DOMINANT PROBLEMS IN THE DESIGN OF HARBOUR STRUCTURES ON MEKRAN COAST

By

DR. JAVED YUNAS UPPAL

and

IZZAT ULLAH SHEIKH

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Summary

Mekran Coast in Pakistan is a difficult site for harbour construction. However, the demand of growing fishing activities in this area is so great that small craft harbours are imperative. The important problems involved in the design of structures on Mekran Coast are wave action, coastal erosion, earthquakes, volcanic mud formation, absence of firm strata for foundations etc. Suitability of particular types of structural elements such as breakwater, quay wall, jetty or pier has to be determined in the light of these problems. Various suggestions are outlined in this paper and examples of a few relevant and recent harbour constructions in the World are also given.

Introduction

It is said that civil engineering is the art of directing the forces of Nature to the convenience of Man. But Nature, either in its brutal form of violent oceans or in its melodious manifestation of a mountain stream does not give away its natural resources so easily. Man has to exert a long way first to understand the forces through the methods of science and then through ingenuity of practical application and management he has to devise means to overcome these forces, ultimately to bring ideas to the profile of reality.

Typical is the case of the proposed harbour structures on the Mekran Coast of Pakistan. The importance of these coastal structures has come into light with the recent realization that the adjoining North Arabian Sea and lower areas of Omani Waters are infact one of the best fishing grounds of the World. In order to approach to these resources

and develop any rewarding fishing industry, a number of coastal structures on the Mekran Coast are a must. At the same time, according to civil engineering consultants,(1) Mekran Coast is one of the most difficult sites for civil engineering construction. The reasons for such a prejudice are.

1. Mekran Coast receives direct hit from the full monsoon swells and waves generated in the Arabian Sea. Estuaries giving reasonable protection are not available.

2. The coastline is being rapidly eroded because of soft to medium dense silty and clayey formations.

3. The area comes under active earthquake zone. Seismic tremors of intensity as large as 8 on Modified Mercalli scale (1931) are observed with epicenters formed directly underneath.

4. Geological formation of the underlying strata has been comparatively recent in Miocene period. The formation is not alluvial but is probably resultant of eruptions of mud volcanoes. The foundations of structures do not meet any bed rock strata to rest upon, and have to be suspended in deep strata of silty clay which is a poor medium for this purpose.

5. The climate is adverse not only in view of the enormous variation of temperatures which must be accommodated but also because of the corrosive effects of humidity and of sea salts on the structural materials which have to be protected.

6. The basic materials required for civil engineering construction such as quarry stone, aggregates, sand and soft water are hardly available in any reasonable quality. Communication system to the interior is also unreliable.

7. There are hardly any structures existing in this area which could give the engineers useful experience. Local skills of the construction industry are virtually absent.

These are some of the hazards against which the builders of the coastal structures on Mekran Coast have to work. In this paper a number of design elements are described which tend to solve these problems. Later in this paper, examples of some existing structures in the

World which are relevant to the area or which have similar problems are also given.

Requirements of structures on Mekran Coast

The main and immediate function of the required structures on Mekran Coast is to handle fishing activities. This includes accommodation of commercial fishing boats, unloading and transport of catch to processing and storage installations in the vicinity, proper care and maintenance of fishing boats, facility for preparation for the next fishing journey, and accommodation for export of fresh and raw fish through coasters and small carriers.

Fishing activity on Merkan Coast is practised by the sparse fishing communities settled in small towns of Gwadar, Pasni, Ormara, Jiwani, Pishukan, Ganz and Sur. Figure 1 gives a map of Mekran Coast showing the location of these towns. At present fishing operations are carried out with help of primitive tools and in moderately small boats. The processing and handling of fish is also being done in sub-hygienic conditions. There are however definite development programmes through which the activity is shortly being brought to modern levels and standards. With appropriate aids from the public sector it is expected that each town will soon become a self-sustained modern commercial centre. It is expected that well within the design life of the coastal structures each town will operate on an average catch of 30,000 tons of fish every year. This figure is important for the design of structures. Commercial fishing boats may be of varying size, draft and dead weight tonnage. But for the purpose of visualising the scale of the problem for designing of coastal structures, reference may be obtained from the fishing boats being handled in Seattle, Washington; USA.[2] The representative sizes are given in Table 1.

TABLE 1 : Representative Fishing Boat Samples.

Length of Boat in feet	Percentage of total number of boats	Beam maximum in feet	Maximum draft in feet
20 and under	1	3′—6″	2′—6″
20 to 30	23	7′—0″	4′—9″
30 to 40	29	6′—0″	6′—0″
40 to 50	18	10′—0″	9′—0″
50 to 60	7	10′—0″	9′—0″
60 to 70	10	12′—0″	10′—0″
Over 70	12	18′—0″	12′—0″

These figures indicate that the tentative structures should be able to handle fishing boats of lengths around 60 to 70 feet and draft 12′—0″. Such boats may carry about 5 to 10 tons of catch at one time. These boats are required to be berthed and unloading may be performed by derrick cranes. Other coasters and carriers which may be expected for export of processed or raw fish, or for other auxiliary purposes may be of 5000 to 8000 DWT size and of draft of 20 to 30 feet. These coasters may not berth and infact may be anchored in the nearby area.

