SOME BEHAVIOURS OF STRONGEST SHORT-TERM COASTAL CHANGE INDUCED BY CROSS - SHORE WAVE ENERGY FLOW AND CORRESPONDING THEORETICAL CONSIDERATION (*)

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ABSTRACT   There is a number of famous theoretical and experimental works that oriented themselves to solve actual problem of coastal change, including the change of coastline, under versatile influence of oceanic wind waves. In this paper the author would like to give supplementally a few new behaviours of that phenomena observed along the coasts of Vietnam, such as coastal collapse & primitive on-the-spot accumulation, material hurl, etc. Most simple theoretical explanation of them grounding on the Newton's second law has been presented and as results of that there appeared such notion as indicator and criterion which could be used for demarcation of different behaviours in initial stage of general coastal changing processes.

Key words : Coastal change, Short-term behaviours, Collapse, Material hurl, Demarcating criterion.

MOÄT SOÁ BIEÅU HIEÄN BIEÁN ÑOÅNG BÔØ BIEÅN MAÏNH CAÁP THÔØI DÖÔÙI TAÙC ÑOÅNG CUÛA DOØNG NAÊNG LÖÔÏNG SOÙNG VOÂ TRÖÏC GIAO VAØ CAÙC VAÁN ÑEÀ LYÙ THUYEÁT TÖÔNG ÖÙNG

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TOÙM TAÉT   Treân theá giôùi ñaõ coù nhieàu coâng trình nghieân cöùu lyù thuyeát vaø thöïc nghieäm caùc vaán ñeà bieán ñoäng bôø vaø noái ven bôø döôùi taùc ñoäng maïnh cuûa soùng bieån. Trong baøi naøy taùc giaû boå sung theâm moät soá bieåu hieän phoå bieán cuûa hieän töôïng ñoù môùi ñöôïc khaûo saùt vaø ño ñaïc gaàn ñaây doïc theo bôø bieån Vieät Nam, chuû yeáu laø ôû vuøng bôø tích tuï Mieàn Trung, thí duï nhö bieåu hieän saït lôû & boài laáp taïi choã vaø bieåu hieän vaät lieäu bò quaêng xa. Phöông phaùp lyù thuyeát ñôn giaûn ñöôïc giôùi thieäu ôû ñaây laø döïa treân cô sôû ñònh luaät Newton thöù hai vaø keát quaû xem xeùt ñaõ daãn ñeán nhöõng khaùi nieäm veà thoâng soá chæ thò vaø chæ tieâu coù theå söû duïng ñeå phaân giôùi caùc bieåu hieän khaùc nhau trong thôøi khaéc ban ñaàu cuûa caùc quaù trình bieán ñoäng bôø toång quaùt.

INTRODUCTION

A recognized achievement of long before investigation of coastal dynamics is really great and abundant, from that there are good methods of forecasting morphological changes at the coasts and coastal zones founded on wave energetic fundament and alongshore sedimentation. A number of individual works and relative new survey books of such authors as Horikawa K. (1987), Freds∅e J. and Deigaard R. (1995), Komar P.D. (1983, 1998), etc., have given a chance for reading and raising knowledge in this scientific field as well as for useful applying it in predicting practice.

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However, carefully searching previous works we are also under impression that there are rich results on prediction models of along-shore hydro-lythodynamical deviation while the results of cross-shore one are comparatively insufficient. It could be seen in any books, for example in Horikawa's one. The sensible tendency of loosing important short-term dynamical features at cross-shore direction in the prediction models is having in mind. But it's necessary to note that under many circumstances of strong wave blows direct morphological changes are first happened in shoreward direction and what is more they are usually momentary and serious. After that only along-shore sedimentation brings into playing. Even though a formation of surf zone and relative along-shore bar (breaking zone) surely depends first upon on-offshore processes (L. P. Trinh 1993, 1998). Bringing out this point we hope for larger attention above such diversiform instantaneous behaviours that we have observed along the monsoon windward coasts of Vietnam, especially above the problems of the conformity with natural laws and then foresight. Two most important (on the point of view of dynamics) behaviours should be presented in this paper, that are coastal collapse & on-the-spot material accumulation and material hurl in coastal zone. Their existence is observed widespreadly along the coasts of Central Vietnam. Certainly, problems of forecasting these phenomena are very difficult, but in order to approach to that we try first to find out their mechanism by simple way grounded on correlation of the whole forces which have simultaneous action to some masses of nearcoastal materials and in the results of which create primary acceleration indicating the directions of material motion. In principle, such indication can be able to distinguish the behaviours of either coastal collapse or material hurl

