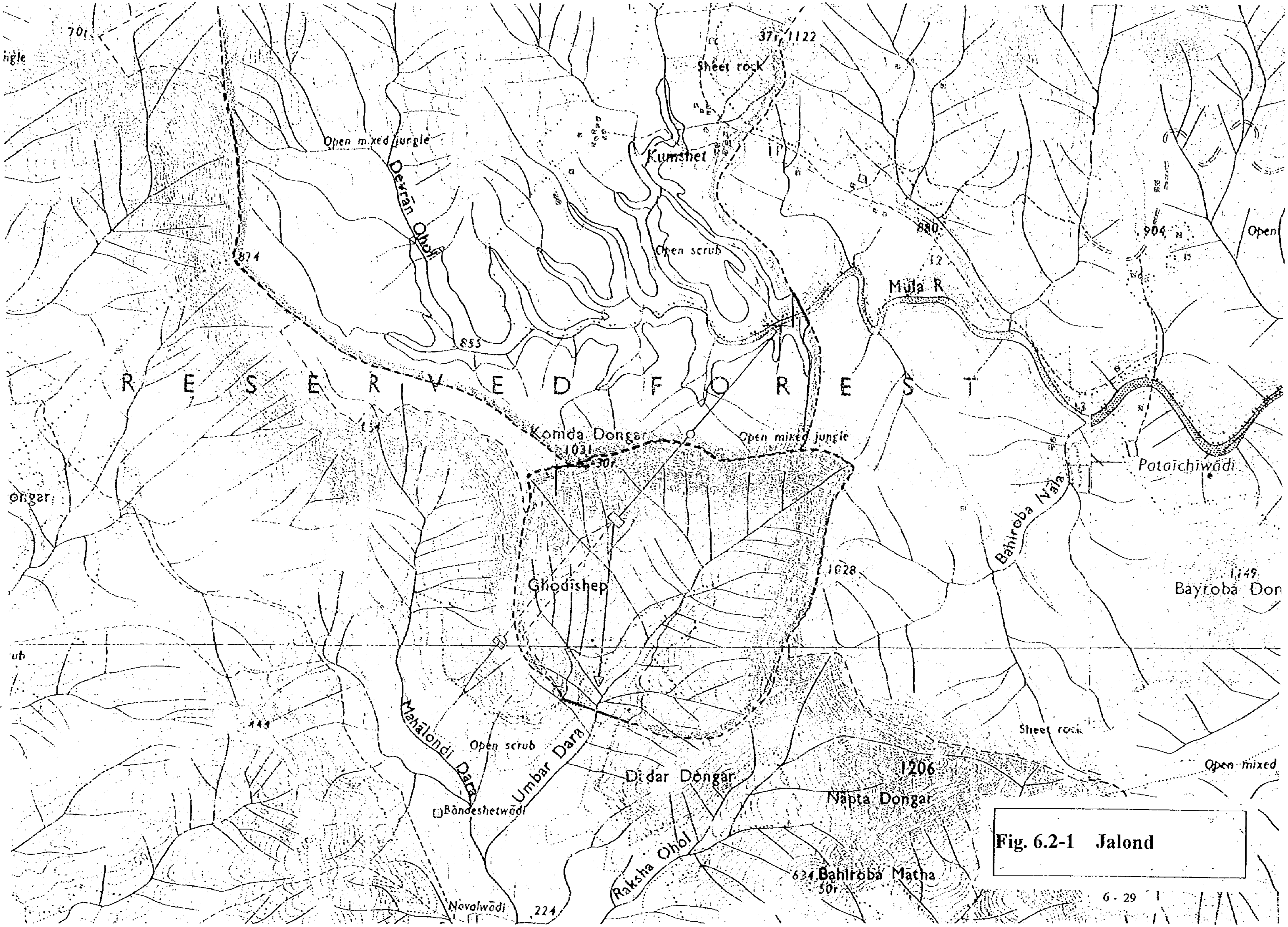

Fig. 6.2-1 Jalond

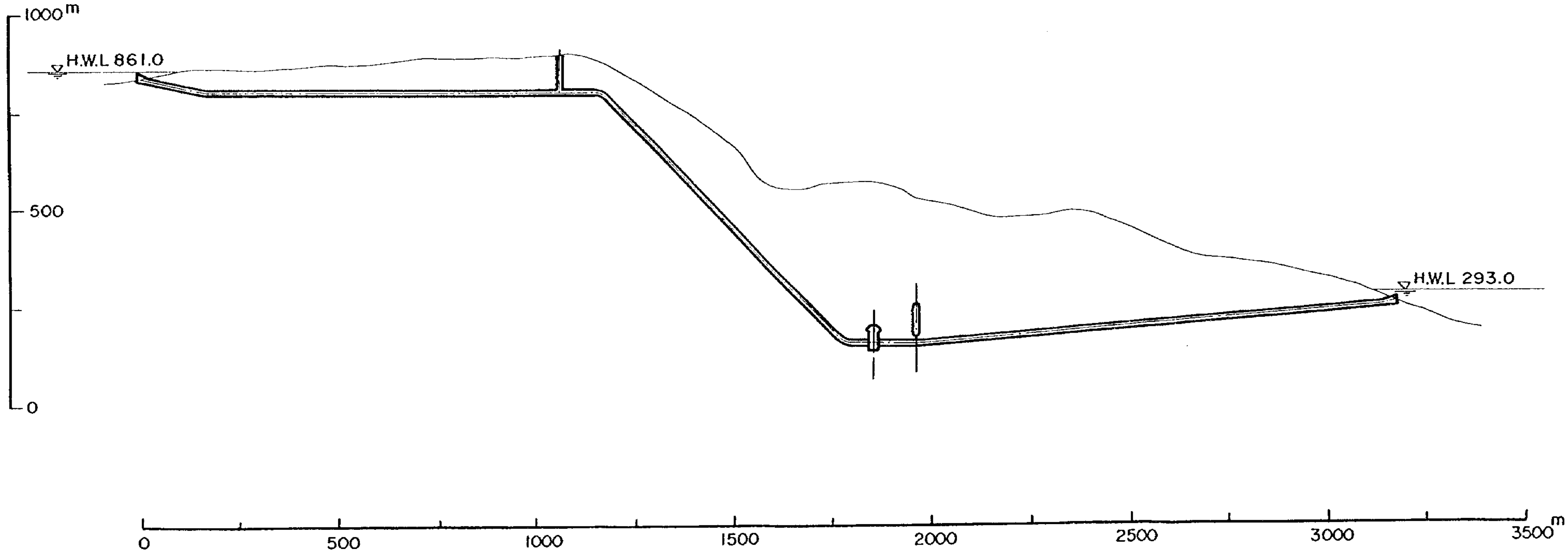

Fig. 6.2-2 Jalond

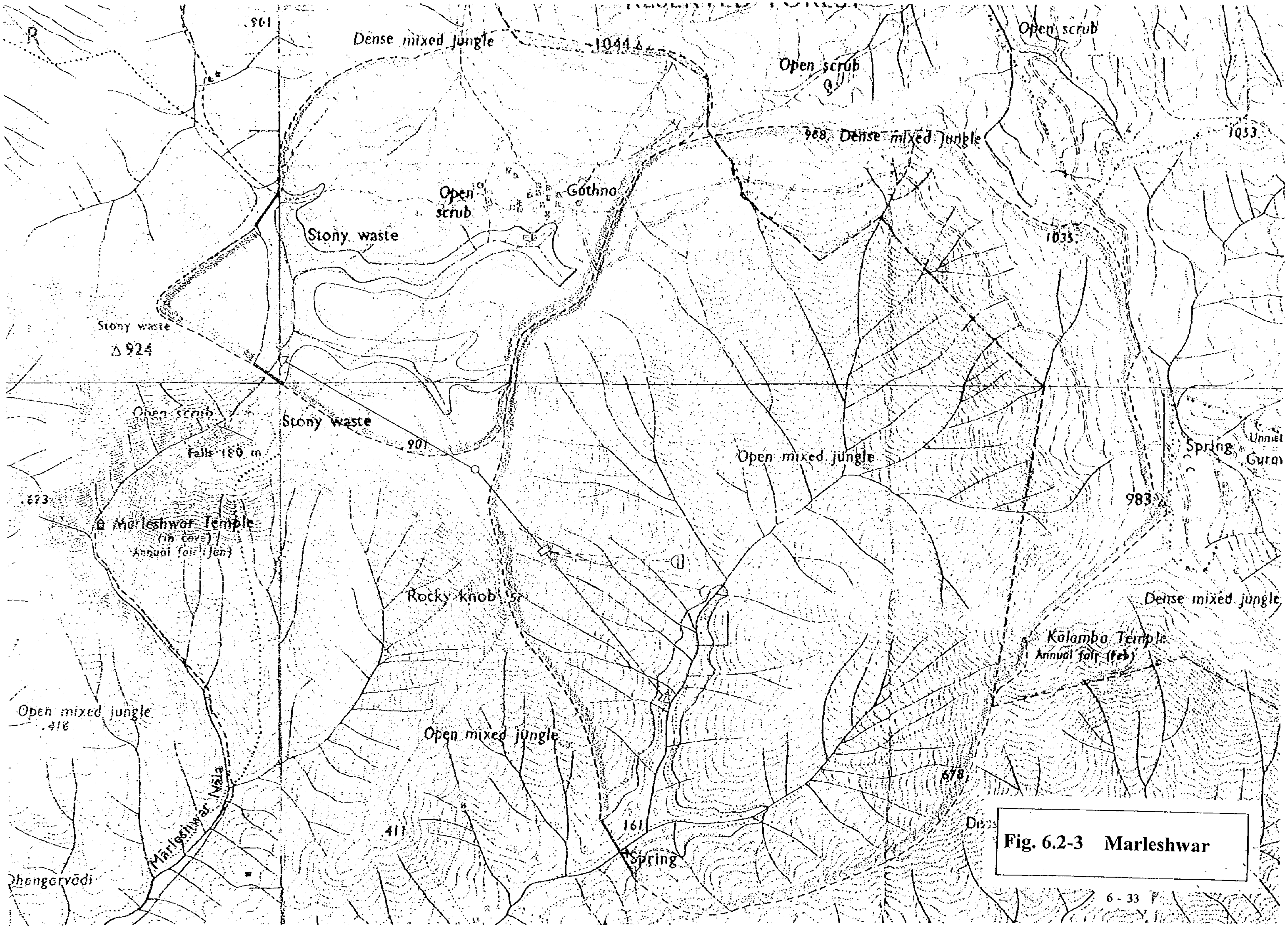

Fig. 6.2-3 Marleshwar

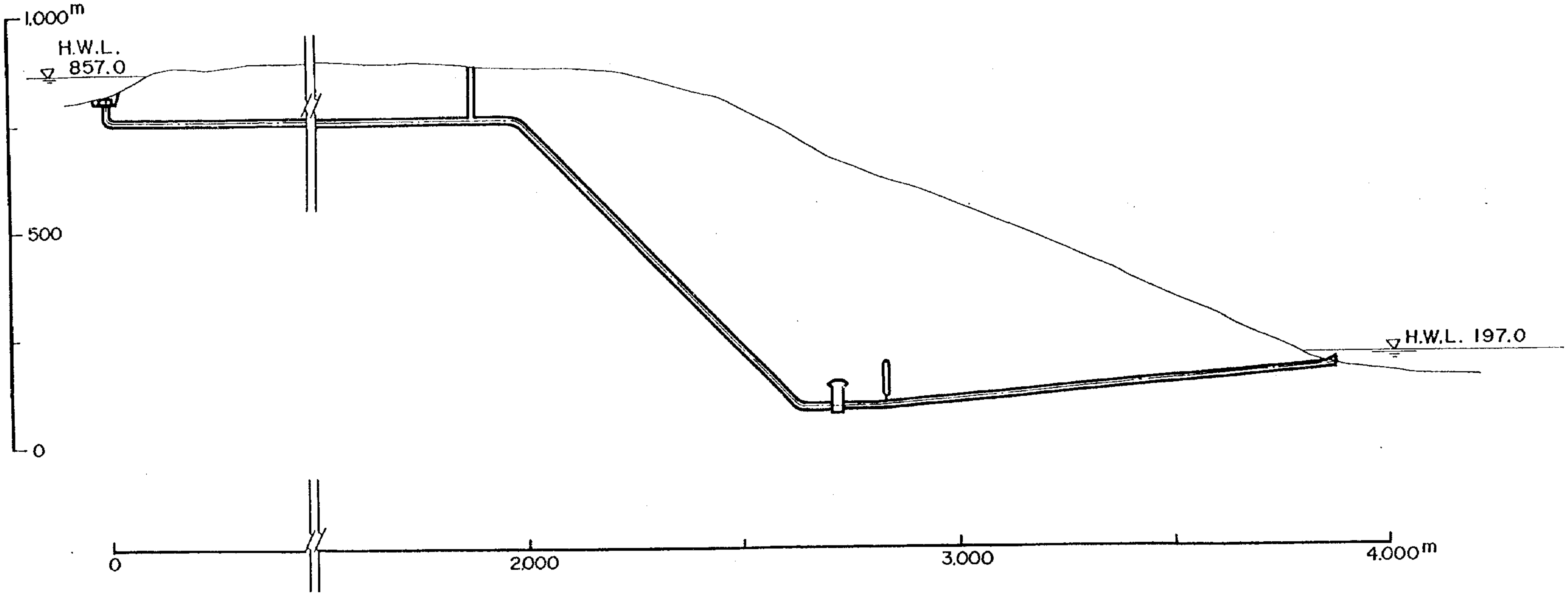

Fig. 6.2-4 Marleshwar

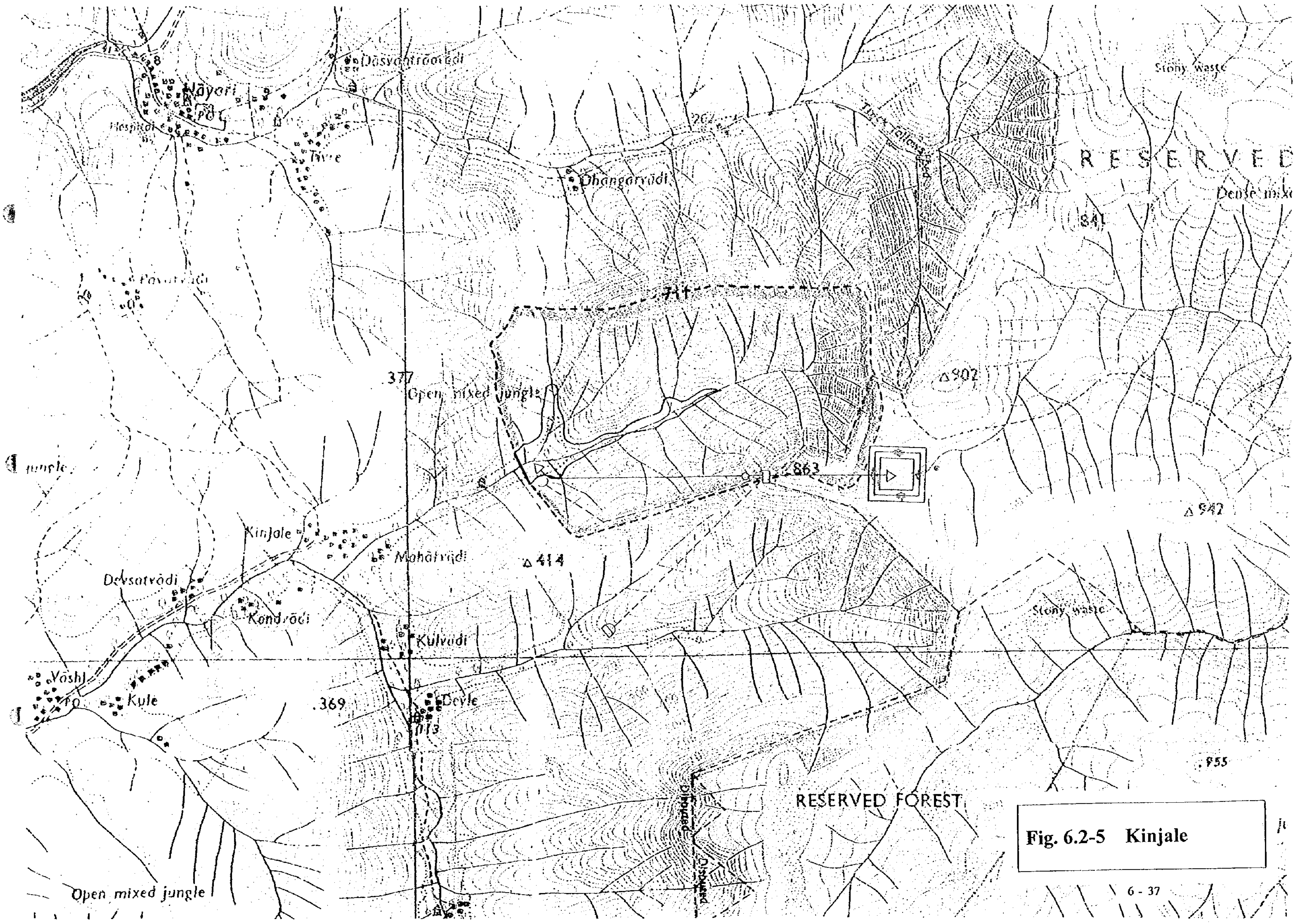

Fig. 6.2-5 Kinjale

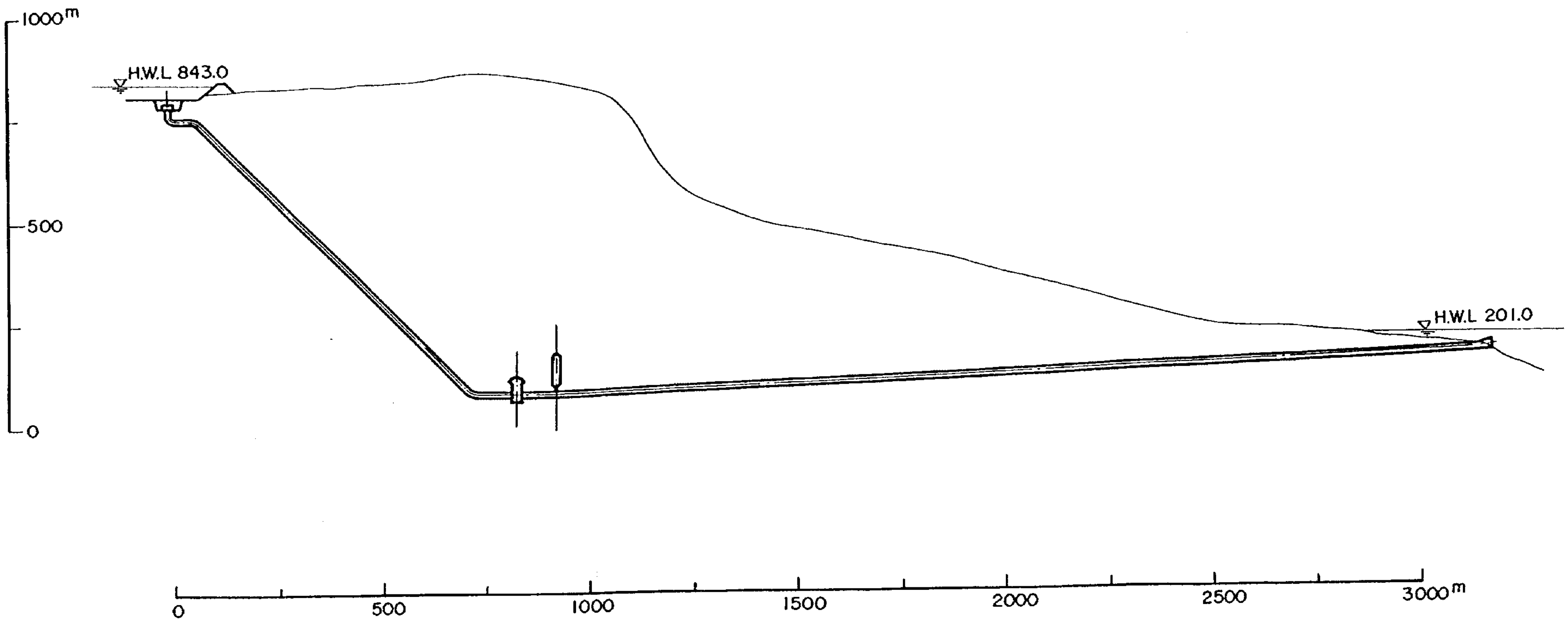

Fig. 6.2-6 Kinjale

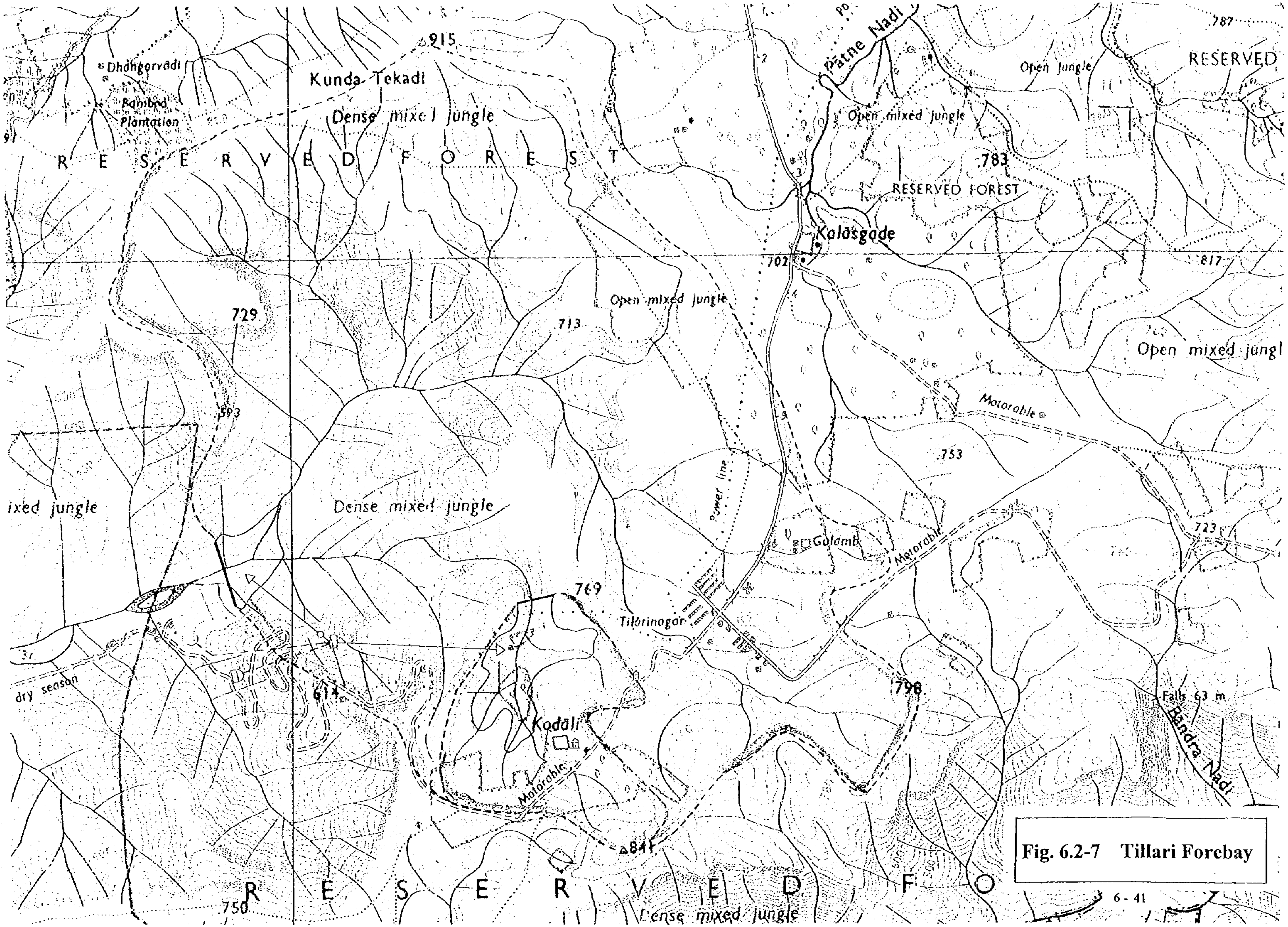

Fig. 6.2-7 Tillari Forebay

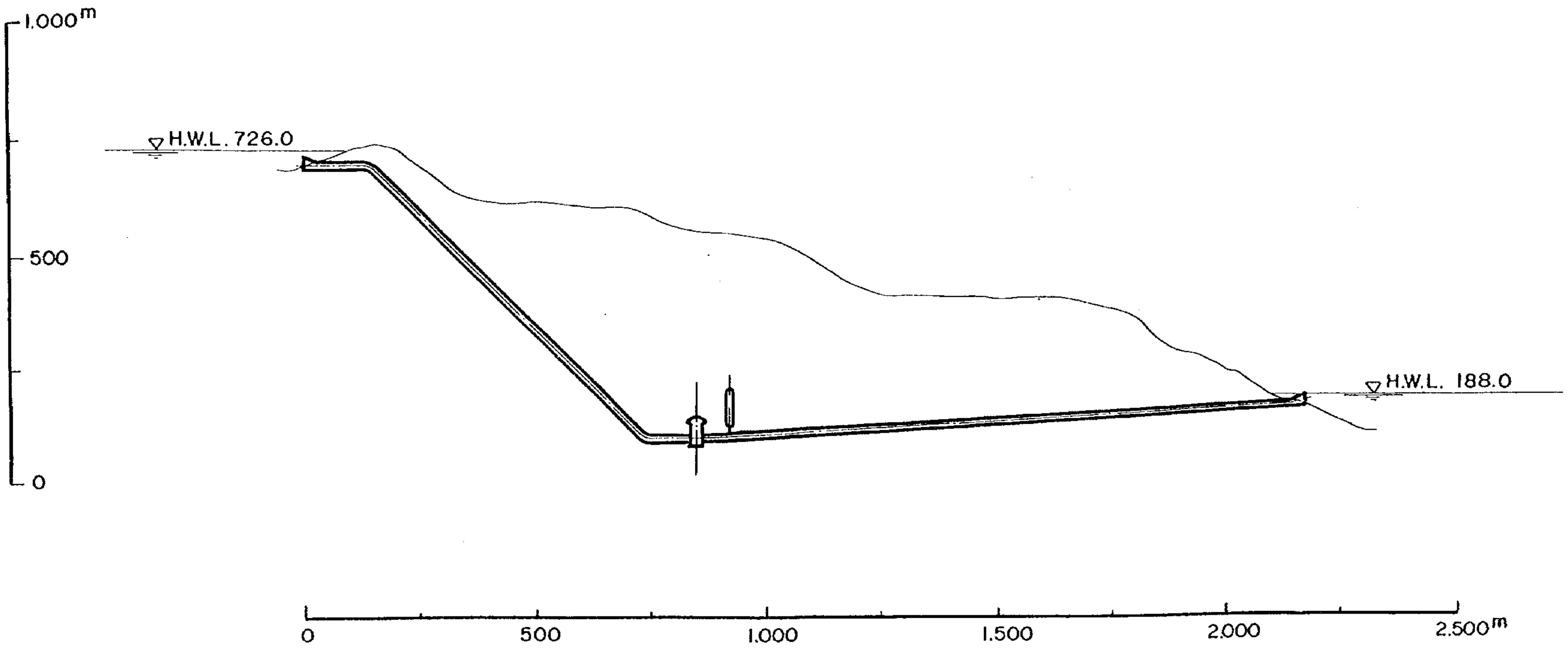

Fig. 6.2-8 Tillari Foreby

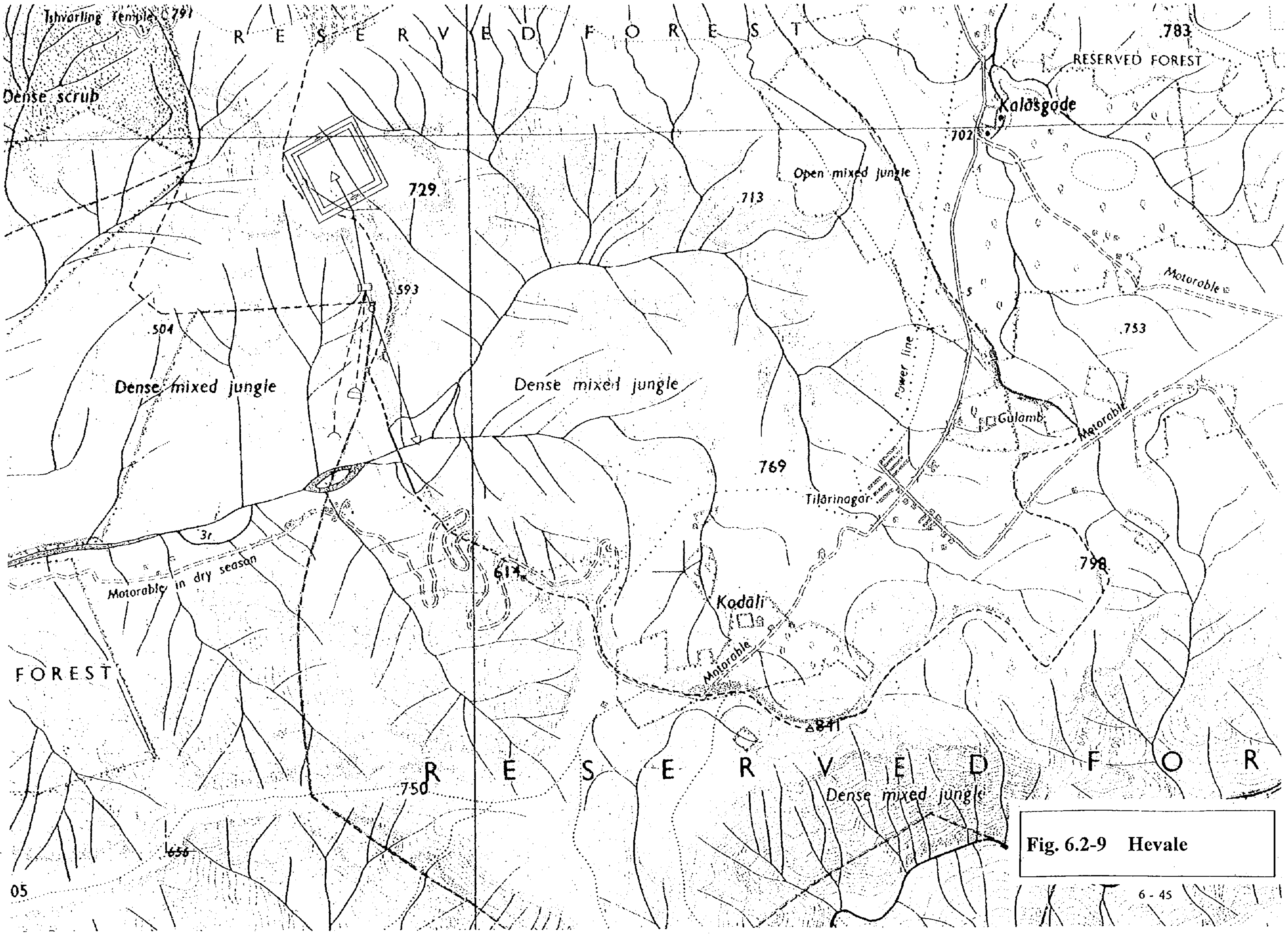

Fig. 6.2-9 Hevale

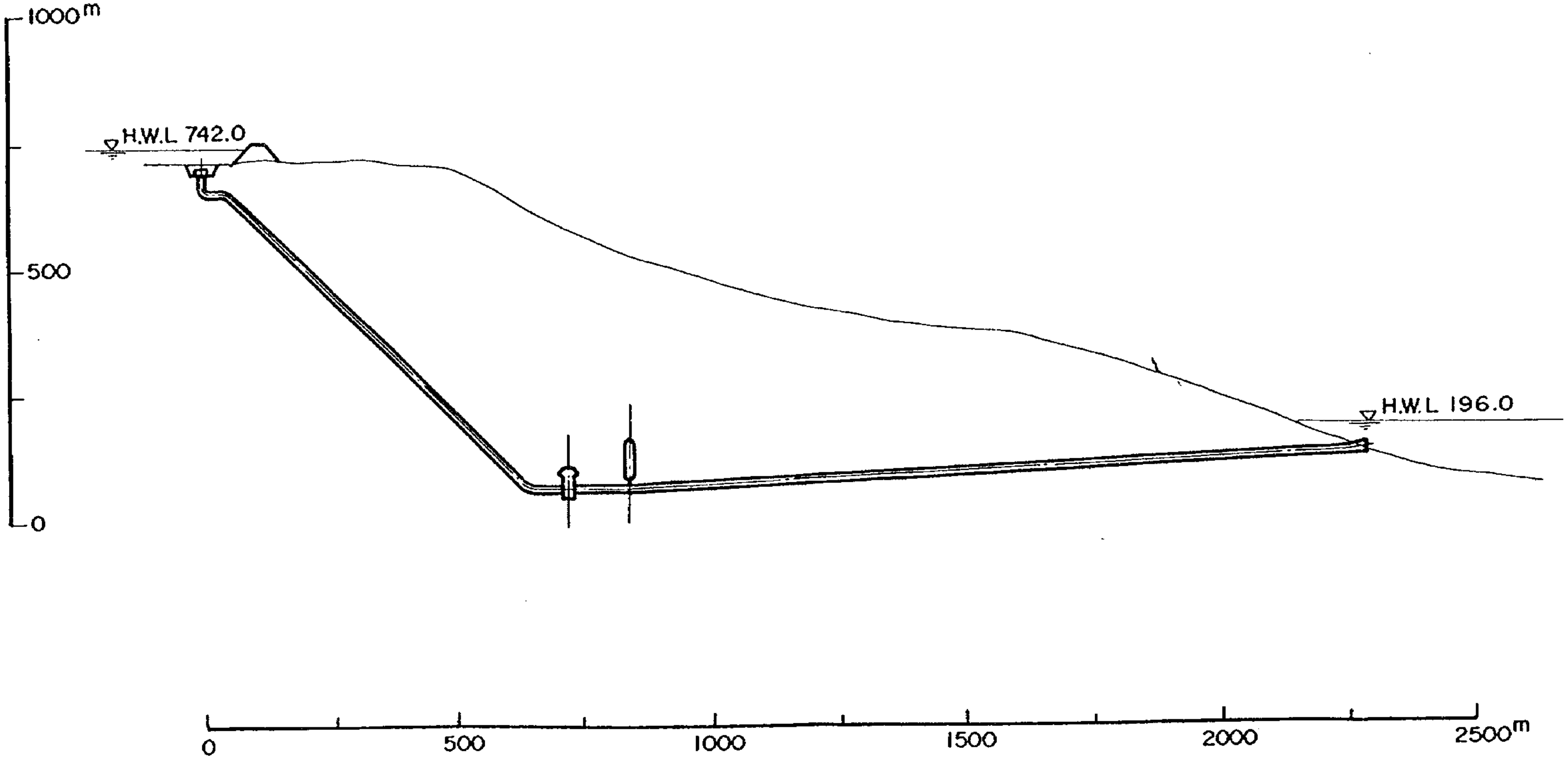

Fig. 6.2-10 Hevale

CHAPTER 7 NATURAL AND SOCIAL ENVIRONMENT AROUND PROPOSED SITE

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CHAPTER 7 NATURAL AND SOCIAL ENVIRONMENT AROUND PROPOSED SITES

7.1 Natural Environment

The proposed three sites are located in the mountain side of the Konkan region. The region lies in a high precipitation zone. The region has three distinctive seasons, namely, Summer (march to May), Monsoon (June to mid-October), and Winter (mid-October to February), and the annual rainfall exceeding 2,000 mm. The main precipitation is brought by Southwest monsoon and about 90% of annual rainfall is received in the rainy season. The average temperature in summer, monsoon and winter seasons in 1990 were 30°C, 27.5°C and 24°C, respectively. The maximum temperature of the year was 47°C, and the minimum temperature was 4°C.

