Challenges in Designing and Unique Revival of an Ancient Tray Well At Indore

Engineer in Charge Sr. Engineers Financial Advisor
akrao266@gmail.com
Department of Atomic Energy, RRCAT, Indore
¹Financial Advisor of Deolite (US), Mumbai

ABSTRACT

In view of persistent erratic rainfall in Malwa region of Madhya Pradesh, since four years, the ground water level has depleted and many of the successful tube wells in city have dried up. In view of very poor rainfall in 2008, when rainfall was recorded as 425 mm as against normal precipitation of 825 mm, the tube wells in city stopped yielding water from November 2008 itself. This has increased dependency of Indorians on filtered Narmada water supplied by Indore Municipal Corporation (IMC). In view of pathetic situation of Indorians, ‘IMC’ had curtailed water supply to bulk consumers like Raja Ramanna centre for advanced technology (RRCAT) which is a premier institute under department of Atomic Energy in Indore, (M.P.). The dual jolt created by the depleting ground water level coupled with curtailment of piped supply by IMC has left the centre with no other option except to adopt some long term & some short term measures to handle the situation. The long term measures are beyond the purview of present paper. Under short term measures, reviving of old wells was taken up as one of the measures. The paper briefly deals with as to how the authors successfully attempted to discover a buried ancient high yield well. The paper deals with failure analysis of collapse of steining/lining of an ancient tray well, identifies deficiency in currently practiced methodology of design of steining, suggests improvement in the method of design of steining giving comparison of thickness arrived at using six different philosophies and briefly highlights challenges faced in restoring the buried well etc.

1. INTRODUCTION

An area in close proximity to cement godown in RRCAT’s premises used to remain waterlogged. The patrolling security personnel often used to report presuming that either water line or sewer line might be leaking in this region. This was never given a serious consideration as no such line was ever laid there. In view of water crisis, the land documents related to land compensation were referred, to find out location of open wells not yet considered for use. As per records the previous land owner of this wet area demanded higher compensation claiming existence of a high yield well. The earlier land owner was called and asked to show the location of high yield well. He confirmed that well was there in the marshy wet area since his childhood but now it seems to have been filled up. In order to find out exact location of the well, Wenner four electrodes resistivity survey was carried out.

Causes of Failure of Ancient Tray Well

Scrupulous investigation of the case reveals that in addition to routine causes of failure, there are some eye opening factors leadings to failure of well as mentioned below:

1. **Location:** The well is located in a low lying area. The adjoining natural catchment steeply terminates in this zone, thus the well is in basin. The level difference of ground is of the order of 5.0 metre in a distance of merely 10.0 meter and then the slope becomes little gentle when for another 10.0 metre length of terrain, it dips by merely 1.00 metre. The wells located in such areas are popularly known as tray well. This is really a case of tapping a localized body of perched ground water which is perched not through a continuous impermeable black cotton expansive soil stratum but on a lenticular bed of impervious material to a limited extent. The nearby existing natural lake appears to be hydraulically connected to this well and this may probably be one of the reason of high yield.
In view of steep slope and heavy rains during seventies or eighties filled up surrounding accumulated excavated earth must have flown towards the well due to excessive exit gradient of flow beyond permissible limit as per Bligh’s theorem and Lacey’s theorem.

2. **Collapse of Brick Lining**: This has occurred due to two reasons:
   (a) **Deteriorating Strength of Bricks**: First class brick lining of class 120 and of 460 mm thickness was found at some places. The compressive strength of brick has come down to 63.84 kg/sq cm due to multiple factors including aging, creep, fatigue and last but not least alternate wetting and drying on outside face. During rains external face of wall is in submerged condition which after monsoon dries up and gets wet again in December’s rain locally called “Mawatha”. This leads to expansion/contraction which leads to cracks. The bricks obtained from collapsed wall of watchman’s shelter in the same locality of same age which has suffered from other factors listed above was also tested and the strength of brick has come down to 106.68 kg/sq cm in this case. The result is significant as it confirms aggravated conditions of deterioration to which the lining was subjected to.

   In this connection, it is mentioned that bricks manufactured in Indore have compressive strength in the range of 35 kg/sq cm to 55 kg/sq cm whereas the result of samples of bricks used for lining/steining under discussion indicates the use of high strength bricks which might have been brought from other places. Use of high strength bricks brought from other places in lieu of rubbles available in plenty, appears to be an act of ignorance. The joints of the brick work may fail thus off shooting the benefit of strength. The tensile strength of masonry does not increase proportionately with the use of high strength bricks. It is however agreeable that high strength bricks are low water absorbent and therefore deteriorate rather slowly.