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- **Reasoning out of general theory of wave influence**

After general theory of cross-shore wave power and relative along-shore water and sediment flows (Longuet-Higgins 1970, Komar 1974, etc.) morphological changes in coastal zone depend closely upon trigonometric functions of θ, where θ is the angle of incidence to the shoreline normal. Like that under fixed wave height, at one side, the critical angle θ of largest value of longshore flow is $\theta'_{cr} = 45^o$, i.e. that is the first boundary direction creating a favourable condition for erosion-accumulation. At the other side, the critical angle θ of largest value of cross-shore wave power, i.e. the other boundary direction for the same phenomenon, is $\theta''_{cr} = 0^o$. It means that the most favourable conditions of a coastal erosion-accumulation have included in $0^o \leq \theta \leq 45^o$, from that the smaller θ the greater wave blasting power as well as the weaker water and sediment flows, and vice versa. Beginning at $\theta'_{cr} = 45^o$ if the $\theta \rightarrow 90^o$ these conditions have decreased quickly and disappeared at $\theta = 90^o$. Attracting attention above the boundary norms of θ''_{cr}, especially when $\theta''_{cr} = 0^o$, is like the original aim of this work because in this case a serious short-term consequence that usually brings out clearly, concretely is observed in coastal zones of Central Vietnam, (L. P. Trinh, 1998).

On basis of all of the above theoretical discussion, the erosion-accumulation coasts of Central Vietnam, with a length of 1350 kilometers from Ngason (Thanhhoa prov.) to Vungtau (Baria prov.), have laid in front of the main wave directions, as follows (Fig. 1). The section from Ngason to Dungquat bay (Quangngai prov.), 650 km long, has laid in front of north-east quadrant of strongest wave action, the section from Dungquat bay to Muidinh (Ninhthuan prov.), 430 km long, has laid in front of northeast-southeast quadrant of strongest wave action and the section from Muidinh to Vungtau, 270 km long, in front of south-east quadrant, respectively. Such division into sections in relationship with the

main wave fields makes it easier to search radical factors of coastal changes, from that first of all are the wind fields.

As common knowledge paramount important factor is monsoon. The divided N-E quadrant of violent waves has been caused mainly by NE monsoon existing in the period of November – March. The S-E quadrant - mainly by SW monsoon with general SE winds in coastal zone existing in the period of May –

December. And finally, the NE-SE quadrant could be able caused by either NE or SW monsoons. Winds in the east direction are often observed in the time of either NE or SW monsoons, too. It's necessary to note that among main wind seasons there are frequent and relatively short periods during that the monsoon winds become very strong, under influence of which the wave height becomes also by far considerable.
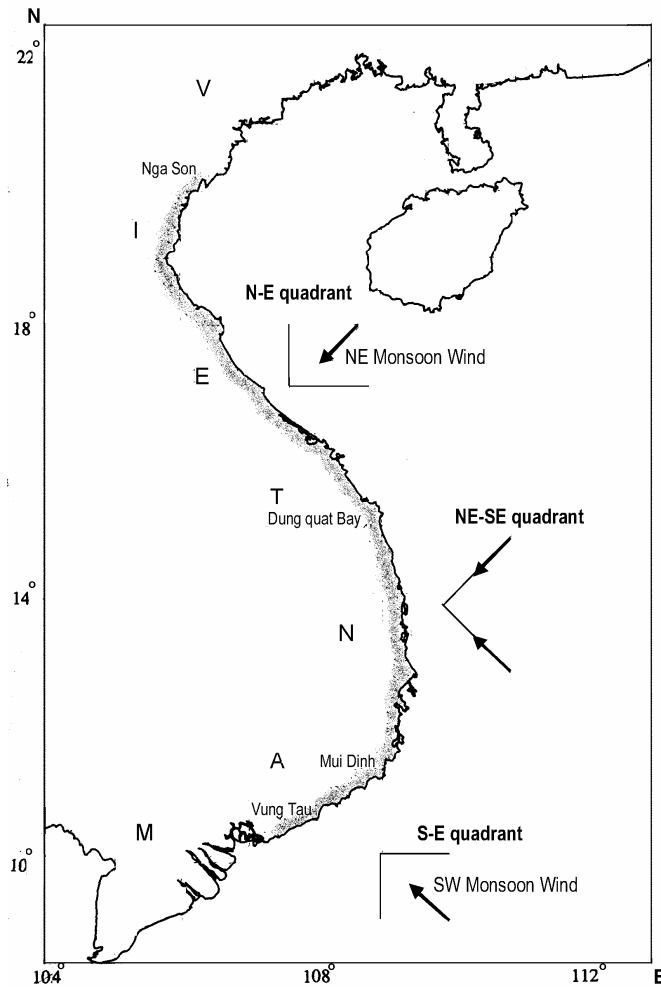

