RECENT TRENDS OF COASTAL PROCESSES RESEARCH IN JAPAN

by

Tsuguo Sunamura

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PREFACE

Dr. Tsuguo Sunamura, Associate Professor of the Institute of Geoscience, University of Tsukuba, was a Visiting Research Associate Professor at the Department of Civil Engineering, University of Delaware from October 1978 to August 1979. This arrangement was made after I visited Tokyo University in 1976-77, under the sponsorship of the Japan Society for Promotion of Science and got acquainted with Professor Sunamura who was then a research associate in their Civil Engineering Department.

During Dr. Sunamura's stay, he carried out joint research with us in the laboratory studying the wave drift velocity at the breaking point. He conducted seminars within and outside the University and attended professional meetings. At my urging, he also agreed to take up the task of reviewing and summarizing the coastal processes research activities in Japan. This report is the end product. I believe that this publication is a valuable one. It will aid the researchers in the United States in better understanding the research work in Japan, which needless to say has been very active but not as well introduced to us as it should.

I also wish to take this opportunity to thank Professor Kiyoshi Horikawa of Tokyo University and Mr. Dennis Conlon of the U. S. Office of Naval Research who have assisted greatly in making this arrangement possible.

Hsiang Wang, Professor
Department of Civil Engineering
University of Delaware
U.S.A.

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I. INTRODUCTION

Coastal processes are the physical, mechanical, or bio-chemical processes occurring in a coastal zone, which, therefore, have aroused the interest of coastal engineers, geomorphologists, geologists, physicists, oceanographers, and ecologists. The present report uses the term "coastal processes" in a narrow sense, which is defined as the physical processes associated with the present-day landform evolution of the coasts made of unconsolidated materials like silt, sand, or gravel. The word "beach processes" is the synonym. The goal of coastal processes research is, especially from the engineering view-point, to make it possible to predict topographic changes of beaches primarily caused by waves. Figure 1 shows a diagram showing the linkage among main elements in coastal processes system. The near-shore external forces are the waves and wave-induced currents, in the surf zone (including the breaking point) where the wave-current interactions usually occur. These external forces transport sediments on/offshore and/or alongshore. The existence of spatial variation of net sediment movement gives rise to the nearshore topographic changes, which in turn influence the external forces. The topography-force feedback relationship characterizes beach changes.

The purpose of this report is to provide the brief introduction of recent coastal processes studies which have been conducted in Japan during the last decade, i.e., the 1970's. A textbook written by Horikawa (1978) includes some useful summaries of this research field.

II. NEARSHORE EXTERNAL FORCES

1. Breaking Waves and Related Problems

The understanding of water-particle motion caused by breakers is necessary for sediment dynamics at the breaking point where the most vigorous wave motion occurs. However, few studies had been done since Adeyemo (1970) explored this basic problem. Recent laboratory investigations by Iwagaki et al. (1974) and Sakai and Iwagaki (1978) indicated that the estimation of horizontal velocity under breaking waves is possible by knowing the beach slope and the deep-water wave steepness. Sato, Y. (1977) found that the small amplitude wave theory predicted better the bottom velocity measured under laboratory breaking waves than the Stokes wave theory did; and the bed-load transport velocity was formulated on the basis of the former theory (Sato, Y., 1978). An attempt to measure directly the bottom shear stress by use of a shear meter has been reported (Sawaragi and Iwata, 1974).

