PUMP-OUT TESTS IN ALLUVIAL SANDS – A CASE STUDY

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ABSTRACT

For design of the dewatering system for construction of a multi-storeyed building with three basements, pump-out tests were conducted to evaluate the various hydraulic parameters of the aquifer. The deposits at site consist of fine sands of alluvial origin. The test results indicated very high permeability of the aquifer, necessitating a complex dewatering system that was not envisaged earlier. The paper presents details of the test conducted and analysis of the test results.

INTRODUCTION

The project site is located near Delhi in northern India. A commercial building (shopping mall) is planned to be constructed which shall have three basements and ground plus 18 storeys. The foundation level shall be about 18 m below the Original Ground Level (OGL). For foundation construction, it was necessary to lower the groundwater level to 21 m depth below OGL.
Since the excavation for the basement required substantial dewatering, pump-out tests were performed after excavation to 7 m depth. The hydraulic parameters obtained from the test were used for design of the dewatering system. Typical borehole data, along with project levels, has been presented on Fig. 1.

GENERAL SITE CONDITIONS

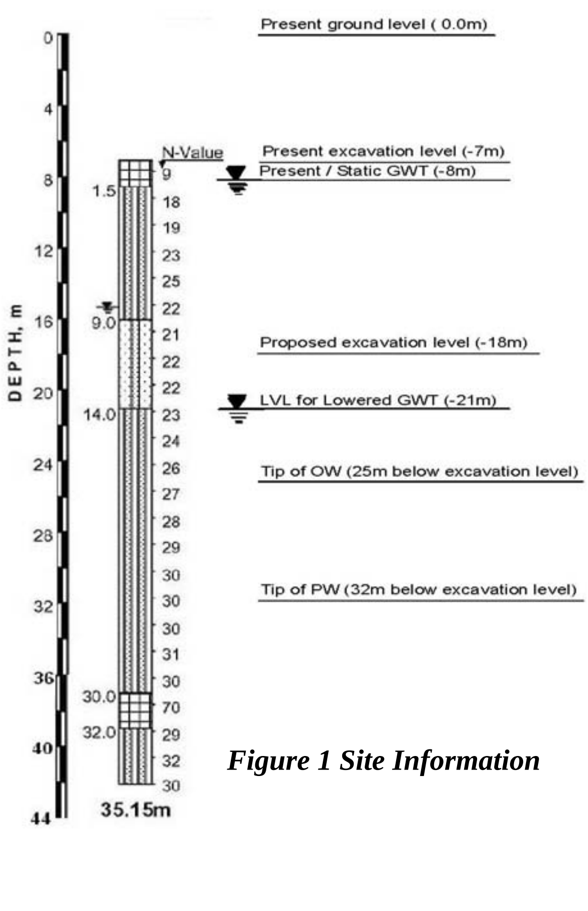

Figure 1 Site Information

Geological Setting

The Indo-Gangetic alluvial tract (Krishnan, 1986) is in the nature of a synclinal basin formed concomitantly with the elevation of the Himalayas to its north. It was formed during the later stages of the Himalayan Orogeny by the buckling down of the northern border of the peninsular shield beneath the sediments thrust over it from the north.
The newer alluvium (age Upper Pleistocene to Recent), locally called "*Khadar*" is encountered in the project area. The soils are deposits of the River Yamuna and consist primarily of fine sands and silty sand.

Site Stratigraphy

Based on the boreholes drilled, fine sand was encountered from the excavated level to 35~40 m depth. The sand is loose to medium dense to about 25 m depth below which it is generally dense in condition with SPT values of 30 to 50. Groundwater was met at 8 m depth. Laboratory permeability tests indicated that the coefficient of permeability of the soils is in the range of 2 to 5 $x10^{-4}$ cm/s.

AQUIFE R PUMP OUT TEST

An aquifer test (full scale pump-out test) was performed at site to determine hydraulic parameters such as drawdown-time relationships, transmissivity, hydraulic conductivity, well storage coefficient, etc. The test was performed in three stages viz., step-drawdown test, constant drawdown test and recuperation test (Gupta & Sundaram, 2003). Hydraulic parameters derived from the tests, averaged over the spatial zone of influence of the test, are used to design dewatering system and to develop a hydro-geological model.

