CHAPTER 2: ENGINEERING GEOLOGY AND HYDROGEOLOGY

SUMMARY OF ENGINEERING GEOLOGY CONDITION IN THE URBAN AREA OF TANGSHAN

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1. Relief and Morphology

Tangshan is situated at the junction of the Yanshan Range and the North China Plain and inclines from NE to SW. The total area of the city is 811 km$^2$ including the suburb area and ranches. In the north there is tectonic erosive hilly land; while in the south the alluvium plain of the Dou River exists.

The urban area of Tangshan is about 40 km$^2$. Relief on the east bank of the Dou River and Donggangyao is comparatively high, 23.4-45.5 m above sea-level; in the south-east and south-west relief is lower 15-20 m generally with a minimum of 13.04 m. Within the city there are some hills such as Dacheng Hill, Fenghuang Hill and Jiajia Hill, etc. The Dou River meanders from north to south passing between Dacheng Hill and Jiajia Hill with a shallow bed, a small slope and low capacity of release; it has been stable in the latest period.

The urban area can be divided into the following morphologic units (Fig. 1):

1) **Erosion hill**, such as Dacheng Hill, Jiajia Hill and Fenghuang Hill. They are erosion hills with outcrop of bedrock.

2) **First-level terrace**. It runs along the banks of the Dou River in the shape of a long narrow strip and is 1-2 m higher than the valley floor. This plain is flat and it inclines from north to south with an elevation of 13.5-18.0 m.

3) **Second-level terrace**. It runs along the right bank of the Dou River, north from Jiaanzi, Ligezhuang to Dacheng Hill and the Qixin Cement Plant in the south, passing through Fujiaotun, Zhanggezhuang, and then passing Fuxing Road to the Nanchang Workshop in the west. It also runs along the left bank of the Dou River, north from Xigangyao to Dasuiwuzhuang in the east, passing through Guogezhuang to Jiajia Hill and Jiagezhuang in the south. The second-level terrace is 2-5 m higher than the first-level terrace. A gulch was developed on the boundary of the terrace south of Zhanggezhuang on the right bank of the Dou River. The water table in the right bank of the Dou river is about 4-8 m; while in the left bank is about 2-6 m.

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2. Geological Structure and Distribution Characteristics of Strata

The urban area of Tangshan city is situated at the intersection of the east wing of the NE Beiziyuan anticline and the west wing of the Kaiping syncline (Fig. 2). The strata fold strongly and invert too. A series of faults, such as F₁, F₂, F₃, F₄ and F₅, striking N30°E approximately are developed with the strata. From Xigangyao to Dacheng Hill is a NNE anticline mainly composed of Ordovician limestone and carbon and Permo-coal series strata. The geological structure is shown in Table 1 and Figs. 2-5.

Most areas of Tangshan are covered by Quaternary alluvial deposits and Ordovician limestone is exposed only in areas around Dacheng Hill and Fenghuang Hill. Shale, limestone, etc. of the Benxi formation (C₂) in the Miocene carboniferous system are also exposed around Dacheng Hill and Donggangyao.

The crust in the Tangshan area had uplifted for a long time after the Paleozoic era therefore, there were no Neogene strata of the Tertiary system of the Mesozoic and Cenozoic groups. However, rivers in the area developed extensively since the Quaternary period. Receiving a large amount of alluvial and diluvial deposits from the Dou River especially, a deposit center was formed east of Jiaanzi in the north and south of Heyuanzhuang in the south-east respectively. Large amounts of Quaternary loose deposits directly covered the Paleozoic bedrock, the thickness of which was controlled by the paleogeography obviously, and the thickness increased gradually from piedmont to the east side and west side from several meters to tens of meters, even to 300 meters. The outcrop of bedrock can be seen on Fenghuang Hill and the thickness of the Quaternary soil layer from here to the Institute of Mining and Metallurgy westward increased suddenly to above 250 m.

The Quaternary loose deposit was mainly formed by alluvium, the characteristics of which were the interbedding of cohesive soil and sandy soil and uniform deposits. In the whole urban area, except for several outcrops of bedrock, the surface layer is clayey soil of 2-8 m thickness generally, and the layer underneath is silt and fine sand of 3-15 m thickness, and in some local areas there is distribution of medium sand. Furthermore, in the vicinity of the erosive hill there is always a thin layer of weathered clay. Figure 6 is a perspective geological map of the Tangshan urban area based on drilling data. Locations of the drilling holes can be found in Fig. 2.

Depth of the water table is 4-8 m, generally, and most of the underground water is stagnant in the upper layer. In the north-east and south of the urban area the water table is more shallow, the depth is 2-4 m. However, in the north-west and in the vicinity of the foothills the water table is deeper, generally above 8 m. From a water analysis the underground water in Tangshan is not harmful to concrete.

3. Site Soils and Their Physico-Mechanical Properties

Site soils in the urban area can be classified as the following three types. Distribution is shown in Fig. 1.
(1) Type I Site Soil (bedrock)

It is distributed around Dacheng Hill, Fenhua Hill and Jiajia Hill. The bedrock is exposed directly on the ground surface, or the cover layer is less than 5 m, and its allowable bearing capacity is over 50 tons/m².

(2) Type II Site Soil

It is distributed on the second-level terrace of the Dou River, the upper layer of which is clayey soil, and the lower layer sandy soil.

The upper clayey soil is a brown color consisting of sand, mica, ferrous oxide, etc. It is plastic, slightly wet and its thickness is 3-6 m, generally. The natural volume weight is 1.8-2.0 g/cm³. The compressibility factor is 0.006-0.016 cm²/kg force, being medium or low compressive soil. The allowable bearing capacity is over 15 tons/m².

The lower sandy soil consists mainly of silt and fine sand with some medium sand locally. Particles of the soil are rather uniform, mainly of quartz and feldspar and a small amount of dark minerals. The sand is rather pure, clearly grouped, and the standard penetration blow is usually greater than 30. The natural volume weight is 1.86-2.07g/cm³ and relative humidity is over 90%. There is an intercalation of lens of clayey soil and light loam in the middle of the lower sand layer, 3-6 m in thickness. No sand boils were found in the Tangshan earthquake.

(3) Type III Site Soil

It is distributed on the first-level terrace along the two banks of the Dou River and in the old river channel. The characteristics of the soil are that it is situated in the low land region in which the water table level is shallow; and it is composed mostly of clayey soil, light loam, saturated silt and fine sand, silty soft clay, wet depressive soil; the allowable bearing capacity is low, being 7-11 tons/m² generally.

Taking Dacheng Hill as a boundary, the properties and behaviors of the types of soil in the north and in the south are different. In the north the soil can be divided into two kinds: silt and fine sand, clayey soil and light loam. The silt and fine sand is a saturated, slightly to medium dense soil, the standard penetration blow number is 9-26, specific penetration resistance is 77-100 kg/cm², deformation modulus is 135 kg/cm², the water table level is 0.7-7.8 m. The clayey soil and light loam is a plastic soil, porosity ratio is 0.43-0.81 with a maximum of 1.06. The compressibility factor is 0.007-0.031 cm²/kg, compressibility modulus is 51-216 kg-force/cm², being a low to medium compressive soil. In the meander of the Dou River in the north a layer of recent deposit is developed under the ground surface 3 m in depth (elevation 15.99 m), generally, possessing wet depressibility (relative humid depressibility factor is 0.019-0.035) and higher compressibility.

In the south the Type III soil is a silty soil developed in the vicinity of the Dou River south-east of the urban area principally. The depth of the soil is 3-5 m, generally. It is dark gray or a grayish dark color, soft and plastic and saturated, having an unpleasant odor. The thickness is 1.5-3.0 m with a pore ratio of >1.1. Its volume weight is smaller, the compressibility factor is 0.069 cm³/km, being a highly compressive soil.

(Translator: Lu Rongjian)
Table 1. Outline of strata in the urban district of Tangshan.

<table>
<thead>
<tr>
<th>Group</th>
<th>System</th>
<th>Series</th>
<th>Formation</th>
<th>Description of Rock Characteristics</th>
<th>Thickness m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td>Quaternary</td>
<td>Q</td>
<td></td>
<td>Upper layer: clay, clayey soil; middle layer: sand intercalated with clayey soil, clay; lower layer: gravel</td>
<td>10-250</td>
</tr>
<tr>
<td></td>
<td>Permian</td>
<td>p2</td>
<td>p2</td>
<td>Upper layer: mainly medium coarse sandstone of a purple and mixed color with a thin inter-calation layer of purple shale; lower layer: grayish feldspathic quart grit; basement: fine conglomerate rock</td>
<td>100-355</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p1</td>
<td>p1</td>
<td>Purple-red, gray alum clayey shale, purple-green sandy shale, interbedding of fine sandstone and medium coarse sandstone with an intercalation of coal layer</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p1</td>
<td></td>
<td>Shale, battle intercalated with coal layer</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Carboniferous</td>
<td>C1</td>
<td>c²</td>
<td>Coal and shale, sandstone</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C1</td>
<td>c¹</td>
<td>Coarse sandstone, sandy shale, k₃ limestone</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2</td>
<td>c₂</td>
<td>Limestone, alum clayey shale with a thin intercalation of coal layer</td>
<td>51</td>
</tr>
<tr>
<td>Neozoic</td>
<td>Ordovician</td>
<td>O₂</td>
<td>Majiagou</td>
<td>Gray, pure, massive limestone</td>
<td>&gt;250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₁</td>
<td>O₁</td>
<td>Argillo-calcareous limestone, shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₁</td>
<td></td>
<td>Limestone</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Geomorphic zonation, classification of site soil and Quaternary isopachs of Tangshan.
Figure 2. Geological structure of the urban area of Tangshan and distribution of drilling holes.
Figure 3. Geological section I-I’

Figure 4. Geological section A-A’

Figure 5. Geological section B - B’
Figure 6. Perspective drawing of geology in the Tangshan urban area
ENGINEERING GEOLOGICAL CONDITIONS OF THE EAST MINING DISTRICT, TANGSHAN

Liu Jingxun

The East Mining District is situated north-east of Tangshan city, 25 km from the urban area. It consists of five large coal mines in Guye and Kailuan (i.e. Zhaogezhuang, Linxi, Tangjiazhuang, Lujiatuo and Fanggezhuang mines in Fig. 1) having a history of about 100 years and is an important part of Tangshan. The area of various kinds of buildings is about 320 m². Earthquake damage in the East Mining District was serious. The seismic intensity in Guye was X and the intensity in the five coal mines was IX. There were several low intensity abnormal locations in this District, namely, the west workers' residence area in Guye, both sides of Gubei Road in Tangjiazhuang, the east site of Linxi Mine, Lujiatuo Mine and Fanggezhuang (Fig. 1).

I. Topography, Morphology and Geological Structure

(1) Topography and morphology

To the north of the East Mining District there are a series of hills arranged in an arc-shape from east to west: Weifen Hill (elevation of 173.8 m), Wan Hill (elevation of 239.2 m), Yu Hill (elevation of 249.7 m) and Chang Hill (elevation of 251 m). South of these hills near Zhaogezhuang, Tangjiazhuang, and Linxi there are a series of secondary disintegrated hills such as Bei Hill, Dong Hill, Tong Hill, Laoshi Hill, Wanghaizhi Hill and Jiguang Hill. South of Guye and Linxi there is a plain which inclines slightly to the south and the elevation of the ground surface is 30-40 m.

In view of morphology, the East Mining District can be divided into two areas: 1) an inclined piedmont hilly area with a wave-like topography in which difference of elevations is larger; and 2) an inclined piedmont plain which consists of terrain and valley flats formed by the Sha River and the Shiliu River. Topography in this area is plain with rising and falling in some locations. The alluvial deposit will be deeper when it goes south with a thickness more than 100 m south of Linxi and around Fanggezhuang (Figs. 1 and 2).

(2) Geological structure

The East Mining District is located on the southern edge of the latitudinal tectonic zone of Yanshan Mountain and the eastern edge of the Kaiping syncline, which is an unsymmetric structure with a NE-SW direction. The strata in the north inclines slightly in the vicinity of Zhaogezhuang, but in the south they become more flat in the vicinity of Linxi. The direction of the syncline axis changes from Guye to Linxi and Tangjiazhuang which is EW (Figs. 2 and 3).

Located at the axis of the Kaiping syncline, the East Mining District is subjected to compression folding. Small faults in the district are more developed. There are comparatively

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large faults, i.e. the Moshiban fault and the Yu Hill translational fault passing through the north-east of the Kaiping syncline. No activities of these faults were found in the Tangshan earthquake

II. Engineering Geology Conditions

Investigations on engineering geology had been carried out only in Tangjiazhuang, Zhaogezhuan and Lixi in the East Mining District. The results are as follows:

(1) **Tangjiazhuang**

Tangjiazhuang is composed of the Tangjiazhuang Coal Mine of Kailuan and its residence area (Figs. 1 and 4).

1. **Topography and morphology.** The area is an inclined piedmont hilly land with Wan Hill and Yu Hill in the north and Dong Hill in the middle running east to west. The gulch is comparatively developed. The residence area and the industrial area are situated on the two sides of Dong Hill respectively. The elevation of the ridge of Dong Hill is 60-73 m, that of Gubei Road (formerly called Xianyang Road) in the north slope is 48-50 m, and that of the south slope crossing to the Beijing-Shanhaiguan Railway, is 44-45 m. The topography is high in the middle and low in the south and the north. On the southern slope of Dong Hill there are individual exposed pits and waste shafts owing to mining of alumina and gangue for making bricks; on the north slope there are also several comparatively large pits owing to mining of limestone, thus, the topography is more complicated.

2. **Geological structure.** The area is located in the north wing of the Kaiping syncline (on the axis of Tangjiazhuang). The strike of rock formation is N60-85° W, inclined to the south-west with a dip of 17-40°, about 30° on the average. No large ruptured belt passes through the area but only a normal fault with a dislocation of about 200 m passes between Bei Hill and Dong Hill.

3. **Quaternary strata.** The Quaternary strata are mainly diluvial deposits and slope-wash layers on the slopes of Wan Hill, Yu Hill and Dong Hill and the low depressed plain. Depth of the strata is rather small and bedrock can be commonly found under 2-3 m or up to more than 10 m from the surface. To the north of Gubei Road and the No. 4 sub-area the strata are thicker. There are only 2-3 layers in the diluvium and slope-wash deposits which consist of clayey soil and clay. There are also clayey soil and clay lens in the local section. The lower layer is mostly clayey soil (Figs. 5 and 6). In individual sections there is a weathered bedrock eluvium layer (clay) but the thickness of the layer is small, only tens of centimeters, or up to 1-2 m and 6 m locally.

In the Waterworks north-west of the Beijiadian Railway Station the diluvial deposit found by boring is thicker, having interbeddings of sand (fine sand) and sandy clay.

Behavior and physical-mechanical properties of the site soil layers are as follows:

1) **Surface soil.** It can be divided into cultivated soil and man-filled land. The cultivated soil is 0.2-0.4 m thick, while the man-filled land is generally 0.2-0.9 m thick. In the quarry pit, small shaft, and exposed pit for alumina mining the filled materials consist of stone, cinder, mineral rock and broken rock with a thickness of 1-4 m.
2) *Clayey soil.* It is yellowish-brown or brown in color and rather uniform and slightly smooth in a sense. It contains plant roots of mica, small iron and manganese nodules, and small amounts of sand particles and gravel. It is a medium dense to dense soil, plastic to hard plastic and insect caves are found in the soil. In the upper slope the soil layer is 0.2-1.0 m thick generally, but the thickness increases at the bottom of the slope with a maximum of 5.8 m. In the individual section the soil layer is divided into two layers; the upper layer is yellowish-brown and not uniform in quality, and the lower layer is a brown color and uniform in quality. The physical-mechanical properties of clayey soil can be found in Table 1.

