Coastal Engineering Technical Note

SURVEYS OF COASTAL STRUCTURES

PURPOSE: To describe the potential use of photogrammetric surveys for coastal structures.

BACKGROUND: The jetty rehabilitation project at Manasquan Inlet, New Jersey, was selected for monitoring in 1982, under the Operation and Maintenance funded Monitoring Completed Coastal Projects (MCCP) Program. In view of the historic problems with maintaining the integrity of the quarrystone armor layers of the jetties and the relative lack of prototype experience with dolosse on the US east coast, a technique was needed to accurately monitor the performance of the dolosse at Manasquan Inlet and to verify the validity of the design procedures and assumptions used in the rehabilitation effort. As a part of the monitoring effort, a test was performed to evaluate the usefulness of photogrammetry for measuring armor unit motion on the jetties. Manasquan Inlet was an excellent location for the test, since it had both dolosse and rubble armor and was easily accessible for conventional land surveying techniques. The success of the test has resulted in the use of photogrammetry at Crescent City, California, and plans for its use at two breakwaters in Hawaii.

DESCRIPTION OF THE TEST: Aerial photography obtained in the monitoring program at Manasquan Inlet included periodic shore-parallel flights covering a 20-mile long zone centered on Manasquan Inlet, combined with lower altitude flight lines over the inlet jetties. The former, with a contact scale of 1" = 400', were used to assess general shoreline conditions in the study region, whereas the latter, with a contact scale of 1" = 100', were used as the data base for photogrammetric mapping of the dolosse on the jetties. Combined high and low altitude flights were obtained in January, June, and September 1983 and in March, May, June, and October 1984 as part of the MCCP Program funded monitoring activities. An additional set of aerial photographic data was obtained in May 1985 with Philadelphia District (NAP) funds.

The initial step in constructing photogrammetric maps of the south and north jetties at Manasquan Inlet was to establish primary targets on stable portions of the jetties and adjacent land area. The targets were surveyed in from nearby geodetic and vertical control benchmarks and were visible in the aerial photography. These primary targets were used to define the horizontal (x and y) and vertical (z) datums to which all measurements on the dolosse were referred. The primary targets on the jetties were located along the centerline of the concrete cap. Each concrete cap section is a monolith 20 feet square by six feet thick, weighing 180 tons, and supported by the core material of the jetty. Primary targets were surveyed periodically to determine their stability as reference points.

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Vertical black and white aerial photography was obtained with a shore-parallel flight line at an altitude of 600 feet, resulting in a contact scale of 1:1200 (1" = 100'). The photographic flights were scheduled to coincide with times of low tide and high sun angle. All photography in this monitoring program was obtained with the same precision cartographic camera, a Zeiss RMK A 15/32. A total of three exposures was required to prepare photogrammetric maps of the jetties; the southern and middle exposures were used for the stereo model of the south jetty, and the middle and northern exposures were used for the stereo model of the north jetty.

The final step in constructing the photogrammetric maps was compilation. A Kern PG 2-AT stereo restitution instrument was used to compile the selected features, in this case the plan view outlines of the dolosse, concrete cap sections, and armor stone. These features were superimposed on a grid based on the New Jersey State Plane Coordinate System, which graphically defined location and orientation of features in the horizontal plane. Vertical data were recorded numerically as spot elevations at selected points on the same features. Using an enlargement factor of 20 times the contact scale, the finished scale of the maps was 1:60 (1" = 5').

The photogrammetric maps were plotted on stable-based transparent drafting material. In this manner, the stability of a dolos from one flight date to the next was determined by overlaying and registering the two maps, then visually comparing the location of the feature of interest on the earlier and later dates. If a dolos moved in the time interval, the horizontal component of movement was evident as a displacement of the outline of the dolos, which was then scaled from the 1:60 maps. Experience with a number of Manasquan Inlet jetty maps has shown that horizontal movements of as little as 0.3 feet can reliably be detected. The vertical component of movement was determined by comparison of the spot elevation data for a particular point.