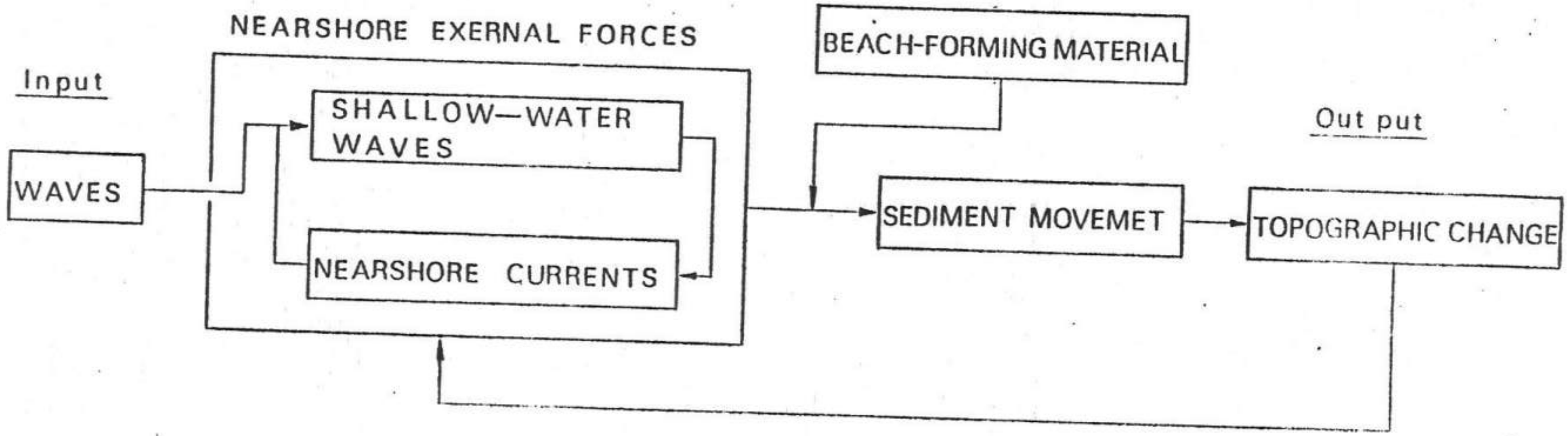

Figure 1 System of coastal processes

Breaker characteristics of irregular waves have also been investigated by Goda (1975) and Iwagaki et al. (1977).

2. Surf- and Swash-Zone Waves and Related Problems

Knowledge of wave mechanics in the surf zone is indispensable for the study of sediment motion and also for the prediction of nearshore current velocity. Applying the concept of radiation stress, Longuet-Higgins and Stewart (1964) elucidated the wave set-up and set-down phenomena; and Bowen et al. (1968) confirmed these in the laboratory surf zone. Since then, numerous model studies have been conducted in Japan under conditions of (1) uniformly inclined beaches with various gradients (Saeki and Sasaki, 1973; Sasaki and Saeki, 1974) and (2) bar- or step-type beaches (Mizuguchi et al., 1978); in the latter study, a model was developed considering the effect of eddy viscosity to predict the surf-zone wave height changes and the model was substantiated by using Suhayda and Pettigrew's (1977) field data. Mizuguchi's (1979a) wave-basin test of wave refraction in the surf zone on a uniform bottom slope revealed that the incident wave angle changes little as broken waves advance to the shore; and this angle proved to be determined approximately by applying the combination of Snell's law and the small amplitude wave theory. His paper also reported that wave celerity after breaking is predictable from the solitary wave theory if wave set-up is taken into account.

The theoretical approaches, based on the radiation stress concept, to the mean water level variation caused by irregular waves, have been attempted by Goda (1975), Hino and Kashiwayanagi (1978), and Sawaragi, Iwata, and Azuma (1978).

Mechanistic studies of wave deformation after breaking have been carried out in a wave flume by Sawaragi and Iwata (1974, 1975); their 1974 study attributed the main cause of wave height decay in the surf zone to energy loss due to turbulence with air entrainment.

A series of field measurements using 7 - 11 synchronized 16-mm movie cameras installed on the Ajigaura pier of Public Works Research Institute, Ministry of Construction, have revealed (1) the changes of wave height and (2) the mean water level variation, in the surf zone (Hotta and Mizuguchi, 1978, 1979). Terrestrial stereo-photogrammetry was also adopted for the wave deformation study (Hattori and Sato, 1979).

Velocity fields in a two-dimensional laboratory surf zone were scrutinized by use of a hot-film anemometer (Isobe et al., 1979), while horizontal velocity component in the actual surf zone was measured by using four electromagnetic current meters vertically set up on a pole (Horikawa et al., 1979).

