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Preliminary Report for KD Subsurface Oil Storage

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Abstract: The rocks exposed in the investigation area are andesite of Late Cretaceous age, and syenite and aplitic granite of Bulgugsa Series of Early Cretaceous Period, which is intruded in the older andesitic rock. The strike and dip of major joint is N10° to 60°E, and 70°SE to vertical respectively.

According to seismic exploration, lower velocity zone, deemed to be fractured and/or crushed zone, is appeared along the gully center of east flank of the area.

Test drilling shows that andesite bedrock is mostly very hard, massive, and very fine to medium grained and has almost 100 percent RQD and core recovery. In comparision with andesitic bedrock, intruded syenite cores show that it is highly crush especially at the depth from 55m to 63m.

1. Introduction

KD Ccompany Ltd is planning to construct "Central Terminal System" as a type of underground oil reservoir at Pusan City.

A surface and sub-surface geologic investigation was carried out for the proposed construction site of the reservoir in accordance with the mutual Contract made on May 2nd, 1980 in order to get the neccessary information for the locating the most probable reservoir site and for the preliminary design work.

The investigation accompanied by seismic exploration, test drilling, and geologic investigation was performed from 5/2 to 5/30, 1980.

Assistance from KD Co is gratefully acknowledged.

2. Contents of the work

2-1. Purpose: The purpose of the investigation is to provide the basic ideas of geologic and geophysical characteristics of the rocks and soil distributed in the proposed area where the cavern is to be constructed and to locate a most probable cavern site.

2-2. Investigation area: The area lies along coastal line of Sin Sun Dae and is located in Pusan between 120°06'30'' to 120°07'00'' in longitude and 35°06'00'' to 35°06'20'' in latitude.

2-3. Scope:

Geologic mapping : 1 Ea

Refraction exploration : 2 Km

Test, exploratory boring : 2 Holes (150m)

2-4 Period:

Field work : 5/2-6/5, 1980

Indoor work : 5/15-6/10, 1980

2-5 Instruments and Equipments:

Seismic refraction exploration: ABEM 12 channel, Trio seismic refraction system, Sweden

Exploratory boring: Long year, hydraulic, 200m capacity, rotary type.

Others : Clinocompass, Transit, etc

3. Methods of Investigation

3-1. Surface: Most of the area is covered by thin unconsolidated deposits such as alluvial and colluvial deposits consisting of coarse grained round to angular gravel having the size from one-half to ten centimeters diameter mixed with reddish clay. Colluvial deposits are containing angular rock fragments with fine silty clay are distributed along the gullies. An alluvial deposit with well sorted and very round gravel ranging in size from one-half and 5cm mixed with reddish clay are distributed in the lower area. The thickness of the alluvial deposit is very thin.

Geologic mapping was concentrated to map minor and major geologic structures such as fault, joint, and shear and fracture zones. Topographic map with 1 : 2,000 scale was used for the investigation.

3-2 Seismic exploration:

a) Layout of the exploration line: The exploration lines were laid out with regard to the proposed direction of the underground oil storage facility to be constructed. Owing to poor topographic conditions in execution of the seismic exploration, obstacles such as thick covered forest and densely spaced graves were skipped or exempted from the line.

b) Method of exploration: The instrument used for the survey was an ABEM Trio SX channel seismic refraction system as mentioned.

11 numbers of geophones were used for each spread having a 10m interval of each geophone. The end geophone is overlapped to the first geophone of the next spread. Therefore length of a spread is 110 meters.

In general, 5 shooting per spread were applied.

Those were two times of off set-shooting, another two times of end shooting, and one time of center shooting. At some places, 3 or 4 times shooting per spread were used due to the explosion obstacles.

c) Method of Interpretation: Time distance curves were drawn up by plotting each arrival time of geophones from the seismographs. In order to calculate the depth of velocity layers, the time distance curves were corrected somewhat because the curves show partial irregularity caused by uneven topographic conditions of each geophone setting place. The possible error of time distance originated from shot hole condition was also corrected by time distance curves of the overlapping end geophones or the reciprocal time distance. 3 milliseconds of time delay originating from detonation was also corrected in order to read real time distance.