The initial maps for the south jetty and the north jetty are the most detailed of the maps prepared in this monitoring program. Spot elevations were determined at two or three locations on all fully visible dolosse and cap sections, with one or two elevations determined for partially visible dolosse and armor stones. Together, these two maps document the location, orientation, and elevation of 754 dolosse, about 57 percent of the 1326 units placed on the two jetties during the 1979 to 1982 rehabilitation. The remaining 43 percent of the dolosse were not mapped because they were either under water or beneath the top layer of dolosse and, thus, not visible in the photography. Subsequent photogrammetric maps have typically included from 20 to 30 percent of the 754 dolosse shown on the initial maps. This smaller sample size reduces the cost of map compilation while still obtaining representative coverage of armor units on the two jetties.

As a check of the accuracy of photogrammetric methods which were previously untested in mapping armor units, standard leveling techniques were used to record two or three spot elevations on a representative sample of both dolosse and armor stones. These level data were obtained from 65 south jetty dolosse on 27 April 1982, 14 March 1983, and 8 September 1983, and for 95 north jetty dolosse on 15 March, 9 June, and 7 September 1983. Neither the surveyors nor the photogrammetrist saw the other's results until after each analysis was completed. Prior to the 7-8 September 1983 leveling and 15 September 1983 photography, the comparison of photogrammetric and standard leveling data suggested that the accuracy of the photogrammetrically derived elevations was on the order of +/-0.3 ft . However, there were two factors identified which could have contributed to the differences between leveling and photogrammetric elevation data. The first factor was that the dates of leveling differed by as much as two or three months from the closest photography. It was possible that dolosse movement had occurred during those periods, contributing to apparent differences between photogrammetric and leveling measurements of the same point. For example, a storm occurred in February 1983 during the six week interval between the January 1983 photography and the March 1983 leveling. The second factor was that prior to September 1983, there were no visual targets on the dolosse to insure that the survey crew and the photogrammetrist were observing exactly the same point when measuring an elevation. Features such as "center of face of vertical fluke" were the nominal targets used by surveyors and photogrammetrist for identifying locations for spot elevations. If the surface was inclined relative to horizontal, as are almost all dolosse surfaces on a jetty, small differences in horizontal location could contribute comparable differences in measured elevation.

The best data set for determining the accuracy of photogrammetric elevations was obtained in the storm-free period of 7-15 September 1983, when both leveling measurements and aerial photography were performed. For these observations, one foot square black targets, actually crosses, were painted on 111 dolosse distributed over the two jetties, assuring that both the field crew and the photogrammetrist would determine elevations at the same points on the units. Elevations were determined to the nearest 0.01 ft for both methods. Comparison of the elevation data from the two methods demonstrated that 84 percent of the photogrammetric values were within +/- 0.1 ft of the elevations determined by leveling and 98 percent were within +/-0.2 ft. The largest discrepancy between the two methods at any point was 0.27 ft. These findings strongly suggested that earlier uncertainties regarding accuracy and resolution of the photogrammetric elevations were due to the time interval between measurements and the lack of point targets on the dolosse. The findings also showed that photogrammetry was capable of accurately resolving a scale of movement of individual armor units which would permit a detailed evaluation of dolosse stability.

Leveling data were essential in verifying the accuracy of the photogrammetric elevations. However, the leveling data do not provide any information on horizontal displacement, whereas both elevation and planimetric information are provided by photogrammetry. Nevertheless, the leveling data suggest a relationship between dolosse movement and storm exposure. Level measurements on the south jetty were obtained from April 1982 to September 1983, during which time two northeasters occurred (October 1982 and February 1983). The north jetty level measurements were obtained between March and September 1983, a relatively storm-free period. The data show that the south jetty dolosse experienced more frequent and greater downward vertical displacements than did the north jetty dolosse.

South and north jetty maps were prepared from aerial photography obtained through September 1983. As previously discussed, these photogrammetric maps did not achieve as high a degree of accuracy in measuring dolosse movement as did later maps. However, analysis of the photogrammetric displacement data through September 1983 did show that 65 percent of the 250 observed points were within 0.3 ft and 91 percent were within 1.0 ft of their initial elevations. The maximum vertical change detected was a drop of 4.2 ft on a dolos at the head of the south jetty. Ninety percent of the vertical displacements which exceeded 1.0 ft occurred on dolosse at the heads of the two structures. The largest horizontal displacement detected was nearly 6.0 ft on a dolos on the channel side of the south jetty. The next largest horizontal displacement was only 3.5 ft, occurring on the head of the south jetty. The mean horizontal movement of all monitored dolosse through September 1983 was about 1.0 ft. The movements were predominantly rotation around the vertical axis (yaw) and displacement in a downslope direction relative to the structures.

