2.3 Geological Survey

The geological survey was carried out to determine subsoil conditions along the route of Karachi Circular Railway (KCR) in Karachi.

The survey included boring survey at specified locations along the rout of KCR. The subsoil samples were collected from the boring, and laboratory tests were conducted.

The survey analysis is based on 90 boreholes (24 boreholes of 15 m in depth, 44 boreholes of 20 m in depth) and the laboratory test results. The fieldwork was carried out from April 09, 2012 to July 28, 2012.

The geotechnical conditions and parameters for the development of the proposed infrastructure and facilities are recommended in this section.

2.3.1 Scope of Work

The scope of work for the geotechnical survey is as follows:

(1) Core drilling with Testing

Core drilling will be made for bedrock, soil and unconsolidated deposits that may contain boulders. The diameter of the boreholes shall be not less than 60 mm. Every effort shall be made for 100% core recovery.

Standard penetration tests (SPT), in accordance with ASTM D1586 or the equivalent, shall be carried out every 1.0 m of depth in the sections of bore holes which are located within soils, unconsolidated deposits or intensively weathered rocks, to evaluate the mechanical strength of those materials.

Undisturbed sample shall be obtained with appropriate equipment and shall be sent to the laboratory for the purpose of the obtaining data to determine physical and mechanical properties of the soils.

Permeability test shall be carried out by piezometer method to determinate hydraulic properties of aquifer in boreholes. Test sections of permeability tests will be instructed by the Engineer.

(2) Laboratory Tests

Laboratory tests shall be carried out to obtain the index and engineering properties of soil foundations for KCR. This work shall comprise sampling, transportation of samples, various sorts of tests in the laboratory, geotechnical interpretation and evaluation of the testing results, and their reporting.

The work also includes installation of Screen Pipes and monitoring of groundwater in all 90 boreholes (recorded twice a month). This monitoring shall continue up to completion of core drilling works.

It was also specified that daily data of sea level at the tide gauge in Karachi harbor shall be obtained to compare the groundwater level in boreholes during ground water monitoring.

(3) Program of Survey

The program of Survey consisted of drilling of 90 boreholes along the entire route of KCR; 24 boreholes up to 15m depth, 44 boreholes up to 20m depth and 22 boreholes up to 30m depth.

In addition, the specifications required additional borings of 25 boreholes up to 5m depth for undisturbed sampling, of cohesive strata, to be done at positions adjacent to actual boring points upto a maximum depth of 5m.However, only 19 boreholes could be carried out for this purpose due to the absence of cohesive strata at remaining boreholes locations.

2.3.2 Program of Investigations:

The program of investigation consisted of drilling of 90 boreholes along the route of KCR; 24

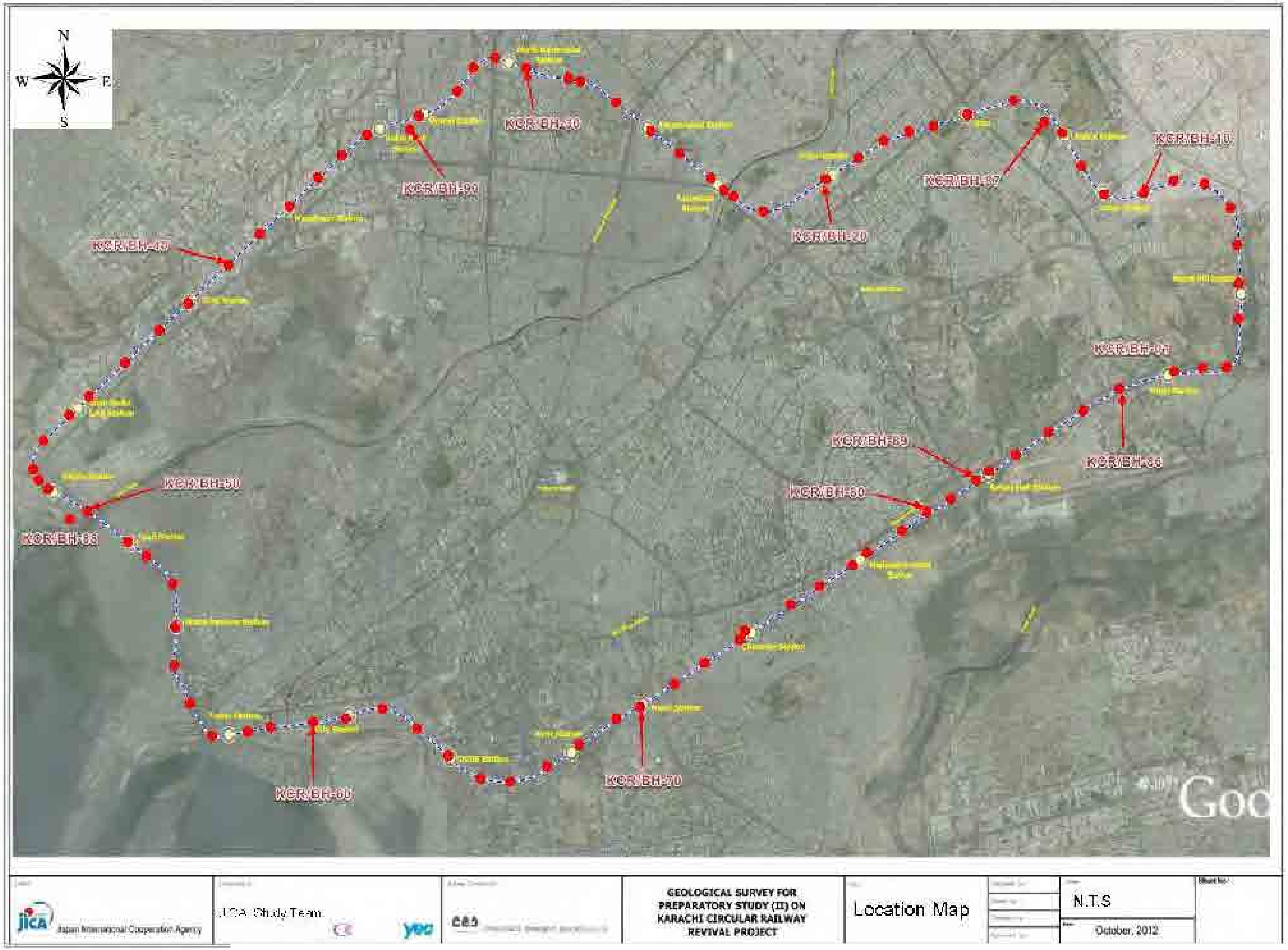
boreholes up to 15m depth, 44 boreholes up to 20m depth and 22 boreholes up to 30m depth.

In addition, the specifications required additional borings of 25 boreholes up to 5m depth for undisturbed sampling to be done at positions adjacent to actual boring points upto a maximum depth of 5m.

However, only 19 boreholes could be carried out for this purpose due to the absence of cohesive strata at remaining boreholes locations.

(1) Borehole Locations and Survey Quantities

Figure 2.3.1 shows the location of boreholes. Table 2.3.1 and Table 2.3.2 show the quantities of borings and laboratory tests respectively.



Source: JICA Study Team

Figure 2.3.1 Borehole Locations along KCR Route

Table 2.3.1 Quantities of Geotechnical Survey.

Borehole No.	Depth (m)	SPT (Nos)	Permeability Test (Nos)	Undisturbed Samples (Nos)	Installation of Drilli Machine (Nos)	Installation of Scree Pipe (Nos)	Geodetic Data (Nos)	Borehole No.	Depth (m)	SPT (Nos)	Permeability Test (Nos)	Undisturbed Samples (Nos)	Installation of Drilli Machine (Nos)	Installation of Scree Pipe (Nos)	Geodetic Data (Nos)	Borehole No.	Depth (m)	SPT (Nos)	Permeability Test (Nos)	Undisturbed Samples (Nos)	Installation of Drilli Machine (Nos)	Installation of Scree Pipe (Nos)	Geodetic Data (Nos)
KCR/BH-1	20.00	18			1	1	1	KCR/BH-31	20.00	18			1	1	1	KCR/BH-61	30.00	18		1	1	1	1
KCR/BH-2	20.00	19			1	1	1	KCR/BH-32	20.00	12			1	1	1	KCR/BH-62	30.00	16		1	1	1	1
KCR/BH-3	20.00	19			1	1	1	KCR/BH-33	20.00	16			1	1	1	KCR/BH-63	30.00	5		1	1	1	1
KCR/BH-4	20.00	19			1	1	1	KCR/BH-34	20.00	13			1	1	1	KCR/BH-64	30.00	10		1	1	1	1
KCR/BH-5	20.00	14			1	1	1	KCR/BH-35	20.00	15			1	1	1	KCR/BH-65	30.00	1			1	1	1
KCR/BH-6	15.00	7			1	1	1	KCR/BH-36	20.00	8			1	1	1	KCR/BH-66	30.00	11		1	1	1	1
KCR/BH-7	15.00	7			1	1	1	KCR/BH-37	20.00	10			1	1	1	KCR/BH-67	30.00	4			1	1	1
KCR/BH-8	15.00	10			1	1	1	KCR/BH-38	20.00	5			1	1	1	KCR/BH-68	30.00	4			1	1	1
KCR/BH-9	15.00	8			1	1	1	KCR/BH-39	20.00	10			1	1	1	KCR/BH-69	20.00	4			1	1	1
KCR/BH-10	15.00	1			1	1	1	KCR/BH-40	20.00	6			1	1	1	KCR/BH-70	15.00	4			1	1	1
KCR/BH-11	15.00	-			1	1	1	KCR/BH-41	20.00	6			1	1	1	KCR/BH-71	15.00	4			1	1	1
KCR/BH-12	15.00	2	1		1	1	1	KCR/BH-42	20.00	9			1	1	1	KCR/BH-72	15.00	5			1	1	1
KCR/BH-13	15.00	2	1		1	1	1	KCR/BH-43	20.00	5			1	1	1	KCR/BH-73	20.00	4			1	1	1
KCR/BH-14	15.00	3	1		1	1	1	KCR/BH-44	20.00	0			1	1	1	KCR/BH-74	20.00	5			1	1	1
KCR/BH-15	15.00	7			1	1	1	KCR/BH-45	20.00	4		1	1	1	1	KCR/BH-75	20.00	4			1	1	1
KCR/BH-16	15.00	3			1	1	1	KCR/BH-46	20.00	6			1	1	1	KCR/BH-76	20.00	4			1	1	1
KCR/BH-17	15.00	7			1	1	1	KCR/BH-47	20.00	9			1	1	1	KCR/BH-77	20.00	2			1	1	1
KCR/BH-18	15.00	7			1	1	1	KCR/BH-48	30.00	9		1	1	1	1	KCR/BH-78	20.00	3			1	1	1
KCR/BH-19	15.00	5			1	1	1	KCR/BH-49	30.00	8			1	1	1	KCR/BH-79	20.00	4			1	1	1
KCR/BH-20	15.00	4			1	1	1	KCR/BH-50	30.00	12		1	1	1	1	KCR/BH-80	20.00	2			1	1	1
KCR/BH-21	15.00	6			1	1	1	KCR/BH-51	30.00	19		1	1	1	1	KCR/BH-81	20.00	3			1	1	1
KCR/BH-22	15.00	9			1	1	1	KCR/BH-52	30.00	20		1	1	1	1	KCR/BH-82	20.00	10			1	1	1
KCR/BH-23	15.00	11			1	1	1	KCR/BH-53	30.00	18		1	1	1	1	KCR/BH-83	20.00	4			1	1	1
KCR/BH-24	20.00	8			1	1	1	KCR/BH-54	30.00	20		1	1	1	1	KCR/BH-84	20.00	7			1	1	1
KCR/BH-25	20.00	14			1	1	1	KCR/BH-55	30.00	19		1	1	1	1	KCR/BH-85	20.00	11			1	1	1
KCR/BH-26	20.00	11			1	1	1	KCR/BH-56	30.00	27		1	1	1	1	KCR/BH-86	20.00	19			1	1	1
KCR/BH-27	20.00	13			1	1	1	KCR/BH-57	30.00	24		1	1	1	1	KCR/BH-87	15.00	5			1	1	1
KCR/BH-28	20.00	13			1	1	1	KCR/BH-58	30.00	24		1	1	1	1	KCR/BH-88	30.00	10		1	1	1	1
KCR/BH-29	20.00	14			1	1	1	KCR/BH-59	30.00	25		1	1	1	1	KCR/BH-89	15.00	9			1	1	1
KCR/BH-30	20.00	19			1	1	1	KCR/BH-60	30.00	12		1	1	1	1	KCR/BH-90	15.00	9			1	1	1
																Total	1900.00	870	3	19	90	90	90

Source: JICA Study Team

Table 2.3.2 Quantities of Laboratory Testing

Sr.No.	Description	Unit	Quantities
3	Laboratory Testing	LS	1
	Partical Size Aanlysis	Nos	1045
	Atterberg Limit	Nos	1061
	Specific Gravity of Soil	Nos	734
	Moisture Content	Nos	1115
	Bulk Density	Nos	296
	Dry Density	Nos	296
	UU Triaxial Compression Test	Nos	16
	Direct Shear	Nos	439
	Consolidation	Nos	42
	Unconfined Compression Strength	Nos	286
	pH Value	Nos	182
	Sulphate Content in Soil	Nos	92
	Sulphate Content in Water	Nos	90
4	Water Level Monitoring	LS	1
5	Core Storage Shed	LS	1
6	Report	LS	1

Source: JICA Study Team

(2) Drilling

The drilling was performed using rotary drilling machine with hydraulic feed having drilling capacity of 100m of vertical depth at a minimum diameter of 65mm through hard rock. Core drilling was accomplished using double tube core barrel whereas in unconsolidated soil strata, single tube core barrel was used and dry coring was adopted. Diamond bit was used in hard rock whereas tungsten carbide bit was employed in soft rock and hard clay.

The core samples were placed orderly in galvanized steel core boxes, in the same length of grooves of the core box as the length which had been drilled. Wooden markers indicating depth and run numbers were inserted at start and end of each running meter as well as placed between core run where strata changed. The core boxes were photographed and transported to the specified storage shed whereas selected samples were sent to the laboratory for further testing.

(3) Standard Penetration Tests

Standard penetration tests (SPTs) were performed at 1.0m interval in sections of the borehole that were drilled through unconsolidated deposits or highly weathered rock until bed rock was encountered. The test was conducted in accordance with ASTM Designation D-1586. The SPT blow count (N-value), an index of relative density / consistency of granular / cohesive substrata, was recorded.

Where Sandy Gravels strata was encountered at the site, SPTs were replaced with Cone Penetration Tests (CPT) which were performed at an interval of 1.0m as per BS 5930-23.2

The soil samples collected through the split-spoon sampler, during the penetration test, were preserved in plastic bags and placed into the core box at the corresponding depth.

(4) Undisturbed Sampling

Undisturbed samples were extracted from additional 5m deep boreholes drilled at positions adjacent to specified boreholes. The undisturbed samples were obtained, using thin-wall Shelby Tube sampler, in accordance with ASTM Designation D-1587.

Immediately after sampling, the tubes' ends were sealed with molten wax and marked with borehole number, sample number and depth. The samples were immediately dispatched to the laboratory and care was taken not to cause any disturbance to the sample.

(5) Permeability Tests

Permeability tests were performed in BH# 12, 13 and 14 by variable head piezometer method in accordance with BS 5930. The tests were conducted at 10 and 15m depth in these three boreholes, as per instruction of JICA Supervisor.

(6) Installation of Screen Pipes in Boreholes

A line of uPVC screen pipes was installed in all (90 Nos) boreholes for the monitoring of ground water table after the completion of drilling operation. The PVC pipe was taken down to full length of the boreholes of 15 and 20m depth and upto 20m in 30m deep borehole. The inside diameter of the uPVC pipe was 50mm and the perforation was not less than 10% of the peripheral area. For filtering effect, shrouding material was filled in the annular space between the hole and the pipe.

(7) Laboratory Tests

Following tests were performed on SPT samples:

Particle size analysis by sieve and hydrometer	ASTM D-422
Liquid limit, plastic limit, plasticity index	ASTM D-4318
Specific gravity of soil	ASTM D-854
Natural water content of soil	ASTM D-2216
Direct Shear on remolded samples	

In case of undisturbed samples following tests were performed:

Particle size analysis by sieve and hydrometer	ASTM D-422
Liquid limit, plastic limit, plasticity index	ASTM D-4318
Specific gravity of soil	ASTM D-854
Bulk and dry density	ASTM D-1895 B
UU Triaxial compression	ASTM D-2850
Natural water content of soil	ASTM D-2216

In case of Rock core samples following tests were performed

Particle size analysis by sieve and hydrometer*	ASTM D-422
Liquid limit, plastic limit, plasticity index*	ASTM D-4318
Bulk and dry density	ASTM D-1895 B
UU Triaxial compression	ASTM D-2850
Natural water content of soil	ASTM D-2216
Specific gravity of soil	ASTM D-854
Unconfined Compression Test	
Consolidation	ASTM D-2435

***** Test performed on soft/weak Mudstone/ Shale/ Sandstone

2.3.3 Description of Regional and Site Geology and Geomorphology

Karachi is located in the southern most part of Pakistan, at 24° 51' N and 67° 0' E. Geographically, Karachi is bounded by Hub-River (Balochistan Province) on West, Badin District on East, Dadu District on North and Arabian Sea on South. The Karachi Circular Railway (Revival Project) route passes through the most populated localities and important industrial sites of Karachi. Its stations cover almost of the populated localities including Drigh Road, Gulistan-e-Johar, North Nazimabad, Orangi, Manghopir, SITE, Tower, City and Cantt Railway Stations and Karsaz (Figure 2.3.1). This section of Report presents the local and regional geology and the structural features of Karachi. The geological rocks types exposed and faults exposed or concealed in Karachi have also been discussed along with subsurface lithological units which may influence planning construction of project.

(1) Geomorphology of Karachi

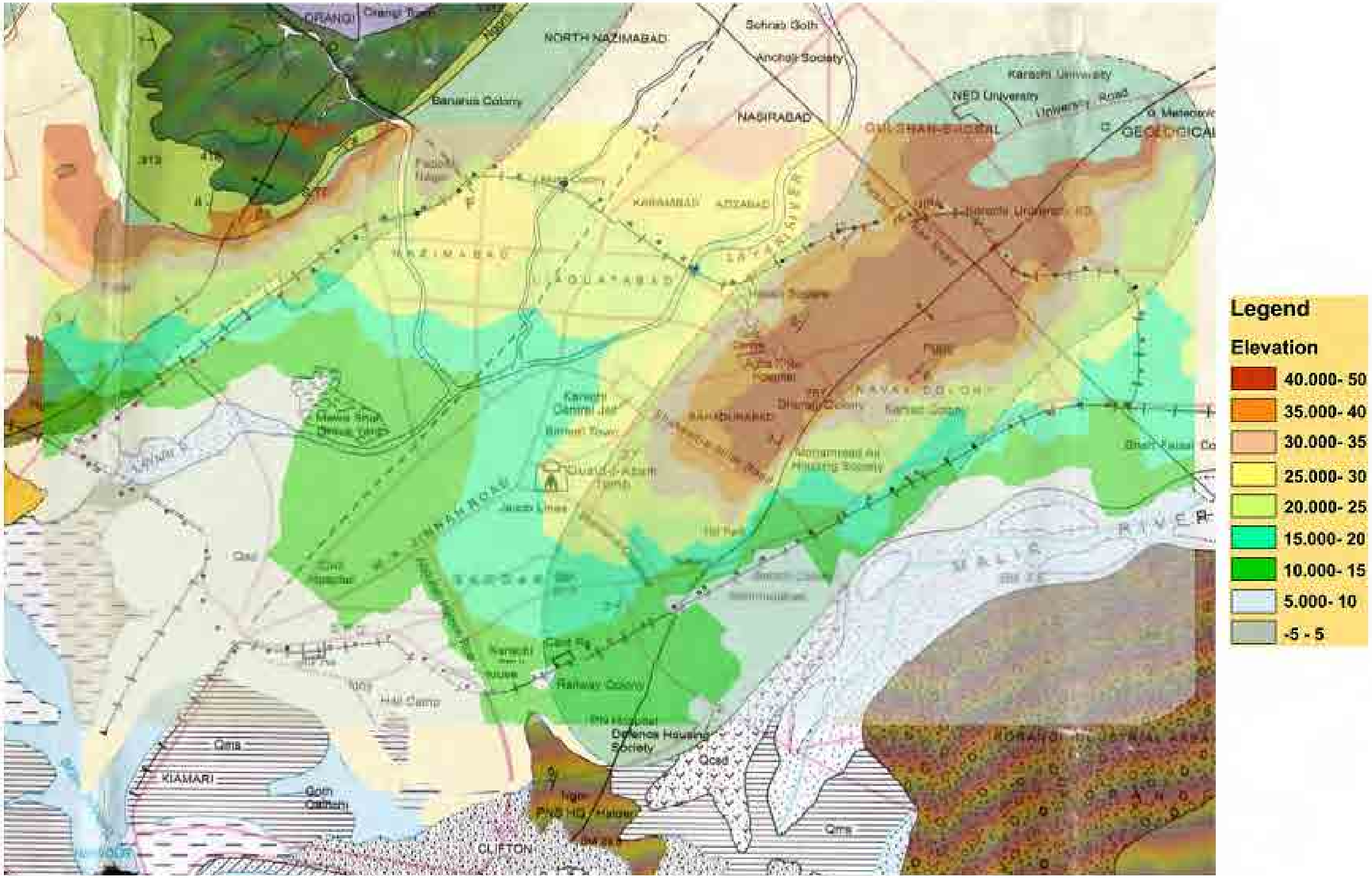
Karachi is located in the south of Sindh, on the coast of the Arabian Sea. It covers an area of approximately 3,600 km^2, comprised largely of flat or rolling plains, with hills on the western and northern boundaries of the urban sprawl. The city represents quite a variety of habitats such as the sea coast, islands, sand dunes, swamps, semi arid regions, cultivated fields, dry stream beds, sandy plains, hillocks. Classified according to physiographic features, Karachi City District can be divided into three broad categories: Hilly Region (Mountain Highland), Alluvial Plain (Piedmont Plain) and Coastal Areas (Valley Floor).

