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Engineering Geology of Delhi: An Overview

V. Gupta*, H.G. Poulos† and S.G. Reid‡

Introduction

The Indian sub-continent can be divided into three major units from geological considerations: (1) The Peninsular Shield, (2) The Indo-Gangetic Basin, and (3) The Himalayas. The Indian shield is the oldest part of the peninsula and has grown through crustal reworking and accretion over a protracted period of time during the Precambrian.

The Indian continental crust appears to have grown around at least three separate nuclei. These are the Aravallis in NW India, Singhbhum in Eastern India and Kamatka in South India. In these proto-continental blocks, rocks with ages varying from 3.8 to 2.5 billion years (b.y.) are found. A simplified geological map of India is shown in Fig. 1 (GSI, 1963).

The rocks of the Delhi and Aravalli Supergroup occupy a very important place in the geological history of the northern part of the Indian peninsula. They constitute the geological foundation of the Aravalli Mountain Range and have a NE-SW trend extending from latitude 24°N to 28°N and longitude 73°E to 79°E, (Verma, 1991). The central part of the Aravalli Mountain Range (Delhi and Aravalli belts) is occupied by the Delhi Supergroup of rocks. The Delhi Supergroup, younger than the Aravalli, formed in graben-like structures around 1900 million years (m.y.) and was intruded by granites around 1700-1650 m.y. However, later activity continued along the axial zone at about 1400 m.y., 1200 m.y. and 1000-950 m.y. Intrusive pegmatite activity has been dated at about 850, 750 and 650 m.y. It is apparent from the foregoing that the Aravalli/Delhi Supergroup of rocks experienced several

* Ph.D. Student, The University of Sydney, NSW 2006, Australia

† Professor, The University of Sydney, NSW 2006, Australia

‡ Associate Professor, The University of Sydney, NSW 2006, Australia

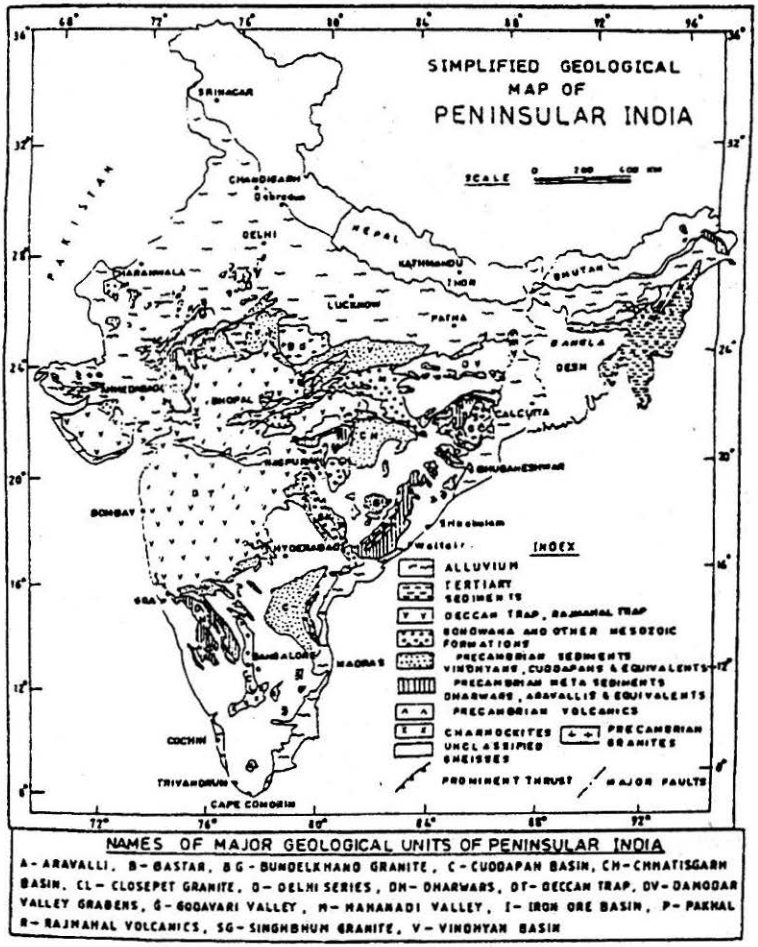

FIGURE 1 : Simplified Geological Map of India (GSI, 1963)

episodes of orogenic activity, granitisation, basic intrusions and metamorphism during its history, which spans from nearly 2600 m.y. to 560 m.y. Major rock formations of the area are shown in Fig. 2 (Choudhary et al., 1984).

