CHAPTER 80

ARTIFICIAL NOURISHMENT OF COPACABANA BEACH

By Daniel Vera-Cruz
Civil Engineer, Research Officer, Laboratório
Nacional de Engenharia Civil, Lisboa, Portugal

ABSTRACT

Results concerning the artificial nourishment of Copacabana Beach (Brazil) with sand are described. The beach, 4.2 km long, was formerly about 55 m wide. After an artificial nourishment with 3.5 million c.m. of sand, a mean width of about 140 m was reached. From that total of sand, 2.0 million c.m. were dumped offshore and the remaining amount stockpiled on the foreshore. Prototype and model results agree quite well. Comments are made on the efficacy of the offshore dumping method and recommendations concerning its use in future cases are presented.

INTRODUCTION

Different methods have been used in artificial nourishment of beaches, namely stockpiling, continuous supply and direct placement. Another method was tried in the past, the offshore dumping, which in many cases makes a large supply of beach material available at low cost, when hopper dredges are used. This is particularly true when feeding material comes from maintenance operations of harbors. Results of past experience of this method, however, were not encouraging. One can say, with J.V.HALL Jr. and George WATTS [1], that those results were negative.

The purpose of this paper is to present a practical case where the offshore dumping method was used with full success in the widening of Copacabana Beach (Brazil).

BRIEF HISTORY

Copacabana Beach is a sandy beach located in the west coast of Brazil, very near Rio de Janeiro, Fig. 1.

Its shape in plan is like a crescent, its length is around 4.2 km and its mean normal width formerly was about 55 m, Fig. 2.

For various reasons, SURSAN - Superintendência de Urbanização e Saneamento do Estado de Guanabara, Brazil, decided to widen the beach from the original mean width of 55 m to about 140 m.

The necessary studies to prove the feasibility of the project were ascribed to LNEC - Laboratório Nacional de Engenharia Civil, in Lisbon, Portugal. A field observation program was prepared and data collected along two years. The analysis of those data allowed to characterize the behavior of the beach and to explain its shape fluctuations. Based on the conclusions of that analysis, a small-scale model was designed, calibrated and run.

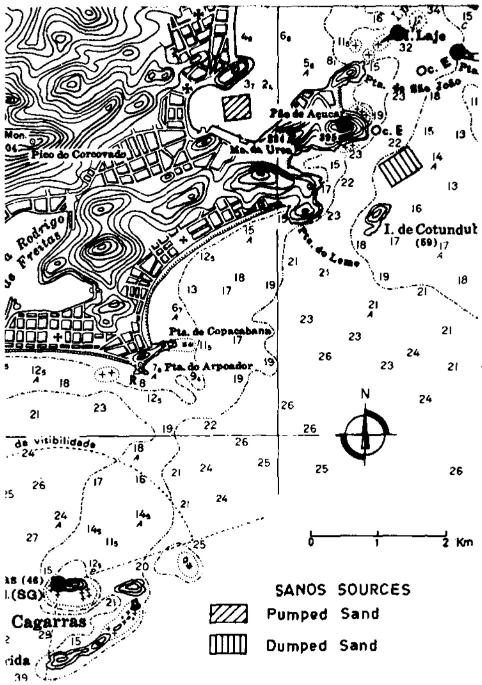

FIG. 1 - Location of Copacabana. Sources of Sand.

BEACH DATA

The field observation program included [2]:

a) Waves

Heights, periods and directions were observed twice a day. The observed values during two years allowed the definition of the local gravity wave regime as follows, summarily:

Heights: 90 % of the significant waves fall below 1.8 m and 50 % below 0.7 m; the highest significant observed height did not reach

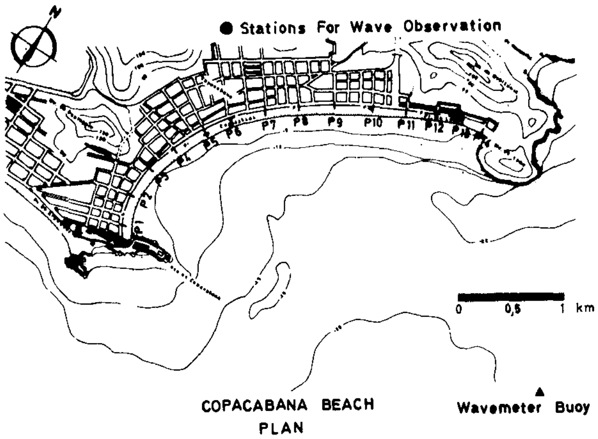

FIG. 2 Location of Surveyed Profiles

4.0 m; in 12 observations the significant height was above 3.0 m; the heights were measured at a depth around 20 m contour;

Periods: 70 % of the mean wave periods were between 9 s and 15 s and 50 % between 10 s and 14 s.