In order to accommodate these activities, a basin area is to be provided in which proper berthing or anchorage can be made. Such a basin may be formed by a 'breakwater' which is a construction in the sea designed to obstruct the incoming waves. The berthing may be done at a 'quay wall', 'pier' or a j'etty'. A 'quay wall' is essentially a construction parallel to the shore where boats may be docked. A 'pier' or a 'jetty' is a construction off the shore going into the sea and is used for the same purpose of docking. Other features required are 'Moorage'; a place where boats can be parked and preparation for the next journey may be made. 'Slipways' are required to carry boats on to the ground for repairs, painting etc. and also to launch newly made boats into the sea. In addition, there may be articulations required to protect the coastline from crosion and there may be means required to stabilise the sea bed against littoral drift. 'Groynes' are vertical barriors erected perpendicular to the coastline to trap the drifting material. Size, form and layouts of these coastal elements structural depend upon the volume of

boat traffic to be handled, the wave forces and sediment movements to be controlled, and the foundation and climatic conditions to be encountered. Under the physical conditions prevalent in the Mekran Coastal area, as already listed, each individual structurat element requires a unique evolutionary design. The following paragraphs describe the lines on which the design of some of the basic coastal structural elements can be followed.

Design of basic structural elements on Mekran Coast

It has been illustrated that the tentative coastal construction will comprise of a few or more of the basic structural elements such as : breakwater, quay wall, pier or jetty, moorage, slipway or groynes. Once the purposes for which these elements are required are described and the various physical conditions and hazards are indicated, the individual design of each of these elements can follow,

1, Breakwater.

A breakwater is an articulation in the sea which obstructs the waves and thereby creates a relatively calm and still enclosure or basin behind: In North Arabian Sea, the waves are generally produced by storms and winds in the deep waters. The wave direction generally is south-west and has varied wave height and time period. Though rigorous statistical data is not available, the sources of British Meteorological Office suggest that a significant wave height of 12 feet and a time period of 10 seconds may be expected in normal storms. When the waves approach shallow waters at an angle, a phenomenon of wave 'refraction' takes place under which the incident wave height reduces. At the same time, another phenomenon known as 'shoaling' occurs due to wave energy getting confined in everdecreasing depth and this results in increase of wave height. If the wave front encounters an obstruction, a 'shadow' in the form of calmer water behind results and this phenomenon is known as 'diffraction'. There are mathematical and graphical formulations available[3,4] with the help of which the extent of refraction [5], shoaling[6] and diffraction [7] can be theoretically estimated in an area if the hydrographical surveys giving formation of bed contours are available. The location and layout of a breakwater has to be

decided upon in such a way that on one hand the required stilling basin area is obtained, and on the other the assistance of the natural refraction and diffraction is fully utilised to have minimum wave height striking at the breakwater so that economy in the design of breakwater results. This exercise is frequently conducted by experiments on small scale test models. (8) Studying the hydrographical and coastline formation of Mekran Coast, one can expect that with careful efforts, a layout may be arrived at such that the significant offshore wave height of 12 feet may actually be reduced to 6 feet at various places. The mean water depths at breakwater may only be 15 to 20 feet.

For the above figures of wave height and water depths, the type of breakwater may now be selected. The choice before the designer is between :

a. rubble mound type,
b. vertical wall sheet pile type or
c. floating barge type.

A typical rubble mound type of breakwater is illustrated in figure 2. The basic features include a bottom blanket layer provided for stablisation of the bed layers, a core of quarry stone dumped into the sea, top layers used for carrying wheel loads and the armor built of large sized stone or artificial blocks used against wave action. Since good quality stone is not available in the vicinity of Mekran Coast. and for the reasons of sea beds of low bearing capacities, this rubble mound type of construction is not very desirable.

The second type of construction is a vertical sheet pile type. Sheet piles create a vertical curtain against which the waves strike and get dissipated. Sheet piles are designed to take mainly horizontal loads and this is done by thrusting the bottom of the sheet piles on to the depth of the bed strata into which these are penetrated. The top of the sheet pile is either left free as cantilever or is anchored through ties or individual piled trestles. The individual piles take direct compression or tension. This type of construction can accommodate extensive prefabrication. utilises minimum construction materials locally and is therefore more desirable. Additional advantage is obtained if the layout is so designed that the breakwater structure is amalgamated into the berthing structure. A typical example is given in figure 3.

The floating type of breakwater is used in deep waters and specially at sites where bed strata is totally unreliable. These conditions are strictly a lot more harsh than those of Mekran Coast.

2. Quay Wall

A quay wall is essentially a structure running parallel to the shore where boats are conveniently docked and a platform connection to the shore is achieved. The common type of construction which is becoming increasingly popular is erection of a sheet pile wall with a relieving type of piled platform. The bed on seaside is dredged to obtain the required water depths and the dredged material is thrown on the landside as a backfill. However, since the dredging process is only economical for large works, and the scale of works involved on Mokran Coast is relatively small, this type of construction is not feasible here. Construction has to be done in such a way that dredging is not involved. The result is that an open pier type of construction running into sea to the required water depths is desired.

3. Pier or Jetty.

A pier or jetty is a dock which runs into sea. There are two broad types of construction :

(a) Open deck type resting on piles, and
(b) closed or solid type built as sheet pile cells or caissons.