The metropolitan area is divided by two non-perennial river streams namely Lyari and Malir Rivers. The Malir River flows from the east towards the south and centre, and the Lyari River flows from north to the south west. Gujjar and Orangi are the two main tributaries of the Lyari River while Thaddo and Chakalo are the main tributaries of the Malir River. The dry weather flow of both rivers carries urban sewage that is ultimately drained in the Arabian Sea. Among the various physiographic features, low flat-topped parallel hills devoid of vegetation, interspersed with widespread plains and dry riverbeds are the main topographic characteristics of the city.

The greatest height of the region is 250 ft that gradually decreases to 5 ft above mean sea level along the coastline. The Karachi Harbour is a sheltered bay to the south-west of the city, protected from storms by the Sandspit Beach, the Manora Island and the Oyster Rocks.

The Arabian Sea beach lines the southern coastline of Karachi. Dense mangroves and creeks of the Indus delta can be found towards the south east side of the city. Towards the west and the north is Cape Monze, an area marked with projecting sea cliffs and rocky sandstone promontories.

Figure 2.3.2 shows the Geomorphological Features along KCR Route.



Source: JICA Study Team

Figure 2.3.2 Geomorphological Map of Area Around and within KCR Route

(2) Geology of Karachi region and Site Area

Karachi is the part of major synclinorium stretching from Ranpathani River in the east to Cape Monze in the west, Mehar and Mole Jabal (Mountains) in the north. Within the synclinorium a number of structures such as Pipri, Gulistan-e-Jauhar, Pir Mango and Cape Monze are exposed. The presence of concealed structures under the Malir River valley, Gadap and Maripur plains can fairly be deduced.

Rock aggregates, sand, limestone and clay are some of the potentials for gainful utilization. Gulistan-e-Jauhar member of the Gaj formation offers groundwater potential for limited use. The area is underlain by rocks of sedimentary origin ranging in age from Eocene to Recent. Major structural trends and the basin axis strike generally south but with a “bulge” to the east also called Karachi Arc (Bender and Raza 1995).

1) General Geology:

According to Bender and Raza (1995), the geological structural setup of Karachi region belongs (Southern India Basin which is a result of the rifting during Triassic, oblique collision of the Indo-Pakistan plate with the Afghan blocks during the Late-Cretaceous and Palaeogene, and by post collision deformation during Neogene and Quaternary periods. Tectonically, the counter clockwise movement of Indian plate during Eocene time, after its collision with Eurasian plate, has resulted in the formation of Karachi Embayment. It has remained as a trough in the recent geological time. It was followed by structural deformation in the late Pleistocene to middle Pleistocene related to the Himalayan Orogeny.

This arc forms the southern-most part of the Kirthar Mountain and the southwestern margin of Lower Indus Basin. It is bounded by Ornach-Nal Fault in the west and Hyderabad High in the East. The southern part of the embayment is submerged in the sea and still receiving sediments from different sources. It is comprised of a series of parallel to sub parallel short, narrow, serrate, accurate (convex to east) enechelon ridges and wide, dome-shaped anticlinal hills. It forms nearly 200 km long and 50 km wide zone between Karachi and Sehwan. The Bhit range, Bhadra range, Lakhi hills and Lakhra hills are some of its more prominent components. The altitude of the Hills varies from 250 m in the south to about 1,100m in the north. The Naing, Baram and MalirRiver are the main streams draining this region.

The Trough is characterized by thick Early Cretaceous sediments and also marks the last stages of marine sedimentation. This localized deposition represents a unique feature where no hiatus in sedimentation occurs. Sembar and Goru (Cretaceous) of several meters thickness, overlain Parh Mughal Kot and Pub formations. The Paleocene sequences are marked by Rani Kot formation. The Eocene is represented by Ghazij Shale and carbonates of Kirthar and Laki formation. The Oligocene is represented by the Nari formation which is underlain by Gaj formation of Miocene age. The submerged part of embayment is still receiving sediments from sources of proto Indus drainage system (Shoaiband Rafi, 2004).

2) Stratigraphy

The main rocks exposed in Karachi are given in Table 2.3.3 as described hereunder.

Table 2.3.3 Rocks Exposed in Karachi

QUARTERNARY	Recent: Alluvial deposits, stream bed deposits Sub Recent: Piedmont and sub piedmont deposits.
PLIOCENE	Manchar Gray Limestone.
PLIESTOCENE	Gulistan-e-Johar: Inter bedded and grey Siltstone, Sandstone, Clay and Limestone

MIOCENE	Gaj Formation Mole : Limestone and Clay Mundro: Predominantly Clay and Sandstone with minor Limestone Orangi : Sandstone with subordinate Clay and Limestone
OLIGOCENE	Nari Formation PirMangho: Limestone, Clay and Sandstone Hab : Massive Sandstone with minor Sandy Clay Tobo : Alternating sandy Rimestree Sandstone and Clay
EOCENE	Jakhar Limestone: Jakhar Limestone: Limestone, concretionary

Source: JICA Study Team

3) Feature of Stratum

Piedmont and Alluvium Deposits (sub Recent to Recent):

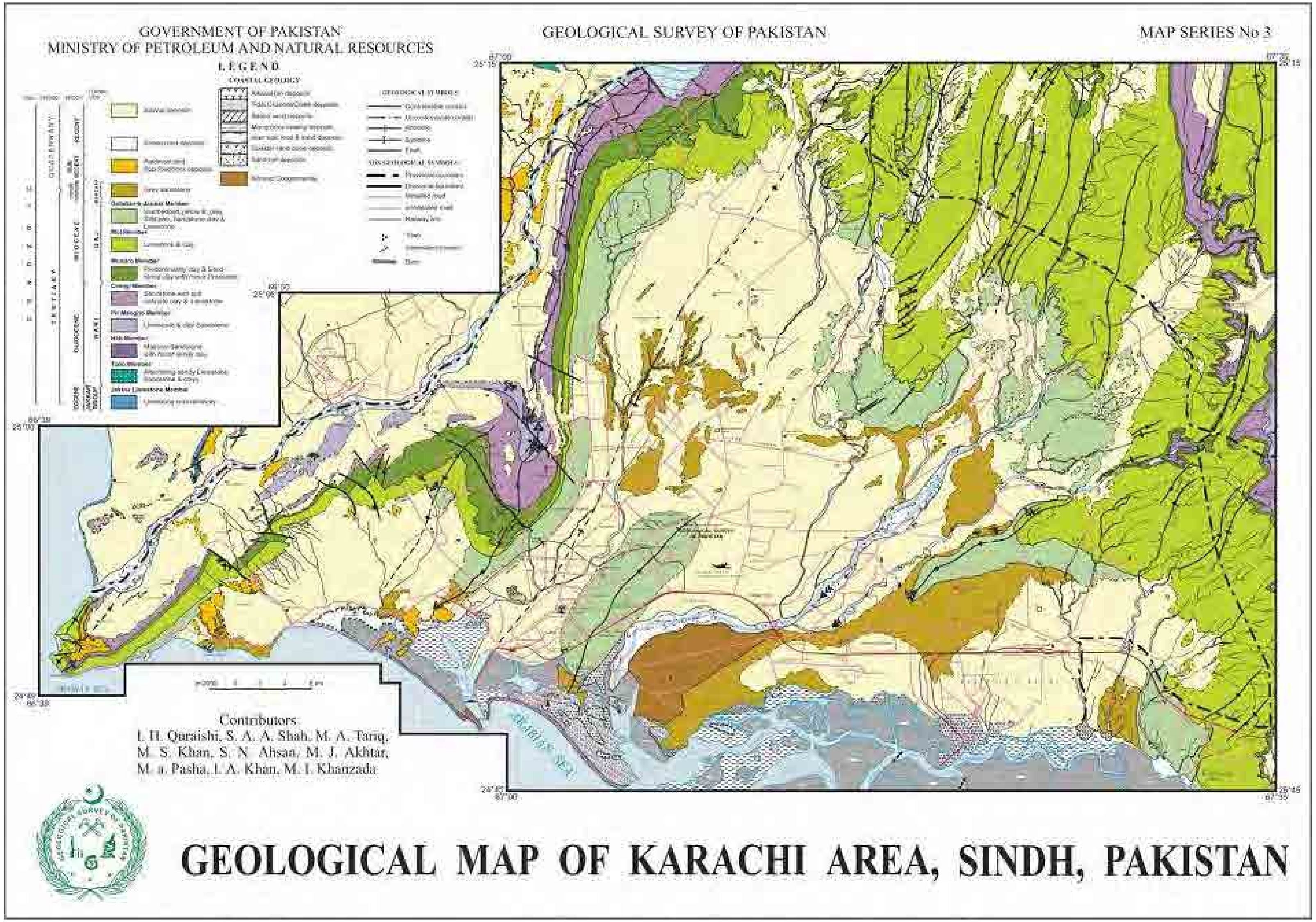
In Karachi mostly stream bed and alluvium (Sand, Silt and Clay) deposits are exposed.

- ✓ **Manchar Formation (Pliocene-Pleistocene):**
  The Manchar formation occupies all the structural lows in the mapped areas and comprises grey Sandstone, grey and brown Clay and Minor Conglomerate. It can be best examined near the bridge over Malir River on the road linking National Highway with the super Highway, Korangi Hills, Maymar bed, the upper reaches of Lyari River and around the Paradise Point.
- ✓ **Gaj Formation (Miocene):**
  The Gaj dominates rock exposures in all use structural highs in and around Karachi and is divisible in the following members:
- ✓ **Gulistan-e-Jauhar Member:**
  It is an assemblage of rocks that are exposed in Gulistan-e-Jauhar and continues obliquely south eastward to the Defence Housing Society. The member has yellow to light brown Siltstone and Sandstone, grey Clays and yellow Limestone. It is also exposed near Dhabeji along the Pipri anticline, in the vicinity of Gadap to the east of Surjani Hills, near Paradise point and south of Jhill Hills near CapeMonze.
- ✓ **Mol Member:**
  The Mole member exposed widely on the Mol Plateau, comprise, Limestone with minor Clay. The Limestone is brown, yellow brown compact and hard. The Clay is grey and greenish grey.
- ✓ **Mundro Member:**
  It comprises of Clay, mostly brown, grey and greenish grey other layers are white calcareous, Sandstones and yellowish Marl, all inter layered.
- ✓ **Nari Formation (Oligocene):**
  Nari Formation is lithologically divisible into following members.
- ✓ **Orangi Member:**
  The Orangi Member is predominantly colored Sandstone and Clay. It also contains subordinate Limestone and lenses of glass sand.
- ✓ **Pir Mangho Member:**
  The Pir Mangho Member contains brown to rusty brown Sandstone and Clay of different hues. It is exposed in Pir Mangho area.
- ✓ **Hub Member:**
  The Hub member comprises of grey, greenish and brownish grey, Massine and cross-bedded Sandstone. Its exposure is along Hub River road, north of Hamdard University.
- ✓ **Tobo Member:**
  The Tobo member comprises of alternating rusty brown Limestone, Sandy Limestone, cross-bedded Sandstone and Clay.

- ✓ **Jakhar Limestone (Eocene):**
  It mainly consists of concretionary Limestone and is not well exposed in Karachi.

(3) Structural Features of Karachi Region and Site Area

In the western part of the Karachi, a series of transverse faults have displaced the rocks. The relative movement of individual block in relation to adjoining block has been towards North West (Figure 2.3.3). The degree of lateral displacement decreases from west to east. The traces of the following faults have been delineated (Hasan and Anisuddin, 1979; Mirza et al, 1984 and Kazmi and Jan, 1997).



Source: after Quraishiet al., 2001

Figure 2.3.3 Geological Map of Karachi Showing Fold and Fault Structures

1) Faults in Karachi

Sona Fault:

The Sona fault is located northwest of Hawks Bay along Sona Pass. The trace is straight, trends N 42° W and exposed for 3800 m. It is left lateral fault with western side moving north for 2200 m.

LalBakhar Fault:

The LalBakhar Fault is located north- northwest of Hawksbay in LalBakhar Pass along the upstream of Kochani Nala. It is a right lateral fault. The relative movement is of the order of about 1680 m.

Golamani Fault:

The Golamani fault is located north of HawksBay in GolamaniPass. The trace is exposed for 6400 m. It is concave towards west in the southern segment and concave towards east in northern segment. It is left lateral fault and relative lateral displacement is of order of 1200m.

Abdullah Fault:

The fault is located north of Hawks Bay near Goth Abdullah. The trace of fault is exposed for 7200 m. It is concave towards southwest in the southern segment. It is left lateral fault and the relative movement of beds is order of about 1000 m.

Khosti Fault:

The Khosti fault is located in the west of Hub Chowki Road near Goth Haji Khosti. The fault trace is exposed for 8400 m. It is concave towards northeast in the central part. It is a left lateral fault. The relative displacement of beds is about 1800m.

Nek Mohammad Fault:

It is located northwest of Lalji village near Goth Nek Mohammad. This appears to be hinge fault.

Metan Fault:

The Metan fault is along the course of Metannala. It is right lateral fault. Nearly all of the above faults may have eastward-concealed extensions under the recent sediments.

Jakhar Limestone: Limestone, concretionary

Along the Kirthar Range Front, there are N-S trending active faults. They are dip-slip are bedding-plane faults. North of Karachi and west of Lakhra, the north-south Surjani Fault cuts across the Quaternary deposits. West of Jhimpir, the southern end of this fault is intersected by the northwest trending Jhimpir Fault. The interaction of these two faults is characterized by at least four teleseismic events of shallow focal depth and magnitude 3-6. The maximum magnitude of the earthquake associated with the Surjani Fault is of the order of M~6.1.

Jhimpir Fault:

Jhimpir Fault is N-W trending. A number of epicenters are located on this fault. The fault has produced an earthquake of M~5.6 on Richter scale.

Pab Fault:

NNW-SSE trending and located in the eastern part of Pab Range. The maximum magnitude of the earthquake associated with this fault is of the order M~7.0 on Richter scale. The Pab fault has dislocated vertically the Quaternary alluvial fans.

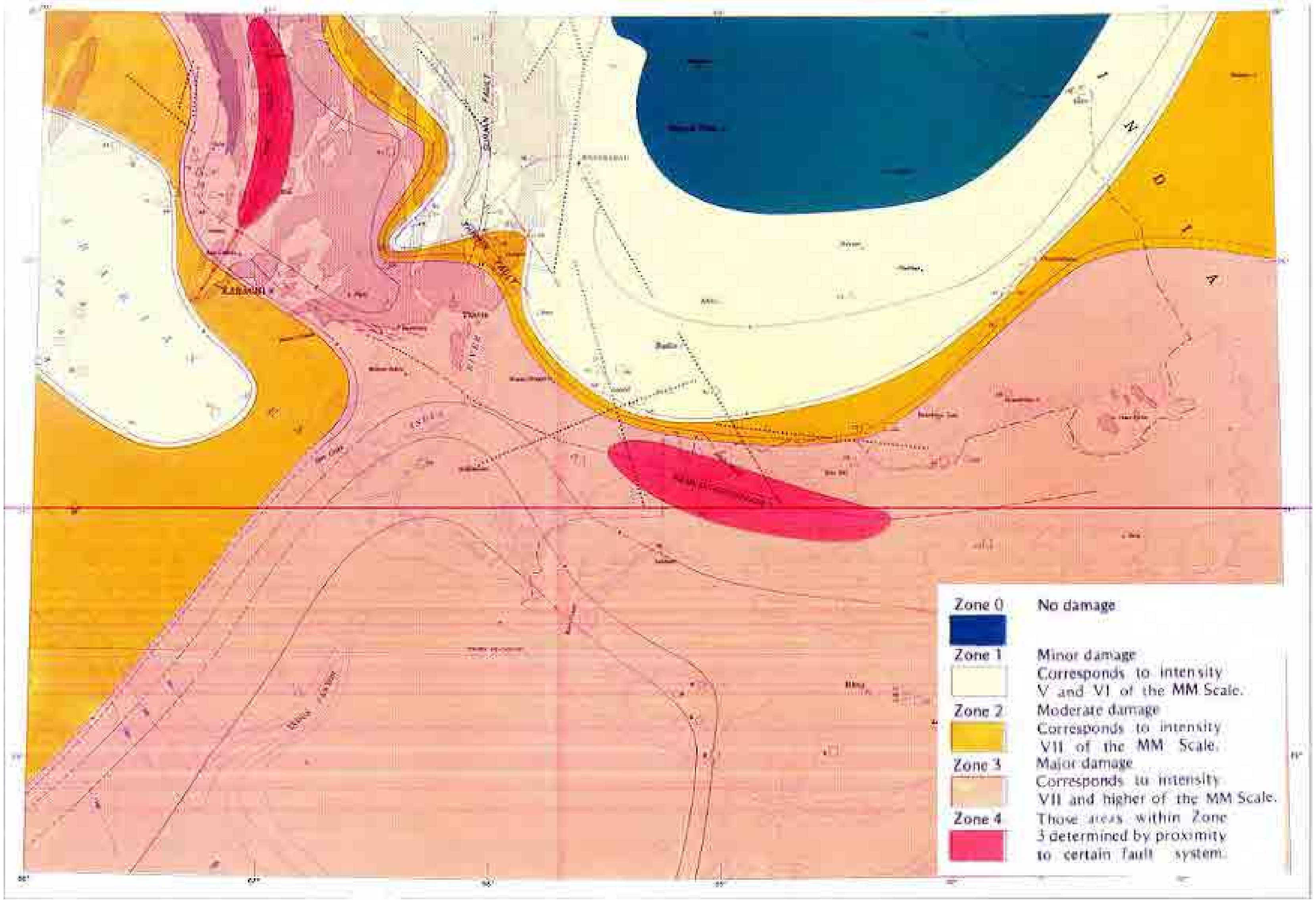
Hub Fault:

The Hub valley is traversed by this fault.

Rann of Kutch Fault:

This E-W trending fault has produced earthquake of the order of M~7.6 on Richter scale. In 1891 and 1956, this fault has been responsible for sever earthquakes in Gujrat, Tharparkar and Indus delta. Previous studies have revealed that this fault traverses the Karachi Metropolitan area and possibly passes through D.H.A. area in Karachi (Mirza et al., 1984).

There are extensions of the active faults from east (Rann of Kutch Fault), west (Jhill and Manghopir faults) and north (Pab and Surjani faults) under the Karachi Metropolis. In addition to above faults, other faults may also be present, concealed under the recent sediments. e.g., a fault is reported running north south(from Karachi university to DHA), but due to the presence of the sediment cover, buildings and roads, the surface trace and nature of this fault can hardly be known. (Figure 2.3.4).



Source: Metropolis (after Minza et al., 1984)

Figure 2.3.4 Seismic Risk Map of Karachi-Hyderabad Divisions, Showing major active Faults around Karachi

2) Folding

Structurally Karachi Trough forms an asymmetric structure. The western flank forms a narrow gentle monocline while the eastern flank is much wider and steeper.

From Karachi as centre in both east and west direction, older formations are exposed ranging from Mio- Pliocene to Paleocene and Eocene. Within this regional setup many narrow folded structures were developed. These can be grouped into system of parallel Anticlinal zone. Within the limit of Karachi area, three major Anticlines separated by Alluviated Synclinal tracks. The Major Anticlinal units are separated by Synclinal troughs.

In the west to east the first major Anticline is Cap Montz Anticline Followed by Pir Mangho Anticline. This Anticline is followed by Liyari Syncline and further to the east and north-east comes the Drigh Road Anticline followed by Malir Synclinal trough.

All above folded structure are plunging and asymmetric where as eastern limbs are steeper than western ones. It follows general SSW-NNE trend with south westerly plunge.

The Anticlines are dissected by erosion whereas, the Synclinal trough are mostly aggraded by recent fluvial deposits and are thus obscured. The structural trend in Karachi trough area particularly in ManghoPir the surrounding is in conformity with the major structural trend in Kirther and Pab Ranges.

The rocks exposed in Karachi were subjected to lateral compression. The prevalent direction of the compression force seems to be ENE. The Mangopir area, where the best Anticlinal structure is exposed, the trend of Anticlinal axis is SSW-NNE. The Anticline is plunges to south. It has 10^o to 15^o dip on western flank but the eastern steep flank has an average dip of 30^o or more and at places the dip is as high as 62^o. In the Syncline laying to the west of Anticline dips are high in the northern part otherwise it displays a general corresponds in its trend with the Anticline.