3) *Clay.* It is brownish-red or brown in color, uniform and slightly smooth in a sense. In the local section it contains a small amount of fine sand and broken rock. It is a medium dense to dense soil, plastic to hard plastic. The thickness of the layer varies greatly from 0.35-5.5 m up to 10 m in the individual section. The physical-mechanical properties of clay are found in Table 2.

4) *Weathered eluvium.* It covers the weathered surface of bedrock generally. It consists of mostly clay, but sometimes clayey soil. Thickness of the layer is 0.2-1.2 m and up to 6 m in some locations. In the lower part of the layer there is a lot of weathered rock debris and also nodules of ferrous oxide and iron-manganese. It is dense, hard plastic to plastic.

4. **Underground water.** Owing to the effect of drainage in coal mining at the Tangjiazhuang and Zhaogezhuang mines, the District is a drain-away district and most of the shallow underground water has been drained away. No water can be found in most of the drilling holes. In 12 drilling holes in the No. 9 and No. 11 sub-areas water can be found only in the upper layer, the elevation of which is 41.9-52.5 m; the distribution of underground water is irregular.

The above-mentioned engineering geological conditions of Tangjiazhuang are rather good. The Quaternary soil layer is thin mostly consisting of clayey soil and clay. Allowable bearing capacity is above 20 ton/m² generally. The water-table is deep, and, during the Tangshan earthquake, no liquefaction of sand occurred in the Tangjiazhuang area. Except for the existing depressed caves and waste shafts in the individual locations, the natural foundation is good. The soil belongs to Type I site soil.

**(2) Zhaogezhuang**

Zhaogezhuang is located north-west of the East Mining District and consists the Kailuan Zhaogezhuang Coal Mine and its residence area (Fig. 7).

1. **Topography and morphology.** Zhaogezhuang is situated in a mountain valley. The Shiliu River and its branch pass through the area from north to south and meet in the south-east. The Shiliu River is a seasonal river generally having a small amount of flow and no water can be found in it during the dry season. The maximum amount of flow reached 54m³/sec (in 1959). The topography is high in the north and west and low in the south and east. Elevation of this area is 47.61-59.17 m. The area is cut by the Shiliu River.
The area is an inclined piedmont hilly land formed by diluvium and alluvium with a small part of slope-wash (in the north-west) or residual deposit (in the south). In the bench of the Shiliu River in the south-east there is a V-shaped gulch.

2. Geological structure. Zhaogezhuang is situated in the north wing of the Kaiping syncline. The strike of the strata is N65°-75°W inclining to the south-west with a dip of 50°-60°. There are no ruptured belts or faults passing through.

Most parts of the area are located on the bedrock layer of the Cambrian system and Ordovician system. Except for the exposed layers of the Cambrian period and the Ordovician period in Chang Hill, Baiyun Hill and Yu Hill, the other parts are covered by the Quaternary alluvium and diluvium (Figs. 8-10). In the south there exists a Mesocarboniferous (C2), Neocarboniferous (C3) and Paleopermian series (P1).

3. Quaternary strata. Based on the engineering geology investigation data of the south part (Nos. 10, 11, 14, 15 sub-areas in Fig. 7) and the central part (No. 3 sub-area) of Zhaojiazhuang, the Quaternary strata are described from the upper to lower layers as follows:

1) Man-filled land. Thickness of the filled land in the residence area is 0.3-2 m.

2) Clayey soil. It is brownish-yellow or dark brown in color and uneven in quality. It contains a small amount of ferrous oxide and nodules of iron and manganese. It can be divided into two layers, upper and lower.

The upper layer of clayey soil is lighter, the plastic index of which is mostly 11-14. It has large pores with a diameter under 2 mm and a small amount of roots or ferrous oxide. Thickness of the layer is 1.45-10 m, generally 3-5 m.

The lower layer is mostly of a brownish-yellow and dark yellow color with some light gray color. It is comparatively dense having only a small amount of small pores containing mica and nodules of iron and manganese. The plastic index is mostly 15-17. It is wet plastic or hard plastic, and is a medium compressive soil. The layer is thick so most of the drilling holes did not pass through this layer.

When the layer of clayey soil is thin the above-mentioned two layers always combine as one layer. Clayey soil is the main bearing layer, the physical-mechanical properties of which can be found in Table 3.

3) Clay. It is mainly formed by diluvium and alluvium of a yellowish-brown or dark brown color containing oxides and their nodules. Sometimes sand particles can be found in the clay with some clayey soil lens (Fig. 9). The soil is uneven, wet to slightly wet, and hard plastic. The position of the soil layer is not fixed. The layer is thick so that most of the drilling holes did not pass through the layer. To the south and to the west of the No. 10 sub-area in Fig. 7 there is a layer of weathered residual clay containing debris of weathered limestone dark brown or dark red in color. It is a kind of highly plastic clay formed by slope-wash. The layer rises and falls with the underlying bedrock. As for the whole area, the clay layer is not generally found. The physical-mechanical properties of clay in Zhaogezhuang can be seen in Table 4.
4) **Crushed stone.** It is mainly composed of debris of quartz sandstone, limestone and breccia, with a rhombus or sub-rhombus shape and is filled with sand particles and clay. This layer is of mixed color and is medium dense. It distributes mostly in layers with a thickness of 0.8-1.1 m, generally. Some of the crushed stone is mixed in the clayey soil layer in lenses.

5) **Breccia.** It is mainly composed of crystalline rock debris. The particle size is generally 4-6 mm with a maximum of 20 mm. It contains a small amount of crushed stone and adhesive soil, medium dense. It appears as layers or lens, not distributed widely. The thickness is 1.5 m in general.

Furthermore, south of Zhaogezhuang (No. 10 and No. 14 sub-areas in Fig. 7) there were drilling holes passing through to the bedrock. The rocks observed are Paleocarboniferous sandstone or shale. Sandstone is yellow in color while shale is dark gray. The rocks were mostly strongly weathered with the appearance of crushed plates.

4. **Underground water.** Owing to the effects of coal mining the water-table is lowered to a great depth. Based on the long-term data observed by the Geological Division north of the Zhaogezhuang Coal Mine (No. 9 sub-area in Fig. 7), the highest water-table during 1961-1979 was 20 m beneath the ground surface for nearly 20 years, and under 50 m in general. During the exploration no underground water was seen in the drilling holes but a small amount of stagnant water was found in the upper layer of some holes. The depth was 5 m under the ground surface.

In summary, the bedrock of most residence areas in Zhaogezhuang is rather shallow. No ruptured belts or large faults are found. The water-table is deep, thus, the engineering geological condition is good. Also, there exists an effect area of mining south of Zhaogezhuang (Fig. 7).

(3) **Linxi**

Linxi is situated in the middle of the East Mining District on the south side of the Beijing-Shanhaiguan Railway where the district government was located before the quake. There are also the Kailuan Linxi Coal Mine, the Kailuan Machine Repairing Plant and other enterprises affiliated with the municipal and district governments besides the residence area (Figs. 1 and 11).

1. **Topography and morphology.** This area belongs to the inclined piedmont hilly land with Jiguan Hill to the west, Baima Hill and Wanhaishi Hill to the northeast, and the elevation of this area is 50-65 m. The Sha River flows to the southeast. Relief along the bank is lower with an elevation of 31.3-37.9 m. Topography of this area is high to the north and low to the south and the west part is slightly higher than the east, and as a whole, the topography is that of a plain.

2. **Geological structure.** Linxi is situated south of the Kaiping syncline and the orientation of the rock layer is N60-70°E, sloping to the NW with a dip of 30-35° (Fig. 3). There are two normal faults, F₁ and F₂, in the south-east (Fig. 11) but no evidence of movement was found after the earthquake.
The Jiguan, Baima and Wanhaishi Hills north of the area are regions of outcrop of aluminia "A" layer, which is the boundary between the Neopermian series P1, the Tangjiazhuang group and the Paleopermian series P2. In the middle of the area, P1, the Paleocarboniferous series (C1) and the Miocarboniferous series (C2) distribute. The excavated area is shown in Fig. 11. The south part (No. 15, 16 and 17 sub-areas in Fig. 11) and most of the Kailuan Machine Repairing Plant are both located on the Mesordovician series (Majiagou formation) limestone bedrock. However, the middle and the southern portions of the area are covered by Quaternary alluvium.

3. Quaternary strata. Based on the drilling data of Linxi, the Quaternary strata are as follows (from the upper layer to the lower layer):

1) *Man-filled land.* It is composed of cinder, rubbish, broken brick and adhesive soil. The soil is ununiform and loose in structure. The thickness of the layer is 0.3-2.4 m.

2) *Clayey soil.* It is brownish-yellow with a large-sized pore structure containing nodules of iron and manganese, unsettled when wet, plastic. Thickness of the layer is 1.1-7.7 m and widely distributed. Its standard penetration blow count number is 8-30 with an average of 16.

3) *Clay.* It is light brownish-red to brownish-red in color containing nodules of iron and manganese as well as small amounts of breccia and is plastic. The buried depth and the thickness of the layer vary. The thickness of the layer is 0.8-7.5 m (some drilling holes did not pass through the layer). The standard penetration blow of the layer is 12-42 with a 19 average. It belongs to old adhesive soil (Fig. 12).

4) *Light loam and medium sand.* The light loam is yellowish-brown in color, wet and plastic. The standard penetration blow count is 7-11. The medium sand is also yellowish-brown in color, feldspar-quartz in quality, medium dense, the standard penetration blow of which is 11-17. Total thickness of this layer is 1.7-3 m, and the elevation of the bottom layer is 30.5-33.4 m. The layer does not occur generally, but only distributes on the sections of the No. 11, 12 and 13 drilling holes based on the existing data (Figs. 11 and 13). It is inferred that south of these drilling holes there also exist light loam and medium sand layers in the vicinity of the bench of the Sha River.

5) *Clayey soil.* It is light gray or yellowish-brown in color, a layered structure and a cohesive soil formed by weathered shale and sandstone a part of which becomes sandy soil. The bottom of this layer transfers gradually to strongly weathered sandstone. Standard penetration blow of the layer is 50. It belongs to compacted residual soil.

The above 2) to 4) layers are of alluvium and diluvium formation. The physical-mechanical properties of each layer are summarized in Table 5.

4. Underground water. Most of the Linxi residence areas are located within the range of the excavated area of the Linxi Coal Mine (Fig. 11), thus, the underground water is not easy to preserve and ground water was not found in most of the drilling holes. Ground water was only found in the No. 11, 12 and 14 drilling holes south of Linxi outside the excavated area. The stable ground water is located 1-2.3 m beneath the ground surface and its elevation is 33.10-34.10 m. The water flows from the northeast to the southwest in accordance with the
slope of the ground. Based on the water analysis results the underground water is not harmful to concrete.

In summary, the topography of Linxi is essentially that of a plain. From the investigation data, the soil in Linxi can be taken as natural foundation, except for the man-filled land. The engineering geological conditions are rather good but the following unfavorable factors still exist.

1. A saturated sand layer of the Sha River exists between the No. 11 and No. 13 holes in the south margin of Linxi (Fig. 11). This sand layer was liquefied during the Tangshan earthquake. In addition, sand blows also occurred southwest of the No. 11 hole, i.e. east of the Kailuan Machine Repairing Plant.

2. Before the shock most of the residence areas in Linxi, i.e. the No. 1, 2, 4, 5, 7-13 sub-areas, are wholly or partly located upon the excavated area based on the information obtained from the Linxi Coal Mine (Fig. 11). The excavated area was formed around 1920 when all shallow coal layers had been excavated away. The area is 30-40 m beneath the ground surface, which suffered natural subsidence for about 60 years.

3. Based on the investigation on the No. 15 and No. 16 sub-areas by the Linxi Coal Mine, it was found that karst of Ordovician limestone exists south of Linxi.

(Translator: Lu Rongjian)
### Table 1. Physical-mechanical properties of clayey soil of Tangjiazhuang in the East Mining District

<table>
<thead>
<tr>
<th>No. of Sub-Areas</th>
<th>Depth (m)</th>
<th>Max. Depth (m)</th>
<th>Water Content (%)</th>
<th>Vol. Wt. (g/cm³)</th>
<th>Porosity</th>
<th>Saturatio n (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index</th>
<th>Liquidity Index</th>
<th>Compressibility Modulus (Kg-/cm²)</th>
<th>Compressibility Factor (cm²/Kg-f)</th>
<th>Allowable Bearing Capacity (ton-f/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2, 3</td>
<td>0.5-1.5</td>
<td>5.80</td>
<td>21.6</td>
<td>1.89</td>
<td>0.76</td>
<td>78</td>
<td>34</td>
<td>17</td>
<td>0.27</td>
<td>61</td>
<td>0.035</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>0.25-1.70</td>
<td>3.40</td>
<td>22.1</td>
<td>1.88</td>
<td>0.778</td>
<td>78</td>
<td></td>
<td>15</td>
<td>0.26</td>
<td>74</td>
<td>0.037</td>
<td>20-25</td>
</tr>
<tr>
<td>7, 8</td>
<td>1.0-3.5</td>
<td>5.40</td>
<td>23.4</td>
<td>2.0</td>
<td>0.681</td>
<td>92</td>
<td>33</td>
<td>15</td>
<td>0.40</td>
<td>87</td>
<td>0.023</td>
<td>23</td>
</tr>
<tr>
<td>upper layer of 9, 11 in the south</td>
<td>0.6-2.0</td>
<td>4.00</td>
<td>22.0</td>
<td>1.93</td>
<td>0.720</td>
<td>84</td>
<td>32</td>
<td>15</td>
<td>0.31</td>
<td>83</td>
<td>0.022</td>
<td>23</td>
</tr>
<tr>
<td>lower layer of 9, 11 in the south</td>
<td>0.5-3.40</td>
<td>&gt;4.00</td>
<td>28.2</td>
<td>1.89</td>
<td>0.834</td>
<td>92</td>
<td>30</td>
<td>13</td>
<td>0.82</td>
<td>45</td>
<td>0.040</td>
<td>17</td>
</tr>
</tbody>
</table>

Remark: Values in the table are average in the sub-areas.

### Table 2. Physical-mechanical properties of clay of Tangshan in the East Mining District

<table>
<thead>
<tr>
<th>No. of Sub-Areas</th>
<th>Depth (m)</th>
<th>Max. Depth (m)</th>
<th>Water Content (%)</th>
<th>Vol. Wt. (g/cm³)</th>
<th>Porosity</th>
<th>Saturatio n (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index</th>
<th>Liquidity Index</th>
<th>Compressibility Modulus (Kg-/cm²)</th>
<th>Compressibility Factor (cm²/Kg-f)</th>
<th>Allowable Bearing Capacity (ton-f/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2, 3</td>
<td>1.0-3.0</td>
<td>&gt;5.7</td>
<td>24.6</td>
<td>1.90</td>
<td>0.803</td>
<td>84</td>
<td>43</td>
<td>20</td>
<td>0.16</td>
<td>93</td>
<td>0.023</td>
<td>23</td>
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<tr>
<td>6</td>
<td>0.35-0.75</td>
<td>1.85</td>
<td>23.9</td>
<td>1.85</td>
<td>0.834</td>
<td>78</td>
<td></td>
<td>21</td>
<td>0.36</td>
<td>36</td>
<td>0.078</td>
<td>20-25</td>
</tr>
<tr>
<td>7, 8</td>
<td>1.0-2.0</td>
<td>4.00</td>
<td>24.8</td>
<td>1.99</td>
<td>0.718</td>
<td>94</td>
<td>45</td>
<td>22</td>
<td>0.18</td>
<td>128</td>
<td>0.015</td>
<td>23</td>
</tr>
<tr>
<td>9, 11 in the south</td>
<td>0.9-1.6</td>
<td>&gt;3.20</td>
<td>22.3</td>
<td>1.84</td>
<td>0.768</td>
<td>79</td>
<td></td>
<td>19</td>
<td>86</td>
<td>0.024</td>
<td>20-25</td>
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Remark: Values in the table are average in the sub-area.
Table 3. Physical-mechanical properties of clayey soil in Zhaogezhuang, the East Mining District.