After all aforementioned corrections were performed, the new time distance curves were drawn up by applying Hagihara's Method which makes it possible to remove top soil layer. This method of difference is used to calculate "time depth".

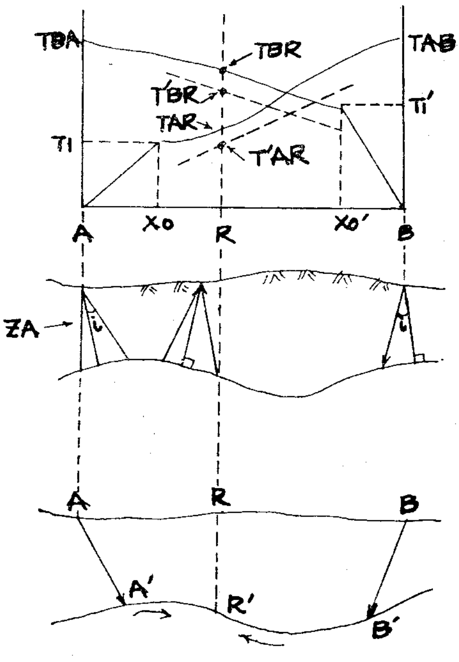

Fig. 3
RT=(TAB+TBA) 2
TAB=Time-distance from A
TBA=Time-distance from B
TAR=Time-distance from A to R
TBR=Time-distance from B to R
ZR=Depth to R'
AR=A'R'

From the Fig. 3 the time depth is calculated by following formula.

$$TR=1/2(TAR+TBR-RT)$$

The velocity of the first layer can be calculated from the time distance curves.

$$V_1=X_0/T_1=X'_0/T'_1$$

and V_2 (velocity of the second layer) is also calculated from the Hagihara's corrected curves.

The depth of the first layer is determined with the following formula:

$$X_R=V_1/COS_i\times TR\ \left(COS_1=\frac{V^2_2-V^2_1{}^{1/2}}{V_2}\right)$$

Therefore the profile of the first layer can be drawn up by plotting Z_R of each point of the geophones.

If there are many numbers of refractor, the depth of each layer can be calculated by the following.

$$Zn=1/2\ Xn\sqrt{\frac{Vn+1-Vn}{Vn+1+Vn}}-\Sigma\ Zn-a\times$$

$$\frac{Vn\sqrt{Vn+1^2-Vn-1^2}-Vn+1\sqrt{1Vn^2-Vn-1^2}}{Vn-1\ Vn+1^2-Vn^2}$$

As mentioned above, the lateral changes of the seismic velocity are quite excessive due to the irregularity of the refractor. This kind of lateral change of the velocity is considered to havea quite close relation with subsurface geologic structure and conditions.

Great attention therefore has been given to analyze this kind of phenomenaat the stage of interpretation.

Low velocity zones which are interpreted as "blind zone" appear in some spreads. These zones are interpreted by the Morgan's method using basic data.

4. Topogaphy

On the western flank of the area, the maximum bedrock level is 173m above mean sea level and the lowest area is 0 level along sea coast. The ridges belong to the southern foot of Tae Boek Mountains. Those ridges runina north direction. A very steep cliff exists along the sea coast at the western part of the investigation area. The drainage system is very poor and the gradient of valley floor is about 1 : 5. Generally speaking, the topography of the areabelongs to early Old stage.

5. Bedrock

Bed rock, as shown in outcrops and revealed by diamond core drilling consists of almost horizontally bedded massive hard and mostly fine-grained andesitic rock ranging in era of early Cretaceous Period and is intruded by syenite belonging to Bulgugsa Series of late Cretaceous Period. The bedrock surface is overlain by a variable thickness of unconsolidated deposits.

