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CONTRACT REPORT CERC-88-1

NEW METHODS OF CONSTRUCTING SCALE MODEL ARMOR UNITS

by
Robert J. Richter

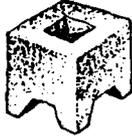
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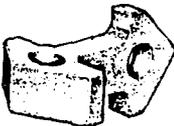
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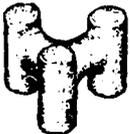
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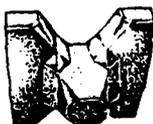
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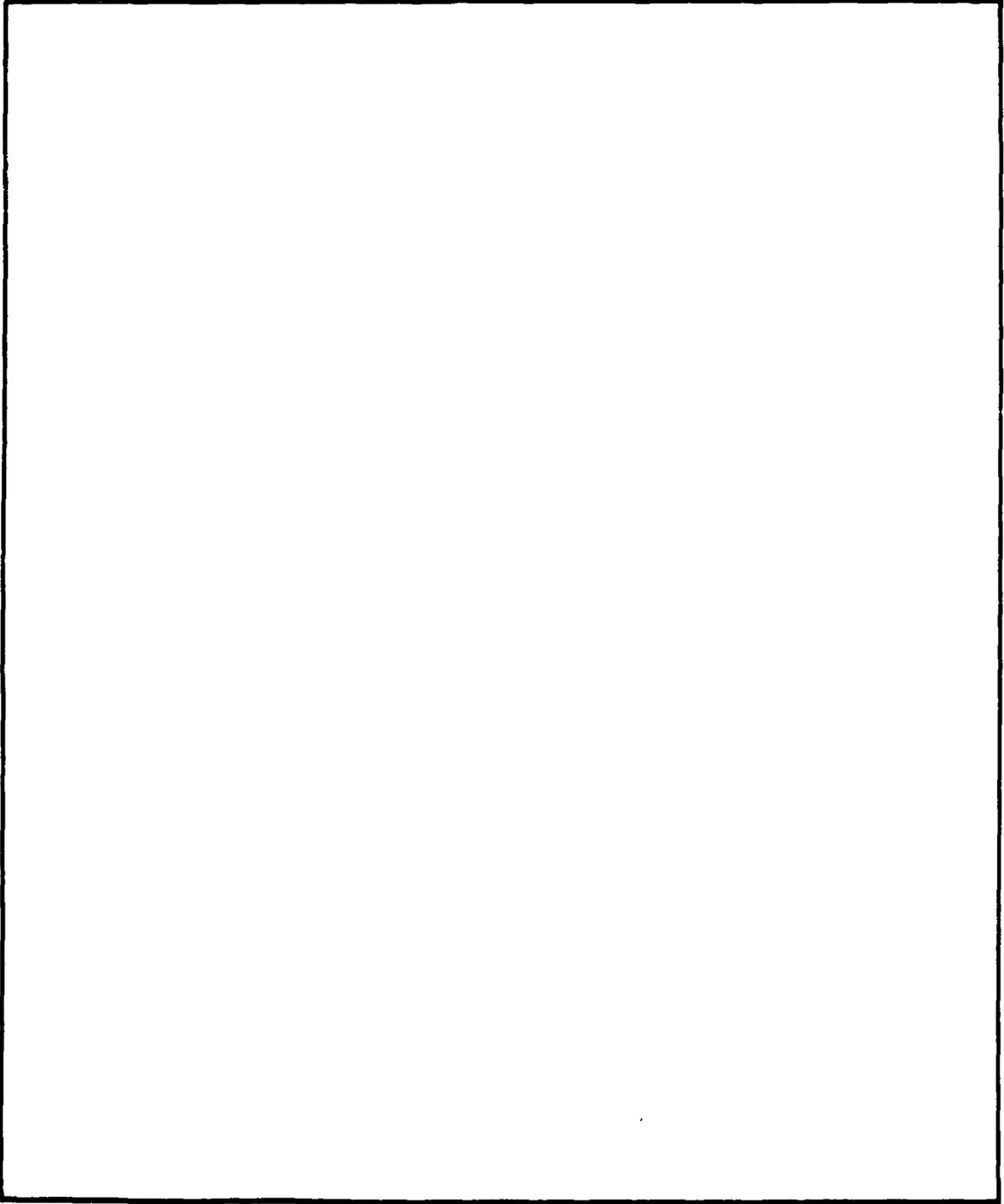
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PREFACE