Figure 1: General quadrants of strongest wave action upon erosion-accumulation coasts of Central Vietnam

Next important role inducing violent waves belongs to hurricanes which occur annually over coastal zones of Vietnam. Corresponding to a trajectory of hurricane

center the right-hand side of storm is always the most dangerous because of its great wave blasting power, especially in the time of hurricane landing. When the storms are still

far from the coasts, for example in the deep sea part, they could have created a wave swells which easier than the other types of surface waves overcome any shallows or bars before reaching shoreline and in the same time faster raise cross-shore wave energy flows, i.e. wave blasting power also becomes fierce in the case of arrived long-range swells.

● **Coastal collapse & on-the-spot accumulation**

A significant change of a coastline usually begins upon instantaneous break-up and collapse of a steep shore structure under strong wave blows. Just after that there is on-the-spot stagnation of fallen-off materials which are always made up a great quantity. Such processes may be happened at any range of the coasts depending on local conditions. In the case of long range a big mass of fallen-off materials is impossible to move at once to another place in spite of incessant wave blows as well as alongshore current dragging. Then it could have established a new form of coastal morphology if stagnation time was noticeable. It means that the behaviour of collapse & on-the-spot accumulation is exactly in an initial stage of general erosion-accumulation phenomenon, and after that only the alongshore transport of materials just left in initial stage has taken place. Transport process may be rather short-term and/or may go on a long time, as often seen, it goes on some months, even some years

The picture in Figure 2 is a fragment of longshore hilly beach (high bed) of Tunghia district (Quangngai prov.) created by stagnation materials which had been fallen out from the coasts under strong influence of the SW-monsoon wind waves in 1997. Such picture has existed up to now, like that the great sand mass of collapsed processes is not yet transported completely to another place. At the same time vertical form of the coast standing behind the hilly beach is ready to fall down if a new attack of wave blasting power appeared. Then either a new similar hilly beach should be created or exactly what is existing but becomes more developed. In addition, the same long hills along the beach of Thuanan (Thuathien prov.) have been observed (Fig. 3). They have been created by SW monsoon and began now to stand the collapsing processes under the same hydrodynamical influence but the monsoon is already holding right in the northeastern direction.

Figure 2: Fragment of longshore hilly beach of Tunghia district, August 1998
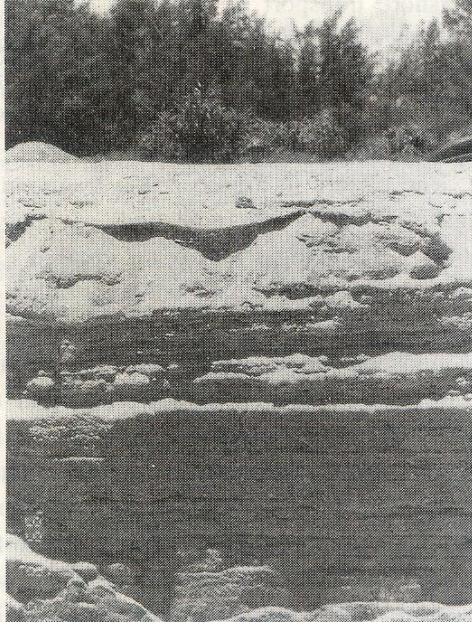(Photo by L.P. Trinh)

Figure 3: Fragment of longshore hilly beach of Thuanan beginning process of collapse, August 1999 (Photo by L.P. Trinh)