The other important structure situated in this area is the Drigh Road Anticline. This shows low dips which ranges between 2-5^o at the most. At places the rocks became horizontal. The Anticline seems to be double plunging with a sag in the central part. It forms an elongated Dome. This encloses only the exposure of Gaj Formation.

(4) Seismology of Karachi region

The city of Karachi, Pakistan, sits close to a plate boundary and within reach of earthquakes on numerous tectonically active structures surrounding the city. Geologically, Karachi is located on the southern margin of the geological trough which lies in the southern extension of the Kirthar range. The trough is delineated by severely deformed mountain ranges namely the Mor Range, Pab Range and Bela ophiolite/melange zone to the west, Kirthar Range to the north and the east, and by the Indus delta and the Arabian Sea creeks to the south. The trough may be subdivided into three principal regions.

A. Northern relatively uplifted region.
B. Southern submerged region
C. Western monocline

1) Active faults

Karachi is situated close to the junction of three tectonic plates (Indo-Pakistan, Arabian and Eurasian Plates). The earth hazard in the Indus Delta and the estuaries of the passive continental margin is mainly from the intra-plate active faults, principally the Rann-of-Kutch Karachi Fault (also known as Karachi-Jati-Allah Bund fault), the Pab-Null Fault and their respective strands. The Rann-of-Kutch Fault passes close to the Eastern industrial Zone of Port Qasim. Karachi coast has three other segments namely the Jhimpir fault, the Pab fault, and the Surjani fault. These are the intra-plate active faults that pose major earthquake hazard in the Indus delta and the estuaries of the passive continental margin. The orientation of the Rann of Kutch fault is roughly east-west; it is 225 km in length and is responsible for the production of earthquakes of considerably high magnitude of up to 7.6 M on Richter scale and of IX to X intensity on the Modified Mercali (MM) scale. The Pab fault on the other hand is 135 Km in length and is oriented north-south. On the basis of the study of the seismic potential of the active faults viz. Rann of Kutch and Pab faults over their entire length, along with analysis of historical and instrumental records of the Pakistan coastal zone the risk factor for this region is estimated to be 7.7 to 8.2 M for the former and 7.2 to 7.8 M for the later.

According to the United States Geological Survey (USGS) the Karachi.Makran coast in the Arabian Sea is seismically quite active. A high seismic activity of Karachi-Makran offshore is indicated by a large number of seismic shocks of 4 to 5 on Richter scale. Generally the areas which are prone to frequent small intensity earthquakes also suffer from major earthquakes (>7) periodically. This period may vary from 50 to 150 years. A list of earthquakes with inland epicenters, since 1668 to date which affected the Indus Deltaic Creeks is given in Table 2.3.4

Table 2.3.4 List of Earthquakes in Indus Deltaic Region and Surroundings within Latitude 23.0.25.0 ^{O}N and Longitude 67.5.71.0 ^{O}E

YEAR	LAT. (E)	LONG.	MAGNITUDE (RICHTER)	REMARKS (LOCATION)
894	24.80	67.90	6.3-7.6	Thatta
1050	24.60	67.73	6.5-7.5	Bhambhor
1668	24.70	67.60	6.3-7	Pipri
1668	25.00	68.00	7.60	Samaji Delta (Near Karachi)
1819	25.30	68.50	4.3-5.0	Hyderabad
1819	23.50	70.50	5.6-6.3	Rann of Kutch
1819	23.60	69.60	8.30	Kutch
1844	23.80	68.90	4.30	Luckput near Karachi
1845	23.80	68.90	5.70	Luckput (Kutch)
1851	26.40	67.90	6.00	Sehwen
1870	25.80	68.80	5.00	Lower Sindh
1920	25.00	68.00	5.60	Jhimpir
1935	24.70	66.00	5.00	Karachi
1960	25.70	67.60	4.00	Karachi
1962	24.10	70.00	5.00	Rann of Kutch
1962	24.70	66.00	4.50	Karachi
1965	24.40	70.00	5.30	Kutch
1965	25.03	67.76	4.50	Karachi
1966	25.00	68.00	5.00	Jhimpir
1966	24.50	68.70	5.10	Hyderabad
1966	25.10	68.00	5.10	Hyderabad
1968	24.61	66.42	4.10	Karachi
1969	24.40	68.70	4.40	Hyderabad
1969	24.54	68.79	3.50	Hyderabad
1969	24.40	68.70	4.40	Hyderabad
1970	24.60	68.60	5.20	Hyderabad
1970	25.28	66.65	4.90	Karachi
1971	25.00	68.00	4.50	Jhimpir
1971	25.10	68.10	4.50	Hyderabad
1972	25.50	66.80	5.00	Bela
1972	25.50	66.80	4.50	Bela
1972	25.35	66.71	4.50	Karachi
1973	25.00	68.00	5.00	Jhimpir
1973	25.54	66.50	4.90	Karachi
1973	25.48	66.33	4.30	Karachi
1973	25.10	68.10	4.80	Hyderabad
1975	25.50	66.80	4.50	Gadani
1975	25.22	66.59	4.70	Karachi
1984	25.58	66.41	5.00	Karachi
1985	24.90	67.39	5.00	Karachi
1985	24.75	67.64	4.70	Karachi
1986	25.34	66.60	4.60	Karachi
1992	25.25	67.76	3.60	Karachi
1992	24.33	68.83	3.70	Karachi
1996	25.06	66.76		Karachi
1998	24.90	66.32	3.80	Karachi
1998	25.96	66.46	4.40	Karachi
1998	24.85	66.35	4.50	Karachi

Source: JICA Study Team

2) Past Earthquakes and Tsunami

✓ Great Earthquake of 1945

On 28 November 1945, a great earthquake, off Pakistan's Makran Coast (Balochistan) generated a destructive tsunami in the Northern Arabian Sea and the Indian Ocean. More than 4,000 people were killed along the Makran Coast of Pakistan by both the earthquake and the tsunami.

Also, the tsunami was responsible for loss of life and great destruction along the coasts of Iran, Oman and western India (and possibly elsewhere).

・***Origin Time and Epicenter***

The great earthquake occurred at 21:56 UTC (03:26 IST), on 28 November1945. Its epicenter was at 24.5 N 63.0 E., in the northern Arabian Sea, about 100 km south of Karachi and about 87 km SSW of Churi (Baluchistan), Pakistan.

・***Magnitude and Earthquake Intensity***

The earthquake's Richter Magnitude (Ms) was 7.8. The Moment Magnitude (Mw) was revaluated to be 8.0; the quake was recorded by observatories in New Delhi, Kolkata (Calcutta) and Kodaikanal.

The earthquake's intensity was high throughout the region. It was strongly felt in Baluchistan and the Las Bela area of Pakistan. It was reported that in the western and southern sections of Karachi the strong surface motions lasted for about 30 seconds. According to eyewitness reports, people were "thrown out of their beds", doors and windows rattled, and windowpanes broke. The underwater cable link between Karachi and Muscat (Oman) was damaged, disrupting communications. The lighthouse at Cape Moze - 45 miles from Karachi - was also damaged. The earthquake was strongly felt also at Manora, where the lighthouse was damaged. It was moderately felt in Panjgaur and Kanpur.

✓ Major earthquake in Pakistan

There have been a number of earthquake in the history of Pakistan but very few tsunamis. Every year minor to moderate earthquake occurs in the northern parts of Pakistan and Balochistan province.

- In 894, an earthquake hit Shah bundar, Sindh killing 150,000 people.
- In1668, an earthquake hit once again Shah Bundar killing 50,000.
- In 1819, earthquake battered the town of Allahbund, Sindh killing 3200 people.
- In 1827, an earthquake hit Lahore city killing 1000 people.
- In 1852, an earthquake hit a town of Balochistan.
- In 1865, an earthquake hit Peshawar.
- In 1889, an earthquake hit a remote area of Balochistan.
- From 1892 till 1931, a number of earthquake hit Balochistan province.
- In 1935, a major earthquake of 7.7 magnitude killed 60,000 people in Balochistan including Quetta.
- In 1945, a tsunami and earthquake killed 4000 people mainly in coastal Pakistan. This is the only recorded tsunami in Pakistan.
- In 1974, a moderate earthquake hit Hunza valley killing 5000 people. The intensity of the earthquake was 6.2 magnitude.
- In 2005, a massive earthquake of 7.8 killed 80,000 people in Pakistan’s Kashmir and Khyber province.
- In 2008, a 6.2 magnitude earthquake killed 200 people in Balochistan including Quetta.
- In 2011, a major earthquake of 7.4 magnitude hit Balochistan province with tremours

jolting from Pakistan to India and Dubai (UAE).

Some scientist say that the geographical location of Karachi is such that a natural curve is formed near the sea shore, as a result, the possibility for a tsunami generated in Indian Ocean to hit the Karachi site is quite remote. They say similar things about a cyclone too, dry air from Arabian peninsula and Thar desert dissipates the cyclone before it could hit Karachi. But only time will tell if they were right or wrong.

(5) Hydrogeological features of Karachi Region

1) Hydrogeology of Karachi

Hydrogeologically, the city of Karachi lies in the Hab River Basin and the Malir River Basin. The Malir River Basin is drained by the Malir River and the Layari River. The aquifer of Karachi is, therefore, mainly recharged by seepage from Hab River , Hab Dam as well as the Malir and the Layari Rivers. The Hab River lies on the western frontier of Sindh and for some distance the boundary between Sindh and the Baluchistan provinces. It located about 30 km to the west of Karachi, along the Karachi- Lasbela boundary. It falls into the Arabian Sea near Cape Monze, with a total drainage course length of 336 km.

During the past several years, a number of pumping wells has been installed to meet requirements for the irrigation-water supply (to raise vegetables, fruits, dairy and poultry) and drinking-water supply for Karachi. Excessive pumping of groundwater and continuous lowering of water-table is likely to result in intrusion of seawater into the Malir Basin under natural seepage conditions and under artificially induced conditions of recharge of saline seawater in the coastal aquifer(s) of Karachi.

2) Recharge sources

Five possible water-sources are contributing to the groundwater recharge in Karachi. The first possible source is the rainfall. As the city of Karachi suffers from deficit of precipitation (only rainfall), the contribution to shallow groundwater storage from rain is very little. However, rainfall in the hinterlands and other areas surrounding Karachi may significantly contribute to the groundwater flow-system. The two freshwater sources are the Hab Lake/Hab Dam and the Indus River. Water from Hab Dam and the Indus River is piped to various residential zones in Karachi for drinking and irrigation purposes. The spring water discharges into Malir River and Layari River and the municipal/industrial waste effluents added to these rivers are also contributing to groundwater storage as a fourth recharge source. Seawater intrusion along Karachi coast is the fifth possible source.

3) Shallow Groundwater

Physico-chemical data of shallow groundwater (depth less than 30 meters) shows that the shallow wells, located in the vicinity of coast and in the proximity of polluted rivers, have relatively higher values of electrical conductivity, salinity and population of Coliform bacteria. The shallow groundwater is moderately saline, representing electrical conductivity values in the range of 1.1 to 1.9 mS/cm and salinity in the range of 1 ppt. The pH of shallow groundwater varies from mildly acidic (~6.3) to mildly alkaline values (~7.9). Areas with quite poor sanitary conditions have relatively low values of pH (~6.3 to 6.8). Shallow groundwater below 20 meters is slightly reducing. The dissolved oxygen is in the range of 1.5 to 7.9 mg/L. Turbidity of shallow groundwater varies between 3.6 NTU and 95 NTU. The concentration of HCO3 - (356 - 514ppm, n=4), Cl^- (82 - 169 ppm, n=4) and $SO4^{-2}$ (38-117 ppm, n=4) in shallow groundwater is very reasonable.

The mean chemical concentrations of Cl^-, SO4 $^{-2}$ and $HCO3^-$ in shallow groundwater are as follows:

Mean Cl^- (Shallow Groundwater): 132.8 ± 36.5 ppm (n=4) Mean SO_4^{-2} (Shallow Groundwater): 63.3 ± 36.7 ppm (n=4) Mean HCO_3^- (Shallow Groundwater): 423 ± 67.4 ppm (n=4)

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in Layari River water is as follows:

$\delta^{18}O$ (Shallow Groundwater) -6.3 to -5.8 ‰ V-SMOW (n=8) $\delta^{13}C$ (TDIC-Shallow Groundwater): -16.5 to -5.5 ‰ PDB (n=8)

The mean stable isotope content of 18O and 13C in shallow groundwater is as follows:

Mean $\delta^{18}O$ (Shallow Groundwater): -5.9 ± 0.32 ‰ V-SMOW (n=8) Mean $\delta^{13}C$ (TDIC-Shallow Groundwater): -10.1± 3.3 ‰PDB (n=8)

The stable-isotope results indicate that the shallow / phreatic aquifers are recharged by a mixture of fresh waters of Indus River and Hab River (draining spring water and flooded rainwater), as well as polluted Layari and Malir rivers and their feeding drains (both under natural infiltration conditions and artificially induced infiltration conditions) and, to a much smaller extent, from direct recharge of local precipitation.

4) Deep Groundwater

In general, Deep groundwater is mostly saline and has high electrical conductivity (range: 1.9-19.1 mS/cm) and salinity (range: 1.7-7.4 ppt), as compared to shallow groundwater.

Based on hydrochemical data of water samples collected from pumping wells, it is assumed that the shallow mixed deep groundwater discharged by large-scale pumping wells mainly represents the deep groundwater from confined aquifer

The mean chemical concentrations of Cl^-, $SO4^{-2}$ and $HCO3^-$ in shallow mixed deep groundwater are as follows:

Mean Cl^- (Deep Groundwater): 2169.2 ± 1828.0 ppm (n=9) Mean SO_4^{-2} (Deep Groundwater): 458.4 ± 691.4 ppm (n=9) Mean HCO_3^- (Deep Groundwater): 353.6 ± 215.4 ppm (n=9)

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in shallow mixed deep groundwater is as follows:

$\delta^{18}O$ (Deep Groundwater): - 6.2 to -4.2 ‰ V-SMOW (n=10) $\delta^{13}C$ (TDIC - Deep Groundwater): -13.2 to -0.3 ‰ PDB (n=10)

The mean stable isotope content of 18O in shallow mixed deep groundwater is as follows:

Mean $\delta^{18}O$ (Deep Groundwater): -5.3± 0.7‰ V-SMOW (n=10) Mean $\delta^{13}C$ (TDIC- Deep Groundwater): -10.5±3.7‰ PDB (n=10)

The hydrochemical and stable isotope results indicate that the confined aquifer hosts a mixture of rainwater from hinterlands and surrounding regions around coastal Karachi, as well as sea trapped water / seawater, through intrusion under natural infiltration conditions or under induced recharge conditions.

5) Groundwater Recharge Characteristics/ Sea water Intrusion

Presently, coastal Karachi is known to have five sources of recharge to its groundwater reserves.

(i) Rainfall,
(ii) Indus River water supply
(iii) Hab-River and Hab Lake water supply

(iv) Polluted Layari and Malir rivers/ contributory channels draining mixtures of domestic industrial and agricultural wastewater, composed of pre-said three sources

(v) Seawater.

The possibilities of major contribution to groundwater recharge of shallow / phreatic aquifer directly by local rainfall seems very small, due to very poor frequency of rainfall events and rainfall intensities in the Karachi and high evaporation rates. The long-term (15 years annual record) mean monthly average precipitation for Karachi is between 0-15 mm during the months of January to June, 23 - 91 mm during the months of July to September, and 0-7 mm during the months of October to December.

The remaining four sources play a significant role in recharge of the shallow aquifer-system and deep groundwater system (confined aquifer) in coastal Karachi.

Unpolluted seawater of Karachi coast is characterized by a δ18O value of ~ +1 ‰ VSMOW and a chloride content of ~23000 ppm. Both the Layari River and Malir River waters, as well as the Indus River water and the Hab Lake water, have extremely very low aqueous contents of chloride and sulfate ions as compared to seawater. The average mean value of δ18O in polluted river waters is ~ 5 ‰ V-SMOW and in shallow groundwater is -5.9 ‰ V-SMOW.

The relatively deeper ground waters representing confined aquifer have a mean δ18O value of -4.3 ‰ VSMOW and excessively high values of aqueous chloride and sulfate.

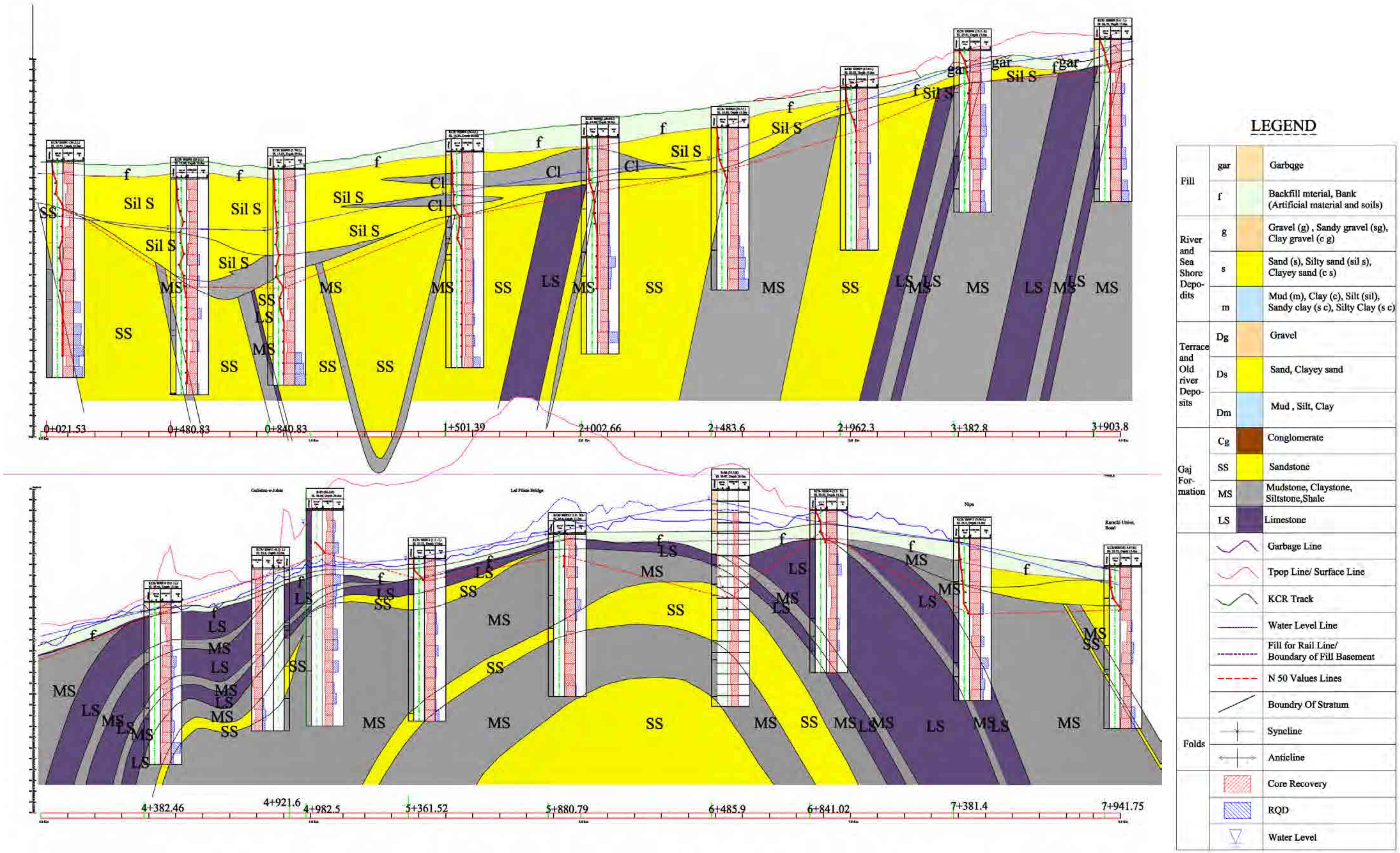
2.3.4 Results of Boring Survey

Geological cross sections were prepared based on borehole data for every 4 km at 1:100 in vertical and 1:4000 in horizontal scale.

The subsoil was classified by their physical characteristics and sequence of occurrence. The top alluvial sand/silt and clay deposits were defined as SAND 1 and CLAY 1. They were generally loose to medium dense and soft to stiff, while underlain sandy/silty soil were defined as SAND 2, SAND 3 and SAND 4 and clayey soil was defined as CLAY 2 and CLAY 3 which consistency was dense to very dense and very stiff to hard.