Open deck type usually is a reinforced concrete poured-in- place, precast or prestressed deck consisting of longitudinal girders and slab or slab alone. Piles are arranged in transverse rows and are capped by reinforced concrete pile caps. This type of construction is suitable where the leads are small, the deck is narrow, the water depths are in 30 to 60 feet range, and the immediate bed strata being unreliable the loads can be transferred to underlying stronger layers. The conditions along Mekran Coast and the type of facilities needed are such that this type of construction is suitable here. A typical arrangement is shown in figure 3.

A solid type of construction is done by driving sheet pile cells capped with reinforced concrete slab at top. The cellular space is infilled with rock or coarse granular material. This type of work is suitable when the vertical loads are fairly large, the deck is wide, the water depths

are below 30 feet and the the immediate bed strata is adequately strong to withstand the gravity loads of fill and superimposed live loads. According to the requirements on Mekran Coast this type of construction has a lesser order of merit than a piled jetty type.

The important feature in the design of piers or jetties on Mekran Cosst is the provision necessary against earthquakes. Earthquake tremors cause oscillations and accelerations in the structures. An actuating force is generated which for most design purposes is assumed to act in horizontal planes. The horizontal forces are to be satisfactorily borne by tensions and compressions in the inclined or raking pile systems. Small horizontal forces can also be taken by the length of piles thrusting against the bearing soil strata. In additiou to horizontal forces earthquakes may also produce oscillations of resonating frequencies. Stiffnesses of structural elements have to be such that such damaging oscillations are not produced. It is also expected that due to earthquakes settlements of non-uniform nature may result in the underlying soft clayey strata. The statical systems of structures have to be such that differential settlements are accommodated without producing stresses of undesirable magnitude. The structures have to be loosely jointed pinned type.

Design of piles in medium dense to soft clayey underlying strata does also need careful consideration. Choice before the designer is between :

(*a*) Bored piles of poured-in-place concrete.

(*b*) Pipe piles, open or close end, in filled with concrete.

(*c*) Precast concrete piles, reinforced or prestressed.

(*d*) Steel piles.

In bored piles a casing is lowered. The core of soil is removed and reinforcing steel bars are suspended. Concreting is done starting from the bottom and as concrete comes up the casing is withdrawn simultaneously. This type of construction is not particularly suited to the clayey soil because when the casing is withdrawn the soil structure is disturbed and looses strength. Furthermore the casing cannot be removed in the water column above the bed. Bored piles cannot be set at an inclination to the vertical.

In pipe piles a steel pipe is driven into the ground with an open bottom end or closed. In case the bottom end is open the driving is

easy but the soil inside the pipe has to be blown out. Then concrete is filled in the pipe. No reinforcement is added in the concrete and the steel pipe itself is assumed to act as reinforcement. Steel, because it is exposed, has to be protected against corrosion. For this purpose bitumenastic paints or concrete collars are used in the upper portions of the piles. The bottom ends of the piles may also be given mushroom or bulb shapes so that additional bearing area is achieved. This type of construction as illustrated in figure 4 is quite suitable for the works on Mekran Coast.

Precast concrete piles are prefabricted piles which are made in a distant precasting yard or on the shore near the site. Long precast piles are difficult to handle although prestressing improves the performance during handling. Precast concrete piles also require more driving force than pipe piles. The greatest disadvantage due to which these are not suitable to the works on Mekran Coast is the fact that these piles are displacement piles. When driven, these piles would displace the clayey soil which results in upheaving and disturbs the existing piles in the vicinity.

Steel piles are easy to handle or drive. Steel piles however do not have large end bearing and have mainly skin friction to depend upon. Skin friction in clayey soils is an issue of great complexity and unreliability. Furthermore steel piles are to be imported at the expense of foreign exchange. Steel piles also need thorough artificial protection against corrosion.

4. Moorage.

Moorage implies tying of boats and provision of services. It includes elements such as fenders, bollards, floats, fuel and water supplies, and shelter in harsh weather. For relatively small boats expected on Mekran Coast the fender system can be simple creosoted wooden plank system. The wooden planks may be buried in the ground at the lower end and suspended with the deck at the top end. These units may be transversely connected so that a complete system of absorbing the kinetic energy of a docking boat may be established. The bollards may be in the form of cast iron anchore blocks fixed on the deck.

5. Slipways.

For the purpose of launching new boats or for heavy repair of these in water, slipways are required. The slipways may be in the form of longitudinal girders and transverse stiffners on piles. Rails may be fixed on the girders so that a wooden craddle carrying a boat may move.

6. Groynes.

In order to protect the coastlines against erosion or material drift, groynes may have to be constructed. These may be in the form of barriers projecting out from coastline to trap the transporting material.

Some examples of existing and relevant harbour structures.

It may be worthwhile to study some of the existing harbour structures in the world which have similar conditions or at least have utilised similar structural elements as suited on Mekran Coast. Particular attention may be given to those structures which are in the geographical vicinity. Another mark of special importance is the date of their construction. Since the technology is rapidly expanding and the desingers are learning more and more, the logical implication is that a more recent structure is a better accumulation of knowledge than a relatively old. Following examples of harbour structures may be mentioned with the suggestion of further and more detailed studies.