Details of Wells Installed

For conducting the test, a pump well of 300 mm diameter with PVC casing of 200 mm diameter was installed to 25 m depth below excavation level (i.e., 32 m below OGL). Four observation wells of 150 mm diameter with 100 mm diameter MS casing were installed to 18 m depth below excavation level (i.e., 25 m below OGL). The spacing between the pump well and observation wells was kept at 10 m. A schematic sketch of the well arrangement is illustrated on Fig. 2.

For the observation wells, top 3 m of MS casing was provided as blank and slotted casing was used up to the bottom of the well. In the pump well, blank casing of 6 m at top and 3 m at bottom was provided. The intermediate section was slotted. Cross-sections of the pump well and observation wells are presented on Fig. 3.

A calyx-boring rig was used for drilling the wells through the alluvium. After the completion of boring to the required depths, the bore was cleaned and M.S. casing pipe of required section was lowered. In pump well, 200 mm diameter casing was used and in observation wells, 100 mm diameter casing was used. The annular space of pump well and observation wells was filled with pea-gravel as filter medium. The wells were developed using compressed air.

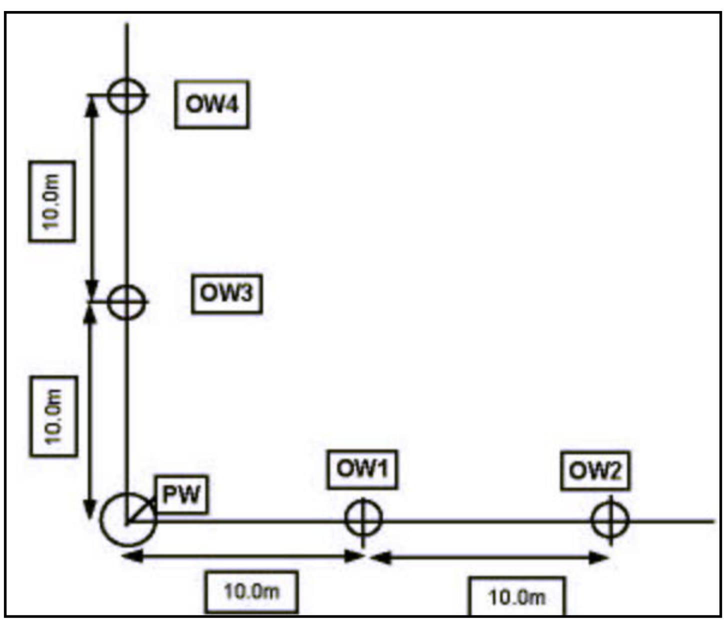

Figure 2 Well Layout Plan

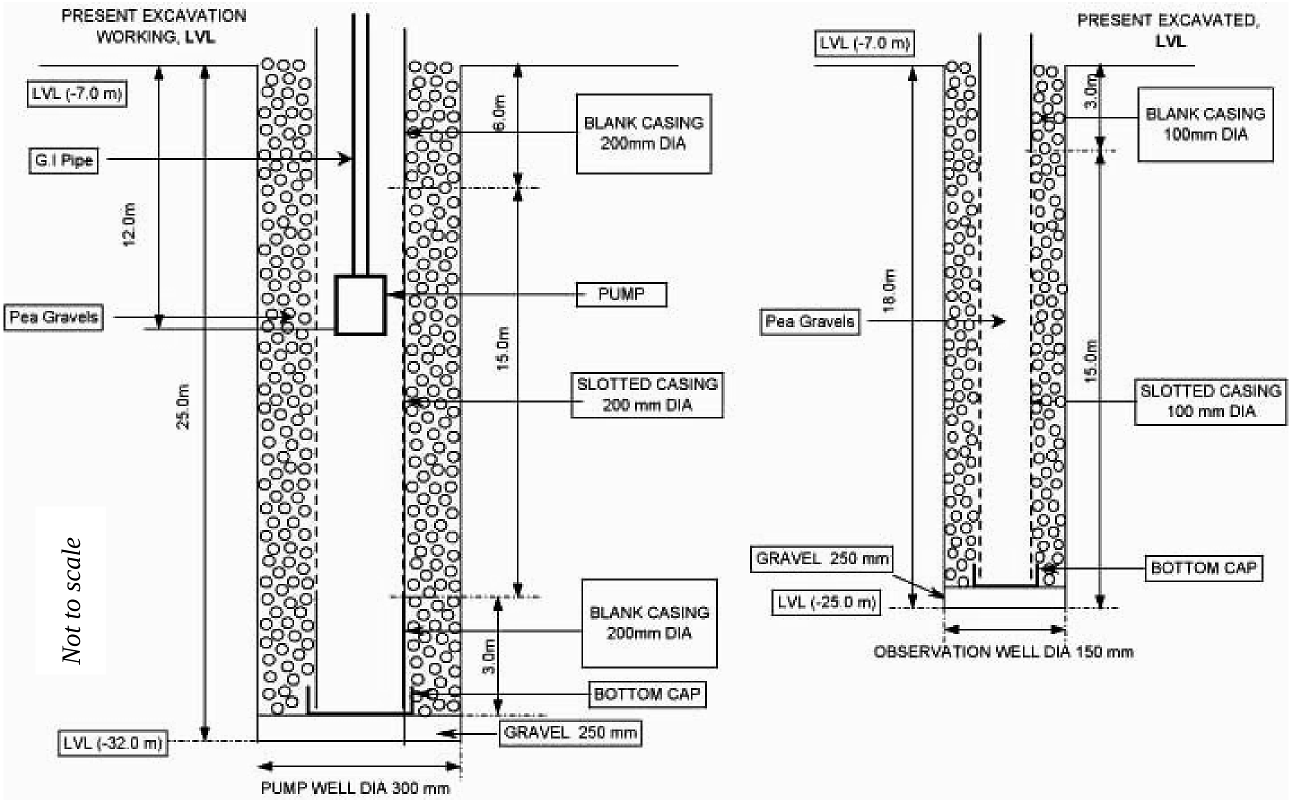

Figure 3 Cross-sectional Profiles of Wells

Set-up

After installation of the wells, a submersible pump was lowered into the pump well. The submersible pump was operated in stages so as to develop the pump well and maintain free-flow of water. The static water levels at all locations were recorded prior to operating the pump. A control valve and flow meter were attached to the delivery line. The water was discharged by a PVC pipe to the discharge point.

Pumping Trials

Pumping trials showed that the field permeability of the sand deposit is substantially higher than the laboratory values and that the lowering of water level was quite less even under high discharge. Initially, a submersible pump of 20 m^3/hour capacity was used; but the drawdown was found to be insignificant. Accordingly, a high capacity submersible pump with a maximum yield of 50 m^3/hour was selected to conduct the test.

Step Drawdown Test (SDD Test)

Step drawdown test is used to establish short-term yield-drawdown relationship. Stage pumping is done to approach the estimated maximum yield of the well.

Ground water level measurements are taken in the pump well and observation wells at frequent time intervals. The average discharge for each step is recorded. The results are plotted as step drawdown vs. time for each step (BS 6316), as shown on Fig. 4. The data is also plotted as specific drawdown (drawdown/ discharge) vs discharge at the end of each step, as shown on Fig. 5.

The relationship is used for estimating the well parameters like – (a) formation loss coefficient and (b) well loss coefficient. The test results are analyzed to estimate the discharge value for steady state/constant discharge test so as to stress aquifer for proper response.

As per the test results, drawdown at maximum discharge ($46.6 m^3$/hour) in the pump well was 1.53 m and in the observation well located at 10 m distance (OW-1) is 0.34 m.