Fresh andesite shows dark grey color. Highly weathered andesite has brownish yellow color. Very small veins of leucocratic feldspar intrudes through the weak fissures of andesite when intruded by the syenite. Their patterns are very irregular. The syenite consists of fine to medium grained lath shaped feldspar, hornfels, and biotite showing light grey and light brown. The outcrop of the syenite is limited along the coastal line and a small gully at the western part of the area and lies in northwest and southeast direction. Small faults are revealed at the eastern coast line. It is assumed that a large fault line runs through the center of the valley locating the eastern flank of the area. This inferred fault can not be detected on the surface owing to the unconsolidated deposit. But time distance curves drawn up in this area shows a low velocity zone along the gully.

Jointing: strike N10°−50°E, dip vertical to NW 70°

The spacing of joints varies from less than 30cm to over one meter.

6. Result of investigation

6-1 Geologic mapping: refer to attachment A-1, Geologic map.

6-2 Seismic exploration:

a) Seismic velocity of each layer and velocity layer. Subsurface layers are classified as follow in accordance with seismic velocity:

Top soil zone: In general, the velocity of top soil zone is recorded in average from 200 m/s to 800 m/s in Korea. But in this area, it shows 500 m/s to 800 m/s because this zone contains a coarse grained gravel bed. This is the layer calculated from time distance recorded to nearest geophone from the shot points and from the direct seismic waves.

Upper weathering zone: The layer having seismic velocity ranging from 500 m/s to 1,000m/s is called the upper weathering zone. According to weathering definition, this zone is completely weathered to highly weathered. Therefore the soil characteristics of this zone are quite similar to top soil if it is residual. The reason why the zone has a little higher seismic velocity than top soil is due to saturation of groundwater and overlain earth pressure. In this report, the upper weathering zone is considered and interpreted as the same zone of top soil.

Lower weathering zone: This zone is the seismic velocity layer having seismic velocity in between 1,000 m/s to 3,000 m/s and belongs to SW (Slightly Weathered) to Fr St (fresh stained) zone. In comparison with the upper weathering zone, this zone is mostly weathered by mechanical processes, not by chemical processes, bearing many numbers of joints and fractures. Soft rock is categorized to this zone.

Hard rock or solid rock zone: This zone is a relatively fresh rock formation and unaffected weathered rock formation having more than 3,000m/s of seismic velocity. Joint faces are quite clean or clay coated. Sometimes this zone contains a low velocity zone which is interpreted as very densely spaced joint and fractured or shear zone. Generally speaking, deep seated hard rock shows over 4,000m/s to 5,000m/s.

By summarizing above mentioned classification, estimated seismic velocity layers are as following table

Tab. 6

Zone	Seismic velocity (m/s)	Remarks
Top soil	200— 800	considered to
Upper weathering	500—1000	be same zone
Lower weathering	1000—3000	
Hard rock	+3000	

b) Geologic structure of each line: refer to attached profile c-1, 2, and 3.

A-A′ profile: The thickness of the first layer having its seismic velocity in average 700m/s ranges from 4m to 6m. This layer is considered to be top soil. The lower weathering zone is a little thicker than the top soil zone. Its seismic velocity is about 2,200m/s and its thickness is about 10m to 15m. This zone is considered as soft rock formation. The fresh hard rock is distributed approximately 15m below land surface with its seismic velocity of 4500 m/s low velocity layer having the thickness cf 20m with velocity 3500 m/s is appeared at marginal place of this line. This low velocity layer is supposed to be extended to the low velocity zones of B-B′ and C-C′ lines.

B-B′ profile: The thickness of top soil zone with seismic velocity of 650 m/s to 850 m/s ranges from 1m to maximum 20m. The deepest soil zone is located just above the low velocity zone at the eastern end of B–B′ line. The lower weathering zone which is considered as soft rock has 6m to 10m in thickness with velocity readings of 1200 m/s to 1600 m/s. Fresh bedrock with seismic velocity of 4000 m/s to 5500 m/s is distributed along the line except along the eastern marginal zone which is considered low velocity or fracture zone with velocity of 2500 m/s.