1. Bullenbay Oil Terminal, Netherlands.

The oil terminal consists of jetties to accommodate modern oil tankers. The project is under completion and is expected to be completed by the end of 1974. The jetty platforms are each about 100 ft. long and 42 ft. wide. The jetties are approached by a bridge of about 400 ft. length which carries a 12 ft. roadlane and an adjacent 22 ft. wide track for oil pipes. The deck of the jetties has been formed of precast slab units placed on steel beams resting on poured-in-place pile caps. The supporting structure is steel pipe piles infilled with poured-in-place concrete. The length of piles is varied with a maximum of 150 ft. The diameters are varied from 24 to 36 inches. The depth of water is about 70 to 80 ft. and the underlying bed strata is stiff clay and rock. Fendering is provided by pneumatic rubber fenders.

2. Bandar Shahpour, Iran.

Bandar Shahpour is an esturine port designed to handle mixed cargo. The project was completed in 1962. Quay structure consists of

80 ft. wide platform deck running along the shore line. Dredging has been used lo accommodate a ship draft of 30 ft. The supporting structure is vertical and raked precast concrete piles of about 90 ft. length. The bed soil consists of marine estuarine deposits of mud, clays, silts and sands of low bearing capacities with no bed rock available. The result is that the piles are designed as friction piles. The area comes under earthquake zone and the design caters for this effect. Fendering is done by 1.75 feet diameter rubber fenders fixed on shields of timber piles.

3. Wharf on River Magdalena, Colombia.

A marginal wharf has been constructed on river Magdalena in 1969. The 350×48 ft. deck structure consists of prefabricated hollow reinforced concrete main beams resting on pile caps. The top slab is 9 inches thick in situ concrete. The supporting structure consists of tubular steel piles of 14 inches diameter and 3/8 inch wall thickness. The piles are approximately 60 feet long. After driving the piles were filled with poured in place concrete.

4. Beaver Harbour, New Burnswick, Canada.

A small wharf 40 ft. wide and 406 ft. long has been built which also acts as breakwater. The deck consists of prestressed concrete channels spanning transversely 37 feet across and rests on poured in place reinforced concrete beams-cum-pile caps running continuously along each side of the wharf. Supporting structure consists of 14 inches diameter concrete filled steel piles. Along seaward side vertical and batter piles are installed in pairs at 6 ft. centres. In addition prestressed concrete sheathing is installed to act as a breakwater. This sheathing is driven 9 ft. into the bed. A gravel berm covered with rip-rap prevents erosion on the seaward side of sheathing. Along shoreward side or berthing face, vertical piles are installed at 16 ft. centres. To protect piles from corrosion they are encased in asbestos bonded asphalt coated corrugated culvert pipe with annular surface between pipe pile filled with concrete. Fendering consists of timber piles driven in subsurface and tied at top with the deck.

5. Berth 1—4, Port of Karachi, Pakistan.

The work on berths 1 to 4 has recently been completed in April, 1973. The quay is developed by a wide deck slab supported on longi-

tudinal beams. The supporting structure consists of pile caps and Rendhex steel piles of 80 to 90 feet lengths. The water depths range from 40 to 48 feet.

Conclusions.

Design of harbour structures on Mekran Coast involves a number of problems such as wave protection, earthquake action, absence of strong bearing strata, rapidly eroding coastline, corrosive climatic conditions and nonavailability of construction materials. The demand of developing fishing industry is so great that coastal structures have to be built and these hazards have to be overcome. The design of basic elements of harbour structures such as breakwater, quay wall, piers or jetties etc., can be evolved with some effort which will cater for these obstacles. Examples may also be obtained from a number of recently built harbou. structures in the World.

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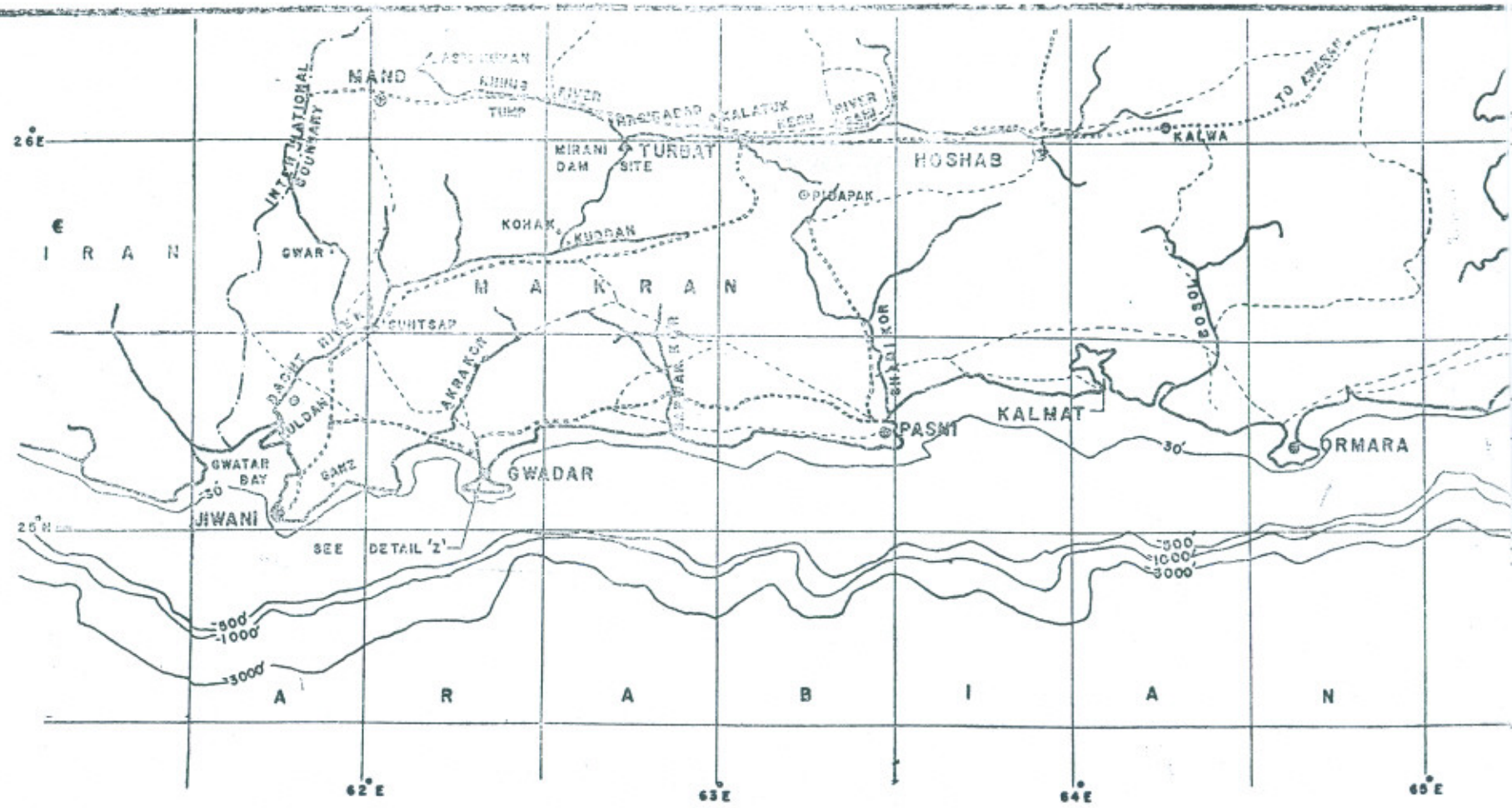