Directions: Wave directions before breaking were concentrated around S-SE. In 70 % of the observations, wave directions were between S-20^{o}-E and S-25^{o}-E.

b) Surveys

A general hydrographic survey in scale 1/2000 was done down to depths around 20 m. During two years 14 cross profiles (Fig. 2) of the shore were plotted every 15 days. When important changes occurred, the cross profiles were extended down to depths of about 10 m.

c) Tides

The tides are of the semi-diurnal type. The tidal ranges are of small amplitude: maximum of about 1.4 m and minimum of about 0.3 m.

d) Sand characteristics

Samples were collected once a month at the mean sea level at sites corresponding to the cross profiles alignments. A first general collecting was done at different levels from shore to offshore. Mineral analysis did not show significant variations. The sand, of which the unit weight was 2.6 gr/c.c., was fine to medium: median diameter from 180μ to 420μ. The prevailing median diameter at mean sea level was 300 μ to 400 μ .

FIG. 3 - Effects of Storm Waves

e) Wind

High velocity winds are not usual. Winds blowing at as much as 40 knots are very infrequent and of very short duration. Usually the maximum speed with significant frequency falls between 20 and 30 knots. Winds blow more frequently from WSW, W, WNW and ESE. This last direction is able to generate some local sea in Copacabana.

MAIN RESULTS OF DATA INTERPRETATION

The analysis of the fluctuations of the cross profiles led to the conclusion that cross movements of sand are very important and that there is not a predominant littoral drift direction. Considering the HWL the surveys revealed recession of about 30 m or more by storm waves. Relating profiles changes with wave condition, the general conclusion is that in Copacabana waves higher than 2 m tend to cause recession and that lower waves tend to rebuild the beach until the equilibrium shape is reestablished. Large recessions are recorded with one day storm duration, while it takes some weeks or even a few months to rebuild the beach.

Although recession is simultaneous all along the beach, some stretches are more vulnerable than others. In fact, the shore can in some points be completely washed out, causing the waves to bump a wall which borders an avenue running along the beach. Fig 3 shows the beach during a storm, and one can see the waves arriving at the bordering wall along a certain stretch.

Storm waves originate sand movements at levels lower than (-10 m). At this level, depth fluctuations before and after storm sometimes reach 2 m.

THE CALIBRATION OF THE MODEL

The model was built with horizontal scale 1/300 and vertical scale 1/75. The sand was represented by crushed bakelite.

The model project was based on VALEMBOIS criterion [3]. The first stage of the calibration of the model consisted in reproducing an equilibrium shape of the beach similar to the prototype, for normal wave condition. During this stage, a few alterations were introduced in the model limits, to correct wave reflection and diffraction patterns. Such corrections derived mainly from the fact that, in order to respect wave refraction, the wave lengths were reproduced according to the vertical scale. The second stage consisted in trying to reproduce erosion in the model by storm waves. The model behavior at this stage was most satisfactory, the beach being more eroded in the model at points corresponding to the more vulnerable areas in the prototype.

The third stage consisted in, after a storm, reproducing again the normal conditions, which were expected to rebuild the beach. Again the model behavior was very satisfactory.

At this point the model was considered as calibrated and the next phase, artificial nourishment, started.

ASSUMPTIONS ON THE BEHAVIOR OF THE BEACH WHEN NOURISHED

As no predominant littoral drift existed, the cross movements of the beach being important and the general shape in plan being a crescent in any stage, this shape was considered as being the equilibrium shape for the natural agents prevailing on the beach.

According to such an assumption, if stockpiles of sand were distributed along the beach or, on the extreme case, if sand were stockpiled in a restricted area on the foreshore, the stockpiles should be acted on by the waves and the sand carried in such a way as to preserve the crescent shape of the beach. Moreover, while sand losses around the rocky arms delimiting the beach do not occur, a certain widening, depending on the sand volume stockpiled, must result.

The first runs of the model were based on such assumptions.

ARTIFICIAL NOURISHMENT IN THE MODEL

General description

Two main nourishment methods were tested: stockpiling on the foreshore, and offshore dumping. Both methods were tested either separately or jointly. When jointly applied, a mixed method results. Two different mixed methods were tested: the non-programmed method and the programmed one.

Stockpiling method

This method was used in two ways. First, in the distributed way, bakelite was stockpiled at regular time intervals at four different points more or less equidistant (3 m in the model). Simultaneously, 1 liter of bakelite was unloaded each 20 min in points P-3, P-6, P-9 and P-12 (Fig. 2). Second, in the concentrated way, 10 litres of bakelite were stockpiled each 20 min over the foreshore stretch between P-11 and P-12.