C–C′ profile: This line is set up in the site of KD with exploration direction of north–east. The top soil zone with seismic velocity of 850 m/s is distributed uniformly having a thickness from 10m to 15m in average through its entire profile. The thickness of the second layer ranges from 6m to 12m with seismic velocity of 1500 m/s which is catagorized as a lower weathering zone. At the eastern part of B–B′ the line has the same property of bedrock with seismic velocity of 3800 m/s. The low velocity zone with 2000 m/s velocity is also intercalated at the eastern part of the spread. Therefore all 3 low velccity zones appearing at A–A′, B–B′, and C–C′ spread are presumed to be connected to each other with a northsouth direction.

D–D′ profile: Top soil zone shows 20m thickness in average with seismic velocity of 1700 m/s and is considered to be compacted. This zone is belongs to the lower weathering zone. The bedrock with 5000 m/s velocity is directly overlain by the overburden.

E–E′ profile: This line is set up at N 60E direction. The thickness of overburden including top soil and upper weathering zones having seismic velocity of 800 m/s varies 8m to 15m. The overburden overlies on the andesite directly. No other considerable low velocity zone is shown in this hard rock formation.

F–F′ profile: Owing to the obstacles such as existing houses and farming land located along the line, the exploration line couldnot be set up straight. The first layer which is deemed to colluvium and an upper weathering zone shows 700 m/s of seismic velocity. The thickness of this zone is deepest toward the southern flank: up to 30m at F–1 and F–2 spread. The lower weathering zone which is considered as soft rock with velocity of 1700 m/s os cropped out at the northern end of the F–1 spread. The thickness of lower weathering zone is ranges from 10m to 20m. Andesitic bedrock shows its seismic velocity of 5000 m/s.

G-G′ profile: The line is set up in a parallel direction of 50m from E–E′spread. The thickness of the top soil zone with 700 m/s and lower weathering zone with 2000 to 2500 m/s of seismic velocity thins towards the eastern direction and finally becomes thinest at the center of the gully. This indicates the weathering process of coarse grained syenite is faster than fine grained andesite. The refore the overburden of weathered syenite and granite is more quickly eroded than the one of andesite.

H–H′ profile: This spread with a total explorated distance of 33m is set up to the west flank of the area. The thickness of top soil zone is ranges from 2m to 13m. This zone with seismic velocity of 550 m/s to 1000 m/s thicken toward the down slope. Lower weathering zone appears at the southern end of the spread with seismic velocity of 2500 m/s. A low velocity zone which is deemed to be a fracture zone is distributed at the southern part of the spread. The fracture zone having 2950 m/s is assumed to extend deeply into the bedrock whose seismic velocity is 4500 m/s.

I-I′ profile: The top soil zone varies from 6-12m in average through the entire profile. Its velocity is about 550 m/s. The lower weathering zone with 2000 m/s of seismic velocity is distributed with a thickness of 5-8m through the profile. That is, bedrock with 5500 m/s of velocity is developed 11m to 20m below land surface.

J-J′ profile: The top soil zone with seismic velocity of 650 m/s has 4m to 6m thickness. The thickness of the lower weathering zone with 2000 m/s to 2500 m/s velocity ranges from 12m to 18m. The low velocity zone (fracture zone) is formed at the center part of the spread with a width of 15m. This low velocity zone is assumed to be continue in to the bedrock.

6-3 Test boring: The location and drill logs of 2 test boring holes are shown on the attached geologic map and drill log.

DH*-*1 Hole: This hole was drilled upto 70. 2 meters with Nx size. Bedrock as shown by diamond drilling is black to dark grey, fine to medium grained, and massive and very hard andesite having almost 100 percent core recovery and RQD values. Steeply dipping joints filled with calcite and some minerals appeared through the entire drilling hole. Ground water level stands up 9m below land surface as measured in the hole after completing of drilling.

DH*-*2 Hole: As shown in drill log, bedrock is light grey to light brown syenite with medium grained, lath shaped hornfels, felspars. Most of cores show that joints are stained by iron minerals and coated by epidote and calcite minerals. At depth from 55. 5m to 63m in the cores, highly crushed and sheared rock fragments belonging to HW (highly weathered) and showing many slickenside appeared.