Wave mechanics in the swash zone where atmosphere, lithosphere, and hydrosphere are in contact with each other, is one of complicated phenomena in the nearshore zone, and it is of great importance for dynamic approach to beach processes studies. Nevertheless, only a few studies have been done. Reanalysis of Savage's (1959) extensive laboratory data of wave run-up on roughened and permeable beaches, clarified that the effect of roughness upon swash is greater in general than that of permeability (Tsuchiya, Kawata, and Yashita, 1978). Based on the field data obtained at Hiratsuka beach, Terada (1976) discussed the effect of sand size upon wave run-up height. An attempt to conduct a simultaneous measurement of (1) swash velocity using an electromagnetic current meter, (2) bottom shear stress using a shear meter, and (3) percolation characteristics of a beach using wells dug on a foreshore, has been initiated recently on Ajigaura beach (Shuto, 1978).

3. Nearshore Current Systems

Remote sensing techniques, which have been used for the high-quality data acquisition of current patterns and/or velocity fields, are categorized as follows: (1) photography from aircrafts including helicopters (Horikawa and Sasaki, 1972; Horikawa, Lin, and Mizuguchi, 1977; Sunamura and Horikawa, 1978; Tanaka and Kato, 1978), (2) photography from tethered balloon(s) (Horikawa and Sasaki, 1972; Sasaki and Horikawa, 1975, 1978; Sasaki et al., 1976), and (3) terrestrial photography (Tsuchiya and Shibano, 1973a; Hattori et al., 1974). Stereo-photogrammetry using two synchronized air-borne cameras (Horikawa and Sasaki, 1972; Sasaki et al., 1976) enables us not only to obtain information of current fields but also to quantify the surf-zone wave height distribution.

The recent advance in the development of measuring instruments as well as remote sensing techniques has empowered us to quantify the surf-zone current field. Multiple field works have been done in the last five years (Hashimoto and Uda, 1978a, 1979a; Nakamura et al., 1978; Sasaki and Horikawa, 1975, 1978; Sasaki et al., 1976); e.g., the observation of infragravity low mode edge waves (Sasaki and Horikawa, 1978), the estimation of bottom friction factor (Hashimoto and Uda, 1978a), and the examination of the nearshore current-edge wave relationship (Nakamura et al., 1978). Invaluable data have been accumulated, but the quantity is scant. Complicated and severe environments have still interrupted the unraveling of the nature of nearshore currents. Based on the existing analytical and observational results, Sasaki (1975) evolved a simulation model of nearshore current systems.

The purposes of laboratory studies conducted so far are classified:

(1) mechanisms of current generation, (2) internal structures of nearshore currents, and (3) current patterns. Category (1) includes Mizuguchi and Horikawa's (1976) and Maruyama and Horikawa's (1977) work, both of which treated rip current generation by cross waves in a small basin; Category (2) covers the measurement of bottom shear stress under wave/current field (Sawaragi, Deguchi, and Taruno, 1978), the distribution of longshore current velocity across the surf zone (Mizuguchi and Horikawa, 1978), and the estimation of average friction factor, in the surf zone, of circulating currents generated by cross waves (Mizuguchi, 1979b); Category (3) involves the observation of rip current spacings (Ozaki et al., 1977; Sasaki and Ozaki, 1977; Sato, M., 1978).

Mizuguchi (1977) gave a theoretical discussion on the generation mechanisms of nearshore currents occurring in a laboratory wave basin.

Following Bowen's (1969) theoretical work which attributed the generation of rip currents to standing edge waves, Hino and Hayashi (1973) and Hino (1974) developed a model based on a hydrodynamic instability theory. Iwata (1976, 1978) and Mizuguchi (1976) treated independently rip current spacings as an eigenvalue problem. Other theoretical considerations have been published more recently by Sasaki and Ozaki (1978, 1979) and Tsuchiya, Yasuda, and Tokuda (1979).

The influence of (1) input-wave angle and (2) lateral mixing parameter on the steady longshore current velocity distribution across the surf zone, has been theoretically treated by Kraus and Sasaki (1979): the maximum current velocity decreases and its location shifts shoreward, with increasing breaking wave angle and the mixing parameter; fitting the theory to laboratory and field data indicates that the suitable mixing parameter is less than about 0.1.