Geologically, Maharashtra forms a part of the peninsula called the Peninsular Shield of India, which is considered to be a very old stable part of the earth's crust. Physiographically, the major part of Maharashtra comprises an ancient plateau exposed for long ages to denudation and approaching peneplain. The mountain systems are of the relict type, the important ones being the Western Ghats or Sahyadri, ranging from north to south, parallel to the coast for almost the entire length of the State with a general elevation of 550 m above the mean sea level. Eastwards, there are plains of Maruthcoda, Khandesh and Vidgrbha. Melghtt range which is a branch of Satpyra hills is on the northern side of the State. It is generally accepted that the western coast has been formed as a result of faulting. The Western Ghats, as a result, comprise the Deccan trap lava flows which are several hundred meters thick near the coast and gradually thin out eastwards. The geographical distribution of minerals in the state have a relation with the type of geological formation in any region. Geologically, the region is formed mainly by layers of basaltic lava. The upper reservoir sites are situated at the elevation of around 700-900 meters from the mean sea level, and the lower reservoir sites around 200-300 meters.

The Western Ghats, where proposed projects sites are located, is one of the evergreen forest regions of the country. The Hevale site comes entirely under semi-green reserved forest, whereas the Jalond and Marleshwar sites comprise both forest and non-forest land including some agricultural land. Forest in Maharashtra is known to be rich in biological diversity. India is rich in biological diversity, with 75,000 species of animals and over 45,000 species of plants. As for the latter, there are 15,000 species of flowering plants, 5,000 of algae, 1,600 of lichens, 20,000 of fungi. Many of these plants have medicinal properties. Although the region still maintains diverse animal and plant communities, the forest degradation is comparably high.

7.2 Social Environment

No villages will be directly affected by the project at any of the three sites, although a few villages are located in the immediate vicinity of the Jalond and Marleshwar sites. Villagers lead a self-sufficient life, cultivating non-irrigated and less fertile land and gracing cattle in stony waste land. They grow rice, bajari, nagli and other crops. Some villagers work in Mumbai during the off-season. Villages have no public facilities, except primary schools with one or two classrooms. Electricity is available, but not all the households are under contract to receive power service. Water source is usually wells and occasionally river water. During the dry season, some villages are provided with tanker water.

Agriculture has been a major occupation for the inhabitants of the rural regions of Maharashtra State. However, except sugarcane, the agricultural production per hectare in Maharashtra is less than the national average. The agriculture, mostly, has to depend on monsoon rain. The central regions of Maharashtra have less rainfall in the monsoon season. The irrigated land out of the total land sown in the State is only 13%. The corresponding figures for other States are higher, mostly, 30-90%. The amount of fertilisers used in the State is 66 kg/ha, which is grossly less compared to the corresponding figures for other States, which often exceed 130 kg/ha. About 70% of the people in Maharashtra depend on agriculture, while only 12% of the total cultivated area is irrigated. The principle food crops are wheat, rice, jowar, bajari and pulses, and the important cash crops are cotton, sugarcane, groundnut and tobacco. Villagers near the project sites earn their living by cultivating small, less fertile land and by keeping cattle. Some of the villages are inhabited by tribal population.

Generally, permanent migration does not take place for the general areas of the Jalond, Marleshwar and Hevale sites. On the other hand, seasonal migration from other states or regions does take place; but it is limited mostly to workers who are brought by contractors for various construction activities for roads, dams, buildings, etc. In Hevale, it has been reported that workers are brought for bamboo cutting. Basically, these workers return to their native places after the completion of work.

The State Government has plans to ensure safe water supply to rural population of the State. The progress in this context, however, is still poor, and villagers still have to depend upon the water supply from shallow wells. These wells often dry up in dry seasons; and the villagers have to transport water from long distances. The incidence of water-borne diseases such as typhoid, cholera, dysentery, and other diseases caused by water-borne parasites such as guinea worm becomes high, although those diseases occur sporadically, and do not reach epidemic proportions.

CHAPTER 8 ROUTES TO PROJECT SITES

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CHAPTER 8 ROUTES TO PROJECT SITES

8.1 General Conditions of Access Roads

Automobiles were used to travel to the sites. Locally obtained jeep-type vehicles were then used to travel between the lodgings to villages neighboring the dam sites. In most cases, the site reconnaissance carried out from these villages to the dam sites were done on foot.

National highways were used to travel between the sites. These national highways are single-lane in both directions and are mainly straight, leading across open fields with wide shoulders which provides good visibility. Road maintenance is relatively good and all the national highways are paved. However, the pavement often suffers damage in the rainy season with overall repair work conducted in all sections after the rains end of rainy season.

Traffic is heavy. This is mainly due to large vehicles such as trucks for material transportation, local buses operated in Maharashtras State, and long-distance buses running between the states. With these large vehicles, there is also a mixture of automobiles, jeep-type vehicles, motorcycles, scooters, auto-tricycles, bicycles, and ox drawn carts.

The traffic on the local roads which connect the national highways is somewhat similar to that of the national highways except there are fewer large vehicles and the roads are narrower.

The final access roads that connect the towns located along these local roads and villages in the vicinity of the dam sites are very different, being narrow, rarely paved and with very uneven, rough surfaces. The roads in the vicinity of the villages near the dam sites are only as wide as the average automobile, and there are sections which are impassable for vehicles other than jeep-types.

Site reconnaissance around the dam sites were conducted on foot. The dam sites and reservoir areas are farmlands and grass lands. These are covered by shrubs with networks of footpaths. Here, local people as well as cattle and sheep grazing in the pastures passed on a few occasions during the survey.

We experienced no problems in movement because this reconnaissance was in the dry season. However, movement during the rainy season is seen as extremely difficult. This is also seen as true of travel on the national highways at that time.

8.2 Joland

8.2.1 Upper Reservoir

The village in the neighborhood of the upper reservoir is Kumshet in the Ahmednagar District. The starting point for Kumshet is Rajur which is located on a local road that connects Ghoti on National Highway #3 and Sananmner on National Highway #50. The following shows the approach to the site;

From	To	Type to Road	Distance (km)
(1) Mumbai	Ghoti	National highway	115
(2) Bhiwandi	Rajur	Tar Road	30
(3) Turn-off	Kumshet	Jeepable Read	25
(4) Kumshet	Dam site	On foot	2

The roads between Rajur and Kumshet can be traversed by jeep-type vehicles. These roads present a mixture of paved and unpaved sections. The road turns to west at a point 11 km from Kumshet and thereafter becomes very narrow and unevenly surfaced.

Except for the dam site itself, the reservoir areas in the present plan is farmland and movement by Jeep was also possible.

There is a regular, once-a-day round trip bus service to Kumshet.

8.2.2 Lower Reservoir

The village in the neighborhood of the lower reservoir is Merdi in the Thana District. The starting point for Merdi is a point 42 km toward Bhiwandi from Otur located on a local road that connects Bhiwandi on National Highway #3 and Ale on National Highway #50.
Merdi is 6 km to the north from this turn-off.
The following shows the approach to the site;

From	To	Type to Road	Distance (km)
(1) Mumbai	Bhiwandi	National Highway	25
(2) Bhiwandi	Turning	Highway	85
(3) Turn-off	Merdi	Tar Road	6
(4) Merdi	Navalwadi	Jeepable Road	2
(5) Navalwadi	Damsite	On foot	2

The study team moved from the rest house at Bandaradara Dam where we stayed at Merdi via Rajur and Otur.

The road between the Turning and Merdi is asphalt pavement and provides good visibility and easy driving. A bus service is available to Merdi. The survey team changed from automobiles to jeep-type vehicles at Merdi to move further into the village of Navalwadi. From there we walked to the dam site. Jeep-type vehicles were used between Merdi and Navalwadi and, as there were no roads, we drove across farmlands and the like.

8.3 Marleshwar

8.3.1 Upper Reservoir

The village in the neighborhood of the upper reservoir is Gothna in Ratnagiri District. The starting point for Gothna is a point 26 km towards Kolhapur from Sakharpa located on a local road that connects Pali on National Highway #17 and Kolhapur on National Highway #4. The team advanced another 24 km from here, then turned to north for Gothna. The Kadvi Dam is under construction at a point 8 km from this turn point. The following is the approach to the site;

From	To	Type to Road	Distance (km)
(1) Mumbai	Pali	National Highway	290
(2) Pali	Turn-off	Highway	42
(3) Turn	Entrance to Gothna	Jeepable Road	24
(4) Entrance to Gothna	Gothna	Jeepable Road	6
(5) Gothna	Dam Site	On foot	2

The study team stayed at a private guest house in Amba, 18 km from Sakharpa in the direction of Kolhapur. The road from the Turning to entrance to Gothna is single-lane only. The traffic on this road is relatively heavy due to trucks hauling earth and sand, probably for use in the construction of the Kadvi Dam. This road is paved up to the Kadvi Dam. Other sections of the road are unpaved and after the dam, becomes a steep gradient with many hairpin curves.

There is a road between the entrance to Gothna and Gothna which although extremely uneven, can be traversed by jeep-type vehicles. This road runs through the projected reservoir site between Gothna and the dam site. Most of the area in these sections are flat farmland and pasture.

8.3.2 Lower Reservoir

The village in the neighborhood of the lower reservoir is Bamnoli in Ratnagiri District. The turning for Bamnoli is 2 km toward Sakharpa from Devrukh which is on a local road that connects Sakharpa and Sangameshwar on National Highway #17. Bamnoli is located 13 km north-east from this turning. On the way, there is a divergence to Marlshwar Temple which is located by a waterfall in the lower reaches of the upper Dam. The following shows the approach to the site;

	From	To	Type to Road	Distance (km)
(1)	Mumbai	Sangameshwar	National Highway	355
(2)	Sangameshwar	Turn-off	Tar Road	18
(3)	Turn-off	Bamnoli	Tar Road	15
(4)	Bamnoli	Dam Site	On foot	2

The study team lodged at the rest house in Devrukh. The tar road that runs through Devrukh is a by-path running from Sangameshwa to Sakharpa and although paved, is narrower than the other local roads.

It is almost the same as the road to Bamnoli, but a section from a point 1 km short of Bamnoli onward is unpaved. We walked from Bamnoli to the dam site along the cultivated farmland lining the riverside.

8.4 Hevale

8.4.1 Upper Reservoir

To reach the Upper Reservoir of Hevale turn right at Motanwadi, which is 11 km short of Tilarinagar which is on the tar road that connects Changad and Tilarinagar, then a further 5 km to get near the Ishvarling Temple, then walk another 2 km to the south through bush land. The following shows the approach to the site;

From	To	Type to Road	Distance (km)
(1) Mumbai	Kudai	National Highway	470
(2) Kudai	Changed	Tar Road	68
(3) Changed	Motanwadi	Tar Road	13
(4) Motanwadi	Ishvarling Temple	Tar Road	7
(5) Ishvarling Temple	Dam Site	On Foot	2

8.4.2 Lower Reservoir

The lower reservoir is located in the neighborhood of the Tillari Hydro Power Station that utilizes the same road. The direct access road is 25 km south of Chandged which lies between Kundai on National Highway #17 and Belgaum of the Karnataka State on National Highway #4. The following shows the approach to the site;

From	To	Type to Road	Distance (km)
(1) Mumbai	Kudai	National Highway	470
(2) Kudai	Changed	Tar Road	68
(3) Changed	Tilarinagar	Tar Road	24
(4) Tilarinagar	Dam Site	Tar Road	5

While the approach from Tilarinagar to the site is relatively easy, permission from MSEB is required to go to the lower reservoir site, since it is necessary to pass through the power station site which is under the control of MSEB. There are also many hairpin bends in the steeply inclined road to the lower reservoir.

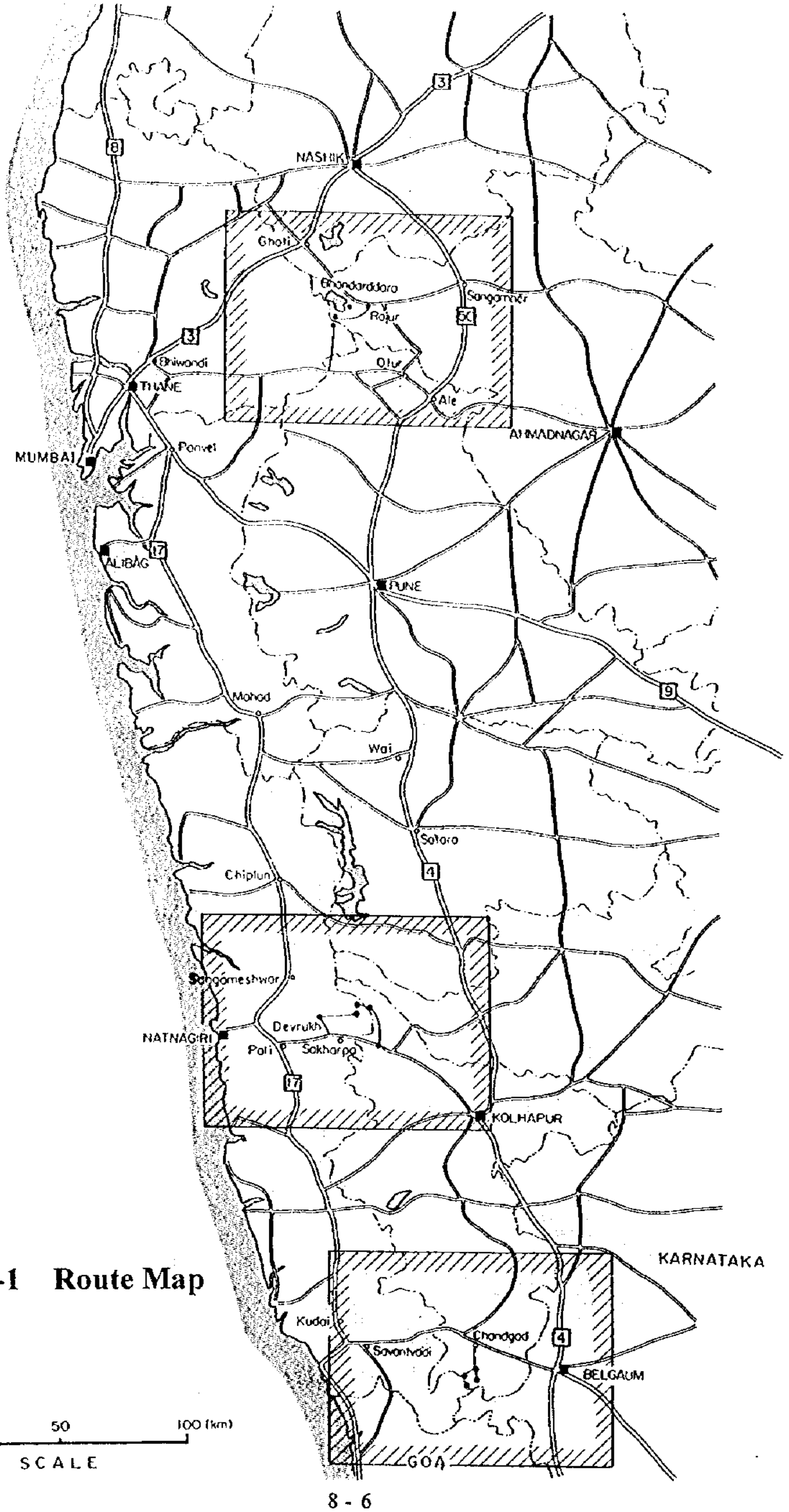

Fig. 8.1-1 Route Map

0 50 100 (km)