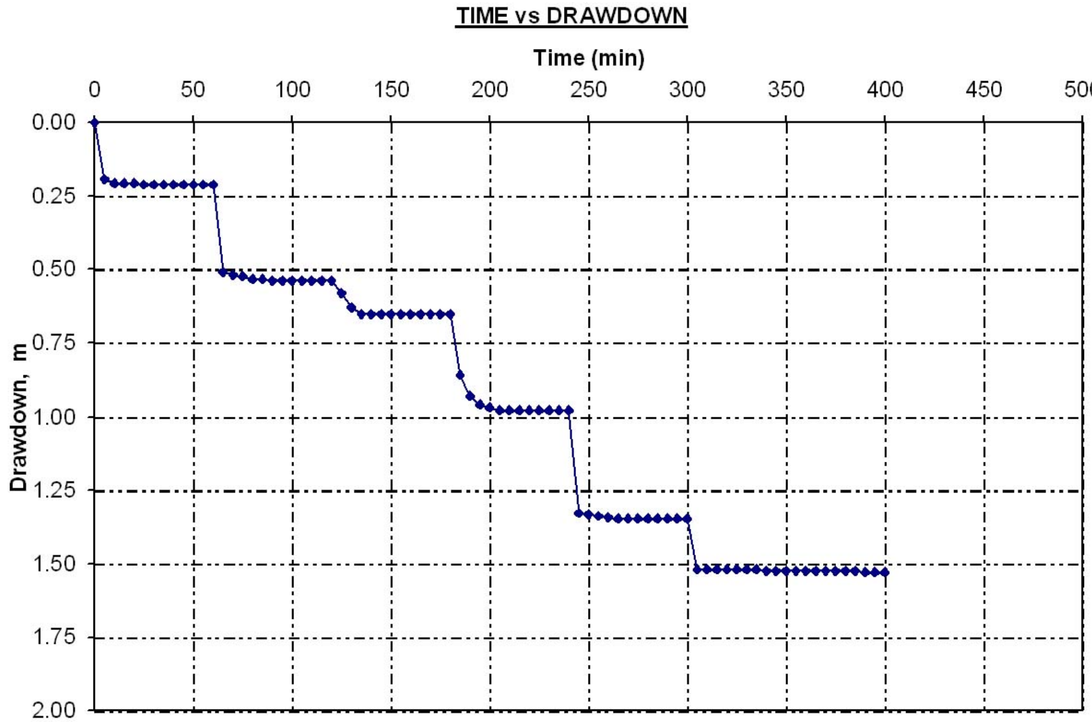

Figure 4 Results of Step-Drawdown Test at PW Location (Time vs. Drawdown)