The scope of work reported herein was conducted in response to Department of Defense (DOD) Small Business Innovation Research (SBIR) Program Solicitation No. 87-1, under Topic No. A87-265. This work and final report were prepared under Contract No. DACA39-87-G-0032 at the US Army Engineer Waterways Experiment Station (WES) during the period 8 May 1987 to 31 January 1988. The study was monitored by Mr. Phillip Stewart, WES SBIR Program Coordinator, with technical guidance from a Technical Review Board consisting of Messrs. D. D. Davidson, Robert D. Carver, and Dennis G. Markle, Research Hydraulic Engineers, Coastal Engineering Research Center (CERC), WES.

This report was prepared by Mr. Robert J. Richter, Exterior Wall Systems (EWS) Ltd., Croton, NY. The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of WES. This report does not constitute a standard, specification, or regulation. The contract was monitored by Mr. C. Eugene Chatham, Chief, Wave Dynamics Division, CERC. Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., are Chief and Assistant Chief, CERC, respectively.

Contracting Officer was COL Dwayne G. Lee, CE, Commander and Director of WES, and Technical Director was Dr. Robert W. Whalin.



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Part I: Introduction

Background

1. This report was prepared under SBIR contract: DACA39-87-C-0032 entitled: Construction of scale model armor units, awarded May 29, 1987. The contract award was made by the Department of the Army, Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. Our work was coordinated with Mr. D. D. Davidson, of the Coastal Engineering Research Center.
2. Our contract as described in this Phase I final report covers new methods and materials to make scale model armor units used by the Waterways Experiment Station for testing and modeling of beach erosion barriers, breakwaters for harbors, and other shore protection structures. Our specific assignment was to develop a suitable method or methods of making scale model units, and to produce 1,500 units each of three different size dolos. The dolos were to weigh 0.30# (136g), 0.51# (232g), and 0.85# (386g).

History

3. Sulfur and sand mixtures have been used to hand cast model armor units in the United States since the mid 1960's (Davidson, 1968)* and in Canada since the early 1970's (Funke and Haines, 1976).** The mixture consisted of concrete cylinder testing

*Davidson, D. D. 1968: "Procedures to Make Molded Armor Units", unpublished. **Funke, E. R. & Haines, S. A., 1976. Production of model armor units for scaled breakwaters," LTR-52, Hydraulics Laboratory, National Research Council of Canada, Ottawa, Canada.

"capping compound" to which various heavy aggregates were added to achieve the desired density. This mixture is potentially flammable when heated to its melting point, toxic vapors are produced and the units require considerable skill in fabrication. Unless heated to a high temperature, the mixture is too viscous to pour well and when overheated the sulfur vaporizes, making it difficult to maintain density requirements. The mixture when cast does not develop high strengths and units can be easily broken in handling.

4. In the 1970's, Public Service Gas and Electric of New Jersey planned construction of an offshore nuclear facility, and had several thousand units hand cast and fabricated from a resin based formula. Hydraulic Research Laboratories of Wallingford, United Kingdom have had units made of ceramic, high density polyethylene plastic filled with glass fiber, and other units that are injection molded of SBA resins.

5. Japanese and French manufacturers have also made injected molded armor units, utilizing various types of filled and unfilled resins. In all cases the injection molded filled samples (to a specified density) are used for testing, while unfilled samples are used for presentation, displays and sales promotion.

6. In the beginning, dolos used in actual construction were usually made of unreinforced concrete. Structural failure (breaking) of dolosse on some projects throughout the world has questioned such practices, and several research facilities are of the opinion that reinforced concrete is required. The density of actual prototype dolosse varies, based upon the type of unit, aggregate, and concrete mix design. In building scale models, it is necessary to accurately scale the specific gravity and weight of the actual unit. Since concrete can range from 2.2 to over 3 in specific gravity, reinforced or not, special heavy weight filler materials are required in the model to achieve this gravity. The resin or binder used in a model is lighter than portland cement and must be compensated for. Aggregate ordinarily used in concrete can not be employed in models as the major component.