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MAP OF MAKRAN COAST SHOWING FISHING TOWNS

FIG. I

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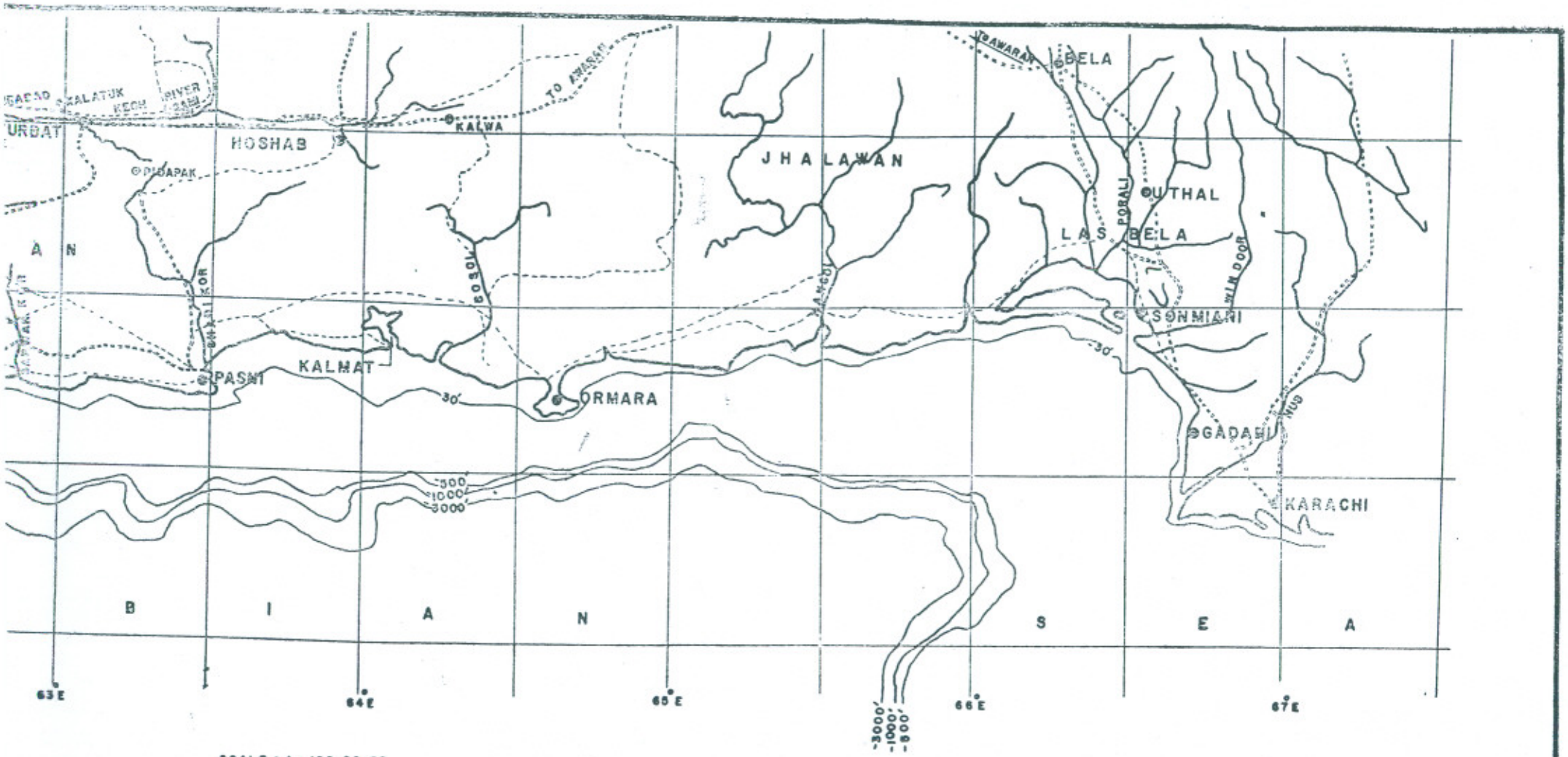
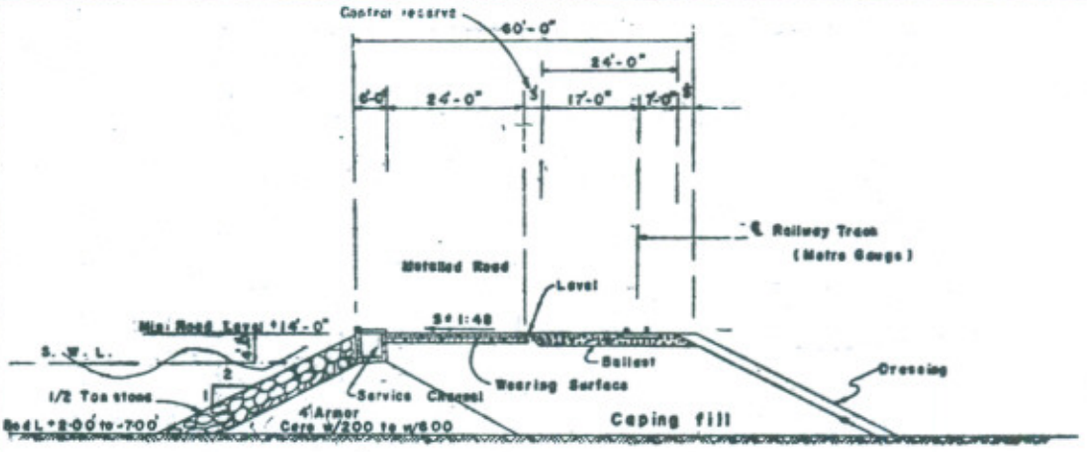