General Features of Delhi

Location

The Union Territory / newly formed State of Delhi occupies an area of 1485 km^2. It lies between latitudes 28°24'17" and 28°53'00" and longitudes 76°50'24" and 77°20'37". It falls within Survey of India topo sheet nos. 53-D and 53-H on 1:2,50,000 scale. Out of a total area of 1485 km^2, the

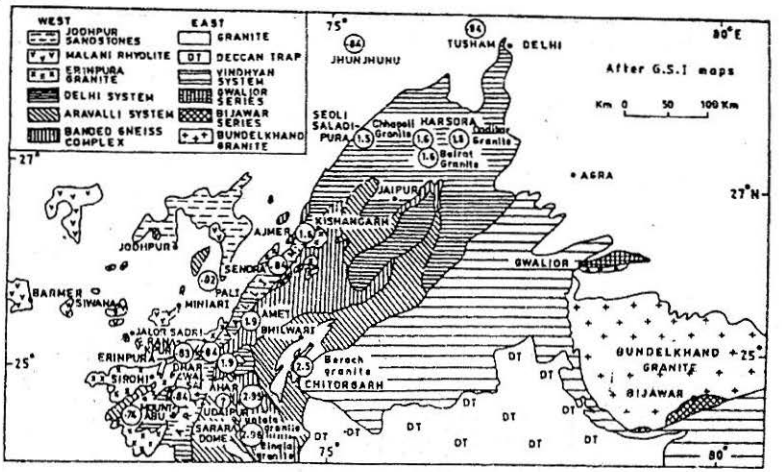

FIGURE 2 : Simplified Geological Map of Rajasthan and Vicinity

rural area is 1015 krn^2 and 470 km^2 forms the urban area. Delhi is bounded in the north, south and west by the state of Haryana and in the east by the state of Uttar Pradesh (Fig. 3).

Delhi is divided into six administrative blocks i.e. (i) City block, (ii) Alipur, (iii) Kanjhawala, (iv) Mehrauli, (v) Shahdara, and (vi) Najafgarh. There are 258 inhabited villages in the union territory.

Physiography

The union territory of Delhi has three distinct physiographic units, viz. (i) the alluvial plain on eastern and western sides of the ridge, (ii) Quartzite ridge, and (iii) the nearly closed alluvial basin of Chattarpur in South Delhi.

The alluvial plain in the area is almost flat and is interrupted by a cluster of sand dunes and quartzite ridges, (CGWB, 1989). The sand dunes, which are more prominent in the western part of the area, are of varying dimensions and have a northeast-southwest trend. The crests of these dunes generally lie between 3 and 10 metres above the surrounding plains. The dunes in the area are more or less fixed with vegetation on them.

The quartzite ridge enters the area from south-eastern part and passes through the eastern part extending upto the Western bank of river Yamuna near Wazirabad. The rocky ridge has a length of about 35 kms and trends in a NNE-SSW direction. Isolated exposures of the quartzites are also formed in the western part of the area. The elevation of the crest of the ridge varies from 213 m to 314 m above mean sea level with an average elevation of 40

m from the surrounding plain. The land surface on east side of ridge slopes towards the river Yamuna with a general gradient of 3.3 metre per kilometre. On the west side of the ridge the ground slopes towards the Najafgarh lake in the southwest.