7. Sizes of model units are determined by the anticipated full size weight and a sufficient size model scale to avoid scale effects. Model scales for stability studies typically range from 1:20 to 1:60, depending on the actual size of prototype units and wave conditions to be scaled.

8. The sizes of the models to be made under our contract were selected by the technical review board, and were to be 0.30# (136g), 0.51# (232g), and 0.85# (386g). The 0.30# (136g) and

0.85#(386g) units were of 2.34 specific gravity, whereas the 0.51(232g) unit was subsequently changed to 0.42#(191g) with a 2.43 specific gravity.

9. The ability to react quickly to a need for new size units is highly desirable. Patterns, molds, and materials should be readily available and/or obtainable.

Purpose

10. The purpose of the investigation conducted herein is two fold:

First, research and/or develop new methods and materials to produce model armor units that are cost effective to make, safe to produce, durable in use, and that meet specified size, shape and density requirements.

Second, to produce and provide to the sponsor 1200 to 1500 model units each of three different sizes of a specified armor unit shape, weight, and density.

Part II: Research & Development

Approach

11. In preparing our original proposal, we researched methods and materials that appeared to be suitable for making model units, including various plastics, gypsum and portland cement matrixes, inorganic fillers of high density, molding compounds and additives. Methods of manufacture were also explored. We submitted our SBIR proposal, designating a base price for R & D and a fixed price for each of three sizes of units. Units were to be made in quantities of 1200 to 1500 pieces for each size.

12. Our first approach after the contract award was to consider the use of injection molded, machine made units. Molders were interviewed, they wanted to know what type of plastic would be used. We then contacted suppliers to molders, Standard injection, Sheet molding compound(SMC), Reaction injection molding(RIM) and Bulk molding compound(BMC) material suppliers. We spent many days on the telephone, interviewing manufactures of basic materials to try and find materials that could be easily fabricated into the dolos shape. The dolos shape and configuration is difficult to manufacture, it has a large cross sectional area, requires very close attention not only to dimension but also specific gravity and total weight per part.

13. In all cases where machine molding is to be used, extensive and expensive dies and molds are required. We then decided to try and find other methods that did not require expensive dies and procedures. Casting was considered, and suppliers and fabricators were interviewed.

14. The results of our surveys indicated that casting units, with a resin system, would be the most cost effective. This was based upon fabricating 1,500 pieces per size and specific gravity. We had interviewed over 300 manufacturers, suppliers, fabricators and other people, visited over 30 plants, shops and offices. A complete literature search was also conducted. If we could have justified the cost, several methods, including the ones mentioned above utilizing injection molding would be ideal. If one could standardize on several different sizes of units, and produce thousands of these for more than one lab, then the cost per piece and delivery time would be greatly improved.

15. Hand casting with a polyester resin system was finally chosen as the method to be used. Even though presently we are casting resin units, we are still investigating new ways of making these units, and have recently discovered another process that will be the subject of a report at a later date.

16. We divided our physical R & D procedures into two parts. materials and methods of fabrication.

Materials

17. Pattern Materials:

1. Aluminum
2. Acrylic
3. Gypsum plaster
4. Wood
5. Bronze
6. Steel

We investigated the use of acrylic plastics and wood for making patterns. they were too soft and easily chipped. Plaster is acceptable for making second generation patterns(patterns used to make sand or other intermediate castings for molds). Aluminum was finally chosen as the appropriate material. Steel and bronze were judged too difficult to work and use and were not tried. In the future. bronze will be considered. since it does not nick and dent as easily as aluminum. The constant handling of patterns. storage on shelves. can cause them to acquire many small nicks.

18. Mold Materials:

1. Silicone
2. Polyurethane
3. Epoxy
4. Aluminum
6. Latex
7. Chemically bonded cement or CBC.

Silicone rubber was the material of choice for several reasons. Silicones are expensive in material cost, however one can expect to get up to 30 or more uses per mold, and the molds are fairly resistant to heat and polyester materials, the resin we were using. Epoxy compounds have a degrading effect, and will often migrate into the mold, causing difficulty in release. Epoxy and polyurethanes are used for some mold units, however the polyester resin system that we have chosen to work with lends itself to silicones. The mold material must be resistant to shrinkage, rigid enough to accurately reproduce the parts, yet soft enough to easily demold.