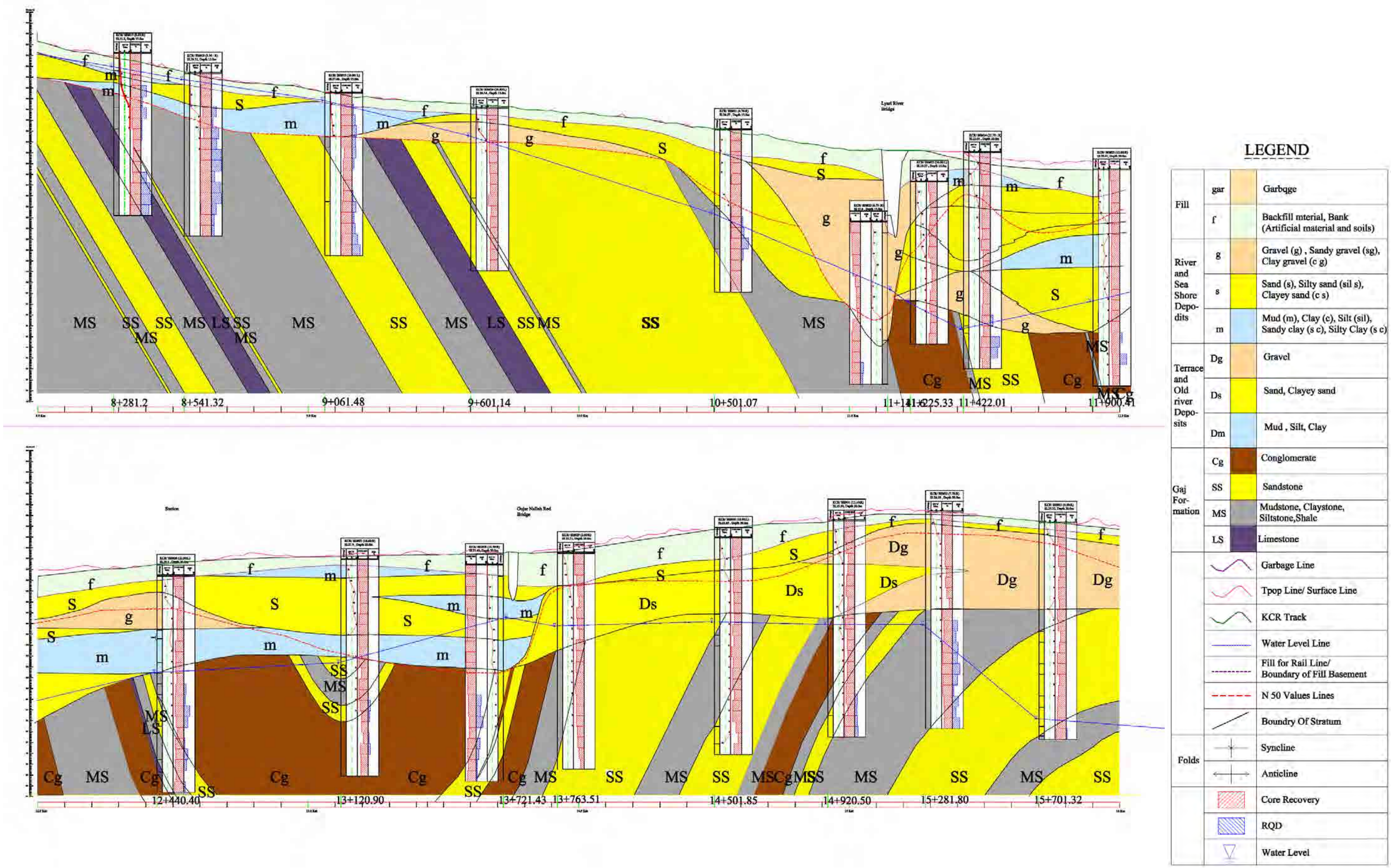
Similarly in rock formation, the same formation was defined in accordance to the sequence of occurrence like LIMESTONE1, LIMESTONE 2 etc.

The whole KCR route was divided into sections of every 8.0 km. The study of borehole logs and cross sectional profiles reveals that the subsoil strata is presented in the following geological cross sections.



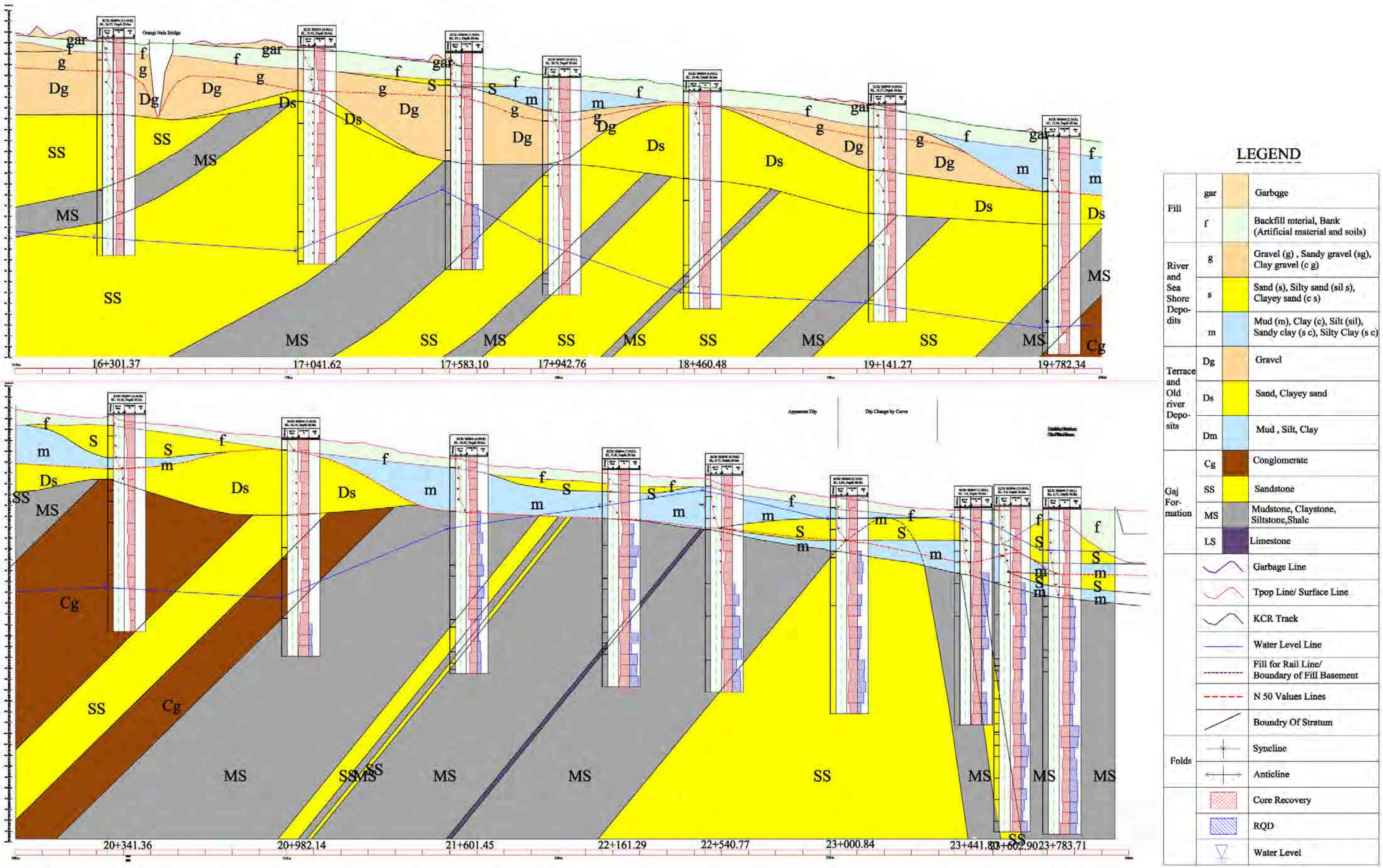
Source: JICA Study Team

Figure 2.3.5 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 0.0km to 8.0km



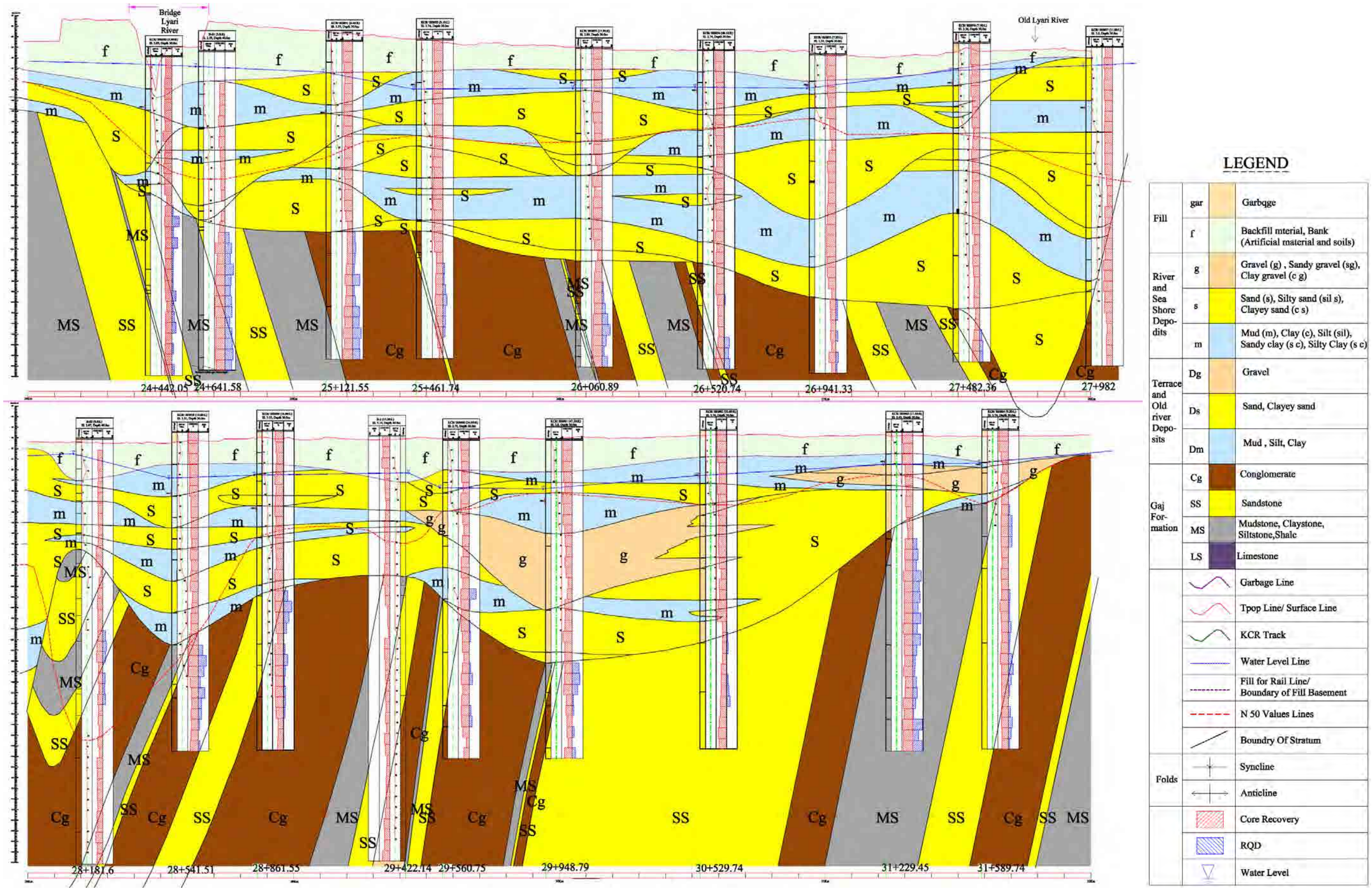
Source: JICA Study Team

Figure 2.3.6 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 8.0km to 16.0km



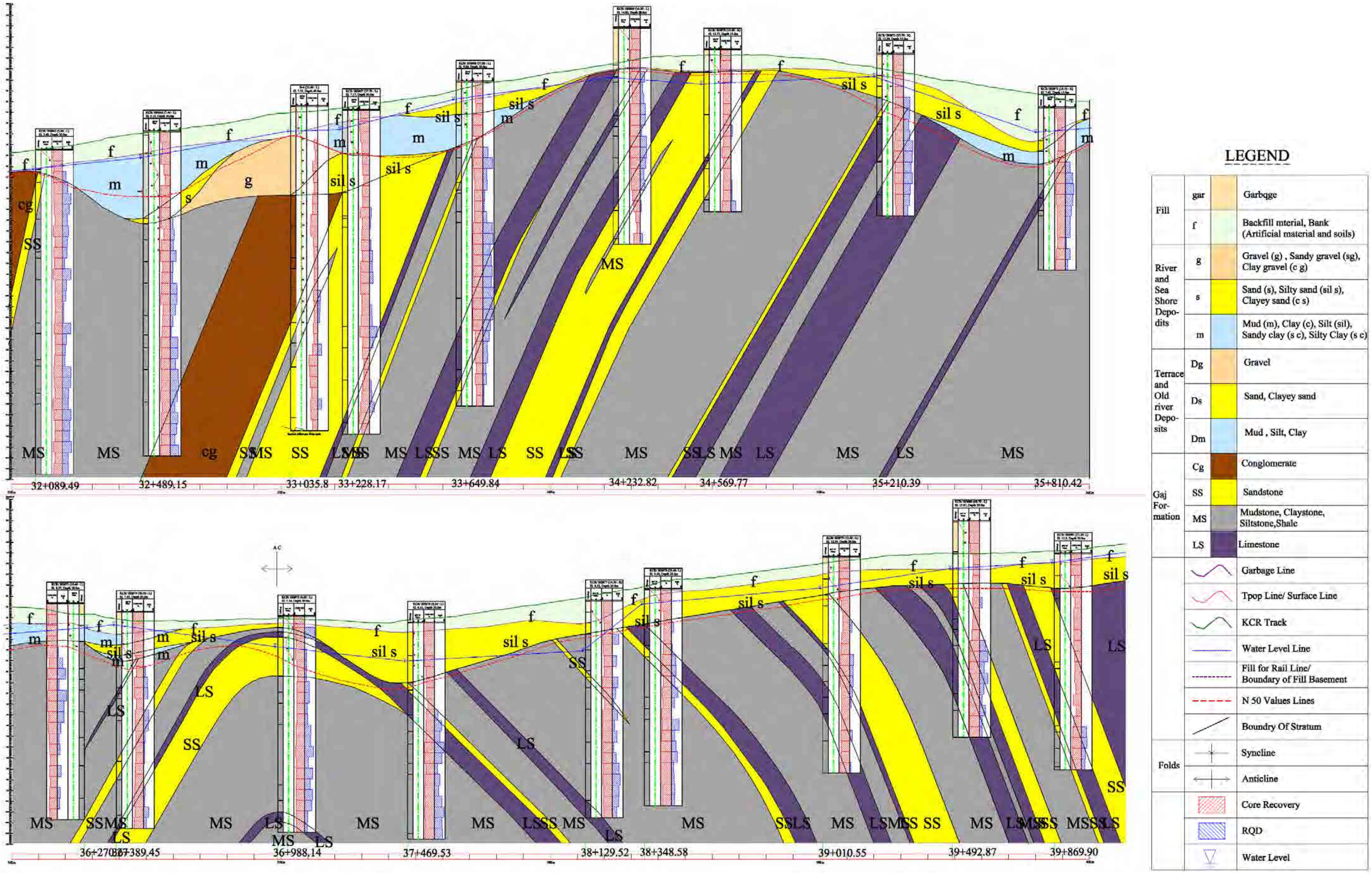
Source: JICA Study Team

Figure 2.3.7 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 16.0km to 24.0km



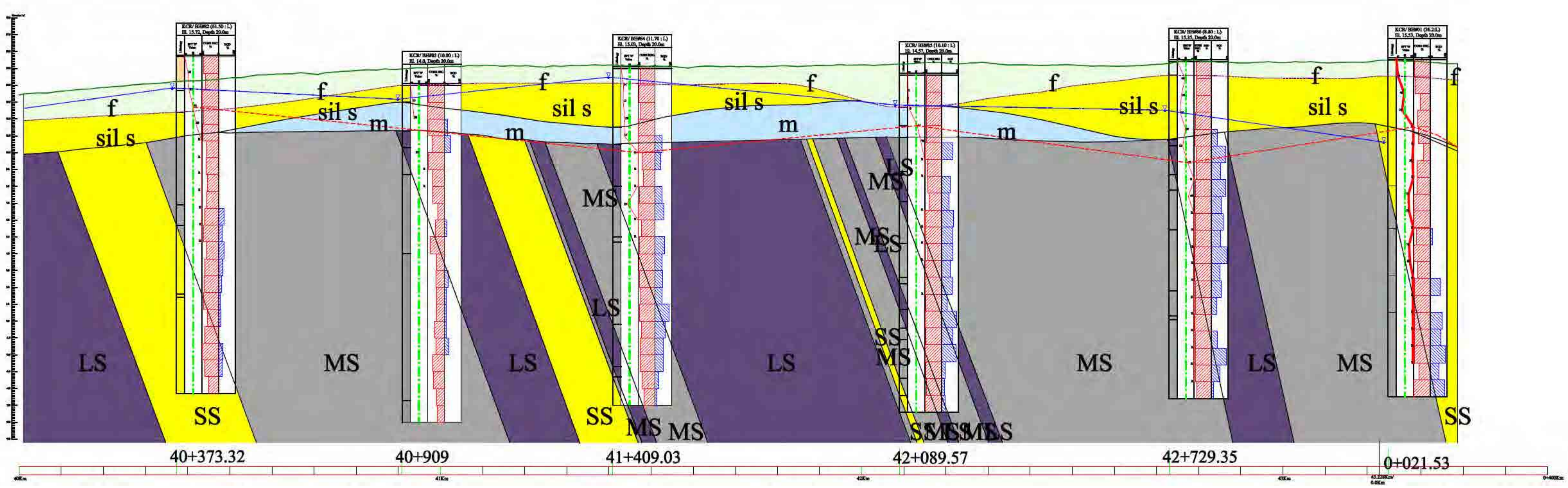
Source: JICA Study Team

Figure 2.3.8 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 24.0km to 32.0km



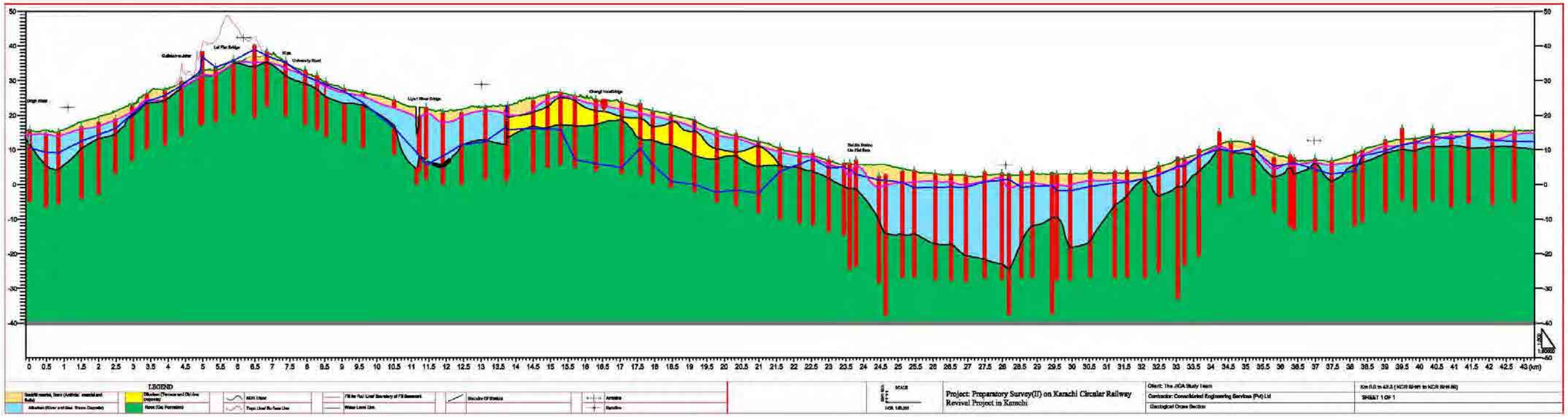
Source: JICA Study Team

Figure 2.3.9 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 32.0km to 40.0km



Source: JICA Study Team

Figure 2.3.10 Geological (Stratigraphical/ Lithological) Cross Sections at 1:4,000 Scale: From 40.0km to 43.2km



Source;: JICA Study Team

Figure 2.3.11 Geological (Stratigraphical/ Lithological) Cross Sections at 1:50,000 Map

2.3.5 Results of Standard Penetration Tests

Standard Penetration Tests (SPT) was performed at 1.0m interval in alluvial/ unconsolidated deposits or highly weathered rock. This test was conducted in accordance with ASTM D-1586.

The SPT is a sounding method in which the standard split spoon sampler of 35mm interval diameter provided with cutting shoe is driven into the subsoil at the testing horizon with a standard of 63.5 kg hammer having a free fall of 762mm. The number of blows for 450mm penetration is recorded for each 150mm penetration. The number of blows for first 150mm penetration is ignored with the consideration of disturbance to subsoil while number of blows required for last 300mm penetration is report as ‘standard penetration resistance’ or the N-value.

Refusal during the SPT is considered to occur when the blow count exceeds 50 without further penetration or when N value ≥ 100. In case of refusal, the number of blows and actual penetration is recorded.

The SPT `N’-value is used in correlations for unit weight, relative density, angle of internal friction and undrained compressive strength. Table 2.3.5 gives SPT correlations for cohesionless soils, while Table 2.3.6 gives SPT correlations for cohesive soils.

Empirical Values for ϕ, D_r and unit weight of granular soils based on the SPT at about 6m depth and normally consolidated [approximately, $\phi = 28^o + 15^o D_r (\pm 2^o)$]

Table 2.3.5 SPT Correlations for Cohesionless Soils

Description		**Very Loose**	**Loose**	**Medium**	**Dense**	**Very Dense**
Relative Density D_r		0	0.15	0.35	0.65	0.85
N'_{70}:	fine	1-2	3-6	7-15	16-30	
	Medium	2-3	4-7	8-20	21-40	>40
	Coarse	3-6	5-9	10-25	26-45	>45
ϕ:	fine	26-28	28-30	30-34	33-38	
	Medium	27-28	30-32	32-36	36-42	<50
	Coarse	28-30	30-34	33-40	40-50	
γwet, kN/m^3		11-16	14-18	17-20	17-22	20-23

Source: Foundation Analysis and Design, 5th Edition by Mr. Joseph E. Bowles, P.E., S.E.