Offshore dumping

In this method 4 litres of bakelite were unloaded every 20 minutes along the model contour corresponding to -5 m in the prototype, taking into account that the loaded draught of the hopper to be used was ~ 6 metres.

Mixed methods

Non-programmed

In the non-programmed method both previous basic methods - stockpiling and offshore dumping - were used simultaneously, in a random way. In this way, the same beach stretch could be nourished at the same time by both methods.

Programmed

The programmed method avoided to nourish simulteaneously the same area of the beach by both methods. Stockpiles took place in points P-3, P-6, P-9 and P-12; however, those points were not fed at the same time. In fact, stockpiling took place only at two of those points each time, while offshore dumping occurred on areas far away from the areas receiving stockpiles. From time to time the method being used in a certain stretch was changed in such a way that the interference of the other method could be considered negligible.

Model study results

The model behavior confirmed the assumptions made. In fact, using the stockpiling method, either in 4 points or on a limited stretch of the foreshore, the material was carried by the waves in such a way that the final plan shape of the beach was similar to the original shape. It must be said also that the model beach cross sections agreed well with the natural beach cross sections.

The concentrated stockpiling [2] was tested with the main aim of confirming the general assumption on the beach material distribution by waves and it could be proved that, although slowly, the bakelite was carried all along the beach until final equilibrium shape was reached.

The model tests showed that the offshore dumping, although displaying more material losses and taking more time than the stockpiling, was efficient. In fact, referring to the mean widening of the beach at +1.1 m level (HWL), the necessary volume of sand to get an enlargement of 85 m would be, according to the model, as follows:

Stockpiles in four points: 2.5×10^6 c.m.
Offshore dumping : 4.0×10^6 c.m.

To reach that enlargement, it was enough to run the model for 30 hours, with the stockpiling method, and for 60 hours with offshore dumping. Later on, based on further model results and on practical consirations, a new approach was made concerning the total stockpiled volume, which was estimated at 3×10^6 c.m. With the mixed method it was expected that a volume between 3×10^6 c.m. and 4×10^6 c.m. would be enough. However, with the non-programmed mixed method a total volume of sand of 4.4×10^6 c.m. was necessary, with a model running time of 53 hours [4]. In that total volume, 2.4×10^6 c.m. were stockpiled and 2.0×10^6 c.m. were dumped. This fact was explained as resulting from an inconvenient interference of the two methods, the falling of the stockpiled sand to deep levels counteracting the climbing of the dumped sand to high levels.

In trying to prove this explanation, the programmed mixed method was tested. The 85 m mean widening was reached stockpiling 1.5×10^6 c.m. and dumping 2.0×10^6 c.m., total of 3.5×10^6 c.m. of sand. This result is considered as a proof of the inconvenient interference of the two methods when used simultaneously in a non-programed way [5].

RECOMMENDATIONS BASED ON MODEL TESTS

Although, according to model tests results, offshore dumping proved to be efficient, those results should be accepted with caution, considering past experience. On the other hand, the fact that dumping sand was much cheaper than stockpiling was a temptation.

Weighing these and other aspects of the problem, a compromise solution was proposed by the Laboratório Nacional de Engenharia Civil: the beach nourishment should start with offshore dumping, not more than half the anticipated total volume of sand should be dumped and stockpiling should start after the dumping operation was over and maintained until the desired final width was reached.

The sand to be used should fulfill specifications particularly as regards mean diameter and percentage of very fine grains. The mean diameter should be not less than that on the natural beach sand and the maximum percentage of fine grains was established according to the size distribution of the natural beach sand.

On this basis, a total volume of sand was estimated around $3.5 \times \times 10^6$ c.m. to reach the final width.

FIELD OPERATIONS PROGRAM

General

The Laboratory recommendations could not be entirely accomplished in the field program, first of all owing to the short time in which the work had to be done and also because the hopper dredge started dumping a couple of months out of schedule.

The final program had to fit the new circumstances and, according to them, the field nourishment started with the stockpiling method at the end of Oct. 1969 and was completed at the beginning of May 70. During this time 1.5×10^6 c.m. of sand was stockpiled in 6 different points of the beach.

The hopper started dumping at the end of Dec. 69 and stopped by the middle of Apr. 70, delivering 2×10^6 c.m. It is to be noticed that stockpiled and dumped sand volumes are the same which were used in the programmed mixed method in the model. In the field works an effort was made to program the sand nourishment as much as possible according to the model program. This was not entirely possible, because the hopper operation started too late. On account of that and because the hopper output was greater than that of the stockpiling method, some areas of the beach were sometimes nourished by both methods simultaneously.