19. Aluminum molds were investigated. In order to be cost effective, several cavities are required for an aluminum mold. The initial high costs of making multiple patterns for a several cavity mold were prohibitive.

20. Latex was not used because of its softness. It is suitable for reproducing parts where great detail is required, and many undercuts are present.

21. While researching mold materials, a promising one appeared to be the use of chemically bonded cement (CBC.) We made several trips to Maryland, furnishing patterns for molds to the leading supplier. It appeared that we might have found a solution when we were advised that our use was not that important to them and no further work would be done.

22. Model Armor Unit Materials:

a. Base material-castable

1. Epoxy
2. Polyester
3. Polyurethane
4. Portland cement
5. Chemically bonded cement(CBC)
6. Gypsum

b. Fillers and modifiers

1. Calcium carbonate
2. Metallic powders
 - a. Bronze alloy
 - b. Iron ore and powder

c. Lead

3. Barytes
4. Zircon sands
5. Silica sands
6. Titanox(titanium Dioxide)
7. Trap or basalt rock
8. Silica Fume
 - a. Cabosil PTR

23. Polyester was chosen to be the material for making units after we had extensively investigated epoxy, polyurethane and portland cement matrixes. We needed a material that would be capable of recreating the dimensional accuracy of the master pattern, have a short pot life and rapid cure rate, would not require a heat cure, and could be easily mixed with simple equipment.

24. Portland cement was tried, however even with accelerators, the set up time was too long and we could not reduce the moisture adsorption. Epoxies and polyurethanes require heat to set the cure, have a higher exotherm and are aggressive against molds.

25. Gypsum was tried in two types of molds. When cast into a silicone mold, the results were good. In metal or other rigid molds, disaster. Gypsum expands enough to prevent it from releasing, and we were forced to chop out the material. Portland cement is easy to work with, it does not expand, rather it shrinks and lends itself to most mold materials. The use of a proper mold release is most important with any of these materials. Both materials absorb too much water, and at present we have not been able to find an additive to reduce the water absorption. Several commercial formulas of latex and other additives were tried, without success. CBC is described elsewhere, it was not tried beyond making several pieces. Gypsum was too water adsorbent, the best that we could obtain with selected additives was 15% water gain.

26. Fillers were tried in many combinations, the best were calcium carbonate and metallic powders. The object is to balance the ratios to obtain a mixture that will be pourable and obtain the required specific gravity. The mix must not separate out while it is being poured. Lead, while it is frequently used in rubber and plastic compounding, was too toxic to use in this application. Titanox was tried, as was barytes, both heavy weight filler materials that increased the viscosity of the mix to a point where it was impossible to pour.

27. Zircons, sands and basalt materials were all tried as fillers and it was decided that commercial fillers of known purity and weight were more reliable. The rock and mineral sands varied in density and weight, this made it impossible to accurately determine the density and gravity.

28. Cab-O-Sil is usually required in very small amounts to slow the settling rates of the heavier fillers. Too much, over 5%, will increase the viscosity to a point where the material is too thick to pour.

Methods of fabrication

28. Types of Fabrication:

Casting:

1. Hand mix and casting
2. Machine mix and hand cast

Machine molding methods:

1. Injection molding
2. SMC
3. BMC
4. Induction molding
5. RIM

30. Casting: Casting can be accomplished by hand or machine mixing. In machine mixing, a proportioning pump dispenses the correct ratio of catalyst to resin, and fillers are added in the mix stream. The equipment is quite expensive. Machines cost from \$20,000 to \$95,000, are not easy to clean, and unless available for other work, it is not cost effective for the number of units we required. Even when available, the waste of setting up and cleaning out pistons and related machinery for small runs of 1,500 units is not worth it.

31. We opted for hand mixing and to weigh each major component individually, then mix each batch in small cups. Even using this procedure, errors were frequently made by the technicians. Units tended to be either under or over weight.

32. Frequently vacuum or pressure is used to control the density and porosity of units. Units are cast, then immediately placed in a chamber. Under pressure, the size of air bubbles are decreased, and smoother finishes result.