The other picture demonstrating a coastal collapse is shown in Figure 4. It is a fragment of strongest short-term change of the coast of Nhatrang City, caused by waves in the hurricane N°8 which had landed over Khanhhoa province in 13 December 1998. This shoreline collapse had kept at arm's length (about 1200 meters along high inclined coast of the city) and its maximal breadth was in 10 meters in size. In this case a real great mass of fallen-off silt-sand materials had had
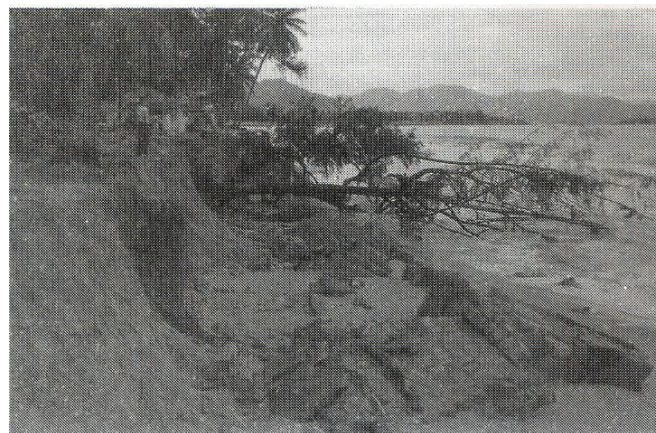
time for transport completely in offshore as well as along-shore directions and it happened two days before this picture had been taken.

• **Material hurl**

There is another widespread behaviour playing as considerable role in near coastal morphology change as the above described collapse, it is the material hurl in coastal zone. Under influence of very strong wave blasting power loose materials near the beach edge easily hurtle through the air. Such process could also happen inside the water layers, for example over underwater bar. The hurtled materials always hold on to the definite trajectories. In the air such trajectories are in form of barabol, but inside the water layers they are only ballastic because of water resistance force. In the place, from that the materials have unloaded for hurl, there is an erosion, in contrary, in the place, to that the materials have loaded because of hurl, there is an accumulation. So depending on such processes it is usually observed in the nature a widespread construction as well as destruction of coastwise beds, both of the long beach bed and the underwater bar. Really, it's easy to meet with rather high sand hills which run along the erosion-accumulation coasts of Central Vietnam and what is more their lateral sea side is usually very steepen. The image at

Figure 4: Fragment of the coast of Nhatrang City collapsed under wave blows in the hurricane N°8, December 1998 (Photo by L.P. Trinh)

Figure 5: The stones hurtled from the beach of Nhatrang under wave blows

in the hurricane N°8, December 1998 (Photo by L.P. Trinh)

Figure 3 is the combined situation of above written behaviours, i.e. the hilly beach had been created first by material hurl and at the present it begins to lay under the processes of collapse & on-the-spot accumulation.

The Figure 5 demonstrates specific event when the hurtled materials are heavy stones. These stones had been piled in heap right against coastal wall of Nhatrang beach and both the stone heap and the wall were constructed in order to protect the coast from any attack of sea storms. Average diameter of biggest stones is 0.60m and of small ones is 0.30m in size. But almost the whole stones had been hurtled into the wall top by waves in the hurricane N° 8. Maximal distance of stone hurl which had been measured in this case is 30m in size, frequently 20 – 25m, and the height of constructed wall is 2.5 m from the beach surface.

There is still another occasion providing hurtled processes, that is the sand trace (sand masses with different weight) stuck on the afforestation trees. The last is scattered everywhere along the coasts of Vietnam. The images in Figures 6 and 7 had been pictured in the plantation directly opposed against the beach of Cuadai (Thubon river mouth) in

August 1997. Such images could be seen in other coastwise forests, for example in Thuathien, Quangngai provinces, etc., (see the Appendix of L. P. Trinh 1998). As it happens under strong action of waves the wet sand masses have risen to a great height and hurtled to a long way off, maximal distances from the beach edge can reach to 5 m in height and 50 m in length respectively. The conclusion is that the influence of wave attack could have caused both the collapse and the hurl of coastal materials.

