In situ permeability and shape factor of flat-base recharge wells using variations of porous walls

Azizah Rachmawati¹, Suhardjono², Ussy Andawayanti², Pitojo Tri Juwono²

1 Department of Civil Engineering, Faculty of Engineering, Islamic University of Malang, Jl. MT. Haryono 193, Malang 65144, Indonesia.
2 Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Jl. Mt Haryono No 167, 65141 Malang, East Java, Indonesia.

E-mail: azizah.rachmawati@unisma.ac.id

Abstract. Shape factors of recharge wells that have existed in various forms can be seen in terms of the absorption and the value. The development of existing recharge wells considers their various shapes and values. The condition factor 5b, according to Dachler (1936) and Sunjoto (2002), needs to be examined. The shape factor is the coefficient of dimension planning, which takes into account the perimeter, area, volume, and water level of the recharge well. The permeability coefficient is very important. An experiment on the field involved three recharge well models in a flat base impregnation, testing the porous wall (L) and well radius (R). The aim of this research is to investigate the shape factor values of the three recharge well models whose upper walls are made of concrete pipes with diameters of 0.6 m, 0.8 m, and 1.0 m. In this study, the results showed that the shape factor simultaneously influenced the height of the porous wall (F = 22.49 > F_table = 5.59; P < 0.05). However, there is a positive correlation between the change in the shape factor and the height of the porous wall on a flat base for the recharge wells (R² = 0.79).

1. Introduction

Shape factors of recharge wells that have existed in various forms can be seen from the absorption and the value. There are 7 forms of recharge wells that have been developed by various researchers [1, 2, 3, 6, 8].

The development of existing recharge wells considers their various well shapes and the value. The condition factor 5b, needs to be studied more deeply because two forms of wells may illustrate the same shape with a flat base, but may have different F values [2, 7].

Rapid population growth and development have caused changes in land use. Many of the lands that were originally in the form of open land or forests have turned into residential or industrial areas. This does not only occur in urban areas, but also in cultivation areas and protected areas. The impact of changes in land use is increasing direct surface flow while decreasing the water that seeps into the soil [9].

One effort to improve the ability of the soil to absorb rainwater is through the construction of recharge wells. Rainwater will be collected and absorbed into the soil so that it can increase the amount of groundwater surface and reduce flow [5].

Recharge wells are one of the engineering techniques of water conservation. The variables that determine the size or dimensions of recharge wells depend on several factors, among others 1) surface
area; 2) rainfall characteristics, including intensity, duration of rain, and interval of rain; 3) the coefficient of permeability; and 4) increased groundwater height.

There are several methods for establishing the dimensions of recharge wells. Conceptualized that the volume of water in the well can be calculated based on the balance between the water entering the well and the water that seeps into the soil [7]. Water that seeps can be calculated from the groundwater level. The bottom of the recharge well is made to reach a porous soil layer so that water quickly seeps into the soil. There are several variables that determine the process of recharge, among others water discharge, soil stability coefficient, dominant duration of rain, and shape factors.

Shape Factors

Shape factors (F) have been examined by several experts, who mathematically analysed shape factors, seen from the conditions of holes with flat-shaped recharge bases, for wells on water-resistant soil at the top and with permeable (porous) layers [1, 2, 3, 4, 8, 10].

Dachler (1936) adds flow analysis through the base and wall of the hole. Samsioe [6], developed a form for the basis of a half-ball located on water-resistant soil and porous soil at the bottom. Sunjoto [7] developed the analysis by Dachler [2], showing that when the bottom of the hole is permeable, vertical flow through the bottom of the hole still exists and theoretically must be replaced by horizontal flow with a height of porous wall (L).

Shape factor values are influenced by the form and conditions. They are influenced by the radius of the well or R, the height of the water surface or H, and the height of the porous wall or L. Based on the description above, to describe the recharge well model with a review of shape factors, direct research was carried out on the field using models of recharge wells. In making wells, the most important parameter that needs to be observed is the starting point of water discharge input into the wells. The aim is to obtain shape factor (F) value variations of the height of the porous wall (L), variations in diameter and radius (R), reductions in water level (H1 and H2) and times of water level reduction (t1 and t2).

2. Materials and Methods

The performed research included the creation of wells directly on the field. The conditions had been previously determined. The various stages of analysis of the research were to be carried out properly. The size of the testing ground was determined based on the type of variable to be observed. Recharge wells were made in the form of a circle with concrete material and applied to flat grounds in land with a minimum groundwater surface of 1.50 meters from the groundwater level and a soil permeability value of ≥ 2 cm/hour. The water that flowed into wells is clean water. The testing land was equipped with a water reservoir and a discharge-measuring device to calculate the amount of flow into the model.

Research location

The research location is flat land in Sukolilo – Jabung, in the area of Malang. The land has an area of 6 x 10.8 m. Recharge wells were made of three pieces with different variations of diameters and porous wall. The model in the field was equipped with a water reservoir for discharge input, and a discharge measuring device. In this study, the wall was made of concrete pipes with cross sections of 0.60 m, 0.80 m and 1.00 m diameters.
The empirical model of water discharge that permeates the recharge wells takes the following:

\[ Q_0 = F \cdot K \cdot H \]  
(1)

\[ Q_0 = (L \cdot L) / (LT ^ (-1)) = [L^3 / T] \]

Where:
- \( Q_0 \) = discharge outflow on the ground that permeates, in m\(^3\)/sec [L\(^3\) / T]
- \( H \) = built-up or water depth in well, in meters [L]
- \( K \) = permeability coefficient, in centimetres/second [L / T]
- \( F \) = shape factor, in meters [L]

\[ F = \frac{Q_0}{K \cdot H} \]  
(2)

and \( F = f (R, \pi, L) \)

- \( R \) = radius of well, in meters [L]
- \( \pi \) = dimensionless number
- \( L \) = porous wall height [L]

Recharge wells have several requirements in order for them to absorb optimally the discharge of water entering the well. The water discharge entered the well from the water reservoir and the time needed to fill the wells until the water level became full and constant was recorded. Then, a measurement was taken of the time required for the water level to decrease. After a trend of correlation between input discharge and pervasive discharge was obtained, the results were used for analysis of intake discharge control.