Some details on dredging operations

The stockpiled sand came from a protected bay, Fig. 1, pumped by two cutter suction dredges with 24" delivery pipes. The total length of pipes was around 5 km. The estimated monthly production of sand was 315000 c.m. and the average solid-liquid mixture was supposed to contain about 15 % of sand with mean diameter equal to 300 mic.. The water depth on the dredging area was around 13 m. The power calculation to attend those requirements recommended the installation of two floating booster stations of 24" and one 20" booster on shore [6]. To obtain greater flexibility in the dredging operations, the two parallel lines

FIG. 4 - The Dredge dumping Sand

of pipes were connected in X, so that any of the two dredges could pump to any of the discharge points. The actual percentage of solids in the solid-liquid mixture was about 12.5 %. During the operation the 500 m floating pipeline was occasionally damaged by wave action, resulting breaking of ball-joints and collars. Also the spud of one of the dredges was once broken by wave action.

The sand dumped on the offshore (between -4.0 m and -6.0 m contours) was carried by a hopper which dredged in the open sea at depths about 10 to 15 m, about 4.5 km away from the center of Copacabana Beach, Fig. 1. The hopper had the following characteristics:

Overall length : 95 m

Beam	:	16 m
Loaded draught	:	6 m
Hopper capacity	:	3,000 c.m.
Suction tubes	:	32"
Dredging pumps	:	2 number-driven by 2x800 h.p engines

The hopper pecullarity consisted of gates sliding on the flat bottom of the hopper. This allowed opening of the gates even when the stem touched the sea bottom. In fact, the hopper approached the beach until touching the bottom. At this moment the foregates were opened, the fore draught decreased and the ship could go a little more ahead. This operation continued until the stern gate was opened and the discharge finished. Fig. 4 shows the hopper in operation.

The normal output for the hopper varied between 15.000 and 25.000 c.m. a day. The rate of discharge was about one discharge each two and a half hours.

Sand samples taken during the works showed that the mean diameter of the stockpiled sand was around 300μ . The hopper sand had a mean diameter greater than 400 μ and frequently greater than 500μ . Only in a few samples was the percentage of fine sediment more than that allowed. On the whole, the new sand is coarser than the previous one.

BEACH BEHAVIOR DURING AND AFTER NOURISHMENT

The 14 profiles located as shown in Fig. 2 were surveyed to observe the beach behavior before, during and after the artificial nourishment.

The beach width referred to the +1.1 m level (HWL).

The initial mean width in each profile was computed as the average of 20 surveys made during the last 10 months which preceded the sand nourishment. The net widening in each profile, during and after the nourishment referred to the former mean width.

The mean widening of the beach is defined as the average of the measured widenings in the 14 profiles. The mean widening in a stretch of the beach is defined as the average of the measured widenings in the profiles included in that stretch. As a similar criterion was adopted during the model tests, the comparison between model and field behavior was very easy. During the works, a few surveys were run along each profile down to depths around the -10 m contour.

Sand samples were taken, either from the hopper dredge, or from pumping pipes, or from points at MWL along the beach, and size distribution plotted.

All the field control program was performed by the Technical Department of SURSAN.

Unfortunately, wave heigth measurement could not be done during the beach nourishment.

In Fig. 5, mean beach widenings according to model study and to field surveys are plotted. Graphs M-1, M-2 and M-3 refer to the model and graph P to the prototype. To plot graphs M-1 and M-2, the sand volumes discharged along the time by the dredge or stockpiled on the foreshore, respectively, were considered; graph M-3 results from adding M-1 and M-2. In plotting M-3, two weeks were assigned to the offshore dumping, concerning its contribution to the foreshore widening. This time lag cannot be proved, since it results from scare indications of field observations of very difficult interpretation.

One can see that the mean beach widening in the prototype exceeds, in the first months, what was expected from the model. This may be a consequence of the exceptionally low waves prevailing during the first 3 months following the beginning of stockpiling. In fact, during that time, only from 10 to 12 Jan are high waves reported, buy it was estimated that they did not reach 2 m.