III. COASTAL SEDIMENT BEHAVIOR

1. Longshore Movement and Transport Rates

Supply sources of beach sediments are rivers (Hosoi, 1976; Onishi and Nishimura, 1977), receding cliffs (Horikawa and Sunamura, 1970), or eroding beaches in an adjacent area. For the functional design of coastal structures and also for the prediction of their influences on the adjacent coastal environments, knowledge on the budget of littoral drift rate of sediments is needed (Sunamura and Horikawa, 1977). For sediment-budget studies, it is necessary to know the long-term, directional trend of littoral drift; sedimentological and/or mineralogical methods have frequently been applied (e.g., Okamoto et al., 1970; Sato et al., 1970, 1972; Sunamura and Horikawa, 1971, 1972; Hattori and Suzuki, 1976; Shuto et al., 1977). Some new concepts for inferring littoral transport prevailingness have been proposed by Sunamura and Horikawa (1972) and Hattori and Suzuki (1976). A tracer study of gravels artificially injected on a beach indicated that (1) the moving speed of the gravels was approximately proportional to the longshore component of wave energy flux, and (2) the longshore variations of gravel size and shape were resulted mainly from the attrition and breakage of the gravels during their travel (Hattori and Suzuki, 1978). A fluorescent tagged sand experiment to understand the alongshore sand-movement in the surf zone has been performed on Ajigaura beach by Hashimoto and Uda (1975). During their experiment significant wave height was 60 - 70 cm and period was 4.9 - 6.4 sec. They concluded that (1) the transport speed was one-tenth of longshore current velocity and (2) average depth of sand mixing was 10 cm. To detect alongshore sediment-transport directions in the swash zone, the fluorescent sand tracer technique has been used (Sunamura and Horikawa, 1976).

Based on topographic changes, Tsuchiya and Shibano (1973) estimated longshore sand-transport rates on the Shimoniigawa coast, and reconfirmed Komar and Inman's (1970) relation. Direct measurement using a sand trap in the surf zone was tried by Sawaragi and Deguchi (1978), but the complexity of natural environments interrupted to produce useful results.

2. On/Offshore Sediment Movement

Attempts to elucidate the mechanics of laboratory sand movement have been made by Noda and Matsubara (1978) and Sunamura et al. (1978); both of them used a 16-mm movie camera to film the sediment behavior. The latter study stressed the importance of vortex formed over asymmetric sand ripples for the suspension-type, offshore sediment-transportation. Sediment sorting was investigated in a wave tank (Yamamoto, 1977), while sand movement in the shallow water area was observed in the full scale environment (Isobe, 1971). Our knowledge on sediment motion is rather limited even at the laboratory level.

In addition, to study the mechanisms of sand movement, multiple efforts have been made to measure or estimate the laboratory on/offshore sediment transport rates (Nakamura et al., 1970; Horikawa, Sunamura, and Shibayama, 1977; Noda and Matsubara, 1979; Sawaragi et al., 1979; Watanabe et al., 1979). The last two studies obtained the transport rates on a sloping beach from the profile changes; irrespective of transport directions, the transport rates were found to be proportional to dimensionless tractive force represented by wave height, period, and sediment size (Sawaragi et al.), while they were linearly related to Shields function (Watanabe et al.). Sunamura et al. (1978) tried to formulate the net offshore transport rate for the case of 0.2-mm sand. A generalized relation of on/offshore sediment flux, based on sediment dynamics, has not been established even in a laboratory.

3. Suspended Sediments

The measurement of suspended sediment concentration in the actual surf zone have been performed by Tsuchiya and Shibano (1973) using pump or bamboo samplers, by Irie (1975) using pump samplers, by Tanaka (1975) using a sled-mounted, siphon-type sampler, and by Tanaka et al. (1979) using a newly developed device which made instantaneous sampling possible. These are all time-integrated samplers except the last one, which is considered to be powerful in use not only in the surf zone but also in the swash zone. The data in the offshore zone also have been accumulated (Inokuchi, 1970, 1972; Inokuchi and Machida, 1970; Inokuchi et al., 1971; Shimada and Yoshitaka, 1974).

A laboratory study using an oscillatory tunnel discussed the relationship between the sediment concentration and the size (Kajima and Saito, 1971). Wave-tank experiments by use of an Iowa-type concentration meter have been carried out (Hosoi and Inagaki, 1975; Hosoi and Ando, 1977).