The nearly closed alluvial basin of Chattarpur (lat. 28°25'30" to 28°32'30", long. 77°07'30" to 77°13'00") in south Delhi occupies an area of about 78 km^2. This is a closed inland basin, the boundary of which is marked by the quartzite ridges. The general slope of the land is towards the center of the basin from the surrounding ridges. The slope in the southern part of the basin is towards the south. The maximum land altitude in the basin is 259 metre above mean sea level (m.s.l.), whereas the land at ridges is about 274 metre above m.s.l.

Geology

The area of Delhi is surrounded in the North and East by the Indo-Gangetic plains, in the West by the great Indian desert popularly known as Thar desert, and in the South by the Malwa Plateau. Most of the area is covered by recent Alluvium, however rocky out-crops are very common in the southern part of Delhi (Fig. 3).

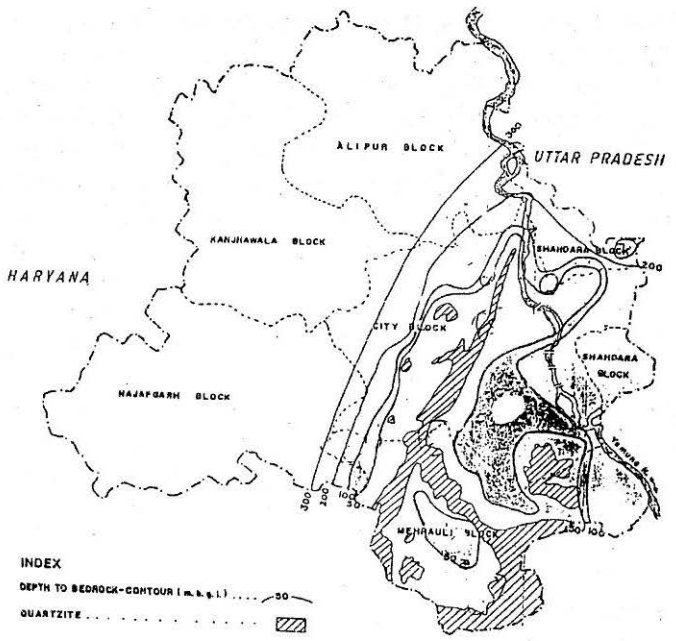

FIGURE 3 : Geology of Delhi (CGWB, 1989)

The terrain is generally flat except for a NNE-SSW trending ridge lying in the central portion of the area. The area topography includes scattered isolated hillocks around Naraina-Inderpuri and Anandpur-Shadipur depot where rocks are exposed. The Delhi region can be divided into 5 main geomorphic units:

1. The recent flood plains on the banks of river Yamuna,
2. Delhi ridge,
3. Alluvial plains West of ridge,
4. Alluvial plains East of ridge, and
5. Alluvial basins in Chattarpur in South Delhi.

The alluvial plain in the area is almost flat and is interrupted by clusters of sand dunes and quartzite outcrops. Sand dunes found in the western parts are prominently aligned in NNE-SSW direction. At many places they have attained a height of 3 to 10 metres above the surrounding plains.

The quartzite ridge enters the area from the South East part and expands into rocky tableland towards the Eastern part, finally disappearing below the Yamuna alluvium. The land surface on the Eastern side of the ridge slopes towards the river Yamuna with a general gradient of about 3.5 metre per kilometre.

The Yamuna river, flowing in a southerly direction in the eastern part of Delhi, is the only perennial river in the area. It has an average gradient of about 1 to 6000 from North to South. During floods, the water level rises and mostly inundates Eastern banks towards Shahdara. The drainage on the East of the ridge enters the Yamuna river whereas on the west of the ridge drainage passes on to the natural depression of Najafgarh lake in the South Western parts of the Delhi metropolis. The Najafgarh drain runs from this lake in a North Easterly direction for about 39 km and finally flows into the river Yamuna at Wazirabad in the North of Delhi. Human influence on the present topography is considerable, as evinced by the construction of a number of storm water drains in the area.

The rock formations exposed in the Delhi area are mainly quartzite of the Alwar series of the Delhi system, having inter-beds of micaceous Schist.