Table 2.3.6 SPT Correlations for Cohesive Soils

Consistency				**N'_{70}**	**q_u kP$_a$**	**Remarks**
Very Soft	NC		Young Clay	0-2	<25	Squishes between fingers when squeezed
Soft				3-5	25-50	very easily deformed by squeezing
Medium				6-9	50-100	
Stiff	Increasing	OCR	Aged/ Cemented	10-16	100-200	Hard to deform by hand squeezing
Very Stiff				17-30	200-400	Very hard to deform by hand squeezing
Hard				>30	>400	Nearly impossible to deform by hand

Source: Foundation Analysis and Design, 5th Edition Mr. Joseph E. Bowles, P.E., S.E.

The SPT N Value measured in each borehole, at various depths, is presented in Borehole Logs. The SPT results of Alluvial Deposits are discussed in the following:

(1) SPT Analysis:

Standard Penetration Tests data has been analyzed to determine the variation of consistency of various subsoil units, in horizontal as well as vertical extent.

The overall SPT data is presented in Table 2.3.5 which also exhibits the extent of various subsoil units as encountered along the KCR route. The subsoil units as shown in Table 2.3.5 essentially consists of the following:

Alluvial deposits:

- Non-cohesive soils have been designated as SAND 1, SAND 2 SAND 3 and SAND 4, referring to their sequence of occurrence.
- Cohesive soils have been designated as CLAY 1, CLAY 2 and CLAY 3, referring their sequence of occurrence.

Rock deposits:

- Rock deposits including SILTSTONE, CLAYSTONE, SANDSTONE, LIMESTONE, SHALE and CONGLOMERATE have been lumped for SPT analysis.

Following discussion is presented with reference to depth of occurrence of various subsoil units at each location of borehole while their elevation of occurrence may vary.

The variation of SPT vs DEPTH is presented in Table 2.3.7 and Table 2.3.8.

It is observed from Table 2.3.7 and Table 2.3.8 that SPT in rock was considered to be “Refusal”. However, N values for alluvial deposit vary in horizontal as well as in vertical from as low as 2 to as high as “Refusal”.

SPT data for all test locations, and all horizons, were analyzed by plotting histograms for range of N values in the range of 0-10, 10-30, 30-50 and 50-100 (see Appendix-2.2). The observations are as follows:

- Over all observation from 886 data points in total is that 75% of N values exceed 30, only 9.6% of N values are ≤ 10 where 15.4% lies between 10 and 30. It is further noted that SPT values in the range of 0-10 and 10-30 are mainly encountered in top 0-5m depth.
- The high frequency of occurrence of N value > 50 is not only due to very dense/very hard consistency of SAND/CLAY but also due to presence of ROCK formation.
- For SPTs conducted in non-cohesive subsoil (layers of SAND 1, SAND 2, SAND 3 and SAND 4), a total of 428 data points were analyzed and found that 75.5% of N values exceed 30, only 8.3% of N values are ≤ 10 where 16.2% lie between 10 and 30. This result also showed that SPT values in the range of 0-10 and 10-30 were mainly encountered in top 0-5m depth. Table 2.3.3 also shows that dense to very dense SAND layers are encountered even at shallow depths, within 5m.
- The SPT data for non-cohesive layers has been further analyzed for SAND-1, 2, 3 and 4. For SPTs in SAND 1 layer, a total of 126 SPTs were conducted in this layer. 30.1% of N values exceed 30, 28.6% are ≤ 10 while 41.3 % of N values lie between 10 and 30.
- For SPTs in cohesive (CLAY1, 2 and 3) layers, a total of 194 SPTs were conducted in these layers. 63.4% of N values exceed 30, 11.9% are ≤ 10 while 24.7% of N values lies between 10 and 30.

Table 2.3.7 SPT Data for All (1/2)

Sheet 1/2

	Depth, m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Structure
0.0 to 8.0 Km	BH # 1		9	46	34	100	100	94	100	72	75	100	75	80	100	100	100	100	100	100	100											VIADUCT
	BH # 2		10	13	33	69	39	49	71	32	70	75	98	100	100	100	100	100	100	100	100											VIADUCT
	BH # 3		11	14	13	23	32	39	30	54	30	33	100	54	65	100	100	100	100	100	100											GROUND
	BH # 4		7	13	11	24	18	77	73	54	100	100	100	100	100	100	100	100	100	100	100											GROUND
	BH # 5		11	9	22	22	58	72	66	86	100	100	100	100	100	100																GROUND
	BH # 6		10	14	26	69	100	100	100																							GROUND
	BH # 7		8	31	74	100	100	100	100																							GROUND
	BH # 8		54	68	100	90	100	100	100	100	100	100																				GROUND
	BH # 9		43	63	100		100	100	100	100	100	100																				GROUND
	BH # 10		100																													GROUND
	BH # 11		100																													CULVERT
	BH # 12		4	100																												CULVERT
	BH # 13			100	100																											CULVERT
	BH # 14		48	52	100																											CULVERT
	BH # 15		3	13	25	37	44	45	100																							GROUND
	BH # 16		7	13	39	100																										GROUND
8.0 to 16.0 Km	BH # 17		4	14	19	50	100	100	100																							VIADUCT
	BH # 18		4	21	15	100	79	100	100																							VIADUCT
	BH # 19		13	18	42	49	100																									VIADUCT
	BH # 20		18	37	100	100																										VIADUCT
	BH # 21		12	7	13	11		48	100																							VIADUCT
	BH # 22		23	13	14	45	25	7	13	4	100	100																				VIADUCT
	BH # 23		23	10	52	57	48	52	100	100	100	100	100	100																		VIADUCT
	BH # 24		100	24	36	60	100	51	100	100																						VIADUCT
	BH # 25		12	12	4	20	100	100	47	65	24	100	52	100	100	100		100	100	100	100											VIADUCT
	BH # 26		40	18	100	100	83	70	100	100		100	100	100	100																	GROUND
	BH # 27		12	33	83	60	68	100	31		100	100	100	100	100	100																GROUND
	BH # 28		4	16	22	18	15	49	49	58	38	82	100	100	100	100	100															VIADUCT
	BH # 29		35	42	60	78	100	100	100	100	100	100	100	100	100	100																VIADUCT
	BH # 30		10	48	36	100	100	100	100	100	100	100	46	100	100	100	100	100	100	100	100											GROUND
	BH # 31		16	32	52	100	100	100	100	47	100	54	100	100	100	100	100	100	100	100												GROUND
	BH # 32		31	59	100	100	100	100	100	100	100	100	100	100																		GROUND
	BH # 33		40	100	100	100	100	100	100	43	100	100	100	100	100	100	100	100														VIADUCT
16.0 to 24.0 Km	BH # 34		25	44	79	45	100	100	100	100	100	100	100	100	100																	VIADUCT
	BH # 35		11	76	65	100	100	100	100	100	100	100	100		100	100				100	100											GROUND
	BH # 36		21	7	30	100	100	100	100	100																						GROUND
	BH # 37		12	12	14	62	100	100	100	100	100	100																				VIADUCT
	BH # 38		100	56	100	100														100												VIADUCT
	BH # 39		49	42	55	100	100	100	40	100	100					100																VIADUCT
	BH # 40		8	6	9	28	100	100	100																							VIADUCT
	BH # 41		8	11	10	17	75	100																								VIADUCT
	BH # 42		54		100	100	100	100	100	100	100	100																				VIADUCT
	BH # 43		22	38	36	39	100																									VIADUCT
	BH # 44		9	12	13	100																										VIADUCT
	BH # 45		4	5	19	42	77	100	100	100	100																					VIADUCT
	BH # 46		17	19	16	100																										VIADUCT
	BH # 47		18	19	42	37	76	100																								VIADUCT
	BH # 48		19	21	12	54	62	97	99	100	100																					VIADUCT
	BH # 49		15	14	16	15	31	54	58	100																						VIADUCT

Garbage/ Solid waste	SAND 1	CLAY 1	
Fill Material	SAND 2	CLAY 2	
ROCK	SAND 3	CLAY 3	
	SAND 4		

Source: JICA Study Team

Table 2.3.8 SPT Data for All (2/2)

Sheet 2/2

	Depth, m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Structure
24.0 to 32.0 Km	BH # 50		4	6	7	10	25	37	44	45	70	80	85	90																		VIADUCT
	BH # 51		4	5	19	21	17	39	54	34	40	65	88	87	65	95	100	100	100	100												VIADUCT
	BH # 52		4	5	4	15	29	25	24	26	87	100	100	100	38	100	41	100	100	100	100	100										VIADUCT
	BH # 53		4	4	9	20	22	32	37	32	100	100	90	90	71	80	83	89	95	100												VIADUCT
	BH # 54		22	4	18	18	21	42	100	57	58	82	100	100	41	41	100	100	100	100	100	100										GROUND
	BH # 55		18	23	3	5	5	51	100					100	100	100	100	74	64	100	100	82	100	100	100							GROUND
	BH # 56		19	26	13	12	20	21	21	48	100	100	100	86	80	85	80	56	64	66	75	80	95	100	100	100	100	100	100			VIADUCT
	BH # 57		5	6	10	7	6	7	14	50	54	35	45	75	72	92	88	70	56	49	57	57	60	61	60	62						GROUND
	BH # 58		32	37	8	18	5	22	23	39	34	45	32	30	45	86	100	100	84	100	39	43	47	58	100	100						GROUND
	BH # 59		3	9	12	16	36	45	50	57	46	57	100	55	58	68	79	50	55	56	52	55	80	83	87	100	100					VIADUCT
	BH # 60		20	29	35	43	23	28	100	100								51	100	100	100											GROUND
	BH # 61		30	27	28	40	64	65	69	67	100	100	100	100	100	100	100	100	100	100												GROUND
	BH # 62		3	4	7	11	35	40	78	78		100	100	35	100	100	100	100	100													GROUND
	BH # 63		23	30	38	85			100																							GROUND
	BH # 64		9	6	9	100	100	47	74	77	86	100																				GROUND
32.0 to 40.0 Km	BH # 65		100																													GROUND
	BH # 66		12	32	38	100	44	100	100	100	100	100	100																			GROUND
	BH # 67		20	24	29	100																										VIADUCT
	BH # 68		16	19	26	27	100																									VIADUCT
	BH # 69		100	100	100		100																									VIADUCT
	BH # 70		10	100	100	100																										VIADUCT
	BH # 71		4	7	67	42	100																									VIADUCT
	BH # 72		4	10	21	42	100																									VIADUCT
	BH # 73		4	5	13	70																										VIADUCT
	BH # 74		6	9	10	43	100									100																VIADUCT
	BH # 75		100	31	26	100																										VIADUCT
	BH # 76		8	4	9	6	100																									GROUND
	BH # 77		9	100																												GROUND
	BH # 78		100	100	100																											GROUND
	BH # 79		17	5	100	100																										GROUND
	BH # 80		55	53																												GROUND
	BH # 81		3	5	100																											GROUND
40.0 to 43 Km	BH # 82		20	25	51	66	100	100	100	100	100	100																				GROUND
	BH # 83		13	20		28	100	100																								GROUND
	BH # 84		14	12	22	17				37	100	100																				GROUND
	BH # 85		2	8	56	78	100	100		100	100	100	100			100																GROUND
	BH # 86		46	24	16	49	32	62	100	65	100	100	100	100	100	100	100	100	100	100	100											GROUND
	BH # 87		100	54	73	65		100																								Elect Sub St.
	BH # 88		9	6	6	9	35	74	56	66	65	100																				Elect Sub St.
	BH # 89		6	9	100	100	100		100	100	100																					Elect Sub St.
	BH # 90		49	100	56	54	100	51	100	100	100																					Elect Sub St.

Garbage/ Solid waste
Fill Material
ROCK

SAND 1
SAND 2
SAND 3
SAND 4

CLAY 1
CLAY 2
CLAY 3

Source: JICA Study Team

2.3.6 Analysis of Investigation:

(1) Geology

The investigation along KCR route reveal that, the Geological features along KCR routes are generally flat or rolling Plains and partially hilly (at Gulistan-e-Johar). The elevation of terrain vary along KCR route and it is as low +2m near Liyari Station and high upto + 38m near ‘Lal Flat’ and ‘Rado Hill Apartment’ before Alladin Park.

The Rock Formations are belong to Tertiary period along KCR route and are overlaid by Deposits of recent Alluvium (Holocene) and sub recent Alluvium (Pleistocene). The recent Alluvium deposits mainly the River and sea shore deposits and some blown material whereas sub recent Alluvium deposits are terraces and old river. The main River in the route of KCR is Liyari River (crosses at Liaqatabad and Gul Bai) with two main tributaries named Gujjar and Orangi Nala.

The recent Alluvium deposits are mainly consists of Sand, Silt and Clay underlain with sub recent Alluvium deposits consists of Sand, Silt, Clay and Gravels. The consistency of the sub recent deposits is relatively dense and hard than top Alluvial soil deposits. The Alluvium deposits are generally 2-6m deep along KCR route, whereas, these are thick as 9 to 15m between Drigh Road to Depot Hill, 10 to 20m thick from Liyari River to SITE area includes Gujjar Nala and Nazimabad area and between Baldia to Cantt station thickness of these deposits are upto 20 to 25m.

The Alluvium/ Diluvium Deposits are followed by Rock formations of Manchar and Gaj formation. These formations mainly consist of Shale, Sandstone, Limestone, Siltstone, Mudstone, Claystone and Conglomerates. The Rocks exposed along KCR route only in Gulistan-e-Johar area. Stratigaphy along KCR routes has been presented in following Table 2.3.9**.**

Table 2.3.9 Stratigaphy along KCR Routes

Geologic Age		Code	Formation Names and Facies
Quaternary	Recent	B	Bank (artificial)
	Sub Recent (Alluvium)	Q	Inter Tidal Mud and Sand Deposits Coastal Sand Dune Deposits, Stream bed Deposits, Alluvial Deposits.....Gravel, Sand, Silt, Clay
	Pleistocene (Dilluvium)	D	Gravel, Sand
Tertiary	Pliocene	Nggs	Gaj Formation, Interbedded yellow and grey Siltstone, Sandstone, Claystone, Shale, Limestone and Conglomerate
	Miocene		

Source: JICA Study Team

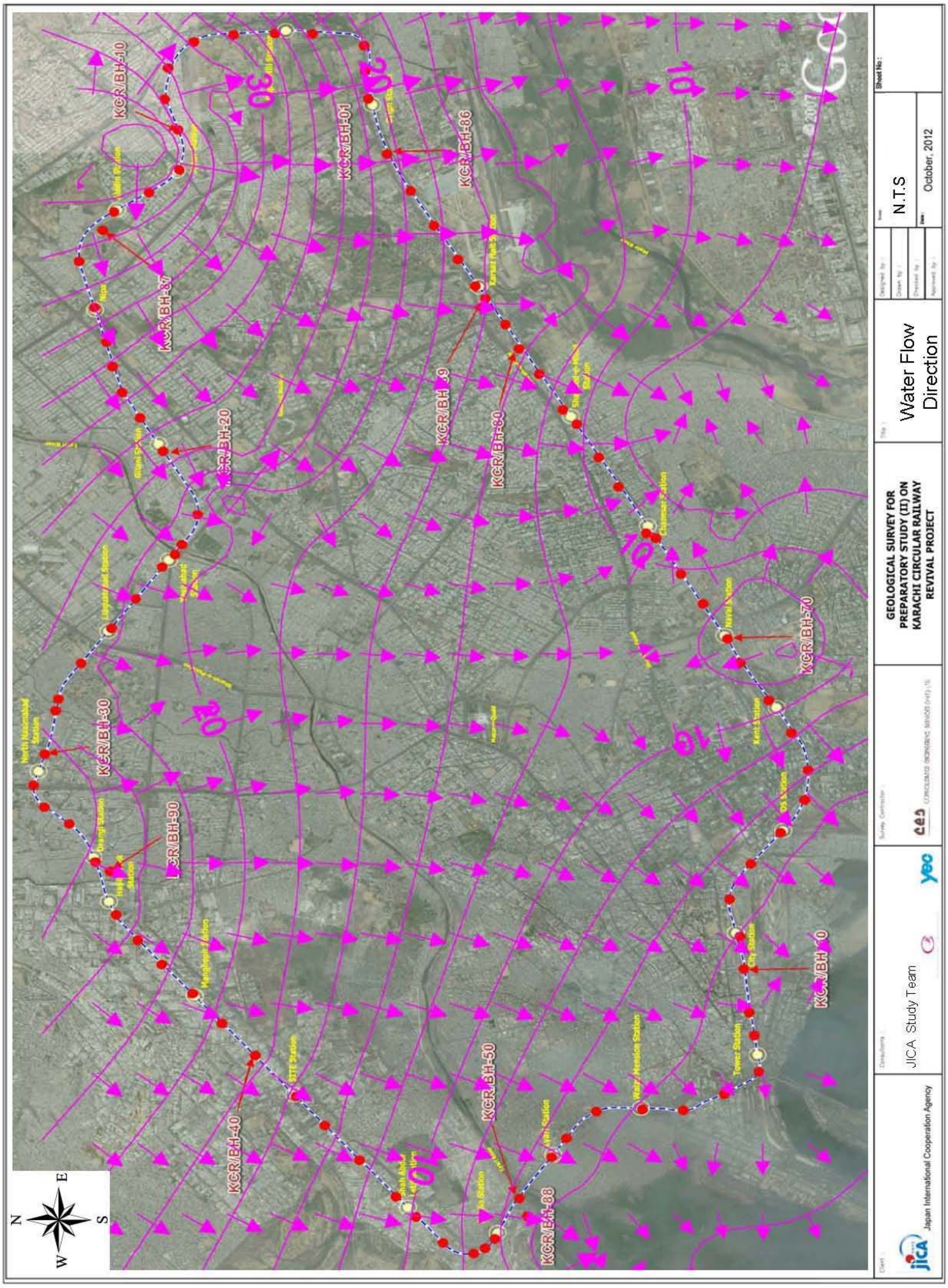
(2) Hydrogeology

The investigation along KCR route includes the monitoring of water levels in boreholes as well as Chemical analysis of Water samples collected from each boreholes. The ground water table is generally at shallow depth from 1.0m to 4.0m depth while it is deeper from 6 to 18m between Liyari River (Liaqatabad) to SITE. As earlier discussed in section 2.3.3(5), the ground water is mainly recharged by Polluted Layari and Malir rivers/ contributory channels draining mixtures of domestic industrial and agricultural wastewater, rainfall and Seawater intrusion along Karachi coast. The Chemical Analysis of Water samples shows that, Salinity of ground water is generally moderate and sever at few locations. The ground water flow direction along KCR route has been presented in following figure.

Permeability of Rock between KCR/BH#12 to 14

The permeability of Rock has been calculated for Rock formation at KCR/BH#12, 13& 14 by Rising/ Falling Head at 10m & 15m depth. The permeability value is generally of the order of 10^{-5} to

10^{-6}m/s. The subsoil encountered in KCR/BH#12 & 13 was Sandy SHALE, SANDSTONE and Sandy SILTSTONE, whereas, in KCR/BH#14, closely jointed LIMESTONE was encountered.



Source: JICA Study Team

Figure 2.3.12 Water Flow Direction Map Along KCR Route

(3) Liquefaction Potential:

1) Procedures for Liquefaction Analysis:

Liquefaction is a phenomenon in which the strength of a soil is reduced by earthquake shaking to cause failure. Liquefaction occurs in "saturated" soils when earthquake stresses increase the "pore pressure" to a degree equal to or exceeding "effective stresses" on soil particles, thus "Liquefying" the soil and causing loss of shear strength, which results in soil behaving like a fluid.

Clayey or Silty Sands and non-plastic Silts are most susceptible to liquefaction. Liquefaction may take place also from blasting or other activities which may enhance pore pressure.

The liquefaction may cause localized failures as well as failure of large areas. Niigata and Alaska Earthquake of 1964 caused liquefaction affecting large extent.

Extensive studies have been conducted by various researchers including Seed & Idriss (1971), Youd et al. (2001), Bray and Sancio (2006) and others. The present day state of knowledge is such that liquefaction potential can be assessed for specific site conditions.

There are a number of different ways to evaluate Liquefaction Potential of a soil deposit, at a particular site. The evaluation procedures vary from Empirical method (Youd et al; 2001), Simplified method (Seed and Idriss, 1971), and sophisticated Computer Analysis.

Commonly, Empirical and Simplified methods of assessing Liquefaction Potential provide adequately reliable assessment.

However, areas prone to large earthquake and historical evidence of liquefaction during past earthquakes require detailed analysis.

The Empirical and Simplified method involve assessment of Liquefaction Potential based on soil classification, groundwater level and SPT N value as obtained from Standard Penetration Tests conducted in Boreholes during phase of field investigation.