6-4. Water pressure test: Bedrock was water pressure tested for permeability in the drilled holes, commencing from the bottom of holes with 2 meter interval under the water pressure of 5 kg/cm^2 and 10 kg/cm^2 per each interval. At the places where high leakage occured, lower water pressure was applied. Double packer was used for the test.

DH-1 Hole: The test was done from the base of the casing whivh was installed from the GL to 12m below GL to the bottom of the hole. The ground water table was 9m below land surface. Because the tested interval from 12m to 38m encounted so may numbers of joints and other permeable openings caused by the weathering processes, higher values of permeability ranging from 2. 39×10-4 cm/sec were recorded. The premeability coefficient of the next interval; that is from 3. 77×10-5 cm/sec. The interval from 48m to 70m showed 100% of core recovery and 100% of RQD with no leakage at all. This means that the interval has not been affected by substantial dynamtic metamorphism revealing impermeable and sounder rock situation.

DH-2 Hole: The water pressure test was done from depths of 16m to 80m with temporary casing installed in the hole. All intervals except 38m to 40m, 54m to 56m, and 60m to 66m shows permeability of less than 1×10-4cm/sec. The intervals from 60m to 66m had very poor core recovery, very poor RQD, and many mumber from 7 to 29 and showing high rate of leakage. The permeability of the interval ranges from 1. 88×10-4 to 2. 5×10-4 cm/sec. This high value is considered to be derived from fracturing and faulting effects occuring in this zone.

DH-1

Depth	Inlet pressure	permeability (K) (×10-4cm/sec)	remark
0 —12. 0	—	측정불가	casing Inserted
12. 0—14. 0	1. 4	8. 05	
14. 0—16. 0	2. 0	6. 895	
16. 0—18. 0	2. 5	7. 05	
18. 0—20. 0	4. 0	2. 39	
20. 0—22. 0	1. 5	8. 5	
22. 0—24. 0	1. 5	4. 59	
24. 0—26. 0	1. 6	8. 625	
26. 0—28. 0	1. 7	9. 225	
28. 0—30. 0	10. 0	0	
30. 0—32. 0	5. 0	4. 367	
32. 0—34. 0	2. 3	6. 897	
34. 0—36. 0	3. 5	5. 979	
36. 0—38. 0	4. 0	4. 004	
38. 0—40. 0	5. 0	0. 377	
〃	10. 0	0. 664	
40. 0—42. 0	5. 0	0. 596	
〃	10. 0	0. 522	
42. 0—46. 0	10. 0	0	
46. 0—48. 0	5. 0	0. 807	
〃	10. 0	0. 613	
48. 0—70. 0	10. 0	0	

DH-2

Depth	Inlet pressure (kg/cm^2)	permeability (K) (×10-4cm/sec)	remark
0 —16. 0			casing
16. 0—28. 0	10	0	
28. 0—30. 0	5	0. 296	
〃	10	0. 093	
30. 0—32. 0	5	0. 485	
〃	10	0. 175	
32. 0—34. 0	5	0. 482	
〃	10	0. 586	
34. 0—36. 0	5	0. 158	
〃	10	0. 114	
36. 0—38. 0	5	0. 271	
〃	10	0. 154	
38. 0—40. 0	5	2. 954	
〃	10	0. 910	
40. 0—42. 0	5	0. 474	
〃	10	0. 280	
42. 0—44. 0	5	0. 097	
〃	10	0. 082	
44. 0—46. 0	5	0. 683	
〃	10	0. 900	
46. 0—48. 0	5	0. 770	
〃	10	0. 321	
48. 0—50. 0	5	0. 329	
〃	10	0. 185	
50. 0—52. 0	5	0. 322	
〃	10	0. 136	
52. 0—54. 0	5	0. 276	
〃	10	0. 218	
54. 0—56. 0	5	1. 822	
〃	10	1. 304	
56. 0—58. 0	5	0. 884	
〃	10	0. 858	
58. 0—60. 0	5	0. 553	
〃	10	0. 332	
60. 0—62. 0	4. 5	2. 510	
62. 0—64. 0	4. 5	2. 501	
64. 0—66. 0	4. 5	1. 887	
66. 0—68. 0	5	0. 635	
〃	10	0. 190	
68. 0—70. 0	5	0. 774	
〃	10	0. 272	
70. 0—72. 0	5	0. 257	
〃	10	0. 114	
72. 0—74. 0	5	0. 368	
〃	10	0. 216	
74. 0—76. 0	5	0. 322	
〃	10	0. 282	
76. 0—78. 0	5	0. 315	
〃	10	0. 176	
78. 0—80. 0	5	0. 307	
〃	10	0. 137	