Concerning the underwater material hurl we have not yet a good data which could serve to clearer disclose such important mechanism as it occurs through the air. Only one that we have observed many time, it is a very quick change of underwater bars in coastal zones, their complete construction as well as destruction. Such short-term morphological deformation could be explained only by underwater persistent blows occurred during short periods of monsoon storms.

THEORY

The above described behaviours of shoreline changes are, certainly, some

additions to that which are not enough discussed about in references. Hence, it's needed to look into them from theoretical angle and most simple problem disclosing their general mechanism has been made as follows.

● **Classical equation of dynamics of short-term coastal change**

It's interesting to track initial motion of any material mass under blow of individual wave. First of all a separate body of coastal materials is in motionless position at an inclining beach. As soon as wave blow has happened such body is set out suddenly and its motion takes the following form of following equation:

$$m_s a_x = g(m_s - m_w + M_c)(\sin\beta - \mu\cos\beta) - (F - R)(\cos\beta - \mu\sin\beta) \qquad (1)$$

where m_s is the mass of material body taking part in these natural processes; m_w - the sea water mass of such volume as of material body; M_c - the mass of the water column above the material body; a_x - acceleration of material body along the x − axis; g - gravitational acceleration; β - angle of coastal inclination; μ - bed friction coefficient; F - acting wave force; R - water resistance force; (see Figure 8).

Figure 6: Sand bodies stuck on the trees of north Cuadai afforestation, August 1997
(Photo by T.T. Hieu)

In fact, this equation is the transformed mathematical expression of Newton's second law corresponding real conditions of a coastal zone, from that it is possible to find the motion laws of material mass on the basis of definition of the acting forces in a body. For eq. (1) the co-ordinate axes are so laid out that one of them coincides with the direction of motion of material mass. Concretely, the x − axis is directed down along the inclined beach surface keeping positive direction of a seaside. Having such assumption that we are agreed to omit alongshore component of motion, i.e. the wave blow is right to the coast without any angle deviation $(\theta = 0^0)$, so x − axis has been at shoreline perpendicular. The origin of left-turn rectangular system of co-ordinates is so chosen in the section that it has given all advantageous conditions to realize proposed problem. Usually, it is in the points of either beach edge or underwater peak.
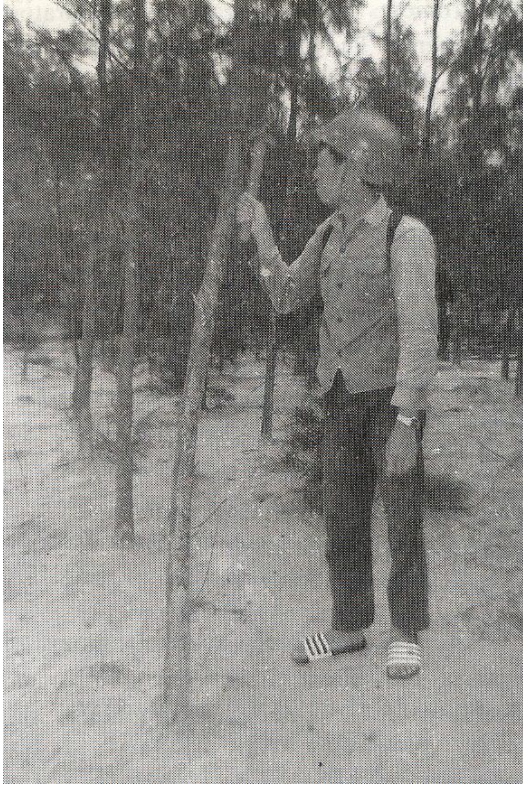
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Figure 7: Sand bodies stuck on the trees of south Cuadai afforestation, August 1997 (Photo by T.T. Hieu)