The KCR Project lies in area of Moderate Earthquake activity (refer section 2.3.3(4) of the report) and no evidence/reporting of previous Liquefaction failures exists. Therefore, Empirical method of elimicling sites, prone to Liquefaction, have been adopted as discussed by Youd et al. (2001), Bray & Sanico (2006) and Boulanger and Idriss (2006). Based on these studies, following criteria were considered for evaluation of Liquefaction Potential of this site:

Groundwater Level

- The existence of groundwater level at shallow depth and within alluvial deposits makes the site susceptible to liquefaction subject to meeting other criteria.
- The groundwater level in Rock deposits, however, screens a site as non-susceptible to liquefaction.

Soil Classification, Saturation and Consistency:

- Non-Cohesive Soils including Sand, Silty Sand and SILT:
  - For soils of very loose to loose consistency (SPT ≤ 10), Potential of Liquefaction exists when these are saturated/submerged.
  - Such soils with dense to very dense constancy are non-susceptible to Liquefaction.

- Liquefaction Potential needs to be analyzed to screen sites with medium dense consistency when such deposits are saturated/submerge. Soils are susceptible to Liquefaction where SPT N value is ≤ 25 (AASHTO Guide Specifications, LRFD seismic Design for Bridges.
- Poorly graded soils are prone to Liquefaction while well graded soils are non-susceptible to Liquefaction.
- Soils with PI ≥ 7 are non-susceptible to Liquefaction. (Boulanger and Idriss, 2006).

• Cohesive soils including Clay, Silty / Sandy Clay:
  - Such soils with stiff to hard consistency are non-susceptible to Liquefaction.
  - Very soft cohesive soils may be susceptible to Liquefaction when saturate / submerged.
• Magnitude of Earthquake:
  - Sustained ground acceleration, that is large enough and acting over long enough period of time develops excess pore water pressure, thereby effective stress is reduced and soil strength is lost.
  - AASHTO Guide states that the Liquefaction Potential is low or the extent is limited for Earthquake Magnitude ≤ 6.
• Thickness of Liquefaction layer and Overburden confinement:
  - The Liquefaction layer must be thick enough so that the resulting uplift pressure and amount of water expelled (due to excess pore water pressure) can result in ground rupture, such as soil boiling / fissuring (Ishihara, 1985; Dobry, 1989).
  - If liquefaction layer is thin and buried under non-liquefiable surface layer, the effects of at depth liquefaction will be prevented from reaching the surface.

2) Liquefaction Potential at KCR Site

In consideration to the procedure for Liquefaction analysis, as discussed above, the site specific data has been analyzed to evaluate Liquefaction Potential. The following are the findings of analysis:

✓ Subsoil in top zone consists of loose to medium dense Silty SAND and Sandy SILT at various locations along KCR route. It is noted from investigation data that subsoil designated as SAND-1 and SAND-2 is loose to medium dense while SAND-3 & SAND-4 is found to be always dense to very dense. For analysis purpose, SAND-1 and SNAD-2 with SPT N value ≤25 have been sorted out. It is noted that such condition prevails at almost 50% of borehole locations (47 out of total 90). Table 2.3.10 shows the depths of occurrence, extent and locations were SAND-1and SAND-2 with SPT N value ≤ 25 was encountered.

The SPT N value and extent of SAND-1 and SAND-2 as well as groundwater level at each location is also shown in Table 2.3.10. The analysis of data shows that extent of this layer is up to 3.0m at almost 50% of the borehole locations (22 out of 47). The maximum extent of this layer is however, 10.0m.

The consistency corresponding to N ≤25 and submergence renders the locations, as given in Table 2.3.10, potentially Liquefiable.

- ✓ Soil Classification data for SAND-1 and SAND-2, within top 10.0m is presented in Table 2.3.15 which shows high fine content (Passing Sieve # 200), essentially due to inclusion of SILT layers in this category. The plasticity is noted to be < 7 at few locations while generally PI exceeds 7.

  The plasticity characteristic screens out majority of the locations to be non-liquefiable and only few locations remain potentially liquefiable.

- ✓ Earthquake data for Karachi and within 200 Km radius is presented in Table 2.3.11. The data shows that Earthquake activity, concerning Karachi, during last 100 years did not exceed Magnitude of 5.6 (1920). However, earlier Earthquakes (894 to 1920) had higher Magnitude up to even 8.3 (1890).

  Based on earthquake history with Magnitude < 6 the Liquefaction Potential remains low and of limited extent.

- ✓ The site investigation discussed here, for assessment of liquefaction, has inherent limitations that the boreholes were located about 500m apart. Table 2.3.10 showing the location prone to liquefaction (SPT N ≤25 and submerged condition) also indicates discontinuity between adjoining areas which are not liquefiable. Therefore, the extent of liquefaction may be considered to be limited.

- ✓ Since extent of liquefiable subsoil in generally shallow, while viaduct (elevated) section of KCR route as well as Station Buildings will be supported on pile foundations, which screens out a large section of KCR to be safe from liquefaction considerations.

- ✓ The remaining locations can be treated individually by providing deep foundations or replacing unsuitable subsoil from top zone. Such treatment may be required for stability of on-ground track.

Table 2.3.10 SPT Data for Sand with N<=25

	Depth, m	1	2	3	4	5	6	7	8	9	10		EXTENT of SAND with N=<25 m	GWT m	SUBMERGENCE CONDITION
0.0 to 8.0 Km	BH # 1		9										1	4.91	DRY
	BH # 2		10	13									3	4.59	DRY
	BH # 3		11	14	13	23							5	5.66	DRY
	BH # 4		7	13	11								4	3.87	SUBMERGED
	BH # 5		11	9	22	22							5	3.23	SUBMERGED
	BH # 6		10	14									3	2.39	SUBMERGED
	BH # 7		8										2	1.95	SUBMERGED
	BH # 12		4										2	0.00	SUBMERGED
	BH # 16		7	13									3	1.41	SUBMERGED
8.0 to 16.0 Km	BH # 17			14									3	1.21	SUBMERGED
	BH # 18		4	21									3	0.50	SUBMERGED
	BH # 20		18										2	2.51	DRY
	BH # 21			7	13	11							5	7.68	DRY
	BH # 22		23	13	14		25	7	13	4			9	6.24	SUBMERGED
	BH # 23		23	10									3	11.11	DRY
	BH # 25			12	4	20					24		5	12.17	DRY
	BH # 26			18									3	8.94	DRY
	BH # 27		12										2	9.52	DRY
	BH # 28		4	16			15						6	4.82	SUBMERGED
	BH # 31		16										2	9.59	DRY
16.0 to 24.0 Km	BH # 34		25										2	18.33	DRY
	BH # 36			7									3	12.62	DRY
	BH # 41		8	11	10								4	15.94	DRY
	BH # 44		9										2	3.38	DRY
	BH # 46			19	16								4	2.06	SUBMERGED
	BH # 47		18	19									3	0.83	SUBMERGED
	BH # 49		15	14	16	15							5	3.79	SUBMERGED
24.0 to 32.0 Km	BH # 50						25						6	0.68	SUBMERGED
	BH # 51				19	21	17						6	2.92	SUBMERGED
	BH # 52							25	24				8	4.63	SUBMERGED
	BH # 53			4		20	22						6	3.74	SUBMERGED
	BH # 56					12	20	21	21				8	2.59	SUBMERGED
	BH # 57		5	6	10	7							5	1.73	SUBMERGED
	BH # 58							22	23				8	4.29	SUBMERGED
	BH # 59				12	16							5	4.11	SUBMERGED
	BH # 60						23						6	4.48	SUBMERGED
32.0 to 40.0 Km	BH # 68		16	19									3	1.60	SUBMERGED
	BH # 71			7									2	2.08	DRY
	BH # 72				21								4	2.24	SUBMERGED
	BH # 74			9	10								4	1.15	SUBMERGED
	BH # 76		8	4	9	6							5	3.52	SUBMERGED
	BH # 79		17	5									3	2.85	SUBMERGED
	BH # 81		3	5									3	0.79	SUBMERGED
40.0 to 43 Km	BH # 84		14	12	22								4	0.52	SUBMERGED
	BH # 86			24	16								4	2.88	SUBMERGED
	BH # 88				6								4	1.62	SUBMERGED
	BH # 89		6										2	1.15	SUBMERGED

Legend (colour key):
- Garbage/ Solid waste
- Fill Material
- SAND 1
- SAND 2
- CLAY 1

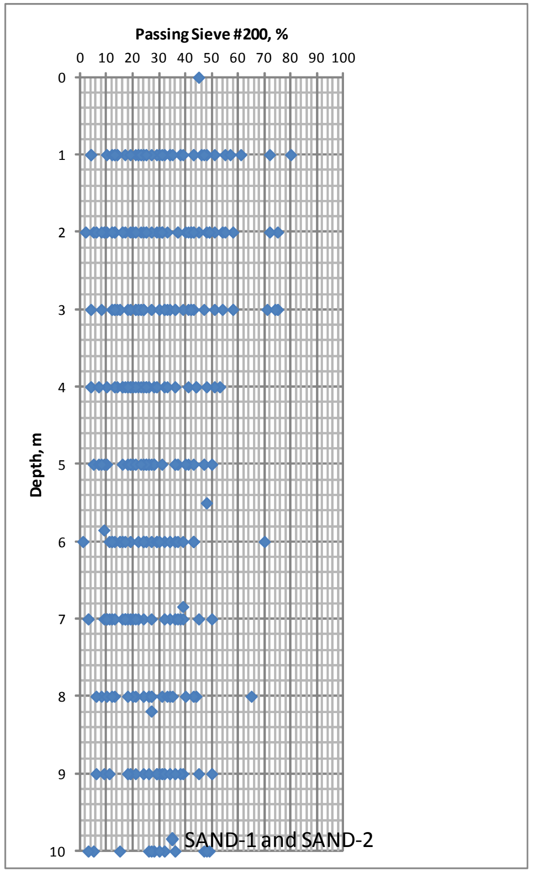
Source: JICA Study Team

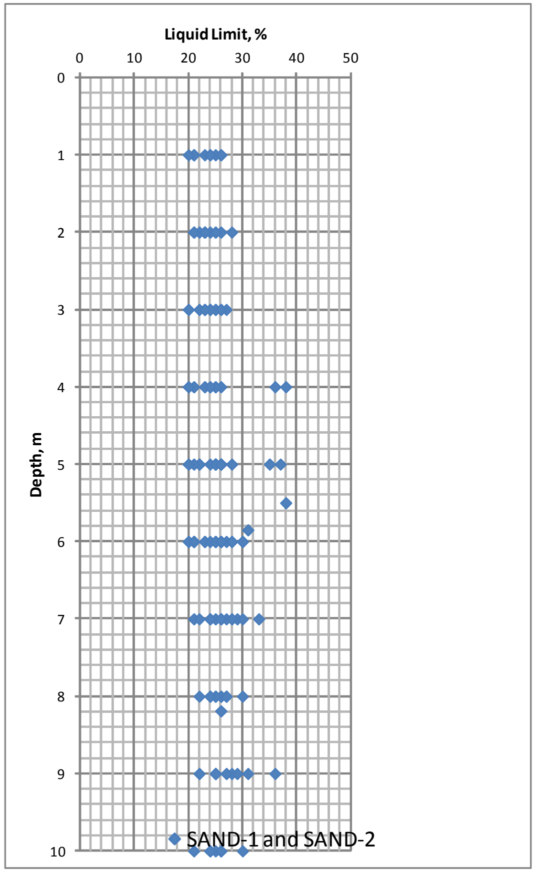
Table 2.3.11 Earthquake Data for within 200 Km of Karachi

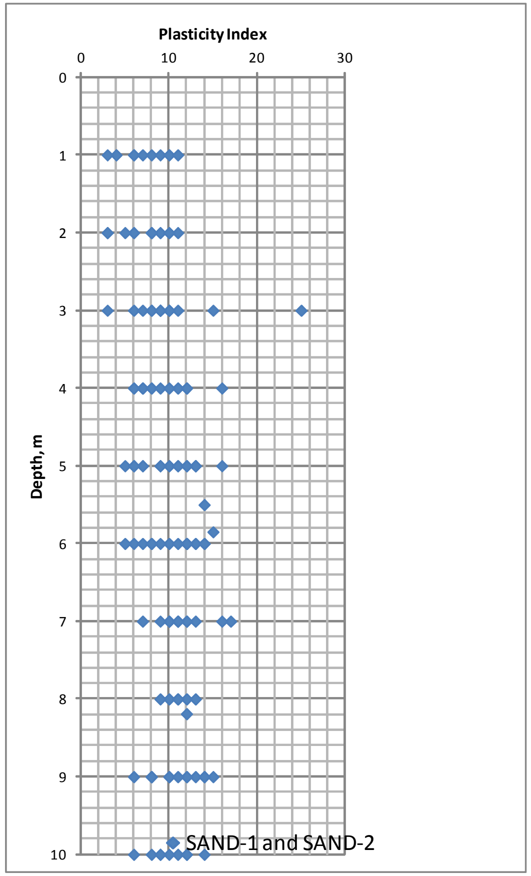
894	24.80	67.90	6.3-7.6	Thatta
1050	24.60	67.73	6.5-7.5	Bhambhor
1668	24.70	67.60	6.3-7	Pipri
1668	25.00	68.00	7.60	Samaji Delta (Near Karachi)
1819	25.30	68.50	4.3-5.0	Hyderabad
1819	23.50	70.50	5.6-6.3	Rann of Kutch
1819	23.60	69.60	8.30	Kutch
1844	23.80	68.90	4.30	Luckput near Karachi
1845	23.80	68.90	5.70	Luckput (Kutch)
1851	26.40	67.90	6.00	Sehwen
1870	25.80	68.80	5.00	Lower Sindh
1920	25.00	68.00	5.60	Jhimpir
1935	24.70	66.00	5.00	Karachi
1960	25.70	67.60	4.00	Karachi
1962	24.10	70.00	5.00	Rann of Kutch
1962	24.70	66.00	4.50	Karachi
1965	24.40	70.00	5.30	Kutch
1965	25.03	67.76	4.50	Karachi
1966	25.00	68.00	5.00	Jhimpir
1966	24.50	68.70	5.10	Hyderabad
1966	25.10	68.00	5.10	Hyderabad
1968	24.61	66.42	4.10	Karachi
1969	24.40	68.70	4.40	Hyderabad
1969	24.54	68.79	3.50	Hyderabad
1969	24.40	68.70	4.40	Hyderabad
1970	24.60	68.60	5.20	Hyderabad
1970	25.28	66.65	4.90	Karachi
1971	25.00	68.00	4.50	Jhimpir
1971	25.10	68.10	4.50	Hyderabad
1972	25.50	66.80	5.00	Bela
1972	25.50	66.80	4.50	Bela
1972	25.35	66.71	4.50	Karachi
1973	25.00	68.00	5.00	Jhimpir
1973	25.54	66.50	4.90	Karachi
1973	25.48	66.33	4.30	Karachi
1973	25.10	68.10	4.80	Hyderabad
1975	25.50	66.80	4.50	Gadani
1975	25.22	66.59	4.70	Karachi
1984	25.58	66.41	5.00	Karachi
1985	24.90	67.39	5.00	Karachi
1985	24.75	67.64	4.70	Karachi
1986	25.34	66.60	4.60	Karachi
1992	25.25	67.76	3.60	Karachi
1992	24.33	68.83	3.70	Karachi
1998	24.90	66.32	3.80	Karachi
1998	25.96	66.46	4.40	Karachi
1998	24.85	66.35	4.50	Karachi

Source: JICA Study Team

Figure 2.3.13 Passing #200, LL and PI vs Depth – SAND- 1 and SAND- 2 Combined Data for Top 10m Depth







Note: Data also includes % Passing Sieve #200 for SILT within these depths.

Source: JICA Study Team

2.3.7 Recommendation for Foundation Design

(1) Design Criteria for Plan

The design criteria shall consider the features of the project, performance requirements, effective life of project, future requirements and design parameters shall be adopted accordingly so that a rationalized, economical and technically sound project is designed and constructed.

The main features of KCR project includes a circular railway track planned to be on ground, elevated (viaduct) and tunnel (culvert) covering various sections along the proposed route. The project also includes construction of station buildings at various locations.

The design of foundations of various structures, for the project, shall consider following:

a) The foundations shall be placed at such a depth which is not influenced by weather, flooding and erosion.
b) The foundation shall be safe against ultimate (shear) failure.
c) The total settlement as well as differential settlement of foundation shall not exceed allowable/tolerable limits. Generally, allowable/tolerable settlement for various foundations system is as follows:
   - ✓ For Individual Foundations the total settlement of 25mm and different settlement of 19mm is considered as allowable/tolerable.
   - ✓ For Raft Foundations, the total settlement of 50mm and different settlement of 25mm is considered as allowable/tolerable.
   - ✓ For Pile Foundations the total settlement may correspond to as high as 10% of pile dia for full mobilization of End Bearing of the pile. However, the tolerable settlement for safe performance of structures, supported on Pile Foundations, may be as low as 1% of pile dia.

Geotechnical and Structure Design engineers should coordinate to adopt appropriate allowable/tolerable limits of settlement with due considerations to soil-structure interaction

Source: Foundation Analysis and Design, 5th Edition Mr. Joseph E. Bowles, P.E., S.E.

(2) Foundation Design Parameters

The field and laboratory investigation and tests data, as presented in earlier sections of the report, has been analyzed to determine the parameters required for selection of foundation system and its design.

The design parameters including Seismicity, Liquefaction and Subsoil are presented hereunder:

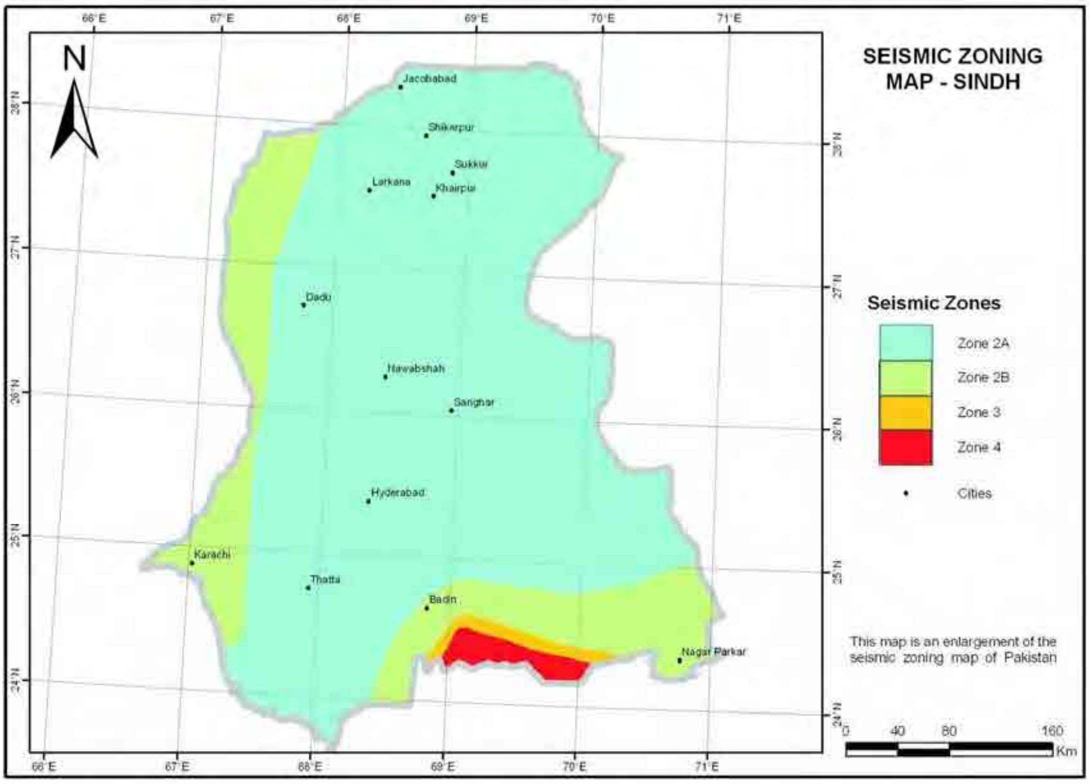
1) Seismic Parameters

Seismicity of project area has been discussed in section 2.3.3(4) of the Report. Pakistan Building Code (PBC) and Unified Building Code (UBC) provide guidelines for ascertaining parameters for design of foundations.