SCALE

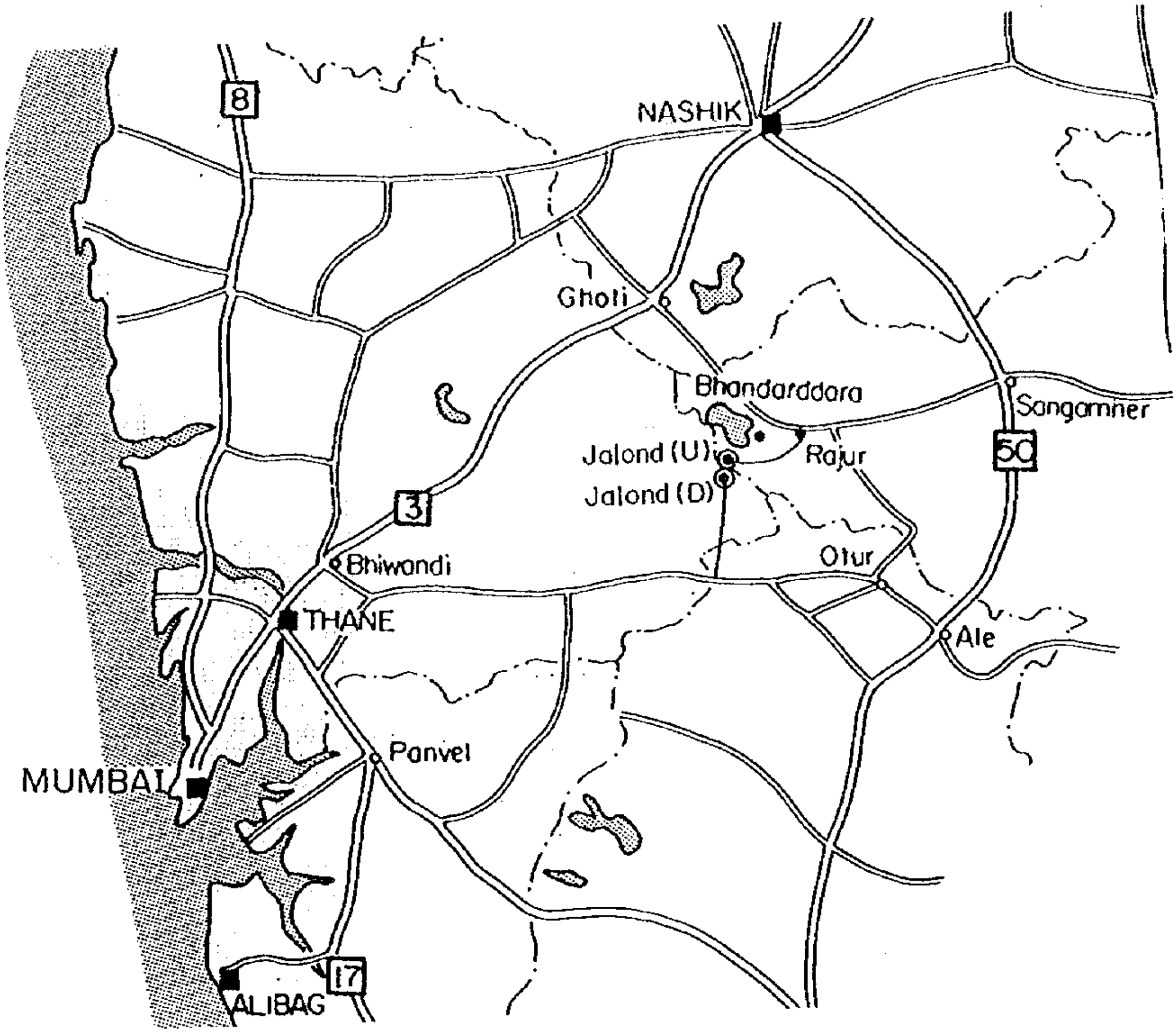

Fig. 8.2-1 Access Route (Jalond)

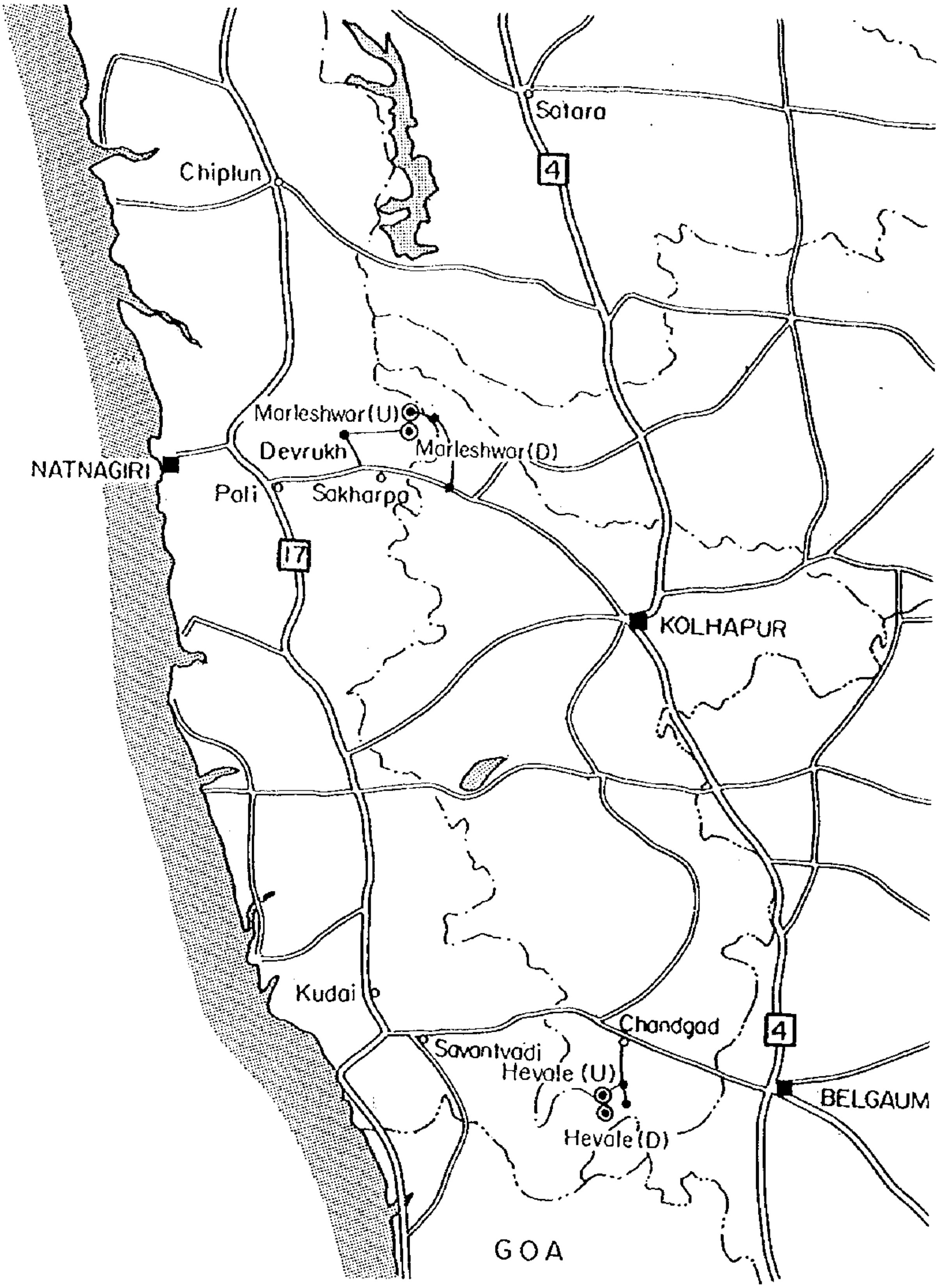

Fig. 8.3-1 Access Route (Marleshwar and Hevale)

Photo 8-1 National Highway

Photo 8-2 Highway

Photo 8-3 Jeepable Road (near Jalond)

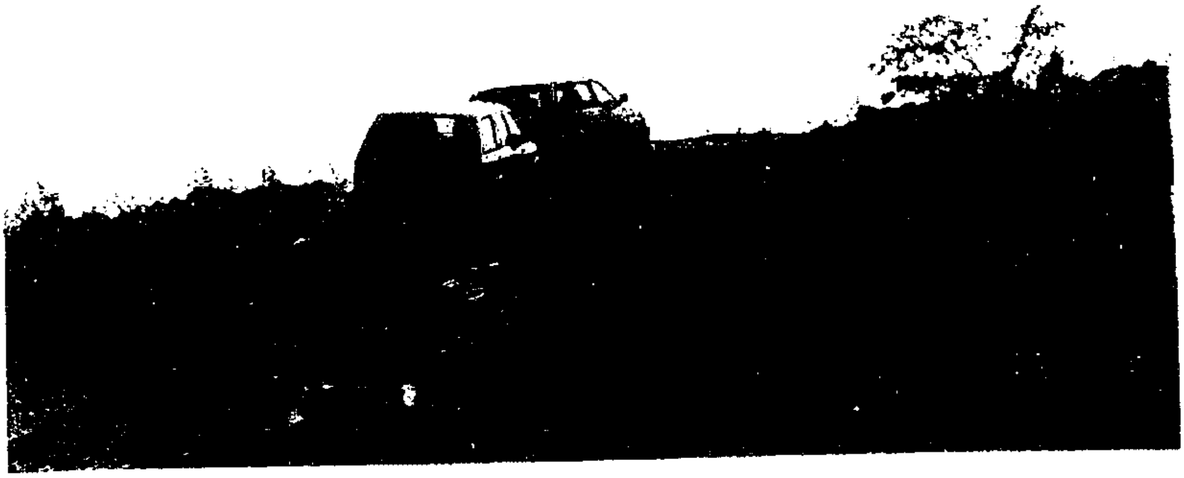

Photo 8-4 Jeepable Road (near Jalond)

Photo 8-5 Jeepable Road (near Marleshwar)

Photo 8-6 Site Investigation on Foot (near Jalond)

CHAPTER 9 TOPOGRAPHICAL SURVEY

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CHAPTER 9 TOPOGRAPHICAL SURVEY

9.1 Preparation of Topographical Map

9.1.1 General

The objectives of the topographical survey (hereinafter referred as the "Survey") are to take aerial photographs at a scale of 1:20,000 covering the three surveys areas of approximately 145km in total and prepare topographical maps at a scale of 1:10,000 covering the same area of approximately 285sq.km with intermediate contour of 5m, as shown on the planning map.

The Survey area covers three proposed areas (Jalond, Marleshwar, Hevale) in Maharashtra state. Survey areas of three sites are as follows:

(1) Jalond 95sq.km
(2) Marleshwar 110sq.km
(3) Hevare 80sq.km

Actual survey works will be carried out by JICA Survey Team in collaboration with a Indian Survey Team.

9.1.2 Scope of Work

In order to achieve the objectives mentioned above, the Survey covers the following work items and quantities;

Items and Volume of the Work

Work Items	Volume	Remarks
Signalization	22 points	
Monumentation	22 points	
Aerial Photography	145 km	Scale 1:20,000
Ground Control Survey	22 points	GPS survey
Leveling & Pricking	230 km	Direct leveling
Field Verification	285 sq. km	
Aerial Triangulation	75 models	
Plotting, Editing and Drawing	285 sq. km	Scale 1:10,000

9.1.3 Operational Standards of the Survey

Survey standards and map accuracy are as follows;

(1)	Geodetic reference ellipsoid	:	Everest 1830
(2)	Datum of height	:	National Bench Marks of INDIA
(3)	Map projection	:	Lambert
(4)	Map scale and Contour interval	:	Map scale 1:10,000 Intermediate contour 5 m
(5)	Map style and application rule	:	Those adopted by the Survey of India
(6)	Maplaccuracy		
	(a) Planimetry of conspicuous ground features	:	Not more 1.0 mm on the map
	(b) Spot height	:	Note more than 2/3 of the contour interval
	(c) Contour Line	:	Not more than 1/1 of the contour interval
	(d) Grid tick	:	Lambert grid lines shall be drawn every 10 cm on the map

9.1.4 Work Plan

The Survey shall be carried out under a three-phase program starting from March,1995, and accomplishing in July,1996. It shall consist of the following three phases in accordance with the time schedule.

The Survey of phase 1 shall be exclusively executed by the Team.

Those of phase 2 and phase 3 shall be carried out by the Survey of India who shall be entrusted and supervised by the Team.

Phase 1. (March, 1995)
Planning and Preparation of the Survey (Including the drawing up of P/O)
Field Reconnaissance

Phase 2. (From October, 1995 to March, 1996)
Signalization on control points
Monumentation of control points
Aerial Photography
Leveling

Pricking

Geodetic Control Point Survey

Field Identification

Aerial Triangulation

Phase 3. (From May, 1996 to July, 1996)

Stereo Plotting

Compilation

Drawing

9.2 Modification of Scope of Work

Accordingly to the original work plan the aerial photography covering Jalond, Marleswar and Hevale was scheduled to be conducted and thereafter a topographic maps of a scale of 1:10,000 would be made on the basis of those aerial photos. However it was found that the Survey of India had already done the aerial photography. The team therefore decided to cancelle the aerial photography and carried out technical support and management for preparation of topographical maps by Survey of India.

GOMID made application to Ministry of Defence regarding taking out of topographic maps. Ministry of Defence did not permit it.

CHAPTER 10 GEOLOGY

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CHAPTER 10 GEOLOGY

10.1 Geology

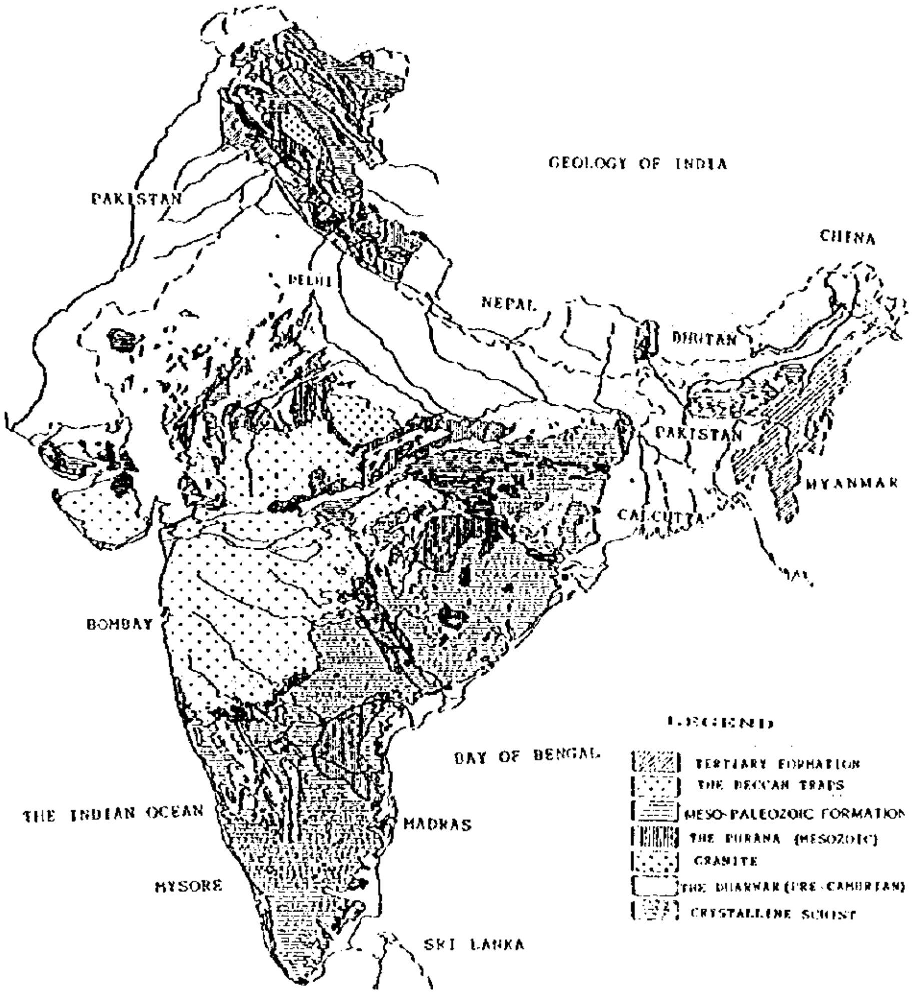
10.1.1 Geology of Peninsula India and of Maharashtra State

(1) Geology of Peninsula India

Topographically and geologically, the Peninsula India is divided into 3 zones of 1) Himalaya, 2) Ganges River and 3) Deccan Traps.

Himalaya is formed by mountainous areas extending for 2,414 km from Kashmir to Myanmar. Himalaya causes abundant rainfall in its southern area by stopping the wet monsoon blowing from the south-west. Along the Ganges River, the broad alluvial plain extends east-westerly from Himalaya to the delta in Calcutta. The weather is dry in the upstream area and wet in the downstream area along the Ganges River. The Deccan Traps are formed by 400 to 1,200m high platform. Western Ghatso Sahyadri (mountains) located at the west of the traps is the highest ridge and the traps slope gently eastward. The traps are in the semi-arid climate.

The geological map of India is shown below:



Geological Map of India

The geology of India is outlined as follows:

(a) Quaternary

Major Quaternary in India is alluvium along the Ganges River and laterite in the hilly areas. The alluvium along the Ganges River is estimated to have the maximum thickness of 1,830m in Bihar State and 2,000m in Calcutta. The laterite is estimated to have been formed in Pleistocene.

(b) Tertiary

Major Tertiary extends from Kashmir State in the southern Himalaya to Brahmaputra in Assam State. It consists of marine, lake and delta deposits formed in the Eocene to the lower Miocene, respectively. These deposits are overlain by fresh water deposits of Siwalik formation in the middle Miocene to the lower Pleistocene. The Siwalik formation consists of fluvial and subaeolial deposits and its estimated thickness is about 9,000m. The formation is estimated to have been overthrusted at the end of Himalayan orogenic movement. The Laki formation containing lignite and the Surma formation containing oil reservoir are also known as the Tertiary.

