/L	R	R/H
Slope 1 in 1·5	1 8	0 125	9 5"	0 070	+12"	1 26
	1 8	0 123	11 4"	0 083	+14"	1 23
	1 8	0 125	8 66"	0 064	+11 5"	1 32
	1 6	0 137	10 45"	0 084	+13"	1 24
	1 6	0 137	8 68"	0·070	+11"	1 27
	1 4	0 173	9 58"	0·097	+11 5"	1 20
	1 4	0 173	7 58"	0 088	+10"	1 32
	1 4	0 180	8 57"	0 091	+11"	1 28
	1 4	0 175	7 64"	0 078	+10"	1 31
	1 2	0 209	9 71"	0 119	+11"	1 13

	Tsecs	d/L	H	H/L	R	R/H
Slope 1 in 1 3	1 8	0 127	9.0"	0 067	+11"	1 22
	1 6	0 149	8 7"	0 076	+10"	1 15
	1 6	0 144	7 26"	0 061	+9 5"	1 31
	1 4	0 177	7 0"	0 072	+9"	1 28
	1 4	0 177	8 6"	0 089	+9"	1 05
	1 2	0 210	7 75'	0 096	+9"	1 16
	1 2	0 205	8 2"	0 098	+10"	1 22

MOULDS

Description

The mould consists basically of eight elements as follows:-

2 lower side supporting elements on props and castors

2 upper side elements

2 inner lower segments

2 inner upper segments

All the elements are inter-connected by means of bolts. Tapered pins are used in some of the bolt holes for drawing elements together during assembly. The supporting elements are provided with props on castors with screw jacks for ease of erection and stripping. On larger sizes opening hatches are usually provided at the gussets for concreting purposes. On smaller sizes small opening lids are provided for vibration purposes only. The top end plates are hinged to the supporting elements and can be used as working platforms but, depending on the method of working, the hinge can be eliminated with some economy. In addition to the above mentioned elements, each mould is provided with two baseplates which are mounted on plinths on which moulds are erected in the casting yard.

Erection and Stripping

Raised concrete plinths are constructed in the casting yard to which the baseplates are bolted and on which the moulds are erected. A small crane is required for handling the mould elements for the larger sizes of Stabits during erection and stripping operations. The complete operation of striking, cleaning, oiling and erection of a mould generally takes $\frac{3}{4}$ to 1 hour. Each mould may be stripped completely 24 hours after casting depending upon the quality of concrete and the climatic conditions. Fig. 10 shows the stripping operation in progress.

CASTING AND HANDLING

CONCRETE

Ordinary portland cement concrete is generally used in making Stabits. The maximum size of aggregate is generally $1\frac{1}{2}$in. but larger sizes up to 3in. may be used with care in mix design. The concrete should have a cube crushing strength of 3,500lb/sq.in. at 28 days or flexural strengths can be specified, if required, as a supplementary or an alternative method of concrete quality control. No reinforcement is required in making Stabits.

Mixing and Placing Concrete

The size of the mixer should be such as to enable each mould to be filled completely in a single operation without any horizontal construction joints. Concrete can be transported to the casting yard by any convenient means where each shutter opening is fed alternatively. Thorough compaction is ensured by internal vibrators. In the case of large Stabits, vibration of the lower parts is carried out by a man standing on the 'saddle' and/or through the inspection hatches. For smaller Stabits, vibration is carried out from the top openings as well as from the small hatches especially provided for this purpose. As the concrete reaches the level of gussets,

Fig.11 - Stabit being lifted by double sling method

Fig.12 - Low loader transporting Stabit

the surplus concrete is skimmed off and the hatches are closed. Average casting times for 29 ton and 7 ton Stabits were found to be 35 mins. and 20 mins. respectively. However, these figures depend very much on the plant used on site.

Handling to Storage

Normally Stabits can be moved to storage 3 days after casting using a simple double sling arrangement which keeps all members in compression. This method of slinging is extremely simple and is illustrated in Fig.11. Mobile cranes, Tournacranes or gantries can be used for handling Stabits to storage.

PLACING

Time of Placing

Generally Stabits are placed in their final position not earlier than 28 days from casting but this period may be reduced to as little as ten days depending upon the quality of concrete, prevailing temperature and other conditions at a particular site.

Transport

The type of transport required for moving Stabits from storage to the site depends on the site and size of units. In most cases, however, ordinary lorries or low-loaders should suffice. Fig.12 shows a 29 ton Stabit being transported by a low-loader.

Cranage

The types of cranes required for placing Stabits in the works depend upon the size of unit and the working radius; Figs.13 and 14 show a Lima 2400 and a floating crane in action.

Slinging

Lifting hooks cast into Stabits are not recommended as they can result in corrosion and bursting of concrete. A simple sling method, illustrated in Fig.13 has been found to be very successful in practice. It will be seen that the sling consists simply of a rope passed through the centre of the Stabit with both ends attached to the crane hook. After the Stabit has been placed in position, the crane hook is lowered and one end of the sling is unhooked by hand or auxiliary wire. The crane hook is then raised thus withdrawing the sling clear of the Stabit.

Method of Placing

Stabits should be placed in such a manner as to achieve fully interlocked armour using the placing patterns described in another section. The method of placing is quite simple. A crane lifts the Stabit using the method of slinging described above and lowers it into the position directed. Sometimes it is found that the best interlocking position is not obtained at the first placing operation. In that event all that is required is to

Fig.13 - Lima crane placing Stabit

Fig.14 - Floating crane placing Stabit

raise and lower the Stabit until it adopts a stable attitude.

Where underwater visibility is good, instructions to the crane driver are given by a man in a boat observing through a glass box projecting into the water. Where underwater visibility is poor, placing has to be carried out to defined grid spacing in relation to a fixed base or wire. For work above water, all placing is carried out by eye to achieve maximum interlock. With a little experience placing can proceed at rates varying from 6 per hour, one mile from the store yard for 29 ton Stabits, to 10 per hour, for 7 ton Stabits in close proximity to the yard.

It must be appreciated that a certain degree of consolidation of the Stabit armouring is likely to occur during wave action after construction. This is quite normal as Stabits settle into their final interlocked positions.

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REFERENCES

1. R. Y. Hudson, Laboratorv Investigation of Rubble-Mound Breakwaters. Proc. Am.Soc. Civil Eng. September 1959, Vol.85 No.WW3, pp.93-119.

2. P. D. L. Holmes and A. G. Park, Design of a Mound Type Breakwater for Port Taranaki. New Zealand Engineering, November 15, 1965.

3. P. D. L. Holmes and A. G. Park, Hydraulic Model Studies for a Mound Type Breakwater. Dock and Harbour Authority, June 1966.

4. K. Y. Singh and L. Draper, Waves off Benghazi Harbour, Libya. Proc. XIth Conf. Coastal Eng. 1968.