Based on site location, Earthquake/Seismicity influencing the project area, area geology, field and laboratory investigation data and proposed structures, Design Parameters, are given here under in accordance with guidelines of **"Pakistan Building Code (PBC-2007)"**:

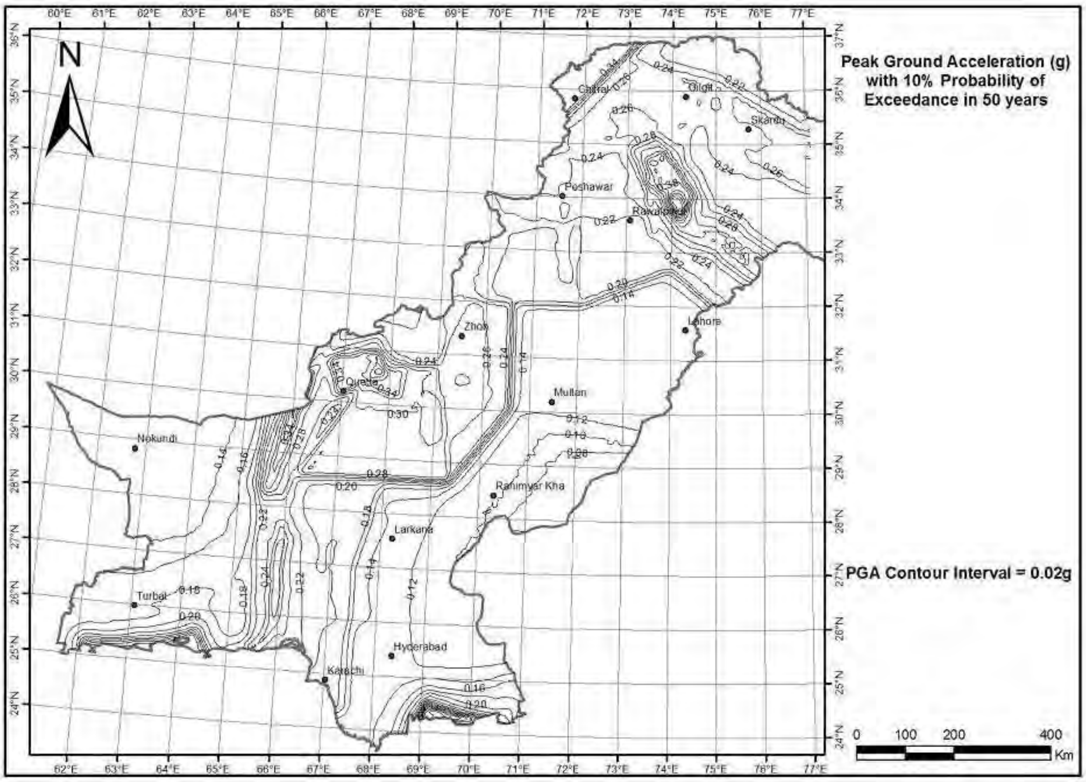
Design Parameter	Design Value	Pakistan Building Code Reference	Remarks
Seismic Zone	2B	Fig 2.3	Reproduced as Figure 2.3.14
Peak Horizontal Ground Acceleration	0.16 to 0.24	Fig A-1 Table 2.1	Reproduced as Figure 2.3.15, Table 2.3.12
Seismic Zone Factor "Z"	0.20	Table 5.9	Reproduced as Table 2.3.13
Soil Profile Type	S_C & S_D	Table 4.1	Reproduced as Table 2.3.14
Seismic Coefficient "C_a"	0.24 to 0.28	Table 5.16	Reproduced as Table 2.3.15
Seismic Coefficient "C_v"	0.32 to 0.40	Table 5.17	Reproduced as Table 2.3.16
Near Source Factor "N_a"	1	Table 5.18	Reproduced as Table 2.3.17
Near Source Factor "N_v"	1	Table 5.19	Reproduced as Table 2.3.18
Seismic Source Type	C	Table 5.20	Reproduced as Table 2.3.19

Source: JICA Study Team



Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Figure 2.3.14 Seismic Zone



Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Figure 2.3.15 Peak Horizontal Ground Acceleration

Table 2.3.12 Seismic Zones

Seismic Zone	Peak Horizontal Ground Acceleration
1	0.05 to 0.08g
2A	0.08 to 0.16g
2B	0.16 to 0.24g
3	0.24 to 0.32g
4	>0.32g

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.13 Seismic Zone Factor Z

Zone	1	2A	2B	3	4
Z	0.075	0.15	0.2	0.3	0.4

Source: JICA Study Team

Table 2.3.14 Soil Profile Types

Soil Profile type	Soil Profile name/ Generic Description	Average properties for Top 30 M (100 ft) of Soil Profile		
		Shear wave velocity V_s m/sec (ft/sec)	Standard Penetration Tests, N[or N_{CH} for Cohesionless Soil layers (blow/ foot)	Undrained Shear Strength S_u kPa (psf)
S_A	Hard Rock	>1500(>4920)	-	-
S_B	Rock	750 to 1500 (2460 to 4920)		
S_C	very Dense Soil and Soft Rock	350 to 750 (1150 to 2460)	>50	>100 (>2088)
S_D	Stiff Soil Profile	175 to 350 (575 to 1150	15 to 50	50 to 100 (1044 to 2088)
S_E[1]	Soft Soil Profile	<175(<575)	<15	<50(<1044)
S_F	Soil requiring Site-Specific Evaluation.			

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.15 Seismic Coefficients C_a

Soil Profile Type[2]	Seismic Zone Factor, Z				
	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4
S_A	0.06	0.12	0.16	0.24	$0.32N_a$
S_B	0.08	0.15	0.2	0.3	$0.40N_a$
S_C	0.09	0.18	0.24	0.33	$0.40N_a$
S_D	0.12	0.22	0.28	0.36	$0.44N_a$
S_E	0.19	0.30	0.34	0.36	$0.36N_a$
S_F	Site Specific geotechnical investigation and dynamic site response analysis shall be performed to determine seismic coefficient for Soil Profile Type S_F				

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.16 Seismic Coefficients Cv

Soil Profile Type[2]	Seismic Zone Factor, Z				
	Z=0.075	Z=0.15	Z=0.2	Z=0.3	Z=0.4
S_A	0.06	0.12	0.16	0.24	$0.32N_v$
S_B	0.08	0.15	0.2	0.3	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.4	0.54	$0.64N_v$
S_E	0.26	0.5	0.64	0.84	$0.96N_v$
S_F	Site Specific geotechnical investigation and dynamic site response analysis shall be performed to determine seismic coefficient for Soil Profile Type S_F				

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.17 Near Source factor N_a

Seismic Source Type	Closest Distance to Known Seismic Source		
	≤2 km	5 km	≥10 km
A	1.5	1.2	1.0
B	1.3	1.0	1.0
C	1.0	1.0	1.0

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.18 Near Source factor N_V

Seismic Source Type	Closest Distance to Known Seismic Source			
	≤2 km	5 km	10 km	≥15 km
A	2.0	1.6	1.2	1.0
B	1.6	1.2	1.0	1.0
C	1.0	1.0	1.0	1.0

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

Table 2.3.19 Seismic Source Type

Seismic Source Type	Seismic Source Description	Seismic Source Definition	
		Maximum Moment Magnitude, M	Slip Rate, SR (mm/year)
A	Fault that are capable of producing large , magnitude events and that have a high rate of seismic activity.	M≥7.0	SR≥5
B	All faults other types A an C.	M≥7.0 M<7.0 M≥6.5	SR<5 SR>2 SR<2
C	Faults that are not capable of producing large, magnitude earthquakes and that have a relatively low rate of seismic activity.	M<6.5	SR≤2

Source: Guidelines of "Pakistan Building Code (PBC-2007)"

2) Liquefaction Parameters

Based on subsoil conditions along KCR route and Earthquake/Seismic data, liquefaction potential for the site has been discussed in section 2.3.6(3) while parameters related to Liquefaction Potential are presented hereunder:

- Loose to medium dense, non-cohesive, submerged, subsoil is encountered at scattered locations along KCR route. Such subsoil conditions may be prone to liquefaction. However, potentially liquefiable locations are isolated while adjoining areas are non-liquefiable.
- It is further noted that extent, depth and thickness of subsoil at Potentially Liquefiable locations is limited and located in Sections of KCR route where overhead (viaduct) structure is planned. Since overhead (viaduct) structure will be supported on Pile Foundations, a number of potentially liquefiable sites are further screened, leaving very few locations to be considered from this aspect.

(3) Soil Parameters.

Based on investigation data and test results presented here above in section 2.3.4, 2.3.5, subsoil parameters along KCR route are evaluated and presented in Table 2.3.20.

We have provided the range and average value of Design Parameters as tabulated hereunder.

It is observed from the data that various in Design Parameters values exist which requires to adopt design parameters value as applicable to specification section of KCR route or to individual locations.

Table 2.3.20 Soil Parameters

Layer Designation	Subsoil	Υ_t gm/cc (kN/m3)			ϕ °			Unconfined Compressive Strength 'qu' Mpa			Coeff. of Consol. Cc			Initial Void Ratio		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
SAND-1	Silty Sandy Silt	2.08 -20.8	2.15 -21.5	2.11 -21.1	26	32	29									
CLAY-1	Clayey Silty Clay	1.78 -17.8	2.32 -23.2	2.1 -21				0.04	0.53	0.26	0.13	0.27	0.22	0.215	0.568	0.415
SAND-2, 3and4	Silty Clayey Sand/ Gravity Sand	1.6 -16	2.61 -26.1	2.21 -22.1	26	32	30									
CLAY-2&3	Silty Clay Clayey	1.95 -19.5	2.53 -25.3	2.16 -21.6				0.05	0.55	0.24	0.14	0.27	0.22	0.277	0.599	0.418
Rock	Sandstone	1.72 -17.2	2.73 -27.3	2.21 -22.1	30	32	31	0.05	9.83	2.03						
	Mudstone	1.48 -14.8	2.9 -29	2.2 -22				0.03	13.2	1.48						
	Limestone	1.58 -15.8	2.75 -27.5	2.24 -22.4	28	28	28	0.4	19.9	7.03						
	Conglomerate	1.97 -19.7	2.33 -23.3	2.18 -21.8	32	32	32	0.06	16.6	5						

Source: JICA Study Team

(4) Slope Stability (Near Alladin Park)

The section of KCR route from Km 4.7 to Km 6.5 has been planned to pass through existing "trench" which was erected by cutting the rock formation from surface level to the level of track (old track of KCR). In this section, two nos of boreholes were located and drilled from bottom of trench. The borehole data reveal existence of Limestone/Sandstone rock extending to maximum drilled depth of 15.0m.

To evaluate Slope Stability of trench sides, it requires detailed, site specific study including Geological Mapping, Rock Mass Classification and test for and engineering characteristics of various Rock formations as can be seem from at the sides of the trench at the site.

However, on the basis of generalized evaluation of site conditions, we are of the opinion that the existing, almost vertical, cut slopes are stable. However, at spots loose blocks of rock are also observed which indicate that some treatment will be necessary. Parameters required for such treatment shall be established by conducting site specific study including Geological Mapping (types of rocks, dip, strike, joints, fissures etc), Rock Mass classification and test for engineering characteristics.

(5) Consolidation Settlement (in KCR Section from Karachi Cantt to Baldia).

Clay layers were encountered in various sections of KCR route. Generally two Clay Layers were encountered which were designated as CLAY-1 and CLAY-2. "Section 2.3.4" of report describes the extent and of consistency of these layers. Undisturbed /Core Samples were extracted from these layers and further tested in laboratory.

The consistency of CLAY-1 is generally stiff to very stiff and hard while at some locations its consistency is soft. CLAY-2 is generally hard to very hard while at some locations its consistency is very stiff.

Consolidation tests were conducted in the laboratory, on CLAY samples to determine consolidation characteristics.

It is noted that soft clay essentially encountered in boreholes between Karachi Cantt and Baldia (BH 45 to BH 74)..

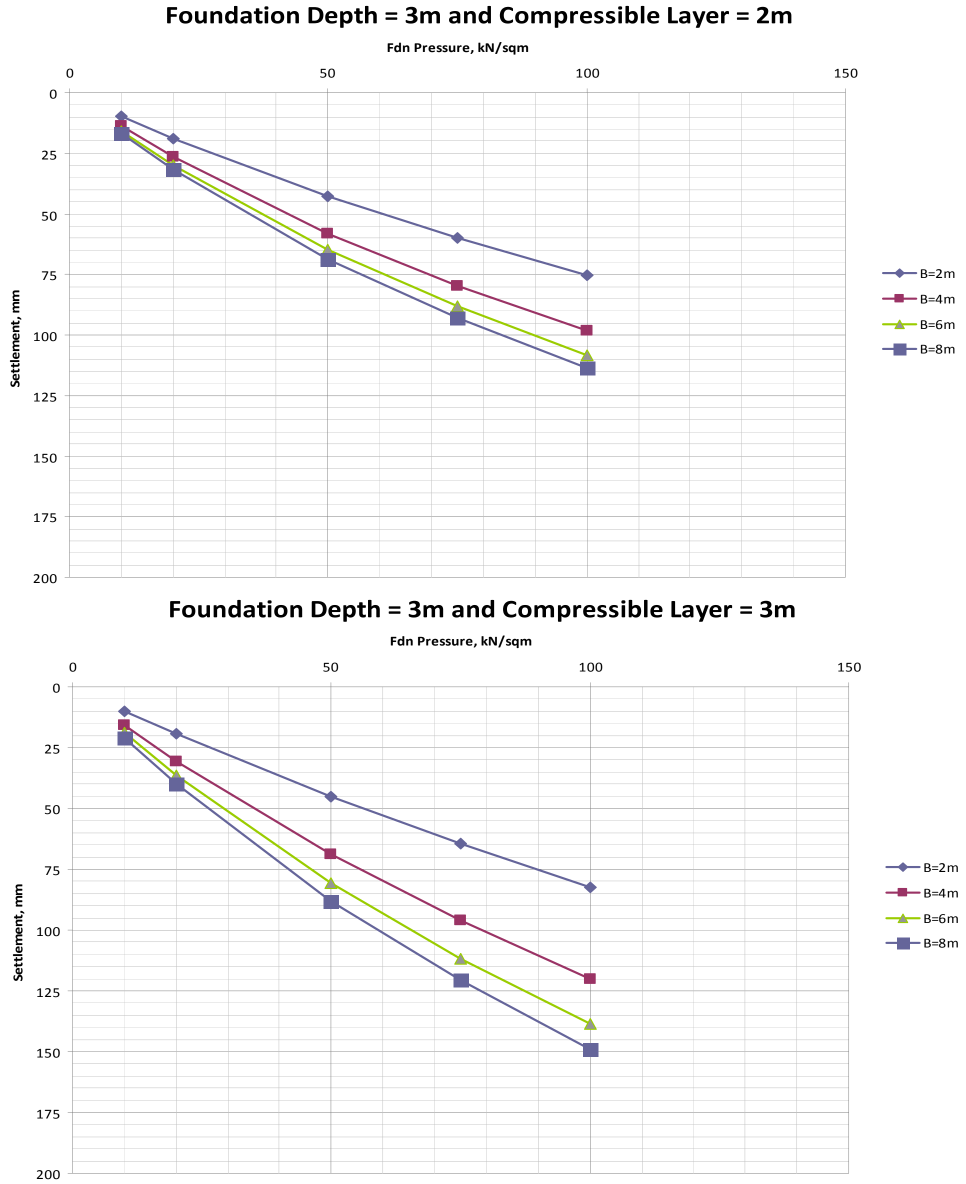
The consolidation settlement corresponding to various thickness of Clay layer and various foundation widths by considering that the foundations will be placed at a depth of 3.0m. Following parameters were adopted for calculation of consolidation settlement:

Total unit weight of Clay, γ_t	=	21 kN/m^3
Coefficient of Consolidation, C_c	=	0.22
Initial void ratio, eo	=	0.40
Depth of foundation	=	3.0m
Thickness of Clay Layer	=	2m & 3m (below foundation. level)

Figure 2.3.16 shows the magnitude of consolidation settlement as calculated on the basis of above given parameters.

It is noted that foundation pressure of 10 to 12 kN/m^2 may induce consolidation settlement of the order of 25mm while layer pressure will induce intolerable settlement.

Based on consolidation settlement analysis, it is determine that shallow foundations would induce intolerable large settlements. Therefore, pile foundation shall be considered at locations where Clay (particularly CLAY-1) is encountered.



Source: JICA Study Team

Figure 2.3.16 Consolidation Settlement in KCR Section where Clay is Encountered

(6) Precaution in Design Foundations

Based on above parameters following precaution should be considered incorporate in designing of Foundations

- The Allowable/ Tolerable limits of settlements should be adopted with due consideration of Soil-Structure interaction.
- The Design structural Engineer should consider the recommended parameters for Seismicity, liquefactions and Soil/ Rock physical properties.
- For the slope stability near Alladin Park, it is required some treatment for stability of loose rock blocks. Such treatment will be established by specific study including Geological Mapping (i.e. type, Dip, Strike, Joints, fissures etc.) Rock Mass classification, and engineering characteristics.

Based on consolidation settlements analysis, it is recommended Shallow Foundations on the locations where Clay (particularly CLAY-1) is encountered.

2.3.8 Conclusions

The Geological Survey of the Karachi Circular Railway entire Route can be concluded as follows:

- ✓ The Geology of the site along KCR route shows that, the Subsoil consists of Alluvium deposits of recent and sub recent Alluvium/ Diluvium period, underlain with Rocks belong to Gaj and Manchar Formations.
- ✓ The terrain along KCR route is generally flat and rolling Plains and hilly at Gulistan-e-Johar.
- ✓ The Consistency of recent Alluvium deposits is generally loose/ soft in top 1-4m depth, whereas it is found medium dense to dense and very stiff to hard in deeper horizons. Whereas consistency of sub recent Alluvium/ Diluvium deposits are dense to very dense and hard to very hard.
- ✓ The parameters for subsoil have been evaluated from Field data as well as Laboratory test results.
- ✓ The permeability of Subsoil has been studied at 3 locations at 10 &15m depth in Gulistan-e-Johar area.
- ✓ The study of water level monitoring shows that, the Ground water table is generally at shallow depth along KCR route i.e. between 1 to 4m depth and deeper at Liaqatabad, Nazimabad and SITE area. The salinity of Groundwater is generally moderate while sever at few locations.
- ✓ The liquefaction potential studies shows that, extent, depth and thickness of subsoil at Potentially Liquefiable locations is limited and located in Sections of KCR route where overhead (viaduct) structure is planned. Since overhead (viaduct) structure will be supported on Pile Foundations, a number of potentially liquefiable sites are further screened, leaving very few locations to be considered from this aspect.
- ✓ The Seismic study shows that, the Karachi lies in Seismic Zone '2B' and Design parameters has been recommended accordingly.

2.3.9 Core Boxes Storage Shed

(1) Result of Soil Investigation for Foundation of Core Boxes Storage Shed

For the construction of proposed Core Box Shed at KUTC Office for Karachi Circular Railway Revival Project, the program of Subsoil Investigation was under taken to determine subsoil conditions. We carried out the program of the soil investigation.

The program of investigation included drilling of one borehole by Hand Auger up to 2.5m depth at proposed site location, collection of representative subsoil samples and to conduct laboratory testing. The scope of this work also included preparation of soil investigation report giving details or the investigation and recommendations of foundations.

This chapter presented the results of the investigations and recommendation for Allowable Bearing Capacity for foundation. The subsoil stratigraphy is presented as shown in Borehole Logs (Figure 2.3.18) while laboratory test results are also included herewith (Figure 2.3.17, Figure 2.3.18).

We recommended to adopt Allowable Bearing Capacity of 5.0t/m2 at 0.6m depth (0.5t/sqft at 2.0ft depth) to support the proposed Shed structures (Figure 2.3.17).