<table>
<thead>
<tr>
<th>No. of Sub-Areas</th>
<th>Statistical Value</th>
<th>Water Content</th>
<th>Porosity</th>
<th>Fluidity Index</th>
<th>Compressibility Factor</th>
<th>Standard Penetration Blow</th>
<th>Allowable Bearing Capacity</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 3</td>
<td>No. of samples</td>
<td>26</td>
<td>26</td>
<td>26</td>
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<td>19-19</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>20-30</td>
<td>0.58-0.91</td>
<td>0.06-0.93</td>
<td>0.006-0.041</td>
<td></td>
<td></td>
<td>Investigation report of Shenyang Exploring Co.</td>
</tr>
<tr>
<td></td>
<td>Ave. value</td>
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<td>0.72</td>
<td>0.30</td>
<td>0.015</td>
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<td>No. 11</td>
<td>No. of samples</td>
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<td>87</td>
<td>87</td>
<td>87</td>
<td>15</td>
<td>19-34</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>14-31</td>
<td>0.63-0.77</td>
<td>0.041</td>
<td>0.007-0.021</td>
<td></td>
<td></td>
<td>Investigation report of Shenyang Exploring Co.</td>
</tr>
<tr>
<td></td>
<td>Ave. value</td>
<td>22</td>
<td>0.69</td>
<td>0.22</td>
<td>0.014</td>
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<tr>
<td>No. 15</td>
<td>No. of samples</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>25</td>
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<tr>
<td></td>
<td>Limit value</td>
<td>12.2-28.8</td>
<td>0.51-0.902</td>
<td>1.0-0.53</td>
<td>0.008-0.045</td>
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<td>Investigation report of Institute of Exploring technique, Academy of Building Research</td>
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<tr>
<td></td>
<td>Ave. value</td>
<td>20.2</td>
<td>0.668</td>
<td>0.22</td>
<td>0.019</td>
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<tr>
<td>No. 10</td>
<td>No. of samples</td>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>24</td>
<td>25</td>
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<tr>
<td></td>
<td>Limit value</td>
<td>19.1-28.9</td>
<td>0.592-0.932</td>
<td>0.09-0.61</td>
<td>0.013-0.37</td>
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<tr>
<td></td>
<td>Ave. value</td>
<td>23.4</td>
<td>0.714</td>
<td>0.31</td>
<td>0.023</td>
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<tr>
<td>No. 14 (upper layer of clayey soil)</td>
<td>No. of samples</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>15.5-28.7</td>
<td>0.578-0.871</td>
<td>&lt;0-0.98</td>
<td>0.09-0.044</td>
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<td>Investigation report of Institute of Exploring technique, Academy of Building Research</td>
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<tr>
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<td>Ave. value</td>
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<td>0.32</td>
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<tr>
<td>No. 14 (lower layer of clayey soil)</td>
<td>No. of samples</td>
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<td>40</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>19.7-30.2</td>
<td>0.620-0.944</td>
<td>0.11-0.62</td>
<td>0.011-0.048</td>
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<td></td>
<td>Investigation report of Institute of Exploring technique, Academy of Building Research</td>
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<tr>
<td></td>
<td>Ave. value</td>
<td>24.7</td>
<td>0.739</td>
<td>0.37</td>
<td>0.022</td>
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Remarks Units of the values in the Table are the same as Table 1.
<table>
<thead>
<tr>
<th>No. of Sub-Areas</th>
<th>Statistical Value</th>
<th>Water Content</th>
<th>Porosity</th>
<th>Fluidity Index</th>
<th>Compressibility Factor</th>
<th>Allowable Bearing Capacity</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital of Zhaogezhuang Mine</td>
<td>No. of samples</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>29</td>
<td>Investigation report, Shenyang Exploring Co.</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>23-27</td>
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<td>Ave. value</td>
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<td>0.009</td>
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</tr>
<tr>
<td>No. 10</td>
<td>No. of samples</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>25</td>
<td>Investigating report of the Institute of Exploring technique, Academy of Building Research</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>21.5-43.9</td>
<td>0.655-1.32</td>
<td>0.03-0.50</td>
<td>0.009-0.029</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Ave. value</td>
<td>25.3</td>
<td>0.77</td>
<td>0.21</td>
<td>0.017</td>
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</tr>
<tr>
<td>NO. 15</td>
<td>No. of samples</td>
<td>7</td>
<td>7</td>
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<td>20</td>
<td>Investigating report of the Institute of Exploring technique, Academy of Building Research</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>22.4-31.6</td>
<td>0.664-1.002</td>
<td>0.19-0.56</td>
<td>0.015-0.032</td>
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</tr>
<tr>
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<td>0.025</td>
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</tbody>
</table>

Remark: Units of the values in the Table are the same as Table 1.

<table>
<thead>
<tr>
<th>Name of Soil Layer</th>
<th>Statistical Value</th>
<th>Water Content</th>
<th>Porosity</th>
<th>Liquid Limit</th>
<th>Fluidity Index</th>
<th>Plastic Index</th>
<th>Compressibility Factor</th>
<th>Compressibility Modulus</th>
<th>Allowable Bearing Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey soil</td>
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<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<td>54-156</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>20-26</td>
<td>0.668-0.761</td>
<td>31-35</td>
<td>0.07-0.54</td>
<td>13-17</td>
<td>0.011-0.031</td>
<td>94.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ave. value</td>
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<td>0.701</td>
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<td>0.30</td>
<td>15</td>
<td>0.021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>No. of samples</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>83-228</td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>22-30</td>
<td>0.671-0.878</td>
<td>38-46</td>
<td>0.11-0.41</td>
<td>17-23</td>
<td>0.05-0.021</td>
<td>156</td>
<td></td>
</tr>
<tr>
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<td>Ave. value</td>
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<td>0.23</td>
<td>19</td>
<td>0.011</td>
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</tr>
<tr>
<td>Light loam</td>
<td>No. of samples</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limit value</td>
<td>18</td>
<td>0.583</td>
<td>23</td>
<td>0.50</td>
<td>10</td>
<td>0.012</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ave. value</td>
<td>18</td>
<td>0.583</td>
<td>23</td>
<td>0.50</td>
<td>10</td>
<td>0.012</td>
<td>127</td>
<td></td>
</tr>
</tbody>
</table>

Remark: Units of the values in the Table are the same as Table 1.
Figure 1. Intensity Map of the East Mining Area, Tangshan
Figure 2. Geological Condition and Quarternary Isopachs of the East Mining Area (after the Hebei Provincial No. 1 Coal Investigation Team).

Figure 3. Geological section A - A' from Tangjiazhuang to Linxi.
1. Neocambrian series, Changshan and Fengshan formation;
2. Paleordovician series, Yeli formation;
3. Paleordovician series, Liangjiashan formation;
4. Mesoordovician series, Majiagou formation;
5. Mesoecarboniferous series (Benxi series);
6. Neocarboniferous series (Taiyuan series);
7. Paleopermian series strata;
8. Neopermian series strata;
9. Normal fault;
10. Inferred translated fault;
11. Syncline axis;
12. Drilling hole and its no.;
13. Cross-section line and its no.;
14. Type of site soil (Type II);
15. Bedrock boundary;
16. No. of microzone;
17. Land for industrial use.

Figure 4. Comprehensive geological map of Tangjiazhuang in the East Coal Mining District
Figure 5. Geological section I-I' of Tangjiazhuang (Legend is the same as in Figure 3).

Figure 6. Geological cross-section II-II', Tangjiazhuang (Legend in the figure, same as Figure 3).
Figure 7. Comprehensive geological map of Zhaogezhuang, East Mining District.

Figure 8. Geological cross-section III-III', Zhaogezhuang.
Figure 9. Geological cross-section IV-IV', Zhaogezhuang
(Legend of the figure is the same as in Figure 8).

Figure 10. Geological cross-section V-V', Zhaogezhuang
(Legend in the Figure is the same as in Figure 8).
1. Meso- and Neocarboniferous series
2. Mesoordovician series, Majiagou formation
3. Neopermian series
4. Normal fault
5. Boundary of bedrock
6. Boundary of engineering geology
7. Empty excavated area
8. Drilling hole and its no.
10. No. of sub-area in planning
11. River bench
12. Piedmont slope

Figure 11. Comprehensive geological map of Linxi, East Mining District.
Figure 12. Geological cross-section VI-VI', Linxi (Legend same as in Figure 8).

Figure 13. Geological cross-section VII-VII', Linxi.
CHARACTERISTICS OF HYDROGEOLOGY IN TANGSHAN DISTRICT

Fu Ronglan, Zheng Yuanshen and Chen Jicai*

The Tangshan District is located south of the Yanshan mountainous land and north of the Jidong Plain and the relief inclines from north to south. The strike of the Yanshan mountain runs east to west and its height above sea-level is 200-600 m. It is cut by the longitudinal rivers and has a series of basin and wide valleys. The Jidong Plain inclines slightly towards the Bohai Sea with a slope of 0.5-2% and sea-level of 2-40 m and it is composed of piedmont inclined plains and coastal plains.

In the District the summer and autumn are hot and rainy while the spring and winter are dry, cold and windy. The average annual rainfall in the District is 746.8 mm and 80% of the rainfall is concentrated in June-September. Some spots on the south slope of Yanshan mountain are rainy. Junhua-Qianxi and Funing-Changli are two rainy zones while Tangshan and Fengran are centers of small rainfall.

The water system in the District is quite developed. There are the Luan River, the Qinglong River, the Huanxiang River, the Dou River and the Shahe River. The Luan River is the longest with plenty of water and the drainage area is 44,945 km² with an average annual run-off of 4,630 million m³ of which about 72.4% is in the flood period.

1 Hydrogeological Characteristics in the Mountainous District

According to the geologic conditions, physical properties, and hydraulic features, the underground water in the District can be classified into four types: 1) pore water in loose rock; 2) karst crevice water in carbonate rock; 3) pore and crevice water in clastic rock; and 4) crevice water in metamorphic rock and magmatic rock.

(1) Pore water in loose rock

Pore water is found in Quaternary loose rock deposits mainly in the wide valleys of the mountains between Qianan and Lulong and in the basins of Junhua, Junzizhen, etc. and in the alluvium and alluvial-diluvial deposits in the river basins of the mountainous district.

The wide mountain valleys between Qianan and Lulong are mainly composed of alluvial-diluvial deposits of the Luan River, the Qinglong River and the Shahe River, and the diluvial deposits of piedmont gully with a thickness of 20-100 m. Underground water is mainly pore water. The first-level terrace of the basin is rich in water and the water-table is shallow. The second and third-level terraces are less rich in water and the water-table is deep. The water bearing bed is mainly composed of sand, egg-stone and gravel layers, the thickness of which is generally above ten meters. The unit discharge of wells in the vicinity of Qianan and Lulong is 30-50 m³/hr m and in the south towards the northwest of Luanxian is 10-30 m³/hr m. Depth of the underground water is controlled by the topography and it is 3-10 m in the south and up to 15 m and more in the north and near the boundary of the valley.

* Provincial Geology Bureau, Hebei
In the center of the Junhua basin, there is a low hilly zone nearly east to west, dividing the basin into the north river plain and the south river plain. Quaternary in the north river plain is generally 150-200 m in thickness, with a maximum above 350 m, and the thickness reduces near the boundary of the basin and the basement is metaphorous rock; Quaternary in the south river plain is generally 100-150 m in thickness, with a maximum above 200 m and the basement is Sinian sub-system. The underground water depth in the north and the south river plain is generally 2-5 m and 5-7 m respectively and that in the boundary of the basin is up to 15-35 m, while that in the gully between the mountains is 3-5 m. In the center and west of the north and the south river plain the unit discharge of the well is 30-50 m$^3$/hr m and 10-30 m$^3$/hr m in the vicinity, and less than 10 m$^3$/hr m in the boundary of the basin.

Quaternary in the Junzizhen basin is 10-100 m in thickness and the thickness increases from the boundary to the center of the basin. Thickness of the water bearing bed is generally 2-20 m, basically consisting of medium and fine sand, however, there are some sand and gravels in the river basin. The unit discharge of the well is 5-10 m$^3$/hr m with a water-table of 2-15 m.

(2) *Karst crevice water in carbonate rock*

It includes the water bearing bed of Ordovician, Cambrian and Sinian limestone and dolomite. Underground water reserves are found in the karst crevice in the mountainous district south of Junhua, Qianxi (exposed type), and Yutian to Fengran of the piedmont inclined plain (buried type) and scattering around Shangying to the north of Taitouying, the Liu River basin and northeast of Luanxian. It is located at the front arc of the w-shaped type of structure as well as the reflecting arc and the composite syncline of Jixian. The crevasse of the structure develops with less filled materials, the composition of which are clayey soil, clay or crushed stone. The karst caves develop mostly along faults, crevasses and beddings. There are many natural outcrops of underground water but the water content of which is not homogeneous. The flow of springs is mostly 1-50 lit/sec with a minimum of 0.1-1 lit/sec to a maximum of 489 lit/sec; most of the large springs are 100-150 lit/sec. Large springs or a group of springs are usually found in the vicinity of the fault zone. A flowing zone of springs has been formed east of Zhenzizh en. The underground water flows on the ground surface, e.g. around Yutian, due to an impermeable layer or blockage of the underground water flow.

(3) *Pore crevice water in clastic rock*

It includes the water-bearing bed of quartz sandstone, conglomerate rock, sandstone and volcanic rock in the Sinian sub-group such as the limestone system, Permian system, Jurassic system and Tertiary system. The underground water deposits are in the crevice pores. The crevasses are developed but not generally and are filled with a small amount of rock debris and sand. The exposed springs are limited by the tectonic crevasse and rock properties. The springs are mostly seen in the areas where quartz sandstone, conglomerate rock in the Sinian sub-group, the great wall system and the Tertiary system occur. The discharge of springs is mostly 0.1-0.6 lit/sec with individual 3.2 lit/sec. No springs are found in layers of the Carboniferous, Permian and Jurassic system.
(4) Crevice water in metamorphic rock and magmatic rock

It includes the water-bearing layers in gneissose of the Archaelian group, magmatized granite or granite mainly of the Yanshan era, distributed over the extensive uplift area between Malanyu to Shanhaiguan. In the metamorphic rock area, owing to the effect of long-term weathering, regional weathered fractures of a network shape are formed with a depth of weathering 5-30 m generally. The number of fractures per unit area and their width reduce with depth. The underground water mainly deposits in the weathered fractures forming potential crevice water while in the local area the tectonic vascular crevice water is formed from the effect of tectonics. In the granite area, owing to the hardness and weathering resistance of the rock, the weathered fractures are not developed however, in the contact area of the tectonic fracture development zone and magma intruded metamorphic rock of the local area, tectonic vascular crevice water often exists. This kind of underground water has a lot of natural outcrops with small discharge, but the seasonal variation of the underground water is small. Discharge of the spring is less than 1 lit/sec while that of the tectonic crevice water is 1-30 lit/sec.

Underground water in the basement rock of the mountainous area is directly supplied by atmospheric precipitation and also by condensed water forming rivers in the mountainous area and drains in the form of springs. The Tangshan District is mostly located in the supplemental area and run-off area of underground water with good run-off conditions. The quality of the underground water is excellent. Its mineralization is under 0.2-0.3 g/lit, generally. It is mainly of a HCO$_3$-Ca (or Ca-Mg) type while in the metamorphic rock and magmatic rock areas it is mainly of a HCO$_3$-Ca-Na type.