The right-hand side of eq. (1) shows an interrelation of all forces attached to studying processes. First member of the right-hand side contains the group of gravitational forces, second one includes both the wave acting force and the water resistance force. In the case when the phenomenon happens in the air $m_w = 0$; $M_c = 0$ and $R = 0$, in the case of inside water layers they have corresponding values. If the first member of right-hand side of eq. (1) is larger than the second one then the right-hand side should have been positive, and then also the acceleration value $a_x \succ 0$. In contrary, if the group of gravitational forces is smaller than the group of acting forces then the acceleration has to receive negative value, $a_x \prec 0$. In addition, initiating velocity ($v_{t \succ 0}$) of material mass right away after sudden wave blow ($t \succ 0$) always keeps the direction coincided with the direction of acceleration a_x (it may be express by $v_{t \succ 0} \uparrow\uparrow a_x$). So in the first case ($a_x \succ 0$) the vector $v_{t \succ 0}$ is directed downward along the inclined bed of near-coastal zone, i.e. material body moves into seaside (behaviour of coastal collapse). In the second case ($a_x \prec 0$) the vector $v_{t \succ 0}$ is directed upward along the inclined bed, i.e. motion of material body keeps the direction into land side (behaviour of material hurl). And finally, $a_x = 0$ is critical value, according to that $v_{t \succ 0} = 0$ and then the occasion of transition from this process (behaviour) to the other is appeared. It follows that the characteristic of change over of digital signs of acceleration a_x is an excellent indicator for watching the directions of very short-term initial motion of material mass on this task problem
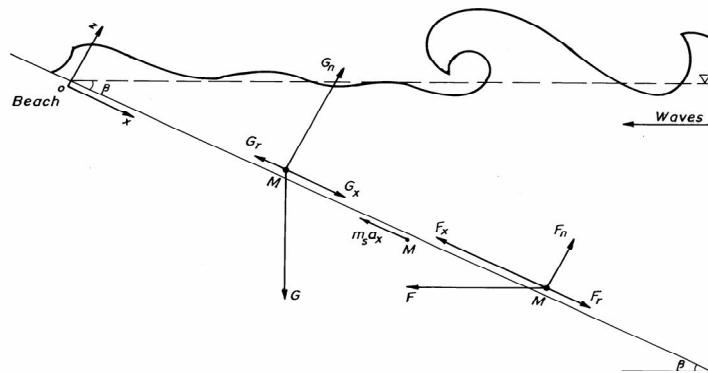

Figure 8: Schema of interrelation of gravitational and wave induced forces acted upon the material mass M at an inclining bottom of near-coastal zone

- **Semi-empirical criterion of demarcation of behaviours**

As stated above many circumstances of short-term coastal change had been inspected, from that there is standing a good chance for solving the equation (1) relatively trigonometric functions in the case of $a_x = 0$. Such action is indispensable because of following causes. First, the angle β of coastal inclination presents itself as the one of many expressions of near-coastal morphological forms. Second, according to such observed statistical information as the wave height, the quality of local structural materials, etc., quantitative and qualitative dependence of inclination element β upon the groups of gravitational forces G and external acting forces F has been expressed by determinate function, from that the critical value comes out as follows:

$$\beta_{cr} = arc\ cos\left\{1+\left(\frac{F+\mu G}{G+\mu F}\right)^2\right\}^{-0.5} \qquad . \quad (2)$$

And semi-empirical criterion of demarcation of the above described behaviours takes the following form of inequality:

$$\beta_{hurl} \prec \beta_{cr} \prec \beta_{coll} \qquad . \quad (3)$$

Statistical data of measurements on local violent natural conditions are background for determination of β_{cr}. After that each concrete situation would be defined by inequality (3), as follows. On the average of investigation area if $\beta \prec \beta_{cr}$ the coastal morphology would be in tendency of material hurl; if $\beta \succ \beta_{cr}$ it'll be in tendency of coastal collapse. Such work presents itself in need of practical foresight. For that very reason β_{cr} has to play the role of demarcating criterion.

- **Reproduction of some moving trajectories**

It is not difficult to reproduce the trajectories of sand and stones hurtled at some distances. For that, these distances are wanted to know before and it may be made by measurements in natural or laboratory experiments. The maximal distances of any hurl are denoted by X on horizontal distance and Z on vertical height respectively and first of all it is necessary to introduce the following expressions of initial velocity $v_{t \succ 0}$ and angle of the hurl γ (i.e. the angle between the tangent of trajectory at origin point and its projection on horizontal axis)

$$v_{t \succ 0} = \left\{\frac{g}{8Z}\left[X^2 + (4Z)^2\right]\right\}^{0.5} \qquad (4)$$

$$\gamma = arc\sin\left\{1+\left(\frac{X}{4Z}\right)^2\right\}^{-0.5} \qquad (5)$$