A decreasing of beach width starts at the middle of March, when the theoretical graph M-3 was very close to the actual one, P. Such decreasing of the beach width is closely associated with wave heights. In fact, after a long period of very low waves, high waves appeared in the first days of Mar., rough sea persisted practically throughout that month, with very high waves being reported from the 25th to the 28th, when the maximum wave height was estimated around 3.5 m. Although sand nourishment was maintained - except the hopper operation which underwent interruptions of a few days in the whole - the mean width of the beach decreased by 15 m during that month. Once the rough sea was over, beach re-formation started and at the end of April, when sand nourishment finished, the beach width had surpassed its previous maximum. By the end of May and, later on, during the last days of Jun and the first days of Jul., new recessions were caused by heavy sea, with subsequent re-formation in both cases. It is to be noticed that beach width at the end of each re-formation phase is always larger than it was at the end of similar phases that had occurred before. This is also true throughout the months following the end of offshore dumping (middle of Apr.) and the end of foreshore stockpiling (beginning of May.). In fact, in spite of alternating recession and re-formation, the evolution of the beach shows a clear trend for increasing widths from May to Oct. The mean net widening in that period was about 15 m. During Oct. and Nov. 1971 the beach seems to have reached its final stage of evolution, with mean widening varying between 85 m and 90 m. The trend showed by the beach for increasing width after the last nourishment operation is considered as a strong confirmation of the contribution of dumped sand for the foreshore widening. Two other factors reinforce this opinion. First, the practically exact prediction by the model concerning the total amount of sand to be used in order to reach the desired width; second, the fact that sand size distributions tend to show an increase of the median diameter compared with the sand existing before nourishment. This is only possible by an important contribution of the material dumped offshore, coarser than the original sand, since the sand stockpiled on the foreshore was slightly finer or at least not coarser than the sand formerly existing.

Fig. 5 still shows mean widening variations of different stretches of the beach. Except as regards the stretch between profiles P-1 and P-3, the fluctuations observed in the other ones closely agree with the fluctuations of the whole beach, which is considered as supporting the criterion adopted for observing the beach evolution.

The singular behavior of the stretch from P-1 to P-3, characterized by a much slower evolution, is firstly explained by the exceptional location of that stretch, where the wave pattern is influenced by diffraction around the rocky spit. This limitation was pointed out in the model study report, which says that, wave diffraction similitude not being reproduced in the model, the results of the tests concerning that corner should be considered with reserve. Besides, no important nourishment was made directly in that stretch, either in the offshore, or on the foreshore. The dredge could not aproach close enough, because the bottom is too flat there; the pipes could not be extended so far, for physical reasons. And, as that stretch of the beach is the one where wave action is the slightest, the sand artificially placed on other areas of the beach takes much longer to come into that corner, by a natural process.

The comparison of Fig. 6 which shows the original beach and Fig.7 which shows the new beach one year after starting artificial nourishment, gives an idea of the work done during that period of time.

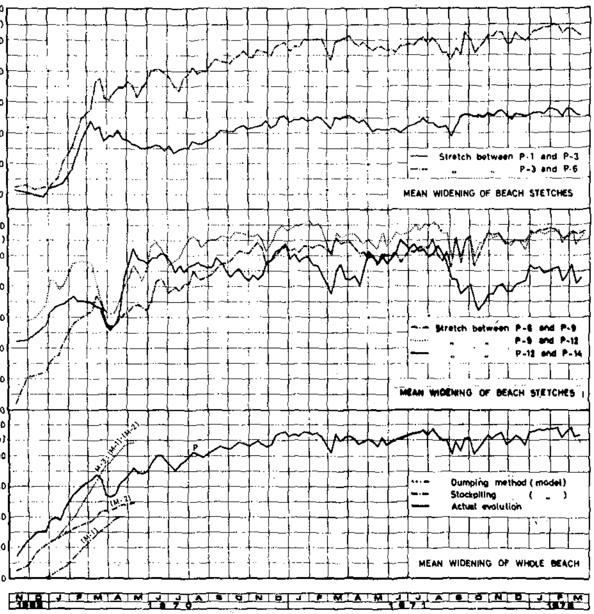

FIG. 5 - Beach Evolution during and after Nourishment

CONCLUSION

The good results obtained in the widening of Copacabana Beach (Brazil) by artificial nourishment of sand, stockpiled on the foreshore and dumped offshore, confirmed the predictions based on the results of a hydraulic model study, specifically run for that purpose. Such a practical success of the offshore dumping method will open new possibilities for its use in similar works in the future.

The use of offshore dumping, however, should result from the analysis of the specific conditions in each case. Knowledge of the coastal history and its correlation with natural agents is of prime importance.

FIG. 6 - View of the Beach before Nourishment

While more experience is not achieved on the offshore dumping method, it is advisable to use it in combination with other methods whose efficacy is already well controlled.

ACKNOWLEDGMENTS

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The Memory of Mr.J.V.Hall Jr., whose contribution to the study of beach processes must be emphasided, is reminded by the author.

FIG. 7 - View of the beach one year after beginning of nourishment

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