2 Hydrogeological Characteristics in the Plain District

(1) Hydrogeological characteristics of the loose rocks of the Quaternary system

The area of this District is 10457 km$^2$. The thickness of the Cenozoic strata north of the Laiyuan-Laoting fault is less than 500 m and greater than 1000 m in the south and up to 2600-2800 m in the vicinity of Nanbao.

1. Classification of the Quaternary strata

Based on the data of exploration the lower boundary of the Quaternary system becomes deeper from north to south (Fig. 1), and the strata structure buried under 300-350 m is rather dense in the form of semi-consolidation to consolidation. The classification of the Quaternary strata is as follows:

- Paleo-Pleistocene series ($Q_1$). The lower boundary of the series in the piedmont plain was 80-350 m three million years ago and 500-560 m in the coastal plain.

- Mio-Pleistocene series ($Q_2$). The lower plate was 40-280 m below in the piedmont plain and 260-300 m in the coastal plain 1.7 million years ago.

- Neo-Pleistocene series ($Q_3$). Depth of the lower plate was 30-140 m.
Holocene series (Q₄). It is mainly a gray and yellowish-gray color and is mostly loam, fine sand of a clayey soil type and silty layer. A layer of silt is widely distributed on the bottom. The buried depth of the lower plate is several meters to 30 m. The piedmont is locally lost.

Since the Pleistocene era ingression had occurred four times in the coastal plain on the north shore of the Bohai Bay (Fig. 2). In the first ingression (corresponding to the last period of Mio-Pleistocene), the buried depth of the upper plate of the marine deposit was 150-170 m and that of the lower plate was 160-180 m generally with a thickness of 1-20 m; in the second ingression (corresponding to the middle period of the Neo-Pleistocene), the regression area became small with drawing from Changli and Laoting in the north-east. The ingression area in the south-west was similar to the first ingression. The buried depth of the upper plate of the marine deposit was 70-100 m and that of the lower plate was 80-120 m with a thickness of 2-4 m generally and a maximum of 40 m. The area of the third ingression reduced (corresponding to the last period of the Neo-Pleistocene), and the buried depth of the upper plate of the marine bed was 25-50 m while that of the lower plate was 30-70 m with a thickness of 4-12 m, generally. The area of the fourth ingression (corresponding to the Holocene) was the smallest with the north-west part extending to Houluoshan, Linnan-Chuang of Yutian County and Xinjuntun of Fengren County. The buried depth of the upper plate of the marine bed was 0.5-24 m, and that of the lower plate was 6-30 m.

2. Lithological characteristics of the water-bearing bed

Hydrogeological conditions are controlled by tectonics, topography, geomorphology, and the capability of water carrying materials. The region can be divided into two hydrogeological areas: the piedmont inclined plain and the coastal plain with a boundary around Nanshunzhuang-Baigezhuang-Matouying.

Distribution of the water-bearing beds from the piedmont to the coast are depicted in Fig 3. The water-bearing beds gradually become tongue-shaped from a fan-shape. Lithology of the water-bearing beds gradually transits from sandy gravel, tabby, medium coarse sand, medium sand to medium fine sand, fine sand and silt. The number of water-bearing beds increases from Leizhuang to Nanbao and the thickness of individual beds is 3-8 m in general, with a maximum of 20-30 m and a minimum of 1-2 m or less than 1 m. The thickness of the Quaternary water-bearing beds is 100-250 m in the piedmont inclined plain, i.e. 40-60% of the total thickness and 100-150 m approximately in the coastal plain, i.e. 20-30% of the total thickness. The lithology of the water-bearing beds in the piedmont inclined plain includes coarse particles with large pores, high permeability, and rich in water while that in the coastal plain is inferior in water.

Flow of water in the water-bearing bed is 15-30 m³/hr m in the alluvial fan area. The unit discharge of water in the well at the top of the alluvial fan is greater than 80 m³/hr m while in the piedmont inclined plain and other areas the flow is 30-50 and 50-80 m³/hr m respectively. Flow in most of the coastal plain area is 10-30 m³/hr m and less than 5 m³/hr m in the coastal area between the river mouth of Luanhe and Laoyujian owing to the undevelopment of the water-bearing beds.
In Yutian, west of Tangshan, the buried depth of artesian water is generally under 100 m and the water head is 0.6-11.52 m above ground level; in the coastal plain artesian water occurs generally at a depth of 270 m under the ground and the water head is 0.76-5.64 m above ground level.

3. Chemical characteristics of the underground water

The boundary between freshwater and saltwater in the mineralization of underground water is 2 g/lit. Nanshunzhuang, Baigezhuang Ranch (No. 6 Branch), Gelouduo of Laoting County, north of Xiaoguanying and Qiaotou and west of Liutaizhuang to Wangguanying of Changli County are all freshwater areas. To the south and east of these areas are saltwater areas. The chemical types of water in the freshwater area are HCO₃-Ca-Mg and HCO₃-Ca-Na and there are also fan areas and areas with poor underground run-off conditions. Mineralization of the water is 0.2-0.8 g/lit.

The buried depth of the top of the saltwater is controlled by the development of a shallow freshwater layer, and the depth becomes larger from east to west and is generally 10-30 m. The buried depth at the bottom is 40 m to the west and becomes large to the east and also to the south and is 110-250 m in the south-east part of the District. Mineralization of the saltwater is 3.5-63.4 g/lit and the water is of a Cl-Na type. The formation of saltwater is mainly due to the invasion of sea water.

4. Supply, run-off and drainage conditions of underground water

Underground water in the piedmont inclined plain is mainly supplied by atmospheric precipitation and the permeating water from the surface. In addition, the ground water in the basin at the south slope of the Yanshan Mountain, the crevice water in the basement rock, and the karst water in the crevice of the Quaternary underlying carbonate rock at the edge of the piedmont area exist. In the deeper part of the plain there exists comparatively thick clayey soil and clay layers. Therefore, the supply from atmospheric precipitation is weakened and only in the axial part of the alluvial fan is the supply easily provided. Underground water is drained through flow to the coastal plain and by evaporation.

The shallow layer water in the coastal plain is mainly supplied by atmospheric precipitation, surface water in canals and pools, and backwash of drainage water, etc. It is drained mainly in the form of exploitation and evaporation. The deep layer water in the coastal plain is mainly supplied by the upstream flow either laterally or vertically. Because the water-bearing beds are extending from the piedmont to the Bohai Sea, the rock particles become smaller but continuity of particles is not as good as in the piedmont inclined plain. Lateral flow of the underground water is slow.

5. Dynamic characteristics of underground water

(1) Dynamic characteristics of local underground water

The underground water is classified as two types of water, i.e. shallow layer water and deep layer water. From the piedmont to the coast the underground water, with a depth not more than 30-40 m, is called shallow layer water, and that with a depth more than 30-40 m is called deep layer water. Depth of measurement is limited in the range of 40-200 m.
Water for industrial and agricultural use and rainfall affect directly or indirectly the dynamic characteristics of underground water. The dynamic characteristics of shallow layer water and deep layer water are now described respectively as follows:

**Dynamic characteristics of shallow layer water.** The flow direction of underground water is consistent with that of rivers. The depth of the underground water is generally 2-4 m however, it is 6-10 m under the railway from Luanxian to Fengnan; 15 m in the vicinity of Longwangmiao (the water source of Tangshan, forming a funnel), and less than 1 m generally in the coastal region.

Dynamic characteristics of underground water are influenced by the rainfall and seasonal artificial exploitation, thus, variation of the underground water level is very obvious (see Fig. 4). Figure 5 shows depths and contours of the water-table in the Tangshan plain area before the 1976 earthquake (in low water table period).

**Dynamic characteristics of deep layer water.** The flow direction of underground water is the same as the shallow layer water. The water head level is greater than 8 m under the surface in the piedmont from Luanxian to Tangshan with a maximum of 14 m. The water head is 2-4 m in the central plain and generally less than 1 m along the coast south-east of Laoting. The artesian water occurs in the individual area (Laoyujian), with a water head of 0.5 m above the surface. Underground water varies periodically and obviously. Dynamic variation in most areas is consistent with the shallow layer water. Variation of the annual water level is 8 m in the funnel area and along the coast it is less than 1 m. Variation of mineralization is not obvious with an annual variation of 20 mg/lit. In recent years the underground water level along the coast has a tendency of decreasing annually.

(2) **Dynamic characteristics of underground water funnel in Longwangmiao, Tangshan**

With the development of industry and agriculture in Tangshan, use of underground water has been increasing with the result that the demand is greater than the supply so the water table decreases annually. For example, in the fifties the underground water level was 1-2 m, in the sixties it was 4-10 m, then in the seventies the level decreased continuously forming a funnel around Longwangmiao and Bujiazhuang in 1975. Details of funnels are described as follows:

**Underground water funnel.** The upper funnel area in the low water level period is 52 km² in area including Beiziyuan, Ligezhuang, Fengshan Village, Liutun, with Longwangmiao as a center. Elevation of the water level in the center is 10.28 m and that in the exterior of the funnel is 17.58 m. The area of the funnel in the high water level period is 20.8 km². In the low water level period elevation of the water level in the center is 13.68 m, 3.4 m higher than that in the low water level period it is 40% as much. Owing to the exploitation over many years most of the wells in the district have been dry or semi-dry.

**Deep layer water funnel.** In the low water level period of 1975, the funnel formed by the water level contour of 6 m was situated in the Longwangmiao funnel area with Bujiazhuang as the center.

**Base rock underground water funnel.** Owing to pumping of a large amount of underground water, the water level in the underlying baserock has been affected for a long time. A
lot of funnels of various sizes are formed at present with the pumping stations as centers. By connecting these funnels a large elliptical funnel is formed along the edge of the Kaiping syncline. The depth of the funnels and their effect on the other areas are different.

(2) **Hydrogeological conditions of buried karst water in carbonate rock of Ordovician system**

Ordovician limestone of the Quaternary system in the piedmont inclined plain is located mainly in some N-E syncline basins from Fengnan to Yutian forming basically small independent hydrogeological units. Within the centers of the basins there are also comparatively thick coal layers covering the basins. Underground water is supplied by atmospheric precipitation, permeating surface water, and water in the baserock in the mountainous area. It is drained mainly by underground run-off toward the lower stream. The area directly covered by the Quaternary system is rich in water but the area covered by the Carboniferous system on the edge of the basin has less water especially at the center of the basin. The underground water is of a HCO₃-Ca-Mg type generally, with mineralization less than 1 g/lit. Quality of the water at the center of the basin is poor and the variation of the water level is 2-5 m generally.

(Translator: Lu Rongjian)
1. Ingression area in the 4th period
2. Ingression area in the 3rd period
3. Ingression area in the 2nd period
4. Ingression area in the 1st period

Figure 2. Ingression areas in the Quaternary era for four periods in the Tangshan Plain District

1. Boundary between the Cenozoic group and basement rock
2. Boundary of the Quaternary system layers
3. Boundary of the water-bearing beds
4. Bottom boundary of salt water
5. Paleo-Pleistocene
6. Mio-Pleistocene
7. Neo-Pleistocene
8. Holocene series
9. Gravel
10. Coarse sand
11. Medium, medium fine and fine sand
12. Fine sand, silt.

Figure 3. Cross-section of the water-bearing beds from Leizhuang to Nanbao in the Tangshan Plain District.
Figure 4. Relationship between precipitation and underground water level of shallow layers in 1976 in Liuzhuangzi, Chengguang Commune, Fengren County.

Figure 5. Depth of the underground water and contours of water table in the low water table period, 1976, in the Tangshan Plain District.
OUTLINE OF ENGINEERING GEOLOGICAL CONDITIONS IN TIANJIN CITY

Shi Zhengquan*

1. Geological Structure

Tianjin is situated northeast of the depression zone of the Neocathaysian North China Plain. In the deep part of the plain a series of NNE upheavals and bending depressions alternatively arranged form the basement of the plain.

Faults in the basement can be divided into two groups approximately: NNE compression-torsional faults and NWW extension-torsional faults. Details of the main basement faults and structural systems are stated in Table 1 and Fig. 1.

No obvious evidence of activity of the basement faults were found during the Tangshan earthquake.

The deposit thickness of the Cenozoic in this district varies. Thickness of the upheaval in the basement is 800-1500 m while that in the bending depression is 2000-3000 m approximately. At present, no conclusion is made for the classification of the Quaternary system and its lower limit. It is believed that the lower limit depth of the Paleo-Pleistocene series is 500 m and that of the Holocene series is about 40 m.

2. Foundation Soil

The strata within the effective depth of the foundation of the industrial and civil buildings in Tianjin (below 30 m) belong to the Neo-Pleistocene and Holocene and their deposit layers are as follows (in sequence): lower continental layer (early deposits from the Neo-Pleistocene to Holocene); middle marine layer (deposits of mid-Holocene); and upper continental layer (late Holocene deposits). In some areas there are recent accumulated deposits or man-filled land (Fig. 2).

Engineering geological characteristics of the foundation soil are described as follows:

(1) Filled land (Q₄₅ ml)

Land formation in Tianjin was rather late. The original land form of most areas is a lagoon depression in the coastal plain. Pits, pools, depressions, etc. are scattered in this district. Historically, filled lands were made early in 1234 with the construction of the city and continued up to the present. The thickness of filled land is generally 2-5 m and reduces gradually from the old town to the suburb. The thickness of filled land in the old town is 4-5 m (11 m in local areas), but approximately 1 m on the edge of the urban area.

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Relief of the New Harbor area in Tanggu is lower than the urban area with filled lands widespread having an elevation of +4.6-+2.0 m. Ordinary buildings in Tanggu were built on the filled land layer.

The filled lands in Tianjin include alluvial filled lands, mix filled lands, and pure filled lands.

**Alluvial filled land.** Alluvium filled land is mainly composed of marine or river mud and sand alluvium. In the urban area alluvium filling began in 1906. Before 1948 the filling area was limited to the south bank of the Hai River with 14 million cubic meters of filled alluvium. Later, the filling area was mainly on the north bank of the Hai River with 2.5 million cubic meters of filled materials.

The plastic index of alluvial filled land in the urban area is mostly greater than 3. The particles in the filled land are comparatively uniform. The natural water content is 24.32%-36.42% with a pore ratio of 0.77 and a liquidity index of 0.50-1.14. The formation period of alluvial filled land was late. The filled land is unconsolidated and its standard penetration blow count is generally lower than 5. As the original land of this area is mostly in the form of pit, pool and depression, the drainage condition is therefore poor and the filled land is mostly in a saturated and soft plastic to a flow plastic state. During strong earthquakes soil liquefaction would occur in some of these areas.

The distribution area of alluvium filled land in the urban area is up to 10.8 km², i.e., 6.2% of the urban area.

Alluvial filled land of the Tanggu New Harbor area is mainly of a silty cohesive soil distributing mostly in the east.

**Mixed filled land.** It includes furnace ash, litter, and debris, etc. It is usually of a gray and dark color but the color is variable mainly depending on its components.

Furnace ash filled land mainly distributes inside the city such as Qiandezhuang, the Children's Hospital, the General Hospital, New Goods Yard and Nankai Ground, etc. The allowable bearing load of the filled land is 3-7 ton-force/m². After treatment, this kind of filled land can be used as foundation for ordinary buildings.

Litter filled land should not be used as foundation. It must be removed or substituted by other suitable soils before use.

Debris filled land distributes mainly in the northeast and southeast corners of the old town area, the maximum thickness of which is above 5 m. It should not be used as foundation generally.