【Allowable Bearing Capacity】 Method Ⅰ Terzaghi

$R_u = (i_c \cdot \alpha \cdot c \cdot Nc + i_r \cdot \beta \cdot \gamma_1 \cdot B \cdot \eta \cdot Nr + i_q \cdot \gamma_2 \cdot D_f \cdot Nq)$ (kN/m2)

Ru(kN/m2)	Ru(tf/m2)	ic	α	c	Nc	ir	β	γ1	B	η	Nr	iq	γ2	Df	Nq	A(m2)	φ
258.85466	26.386815	1	0.847813	0	18.05	1	0.347813	17.658	4.87	1	4.82	1	17.658	0.75	8.66	31.168	23.94427

Long time $R_a = R_u/3$ (Safety factor : 3)

Ra(kN/m2)	Ra(tf/m2)
86.284887	**8.7956052**

Short time $R_a = 2*R_u/1.5$ (Safety factor : 1.5)

Ra(kN/m2)	Ra(tf/m2)
172.56977	17.59121

【Allowable Bearing Capacity】 Method Ⅱ Terzaghi

Long time Ra = (α・c・Nc + β・γ1・B・Nr + γ2・Df・Nq)*1/3 (kN/m2)

Ra(kN/m2)	Ra(tf/m2)	α	c	Nc	β	γ1(kN/m3)	B	Nr	γ2(kN/m3)	Df	Nq	A(m2)	φ	N value
86.284887	**8.7956052**	0.847813	0	18.05	0.347813	17.658	4.87	4.82	17.658	0.75	8.66	31.168	23.94427	4

$\phi = \sqrt{(20 \times N)} + 15$

Maximum Weight **274.14142 (t)**

α	β	B	L
0.847813	0.3478125	4.87	6.4

Total Weight	W (t)
・Core Boxes(384 boxes)	6.8
・Base material (Concrete)	36.8
・Building of Storage Shed	100
Total	143.6

(4.6 t/㎡≒5.0t/㎡)

Shape of the bottom surface of Foundation

Shape of the bottom surface of	Continu - ousness	Square	Rectangle	Circle
α	**1.0**	**1.2**	**1.0+0.2(B/L)**	**1.2**
β	**0.5**	**0.3**	**0.5−0.2(B/L)**	**0.3**

Bearing capacity factor

φ(°)	Nc	Nγ	Nq	φ(°)	Nc	Nγ	Nq
0	5.14	0.00	1.00	21	15.81	3.42	7.07
1	5.38	0.00	1.09	22	16.88	4.07	7.82
2	5.63	0.01	1.20	23	18.05	4.82	8.66
3	5.90	0.02	1.31	24	19.32	5.72	9.60
4	6.19	0.04	1.43	25	20.72	6.77	10.66
5	6.49	0.07	1.57	26	22.25	8.00	11.85
6	6.81	0.11	1.72	27	23.94	9.46	13.20
7	7.16	0.15	1.88	28	25.80	11.19	14.72
8	7.53	0.21	2.06	29	27.86	13.24	16.44
9	7.92	0.28	2.25	30	30.14	15.67	18.40
10	8.34	0.37	2.47	31	32.67	18.56	20.63
11	8.80	0.47	2.71	32	35.49	22.02	23.18
12	9.28	0.60	2.97	33	38.64	26.17	26.09
13	9.81	0.74	3.26	34	42.16	31.15	29.44
14	10.37	0.92	3.59	35	46.12	37.15	33.30
15	10.98	1.13	3.94	36	50.59	44.43	37.75
16	11.63	1.37	4.34	37	55.63	53.27	42.92
17	12.34	1.66	4.77	38	61.35	64.07	48.93
18	13.10	2.00	5.26	39	67.87	77.33	55.96
19	13.93	2.40	5.80	40	75.31	93.69	64.20
20	14.83	2.87	6.40	41	[illegible]	[illegible]	[illegible]

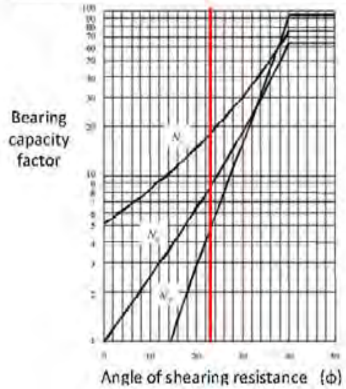


Figure 2.3.17 Result of Allowable Bearing Capacity by Terzaghi Theory

Source: JICA Study Team

BOREHOLE LOG

PROJECT: Soil Investigation for Proposed Core Box Shed at KCR Office for Samples of Karachi Circular Railway Revival Project		BOREHOLE# BH-01	Sheet: 1 of 2
CLIENT: The JICA Study Team			
DRILLING EQUIPMENT Hand Auger	SAMPLER : SPT	PROJECT # :	CES - 12480
BOREHOLE DIA : 100mm	Casing dia:	DATE STARTED :	4-Jun-12
SPT HAMMER WEIGHT : 63.5 kg Drop: 76 cm	Casing Length:	DATE COMPLETED :	4-Jun-12
Geologist: Efaz	DRILLER : Akram	GWT :	0.6m

DEPTH (m)	LOG	DESCRIPTION	SAMPLE/ TEST #	SPT BLOWS, N/30 cm (10 20 30 40 50)	N Value	REMARKS
0.0		Brown loose, Clayey SAND, trace to little Gravels				
0.5			SPT-1 0.5 m		6	
1.0			SPT-2 1.0 m		4	
1.5		Grey, very loose, Silty SAND little Gravels	SPT-3 1.5 m		5	
2.0			SPT-4 2.0 m		33	
2.5		Brown, dense, Silty fine to coarse SAND				
		End of Borehole at 2.5m depth				

SPT: Standard Penetration Test CRS : Core Sample CR:Core Recovery RQD:Rock Quality Designation, DS: Disturbe Sample

Source: JICA Study Team

Figure 2.3.18 Result of Borehole Log

Table 2.3.21 Grain Size Analysis (Percent Filter by Weight)

L.R # 71/12
Date: 12-06-2012

Project: Soil Investigation for Proposed Core Box Shed at KCR Office for Samples of Karachi Circular Railway Revival Project in Karachi.
Client: The JICA Study Team

GRAIN SIZE ANALYSIS (PER CENT FINER BY WEIGHT)

SIEVE ANALYSIS

HYDROMETER (Dia in mm)

S.NO.	BORING NO.	SAMPLE	DEPTH (m)	3"	1.5"	3/4"	3/8"	#4	#8	#16	#30	#50	#100	#200	0.05	0.01	0.002	0.001
				75 mm	38 mm	19 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.600 mm	0.300 mm	0.150 mm	0.075 mm	0.05 mm	0.010 mm	0.002 mm	0.001 mm
1	BH-A-I	DS-1	0.00 - 0.40				100	86	80	75	71	68	53	42				
2	BH-A-I	SPT-1	0.5				100	91	87	80	75	71	57	43				
3	BH-A-I	SPT-2	1.0				100	83	76	66	57	52	36	27				
4	BH-A-I	SPT-3	1.5				100	96	93	88	84	81	65	49				
5	BH-A-I	SPT-4	2.0					100	98	93	86	79	58	41				

Source: JICA Study Team

Table 2.3.22 Atterberg Limits

L.R # 71/12
Date: 12-06-2012

Project: Soil Investigation for Proposed Core Box Shed at KCR Office for Samples of Karachi Circular Railway Revival Project in Karachi.
Client: The JICA Study Team

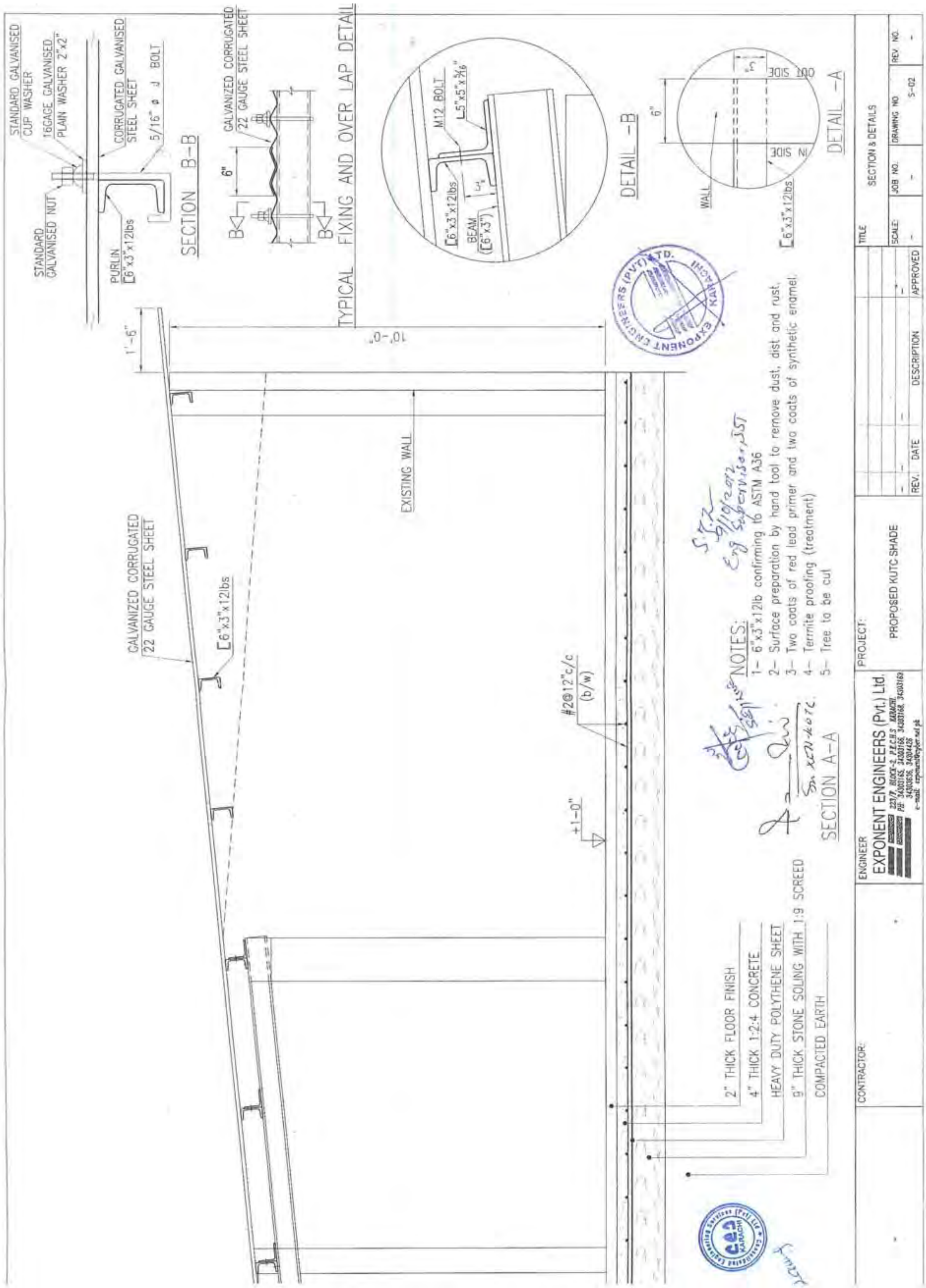
ATTERBERG LIMITS

S. NO.	BORING NO.	SAMPLE	DEPTH (m)	LIQUID LIMIT	PLASTICITY INDEX	Moisture Content (%)
1	BH-A-I	DS-1	0.00 - 0.40	21	6	15.11
2	BH-A-I	SPT-1	0.5	21	5	20.81
3	BH-A-I	SPT-2	1.0	Non-Plastic		35.39
4	BH-A-I	SPT-3	1.5	Non-Plastic		15.21
5	BH-A-I	SPT-4	2.0	Non-Plastic		14.57

Source: JICA Study Team

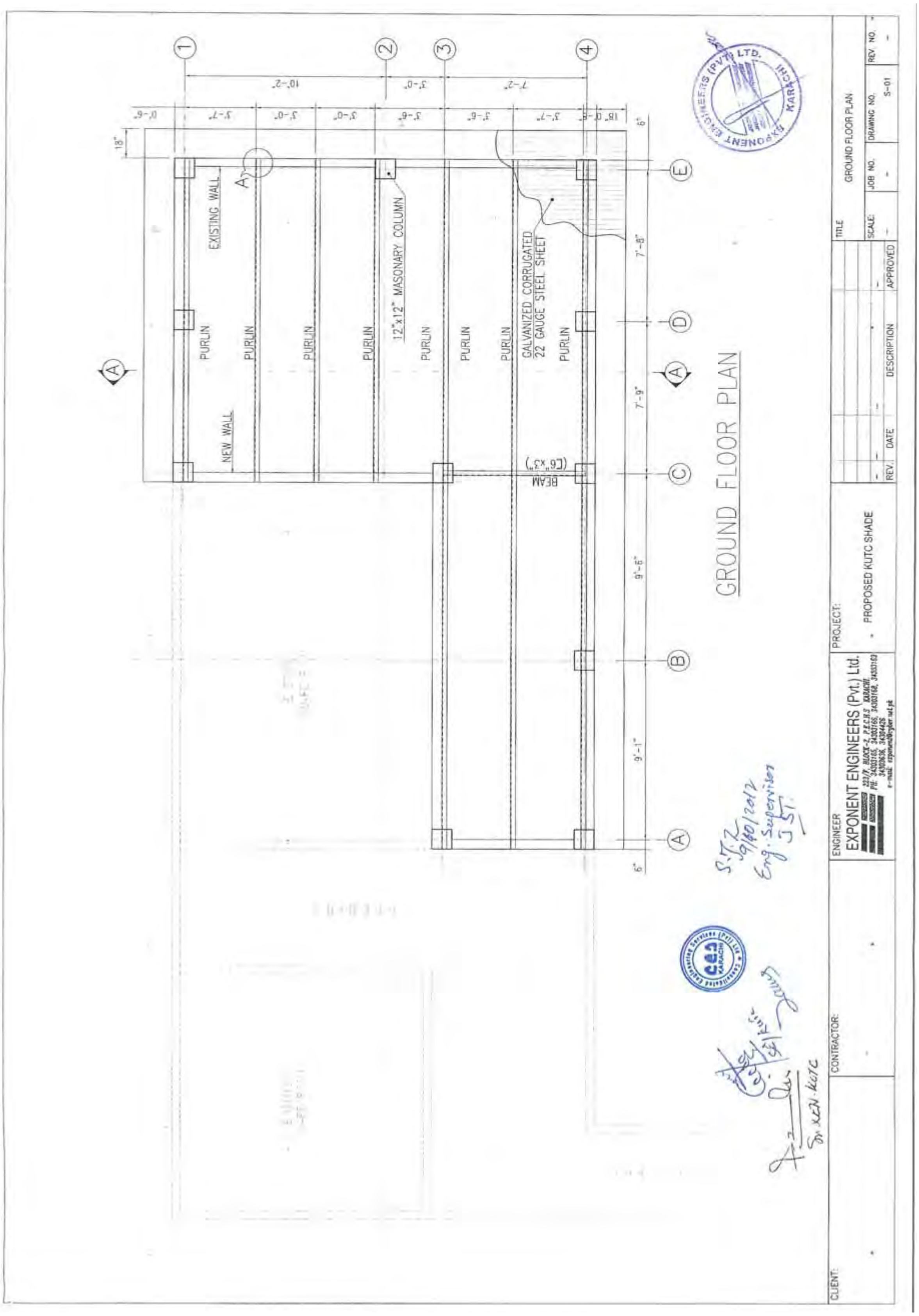
(2) The design and drawing of Core Boxes Storage Shed

The design & drawing of the shed for core boxes has been prepared by Local Consultant (Figure 2.3.19, Figure 2.3.20). The top supervision of construction was provided as well. This engineer visited the site once a week for supervision of work.



Source: JICA Study Team

Figure 2.3.19 Design & Drawing of the Shed for Core Boxes (1)



Source: JICA Study Team

Figure 2.3.20 Design & Drawing of the Shed for Core Boxes (2)

2.4 Survey on Power Supply Conditions

The survey on power supply conditions in the proposed project area was conducted and the results are used to examine the consistency with the electric facilities planning formulated in SAPROF (I).

2.4.1 Current Status of Karachi Electric Supply Company (KESC)

It is expected that electric power for KCR train operation is supplied from Karachi Electric Supply Company (KESC). KESC is providing services to Karachi city and its surrounding area of 6,000 km^2. Installed generation capacity of KESC is 2,341 MW and external power resource such as Independent Power Producer (IPP) and Water and Power Development Authority (WAPDA) is estimated at about 1,000 MW based on power purchase agreements.

KESC has been receiving certain amount of power from IPPs and WAPDA through transmission network. According to power supply record in 2012, about 49% of total power supply is purchased from IPPs and WAPDA and the remaining 51% of that is generated by KESC's power plant.

Current operating facility of KESC and Power Supply Record of KESC's Service Area are shown in Table 2.4.1and Table 2.4.2 below.

Table 2.4.1 Operating Facility of KESC

Power Plant	Name		Installed Generation Capacity (MW)
	Bin Qasim Power Station 1		1,260
	Bin Qasim Power Station 2		560
	Korangi Thermal Power Station		125
	GEJB-1		88
	GEJB-2		88
	Combined Cycle Power Station		220
	Total		2,341
Grid substation	Total 60		
Transformer	220kV/132kV	132kV/11kV	
	12	124	
	Total 136		
Transmission line	1,248km		
	220kV：20Line	132kV：98Line	66kV ：3Line
	338km	761km	149km

Source: KESC

Table 2.4.2 Power Supply Record of KESC's Service Area

		July - June 2010 - 2011	July - June 2011 - 2012
Power Supply	Maximum Demand	2,565MW	2,564 MW
	Generated Power	7,234,365 MWH	7,394,029 MWH
	Purchased Power	7,602,760 MWH	7,230,325 MWH
	Total Power Supply	14,837,125 MWH	14,624,354 MWH

Source: KESC

According to KESC's annual report 2011-2012, generation capacity of 1,010MW has been added to previous generation capacity up to date since September 2008. Efficiency rate has also increased from 30.9% to 38%. This is showing significant improvement of service capacity of KESC.

KESC has future development plan of generation facility as follows.

In order to reduce outages due to fuel supply interruption of gas and oil, KESC has started fuel diversification project that 2 units of 210MW each of Bin Qasim Thermal Power Station will be converted to Coal Generation Plant as Phase 1. The project will be implemented by KESC and BEEGL (Hong Kong Based Investment Company) with a joint agreement of USD 200Million. As Phase 2, the other 2 units of 210MW are expected to be converted to Coal Generation Plant.

Further, KESC has reached joint development agreement with Oracle Coalfields of UK for development of THAR Coal Mine in Sindh Province. THAR coal resource can be used for power generation and has the potential of providing energy security to the country. Mining lease for the development and exploitation of THAR Coal Mine has been awarded while Oracle Coalfields plans to develop open-cast coal mine.

In addition, KESC and Oracle Coalfields have a development plan of initially constructing 300MW power plant nearby THAR Coal Mine by 2015 and increasing generation capacity gradually. The project is expected to overcome shortage of gas and oil supply problems.

2.4.2 Stable Power Supply from KESC

KESC has been facing demand and supply gap due to power shortage, because generating capacity of KESC is inadequate and external power supply from WAPDA and IPPs cannot meet the demand as well. Recently power shortage has been occurring frequently in WAPDA power supply network throughout Pakistan. Therefore load shedding has been carried out not only in KESC's service area but also in almost whole area of the country.

Accordingly the current situation shows that stable power supply for KCR seems to be difficult unless KESC ensures priority power supply to KCR as a strategic customer with a special agreement between KESC and KUTC. KESC has a policy to supply uninterrupted power to all strategic customers. Therefore strategic customers will not be subject to any planned load shedding under the load shedding exemption policy.

In this regard, KESC assured priority power supply to KCR as the strategic customer with the letter of comfort in June 2011. In addition, KESC's track records of performance to the strategic customers and industrial customers are showing considerably stable power supply to those customers.

2.4.3 Current Situation of Power Supply to Strategic Customer and Industrial Customer

The following is current situation of power supply to strategic and industrial customers.

Karachi Water and Sewerage Board (KWSB) is providing services of water supply and sewerage treatment for Karachi City with population of 18million and designated as strategic customer by KESC. The letter from KWSB in May 2011 about track record of KESC's performance states that electric power supply to water and pumping/process facilities is quite satisfactory.

According to the findings from a factory visit to Lotte Pakistan PTA Ltd which is private chemical companies in Port Qasim Industrial Area, the factory has not experienced any power shutdown since 2009 although they have faced some frequency and voltage fluctuation problems during that time. KESC has been supplying the company with electric power of 220 kV through dedicated distribution system from KESC grid station based on power purchase agreement. Average electric power consumption of the factory is around 25 MW. All costs for switching facilities connected to KESC's grid, transmission line and substation facilities were borne by the company. Maintenance work of transmission line and substation are being conducted by the company with some technical support from the third party on contract basis. This is a typically similar case of power supply situation as strategic customers.

Sindh Industrial Trading Estates Limited and King's Food Ltd are industrial customers of KESC and the letters from both companies about track record of KESC's performance states that total break down during over 3months is 4.3 and 4.4% respectively because of planned load shedding.

According to the previous KESC's performance of power supply to strategic and industrial customers shown in Table 2.4.3 below, it can be expected that KCR will be supplied with stable power supply from KESC as the strategic customer.

Table 2.4.3 KESC's Performance of Power Supply to Strategic and Industrial Customers

Type	Organization	Performance Record	Current Situation
Strategic Customer	Karachi Water and Sewerage Board (KWSB)	Not Available	Power supply to water and pumping/process facilities is quite satisfactory.
Industrial Customer	Lotte Pakistan PTA Ltd	Not Available	Factory has not experienced any power shutdown since 2009.
	Sindh Industrial Trading Estates	KESC Break Down Rate 4.3% 111 hours/2,592 hours	Track Record for Availability is almost 96% and fairly good.
	King's Food Ltd	KESC Break Down Rate 4.4% 103 hours/2,328 hours	Track Record for Availability is almost 96% and fairly good.

Source: JICA Study Team

2.4.4 Procedure for Power Receiving from KESC Transmission Network

The procedure for new connection to KESC transmission network is that a formal request letter should be submitted from KUTC to KESC with basic information such as the location of traction substation (TSS), estimated power load, desired voltage level and commissioning year. After the request is accepted by Project Development and Planning Department of KESC, simulations and system studies will be conducted to examine the load flow, stability of power supply and influence on existing transmission network by relevant department of KESC. Based on the result of simulations and system study, KESC determines the best possible grid substation for power supply to KCR.

2.4.5 Transmission Network System and Future Development Plan of KESC

KESC has a high voltage transmission network system. KESC has recently added about 400MW and 560 MW power supply capacity into its system. KESC is expected to continue the development work to improve the gap between demand and supply within the KESC's service area.

2.4.6 Electricity Tariff System of KESC

Regarding tariff for electricity consumption, industrial supply tariff system of KESC will be applied to KCR as shown in Table 2.4.4 below. This tariff system is presently enforced by SRO-368 dated 6th May 2011, Ministry of Water and Power, Government of Pakistan.

In the KCR case, B4 (b) and B5 will be applied due to receiving voltage of 132 kV and 220 kV.

Table 2.4.4 Tariff System Applicable to KCR (Industrial Supply Tariff)

Sr. No.	Tariff Category	Fixed Charges Rs/kW/Month	Variable Charge Rs/kWh	
			Peak	Off-peak
B2 (b)	5-500 kW (at 400 Volt)	367	11.52	6.76
B3 (b)	For all loads (at 11 kV, 33 kV)	356	11.43	6.50
B4 (b)	For all loads (at 66 kV, 132 kV and above)	343	11.12	6.21
B5	For all loads (at 220 kV and above)	340	9.41	6.17

Note: B4 (b) consumers and B5 consumers shall be subject to a fixed minimum charge of Rs 500,000 per month and Rs 1,000,000 per month respectively.

Source: KESC