33. Machine Molding Methods: The plastic molding business requires several textbooks to cover all the different ways that components can be made. The various processes listed above are all covered in standard texts on plastic fabrication. Our requirements for 1,500 units of a size were not sufficient to allow

the use of any automated equipment. Die. setup, mixing costs preclude the use of this technology. Ten thousand or more units would be cost effective, and could be made by any one of several processes. We investigated the use of various "low cost" dies. none were low enough in cost to permit their use.

Fabricators:

34. Types of Fabricators:

1. casters
2. model makers\prototype shops
3. Plastic injection molders

Casting shops are generally small operations(5 to 20 people) that produce cold cast units utilizing various polyurethane, polyester and epoxy mixes. The term "cold cast" is used to differentiate between a foundry using hot metal, casting in bronze and other metals, and cold casters, who use powdered bronze in a resin mixture.

35. Many model and prototype shops do casting, however they are accustomed to doing one or two units at a time, and generally their operations cannot handle production runs at a competitive cost. Plastic injection molders come in all shapes and sizes.

shops are numerous. and some specialty fabricators work with a limited range of materials. Most shops will mold several types of resin.

Part III: Procedures For Making Model Armor Units

How To Make Patterns:

36. We developed techniques to machine the aluminum to very close tolerances. We used standard milling machines and shop equipment, and then developed procedures and methods of assembling the various pieces into a finished dolos. By making the dolos in three pieces, the waist and two arms, we could maintain accuracy in the slope and thickness. We then machined out each end of the waist and bolted the two arms to it through the ends. By placing shims in the space, we could adjust the overall length.

37. Fillets were added as required, using epoxy filled with inorganic material. Some epoxies are not compatible with silicones. Care should be exercised when making the fillets, otherwise the silicone will not set up where it contacts the epoxy. This occurred even where mold release agents were used.

How To Make Molds:

38. It is very important that all molds be prepared by a professional mold maker. Molds are made by suspending the pattern in a form, then pouring in silicone till the material reaches a point that has been selected for a break or jointing line. After the first part is allowed to cure, the mold frame is inverted, and the second half is poured. Suitable indentations and locking keys must be made in the two halves so that the mold will align properly.

39. The molds must be carefully designed to part at a natural joint or edge line. This reduces the amount of finishing work required. Ideally, the units should be capable of being demolded without any need for finishing along the parting line. The sprue or pour hole is ground off after the units are demolded.

40. Each mold should be marked with an identifying mark that will reproduce on the part to be made. We use a small "dot" drilled into the mold. We start with none for the first mold and work our way up. The dots do not need to be any larger than 1/32" in diameter. At least five and preferably 10 molds are required. After the molds are marked, they are coated with a mold release and brought to a uniform temperature before casting starts.

Casting Of Units:

41. The components are weighed into separate measuring cups or containers. Twenty five or more are weighed and set out at a time. the resin is added to the filler mix. stirred and poured. Vacuum or pressure can then be used to eliminate as much air as possible. Normally the setup or gel time is two to three minutes. Immediately after gelling, the units are demolded and placed aside to cure. Frequently, the exothermic cure reaction will generate considerable heat. the units becoming too hot to handle. We are investigating whether the units should be constrained in a mold at this time. or if air curing is satisfactory. Preliminary results would seem to indicate that it is at this time that a change in volume or density occurs.

Part IV: Production of Model Units

SIZES

42. The final units were to be of three sizes and one type as shown below:

| <u>TYPE UNIT</u> | <u>WEIGHT</u> | | <u>Specific Gravity</u> | <u>Sp. Weight</u> |
|------------------|---------------|-------|-------------------------|-------------------|
| | lb. | grams | | |
| Dolos | 0.30 | 136 | 2.343 | 146.25 |
| " | *0.51 | 232 | 2.343 | 146.25 |
| " | 0.85 | 386 | 2.343 | 146.25 |

* A subsequent request changed the middle size dolos to 0.42lb. (191g) with a specific gravity of 2.46 (153.5 lb./cubic foot).

We were to produce 1,500 of each size unit, for a total of 4,500.

The original request for proposals called for 18,000 units, with several different sizes and weights to be furnished after contract award. Our Phase II grant request addresses the remainder of units.