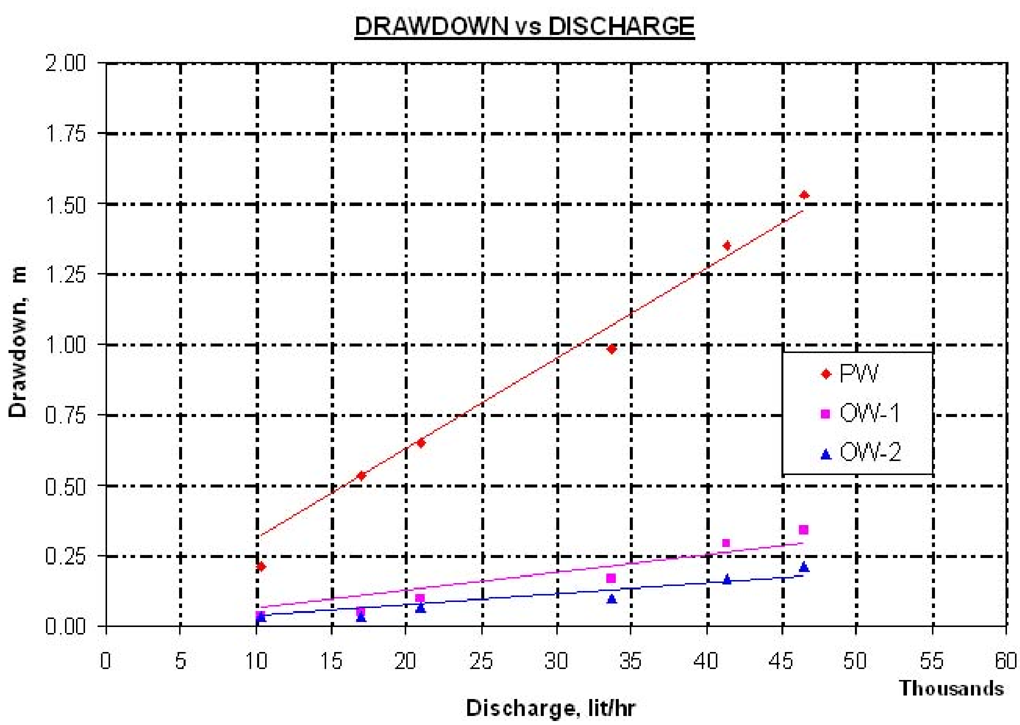

Figure 5 Results of Step-Drawdown Test (Drawdown vs. Discharge)

Constant Discharge Test (CD Test)

Constant discharge test provides data on the hydraulic characteristics of the aquifer within the radius of influence of the pump well. The pump well is continuously pumped at constant discharge rate so as to ensure the desired depression of water level at steady state.
Water level readings were recorded at the pump well and the observation wells at regular time intervals till the near steady state/equilibrium is reached. The test was continued over a period of about 60 hours to ensure steady state response. The pump was operated at a constant discharge of 48000 litres/hour. The results are plotted as corrected drawdown vs. time on semi-log scale for the pump well and observation wells. Test results for the pump well location are plotted on Fig. 6.

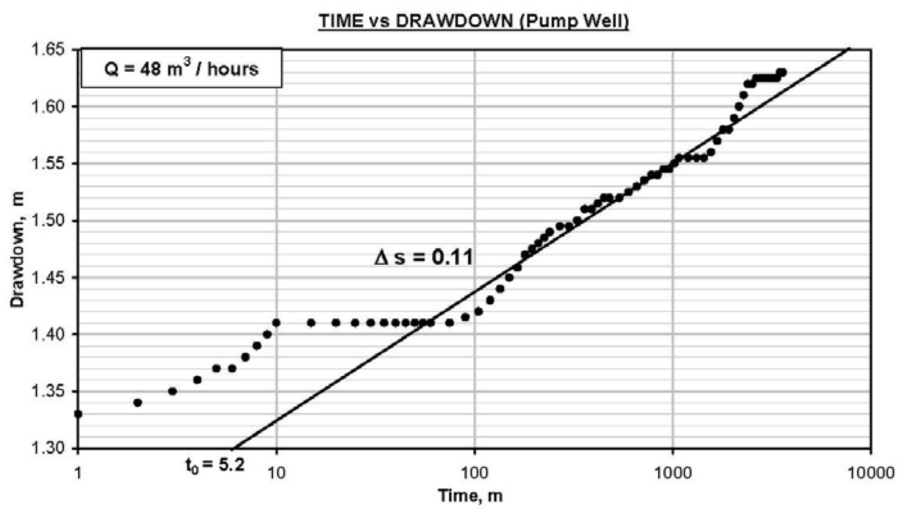

Figure 6 Results of Constant-Drawdown Test (Pump Well Location)

The results have been analyzed by Cooper Jacob's method (Todd, 1995[4]; BS 5930[3]) to compute various parameters.

Recovery/Recuperation Test

After completion of pumping out test, the pump is shut down for the recovery test. During recuperation, the water level measurements are recorded in the same sequence as that of during pumping stage. The recovery test data is used to compute aquifer parameters based upon Theis' recovery method (Todd, 1995). The results are plotted as residual drawdown vs. time ratio (t/t') on semi-log scale for the pump well and observation wells. Test results for the pump well location are plotted on Fig. 7.