(c) Tertiary to Cretaceous (Deccan Traps)

Basaltic rocks at the Deccan Traps were formed in this period. The basaltic rocks consist of numerous lava derived from fissured eruption and the lava is stacked up countlessly. The lava interbeds dark thin tuff and freshwater deposits locally. A wide range of rock types such as Rhyolite, Trachyte, Syenite, Diorite, etc. are also found as lava and dyke. Underneath the basaltic rocks, there are marine, fresh water, lake deposits, limestone and some deposits formed during Cenomanian marine transpression.

(d) Mesozoic to Paleozoic

(i) Mesozoic

Lilang formation, Kioto limestone and Bpiti shale belong to the Mesozoic. Giumal formation in the Cretaceous consists of sandstone and shaly quartzite and Lameta formation consists of thick fluvial or lake deposits.

(ii) Paleozoic

Formed in the Cambrian were Haimanta formation and Garbyang formation consisting of limestone, phyllite, calcareous sandstone and dolomite sandstone. Ordovician to Silurian, Silurian to Devonian, and Carboniferous to Permian are also found in a complex manner. They consist of sandy shale, limestone, conglomerate, quartzite, phyllite, etc.

(e) Gondwana System

The geological formations in this system are formed in the Permian to the Jurassic and distributed in valleys at Damodai, Mahanadi, Son, Narmada and Godavari. The formations consist of freshwater, lake and fluvial deposits of conglomerate, shale and coal. Gondwana is known as Gondwanaland which is an ancient continent including Australia, Antarctica, Africa, South America and the south of Ganges River in India. The Gondwanaland was divided into several continents and drifted apart since the early Triassic Time. This is known as a plate tectonics. The name "Gondwana" is derived from Condo Kingdom of ancient India. The formation was found in Normada which is located in the south of Gondo Kingdom.

(f) Granite

Main granitic intrusion took place in the periods of Shampion Gneiss time, Peninsula Gneiss time, and Closept Granite time. Other late intrusion is estimated to also have taken place in the early Paleozoic, late Eocene and Miocene.

(g) Dharwar System

Dharwar system consists of green rock, hornblende schist, quartz schist, gneiss, banded iron ore, crystalline limestone, cordierite gneiss, granitic rocks, etc. This system is categorized as Basement Complex, but the geological age of this system has not been clearly established (probably the lowest Pre-Cambrian).

(h) Crystalline Schist

Crystalline Schist widely distributes in South India. The relationship with the Dharwar system is not clear and the geological age has not been established. At the Hevale site, the schist lies unconformably under the basalt of Deccan Traps.

(2) Geology in Maharashtra State

Geology in Maharashtra is shown on the geological map of Maharashtra (**Fig. 10.1-1**) and the Quarternary map in **Fig. 10.1-2**.

Geological Formations of Maharashtra

Age	Geological Formation	Major Rock Type
Quaternary		Older Alluvium of flood planes of rivers. Laterite and bouxite
Eocene ~ Cretaceous	Deccan Traps	Basalt, Rhyolite, Trachyt, Diorit, etc. In the Deccan Trap basalt, the vesicles are usually filled with one or more of the secondary minerals such as zeolites or different forms of silica or chloro-phaeite.
Cretaceous	Infratrappeans	Cherty limestone, Calcareous sandstone.
Lower Cretaceous ~ Upper Carboniferous	Gondowanas	Buff and olive colored shale. ,Sand-stone, Conlomerat, Coal bed, etc.
Early Cambrian ~ Late Pre-Cambrian	Vindhyans	Limestone, Shale, Sandstone
Pre-Cambrian	Kaladgis	Conglomerate, Quartzit, Sandstone, Shale, Limestone, etc.
Pre-Cambrian	Dharwar	Mica schist, Quartzit, Hematite, Calcgranulit, Mable, Amphibolit.

(3) Basalt of Deccan Traps

Among the above geological formations, basalt of the Deccan Traps is widely encountered in the proposed project sites and its characteristics are described briefly as follows:

(a) Most of basalt is Tholeiitic and has porphyritic texture. Phenocryst consists of plagioclase such as anorthite and bytownite, augite and olivine. The basalt with olivine is called Olivine Oasalt. The plagioclase is generally 3 to 10mm in diameter and sometimes reaches 50 to 100mm in diameter. The basalt including large plagioclase is called Giant Phenocryst Basalt, which was not found in the proposed project sites.

(b) Practically, the basalt is classified visually into the Compact Basalt and Amygdaloidal Basalt based on amounts and size of gas cavity or vesicular. Basalt having intermediate features is temporarily called Porphyritic Compact Basalt or Porphyritic Amygdaloidal Basalt. The gas cavity is filled with zeolite, silicate minerals, chlorophaeite, etc.

(c) In the upper and lower reservoirs in Marleshwar, a few layers of 4 to 10m thick reddish Volcanic Breccia are embedded in the basalt. The breccia is locally Tachylytic with 1 to 1.5m in thickness and is brittle. Matrix of the breccia is generally weak. However, the breccia is feasible as foundation of the proposed dam if the breccia is not heavily weathered or altered.

(d) At each site, the surface of basalt flow consists sometimes of brittle and glassy basalt with a thickness of 0.5 to 3m. This basalt is called Tachylytic Basalt (Basaltic glass). The colour of the Tachylytic Basalt is black at the upper reservoir in Hevale and red in Marleshwar. This basalt contains numerous micro cracks. Solid cores can be obtained by drilling, but they are broken into pieces in a few days after sampling. Therefore, the cores were kept in paraffin wax. The Trachylytic Basalt gives difficulties in stability of cut slope and excavation because of its brittle feature. Practically, grouting into the basalt is not effective, therefore, the basalt is usually replaced by better materials such as concrete.

(e) Basalt in Marleshwar and Jalond has partially or entirely experienced hydrothermal alteration. The degree of alteration varies from location to location.

(f) Compact Basalt extends widely and thickly. At the proposed sites, the Compact Basalt has a thickness ranging from 20 to 50m or more. The basalt in Deccan Traps is generally water-tight. However, the non-vesicular Compact Basalt is more permeable than Amygdaloidal Basalt because the basalt is severely fissured. The Compact Basalt is feasible as construction materials, but large size of materials are not able to be obtained from the Compact Basalt because of its fissure.

(g) Each flow of the Amygdaloidal Basalt is thin and not laterally continuous. However, numerous flows are stacked up and eventually form very thick mass. The basalt is massive, and has few fissures. Its strengths are greater than 300 kg/cm^2. Therefore, the Amygdaloidal Basalt is better as foundation of the dam than the Compact Basalt.

(h) Previously, the zeolite in vesicle of the Amygdaloidal Basalt was suspected to react to cement. However, the recent research proved that the zeolite does not react to cement. Accordingly, the Amygdaloidal Basalt can be used as aggregate although it contains zeolite.

(i) Fine aggregate is hardly obtained from the river deposits along the rivers near the project sites. If the fine aggregate is produced from the basalt, massive or less fissured basalt such as the Amygdaloidal Basalt needs to be used. The other types of basalt such as basalt with columner joints are not suitable to produce fine aggregate. Heavily weathered Amygadaloidal Basalt is suitable neither for producing fine aggregate. Zeolite in the fine aggregate is not a problem as mentioned earlier. The materials are usually obtainable within 3 to 5km in distance.

(j) Properties of Basalt

Compressive Strength and Absorption

Rock type	Compressive strength (kg/cm^2)						Absorption (%)		
	Dry			Wet			Min.	Max.	Ave.
	Min.	Max.	Ave.	Min.	Max.	Ave.			
Compact Basalt	344 (102)	2,814 (1,616)	1,295	315	2,710	1,290	0.10 (0.50)	1.76 (6.10)	0.67
Amygdaloidal Basalt	180 (262)	1,433 (1,070)	681	90	1,360	659	0.55 (1.02)	6.40 (4.20)	3.44
Volcanic Basalt	117	522	406	21	168	90	0.52	6.88	4.46

Modulus of Elasticity and L-wave Velocity

Rock type	Modulus of elasticity ($\times 10^5$ kg/cm^2)						L-wave velocity (m/sec)		
	Dry			Wet			Min.	Max.	Ave.
	Min.	Max.	Ave.	Min.	Max.	Ave.			
Compact Basalt	6.77 (1.23)	9.95 (10.12)	8.25	—	—	—	5,441 (2,646)	6,055 (4,930)	5,837
Amygdaloidal Basalt	1.87 (1.50)	3.56 (9.30)	2.56	1.67	3.20	2.47	3,774 (3,231)	5,761 (5,190)	4,573
Volcanic Basalt	1.04	2.54	1.32	0.30	1.89	1.04	1,558	3,139	2,132

(Data obtained by the survey in this study is shown in parenthesis.)

(k) Laterite is thick at the upper reservoirs of Hevale and Marleshwar. The laterite in Hevale has a thickness of about 15m and SPT-value of 50 or greater. The laterite in Marleshwar is 9 to 11m thick and has SPT-value of 6 to 32. The grain size consists of 26 to 29% of sand, 28 to 35% of silt and 27 to 37% of clay.

The natural moisture content is 7% and the maximum dry density is 1.57 to 1.60 g/cm^3 at the optimum moisture content of 26 to 29%. The laterite contains large amount of fines and the maximum dry density is low. Considering the low natural water content, it is estimated that the sample was obtained near the ground surface. However, lateritic boulders or gravel are generally found elsewhere in the laterite. The sampling method or mixing method shall be adjusted in order to keep fines of 10 to 15% and to maintain impermeability of the material.

Because the river deposits at the project site generally contain little sand, it is not possible to mix with laterite. The properties of core materials generally used in Maharashtra state are tabulated for reference as follows:

Optimum Moisture Content	:	23 to 26%
Maximum Dry Density	:	1.33 to 1.71 g/cm^3
Cohesion	:	0.0976 to 0.488 kg/cm^2
Tan ϕ	:	0.00 to 0.48
Coefficient of Permeability	:	1.8×10^{-7} to 2.88×10^{-6} cm/sec

(4) Rock Mass Classification and Evaluation

(a) Rock Mass Classification and Evaluation Methods

Rock mass classification based on drilling cores was conducted in accordance with the method by Electric Power Development Co. Ltd. of Japan (EPDC). The classification was made after consideration of rock mass conditions observed at the site. It was found that the rock mass classification based on drilling cores by using the EPDC method agreed with the rock mass conditions found at the site for fissured and strong Compact Basalt, massive and weathered Amygdaloidal Basalt, fragmented Volcanic Breccia, etc. The Pre-Cambrian Crystalline Schist lying beneath the basalt at the lower reservoir in Hevale was also classified by using the same method.

Rock mass evaluation was made considering all aspects such as observation results and the engineering experience in India as well as unconfined compression strength, RQD, permeability, etc. since there is doubt as to the transportation method and the accuracy of laboratory tests for core samples judging from the considerable variety in the test results.

Standard of Rock Mass Classification for Drilled Core

Weathering		Hardness		Crack spacing	
1	Very fresh. No weathering of mineral component.	A	Very hard. Broken into Knifeedged pieces by strong hammer blow.	I	Over 30 cm
2	Fresh. Some minerals are weathered slightly. Usually no brown cracks.	B	Hard. Broken into pieces by strong hammer blow.	II	10 - 30 cm
3	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered material.	C	Brittle. Broken into pieces by medium hammer blow.	III	3 - 10 cm
4	Weathered. Fresh portions still remain partially.	D	Very brittle. Easy broken into pieces by medium hammer blow.	IV	1 - 3 cm
5	Strongly weathered. Most minerals are weathered and altered to second minerals.	E	Soft. Possible to dig with a hammer.	V	Under 1 cm

(b) Proposal for Rock Mass Evaluation Method

Rock Quality Designation (RQD) proposed by Deere, et.al. in 1996 is commonly used for the evaluation as indicated below.

RQD and State of Rock Mass

RQD (%)	State of Fracture
0～25	Very Poor
25～50	Poor
50～75	Moderate
75～90	Good
90～100	Very Good

It is also proposed that rock mass is evaluated i) first, by classifying it based on a combination of unconfined compressive strength (qu) and sonic velocity (Vs) of intact rock core and based on the EPDC method, ii) then by combining two groups classified in i). The following grouping is proposed.

Classification of Core Based on qu and Vs

* Based on Unconfined Compressive strength, qu	H_1	: qu is greater than 1,000 kg/cm^2
	H_2	: qu is between 500 and 1,000 kg/cm^2
	H_3	: qu is between 300 and 500 kg/cm^2
* Based on sonic velocity, Vs	V_1	: Vs is greater than 5 km/sec
	V_2	: Vs is between 4 and 5 km/sec
	V_3	: Vs is between 3 and 4 km/sec
	V_4	: Vs is between 2 and 3 km/sec
* Based on both strength and sonic velocity	X-group	: V_1H_1, V_1H_2, V_2H_1 (Very good)
	Y-group	: V_2H_2, H_2H_3, V_3H_2 (Moderate)
	Z-group	: V_3H_3, V_4H_2, V_4H_3 (Poor)

Classification of Core Based on the EPDC Method

Class	Description	Subdivision combination (Example)
(A)	Good	A I a, A I b, B I a, B I b
(B)	Moderately good	A I c, A II a, A II b, B I c, B II a, B II b, C I a
(C)	Moderately poor	A II c, C I b, C I c, C II a, C II b
(D)	Poor	The rest combination

The above groups are combined as shown below:

Proposed Evaluation Method of Rock Mass

	A	B	C	D
X	AX (G)	BX	–	–
Y	AY	BY (MG)	CY	– (MP)
Z	AZ	BZ	CZ	–

G : Good

MG : Moderately good

MP : Moderately Poor

The above grouping may be used to select the dam type, however, the reliability of this method, including the reliability of test results, needs to be further studied for future application.

10.1.2 Geology at Proposed Sites

Geological conditions of three possible sites (Jalond, Marleshwar, and Hevale) for the pumped storage power station will be reported hereinbelow. Geology at Jalond, Marleshwar, and the upper reservoir in Hevale is Deccan Trap Basalts. Hard fine Precambrian crystalline schist, which underlies the basalt, is distributed at the lower reservoir of Hevale.

The proposed dam site is generally characterized with complex large-scale erosional topography of lava plateau and rock terrace. It is not always the case that the thicker basaltic laterite is distributed at the older terrace or erosional plane because of complex forming mechanism of laterite. The geological survey was performed considering the above mentioned geological and geomorphic conditions. Seismic survey, drilling, and laboratory tests were carried out in order to understand weathering depth, strength, deformation characteristics, and permeability of the rock mass at the upper and lower reservoirs of each possible dam site. For survey of soil materials, laboratory tests were performed on the samples obtained from the test pits around the possible dam sites. Because the upper reservoir of Jalond is located in the Sanctuary area, the seismic survey using stacking method was performed.

At both of the upper and lower reservoirs in Jalond the rock mass conditions are good. However, it is located in the Sanctuary area. At the lower reservoir in Marleshwar the interbeded Tachylytic Basalt is distributed. The Tachylytic Basalt is broken completely in a few days after removing pressure on it. Furthermore, a landslide topography was recognized at the reservoir. At the upper reservoir in Marleshwar the riverbed consists of good rock mass at the planned main dam. However, thick laterite is distributed at the abutments of the planned main dam and the planned auxiliary dam site. The detailed geological survey is necessary. At the upper reservoir in Hevale the rock mass condition is generally good, however, the Tachylytic Basalt is distributed at the base rock of the planned dam. At the lower reservoir in Hevale, although the base rock crystalline schist itself does not have any problems, the upper reaches of the river are devastated and debris flows are distributed. As mentioned above, each possible site has some problems to be further investigated.

(1) Jalond Site

(a) Upper Dam Site

Seismic survey using a stacking method was carried out because of the presence of the Sanctuary area.

(i) Seismic Refraction Survey

The subground is divided into 2 velocity zones of surface layer and bedrock. The velocity of bedrock is 4.5 km/sec at the left bank of the river and 4.0 km/sec at the right bank. It is considered that these velocities represent the hard fine basalt (Compact Basalt). The sonic velocity of intact core is 5.4 to 6.0 km/sec.

The velocity at the left bank is similar to the velocity of 4.9 to 5.0 km/sec at the upper reservoir of Hevale where the Compact Porphyritic Basalt and Amygdaloidal Basalt are present, while the velocity at the right bank is similar to the velocity of 4.0 km/sec at the lower reservoir of Marleshwar where the Amygdaloidal Basalt is present. Therefore, the left bank of the river is expected to be underlain by the Compacted Porphyritic Basalt and Amygdaloidal Basalt and the right bank be underlain by the Amygdaloidal Basalt.

(ii) Other Surveys

Drilling, in-situ permeability and laboratory tests for construction materials were not carried out. Drilling needs to be carried out in the future for the confirmation of geology at the site.

(iii) Construction Materials

Because the dam site is topographically in a steep valley, a masonry type dam is considered to be feasible. The Compact Basalt is expected to be present at the left bank of the river based on the seismic survey results. The Compact Basalt is highly fissured and construction materials may not be obtained from this basalt. The Amygdaloidal Basalt is less fissured and may be used for materials if it has enough strength. The borrow area is expected on the basalt platform at the proposed reservoir.