7. Conclusions and Recommendations

1. The rocks exposed in the investigation area are andesite of late Cretaceous age and syenite and Aplitic granite of Bulkugsa Series of early Cretaceous Period, which inruded the older andesitic rock.
2. The strike and dip of major joint is N10° to 60°E, and 70°SE to vertical respectively.
3. Accoding to seismic exploration, lower velocity zone, deemed to be fractured and/or crushed zone, is appeared along the gully center of east flank of the area.
4. Test drilling shows that andesite bedrock is

mostly very hard, massive, and very fine to medium grained and has almost 100 percent RQD and core recovery. In comparision with andesitic bedrock, intruded syenite cores show that it is highly crushed especially at the depth from 55m to 63m.

5. More detailed information of subsurface geology and geologic structures are needed at the stage of final design work. Syenite body distributed along the gully of western part of the area should be avoided from the proposed line of main cavern owing to highly crushed weak zone.

원유 비축시설 건설을 위한 예비조사

한 정 상 · 허 진

요 약 : 원유 비축시설 건설을 위한 예비조사로서 지표지질조사, 탄성파탐사 및 시추조사를 실시하고, 그 결과를 종합분석하여 본보고서를 작성하였다.

본지역의 지질은 백악기의 중성화산암류인 안산암과 이를 관입한 후기 백악기의 불국사통에 속하는 섬장암과 반화강암으로 구성되어 있으며, 절리는 불규칙적이기는 하지만 N10°~60°E, 70°SE 내지 수직이 우세하다. 탄성파 탐사결과에 의하면, 본조사지역 동반부에 남북방향의 저속도대가 발달하고 있음을 확인하였으며, 지층별 추정탄성파속도를 요약하면 표토층, 200~800 m/sec; 상부풍화대 500~1000 m/sec; 하부풍화대와 연암, 1000~3000 m/sec; 경암, 3000 m/sec 이상이다. 시추결과에 따르면, 안산암은 매우강하고, 치밀하고, 암심회수율과 RQD는 거의 100%에 달하고 있었다. 섬장암의 분포지역은 절리가 발달해 있었고, 55~63m (DH-2 hole)구간에 특히 발달되어 있었다. 수압시험은 double packer를 이용하여, 공저에서 부터 매 2m 간격으로 5kg/cm² 와 10kg/cm² 의 압력으로 수압시험을 실시하였으며, 누수현상이 일어나는 구간은 5kg/cm² 이하의 압력으로 실시하여 매구간별 투수계수를 구했다. DH-1 hole의 경우 자연수위는 지표하 9m였고, 38~40m 까지는 투수계수가 3.77×10^{-4}~6.44×10^{-4}cm/sec에 이르며 48~70m 구간까지는 10kg/cm² 의 수압하에서 전혀 누수현상이 발생하지 않았으며, 매우 견고한 암석임을 암시하고 있다. DH-2 hole의 경우, 파쇄 및 변층작용으로 본구간의 투수계수는 1.88×10^{-4}~2.5×10^{-4}cm/sec를 나타내고 있다.

현재까지 조사된 결과로 보면, 서반부에 발달한 계곡을 따라 섬장암체가 심히교란되어, 본지역을 피하여 지하비축 구조물이 설치되어야 할것으로 사료된다.

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