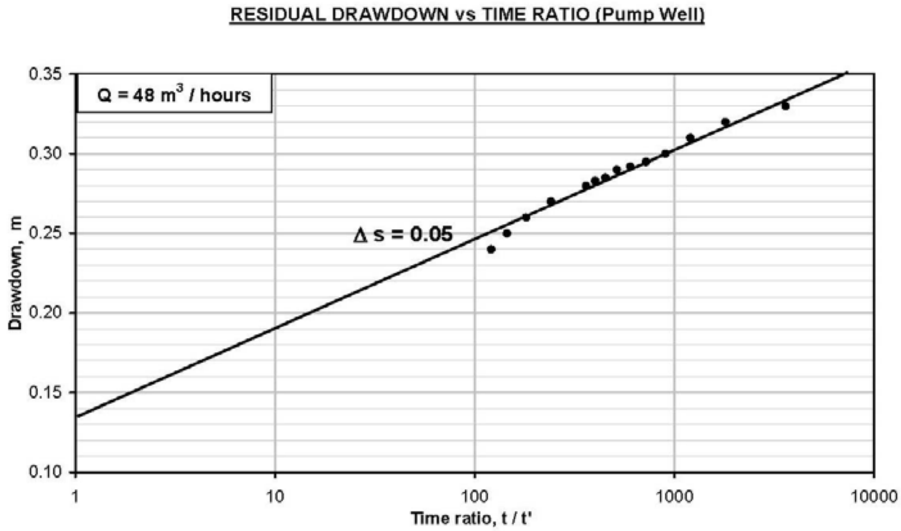

Figure 7 Results of Recovery/Recuperation Test (Pump Well Location)

CONCEPTS FOR ANALYSIS

The various analyses approaches of unsteady flow and equilibrium methods are applicable for confined aquifer and fully penetrating wells.

The analyses assume uniform, homogeneous soil mass with uniform properties. It is further assumed that the permeability of strata below the well tip is very low; as such data is analyzed considering fully penetrating well. Further, if the bottom of well casing is plugged with sufficient bottom blank casing portion, only radial flow will occur. The vertical flow shall be negligible.

From the analysis, aquifer parameters like coefficient of Transmissivity (T), coefficient of permeability / hydraulic conductivity (k) and storage coefficient (S) for CD test and recovery test have been computed by Cooper – Jacob method.

As per Cooper-Jacob analysis, the various expressions are: -

$$T(m^2/day) = \frac{2.303Q}{4\pi\Delta s} \qquad K\,(\text{m/sec}) = \frac{T}{b} \qquad S = \frac{2.25\,T\,t_0}{r^2}$$

where
- s = observed drawdown, m
- b = aquifer thickness, m
- Q = constant discharge, m^3/day
- Δs = change in drawdown, m
- t_0 = extrapolated time at zero drawdown, days
- r = radial distance of observation well from pump well, m
- K = Coefficient of permeability, m/sec
- T = Transmissivity coefficient, m^2/day
- S = Storage coefficient

TEST RESULTS

The following table summarizes the hydraulic parameters as interpreted from the constant discharge test results using the Cooper-Jacob method:

Well No.*	Parameters from Field Data		Transmissitivity, T (m^2/day)	Coefficient of Permeability, K (cm/sec)	Storage Coefficient, S $\frac{2.25\ T\ t_0}{R^2}$
	Δs, m	t_0, min			
OW-1	0.14	1.8	1507	1.6E-01	42E-03
OW-2	0.12	4.7	1757	1.9E-01	32.25E-03
OW-3	0.12	3.0	1757	1.9E-01	82.35E-03
OW-4	0.10	2.4	2108	2.2E-01	5.9E-03
PW	0.11	5.2	1917	2.0E-01	-
* PW: Pump Well , OW: Observation Well					

The following table summarizes the hydraulic parameters as interpreted from the recuperation test:

Well No	Δs in m	Transmissitivity, T (m^2/day)	Coefficient of Permeability, K (cm/sec)
OW-1	0.05	4222	4.5×10^{-1}
OW-2	0.05	4222	4.5×10^{-1}
OW-3	0.06	3519	3.8×10^{-1}
OW-4	0.05	4222	4.5×10^{-1}
PW	0.05	4222	4.5×10^{-1}

CONCLUSIONS AND RECOMMENDATIONS

Reviewing the test results, it is observed that the global coefficient of permeability as determined from the pumpout test is substantially higher than the laboratory coefficient of permeability by nearly three orders of magnitude. The transmissitivity and storage coefficient of the aquifer is also substantially high.

The test results were used to design the dewatering system for construction of the building. As per the planned excavation level, it was necessary to lower the water table by nearly 15 m below the static groundwater table level. The final dewatering system adopted was a composite system of pump wells spaced about 25~30 m apart.

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