(iv) Rock Mass Evaluation at Dam Site

Based on the site reconnaissance and seismic velocity, a gravity dam is expected to be feasible. However, if the Compact Basalt is present at the dam site, the Compact Basalt causes water seepage although the coefficient of permeability (Lugeon value) is low. There is a report that cement grouting is not effective in the Compact Basalt. The water seepage is expected through the joints and at the boundary between the Compact and Amygdaloidal Basalts. If the Compact Basalt has such problem, blanket or facing to prevent water seepage needs to be considered both at the dam site and reservoir area after the economic evaluation.

(b) Lower Dam Site

(i) Seismic Refraction Survey

The lower reservoir site is formed also by 2 zones of surface layer and bedrock. The velocity of the bedrock of basalt is 4.5 to 4.6 km/sec at the both sides of the river. The high velocity (4.6 km/sec) was obtained at the riverbed, too. There is no low velocity zone in the bedrock. The surface layer is expected to consist of talus deposits based on the recorded velocity of 0.35 to 0.4 km/sec. The thickness of talus deposits is 7 to 10m on the slope of the right bank of the river and about 1m on an average on the slope of the left bank. The maximum thickness of the talus deposits at the left bank is 5m. It was anticipated, at the initial stage of the study, that the rocks at the ridge of right abutment of the dam site were heavily weathered. However, the high seismic velocity of 4.5 km/sec was obtained. On the ridge, an about 10m thick weathered zone with open joints is expected to be present.

(ii) Rotary Core Drilling

Porphyritic Amygdaloidal Basalt and Amygdaloidal Basalt are mainly present at the lower reservoir. The Compact Porphyritic Basalt locally exists and is less fissured than the Compact Basalt. The Porphyritic Basalt is very strong and causes metallic sound by hammer. Talus deposits of 2 to 3m thick and river bed gravel of about 1.5m thick cover the basalt. Upper 10m of the rock is weathered and indicates RQD. value of 60 to 80%. Generally, the drilling cores are in good conditions.

(iii) Permeability

The Lugeon values are about 3 to 4 at the open joint portion of the Compact Basalt and about 1 at the closed joint portion. It is less than 4 Lugeon at the weathered portion. However, it is said that seepage occurs when the reservoir is filled with water.

(iv) Laboratory Test

Unconfined compressive strength of the Compact Porphyritic Basalt is 800 to 1,500 kg/cm^2 and that of the Amygdaloidal Basalt is 415 to 780 kg/cm^2. The unconfined compressive strength varies depending on method of sampling, preservation, and transportation. However, since the average strength is 500 to 600 kg/cm^2, a masonry type dam is expected to be feasible.

(v) Construction Materials

At the lower reservoir, the Compact Porphyritic Basalt, Porphyritic Amygdaloidal Basalt and Amygdaloidal Basalt lie alternately. They can be good aggregates for a masonry type dam. If a fill type dam is adopted, laterite for impermeable materials and river deposits for both impermeable and intermediate materials are considered in the area as shown in **Fig.10.1-3**. The river deposits are widely distributed, but as thin as 2m. Therefore, excavation and sampling may not be efficiently performed. The fine aggregate is insufficient. The large size gravel or boulders need to be crushed. The volume of river deposits (laterite) which can be used as fill material (core material) is estimated to be about 3 million m^3.

(vi) Rock Mass Evaluation at Dam Site

The basalt at the riverbed and both abutments is good in rock quality and as a foundation of the dam. In terms of permeability, the weathered portion indicates less than 4 Lugeon and there are no problems. Furthermore, there are no problems in terms of strength either. Considering availability of aggregate, a masonry type dam is feasible at this site. For a fill type dam, laterite and lateritic basalt are to be used for the fill materials. However, the volume of the laterite may be insufficient. The river deposits are also insufficient and contain a small amount of sand particles and large gravel or boulders which need to be fragmented for use.

(2) Marleshwar Site

(a) Upper Dam Site

(i) Seismic Refraction Survey

The subground is divided into 3 layers with the different seismic velocities. The 3 layers consist of surface layer, laterite and bedrock basalt. The bedrock with the velocity of 4.6 km/sec exposes on the riverbed. The laterite with the velocity of 0.7 to 1.5 km/sec covers the bedrock with the thickness of 32 to 33m at both banks of the river. Since the laterite is thick at the right bank, the depth to the bedrock is not clear. The bedrock may not raise its elevation towards the ridge as drawn in the seismic profile. The thickness of the laterite of about 30m is estimated based on the borehole result at UM1. The seismic survey line was set on the foot of right bank of the river in parallel with the river flow and the survey detected 5 to 10m talus deposits with the velocity of 0.4 to 0.5 km/sec. Beneath the talus deposits, there is 18 to 20m thick laterite with 0.7 to 1.2 km/sec velocity. The 4.6 km/sec velocity layer lies underneath the laterite (the layer has no low velocity zone).

Two saddle dam sites are underlain by about 20m thick laterite with 1.1 to 1.5 km/sec in velocity, and the bedrock of weathered Porphyritic Basalt with 4.0 km/sec velocity underlies the laterite.

(ii) Rotary Core Drilling

The both abutments of dam site are covered by 32 to 33m thick laterite or lateritic zone. Top 2 to 3m of the underlying basalt is heavily weathered and highly fractured. The rocks at the riverbed have open joints to the depth of 9m below the top of rock. The Porphyritic Basalt mainly exists and it has been altered into dark greenish color. At three boreholes at the dam site, 3 to 8m thick Volcanic Breccia was found at the depths between 15 and 33m. The Tachyritic Basalt is also locally present together with the Volcanic Breccia. Since the borehole lengths at the saddle dams were short, the Volcanic Breccia was not encountered.

(iii) Permeability

The Lugeon values obtained at the dam site are less than 1 even from the tests conducted at the boundary of laterite and weathered basalt. The test was not able to be carried out in the laterite and lateritic zone because the casing was used. The coefficient of the laterite is known to vary widely from 10^{-1} to 10^{-6} cm/sec depending on the degree of laterization.

(iv) Laboratory Test

The unconfined compressive strengths of the Compact Porphyritic Basalt at the river bed vary from 873 to 1,092 kg/cm^2 with the natural water content of 1.5 to 2.6%, while those of the Porphyritic Amygdaloidal Basalt vary from 100 to 440 kg/cm^2 with the natural water content of 2.2 to 9.8%. The strengths of these types of basalt are obviously different.

(v) Construction Material

For the survey at the upper reservoir, laterite near Gothna Village was investigated as shown in **Fig. 10.1-4**. The laterite is classified as CL to CH based on unified soil classification and contains fine of 52 to 88%.

The maximum dry density varies from 1,455 to 1,550 g/cm^3 at the optimum moisture contents of 22 to 30.5%. As mentioned earlier, the grain size needs to be adjusted by mixing with the other materials when the laterite is used for the fill materials. Furthermore, permeability tests also need to be carried out for the mixed materials. For the compaction of the fill materials, adjustment of moisture content and storage method of the fill material corresponding to the seasonal climate conditions need to be considered.

(vi) Rock Mass Evaluation at Dam Site

At the dam site, the basalt is located deep and is overlain by 30m thick laterite. It can be said that this dam site is unsuitable for construction of any type of dam from an aspect of permeability. A man-made reservoir could be a possible alternative, however, excavatability of laterite nees to be studied in detail because the laterite contains a lot of boulders at the deeper portion than 23 to 24 and its strength has a wide range.

(b) Lower Dam Site

(i) Seismic Refraction Survey

[Downstream dam site (Dam Axis I)]

The subground is divided into two zones of surface layer and bedrock. The velocity of the bedrock is 4.0 km/sec at the riverbed and the both abutments. There is no low velocity zone in the bedrock. Talus deposits or colluvial debris cover slopes of the both abutments and have the velocity of 0.35 to 0.4 km/sec and the thickness of 5 to 10m.

The slopes at both sides of the river are formed by primary gentle slope at the high level and secondary steep slope at the low level. The boundary of the two slopes is located at the elevation of about 230m at the left bank of the river. The colluvial debris was found on the primary slope and the thin talus deposits were found on the secondary slope. The boundary of the two slopes at the right bank of the river is located at the elevation of about 240m. The surface layer is thin at the borehole LM1 which is located on the secondary slope.

[Upstream dam site (Dam Axis II)]

There are two zones of surface layer and bedrock. The bedrock has the velocity of 4.0 km/sec and no low velocity zone was found. The slopes at both banks of the river consist of primary and secondary slopes at high and low elevations, respectively. The boundary of the two slopes is located at the elevation of about 230m. The talus deposits cover the secondary slope with a thickness of about 5m on the both banks. There are some rock exposures at the right bank of the river. The primary slope at the left bank is covered by colluvial debris with a velocity of 0.4 km/sec. The primary slope at the right bank is covered by a layer with a velocity of 0.35 to 0.4 km/sec. This layer is assumed to be talus deposits and may be landslide mass. The detail study using aerial photographs should be carried out.

(ii) Rotary Core Drilling

[Downstream dam site (Dam Axis I)]

The bedrock is the Compact Porphyritic Basalt with phenocryst of dark greenish chlorite. The basalt embeds a few layers of 10 to 13m thick reddish Volcanic Breccia and a few layers of thinner Volcanic Breccia. The Volcanic Breccia accompanies reddish Tachylytic Basalt. Tachylytic Basalt contains plagioclase and augite, and since it is glassy and has micro cracks, the basalt is broken into small pieces when excavated. Clay minerals are not included. Although unconfined compressive strengths of the Tachylytic Basalt vary from 100 to 450 kg/cm^2, the basalt is brittle. When the Tachylytic Basalt appears at the foundation level of dam, the basalt is, in general, totally removed and replaced by concrete. Another recommended option is to leave the basalt of 3 to 5m thick above the foundation base. At the borehole LM2, the 2 to 3m thick Tachylytic Basalt was encountered above a 4m thick layer of the hydrothermally altered, reddish Volcanic Basalt which lies at the depth of 5 to 9m in the bedrock. The occurrence of Tachylytic Basalt is irregular. Therefore, its occurrence shall be investigated in detail.

[Upstream dam site (Dam Axis II)]

The site is underlain by Porphyritic Basalt, reddish Volcanic Breccia and Tachyritic Basalt. The rock quality is good at the left bank and is slightly better at the right bank than that of the downstream dam site.

The rocks at the riverbed consist of about 13m thick reddish Volcanic Breccia at the depth of 10m below the rock level and accompany with 3 to 4m thick reddish Tachylytic Basalt at the top and bottom of the breccia. Therefore, the rock quality at the riverbed is apparently worse than the downstream dam site. In terms of foundation treatment, the downstream option may have advantage. As mentioned earlier, the occurrence of Tachylytic Basalt needs to be investigated in detail.

(iii) Permeability

[Downstream dam site (Dam Axis I)]

The Lugeon values vary from 8 to 12 to the depth of 15 to 16m below the rock level at the right bank of the river. The Lugeon values are less than 1 at the riverbed and less than 9 to the depth of 7m at the left bank. The Volcanic Basalt and Tachylytic Basalt have Lugeon values of less than 1, thus, the improvement of the strength by consolidation grouting is not possible.

[Upstream dam site (Dam Axis II)]

The Lugeon value is zero below the rock level at the right bank and generally at the riverbed and left bank except at the Volcanic Breccia. The Lugeon values of the Volcanic Breccia are 3 to 13 at the depth of 53m at the riverbed and less than 1 at the depth of 50m at the left bank of the river.

(iv) Laboratory Test

[Downstream dam site (Dam Axis I)]

The Compact Porphyritic Basalt has unconfined compressive strengths of 650 to 1,460 kg/cm^2 and natural water contents of 2.6 to 2.8%. The altered Porphyritic Basalt is weak, and has unconfined compressive strength of 110 to 570 kg/cm^2 and natural water contents of 2.5 to 4.8%.

[Upstream dam site (Dam Axis II)]

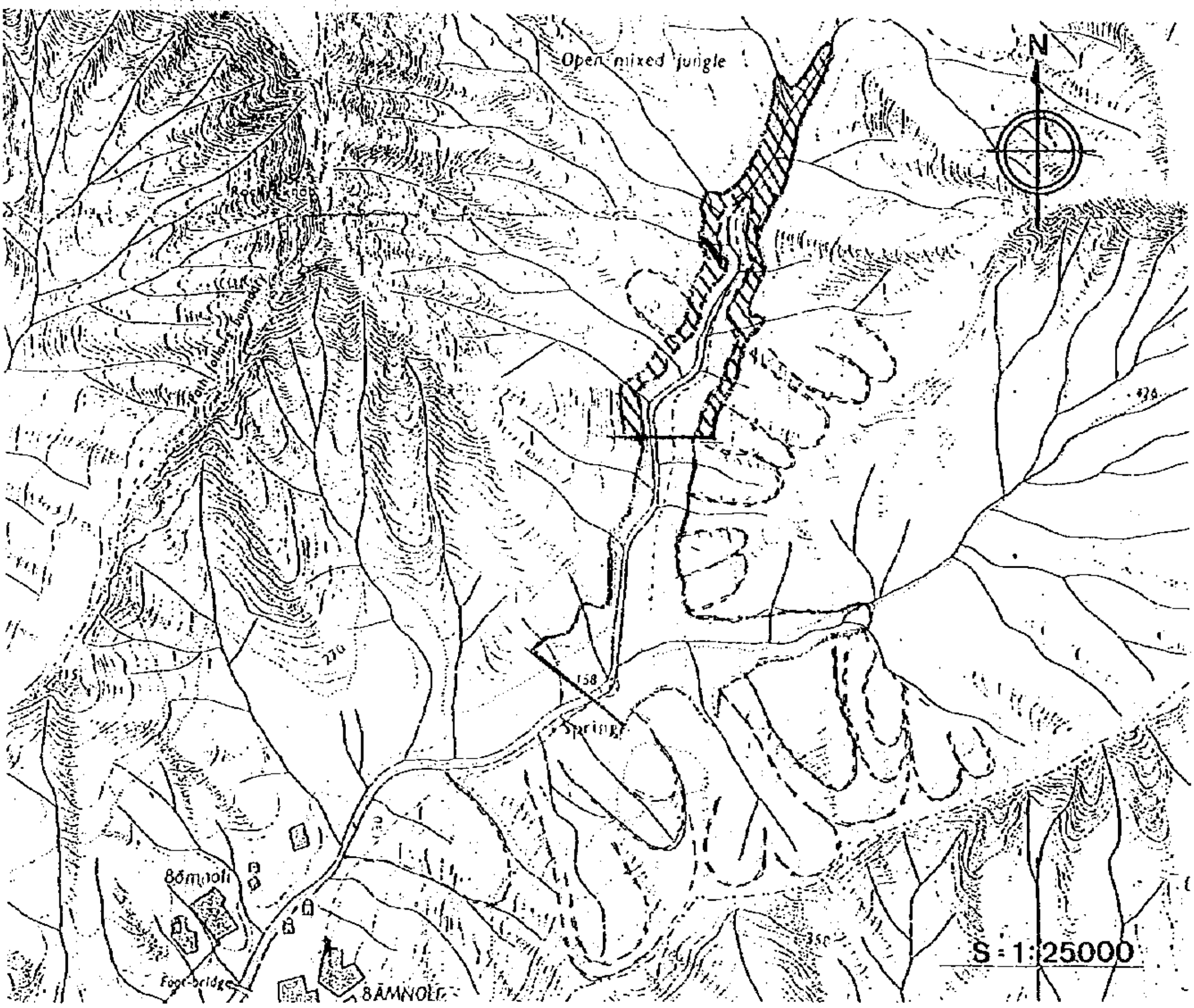
The unconfined compressive strengths of Porphyritic Basalt vary widely from 130 to 830 kg/cm^2 and natural water contents vary from 2.77 to 4.33%.

(v) Construction Material

The river deposits and talus deposits at the downstream of Bav Nadi were investigated for construction materials. The talus deposits show SM to GP based on the unified soil classification and have a thickness of 4 to 55m. A total volume of 5 million m^3 is estimated. Rock material may be obtained from the Compact Porphyritic Basalt at the ridge of left bank of the upstream dam site (see **Fig. 10.1-4**).

(vi) Rock Mass Evaluation at Dam Site

Based on alteration, fissure, strength and presence of Tachylytic Basalt, the rock mass quality is classified as moderately poor. Landslide masses found at the reservoir and dam site are expected to be unstable when the dam is constructed. The landslide mass may have been formed in such a way that talus deposits were firstly derived from alteration of rocks and presence of Tachylytic Basalt, the deposits were then developed on the primary slope, and the deposits finally became unstable together with the development of secondary slope at the lower portion of the slope. The secondary slope has been formed by erosion in Quaternary, thus the landslide mass is expected still active. There is an active landslide located downstream of the downstream dam site. Detailed study on the landslide by analyzing aerial photographs shall be carried out.



Possible Landslide Mass

(3) Hevale Site

(a) Upper Dam Site

(i) Seismic Refraction Survey

The subground is divided into two layers of laterite and bedrock. The laterite has a velocity of 0.45 to 0.5 km/sec and a thickness of 6 to 13m. The bedrock has the velocity of 4.0 to 5.0 km/sec and consists mainly of the Compact Porphyritic Basalt with columnar joints. The bedrock contains two layers of 3 to 5m thick blackish Tachylytic Basalt. These layers are not detectable by the seismic survey.

(ii) Rotary Core Drilling

The site is underlain mainly by the strong Compact Porphyritic Basalt. Tachylytic Basalt is embedded in the Compact Porphyritic basalt. Although the Tachylytic basalt appears on the side wall of upper reservoir and on the excavation base of the dam site, it is possible to totally remove this because of its thin layer and shallow occurrence. Once the Tachylytic Basalt is obtained as solid cores from boreholes, it is broken into small pieces within a few days. This is not due to clay mineral but due to the presence of micro cracks. The unconfined compressive strength of the Tachylytic Basalt varies from 100 to 450 kg/cm^2. The local practice recommends to replace the Tachylytic Basalt by concrete when it appears at the foundation level.