P OF MAKRAN COAST SHOWING FISHING TOWNS

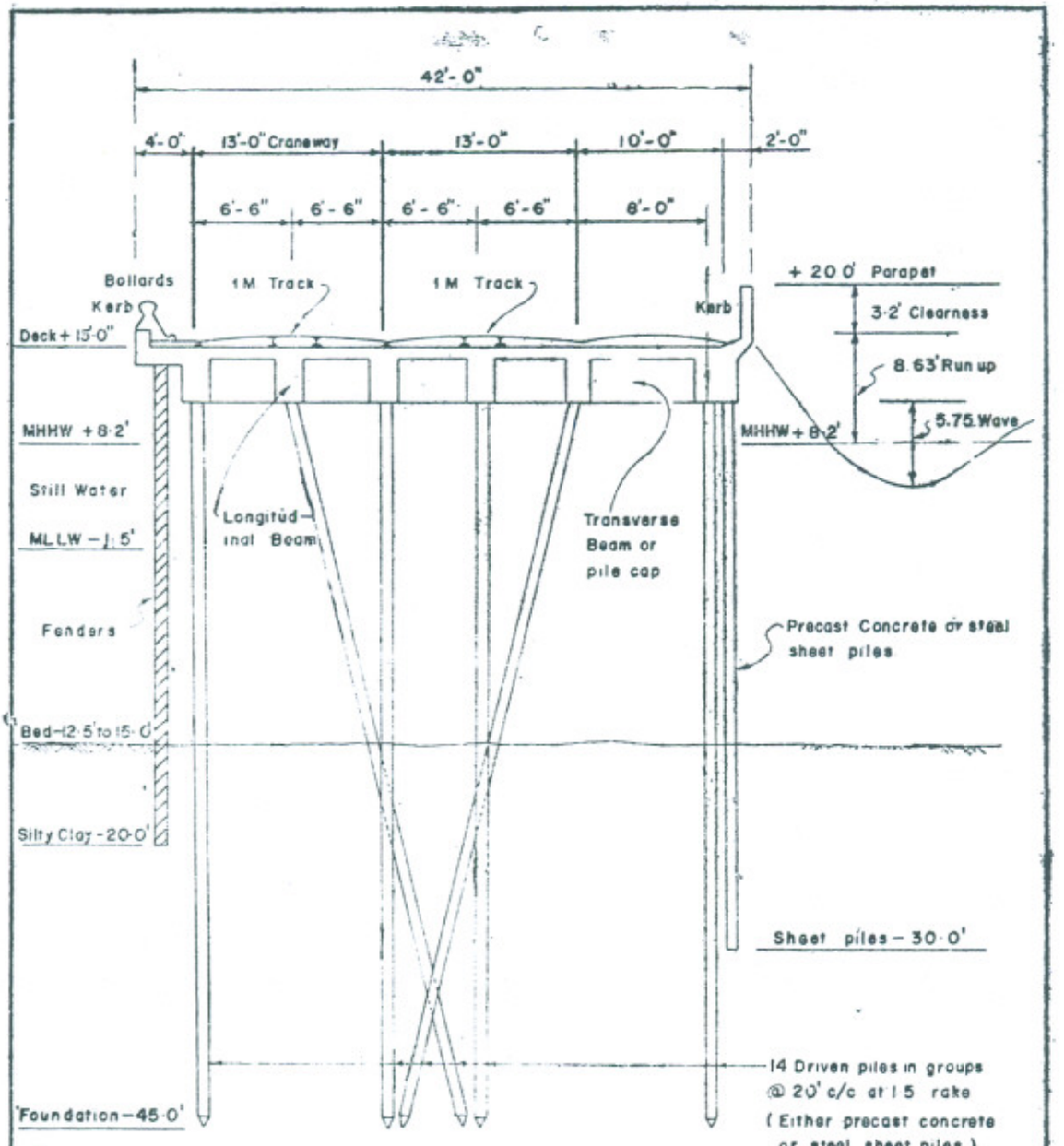
FIG. I

M.J.A



TYPICAL CROSS SECTION OF A RUBBLE MOUND BREAKWATER