The Delhi System extends along the main access of folding of Aravalli from near Delhi in the North to Idar in the South across Mewar. The Delhi quartzite (metamorphic) consists of narrow strike-ridges in which rock shows moderate folding. The quartzite ridges prominently exposed in Delhi have been weathered to varying degrees.

Geological Succession

The geological succesion as found in Delhi area is given in Table 1.

Table 1
Geological Succession in Delhi Area (Rao, 1995)

Geological Group	Series	Characteristics
Present and Sub-recent (Pleistocene)	Younger Alluvium	Yamuna river bed sand and other sediment deposits in the stream bed
	Older Alluvium	Yellow and reddish soil comprising silt clay with kankar (pebbles) beds, sand pockets and sometimes small *ferruginous concretions*
Post Delhi Intrusives	—	Quartz veins and Pegmatite's
Delhi Super Group (System) (Pre Cambrian)	Alwar Series	Quartzites, greyish, bluish and pinkish in colour, fine to coarse grained and thin inter beds of micaceous schists.

Alwar quartzites

The Alwar Quartzites are the basement rocks exposed in the area and belong to the Delhi system of Precambrian age (CGWB, 1989). These are composed mainly of quartzites with interbeds of mica-schists and are intruded locally by pegmatities and quartz veins.

The quartzites are generally hard, compact, massive and jointed but on weathering give rise to friable rock zones. The effects of weathering are more pronounced along the joint plains and quartzite blocks become subrounded on the surface. The weathering of pegmatites gives rise to clay, which is being mined in many areas in Delhi.

The strike of the quartzites varies from NE-SW to NNE-SSW with steep dips towards the east and south-east. Four sets of joints; viz. bedding joints, dip joints, strike joints and diagonal or oblique joints, are prominent and form rectangular blocks of these rocks. The strike of fault and shear zones varies from NE-SSW to NE-WSW. The major folds trending from NNE-SSW to NW-SE are lightly compressed and double plunging folds. The ferruginous and gritty type of quartzites, on weathering and subsequent disintegration, produce coarse sand locally known as 'Badarpur Sand'.

Aeolian deposits

The aeolian deposits are mainly loam: silty loam and sandy loam. They are generally finer in grain size having tiny and tarnished brown flakes and dissemination of kankar nodules. Recent studies by the Central Ground

Water Board (CGWB), utilising bore hole data and a geomorphological map prepared on the basis of photo-interpretation and field checks, have shown that the bedrock is overlain by aeolian deposits which are further overlain by alluvial deposits. The occurrence of aeolian deposits directly over the bedrock suggests that the river Yamuna has possibly come into existence in this area after the deposition of the aeolian soils.

Older alluvium

The older alluvium, which is of Pleistocene age, occurs extensively in the area. This generally consists of inter-bedded, lenticular and inter-fingering deposits of clay, silt and sand, ranging in size from very fine to very coarse, with occasional gravels. Kankar, which is generally hard, compact and irregular, occurs mixed with almost all these deposits. Except for Shahdara block, where the older alluvium is sandy, it is clayey in nature.

In the Chattarpur basin, the alluvium has been derived from the weathering of the underlying and surrounding quartzites and subsequent transportation and deposition of the weathered materials by the streams emerging from encircling ridges.

Newer alluvium

The newer alluvium is recent in age and is mainly confined to the narrow, elongated flood plains of river Yamuna. These deposits are mostly grey coloured sands containing minor proportions of fines i.e. silt, clay and fresh mica. These deposits are generally characterised by the absence of kankar.

Bedrock Topography and Thickness of Alluvium

City Area

The depth to bedrock in the North Delhi area is very shallow adjacent to the Quartzite ridge on both sides and gradually deepens on either side of the ridge (Fig. 3). The depth to bedrock is within 30 m on the east side of the ridge with a gradual downward slope towards river Yamuna. In contrast, on the west of the ridge near Mall Road and Vikramaditya marg, the depth to bed rock varies from 10 to 30 m below ground level. Further west, and east of Najafgarh drain, there is a sudden increase in depth to 100 m. Near Sabzimandi, Rani Jhansi Road, Chandni Chowk and Sadar Bazar areas, the thickness of alluvium is of the order of 0 to 20 m, whereas near Roshanara Garden the thickness is about 200 m.