(iii) Permeability

The Lugeon values of bedrock are less than 1. The basalt with columnar joints causes seepage when the reservoir is filled with water, but the grout will not be effective. Therefore, a measure to prevent water seepage is necessary at the excavation base.

(iv) Laboratory Test

The Amygdaloidal Basalt at the borehole UH1 has the unconfined compressive strength of 130 to 350 kg/cm^2 and the natural water content of 1.91 to 2.55%.

The bedrock at the upper reservoir is the strong Compact Porphyritic Basalt of which the unconfined compressive strength varies from 570 to 1,620 kg/cm^2, natural water content from 0.17 to 1.33% and density from 2.77 to 3.18g/cm^3.

(v) Construction Materials

In the preliminary stage of the study, laterite was expected to be used for construction and 12m thick laterite was confirmed at the borehole UH1. However, since the laterite includes a lot of fine particles, grading would be required before using it as the construction material. A large amount of basalt will be excavated for the creation of man-made reservoir and this basalt can be used for the construction materials of dam. Therefore, the laterite is not necessary to be used.

(vi) Rock Mass Evaluation at Dam Site

The bedrock quality is good. The Tachylytic Basalt is thin and is present at the shallow depth. Therefore, it can be removed without difficulties. Geologically, there is little problem at this site.

(b) Lower Dam Site

(i) Seismic Refraction Survey

The subground is divided into two zones of bedrock and surface layer consisting of talus deposits. The bedrock consists of the strong Pre-Cambrian Crystalline Schist with the velocity of 4.8 to 5.0 km/sec.

The talus deposits has velocity of 0.4 to 0.5 km/sec and a thickness of about 10m. There is a gravel layer with the velocity of 1.5 km/sec at the riverbed and there is a topographic depression beneath the gravel layer. This depression is considered to be the old riverbed. The foundation of the dam needs to be designed taking the old riverbed into account.

(ii) Rotary Core Drilling

The surface of the slope is covered by 10 to 15m thick talus deposits containing boulders. Standard penetration test is not possible to be carried out. The

Furthermore, there is a variation in the strength of rocks. These matters should be considered in the dam design.

The talus deposits which may have been formed by mud flow are present along the river. The talus deposits exist on the gentle slope upstream of the dam site or at the mouths of small valleys. Therefore, the transportation and deposition of the soils into the reservoir need to be examined.

The geological features of each project site from an engineering point of view is summarized as follows:

a) Jalond site has no major geological problem. The dam height needs to be adjusted based on the actual topography. The presence of Sanctuary area needs to be considered in the design. A masonry type dam is suitable considering availability of the construction materials.

b) Marleshwar dam site is covered by 30m thick laterite and the bedrock for dam foundation lies deep. Therefore, a man-made type reservoir seems better. As for the two alternative lower dam sites, there are landslide masses in the reservoir areas and partially at the dam locations. The landslide needs to be studied in detail using aerial photographs, etc. The rock mass quality is classified as moderately poor because of the presence of altered basalt, Volcanic Breccia and Tachylytic Basalt.

c) At Hevale site, poor Volcanic Breccia and Tachylytic Basalt are present in the bedrock at the upper reservoir. Their occurrence is shallow and limited to the small extent and thus, these materials can be treated properly by removal or replacement. The lower reservoir is underlain by the strong Pre-Cambrian Crystalline Schist. Generally, the schist has no problem as a foundation of dam. However, the schistocity or lineament in the schist shall be taken into account for the design. The presence of talus deposits derived from mud flow implies transportation and deposition of soils into the proposed reservoirs.

Geological cross sections at each site are shown in **Figs. 10.1-12 ~ 10.1-19**.

10.2 Geological Exploration

10.2.1 Geological Exploration and Quantity of Field Works

(1) Outline of Site Investigation

JICA study team carried out the geological survey at the proposed sites involving exploratory drilling, laboratory tests on different materials and seismic refraction survey.

The topographical survey was carried out along the identified geophysical investigation lines (profiles) using a Total Station TOPCON GTS-6. A temporary bench mark (TBM) was marked at each site and approximate value of ground reduced level (GRL) was selected from the topographical sheet of Survey of India. The survey was carried out for the entire length of investigation lines (profiles) and ground levels were taken at 5m intervals where the geophones were to be placed for the seismic profiling. The blasting points were marked on the ground.

From the above, "RL (Reference level)" used in this report should be regarded as approximate elevation since the site elevation was not surveyed based on the national bench mark.

(a) Seismic Refraction Survey

The detailed seismic refraction survey involving continuous seismic in-line profiling was carried out using 24-channel signal enhancement seismograph with 5m geophone spacing and one overlapping geophone. Repeated shooting technique was adopted with 6-7 shots for each profile. The additional direct and reverse off-set, shots were recorded at a distance of 100m outside the ends of each continuous seismic line. The requisite quantity of charges (80% gelatine and zero delay electric detonators) were placed in 1m deep holes; hammer seismic involving stacking technique was also utilized at shallow cover locations.

(b) Rotary Core Drilling

Drilling was executed by two types of rotary core drilling rigs, namely, Swanska and Calyx with diamond bit and double tube core barrel using water as circulating fluid. The cores are of N_x size. The diameter of borehole and rock core are 78mm/100mm and 54.7mm respectively. The cores were arranged properly in core boxes and are handed over to the Government of Maharashtra, Irrigation Department (GOMID) for preservation.

(c) Standard Penetration Test (SPT)

Standard Penetration Test was carried out in the boreholes for the overburden soil in accordance with ASTM D 1586-67/equivalent IS Standard (IS:2131). A standard 50mm diameter sampling spoon was dynamically driven into the overburden soil of the borehole by dropping a 63.5 kg weight with a free fall of 0.75m. The first 15cm of penetration was ignored. The SPT-value (or N-value) is the number of blows required to penetrate the next 30cm. In case of very dense materials and rock, the test was stopped when the blow count reached 50 for penetration below 30cm. The test results (N-values) are recorded in borelog and core log.

(d) Field Permeability Test in Boreholes (Lugeon Test)

Permeability test (Lugeon Test) was conducted in completed boreholes in rock stratum in accordance with BS 5930:1981/IS:5529 using double packers from bottom to top, i.e. in ascending order. Length of the perforated tube in between the packers was in general 3m.

The test procedure involves injecting water into the testing zone of borehole and measuring the amount of water that can be forced into the test section of the hole within a given time and at a given pressure. Each stage was tested at 4 different pressures in cyclic order. From the water loss noted at different pressures in onward and return cycles, Lugeon value is estimated as "intake of water in litre per meter per minute at a pressure of 1 Mpa".

(e) Laboratory Tests on Soil Samples

The laboratory tests on soil samples from borrow pits/overburden were as follows:

(i) Grain size distribution by sieve analysis and hydrometer analysis.
(ii) Determination of specific gravity.
(iii) Atterberg limits.
(iv) Maximum dry density (MDD) and optimum moisture content (OMC) by Compaction Test.

(v) CBR tests on overburden samples moulded at 95% of maximum dry density at the optimum moisture content.

(vi) Water content.

(f) Tests on Rock Samples

The tests on selected rock samples were as follows.

(i) Uniaxial compressive strength on (soaked for 24 hours) rock samples

(ii) Porosity

(iii) Water absorption

(iv) Bulk and dry density

(v) Modulus of elasticity

(vi) Poisson's ratio

(vii) Ultrasonic pulse velocity

(viii) Tensile strength

(ix) Specific gravity

(2) Quantity of Field Works

The following is the quantity of field works.

Quantities of Geological Investigation (1/2)

Description	Unit	Tender Quantity	Final Quantity
1. Mobilization and Demobilization	Ls	1	1
2. Rotary Boring for Rock			
a. Setting, Dismantling and shifting of equipment	No	23	20
b. Rotary Core drilling	m	1300	1110
c. Standard penetration test	No	120	77
3. Field Permeability Test	No	434	277
4. Laboratory Tests for Core Samples taken by Boring			
a. Specific gravity, absorption, water content and dry desnity test	No	115	114
b. Unconfined compression test including elastic modulus and Poisson's ratio measurement	No	115	114
c. Tensile test	No	115	100
d. Ultra sonic waves measurement	No	115	106
5. Laboratory Tests for Disturbed Soil Samples at Borrow Pits including sampling			
a. Specific gravity, absorption, water content and dry desnity test	No	12	32
b. Grain-size analysis	No	12	31
c. Atterberg limits	No	12	31
d. Compaction test	No	12	12
e. Permeability test	No	12	12
f. Water content	No	12	12
6. Laboratory Tests for Concrete Aggregate at Borrow Pits			
1) For coarse aggregate			
a. Specific gravity and absorption	No	6	6
b. Sieve analysis	No	6	6
c. Abrasion loss test	No	6	6
d. Alkali aggregate reaction test	No	6	6

Quantities of Geological Investigation (2/2)

Description	Unit	Tender Quantity	Final Quantity
e. Soundness test	No	6	6
2) For fine aggregate			
a. Specific gravity and absorption	No	6	6
b. Sieve analysis	No	6	6
c. Alkali aggregate reaction test	No	6	6
d. Soundness test	No	6	6
e. Organic impurities	No	6	6
f. Clay content and friable particle	No	6	6
7. Seismic Refraction Survey including analysis	km	9.5 (12 lines)	9.31 (11 lines)
8. Reporting	Ls	1	1

Detail Quantity of Field Works

[ ] Tender Quantity [ ] Final Quantity

<Investigation with Rotary Core Drilling>

Location	Borehole No	Drilling Depth (m)		S.P.T. (No)		Field Permeability Tes (No)		Laboratory Test : No			
								a	b	c	d
Jalond Site U / D	UJ 1	70	-		-	24	-	-	-	-	-
	UJ 2	50	-	-	-	17	-	-	-	-	-
	UJ 3	70	-		-	24	-	-	-	-	-
L / D	LJ 1	70	70		3	24	18	6	6	6	6
	LJ 2	70	70	24	1	24	22	6	6	6	6
	LJ 3	70	70		3	24	20	5	5	5	5
Marleshwar Site U / D	UM 1	50	60		11	17	10	8	8	7	8
	UM 2	80	60		4	27	16	8	8	6	7
	UM 3	50	60	24	9	17	10	8	8	6	7
	UM 4	30	30		9	10	Nil	2	2	2	2
	UM 5	30	30		4	10	Nil	1	1	1	1
L / D	LM 1	60	60		1	19	17	7	7	6	7
	LM 2	60	60		5	19	17	5	5	5	5
	LM 3	60	60	24	4	19	17	5	5	5	5
	LM 4	60	60		5	19	17	5	5	5	5
	LM 5	60	60		Nil	19	18	7	7	5	7
	LM 6	60	60		3	19	18	5	5	5	5
Hevale Site U / D	UH 1	30	30		5	10	Nil	6	6	5	5
	UH 2	30	30	24	Nil	10	9	6	6	5	5
	UH 3	30	30		Nil	10	9	6	6	5	5
L / D	LH 1	70	65		6	24	18	6	6	5	5
	LH 2	70	80	24	1	24	23	6	6	5	5
	LH 3	70	65		3	24	18	6	6	5	5
TOTAL	23 / 20	1300	1110	120	77	434	277	114	114	100	106

a : Specific gravity, absorption, water content and dry density test

b : Unconfined compression test including elastic modulus and Poisson's ratio measurement

c : Tensile test   d : Ultra sonic waves measurement

Quantity of Field Works

<Seismic Refraction Survey>

Location	JALOND	MARLESHWAR	HEVALE	TOTAL
U / D	0.8 km x 1 line 0.4 km x 1 line	0.8 km x 1 line 0.5 km x 3 lines	1.3 km x 1 line	4.8 km x 7 lines
	0.69 km x 1 line	0.81 km x 1 line 0.5 km x 3 lines	1.38 km x 1 line	4.38 km x 7 lines
L / D	1.4 km x 1 line	1.0 km x 2 lines	0.9 km x 1 line 0.4 km x 1 line	4.7 km x 5 lines
	1.4 km x 1 line	1.035 km x 2 lines	1.0 km x 1 line 0.46 km x 1 line	4.93 km x 5 lines
TOTAL	2.6 km x 3 lines	4.3 km x 6 lines	2.6 km x 3 lines	9.5 km x 12 lines
	2.09 km x 2 lines	4.38 km x 6 lines	2.84 km x 3 lines	9.31 km x 11 lines

Tender Quantity (unshaded)
Final Quantity (shaded)

10.2.2 Jalond Site

(1) Seismic Refraction Survey

(a) Upper Dam Site

The observed seismic compressional wave velocities (Vp) for the successive subsurface zones at the location of the dam axis and the corresponding inferred lithology are as follows:

350 - 450 m/s	Soil
4,000 - 4,500 m/s	Bedrock (Basalt)

The results of the refraction seismic survey, given in the form of seismic sections reveal the following:

i) A thin superficial layer of soil exists in patches along the profile line on the left bank and the right bank, having the average thickness of 1m. This layer is observed between Ch. 0m & Ch. 75m and between Ch. 287m & Ch. 312m on the left bank. On the right bank, it exists between Ch. 568m & Ch. 680m and between Ch. 708m & Ch. 840m.

ii) Bedrock (Basalt) is largely exposed in the profile stretch, both on the left and right banks. Elsewhere it underlies a nominal soil cover and is estimated to lie between RL 841m and RL 846m on the left bank and between elevation RL 839m and RL 844m on the right bank.

The computed seismic compressional wave velocity for the bedrock (Basalt) is Vp = 4,000 - 4,500 m/s indicating sound and good quality rock in the area.

(b) Lower Dam Site

At the location covered by the seismic profile along the dam axis, the observed seismic compressional wave velocities (Vp) for the successive subsurface zones and the corresponding inferred lithology are as follows:

350 - 400 m/s	Soil
4,500 - 4,600 m/s	Bedrock (Basalt)

The results of the seismic refraction survey, given in the form of seismic sections, reveal the following:

(i) A layer of soil covers the left and right banks of the dam axis, having the average thickness of 8m on the right bank and 5m on the left bank. The soil cover is thin near the middle part of the axis.

(ii) The underlying bedrock of basalt is exposed at a number of stretches on the left bank and near the middle part of axis (the riverbed). The bedrock lies under a thin cover of overburden, the maximum depth being about 10m on the right bank.

The computed compressional wave velocities (Vp) for the bedrock (Basalt) is 4,500 - 4,600 m/s testifying to sound good quality rock.

(2) Rotary Core Drilling

It is proposed to construct two reservoirs at the upper and lower dam sites. Out of these two dam sites, the lower dam site was explored by 3 boreholes viz LJ1, LJ2 and LJ3.

[Lower Dam Site]

The lower dam will be 62m high and its crest length will be 550m. The dam site is located on Deccan Trap basalt. The Deccan Traps cover about 85% of Maharashtra state.

The most common divisional planes that are present in the Deccan Trap rocks are the joints, and they play a very important role in the safety and stability of a dam. Out of 1,074 pieces of samples taken at three boreholes (LJ1, LJ2 & LJ3), only 151 pieces were broken along the joints and the remaining 923 pieces were broken mechanically. Although this area is located in the zone with closely spaced joints, suitable treatment is required before founding the dam.

The crushing strengths of various specimens tested vary between 260 kg/cm^2 and 1,060 kg/cm^2. The water absorption varies between 0.32% and 2.03%. From the various physical properties of the specimens tested, it is seen that the basalt possesses adequate compressive strength. Therefore, the foundation rocks, as far as strength is concerned, are quite good. But, in certain zones, grouting will be necessary.

(i) LJ1 (RL 310.80m at the surface)

Between RL 310.80m and RL 307.05m, there is overburden. Between 307.05m and 285.775m, there is a flow of Compact Porphyritic Basalt (21.275m thich). Between RL 285.775m and RL 240.95m (the end of the borehole), there are various flows of Porphyritic Amygdaloidal Basalt. Up to RL 296m below the overburden, there are a large number of joints in the flow of Compact Porphyritic Basalt. Majority of the joints are stained.

If a masonry dam with 62m high is constructed, it is suggested to found the dam at RL about 296m. It is also suggested that grouting should be carried out between RL 296m & 295m and RL 292m & 289m. Below RL 285.775m there are flows of Porphyritic Amygdaloidal Basalt. As discussed earlier, the Amygdaloidal Basalt is nearly massive i.e. joints are very few and widely spaced.

(ii) LJ2 (RL 240.80m at the surface)

Between RL 240.80m and 238.55m, there is overburden. Between RL 238.55m and 234.80m, there is a flow of Porphyritic Amygdaloidal Basalt. Between RL 234.80m and RL 222.77m, there is a flow of Compact Porphyritic Basalt. Between RL 222.77m and 170.80m, there are various flows of Amygdaloidal Basalt. Below the overburden (between RL 234.80m and 229m), there are a large number of joints in the flows of Compact Porphyritic Basalt (majority of the joints are stained).

The dam is expected to be 62m high and founded at RL about 229m. It is suggested that grouting should be carried out between RL 223m & 221m, RL 213m & 211m, RL 209m & 206m and RL 203m & 199m.