After that the classical equations of material movement have given all-round possibility for numerical computing the moving trajectories. But, it needs to pay attention to water resistance force when the problem is concerning underwater material hurl.
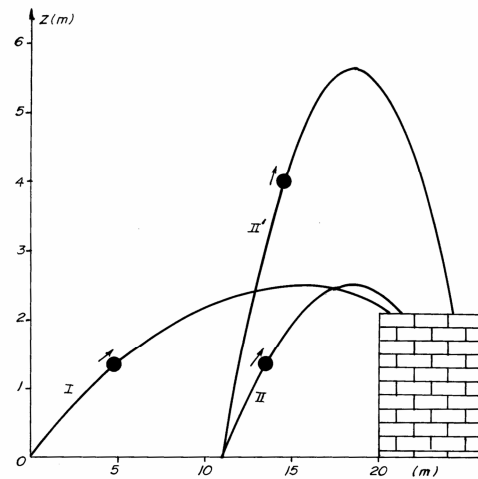

Figure 9: Trajectories of stones hurtled from the beach of Nhatrang in the hurricane No. 8, 1998

(Wave height: 2,0m; Hurtled angles:
I − 18⁰16′, II − 33⁰41′, II′ − 56⁰19′;
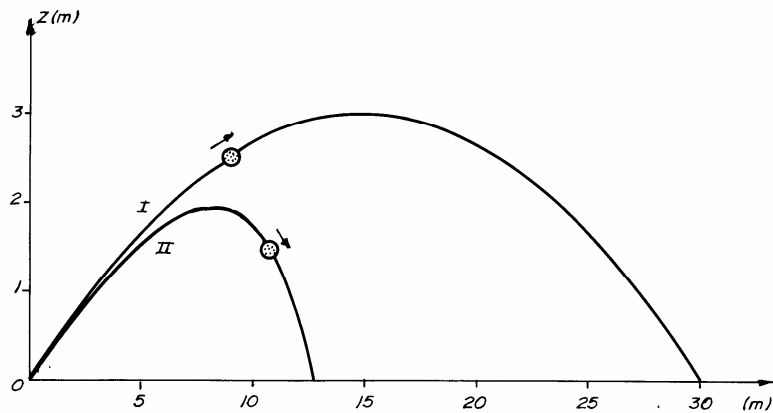Net stone weight: 165KG)

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Figure 10: Trajectories of a blocking sand mass hurtled from the beach (I) and
from the bar (II) of Cuadai because of a blow of breaking wave
(Wave height : 2,0m; Hurtled angle : 21°48'; Net sand weight : 130 KG)

Examples:

I) In the case of storm at Nhatrang beach in 13 December 1998 we have obtained: $X_1 = 25.0\,m$; $X_2 = 15.0\,m$; $Z_{1,2} = 2.5\,m$.

The results are $v_{t \succ 0;1} = 22.1\,m/s$; $\gamma = 18°26'$ and $v_{t \succ 0;2} = 12.6\,m/s$; $\gamma = 33°41'$. The respective trajectories are presented in Fig. 9.

II) In the case of measurements of material hurl in Cuadai beach (Figs. 5 & 6) we have obtained: $X = 30.0\,m$; $Z = 3.0\,m$. The results are $v_{t \succ 0} = 20.7\,m/s$; $\gamma = 21°48'$. The respective trajectory of sand body (I) is presented in Figure 10, it is given by the barabolic form. We have to use also the above numerical results of initial velocity and angle γ with some approximation of water resistance force for numerical experiment in the case of underwater hurl. The respective trajectory of sand body (II) hurtled inside the water layer is shown in Figure 10, too. Here it is taken in ballastic form.

CONCLUSION

(1) The short-term behaviours of coastal collapse & on-the-spot accumulation and material hurl in coastal zone have been observed widespreadly along the coasts of Central Vietnam. In the natural conditions they are proven as significant initial stage of general processes of coastal morphology change. Neglecting them in any investigation or practicing problems is disadvantageous.

(2) The digital signs of movement acceleration of material body in initial stage are good indicators for watching the directions of motion which characterize short-term coastal morphology change. The critical angle of coastal inclination plays role of demarcating criterion of behaviours in initial stage of coastal change. Experimental reconstruction of the trajectories of material mass taking part in the behaviours is one simple method which guides on advanced foresight on the short-term change of coastal morphology.

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