In the central part of the city area near Dayabasti Railway Station,

Karampura, Patel Nagar Railway Station, the bedrock occurs within 30 m depth. However slightly east of Karampura, in D.C.M. Chemical Works, the bedrock depth is more than 182 m. Such sharp and sudden changes in thickness of alluvium may be due to faulting. On the east of ridge up to New Delhi Railway Station, the thickness of alluvium is about 30 m. In the Irwin Hospital, Delhi Gate, Daryaganj, Vijay Chowk and Pusa Road areas, the depth to bedrock varies from 5 to 10 m below ground level. In Red Fort and Rajghat areas, the depth to bedrock varies between 40 and 60 m below ground level.

The thickness of alluvium is 90-100 m around India Gate and on the western bank of river Yamuna and it is about 150 m in the river Yamuna. In general, the bed rock topography is undulating in nature with several 'bumps' and depressions.

Rural Area

The thickness of alluvium varies from 297 metres to more than 300 metres in the South - Western part of the union territory of Delhi and the west side of the ridge. On the east side of the ridge in Shahdarda block the thickness of alluvium varies from 106 metres (at Khichripur) to 199 metres (at Karawal Nagar). In Alipur and Nangloi blocks, the thickness of alluvium is more than 300 metres as no borehole has as yet reached the bedrock.

In Chattarpur basin the alluvium thickness varies from a few metres near the periphery to 125.0 metres in the centre of the basin from all sides. The buried valley is considered to be very narrow.

The depths at which the bedrock is encountered during the study of a number of bore holes are given in Table 2.

Geotechnical Stratigraphy

In this section an attempt is made to present the detailed geotechnical stratigraphy of Delhi. Based on the extensive bore hole drilling and further field and laboratory testing carried out in the whole Delhi region by RITES (1994), IIT, CGWB, CSMRS, CRRI and other organisations/private consulting firms a synthesis has been made. Delhi has been divided into a grid of size 3 km by 3 km, as shown in Fig. 4. Cross-sections have been drawn along the different grid axes, and are shown in Figs. 5 to 8. These cross-sections essentially show the Delhi topography as well as the rock profile below ground level. The ground profile has been drawn based on the topographical maps of Delhi available from Survey of India (No: 53H/2/NW, 53H/2/NE, 53H/2/SE and 53H/2/SW). The soil stratigraphy below ground level is based on the various boreholes drilled by different agencies in Delhi for their

TABLE 2
Depth of Bed Rock below Ground Level, CGWB (1989)

Location	Nature of Bed Rock	Depth to Bed Rock (in Metres)
Willington Hospital	Quartzite	35.66
Lady Harding Hospital	Mica Schist	42.00
Qudasia Garden	Quartzite	23.16
Silver Jubilee Hospital	Quartzite	145.00
Irwin Hospital	Quartzite	22.86
Vikas Bhawan	Quartzite	107.30
Ranbaxy Lab., Okhla	Quartzite	39.01
Okhla Industrial Area	Quartzite	46.93
West Patel Nagar	Quartzite	63.70
Malaria Institute	Quartzite	24.38
Swiss Embassy, Diplomatic Encl.	Quartzite	33.35
Australian High Commission	Quartzite	30.78
Swantantra Bharat Hills	Quartzite	150.87
DTC Bus Depot, Vinay Nagar	Quartzite	28.95
IP College, Alipur Road	Quartzite	25.3 to 28.35
NPL, Pusa	Quartzite	8.23 to 13.41
Palarn Airport	Quartzite	16.46
Karawal Nagar	Quartzite	198.8
Kichripur	Quartzite	105.93
Madanpur Khadar	Quartzite	137.00
Mandauli	Quartzite	42.67
Dhansa	Quartzite	297.00
Pindawala Kalan	Quartzite	300.10
Ghitorni	Weathered Quartzite	64.00
Rajpur	Weathered Quartzite	90.83
Satbari Bund	Weathered Quartzite	125.00
Ghonda	Weathered Quartzite	48.76