Mixed filled land in the urban area distributes mainly in the old town and its vicinity with an area of 21.9 km², i.e., 12.6% of the total urban area.

Mixed filled land in the Tanggu New Harbor area consists mainly of building debris distributing mainly in the west.
Pure filled land. It distributes mostly on the marginal area of the city, with an area of 53.9 km², i.e. 31% of the total urban area. The pure filled land is of a cohesive soil, the natural water content of which is 25-35%, a pore ratio of 0.80-1.10, and a liquidity index of 0.34-1.00. Uncompacted pure filled land is comparatively loose and not suitable for use as foundation, but those for which the filled period has exceeded ten years and thus has been compacted can be used as foundation for ordinary buildings.

Pure filled land in the Tanggu New Harbor area is mainly of a cohesive soil, distributing mostly in the west.

(2) Recent deposits (Q₄ᵃˡ)

Recent deposits in the urban area distribute mostly in the accumulation areas of the modern river, the ancient river channels, and the abandoned river channels in the bend of the river. Recent deposits belong to riverbed facies and valley flat facies. The lithology is mainly of light loam of gray and brown color. If the content of organic materials in the light loam is higher the color will become dark gray. The bottom plate elevation of the recent deposit is approximately −5-8 m in the urban area.

The formation history of recent deposits in the urban area is comparatively short, only several decades to a hundred years. For example, in the Liulin area south of the urban area the recent deposit was buried on the abandoned channel of the bend of the Hai River in 1902-1904. As the formation period is short, the land is poorly consolidated, and is in a soft plastic to a flow plastic state.

The recently deposited light loam in Tianjin would be liquefied seriously in a strong earthquake.

The liquefied light loam and the non-liquefied light loam are different, obviously, in their particle sizes. The silt content of the liquefied light loam is higher while the clay content is lower. The statistics of particle size analysis for 252 undisturbed samples obtained in the urban area is listed in Table 2.

Thickness of the recent deposit in the urban area is 8-12 m in general, with a maximum of 15 m.

(3) Upper continental deposit layer (Q₄ᵃˡ)

The upper continental deposit layer is also called the upper yellowish-brown layer and is mainly composed of alluviums from the Hai River system and the Yellow River. In local areas, such as to the north of Beichuang and Yixingfu and Nandan in the north suburb, there is lake deposit.

The average thickness of the upper continental layers is approximately 4.5-5.5 m. The thickness gradually decreases from west to east and south. In the western area the thickness may exceed 7 m while in the eastern and southern areas only 2-3 m. The layer vanishes towards the coast of the Bohai Sea.

The upper continental layer consists mainly of yellowish-brown and grayish-brown clayey soil and clay. Along the banks of the Hai River (from the Golden Steel Bridge to the
(4) Middle marine deposit layer ($Q^2_4 m$)

The middle marine deposit layer is also called the middle gray layer. The ingression area on the west coast of the Bohai Bay in the Holocene post-glacial period was comparatively extensive and deposits of stable shallow marine facies and coastal facies (including lagoon facies) were generally laid down in Tianjin. The particles of the marine layer are comparatively fine and their fractions uniform. Several fossils of marine Mollusca such as Helan mussel, Guanhualan clam, etc. are found in the layer.

Elevation of the bottom plate of the marine layer in the urban area is $-10$ to $-14$ m. Thickness of the layer is approximately 9-10 m, gradually increasing from west to east. The thickness in the eastern coastal area, such as Tanggu New Harbor, is up to 17 m.

Based on the exploration data, the marine layer is mainly of a gray to dark gray clayey soil and light loam intercalated usually with silt, clay, silty soil or a thin layer of humus soil. Drainage conditions of the marine layer is poor, thus, the layer is in a soft plastic to a flow plastic state having medium to high compressibility and the allowable bearing load of which is generally lower than 10 ton/m$^2$. Up to the present the marine layer has not been used as foundation in the urban area.

Based on the C$^{14}$ measurement by the Tianjin Geology Bureau, the age of the marine deposit in the urban area is approximately 8000 years. For example, the C$^{14}$ age of the marine layer in Beining Park is $8265\pm120$ years (the depth of the layer is 16.89 m), and that in Chentangzhuang is $8825\pm140$ years (the depth of the layer is 13.49 m).

The main physical-mechanical properties of marine layers in the urban area are shown in Table 4.

Formation history of the marine layer in the Tanggu New Harbor area is comparatively short, only several hundred years to about 2000 years. The layer is of uncompacted and unconsolidated soil, its natural water content is greater than the liquid limit, and the pore ratio is greater than 1. It is a silty cohesive soil or silt with an allowable bearing load of only 4-8 ton-force/m$^2$.

The marine layer in the Tanggu New Harbor area is classified by the Exploration and Design Institute of the No. 1 Navigation Bureau, Communication Department, as the following two sub-layers.
**Upper sub-layer.** The upper sub-layer is about 3.5-7.0 m in thickness. It is mainly composed of a grayish-brown silty clayey soil intercalated with a thin layer of silt and light loam belonging to the deposit of the shallow water region. It has a short formation period of only 300-400 years. It is rich in organic materials and in a flow plastic to flowing state. Its plasticity is higher and the degree of saturation is above 95% with a medium sensitivity.

**Lower sub-layer.** The lower upper sub-layer is mainly composed of grayish-brown silty clay belonging to deposit of the deep water region. It is in a plastic to soft plastic state with a high sensitivity.

Physical-mechanical properties of the upper and the lower sub-layer are different (see Table 5).

It was found in the damage survey of the Tangshan earthquake that in some places on the east coast, such as in the vicinity of Shangulin in the Dagang area, the saturated light loam thin layer (or lens) at the top of the marine layer was liquefied under the strong earthquake effect. The marine silty clay layer or silty soil layer in the Tanggu New Harbor area depressed greatly during the earthquake. For example, a 3-story apartment building in Wanghailou in the New Harbor settled up to 25 cm.

**(5) Lower continental deposit layer (Q_{3}^{1-4} al)**

The lower continental deposit layer is also called the lower yellow layer and was formed by the deposits during the last period of the upper Neo-Pleistocene to the initial period of the Holocene. Formation of the layer was in the Tali glaciation, in which the sea level generally decreased while the Tianjin area uplifted and accepted a large amount of river alluvium, forming a continental layer extensively distributed.

Based on the exploration data of the urban area the lower continental layer is mainly of a yellow light loam containing calcium kern and fresh water Mollusca fossils. The layer is well consolidated with an allowable bearing load which is 20-30 ton-force/m² in general, and a standard penetration blow of 40-50, and is a non-liquefied layer. The layer is also a good bearing layer for pile foundation, the physical-mechanical properties of which are shown in Table 6.

It is shown by the exploration data that a transition layer from marine to continental facies, with a thickness of approximately 0.5 m, exists at the top of the lower continental layer. The transition layer is composed of a marsh deposit of a grayish-black to grayish-white color. Under the depth of 25 m there is also a fine sand layer, the allowable bearing load of which is greater than that of the upper cohesive soil.

The lower continental layer in the Tanggu New Harbor area has the characteristics of a delta deposit.

Based on the data of the Design Institute of the No. 1 Navigation Bureau, the lower continental layer in the Tanggu New Harbor area can be divided into two sub-layers.

**Upper sub-layer.** The upper sub-layer is about 5-6 m in thickness (elevation at the bottom of the sub-layer is 18-21 m). It is mainly of a yellowish-brown clayey soil belonging
to normally compacted soil in a plastic to soft plastic state with a standard penetration blow of 6-8. In many places there is a medium dense layer of light loam or silt at the top of the sub-layer (elevation of −14-15 m).

**Lower sub-layer.** The lower sub-layer is mainly composed of a yellowish-brown silt usually intercalated with cohesive lens. The silt layer is in a medium dense state, the standard penetration blow of which is up to 15-50. It is a good bearing layer for pile foundation.

The main physical-mechanical properties of the two sub-layers are shown in Table 7.

**Region I.** There are recent deposits of old riverbed and valley of 6-11 m thick (up to 14 m individually) on the top containing mainly clayey soil, light loam, and silt. The structure of the soil is loose, the allowable bearing load of the soil is generally 8-10 ton-force/m², and underlying is the marine accumulated layer. During a strong earthquake all areas with light loam and silt will be liquefied quite easily and in other areas no liquefaction would occur, yet seismic depression, lateral drift, and ground fissures parallel to the old river channel would have occurred.

**Region II.** There are alluvial deposits of 2-3 m thick on the top mainly containing light loam, clayey soil and clay. The soil is loose with a bearing load of 8-20 ton-force/m² and during a strong earthquake the light loam would be liquefied and seismic depression and ground fissures would easily occur in other areas.

**Region III.** The upper alluvial filled land or mixed filled land is under 1 m thick, and the pure filled land is 1-3 m thick. In the underlying alluvial layer there are light loam, silt or silty soil layers with a single layer thickness of less than 1 m and an accumulated thickness of more than 2 m and a bearing load of 10-15 ton-force/m². During a strong earthquake the light loam or silt intercalations would be liquefied but would not spout on the surface; in the area with silty soil intercalation seismic depression would occur.

**Region IV.** The thickness of the upper mixed filled land is generally 2-4 m. On the bottom of the region there are continental alluvial layers and marine accumulation layers. The bearing load of the layer is 6-8 ton-force/m². The mixed filled land is extremely inhomogeneous, and during a strong earthquake differential settlement would easily occur especially on the edge of the pool, pit, and trough, and slipping would easily occur toward the center.

**Region V.** There is no alluvial filled land and mixed filled land on the top (the thickness is less than 1 m). Thickness of the pure filled land is greater than 1 m. The underlying consists of an alluvial layer formed by clayey soil and clay, and a marine accumulated layer with light loam and silt intercalations locally, but thickness of a single layer is less than 1 m, and accumulated thickness is less than 2 m. Its bearing load is 10-15 ton-force/m² and its earthquake resistance is good.

3. **Underground Water**

Ground water levels of the urban area and the Tanggu New Harbor area are different.
The ground water level of the urban area is shallower, only 1-2 m in most parts of the area. Based on the observation data in 1962-1965, the high level period is from August to September annually and the low level period is from April to May. Annual variation of the ground water level is about 0.8 m in average. The buried depth of confined water is greater than 15 m approximately, and that of the water head is 5-10 m.

The ground water in the Tanggu New Harbor area can be classified as the following three types:

1. **Upper stagnant water.** It is supplied by the surface water, and the water level varies seasonally. The stable level is +2.5-+3.8 m.

2. **Ground water.** The water-bearing layer is a silty cohesive soil of low plasticity. There is a hydraulic relationship between ground water and river water. The stable water level is +1.0-+2.5 m.

3. **Confined water.** The water-bearing bed is buried at a level of −14.0 to −15.0 m, or in the silt and fine sand layer under −20 m. The stable water level is ± 0.0-1.0 m. It is supplied by sea water.

In summary, the ground water level of Tianjin is generally high. This is not only a main effect for soil liquefaction but also for unfavorable geological effects such as occurrence of drift sand, underground corrosion, or pit spout, etc.

### 4. Classification of Site Soils

Owing to the limit of accumulated data, it is difficult to describe the types of site soils in the whole city in detail. At present, an outline of types of site soils can only be given based on the related regulations in the Chinese Seismic Code for Industrial and Civil Buildings (TJ11-78).

Type III site soil specified in the above code mainly includes the following three soil conditions:

1. **Recent deposits of old river bed facies and old valley flat facies.** They are mainly composed of saturated light loam with loose structure, and the underlying is a silty cohesive soil layer of marine deposits mainly distributing on both banks of the Hai River south of the urban area and along the banks of the south and north canal. Earthquake resistance of this type of soil is very poor, and the soil is not suitable for the use of foundation.

2. **Alluvial filled land by mud and sand from the Hai River.** It is a recently man-filled land with loose structure and poor consolidation. The underlying is a continental cohesive soil distributing mostly on both banks of the Hai River south of the urban area.

3. **Mixed filled land.** It includes construction debris, furnace ash, and litter, etc. complicated in composition and inhomogeneous in property. The thickness varies greatly. It is located in the old town area and its vicinity.

Except for the above soils, the other continental layers which can be used as building foundations, can be classified as Type II site soil in the code.
In summary, the site soils in the urban area are more complicated. Within the effective depth the layer is often of a multi-structural soil. It is proposed to be evaluated comprehensively for the use of building foundation.

(Translator: Lu Rongjian)
Table 1. The main basement faults.

<table>
<thead>
<tr>
<th>Group</th>
<th>Name of Faults</th>
<th>Location</th>
<th>Strike</th>
<th>Length (km)</th>
<th>Drop (m)</th>
<th>Depth of Fractured Point (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NNE compression-torsional reversal faults</td>
<td>North Tianjin Fault</td>
<td>Passing through the urban area</td>
<td>NE</td>
<td>44</td>
<td>30-60</td>
<td>500-1500</td>
</tr>
<tr>
<td></td>
<td>West Baitangkou Fault</td>
<td>Extending to the urban area from the south</td>
<td>NNE</td>
<td>28</td>
<td>100-200</td>
<td>360-800</td>
</tr>
<tr>
<td></td>
<td>Cangdong Fault</td>
<td>From Jinghai to the south suburb</td>
<td>NE</td>
<td>180</td>
<td>60-200</td>
<td>600-1000</td>
</tr>
<tr>
<td>NWW extension-torsional normal fault</td>
<td>Chenglinzhuan Fault</td>
<td>North bank of the Hai River (east suburb to north of the urban area)</td>
<td>NNE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haihe Fault</td>
<td>Extending along the Hai River, from Dagu to south suburb</td>
<td>EW</td>
<td>40-80</td>
<td></td>
<td>1320-1600</td>
</tr>
</tbody>
</table>

Table 2. Statistics of particle size of recent deposits.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Particle Size (mm)</th>
<th>Ave. Diameter of Particles (mm)</th>
<th>Inhomogeneity Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25-0.1</td>
<td>0.1-0.05</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Unliquefied</td>
<td>3.0/12.0-1.5</td>
<td>66.4/76.7-53.7</td>
<td>0.063/0.072-0.054</td>
</tr>
<tr>
<td>Liquefied</td>
<td>5.3/21.7-2.7</td>
<td>59.2/71.0-42.0</td>
<td>0.060/0.079-0.046</td>
</tr>
</tbody>
</table>

Note: Data in the table denotes: Average value (maximum average value).

Table 3. Physical-mechanical properties of the upper continental layer.

<table>
<thead>
<tr>
<th>Index Type of Soil</th>
<th>Water Content (%)</th>
<th>Natural Volume Wt (g/cm³)</th>
<th>Pore Ratio</th>
<th>Liquidity Index</th>
<th>Compressibility Factor (cm²/kg·f)</th>
<th>Compressibility Modulus (kg·f/cm²)</th>
<th>Allowable Bearing Load (ton·f/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>27.40-39.64</td>
<td>1.64-1.92</td>
<td>0.81-1.15</td>
<td>0.25-0.75</td>
<td>0.028-0.059</td>
<td>31.9-54.4</td>
<td>10-17</td>
</tr>
<tr>
<td>Clayey soil</td>
<td>24.78-32.46</td>
<td>1.64-2.03</td>
<td>0.74-0.94</td>
<td>0.46-1.14</td>
<td>0.015-0.041</td>
<td>72.24-79.75</td>
<td>13-17</td>
</tr>
<tr>
<td>Light loam</td>
<td>26.56-31.52</td>
<td>1.76-2.00</td>
<td>0.77-0.90</td>
<td>0.99-1.87</td>
<td>0.012-0.022</td>
<td>88.98-153.98</td>
<td>15-20</td>
</tr>
</tbody>
</table>
### Table 4. Physical-mechanical properties of marine layers in the urban area.