Horikawa and Watanabe (1970) developed an electrolytic turbulence transducer for the measurement of turbulent velocity fluctuation superimposed on the oscillatory flow field, and investigated the fundamental mechanism of sediment suspension due to progressive waves. Following this work, mechanistic studies of Noda and Iwasa (1971, 1973) and Hosoi and Kida (1973) have been reported. The physics of wave-induced sediment suspension has still been veiled especially in (1) the shallow water region where asymmetric velocity field is produced and (2) the surf zone where turbulent velocity field is created. There are many questions to be answered.

IV. TOPOGRAPHIC CHANGES

1. Long-Term Shoreline Changes

In the last 20 years, Japanese shorelines had severe erosion due not only to the construction works on the coasts (Ozasa, 1977) but also to the man-caused environmental changes, e.g., the decrease in river-sediment discharge that the dam construction on rivers had brought about. The supply rate-beach erosion relationships at specified locations have been reported by Hosoi (1976) and Onishi and Nishimura (1977). Seventy-year-period shoreline changes in Japan have been mapped (Koike, 1977). Some case studies have been conducted at Kaike (Noda, 1974), at Naoetsu (Tsuchiya et al., 1976), and at Shimoniigawa (Shibano et al., 1977).

2. Short-Term Beach Changes

Three kinds of relations predicting laboratory shoreline erosion/ accretion have been proposed respectively by the following research groups: University of Tokyo (Sunamura and Horikawa, 1974; Horikawa et al., 1975), Hokkaido University (Ozaki and Watanabe, 1976; Ozaki and Hikita, 1977), and Chuo University (Hattori and Kawamata, 1978). Attempts to analyze field data have been made by Sunamura and Horikawa (1974) and Hattori and Kawamata (1978).

Quasi-equilibrium profiles of laboratory eroding beaches were tested (Mitsui et al., 1974), while the formative condition of beach ridges or berms which are seen on accretional beaches was examined in a laboratory environment (Sunamura, 1975a). Other wave-tank studies include a series of Masuda and Ito's (1971, 1974, 1975, 1977) work, and Tsuchiya and Inada's (1974) experiment using wind waves.

Wave-basin experiments of shoreline rhythmicity by Tamai (1974, 1975, 1977, 1978) had the purpose of investigating the formation of beach or large cusps on a model beach in connection with the surf-zone wave- and current-properties.

The scale relationship should be known when we extend the laboratory result to the full-scale environment or we do modeling of natural beaches. There were only two studies on this subject (Yamamoto and Nozumi, 1975; Noda, 1978). Field investigations as well as laboratory approaches are needed more for the solution of the problem.

The dimensional analysis led to the following equation relating beach slope in the field to sediment and wave properties (Sunamura, 1975b):

$$\tan \beta = 0.1^{0.5}\, d^{0.5}\, T/H_b$$

where $\tan \beta$ = beach slope, d = sediment size, T = wave period, H_b = breaker height, and g = acceleration of gravity.

Three-dimensional topographic changes of foreshore zone on Kashima beach were monitored during one storm cycle by Sasaki (1979); this study described the response of foreshore topography to waves and currents, presented the correlation of rhythmic topography appeared in shallow-water and in swash zones, and developed a beach process model. Tamai's (1979) work, based on the data analysis of spatial and temporal changes of shore profiles along the Kochi coast, indicated the existence of a close relation between a large-scale cuspate shoreline and a meandering longshore bar. Based on the data during the period from 1969 to 1973, the behavior of longshore bars along the Niigata coast has been analyzed by Tanaka and Kato (1976) applying empirical eigenfunctions, which were initially introduced for beach-change studies by Winant et al. (1975); one of the conclusions is that the longshore migration speed of the bars was estimated at 250 m/year. The dimensions of shoreline rhythmic topography have been reported from various locations (e.g., Tazuke, 1970; Shirai and Tsuchiya, 1974; Tamai, 1976). Mechanistic studies of the rhythmicity formation have not advanced rapidly due mainly to the lack of data on nearshore wave and current fields.