projects. Figure 5 shows the cross-section through axis 5-5 (Fig. 4) from SW to NE of Delhi. The ground has a level difference of about 63 m with a hillock having its peak above 'K'. The bedrock, quartzite in nature, rises upto the ground level in 'L' zone. The soil profile. mainly consists of alternate layers of clay and sand with varying proportions of kankars. Figure 6 is a cross-section through axis 9-9. The ground is fairly level except for the southern ridge above 'L' and 'M', which has its peak approximately 40 m above the adjoining area. Again the bedrock reaches the ground level in the 'L' zone. The soil strata are generally clay and kankar with a thin band of

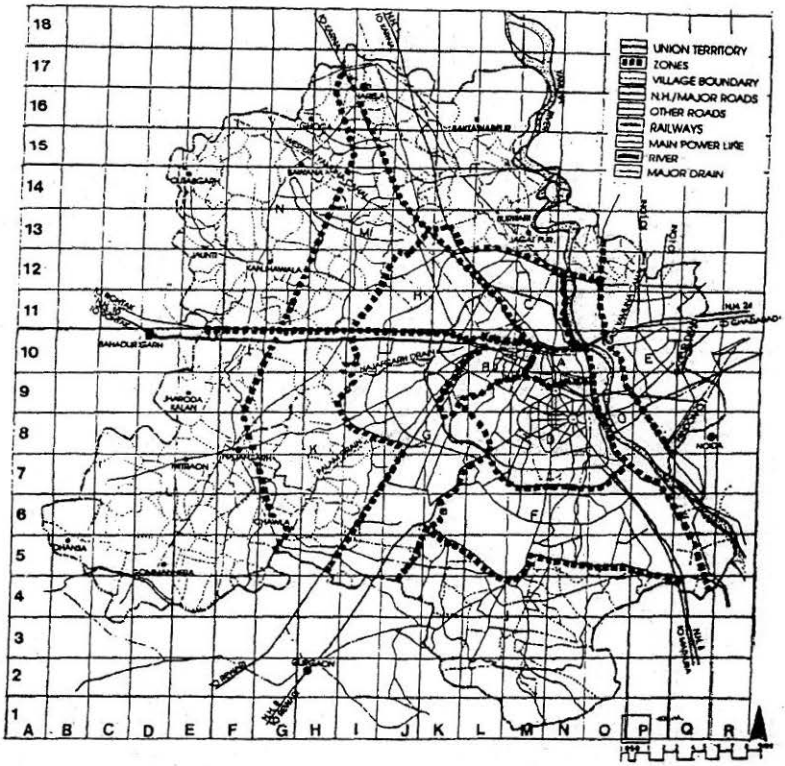

FIGURE 4 : Union Territory of Delhi (DDA, 1990), Dividing into a grid of 3 km × 3 km size