All photogrammetric measurements on maps for the period from September 1983 through May 1984 utilized targets established in September 1983 and are therefore assumed to be of comparable accuracy. Note that the period from 15 September 1983 to 27 March 1984 was relatively storm free, whereas the interval from 27 March to 9 May 1984 was not. Measurements of vertical and horizontal displacements over these two intervals reinforced the earlier findings that dolosse movements were predominantly related to storm effects.

In the six month period from 15 September 1983 to 27 March 1984, the mean vertical displacement for all points monitored on the two jetties was -0.15 ft and only 10 percent of the monitored dolosse experienced detectable horizontal displacements, the largest of which was about 1.0 ft.

<u>CONCLUSIONS</u>: Use of photogrammetric mapping of the jetties allowed a detailed evaluation of the motion of the armor units. This technique was found to be cost-effective and accurate, providing accuracy comparable with standard leveling techniques. Comparison of the results of this study with preliminary results from Crescent City, California, seems to verify an hypothesis made by Kendall (1988) that dolosse armor units on slopes flatter than 3.5H:1V tend to be displaced up the slope by forces associated with wave run-up, while those on steeper slopes, such as at Manasquan where the structure slope is 2H:1V, will be moved down slope by wave run-down or as a result of being destabilized by initial wave impact. Photogrammetric monitoring of the dolos rehabilitated Cleveland Harbor breakwater showed downward migration and in-slope rotation of the dolos. In this case the in-slope rotation was not related to wave run-down or destabilization, but simple shifting of the dolos into a more tightly packed layer.

One of the particular successes of the monitoring effort was the application of photogrammetric mapping to surveying the structural condition of coastal structures. While it was applied to dolosse armor in this study, it is equally applicable to structures with any type of natural or man made armor. The accuracy of photogrammetry is more than adequate to evaluate armor unit stability. Periodic mapping of a coastal structure would permit detection of incipient or progressive failure along any visible portion of the structure before such a problem was readily detected by other means. This would allow for early assessment and possible correction of the problem.

Photogrammetry offers several advantages over conventional land surveying techniques. First, it is possible to map armor units at or near the waterline of the structure, units that would be inaccessible or too hazardous to reach on foot. Second, photogrammetry is flexible in that all the information needed to perform the mapping can be obtained almost instantaneously, permanently, and at fixed cost with one aerial photographic flight. The mapping can then be performed at any time thereafter or not at all, depending on available resources, need for information, etc. In contrast, land survey methods capable of obtaining the location, orientation, and elevation data for mapping every visible armor unit are labor-intensive and would require more time and expense than photogrammetry. Had both base maps been prepared at the same time at Manasquan, the total cost of the initial, and most detailed, mapping of the jetties would have been about $6000. For that amount, a map was produced of all visible dolosse with the positions of several points established on each of the 754 dolosse. The cost of leveling a total of 160 dolosse was reconstructed to be about $3000. That cost is half that of the photogrammetry but produced elevations only on less than 21 percent of the visible dolosse. With the wider use of total stations, it is now possible to rapidly obtain position data using what has become standard surveying methods, but it is unlikely that improvements in survey techniques will reduce costs enough to challenge the cost effectiveness of photogrammetry.

A final advantage of photogrammetry is that the product is digital and can be displayed graphically. It is, therefore, more readily interpreted with respect to location and magnitude of armor unit displacements.

Photogrammetry has been shown to be a quick, cost effective method for monitoring armor unit stability. It's expanded use could help all coastal CE offices better monitor structures with concrete armor units. Use of photogrammetry on rubble mound structures with rock armor is more difficult. Irregular rock surfaces make identifying identical points on different photographs more difficult due to the variably sloped surfaces, shadows, or parallax.

ADDITIONAL INFORMATION: Advice on the use of photogrammetry can be obtained from Mr. Jeffery Melby at (601) 634-2062, Jeffrey.A.Melby@usace.army.mil.

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