FIG. 2



TYPICAL CROSS SECTION OF A PILED JETTY

FIG.3

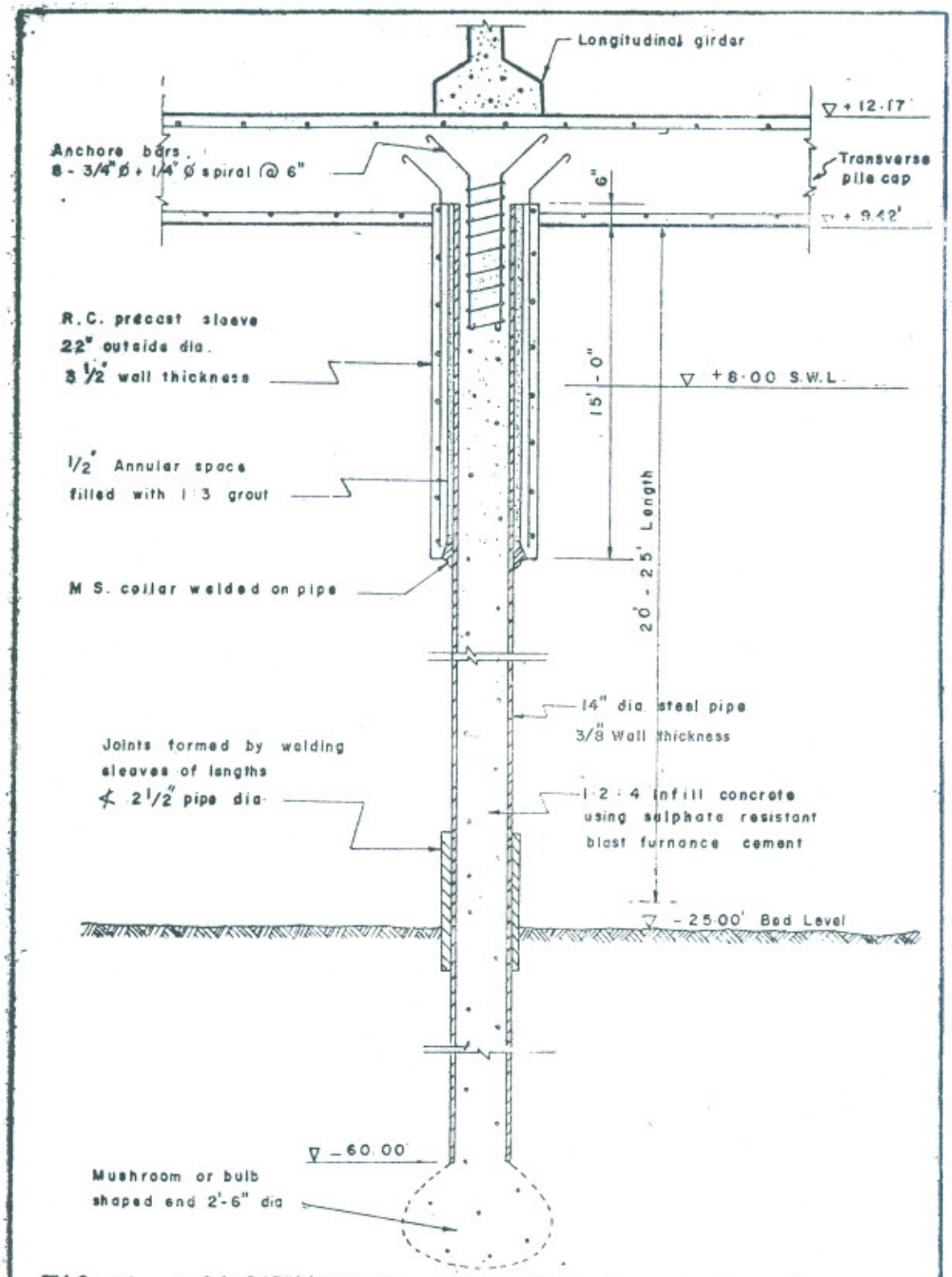
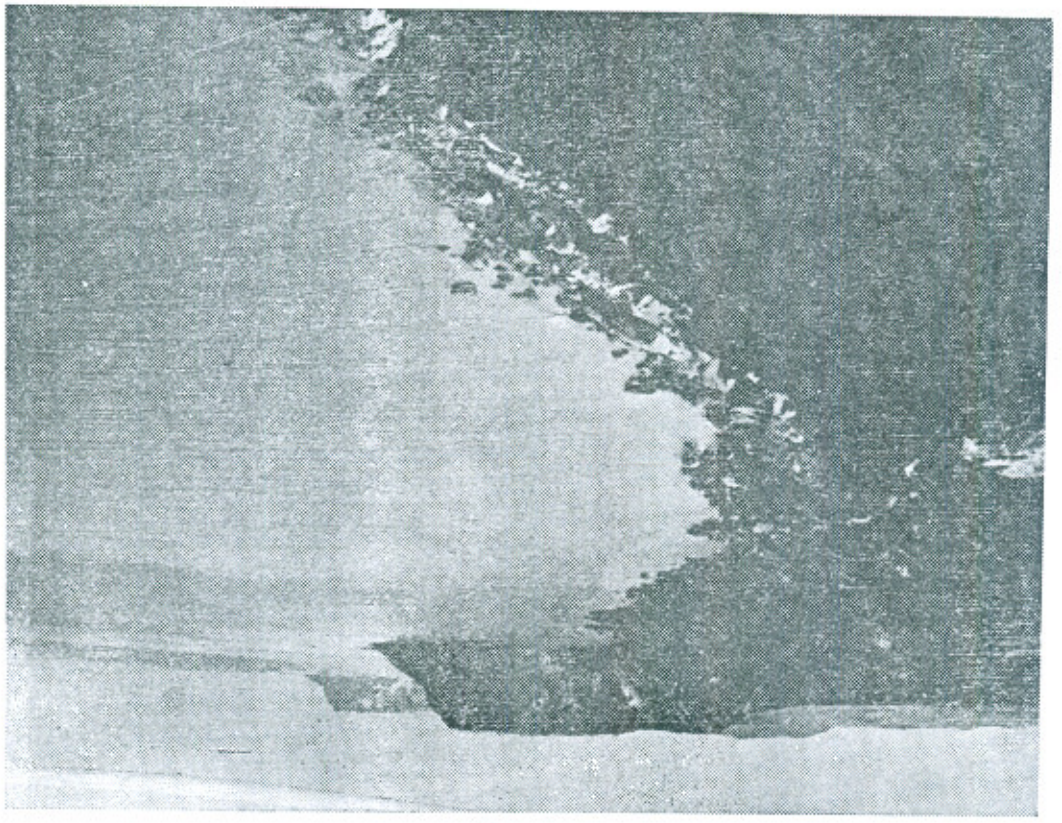