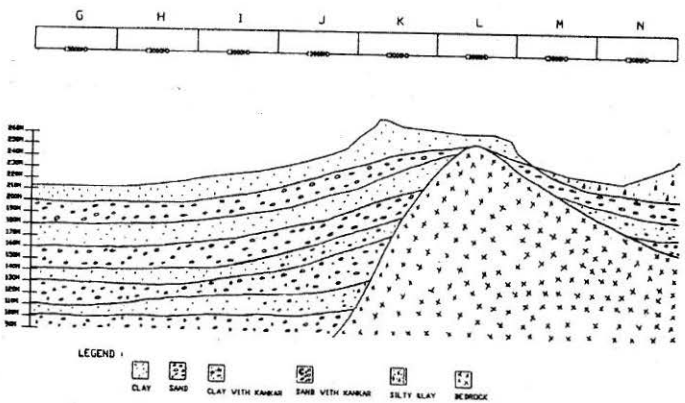

FIGURE 5 : Cross Section Through Axis 5-5

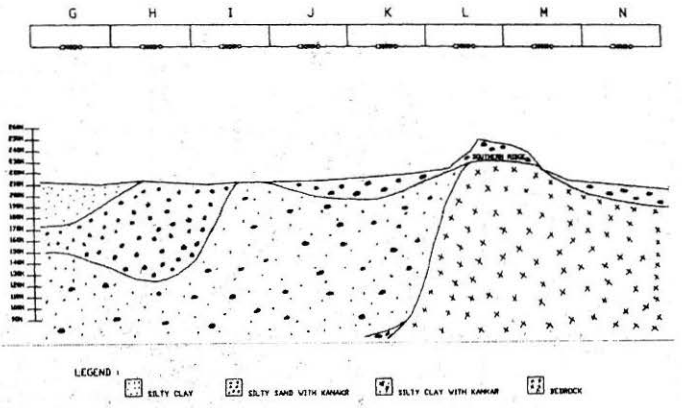

FIGURE 6 : Cross Section Through Axis 9-9

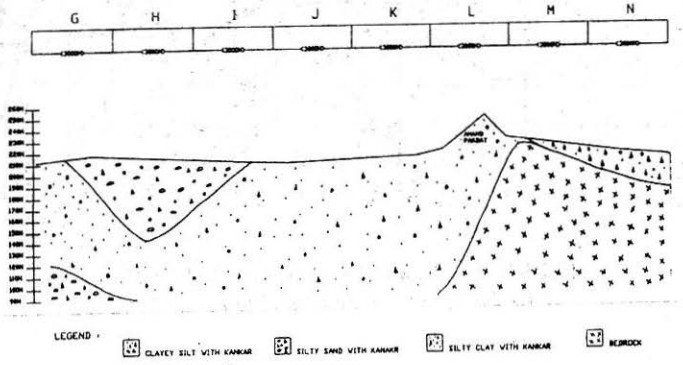

FIGURE 7 : Cross Section Through Axis 10-10

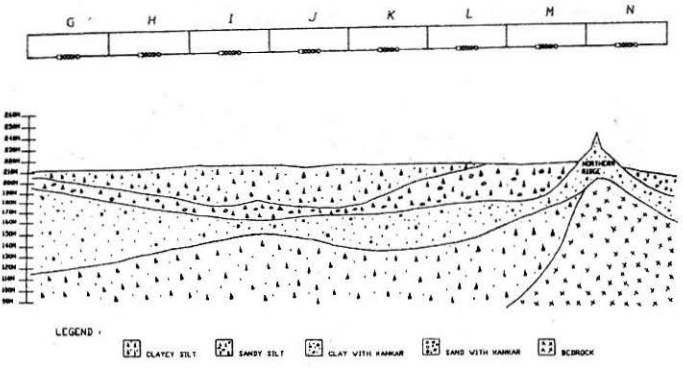

FIGURE 8 : Cross Section Through Axis 11-11

silty sand below ground level. Figure 7, a cross-section through axis 10-10, is similar to Fig. 6. Approximate plain ground with Anand Parbat above 'L' has a ground level difference of 40 m. The soil below ground level is mainly silty clay with varying proportions of kankar. Figure 8 is a cross-section through axis 11-11 towards the North East of Delhi. Fairly level ground is interrupted by a Northern ridge at 'N' having its peak about 37 m above adjoining ground. Bedrock peak shifts towards 'N' from 'L'. The soil below ground consists of clayey silt and sandy silt in alternate layers with varying thickness at different places.

Conclusions

As an essential part of the geotechnical characterisation of the Delhi area, a study has been undertaken of the engineering geology of the area. This paper summarises the results of this study. The geotechnical stratigraphy of Delhi has been described based on the cross-sections developed using the information from bore holes obtained by various institutions/organisations in India. The study shows that the Delhi area is underlain by quartzite formation, which is covered with variable thickness of recent to sub-recent alluvial sediments. The substrata are mostly sandy silt/silty sand or clayey silt.

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