<table>
<thead>
<tr>
<th>Index Type of Soil</th>
<th>Water Content (%)</th>
<th>Natural Volume Wt. (g/cm³)</th>
<th>Pore Ratio</th>
<th>Liquidity Index</th>
<th>Compressibility Factor (cm²/kg.f.)</th>
<th>Compressibility Modulus (kg.f/cm²)</th>
<th>Allowable Bearing Load (ton·f/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>31.52-44.43</td>
<td>1.73-1.97</td>
<td>0.89-1.25</td>
<td>0.43-1.05</td>
<td>0.03-0.064</td>
<td>36.13-53.62</td>
<td>8-16</td>
</tr>
<tr>
<td>Clayey soil</td>
<td>27.54-34.10</td>
<td>1.63-2.03</td>
<td>0.78-0.96</td>
<td>0.77-1.41</td>
<td>0.016-0.042</td>
<td>53.00-113.00</td>
<td>9-15</td>
</tr>
<tr>
<td>Light loam</td>
<td>26.41-32.47</td>
<td>1.80-2.03</td>
<td>0.76-0.94</td>
<td>0.93-2.09</td>
<td>0.009-0.04</td>
<td>79.07-143.07</td>
<td>12-19</td>
</tr>
</tbody>
</table>

### Table 5. Physical-mechanical properties of the marine layer in Tanggu New Harbor.

<table>
<thead>
<tr>
<th>Index Type of Soil</th>
<th>Water Content (%)</th>
<th>Natural Volume Wt. (g/cm³)</th>
<th>Pore Ratio</th>
<th>Liquidity Index</th>
<th>Compressibility Factor (cm²/kg.f.)</th>
<th>Compressibility Modulus (kg.f/cm²)</th>
<th>Allowable Bearing Load (ton·f/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper sub-layer</td>
<td>33.9-54.6</td>
<td>1.68-1.83</td>
<td>0.99-1.56</td>
<td>1.06-1.50</td>
<td>0.042-0.033</td>
<td>19.0-50.0</td>
<td>5.5-8.0</td>
</tr>
<tr>
<td>(clayey soil, silt)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower sub-layer</td>
<td>42.5-49.0</td>
<td>1.73-1.78</td>
<td>1.20-1.36</td>
<td>1.11-1.28</td>
<td>0.083-0.119</td>
<td>20.028.0</td>
<td></td>
</tr>
<tr>
<td>(silty clay)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6. Physical-mechanical properties of the lower continental layer in the urban area.

<table>
<thead>
<tr>
<th>Index Type of Soil</th>
<th>Water Content (%)</th>
<th>Natural Volume Wt. (g/cm³)</th>
<th>Pore Ratio</th>
<th>Liquidity Index</th>
<th>Compressibility Factor (cm²/kg.f.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>27.52-34.80</td>
<td>1.87-1.96</td>
<td>0.64-0.86</td>
<td>0.37-0.60</td>
<td>0.019-0.031</td>
</tr>
<tr>
<td>Clayey soil</td>
<td>21.14-28.76</td>
<td>1.93-1.98</td>
<td>0.60-0.80</td>
<td>0.42-0.94</td>
<td></td>
</tr>
<tr>
<td>Light loam</td>
<td>22.50-25.00</td>
<td>1.92-2.08</td>
<td>0.60-0.70</td>
<td>0.60-1.10</td>
<td>0.01-0.025</td>
</tr>
</tbody>
</table>

### Table 7. Physical-mechanical properties of the lower continental layer in Tanggu New Harbor.

<table>
<thead>
<tr>
<th>Index Soil Layer</th>
<th>Water Content (%)</th>
<th>Natural Volume Wt. (g/cm³)</th>
<th>Pore Ratio</th>
<th>Fluidity Index</th>
<th>Compressibility Factor (cm²/kg.f.)</th>
<th>Compressibility Modulus (kg.f/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper sub-layer</td>
<td>26.1-28.6</td>
<td>1.95-1.97</td>
<td>0.74-0.78</td>
<td>0.74-0.88</td>
<td>0.028-0.030</td>
<td>67.0-78.0</td>
</tr>
<tr>
<td>(clayey soil)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower sub-layer</td>
<td>19.2</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td>200-300</td>
</tr>
<tr>
<td>(silty clay)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(for reference)</td>
</tr>
</tbody>
</table>
Figure 1. Outline of geological structure of Tianjin.

Figure 2. Geological profile between Tianjin city and Tanggu New Harbor.
Figure 3. Distribution of foundation soil in Tianjin urban area.
HYDROGEOLOGICAL CHARACTERISTICS
OF THE PLAIN AREA IN TIANJIN

Guo Weijun*

Tianjin City is situated south of Yanshan Mountain on the coast of the Bohai Sea and adjacent to the Tangshan District in the east and the extensive Hebei plain in the south-west. The relief of Tianjin is high in the north and low in the south, sloping gradually. North of the Beijing-Shanhaiguan Highway is a low hilly area; from the south to Qingdianwa is an alluvium and diluvium plain area with a slow slope; most of the Baodi and Wuqing areas are alluvial and lake deposit plains; Ninghe, suburbs of Tianjin, Jinghai and south of Baodi are alluvial, lake and marine deposit plains; along the Bohai Sea is the coastal plain (Fig. 1).

1. Hydrographic Conditions

The two large river systems flowing through the Tianjin area are:

The Ji Canal system. The Zhou River in the north connects with the Ju River in the northwest to form the Ji Canal which flows to the south and connects with the Huanxiang, the Chaobaixin and the Qinglongwan rivers and then flows into the sea at Beitang.

The Hai River system. The Hai River which connects with the north canal, the Yongding River, the Daqing River, the Ziya River, the Heilonggang River, and the south canal, enters the sea at Tanggu (Fig. 2).

The climate in the Tianjin area is a monsoon type continental climate in the temperate zone. It is cold and dry in the winter and rare in rainfall, but hot and rainy in the summer. The rainfall in the summer is about 76% of the total amount in a year (the amount of rainfall is greatest in July and August with a total of 65% of the annual rainfall). Except for the Hai River and the Ziya River, which have water all year, the others are all seasonal rivers.

Owing to the flat relief in the alluvial plain, concentration of rainfall, floods, frequent change of river channels, and disastrous showers, many water-logged depressions were formed between large rivers such as Qingdianwa, Taihewa, Huangzhuangwa and Liziuguwa, etc., from north to south. In the coastal plain, owing to the accumulation of rivers, regression of the sea, lagoons, water-logged depressions and shallow lakes were also formed such as Qilihai, Tuanpowa, and Beidagang, etc. (Fig 2). Pits, pools, ponds and lakes also exist everywhere. From previous surveys, 45 water pits of various sizes were found in the urban area, mostly distributing along both banks of the Hai River. Most of these pits are now filled by soil and mixed materials with a thickness of 3-4 m and a maximum depth of 10 m approximately. It is also found that in the urban area there are some buried old riverbeds in Sanchahekou, Liulin, Maotiaochang, Guajiaishi, and Xidawan, etc., and in the old channels of the Jinzhong and the Daqing rivers. The area of water pits and old riverbeds is about 8.2 km², i.e. 4.7% of the city area. Based on the aviation telemetric IR scanning

* Tianjin Geology Bureau
results, verified by geophysical exploration and boring, a lot of old riverbeds are buried around Jinghai, Nanjiao and Dagang, the buried depth of which is shallow and the layer is mostly silt.

2. Hydrogeological Condition

(1) Quaternary strata and lithological characters of the water-bearing layers

The Quaternary strata are classified as follows:

1) Lower Pleistocene series (Q₁). The bottom boundary is 530-650 m. The lithological characters are: a thick layer of red-brown and yellowish-brown clay intercalated with gray to light gray medium fine or silt layers of different thicknesses, which is in an angle with the underlying layer, and is mainly of lake deposit.

2) Middle Pleistocene series (Q₂). The depth of the bottom plate is 340-390 m with a thickness of about 250 m. It can be divided in two parts: the lower portion is 166-230 m thick, mainly of a brownish-yellow, reddish-brown, grayish-green and gray clay and sand and stone layer; the upper portion is 76-93 m thick, is an interbedding of clay and sand of grayish-green, yellowish-green, brownish-yellow and grayish-brown color. It is mostly river deposit and marine and lake deposit.

3) Upper Pleistocene (Q₃). The depth of the bottom plate is 150-205 m and is 130-180 m thick. It is an interbedding of marine and marine-continental layers. It can be divided into two parts: the lower portion is 68-110 m thick consisting mainly of sandy clay, clayey sand and clay interbedding of grayish-yellow and yellowish-gray color intercalated with a fine sand layer; depth of the bottom plate of the upper portion is 67-112 m and is 48-90 m thick. It consists mainly of clay of a grayish-yellow, yellowish-brown and brown color and is also 3-4 layers of silty sand and 1-2 layers of silty mud.

4) Holocene series (Q₄). The depth of the bottom plate is 10-25 m. It consists of silty clayey sand, sandy clay and silt layers of a yellowish-gray and gray color. Its lower boundary is often a silty mud layer and marine layer.

The lithological characteristics are sandy light soil, clayey soil, and clay and sand interbeddings. The sand layer with a depth of 200 m varies from north to south. North of Houjiaying and Xinanzheng, around Shangzi, and Shangchuan, the sand layer is mainly medium coarse sand with a thickness of up to 30-100 m. In the urban area and in the south suburb, silty sand layers distribute extensively and those in the south are the thinnest, with a thickness of 10-30 m. The depth of the sand layers within 200 m deep reduces from the southeast to northeast, and the content varies from medium fine sand to silt.

(2) Hydrochemical characters

Chemical composition of underground water is obviously different horizontally and vertically from the north to the southeast. Water in the entire freshwater region in the north is mainly of a HCO₃-Ca (or Ca-Mg, Ca-Na), HCO₃-SO₄-Ca-Na and HCO₃-Na type, and also of a HCO₃-SO₄-Na-Ca type, with mineralization less than 1g/lit generally. Chemical composition of the central saltwater and freshwater region is SO₄-HCO₃-Na and SO₄-Cl-Na respectively, with mineralization of 1-2g/lit generally. The southeast and the sea coast are mostly
of a \( \text{SO}_4\text{-Cl} \) or \( \text{Cl-SO}_4\text{-Na} \) type water and \( \text{Cl-Na} \) type water. Owing to the strong evaporation its mineralization is 2-5-10g/lit or >10g/lit. On the vertical profile a division of layers is also apparent. In the freshwater region all water-bearing layers from the top to the bottom are of a \( \text{HCO}_3\text{-Ca} \) (or \( \text{Ca-Na} \)) type or \( \text{HCO}_3\text{-SO}_4\text{-Ca-Mg} \) type, with mineralization of approximately 0.5g/lit. The region is supplied by the vertical precipitation and the lateral run-off from the mountainous areas and its reserve and regulating capacity is comparatively large. The underground water at both sides of a river and in the area between rivers in the salt-freshwater region is mostly of a \( \text{HCO}_3\text{-Ca} \) or \( \text{HCO}_3\text{-SO}_4\text{-Ca} \) and \( \text{HCO}_3\text{-Na} \) type. It is mainly supplied laterally by rivers other than the precipitation vertically. Water is greatly affected by human activities and has seasonal features. In the upper layer, in the extensive plain area, salt water layers of different depth and thickness exist and the chemical composition is \( \text{Cl-Na} \), \( \text{Cl-SO}_4\text{-Na} \), with mineralization of >2g/lit. It is composed mostly of silt which results from salting and ingestion. Under the bottom plate of the saltwater layer the water is mostly of a \( \text{HCO}_3\text{-Na} \) and \( \text{HCO}_3\text{-Cl-Na} \) type in the center of the urban area, and of a \( \text{Cl-HCO}_3\text{-Na} \) or \( \text{Cl-SO}_4\text{-Na} \) type in the southeast and coastal areas. Owing to the variation of distance from the supply area, material of the water-bearing layer, hydrodynamic conditions, and, in addition, the effect of the recent geological structure movement, hydro-chemical characteristics are different with the depth. In the deeper part high temperature alkaline water occurs, and the chemical type of water varies not so much with depth but with fluorine ions that increase with depth.

(3) Water of the water-bearing layer

The water-bearing layer in the freshwater region is rich in water comparatively. Fresh water of the shallow layer in the salt and freshwater region is generally in the shape of strips. The water-bearing sand layer is thin and narrow and poor in water. Water in the layer varies seasonally. During the flood season the river is rich with water while in the dry season the water is less or even dry. In the exploration area the water head of the load-bearing fresh water within the depth of 200 m decreases greatly, leading the water head in the vicinity and other far away areas to decrease also. As a lack of supply of underground water the settlement of ground and pollution of underground water have occurred.

(4) Depth of the bottom plate and distribution of the salt water layer

South of the boundary between the fresh and saltwater regions, the depth of the bottom plate of the saltwater layer is approximately 10-30 m, and increases up to 200 m from the northeast, north, northwest and southwest to the Bohai Bay.

3. Buried Depth and Dynamic Conditions of Underground Water

(1) Buried depth of underground water

Based on the observation data in June 1976, the buried depth of underground water in the plain area is deeper, being 10-20 m in the piedmont zone; around Jixian and Baodi the depths are all under 4 m; in the middle area 6-10 m, but the depth increases toward the south becoming 10-25 m. However, in the urban area and in Tanggu, Hangu and Jinghai, a big and deep water funnel 30-60 m was formed owing to drawing of a large amount of underground water. The deeper the water bearing layer the greater the annual decrease rate of the under-
ground water level, which is about 1-6 m. Buried depth above the bottom plate of the saltwater layer is 4-6 m generally and 6-14 m in the coastal area.

(2) Dynamic condition of underground water

Based on the observation data for many years, low level periods of underground water are usually in April, May or June mainly depending on the effect of drawing of underground water. However, high level periods for different areas are quite different. In Jixian, Baodi and north of Wuqiu, the high level period of underground water within 200 m is in June, July, and August, consistent with the rain season showing that underground water is supplied locally. In the south area the high level period is in January, February, and March half a year later than the rain season. In individual areas the high level period is in February, April and May and in April, May and June owing to the fact that the underground water is supplied by the reserve water and run-off in the vicinity. Because the amount of drawing water is different for different areas, annual variations of the water level is great, about 1-10 m. In the north the water level has been increasing or has been in a balanced state, while in the south the water level has a tendency of decreasing annually.

(3) Variation of water level in the shallow layers of Tianjin before and after the July 28, 1976 Tangshan earthquake

Variation of the well water level is comparatively obvious both before and after the earthquake. In the north area the water level was deeper in the piedmont, but more shallow in the plain from 10-12 m to 6-8m, and 4-6 m in the west area, and 8-10 m in the southeast i.e. Tanggu and Hangu before the earthquake. After the earthquake the water level increased slightly with an increase of 0.02-0.03 m generally, however, the water level greatly increased in individual boring holes. For example, in Xinli Village which is situated in the east suburb the water level was 0.936 before July 27, i.e. before the earthquake, but on July 28 after the earthquake the water level was 0.870 m, increasing 0.066 m. Increase of water levels is different for various areas, large on the east coastal area and small in the northwest area (Figs. 3 and 4).

(Translator: Lu Rongjian)
Figure 1. Geomorphic zoning of Tianjin.
Figure 2. Zoning map of lithology and watery of the water-bearing layers in Tianjin.
Figure 3. Variation of water table in the shallow layers of Tianjin before and after the Tangshan earthquake.
Figure 4. Variation of water table in the shallow layers of Tianjin before and after the Tangshan earthquake (based on the data of Tianjin Seismology Bureau).
OUTLINE OF ENGINEERING GEOLOGICAL CONDITIONS IN THE PLAIN AREA OF BEIJING

Yao Binghua*

1. Outline of Topography and Geomorphology

Beijing is situated close to the northwest boundary of the North China Plain. The total area of Beijing is 16,808 km², of which 62% is the mountainous area and 38% is the plain area.