   (b) **Structural Inadequacy**: Majority of the village farmers leave the job of lining/steining to mason’s wisdom. A thickness of 460 mm (Two traditional bricks) is too less for steining at a depth of approximately 6.0 meter. Inadequate thickness of lining could not sustain the earth pressure leading to collapse of high yield well. Even the text books do not suggest proper method of design of lining of tray well. As per the method suggested in text books the thickness of 460 mm is correct. The test results of old bricks indicate that bricks are of good quality hence failure is not due to use of inferior material. As per visual inspection workmanship appears to be good. These points lead us to believe that there is some deficiency in design methodology. The updated method is therefore elaborated in this paper.

   (c) **Lack of Foundation Concrete**: The brick lining was laid over compacted soil as per practice prevailing at that time. The dismantled material and the excavated earth did not show traces of concrete thus confirming the presumption.

3. **Reduction in Shear Strength of Soil**: Non compaction of the filled up soil around tray well dug decades ago was a normal practice and no surprise, it remains a practice even today giving strange logic that it ensures better percolation. Although the filled up soil underwent secondary consolidation but still it is voided. The poorly compacted soil absorbs considerable water. It is an accepted fact that absorbed water causes significant reduction in the shear strength of soil. The shear strength of normal soil mass is governed by the following. This is practically balanced by stored water but due to fluctuating water level, consideration of such balancing may prove detrimental hence such balancing is ignored. The well lining is thus designed as thick cylinder. In order to design the thickness of lining, first step is to finalize the material of lining which could be either bricks or stone or concrete. External radius is known while internal radius depends upon the thickness hence the same is initially unknown. Pressure is calculated using Rakine’s formula and \( \rho_{\text{max}} \) is found out in terms of internal radius \( R_i \). The hoop stress calculated in terms of \( R_i \) is equated to permissible hoop stress. As the value of hoop stress is directly proportional to depth \( H \) hence the thickness of lining is maximum at bottom and gradually reduces to minimum required at top equation:

\[
\phi = C + \tan \theta \]

where \( \phi \) stands for shear strength, \( C \) stands for cohesion of soil, \( \theta \) stands for normal strength and \( \phi \) stands for angle of repose of soil.

If the voids of soil is filled with water then shear resistance reduces as per following equation:

\[
\phi = C + (\rho - \rho_{\text{max}}) \tan \theta \]

where \( \rho \) = pore pressure exerted by filled up water.

The shearing strength of soil is reduced further if water accumulates at back of soil. The reduction in shear strength results in slope instability which leads to land slide/collapse etc.

4. **Soil Creep**: Geo-technically speaking soil creep is slow flowage of soil mass which is imperceptible and occurs even under thick vegetation. Special case of rapid soil creep, termed as Talus creep caused reduction in shearing strength of soil consequently affecting the slope stability of surrounding soil which ultimate resulted collapse of lining of well.
5. **Swelling Pressure of Soil. Flaw in the Prevailing Method of Designing of Steining/Lining**: Wells are basically a hole made in the ground by penetrating in to an aquifer to withdraw water. In case of soil the cross section of well is circular while in case of rock it may be square. Indeed circular wells are easy to sink in alluvial soils. The tray well under discussion is a gravity type circular well as the water in the well is at atmospheric pressure. In order to prevent collapse of earth lining also known as steining is provided. In view of circular shape hoop stresses and radial stresses are developed. These are evaluated as per Lame’s theory. The expression for the same are as follows:

Hoop Stress = \( \frac{\text{P} (R_2^2 - R_1^2)}{2(1 + \sin \phi)} \)

Radial Stress = \( \frac{\text{P} (R_2^2 - R_1^2)}{2(1 + \sin \phi)} \)

Where \( R_1 \) and \( R_2 \) stands for internal & external radius of well and \( \text{P} \) stands for Rankine’s earth pressure given by:

\[ \text{P} = \frac{\gamma H(1 - \sin \phi)}{(1 + \sin \phi)} \]

Where \( \gamma \) = submerged unit weight of soil, \( H \) = depth of lining & \( \phi \) = angle of internal friction.

As hoop stress is twice the radial stress hence design of steining is based on hoop stress. The lining is designed to resist lateral thrust evaluated as per lame’s theory. In wells.

Book: Soil Mechanics & Foundation Engineering under Para 9.3 The seepage pressure \( P \_s = i \cdot H \) where \( i \) stands for hydraulic gradient and \( H \) is unit weight of water. It is interesting to note that Dr B C Punmia in his famous book “Soil Mechanics & Foundation Engineering under Para 9.3 states that hydraulic gradient of cohesion less sand having specific gravity of 2.67 and void ratio 0.67 works out to unity. The expression for seepage pressure thus becomes the same as that of water pressure as being insisted by the authors. Alternatively hydraulic gradient for a particular case may be determined using Darcy’s equation.