(iii) LJ3 (RL 310.80m at the surface)

Between RL 310.80 and 304.80m, there is overburden. Between RL 304.80m and 296.60m, there is a flow of Compact Porphyritic Basalt. Between RL 296.60m and RL 240.75m (the end of the borehole), there are various flows of Amygdaloidal Basalt.

Up to RL 292m below the overburden, there are a large number of joints in the flows of Compact Porphyritic Basalt and also in top portions of the flow of Porphyritic Amygdaloidal Basalt (majority of the joints are stained).

If a masonry dam with 62m high is constructed, it is suggested to found the dam at RL about 292m. It is also suggested that grouting should be carried out between RL 277m & 269m and between 258m & 256m.

(3) Geotechnical Appraisal of Lower Dam Site

The geological conditions at Jalond dam site are quite good in the engineering point of view. Below the foundation level at all the three boreholes, flows of Amygdaloidal Basalt occur. They are nearly massive i.e. unjointed and these are excellent as dam foundation. It is recommended that detailed geological investigation should be carried out for the upper dam site also.

10.2.3 Marleshwar Site

(1) Seismic Refraction Survey

(a) Upper Dam Site

(i) Main Dam

The computed seismic compressional wave velocities (Vp) for the successive subsurface zones in the main dam site area and the corresponding inferred lithology are as follows:

300 - 400 m/s	Soil
700 - 1,500 m/s	Laterite
4,600 m/s	Basalt

- A thin layer of soil is observed along the dam axis between Ch. 350m and Ch. 435m on the left bank and between Ch. 865m and Ch. 925m on the right bank.
- Laterite is exposed in rest of the section of the dam axis.
- A deeper rock formation is observed on the right bank between Ch. 800m and Ch. 900m which is likely to correspond to basalt having Vp = 4,600 m/s. It is estimated to lie between RL 833m and RL 850m on this bank. On the

left bank, basalt is partly observed between Ch. 380m and Ch. 468m lying between RL 837m and RL 825m.

In the cross profile laid on the left bank terrace, soil cover of maximum 8m thickness is observed along the seismic line.

(ii) Saddle Dam I

The seismic compressional wave velocities (Vp) for the successive subsurface zones in the saddle dam I and the corresponding inferred lithology are as follows:

400 m/s	Soil
1,100 - 1,500 m/s	Laterite

The results of the seismic refraction profiling carried out in the area, given in the form of seismic section reveal the following:

- A thin soil cover lies in the area between Ch. 120m and Ch. 337m having the average thickness of 3m.
- Hard laterite underlies brown soil and is also exposed along rest of the profile line.

(iii) Saddle Dam II

The seismic compressional wave velocities (Vp) for the successive subsurface zones in this area and the corresponding inferred lithology are as follows:

350 m/s	Soil
1,100 - 1,200 m/s	Laterite
4,000 m/s	Basalt

The results of the seismic refraction profiling carried out in the area, given in the form of seismic section, brings out the following:

- A thin brown soil cover having the average thickness of 2m lies in patches in the area.
- Laterite is exposed thickly along the seismic line and underlies the soil cover with 20m thickness.
- Bedrock of basalt underlying the laterite and having Vp = 4,000 m/s is estimated to lie between RL 851m and 865m.

(b) Lower Dam Site

(i) Dam Axis I (Downstream Alternative)

In the location covered by the seismic profile along the dam axis, the observed seismic compressional wave velocities (Vp) for the successive subsurface zones and the corresponding inferred lithology are as follows:

350 - 400 m/s	Soil
900 m/s	Pebbles & boulders/weathered rock
4,000 m/s	Bedrock (Basalt)

The results, given in the form of seismic sections, reveal the following:

- A layer of soil having the average thickness of 10m covers both banks of the dam axis. In the middle part of the axis, a thin layer of soil/silt is observed.
- An underlying layer of pebbles and boulders/weathered rock is observed between Ch. 290m & Ch. 400m and between Ch. 670m & Ch. 850m.
- The bedrock (Basalt) underlies a cover (about 10m thick) on the right and left banks along the dam axis. An the center of the river, the bedrock is partially exposed.

(ii) Dam Axis II (Upstream Alternative)

The observed seismic compressional wave velocities (Vp) for the successive subsurface zones at the dam axis and the corresponding inferred lithology are as follows:

350 - 400 m/s	Soil
900 m/s	Pebbles & boulders/weathered rock
4,000 m/s	Bedrock (Basalt)

The results of the seismic refraction survey, given in the form of seismic sections, reveal the following:

- A layer of soil having the average thickness of 5m covers both banks of the dam axis. In the middle part of the axis, a weathered layer/boulder zone is observed.

- A layer of weathered rock/boulder is observed on the upper right bank between Ch. 40m & Ch. 160m.
- The bedrock (Basalt) is estimated to lie between RL 367m and RL 347m on the right and left banks along the dam axis and at RL 174m in the middle part.

(2) Rotary Core Drilling

(a) Upper Dam Site

At mentioned earlier, this site is located on Deccan Trap basalts. The proposed masonry dam in the upper Marleshwar is about 76m high with 350m crest length.

The dam site was explored at 5 boreholes, three along the main dam axis (UM1, UM2 and UM3) and one each at the two saddle dam locations (UM4 and UM5). All the boreholes are vertical. At the boreholes UM2 and UM4, the ground water was encountered at a depth of 0.2m and 5m respectively. However, at other boreholes (UM1, UM3 and UM5), the ground water was not encountered. In addition to drilling, two borrow samples (UMP1 and UMP2) were collected for laboratory tests. The locations of borrow pits are shown in the layout plan **(Fig. 10.1-4)**.

From the five boreholes (UM1, UM2, UM3, UM4 and UM5), 969 samples in total were taken. Out of 969 pieces, 301 pieces were broken along the joints and the rest 668 number of pieces were broken mechanically. Moreover, there are a number of closely spaced joints.

The crushing strength of various Deccan Trap specimens is in a range between 100 and 1,460 kg/cm^2. The water content varies between 2.2 and 9.8%. From the test results, it can be seen that the basalt possesses adequate compressive strength. Therefore, the foundation rocks, as far as strength is concerned, are moderately good.

(i) UM1 (RL 871.092m at the surface)

Between RL 871.092m and 834.192m, there are overburden, laterite and weathered rock etc., where RQD is zero and the core recovery varies between nil and 80%. Below this, both core recovery and RQD improve, but there are a large number of joints down to RL 811.082m (the end of the borehole).

Majority of the joints are stained. Along some joints, weathering of rock has also taken place.

(ii) UM2 (RL 826m at the surface)

Between RL 826m and 814m, there are overburden, boulders and some rock pieces which are in weathered condition. In this zone, RQD is nil and the core recovery varies between 10% and 53%. Below RL 814m, both core recovery and RQD improve. Between RL 814m and RL 765m (the end of the borehole), there are a large number of joints. Nearly all joints are stained and, along some joints, the rock has been weathered.

(iii) UM3 (RL 871m at the surface)

Between RL 871m and 840m, there is laterite. Between RL 840m and RL 838m, RQD is nil and the core recovery varies between nil and 90%. Between RL 838m & 824m and between RL 821m & 811m (the end of the borehole), the Porphyritic Amygdaloidal Basalt exists. Between RL 824m and 821m, the Volcanic Breccia is distributed (RQD is nil).

(iv) UM4 (RL 849.195m at the surface)

Between RL 849.195m and 826.69m, there are laterite and overburden. Below this, the core recovery varies between nil and 56% and RQD varies between nil and 26.66%. The rock is in weathered condition.

(v) UM5 (RL 874.221m at the surface)

Between RL 874.221m and 854.72m, there are laterite and weathered rock. Below RL 854.72m, RQD is nil and the core recovery varies between nil and 25.71% (the rock is in weathered state).

(b) Lower Dam Site

Both alternative dam axes are located on Deccan Trap basalt. The proposed dam height is about 56m and the crest length is 550m.

Two alternative dam alignments (Dam Axis I and Dam Axis II) were explored at 3 boreholes each (LM1, LM2 & LM3 for one alignment and LM4, LM5 & LM6 for another). All the boreholes are vertical. At the boreholes LM2 and LM5, the ground water was encountered at a depth of 3.8m and 1.1m respectively. However, at the other boreholes (LM1, LM3, LM4 and LM6), the ground water was encountered. In addition to the boreholes, two borrow samples from the borrow pits and riverbed (LMP1 and LMP2) were collected for laboratory tests. The location of borrow pits are shown in the layout plan (**Fig. 10.1-4**).

The most common divisional planes present in Deccan Trap rocks are the joints and they play a very vital role in the safety and stability of a dam. In the three boreholes, LM1, Lm2 and LM3, drilled along the Dam Axis I, 238 pieces out of 703 pieces in total were broken along the joints. In the other three boreholes, LM4, LM5 and LM6, drilled along the Dam Axis II, 174 pieces out of 694 pieces in total were broken along the joints and the rests were broken mechanically. Moreover, there are a number of closely spaced joints, for which suitable treatment is required before founding the dam.

The crushing strengths of various rock core specimens are in a range between 109 and 1,463 kg/cm^2. The water content ranges between 2.6 and 2.8%. From the test results, it can be said that the basalt possesses adequate compressive strength. Therefore the foundation rocks, as far as strength is concerned, are moderately good.

(i) Dam Axis I (Downstream Alternative)

a. LM1 (RL 219.897m at the surface)

Between RL 219.897m and RL 213.647m, there is overburden. Between 213.647m and 193.30m, there is a flow of Compact Porphyritic Basalt. Below this down to RL 181.647m, there is Volcanic Breccia. Down to RL 159.097m (the end of the borehole), there is a flow of Compact Porphyritic Basalt.

Below the overburden down to RL 202m, there are a large number of joints; majority of the joints are stained. Along some joints, weathering of rocks has taken place.

Down to RL 207.897m, the core recovery varies between 57 and 96% and RQD varies between 46 and 76%.

b. LM2 (RL 156.942m at the surface)

Down to RL 148.942m, there is overburden. Below this down to the bottom of the borehole (RL 96.772m), there are various flows of Compact Porphyritic Basalt, Volcanic Breccia and red Tachylytic Basalt.

Down to RL 143.142m, the core recovery varies between 7 and 100% and RQD varies between nil and 90%.

c. LM3 (RL 220.618m at the surface)

From the surface to RL 214.718m, there is overburden. From this down to RL 212m, the rock is in highly weathered state. Below this, there are flows of Compact Porphyritic Basalt and Volcanic Breccia.

Down to RL 202m, there is a large number of joints and majority of these joints are stained.

(ii) Dam Axis II (Upstream Alternative)

a. LM4 (RL 239.292m at the surface)

From the surface to RL 231.792m, these is overburden. Below this down to the end of borehole, there are various flows of Porphyritic Amygdaloidal Basalt, Volcanic Breccia and Compact Porphyritic Basalt. From RL 231.729m to RL 223m, there are a number of joints with various angles. Majority of these are stained.

b. LM5 Top RL 174.073m

From the surface to RL 172.943m, there is overburden. Below the overburden down to the end of the borehole, there are various flows of Amygdaloidal Basalt and Compact Porphyritic Basalt. At some places, there are injections of red Tachylytic Basalt. From RL 172.943m to RL 166m, there are a number of joints and majority of them are stained.

c. LM6 (RL 251.260m at the surface)

From the surface to RL 247.46m, there is overburden. Below the overburden down to the end of borehole, there are various flows of Porphyritic Amygdaloidal Basalt, Volcanic Breccia and, at some places, red Tachylytic Basalt. From RL 247.46m to RL 240m, there are a number of joints which are stained. Down to RL 242m, the rock is hydrothermally altered.

(3) Geotechnical Appraisal

(a) Geotechnical Appraisal for Upper Dam Site

The overburden at the upper dam site comprises of firm to hard reddish brown silty clay with sand and highly weathered laterite containing boulders. The soil is residual in character, derived from hydrothermal weathering of rock below. The overburden is about 11 to 28m in thickness.

SPT-value of 6 to 32 was obtained in the upper 17m at UM4 and UM5 indicating firm to hard consistency. At UM1, UM2 and UM3, SPT refusal was obtained due to the presence of lateritic weathered rock. At UM3, between depths of 14 and 20m, SPT-value of 8 to 31 blows was obtained due to the presence of highly weathered lateritised layers.

The overburden is classified as CL or CH. The geotechnical properties are as follows:

a)	Gravel	:	Nil to 8%
b)	Sand	:	8 to 40%
c)	Silt	:	26 to 45%
d)	Clay	:	26 to 45%
e)	Liquid limit	:	42 to 48%
f)	Plastic limit	:	20 to 24%
g)	Plasticity index	:	18 to 25%
h)	Specific gravity	:	2.63 to 2.68

It is possible to adopt shallow foundations at this site for structures such as control buildings, pump houses, etc.

On the other hand, the dam axis is proposed crossing Marleshwar Nala which drains the Gothna area. At the dam axis, the valley is wide and one can walk along the dam axis. By and large the rolling topography represents the lateritic landscape which is common in western plats. Except for a certain layer of silt on the left and right banks, the major portion of the dam axis is covered with hard laterite and lateritic soil.

The salient observations are:

(i) At the bottom of the valley (borehole UM2), the depth to acceptable foundation grade for the contemplated masonry structure is 14m (RL 812m). The same for left and right banks are 34m (RL 837m) and 38m (RL 833m) respectively.

(ii) No data on permeability of overburden of laterite is available at the dam axis. Consequently it is difficult to prognosticate if the thick laterite (34-38m depth) would permit leakage through the abutment or not.

(iii) Besides the optimization of dam height, the designers may possibly evaluate the feasibility of:
- a composite dam with a central spillway in riverbed and earthen/rockfill flanks.
- a complete embankment dam with a chute spillway on flank.

Saddle Dam I was proposed on the right rim of the reservoir and the elevation of the deepest point is RL 846m.

The main observations are:

a. Soft laterite and lateritised rock exist up to a depth of 22m. SPT-value is about 9 and the characteristics are similar to silt.
b. Volcanic Breccia and highly weathered basalt exist from 22m deep down to the bottom of hole.
c. The surface layer (silty) is 3.6m in thickness.
d. No data on permeability of overburden (laterite) is available.
e. The cut of trench of the saddle dam would be decided primarily by permeability.

Saddle Dam II was originally envisaged to be constructed at the saddle point on the left rim of the reservoir. But, since the ground level is RL 873m (FRL = RL 857m), it is not required to construct a saddle dam.

The main observations are:-

a. The exploration proved the presence of laterite down to a depth of about 23.4m underlain by weathered basalt.

b. Permeability of overburden was not tested. This test should be performed at an appropriate stage because problem of leakage from the rim is still in question.

(b) Geotechnical Appraisal for Lower Dam Site

The overburden of about 1.5m in depth was observed at LM1 & LM5, about 3.0 to 4.5m at LM2, LM3 & LM6 and 7.5m at LM4.

SPT-value of about 9 to 23 was obtained in the upper 5m depth at LM3 indicating firm to stiff consistency, 30 to 38 at LM6 and more than 50 at LM1, LM2, LM4 & LM5, all indicating hard consistency.

The overburden is classified as CI or MI - CI at LM3 & LM4, SM-SC or SW-SM at LM1 & LM6 and GP-SP at LM2.

The properties are as follows;

At LM3 and LM4

a)	Gravel	:	6 to 12%
b)	Sand	:	30 to 42%
c)	Silt	:	26 to 29%
d)	Clay	:	26 to 29%
e)	Liquid limit	:	42 to 43%
f)	Plastic limit	:	25 to 26%
g)	Plasticity index	:	16 to 18%

At LM1 and LM6

a)	Gravel	:	10 to 34%
b)	Sand	:	49 to 79%
c)	Silt & clay	:	11 to 17%

(i) Dam Axis I (Downstream Alternative)

At the borehole LM1 (right bank), a zone of Volcanic Breccia/Tachylytic Basalt was encountered from RL 193m to 183m and from RL 173m to 158m.

Presuming that this zone is horizontally formed, it would be necessary, in case a masonry/concrete spillway is envisaged here, to strip down to RL 181.6m so that this soft zone is completely replaced with concrete. Similarly at the borehole LM3 (left bank), 10m thick Tachyritic Basalt was encountered between RL 192m and 182m. Possibly this is a strike extension of the Tachylytic zone encountered at the borehole LM1. At this location also, because of the steep dip of the bed rock profile towards the river, it is necessary to strip down to the bottom of this zone (RL 182m) to found rigid structures. In the riverbed (borehole LM2), the foundation grade for a masonry/concrete structure may be kept at the bottom of the first Tachylytic Basalt layer of about 14m deep i.e. at about RL 145m.

With the given geological conditions, a composite structure with rockfill flanks and a central spillway can be conceived at this location. However, deep excavation to remove the 10m thick soft zone of Tachylytic Basalt at the abutments and riverbed would be costly and difficult.

(ii) Dam Axis II (Upstream Alternative)

Crest level of dam is not known. But it is difficult to retain or strip off the top Tachylytic Basalt layers between RL. 205m and RL 196m encountered at the borehole LM4 and from RL. 196m down to the bottom of hole at the borehole LM6.

Considering a narrow and partially rocky valley at Dam Axis II, this alternative is preferable to Dam Axis I.

The choice of dam axis, among the two investigated alternative alignments, depends on many factors. However, from a geological point of view, Dam Axis II is found to be more advantageous for construction of a rigid dam (concrete or masonry). However, due to rapid diurnal fluctuation of water level in the reservoir, fairly steep rim of the reservoir is likely to develop instability of slope. This aspect needs to be addressed at an appropriate stage.