Applying empirical eigenfunctions to Ajigaura-beach data, Hashimoto and Uda (1976, 1977, 1978b) found that the first, second, and third eigenfunctions represented respectively (1) average beach profiles, (2) topographic changes caused by longshore transport of beach material, and (3) those by on/offshore sediment transport. The temporal variation of beach changes due to longshore drift was well correlated with that of wave directions and longshore current velocities; and similar correlation existed between topographic changes caused by on/offshore sand movement and significant wave heights. Other beach processes studies have been carried out in various places: e.g., along the Shimoniigawa coast by Tsuchiya and Shibano (1973b), along the Shizunai coast by Ozaki (1974), on the Ogata coast by Shirai and Tsuchiya (1977), at Totado beach near Shimoda by Isobe (1979), and along the Shibushi coast by Nagatomo et al. (1979). There are two unique case studies: one attempted to measure the dynamic response characteristics of bottom topography in the surf zone under stormy conditions using a depth meter installed on a post (Sato and Irie, 1971), and the other treated submarine slope failure by storm waves which occurred at a small island in the Sea of Japan (Saito et al., 1976).

After Mashima's (1973) mathematical expression of the plan shape of beaches, several simulation models have been proposed (e.g., Hashimoto, 1976; Sawaragi and Deguchi, 1976; Tsuchiya and Yasuda, 1978; Hashimoto and Uda, 1979b); most of them were based on so-called "one-line theory" in which the effect of on/offshore sediment transport upon shoreline changes is ignored. In order to make up for defects of the one-line theory, Hashimoto and Uda (1979b) developed a model based on modified empirical eigenfunctions: water depth, h, which is a function of (1) offshore distance, y^*, (2) longshore distance, x^*, and (3) time, t, was expressed by

$$h(x^*, y^*, t) = \sum_{i=1}^{n} e_i(y^*, t) \cdot c_i(x^*, t)$$

Using six-year field data, they clarified that e_1, e_2, and e_3 are all independent of time, and also that (1) c_1 has little temporal variation, (2) c_2 is expressed by only y, the offshore distance from the shoreline to a reference point, and (3) c_3 is linearly related to y', the offshore distance from the shoreline to a point representing offshore topographic change (e.g., a point showing the extreme of e_3); y and y' are determinable from the one-line and the two-line theories, respectively.

Therefore this model has a feasibility of predicting three-dimensional topographic changes. A theoretical treatment of beach topography in connection with rip currents has been made by Hino (1974, 1976).

The shoreline configuration of pocket beaches in Japan and Asian areas was quantified by Tsuchiya, Shibano, and Tokawa (1978), and they investigated a stable plan shape in an attempt to apply Silvester's (1976) idea of headland control to the actual preventive measures of beach erosion; a few examples of this application were presented by Tsuchiya, Silvester, and Shibano (1979).

3. Microtopography on the Sea Bed

Wavy bedforms in the shallow water region of a pocket beach have been measured by use of the moiré photography (Matsumoto, 1971; Inokuchi and Matsumoto, 1971) and by use of a comb-type device (Machida et al., 1972). There existed three kinds of ripples, i.e., parallel, diagonal, and lunate ripples, which appeared in this order with decreasing water depth. Matsumoto (1980) tried to explain this sequence in terms of Manohar's (1955) function. Shallow-water bedform researches should be pushed further with special reference to (1) flow field and (2) sediment transport patterns and rates. Incidentally, some hydrodynamic investigations of flow characteristics over an artificially rippled surface have been conducted in a laboratory (Hino and Fujisaki, 1975; Sawamoto and Yamaguchi, 1978; Honji and Matsunaga, 1979; Sawamoto and Yamashita, 1979).

V. CONCLUDING REMARKS

The rapid progress in coastal processes research has taken place during especially the last five years. However, general solution for the prediction of beach changes has not yet been established. The input-output relationship in the coastal processes system (Fig. 1) should be formulated by linking the elements on a physical basis. This formulation requires the basic data which can only be obtained from continuous, synchronized, long-period monitorings of (1) input waves, (2) nearshore current fields, (3) sediment transportation, and (4) resultant topographic changes.

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