In the text books density \( \gamma \) corresponds to submerged unit weight of soil has been considered, which in the present case is 1380 kg per Cum. In real life situations, during dry season, the upper layer of non submerged normal soil has a higher density and it is about 2380 kg per Cum in the present case. As lateral thrust \( 'P' \) as per Rankine’s earth pressure formula is directly proportional to density \( \gamma \) hence the required thickness of lining shall be more during dry season. If the design is to be based on worst condition, the thickness of lining shall proportionately increase by about 70 %. Moreover even during submerged state in case of tray well the submerged soil itself is worst affected by water pressure caused by heavy down pour creating dashing effect especially owing to stiff gradient. This water pressure, relevant in case of tray wells is resisted by submerged soil which ultimately transfers all thrust to the lining hence water pressure equal to ‘\( \gamma \cdot H \)' is required to be added in Rankine’s earth pressure formula to arrive at most probable value of lateral pressure \( 'P' \). If water pressure is also considered then the thickness of lining increases by more than three times as compared to what is calculated for submerged backfill conditions. Water pressure is calculated considering \( \gamma_\_w \), the unit weight of water. It is interesting to note that Dr B C Punmia in his famous.

<table>
<thead>
<tr>
<th></th>
<th>IV Design considering the cohesion less backfill dashed by water pressure</th>
<th>880 mm</th>
<th>3.50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V Design considering the cohesive backfill dashed by water pressure</td>
<td>970 mm</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>VI Design considering the rigidity of lining dashed by submerged backfill &amp; water pressure</td>
<td>1110 mm</td>
<td>4.40</td>
</tr>
</tbody>
</table>

Above table vividly put forth meaningful elucidation. Traditional method of design not only ignores the nature of backfill but also the water pressure, swelling pressure etc which act like impact forces. As per laws of mechanics force applied with impact is more aggressive than gradually applied force of same magnitude. The thickness of Random Rubble masonry lining in our case is provided as 1.20 metre at 6.00 metre depth, 1.00 metre at 4.00 metre, 800 mm at 2.00 metre depth and merely 600 mm above ground. In the present case swelling index being 33 %, the thickness of lining up to 2.00 metre below ground has been increased to account for swelling pressure. No such increase is made beyond this depth.

During reviving measures, R C C kerb has also been provided at two metre intervals and is designed as beam with additional moment empirically equal to \( wL^2/10 \) where \( w \) is density of soil and \( L \) is one third of mean circumference of well.

In case if the backfill is non cohesive in lieu of Rankine’s formula Bell’s equation must be followed to work out design force. Unfortunately the text books do not suggest the same. The thickness of lining arrived at using Bell’s expression with water pressure is about four times as compared to what is calculated for submerged backfill conditions.
As most of the lining materials in use are rigid hence it would be most appropriate to consider the backfill at rest and then work out the pressure considering water pressure which cannot be ignored in case of tray well. The thickness of lining considering soil at rest and resisting water pressure is more than four times as compared to what is calculated traditionally for submerged backfill conditions.

The details are summarised in the following table:

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Adopted Design Philosophy</th>
<th>Thickness of lining as per Adopted Design Philosophy</th>
<th>Increase in thickness of lining as Compared to Case I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Design considering the cohesion less submerged backfill</td>
<td>250 mm</td>
<td>1.00</td>
</tr>
<tr>
<td>II</td>
<td>Design considering the cohesion less dry backfill</td>
<td>441 mm</td>
<td>1.76</td>
</tr>
<tr>
<td>III</td>
<td>Design considering the cohesion less submerged backfill and seepage force</td>
<td>880 mm</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Authors further conclude that design of lining as rigid material gives the best result and in this case expression of pressure for soil at rest coupled with dashing water pressure need to be considered. Finally the designers need to visualise all the above state of backfill and design for the condition of maximum pressure. The lining so designed can safely withstand worst condition of pressure. The top layer of lining should be capable of exerting swelling pressure of soil if applicable. The method for considering impact of swelling pressure is also indicated.

Weep holes are never considered in the design of steining to ensure that lining does not fail even if weep holes are choked up. Nevertheless pre-monsoon cleaning of clogged weep holes ensures its effective performance in releasing water pressure thus enhancing factor of safety thereby adding to stability. In nutshell authors conclude that text book methods are applicable for one particular case and also for a normal well. The designers must take in to consideration the field conditions.

2. CONCLUSION

Extreme care must be taken in designing the steining of a tray well. In case of tray well, the submerged soil itself is worst affected by water pressure caused by heavy down pour creating dashing effect owing to stiff gradient. The lining of tray well should therefore invariably be designed to resist pressure exerted by submerged soil coupled with dashing water. The traditional method of designing the steining to resist submerged soil pressure alone results in under design thus causing failure in the long run. Authors based on real life experience suggest that steining of tray well should be designed for lateral forces worked out as per Rankine’s formula or Bell’s formula, depending upon the nature of backfill and irrespective of nature of backfill; water pressure needs to be considered as this water pressure is resisted by submerged soil which is ultimately transferred to steining.

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