FIG. 4 LONGITUDINAL SECTION OF PIPE PILE



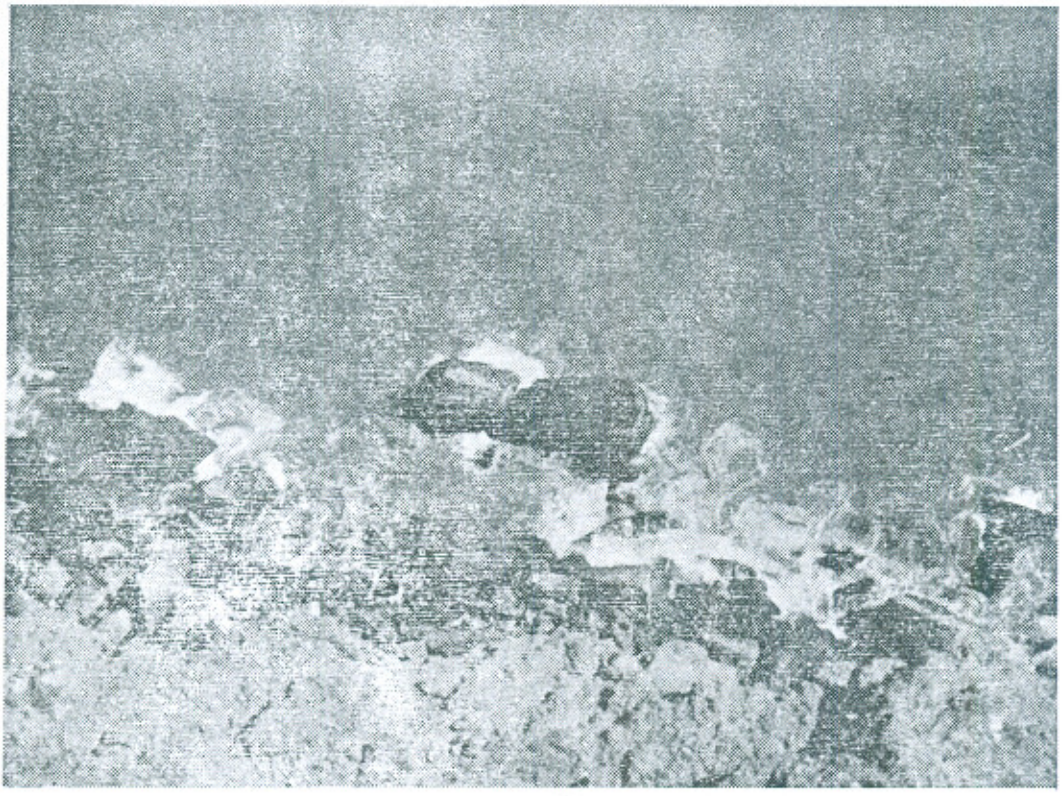


Photo No. 1&2 *Typical views of Makran Coast*



Photo No. 3 *View of Cleavages Produced by earthquakes.*