Most of the north and west portions of Beijing are rugged mountain lands except for the vicinity of Yanqing and Yongning, which are component parts of the Huailai Basin. The hill lands in the west are called Xi mount or Xishan; those in the north are called Jundou mount. Xi mount and Jundou mount meet in the vicinity of Nankou forming a semi-circular arc extending towards the Beijing Plain. The Yongding River, the Chaobai River, the Wenyu River, the Juma River, and the Ju River enter the Bohai Sea passing the Beijing Plain meanderingly.

The Beijing Plain is close to the hill lands having the characteristics of a piedmont plain. There exists undulating hill lands covered by residue deposits and slope wash deposits, and monadnock and geomorphic units such as cones of diluvium and piedmont plateaus. In the piedmont the alluvial and diluvial fans develop extremely and river terraces, natural embankments and depressions on the fan edge distribute extensively with individual sand dunes and marsh lands scattering.

This district is mainly composed of alluvial and diluvial fans of the above rivers connected with the alluvial plains. Undulation of the modern ground surface and the landform are basically controlled by erosion and accumulation of rivers of different sizes. Among the rivers the drainage area and discharge of the Yongding River are the greatest and the alluvial fans, diluvial fans and alluvial plains formed by rivers are most extensive. The Beijing urban area is located on the alluvial and diluvial fans of the Yongding River.

The topography of the district gradually slopes from the north-west to the south-east. The top sea level of the alluvial and diluvial fans of all great rivers is about 90 m generally while that at the top edge is about 60 m. The elevation of the bottom edge of the fans is mostly under 25 m. The average slope of fans is 1-3% with the slope at the top being steeper and the middle and the bottom being less steep. Topography of the alluvial plain below the fans is lower and smooth and the average slope is less than 1% in general. On the lower part of the alluvial plain, i.e. around the southeast of the Beijing urban area, the elevation reduces to approximately 15 m.

Except for the above-mentioned overall trend sloping from the north-west to the southeast local slopes vary extremely and differences in elevations can be several meters to several

* Beijing Exploration Survey Department
tens of meters violating the simple scene of the plain. Monadnocks (e.g. Babao Hill, great and small Tang Hill, Jiuli Hill, Niulan Hill, etc.), piedmont plateaus, terraces on the banks of rivers, natural embankments and the "back-bone" of fans and sand dunes are all relative uplifts in the plain; while river channels, valley flats, fan edges, depressions behind natural embankments and gulches are the relative depressions.

2. Outline of the Geological Conditions

The Beijing Plain is located at the north edge of the North China downwarping area and the south edge of the Yanshan mountain upwarping area. The main tectonic frame in the area was formed in the Mesozoic era and had been reformed since the Cenozoic era. One of the basic characteristics of the tectonic structure is that the faulting structure develops extremely. Based on the existing data three groups of basement faults in the northeast (or NNE), northwest and near the eastwest have developed of which the northeast faults and the northwest faults are the main faults in the plain area. Of the northeast faults there are the Huangzhuang-Gaoliying fault, the Nanyuan-Tongxian fault and the Xiazhi-Mafang fault. These faults divide the rock mass inside the plain into a structure of “two upwarps and two downwarps” i.e. west Beijing upwarping, Beijing downwarping, Daxing upwarping and Dachang downwarping. This NE structure was further complicated by the NW Nankou-Shunhe fault which divided the west Beijing upwarping into the Changping-Huairou upwarping and Shahe downwarping and further divided the Beijing downwarping into the Fangshan upwarping and Shunyi downwarping while the single Pinggu downwarping cut out the 20-li Changshan fault (Fig. 1).

The west Beijing upwarping and part of the Daxing upwarping area lack Tertiary deposits but thickness of the Tertiary deposits of the Beijing downwarping and Dachang downwarping areas is up to 2000-3000 m, showing that the Tertiary structure remains to be the Mesozoic structure in which two upwarps and two downwarps exist. Since the Quaternary era the differential movement of the Beijing Plain has been very vigorous, and controlled by the faults of different orientations. Different thicknesses of the Quaternary deposit layers in the recent Beijing Plain areas were formed. For example, in Shahe, Pinggu, Tianzhu and south of Huairou there occurred Quaternary deposit basins of different sizes in which the thickness of the deposit layer in the middle of the basin was 300-400 m generally, with a maximum of above 600 m. But the thickness of the Quaternary deposit layers in the Beijing urban area is approximately 60-80 m and some of the layers in the west suburb, such as Babao Hill and Gongzhufen, are only 10 and more meters thick and outcrops of base rock can even be seen somewhere. From the view of the above-mentioned it can be seen that before the Quaternary era the ancient landform of the Beijing Plain was rather complicated with many gulches, cliffs and crypto-hills scattering (Figs. 1 and 2).

3. Engineering Geological Conditions of the Sectors of the Plain in Beijing

The Beijing Plain is situated in the piedmont and therefore, the foundation soils of Beijing are of different eras, formations and engineering features. Topography and underground water levels of all sectors are also different and the engineering geological conditions are complicated comparatively.
(1) **Engineering geological conditions along the hill lands**

1. **Piedmont hill land.** In the west and north zones along the mountains there exist hill lands extending from the mountainous area to the plain. Some of the landforms are undulating with developed gulches, isolated hills, and monadnocks some of which have been transformed into terraced fields, different in elevation. The zone is composed mainly of residue slope washes with poor sorting and poor local density. The soil can be easily compressed when the water content is high. The soil mass could slip easily in the sector of the zone where the underlying base rock surface is steeper so it has an effect on the stability of the foundation. Owing to the difference in thickness of the overlying materials in different sectors and the source of supply of the water-bearing bed, the underground water level varies greatly. Thus, the engineering geological conditions in this zone are rather complicated.

2. **Diluvial fan.** Most diluvial fans are located in the gaps of mountains and generally have a slope of 1-3%. The underground water level is rather deep and the closer to the top of the fan, the deeper the water level. The depth of some ground water may be tens of meters. On the top of the foundation soil there are drifted stones of poor sorting intercalating intermittently with gravel layers with cohesive lens, or interbeddings of cohesive soil and gravel or stones, the compressibility of which is small to medium. Although the composition of this kind of foundation soil is rather complicated and poor in homogeneity its consolidation is better than the slope wash layer because it belongs to marine deposits.

3. **River terrace.** On the river banks along the mountains is always a terrace. The terraces are usually plain and smooth and the underground water level is generally greater than 4.5 m. The foundation soil is most obvious in stratification and is of a medium cohesive soil or interbedding of cohesive soil and sand gravel with medium nonhomogeneity and small to medium compressibility. Therefore, the engineering geological conditions are good. Miyun, Huairou, Pinggu, and Fangshan counties affiliated with Beijing are all located on the river terrace.

4. **Piedmont terrace.** The piedmont terraces distribute extensively along the mountains and especially found everywhere in Miyun, Huairou and Changping. The piedmont terrace is an inclined terrace and the gulch in the sector close to the mountain and on the boundary of the terrace is developed with deep cutting forming a vertical wall several meters to more than ten meters in height and having the characteristics of ordinary loess terraces. The water table is very deep, even to tens of meters. The foundation soil is mainly a loessive cohesive soil with no obvious bedding with vertical joints, a lot of large pores, and containing calcium nuclei. It contains thin intercalations of crushed stones or debris particles and can be settled locally when the water content is high. But the existing loess in Beijing is mostly secondary and it does not settle seriously.

(2) **Engineering geological conditions of alluvial-diluvial fan of large rivers**

The alluvial-diluvial fan of large rivers inclines from the top to the bottom edge. The top portion of the fan is rising and smooth. The slope of the fan is generally 1-5%. Below the top part the land gradually becomes low and flat, with a slope reducing to approximately 1%. The foundation soil at the top is mainly sand and gravel. The layer is thick over the entire surface. Below the top the soil is mainly coarse gravel and stone and gradually becomes to be sandy soil and cohesive soil. The gravel layer is deep from the surface and, at the same
time, interbeddings of gravel, fine sand and cohesive soil gradually increase forming a branch shape (Fig. 3).

Under the top of the alluvial-diluvial fan the depth of the underground water level is very deep, even up to the top. Owing to the fact that the slope of the land is greater than that of the ground water level and the fact that transition of coarse rock to fine rock occurs, the water level gradually becomes shallow. In the middle and lower part of the fan the water level becomes deeper again because the slope of the land is slightly smaller than that of the water level. It must be pointed out that the underground water level of the urban area of Beijing, which is located on the alluvial-diluvial fan of the Yongding River, is decreasing gradually due to the drawing out of a large amount of underground water. Thus, the water table of most of the urban area has decreased more than ten meters changing the above law for the variation of water level. The law fully shows the variation features of the natural conditions of the alluvial-diluvial fan. This kind of variation causes differences in engineering geological conditions in different sectors of the fan as follows.

1. **At the top of the fan.** To the west of the urban area of Beijing, west of Wujiaochun-Xihuachun-Zhangyichun, north of Daxinzhuang-Jingezhang, the area south of Nankou town in Changping-Lijiazhuang-Liujiangzhuang, and the area west of Banbidian in Fangshan-Maojiatun are the tops of the alluvial-diluvial fan of the Yongding River, the Chaobai River, the Wenyu River and the Beijuma River respectively. The land slope in these areas is generally about 3% and therefore the drainage conditions are better. Foundation soil is mainly composed of thick layers of sand, crushed stone and gravel of small compressibility. The cohesive soil overlying these layers is generally not thick, with some layers exposed on the ground surface in part of the areas. In general, the depth of the water table is greater than 6 m. The closer to the top of the fan the deeper the underground water level and the depth may be tens of meters. Therefore, the upper portion of the fan is the area of good engineering geological conditions in the Beijing Plain.

2. **Areas of ground water discharge in the fan.** Areas of ground water discharge distribute at the lower end of the top of the fan, e.g. Zhougezhuang to Wanghuanan in Shunyi County, Machikou to Baiquanzhuan in Changping County, and Kunming Lake, Zizhuyuan Park, Wanquansi, Dajing, Xiaoqing, and Majiabao within the urban area of Beijing. These were areas of ground water discharge before the drawing of large amounts of underground water. These areas are relatively low and depressed with a high water table. Over the foundation soil there are mostly layers of cohesive soil, silt and silty soil (recent deposits) of medium high to high compressibility and approximately 3-4 m in thickness; under the soil there are layers of sand, crushed stone and gravel. Engineering geological conditions in these areas are relatively poor.

3. **Middle and lower part of the fan.** This region includes the extensive area from the ground water discharge area in the alluvial-diluvial fan of all large rivers to the alluvial plain southeast of Beijing. It is basically located in the middle of the plain, flat in relief, and the average slope is about 1%. The foundation soil is mainly a Quaternary strata of clayey soil, light loam, silt and fine sand with some intercalations of sandy soil and clay. The soil possesses medium to medium low compressibility. The allowable bearing load is 1.5-3.0 kg·f/cm² in average, and the ground water level is generally 2.5-4.5 m. The water level
in some areas is deeper due to drawing a lot of underground water. In summary, engineering geological conditions in the middle and lower portions of the fan are comparatively good.

(3) Engineering geological conditions in the alluvial plain of south-east of Beijing

The land in the alluvial plain is low and flat with an average slope of less than 1% generally. Foundation soil is mainly of recent deposits. In the recent river accumulation region and some old river channel areas the top part is late Holocene cohesive deposit with silt and fine sand lens in between. The soil is of a brownish-yellow and gray color, soft and plastic, of medium high to high compressibility, and thickness of the soil layer is generally 2-5 m. The middle part is a Holocene silt and fine sand layer in the late and middle period intercalated with fine sand and clayey soil thin layers. It is of a gray and brownish-yellow color, medium compacted to densely compacted, and thickness of the layer is usually 6-8 m. Along the banks of the rivers, sand dune distribution areas are formed by wind. On the cohesive soil layer a newly deposited loose fine sand layer is overlaid, the allowable bearing load of which is approximately 0.8-1.2 kg.f/cm². In other areas the foundation soil is chiefly composed of moderately to highly compacted thick layers of clayey soil sometimes with silt and fine sand interbeddings. The water table in this region is relatively high, 1-3 m generally. Therefore, the engineering geological conditions are poor.

In addition, in the vicinity of the rivers flowing through this region, there are always water-logged depressions in back of the embankment such as Daodian to Renxianfa on the west bank of the Yongding River and Beitiantang, Lucheng and Efangchun on the east bank. These villages are often in marshland caused by the low depressions, shallow water table, and seepages. The foundation soil and engineering geological conditions in these areas is quite poor.

(4) Engineering geological conditions in the thick man-filled land areas in the old city and vicinity outside the old city wall

The old city and vicinity outside the old city wall of Beijing (about 70 km² in area) were the areas for public activities in ancient times; the strata of which were seriously damaged artificially. At the same time there are also many buried old rivers, lakes, ditches and pits (see Fig. 4) therefore, very thick filled lands were accumulated with a thickness of approximately 3-6 m and maybe up to 10 m. Among the filled lands there are pure filled lands, litter, furnace ash, and debris, etc. The distribution of these filled lands is irregular; nonhomogeneity of which is serious and some of which can be settled when the water content is high. At the bottom in the distribution zone of buried rivers, lakes, ditches and pits there is a layer of silt intercalated with silty soil. Therefore, the foundation is hardly to be processed. An allowable bearing load of pure filled land accumulated for a long time is approximately 1.2 kg-force/cm² so this kind of filled land can be used as natural foundation.

4. Distribution of All Types of Site Soil

Based on the classification of site soil in the Chinese “Seismic Design Code for Industrial and Civil Buildings (TJ 11-78)”, distribution of all types of site soil in the Beijing Plain are outlined as follows.
(1) Type III site soil

1. Weak cohesive soil, silt and silty soil. These types of soil are mainly in the areas of ground water discharge in the alluvial-diluvial fan of large rivers, depressions on the fan edge, relatively low depressions developed by ancient river channels or on the two banks of modern rivers such as the depressed lowland along the banks middle and downstream of the Chaobai River, the Xiaozhong River, the Wenyu River, the Qing River and the Xiaoqing River, in the area between Dalongzhuang and Kunming Lakes, and the areas south of the Liangshui River through which the ancient Yongding River passed (i.e. the Gului River). In addition, Type III site soil is also distributed between Beixiaoying to Macikou of Changping County, Xiaotangshan, Niejiaying, Sujiatuo in the Haidian District of Beijing, Banqiao of Hairou County and in the vicinity of Pinggu County. The weak cohesive soil located in these areas is mainly of recent deposits and is not weak as that distributed on the coastal plain in China, but when compared with the ordinary old Quaternary deposit in Beijing it is actually rather weak.