43. Our preliminary literature research at proposal time indicated that units were typically 0.25 to 1 pound in size. Since we did not know what tolerances of dimension, weight, and specific gravity would be required, and in the original request for proposals none were given, we based our proposal on the following: All tolerances to be plus or minus 2% of the indicated values. In addition, we grouped our pricing into three areas, covering the above range of weights.

Quality Control

44. After casting, each unit was given a number, usually with a permanent marker. Then it was weighed in air, marked with its weight and then weighed in water. The date of manufacture, mold number, weights and values were entered on a spread sheet in our computer. From this data the specific gravity, tolerance and acceptability was determined. We were also able to run various quality and production controls with this system. This is a time consuming procedure, however we felt that it was necessary to insure that all units were within the tolerances. After the units were weighed, and before shipment, an additional sampling and random testing program was run. Samples were taken at random from the various production runs, usually at least 8% and sometimes more if the batches were under 30 pieces. These samples

were checked for dimensional tolerance, given a break test that we had devised (this consisted of dropping a unit from a predetermined height onto a concrete floor). Normally units could withstand at least an 18 inch drop without breaking. Then one half of the sample batch were again checked for weight in air and water. When we shipped units, we were confident that they were within tolerance. Since we now have a permanent record of each unit, the weathering and performance can be checked at any time.

Problems Encountered:

45. We produced patterns, made molds and began to make model armor units. Units were cast from a proprietary mixture of polyester resin, bronze powder and other fillers. The units were then delivered to WES for evaluation. After performing various measurements based on the values given in the Coastal Engineering Handbook, "Shore Protection Manual (1984)",* WES advised us that the units were 3.0% low in volume. We made new patterns, molds and cast new units.

46. The dolos dimensions used by WES are all related to the overall dimension of a dolos leg, "C", (Figure 7-112, Shore Protection Manual, 1984).²

* Shore Protection Manual, 1984, 4th ed. 2 vol., US Army Engineer Waterways Experiment Sta., Coastal Engineering Research Center, US Govt. Printing Off., Wash. DC

The volume is determined by multiplying "C" cube by a factor of 0.16. After making many new samples, checking dimensions and weights, and spending over two extra months, we discovered that the 0.16 factor was not sufficiently accurate to base volume/dimension relationships and stay within the ± 2 by weight and the ± 1 percent by specific gravity specified for the model units.

47. To the best of our knowledge, this factor of 0.16 had been rounded in the literature for prototype use and is probably still sufficiently accurate for that use, but it is not accurate enough to calculate volume/dimensions relations in our scale models. This in turn effects the weight/specific gravity tolerances. Since the dimensions of patterns, molds and finished pieces were on the order of accuracy of 0.005", WES rechecked the literature (Lillevang and Nichols, 1976)* and found the original factor to be 0.155. Using this new value our units were very close to the anticipated volume.

48. This additional work to prove the formula wrong for the tolerances given added well over two months and considerable cost to our contract. We have since run many more tests, and all things considered, we believe that the factor should probably be closer to 0.153. Since "C" is cubed in the equation, any error³

* Lillevang, O. J. and Nichols, W.E., 1976. "Experimental Studies of Stresses Within The Breakwater Armor Piece" Dolos", Proceeding of the 15th Coastal Engineering Conference, ASCE.

is multiplied by three. We are pleased that our techniques, patterns, modeling, casting have been able to produce units this accurate.

49. We then proceeded to cast prototype units. Due to the change in the constant from 0.16 to 0.155, as described above, weight and specific gravity requirements were recalculated, according to change in volume.

Part V: Conclusions, Recommendations And Comments

Conclusions

50. The results of our SBIR Research and Development Phase 1 contract have been successful. We do however, need more experience in fabricating additional sizes and shapes of breakwater units to develop our costing and fabrication techniques. We expect to acquire this in our Phase 11 contract.

51. It is highly desirable to remove as many variables as possible from the fabrication process. Technique has a lot to do with the quality of units. In our initial work, we were able to achieve close tolerances when the work was done by the principal investigator and an experienced caster. When we moved the operation to the production line, the rejection rate dramatically increased to over 50%. By analysis of the techniques used by workers, and in some cases replacing them, we achieved a rejection rate of 35%, then finally 10%. The rejection rate can increase for no apparent reason, and in several cases we personally spent full days working on producing pieces, only to have the rejection rate increase to over 50% again. We have tried to simplify the molding process, if we are to continue the work, a new approach will be taken.

Recommendations

52. We are applying for a Phase II grant request and recommend that it be funded. We are also going to solicit other Government Agencies and civilian organizations for scale model work, based upon the limited experience we have acquired in performing our Phase I contract. One quotation has already been tendered, to the National Research Council in Canada. Arrangements have been made to display our product line at "Breakwaters 88" in England in May 1988.

53. The new recommended approach will be to make aluminum molds and cast all units under vacuum, using a large chamber that can handle several units at once. The cost of this chamber should be more than offset by the low rejection rate of Phase II. We will try to eliminate as many variables as possible under this new concept. It is a question of technique and personal feel for the molding process. In some cases, we question whether temperature and humidity are also involved.

Commentary:

54. The injection molders we spoke to and visited wanted information on the material we were going to use, before they would commit themselves. We spent considerable time talking to basic material suppliers. Large petrochemical companies advertise their ability to solve molding problems. however, after talking to them. the first question was. "How many tank cars of product do you want?" Even on a pilot plant or sample order basis. all of the large companies we contacted told us that our specific requirements for density precluded their making it. The equipment would have to be specially cleaned of heavy aggregate and the cleaning alone would use up at least as much material as our orders.

55. At the time of our original proposal preparation. we had discussed our requirements with several castable plastic suppliers and 2 small molders(prototype shops.) I was assured at that time that materials, processes and people capable of fabricating units were not a problem. This was not so. After considerable effort one caster was located who claimed to have

the expertise to fabricate units requiring the dimensional tolerances and alleged quality control we needed. He was booked for production capacity until January or later in 1988.

56. It's amazing how things change when one starts asking for cost effective performance and on-time delivery, be it a suitable plastic, metal, raw material or product. Incompetent salesmen and in some cases so called technical advisors constantly wasted our time. Time after time we would receive a beautiful brochure and then a telephone call, followed by a personal visit from the sales department. "No problem was the typical assurance." They extolled the wonderful properties of \$10 to \$18 per pound plastics or other materials when we were looking for plain, under \$1.00 a pound material. Especially when we described it as a Government order, "oh you could make your dolos from the same materials as used in torpedo nose cones, or even of space age composites (slightly higher in price of course.)" When I explained that we wanted a reasonable quantity of VALUE ENGINEERED material or product, the next question was, "Can I use your telephone to call my lab?" The final answer usually was "we don't make it."

57. In trying to make patterns, we ran into a blank wall more than once. people were trying to sell us the services of their CNC, CAD, or automatic profilers. We finally found a small shop, sat down with the owner one night, and with pencil and

paper worked our way through the angles and lengths required. The cost was one -tenth of what the other quotes were. This was the same frustrating procedure that we went through in trying to obtain mold materials, fabricators and even shipping, where vendors wanted to sell us custom molded individual containers to ship the dolos in. We eventually shipped them loose in plain boxes, with plastic bubble filler, and to date none have arrived in Mississippi broken.

58. We of course had only one problem; we had committed ourselves beforehand to a fixed price. This was based upon our cost studies prior to submitting our original proposal. This did present some major problems, especially since the cost of copper, a major component of the units, had more than doubled in price. Without the fixed price, the problem didn't exist. We finally found the solutions. All it took was a lot of hard work, calling people, following up on leads, developing new techniques and modifying existing procedures.

59. Since the Principal Investigator is a practicing Value Engineer/Analyst, we applied the basic practice and techniques of Value Engineering and were able to achieve our goals. It required considerable time and effort, however this resulted in a perfect, successful exercise.

60. After working for 35 years in industry (and with information and technology supposedly expanding) I am amazed that our sales and technical assistance levels of competence in product knowledge are dropping, rather than increasing. A large part of our time was spent on the telephone or in person interviewing people and trying to locate materials and services. In all of the contacts that I made (over 300), I found, at most, 15 people who could give me not only correct answers but direction and solid guidance. Most of the information and especially referrals were useless.