2. Saturated loose liquefiable sand soil. It mainly occurs in the accumulation areas of modern rivers and areas developed by old river channels. It is especially extensive in the alluvial plain in the middle and downstream of the Chaobai River. In the Chaobai Basin the liquefiable soil is distributed on both sides of the river course south of Suocaolin, about 3-8 km in width. South of Tongxian it is distributed more extensively, spreading between the Chaobai River and the North Canal with a maximum of up to 10 km in width. The depth of the saturated loose liquefiable fine sand layer in this area is generally 2-6 m and the depth of other liquefiable layers can be 8-12 m. In the Xiaozhong River Basin the liquefiable soil is distributed on the low depressed lands on both sides of the river south of Changgezhuang, about 2 km wide. The buried depth of the saturated loose fine sand layer is 1-2 m in general, and that of other liquefiable layers is 4-8 m. On the Wenyu River Basin the liquefiable soil is distributed in areas such as Shaziyiing, Baxianzhuang, and Baigezhuang located along the riverbank, and the depth of the liquefiable sand layer is usually 2-3 m. On the west bank of the Yongding River the liquefiable soil is distributed south of Daotianchun and is about 5 km wide including areas where the Xiaoqing River passes through; on the east bank the liquefiable soil is distributed northwest to southeast in a form of strips south of Yonghezhuang. The depth of the layer in this area is approximately 1 m. The upper layer is mostly silt and light loam and the lower is fine sand. The thickness of each layer is not great and the inter-bedding usually with cohesive soil and the depth of the liquefiable layer can be up to 8-10 m. Furthermore, liquefiable soil is also distributed on the right bank of the Liangshui River from Hongshichun to Majuqiao and in the vicinity of Gaoguizhuang, and the low depressed lands on both banks of the Ju River and Cuo River in Pinggu County. The standard penetration blow of the liquefiable saturated fine sand layer in the above areas is generally 5-18 with 12 in average.

3. Thick layer of filled land. It is distributed mainly in the above mentioned filled land areas in the Beijing old city and the vicinity outside the old city wall.

(2) Type I and II site soil

1. Type I site soil (bedrock). It is distributed along the mountainous land principally and in the areas where isolated hills exist and monadnocks and their vicinities.
2. **Type II site soil.** It exists in the areas other than the above-mentioned distribution areas of Type I and Type III site soil. The layer is mainly a cohesive soil of moderate density and above and of sandy soil, gravel and crushed stone.

In order to study the dynamic characteristics of site soil more than 30 sites, about 360 km² in area, in the central urban area of Beijing have been selected by the Beijing Exploration Survey Department for in-situ measurement of transversal wave velocity of soil layers. The measurement results for Type II and III soil in different depths are listed in Table 1.

### Table 1. Transversal wave velocity of site soil.

<table>
<thead>
<tr>
<th>Type of Site Soil</th>
<th>Depth of the Layer, H (m)</th>
<th>Average of Transversal Wave Velocity (m/sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey soil and sandy soil</td>
<td>H ≤ 10</td>
<td>194</td>
</tr>
<tr>
<td>(plastic to hard plastic)</td>
<td>10 &lt; H ≤ 20</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>20 &lt; H ≤ 30</td>
<td>277</td>
</tr>
<tr>
<td>Sand soil (medium dense to densely compacted)</td>
<td>H ≤ 10</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>10 &lt; H ≤ 20</td>
<td>357</td>
</tr>
<tr>
<td></td>
<td>20 &lt; H ≤ 30</td>
<td>386</td>
</tr>
<tr>
<td>Crushed stone, gravel</td>
<td>H &lt; 10</td>
<td>284</td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modern cohesive soil</td>
<td>H &lt; 10</td>
<td>127</td>
</tr>
<tr>
<td>Modern silt</td>
<td>H &lt; 10</td>
<td>155</td>
</tr>
<tr>
<td>Mixed filled land</td>
<td>H &lt; 5</td>
<td>162</td>
</tr>
<tr>
<td>Type III</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Translator: Lu Rongjian)
Figure 1. Outline of the tectonics of the plain area of Beijing.
1. Quaternary isopach (m). 2. Boundary between mountainous area and plain area.

Figure 2. Quaternary isopaches of the Beijing Plain Area (after Beijing Hydrogeology Cop.).
Figure 3. Perspective representation of Quaternary deposits in Beijing urban area.

Figure 4. Distribution of buried rivers, lakes, ditches, pits in Beijing urban area.
HYDROGEOLOGIC CHARACTERISTICS OF THE PLAIN AREAS IN BEIJING

Zhou Zuoxin *

1. General

The plain area in Beijing is located on the north boundary of the North China Plain. It is a piedmont inclined plain formed by the alluvial and diluvial deposits of the Yongding River, the Chaobai River, the Wenyu River, the Dashi River and the Ju River, etc. The area of the plain is about 6,400 km², i.e. 38% of the total area of Beijing. From the beginning of the Quaternary period the recent tectonic movement had been very obvious and characterized by the uplift of the mountainous area and depression of the plain so that the Quaternary system was developed extensively. The Quaternary deposit thickness increases gradually from the piedmont to the plain from several meters to 500 meters.

The underground water in the plain mainly consists of the Quaternary void water and load-bearing water. The karst crevice water is also buried in part of the area. Distribution, buried depth, supply, run-off and drainage conditions of underground water are mainly controlled and influenced by the lithology, tectonic structure, topography, geomorphology, hydrology and meteorology of the area. The hydrogeologic conditions of the plain in Beijing are mainly controlled by the alluvial and diluvial fans of the main rivers and have obvious features horizontally, dependent on the two alluvial-diluvial fans of the Yongding River and Chaobai River (Fig. 1). The lithological particles in the water-bearing layers become finer from west to east and from north to south generally, and the layer becomes multi-layered from a single layer gradually. The permeability and flow become weak and the quality of ground water becomes poor.

Based on the supply, run-off, drainage, lithology and layer conditions of the Quaternary water-bearing layers in this area, four zones can be classified from the piedmont to the plain approximately as follows.

(1) Piedmont zone. It is a transitional zone from the mountainous area to the plain area with a large slope of up to 3% to 5%, and a width of one to several kilometers. The water-bearing layer is mainly composed of cohesive soil layers containing broken stones formed by alluvium, diluvium and glacial till. The permeability of the layer varies greatly and the water level is rather deep, greater than 10 m generally. Underground water in this zone is basically supplied by the lateral run-off of water in the base rock and the water permeating from the surface in the gulch in the mountainous area and drains downstream in the form of lateral run-off. Variation of the water level is generally above 5 m and can be up to 10-20 m in individual locations.

(2) Zone at the top of the alluvial-diluvial fan. It is located approximately north of Suchun of Fanshan on Dashihe River, west of Lian-hua-ci and Kunming Lake in the west

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suburb of Beijing, west of Yangfang and Macikou in Changping, north of Beijing in Huairou and in the area east of the Miyun Plain and Pinggu County, i.e. the top areas of the alluvial-diluvial fan of the Dashi, the Yongding, the Wenyu, the Chaobai and the Ju rivers. The water-bearing layer in this zone is mainly composed of a single layer or 1-2 layers of sand and gravel with different thicknesses, 20-70 m in general. The permeability, hydraulic gradient and water table of the water-bearing layers are comparatively great and decrease from the top of the fan to the water discharge area. The underground water in this zone is mainly supplied by the atmospheric precipitation, water permeating from the surface, and by the lateral run-off in the ground. It is depleted by the lateral run-off and artificial exploitation. The variation of the water level is generally 3-5 m annually, and the quality and quantity of underground water are good. During the wet and dry years variation of the water level is relatively great. In the area where the thickness of water-bearing layers is small the ground water will be dried up in the dry years.

(3) **Ground water discharge zone of the alluvial-diluvial fan.** It is located at the edge of the top of the alluvial-diluvial fan. It varies with the rise and fall of the underground water. During the wet year (the supply period of underground water), the discharge zone shifts to the upstream of the underground water; while in the dry year, the discharge zone withdraws to the downstream. In the fan area of the Yongding River, where underground water is drawn excessively, the discharge zone vanishes due to the decrease in water level.

The width of the ground water discharge zone is usually several kilometers and the water-bearing layer in the zone becomes multi-layered from a single layer. Lithological particles and hydraulic gradient become small, permeability reduces, and the ground water discharges to the surface owing to blockade. It is a transitional zone from the groundwater layer to the load-bearing water layer, with the water level and its variation generally less than 1 m. The underground water in this zone is mainly supplied by the lateral run-off of the upstream and secondly, by the rainfall permeating into the ground. It is drained rapidly by the discharge and the evaporation from the ground water surface and part of the water runs off downstream. The zone is rich in ground water of good quality. It is the main underground water exploitation area at present.

(4) **Alluvial diluvial plain zone.** It is situated southeast of Fangshan, north of Haidian, east of Macikou-Yangfang in Changping, and west of Pinggu County and the plain in Chiaoyang, Shunyi, Tongxian and Daxing. This is an underground water-load bearing water zone composed of shallow ground water layers and deep load-bearing water multi-layers.

The shallow ground water layer is mainly buried in the Holocene sand layer in the old river channel. Particles in the sand layer are fine and the water level is shallow. Under the effect of earthquakes the layer can easily be liquefied. For example, the water-bearing layers in Xiji of Tongxian and Caiyu of Daxing are composed of powdered fine sand layers in the old river channels, the water level of which is generally about 2 m. These layers were generally liquefied in the Tangshan earthquake. In areas without old river channels the underground water is buried in the cohesive soil of poor permeability and the quality of water is poor and small in quantity. Underground water in this zone is mainly supplied by rainfall and water from the ground surface and is drained by evaporation and artificial exploitation. Depth of the water level is usually 1-3 m and with an annual variation of which is generally 1-2 m.
The deep load-bearing water layer is composed of layers of sand and sandy gravel with smaller particles the thickness of which is not great. The number of water-bearing layers increases gradually from the discharge zone to the plain area downstream. The permeability and hydraulic gradient also reduce. In the unexploited areas the load-bearing water head is higher than the ground water level therefore, the artesian water is formed naturally in the depressed lands or even in some locations it is higher than the ground surface. In the exploitation area load-bearing water head decreases with the amount of drawing and becomes lower than the water table so the ground water is forced to be supplied from the flow in other areas, so, the water head changes greatly.

In addition, to the north of Daxing and in the vicinity of Kunming Lake to Wali in the plain area, there are limestones of the Sinian sub-group and Paleozoic group under the Quaternary system rich in karst crevice water.

2. Dynamic Characteristics of Underground Water

Dynamic characteristics of the underground water of the Quaternary system (underground water, load-bearing water) in the plain are controlled by local geological and hydrogeological conditions and are strongly affected by hydrological and meteorological factors and human activities in the area. Before the large scale exploitation, the dynamic characteristics and types of underground water in the area are relatively apparent. At present, in the alluvial-diluvial fan of the Chaobai River and Nankou the dynamic characteristics of underground water still remain in a natural state due to small scale exploitation, while in other areas exploitation of underground water has been carried out tremendously, therefore, the effect of human activities on the dynamic characteristics has been increased annually showing strong variation. Dynamic characteristics of underground water are outlined as follows.

(1) Dynamic characteristics of underground water level

In the Quaternary strata of the plain area in Beijing natural variation and types of ground water are comparatively obvious. Based on local conditions the seasonal variation of ground water is basically consistent with the rainfall season. In a hydrologic year there is an ascending period and a descending period for the ground water level. In general, the ground water level ascends in June to September and descends from September to June in the next year with the maximum level in August to September and the minimum in May to June annually. The water level becomes lower annually from the top of the fan to the discharge zone then becomes higher from the discharge zone to the lower plain area. Except in the concentrated exploitation area where the water level has a tendency of decreasing annually, the water level in most other areas is associated closely with atmospheric precipitation. In this area the highest water level occurred in the wet period in 1959 (from August to September) and the lowest in the dry periods in 1973 and 1976 respectively (from May to June).

Based on the measurement data of ground water levels for more than 20 years in this area, ground water can be classified as a run-off type, a permeating and evaporating type and a transitional type according to its dynamic characteristics. It can also be classified based on the effect of artificial factors as water permeating from rivers (ditches), drainage water on the ground surface, underground drainage water, and concentrated exploitation water.
The load-bearing water distributes in the plain areas situated in the lower middle part of the alluvial-diluvial fans. At present, the load-bearing water flow is affected by the exploitation to a various extent. For the ground water, 150 m under the surface, exploitation for use is small, therefore, the natural state of water still remains.

From the variation of the water head of the load-bearing water, the seasonal variations of the load-bearing water head are basically consistent with that of ground water but the load-bearing water changes slower than the ground water so variation will take place later than that of ground water.

Variation of the load-bearing water is mainly influenced by exploitation of underground water. Exploitation for city use is carried out locally and continuously and a large amount of water has been drawn up. Exploitation for agricultural use is carried out seasonally and in many areas. Therefore, the effect of exploitation on the load-bearing water is quite different for different uses. Effects of permeation of rivers (ditches), drainage by use of surface water and by use of ground water (well water) are seasonal factors, which can only influence the load-bearing water for a certain period, but cannot change the natural state of the load-bearing water. Exploitation in the city is a constant factor during the year so if the effect of the artificial factors exceeds that of the natural factors the natural state of the load-bearing water will be destroyed.

(2) Dynamic characteristics of underground water level before the 1976 Tangshan earthquake

From the tendency of variation of underground water in recent years in this area, the ground water level had a tendency of decreasing gradually before the earthquake. In May to June 1976 the lowest water level ever recorded had been found in most of this area.

Before the earthquake ground water in the Miyun, Huairou, and Shunyi areas mainly flowed from north to south (Fig. 2). Inside the territory of Miyun County the ground water is supplied by rivers, while within Huairou and Shunyi they are supplied by drainage water. From Changping County to its suburb area the ground water flows mainly from west to east. The Wenyu River passing through this area plays a main role in draining the ground water. The ground water in Daxing to the Tongxian area flows from northwest to southeast, and the Chaobai River and the North Canal also drains away the ground water while the Yongding River supplies the ground water in this area. Furthermore, the Dashi River in Fangshan and the Ju River, and the Cuo River in Pinggu supply the ground water in the piedmont but in the plain area they mainly drain the ground water away.

Ground water level before the earthquake (Fig. 3). There is a close relationship between the ground water level and topography, geomorphology and hydrogeological conditions and degree of exploitation. In the ground water discharge zone of the alluvial-diluvial fan of the Chaobai River and the rice field irrigated by ground surface water in Daxing to Tongxian, the ground water level was less than 2 m. In the plain areas in the east such as Daxing-Tongxian, Changping and Shunyi the ground water level was 2-5 m. In the terrace of the second level the water level was generally 5-10 m. In addition, in the suburb areas of the city the water level decreased annually due to drawing large amounts of underground water so the water level had decreased up to 10-20 m.
Before and after the great Tangshan earthquake the ground water in Beijing 160 km away from the epicenter changed. Several days before the earthquake the well water became muddy, the color changed, the taste and smell were bad, and bubbles and sand generally appeared on the surface. The water level either increased or decreased. Sand spouts also occurred after the earthquake. In some areas where the water level increased or decreased before the earthquake the level varied oppositely after the earthquake. The above-mentioned anomalous areas distribute mainly in the plain areas of the lower alluvial-diluvial fan of the Yongding River, the Chaobai River, the North Canal, the Ju River and the Dashi River, especially on both banks of the river and the connecting part of the two rivers and mostly in the plain areas where the Holocene old riverbeds exist, such as, Xiji, Longfu, Matou, Mizidian, and Yonglodian in the south of Tongxian County, Caiyu, Taiziwu in Daxing County, Mafang in Pinggu County, Changgou in Fangshan County and northwest of Beijing. The ground water layer in these areas is mainly of a fine sand layer with a water level less than 5 m. It can be concluded from the above that the anomalous areas of ground water before the earthquake and the sand spout areas after the earthquake have a close relationship with the local geological and hydrogeological conditions.

(Translator: Lu Rongjian)
1. Gravel and sand layer
2. Multi-layers of sand gravel
3. Multi-layers of sand intercalated with gravel
4. Multi-layers of sand
5. Area without good water-bearing layers

Figure 1. Distribution of Quaternary shallow water-bearing layers in the plain area of Beijing.

1. Isobath of water table and its value
2. Boundary between mountainous area and plain area

Figure 2. Isobath of water table of the plain area in Beijing in July 1976.
1. Depth less than 2 m
2. Depth between 2-5 m
3. Depth between 5-10 m
4. Depth greater than 10 m

Figure 3. Depth of water table of the plain area in Beijing in July, 1976.