The recharge well construction was performed directly on the field with several pieces of equipment. 1) A water pump was utilized as a device to take in and push water from a water source that will then flow into reservoirs through the installation of pipes for water supply. 2) Reservoirs were used as clean water storage tanks for the input discharge; in this study, the utilized reservoirs were artificial reservoirs constructed from refined masonry walls inside with the size specifications being 1.15 m in length, 2.05 m in width, 1.07 m in height, as well as the capacity or volume of reservoir being 2,522 m\(^3\). 3) PVC pipes were used in installations to carry intake water from reservoirs into infiltration wells measuring 4 inches or 10.16 cm. 4) Concrete pipes with diameters of 0.80 m, 1.00 m, and 1.20 m were used for the wells. Other necessary equipment included 5) carpentry equipment and 6) measuring tapes, rulers, stopwatches, flashlights, and cameras.
The experiment was performed on the field through the following stages. 1) The reservoirs were filled with water until they were full; water was then drained from the reservoirs into the wells while calculating the incoming discharge with a measuring device. 2) The water level was measured. 3) The decrease in water level \((H)\) and time \((t)\) were measured. 4) Water level reduction \((H)\) was observed at \((t)\) intervals of 3 minutes and 5 minutes. 5) The observations continued to be carried out until the water completely drained. 6) The procedure was repeated according to the three design conditions of \(L = 0.30\) m, \(L = 0.70\) m, and \(L = 1.00\) m.

![Image](image1.jpg)

**Figure 2.** Performing the experiment for \(Q\) (inflow into the well) and \(Q_o\) (discharge outflow to the ground) (photo: Azizah R.)

3. **Results and Discussion**

The observations for each well resulted in the volume value and the time needed to fill the discharge. From these values, \(Q_i\) as the observed filled depth of the channel with respect to time was obtained. Table 1 shows the discharge inflow, *in situ* permeability, and shape factor. The complete measurement results are presented in Table 1 below.

| Recharge Well | D (m) | R (m) | L (m) | H (m) | K (cm/sec) | Qi (m³/sec) | F (m) |
|---------------|-------|-------|-------|-------|------------|-------------|-------|
| Recharge Well 1 | 0.6   | 0.3   | 0.3   | 1.3   | 0.00205    | 0.00707     | 2.65103|
|               | 0.6   | 0.3   | 0.3   | 1.3   | 0.00205    | 0.00668     | 2.50643|
|               | 0.6   | 0.3   | 0.3   | 1.3   | 0.00205    | 0.00612     | 2.29756|
| Recharge Well 2 | 0.8   | 0.4   | 0.3   | 1.3   | 0.00205    | 0.00816     | 3.06341|
|               | 0.8   | 0.4   | 0.3   | 1.3   | 0.00205    | 0.00806     | 3.02559|
|               | 0.8   | 0.4   | 0.3   | 1.3   | 0.00205    | 0.00787     | 2.95269|
| Recharge Well 3 | 1.0   | 0.5   | 0.3   | 1.3   | 0.00205    | 0.00981     | 3.68199|
|               | 1.0   | 0.5   | 0.3   | 1.3   | 0.00205    | 0.00936     | 3.51309|
|               | 1.0   | 0.5   | 0.3   | 1.3   | 0.00205    | 0.00911     | 3.41899|

*Table 1. Shape factor and *in situ* permeability for a porous wall of 0.3 m*
Table 2 shows the field shape factor data (F field) obtained from input discharge data (Qi), built-up or water depth in the well (H), and coefficient field permeability (K). The value of permeability on the field was obtained by testing the permeability of falling head by drilling directly on the field with an auger boring tool. The complete measurement results are presented in Table 2 below.

### Table 2. Shape factor and *in situ* permeability for a porous wall of 0.7 m

| Recharge Well   | D (m) | R (m) | L (m) | H (m) | K (cm/sec) | Qi (m³/sec) | F (m)  |
|----------------|-------|-------|-------|-------|------------|-------------|--------|
| Recharge Well 1 | 0.6   | 0.3   | 0.7   | 1.7   | 0.00298    | 0.00924     | 1.82370|
|                | 0.6   | 0.3   | 0.7   | 1.7   | 0.00298    | 0.00873     | 1.72422|
|                | 0.6   | 0.3   | 0.7   | 1.7   | 0.00298    | 0.00801     | 1.58054|
| Recharge Well 2 | 0.8   | 0.4   | 0.7   | 1.7   | 0.00298    | 0.01068     | 2.10738|
|                | 0.8   | 0.4   | 0.7   | 1.7   | 0.00298    | 0.01054     | 2.08137|
|                | 0.8   | 0.4   | 0.7   | 1.7   | 0.00298    | 0.01029     | 2.03121|
| Recharge Well 3 | 1.0   | 0.5   | 0.7   | 1.7   | 0.00298    | 0.01283     | 2.53291|
|                | 1.0   | 0.5   | 0.7   | 1.7   | 0.00298    | 0.01224     | 2.41672|
|                | 1.0   | 0.5   | 0.7   | 1.7   | 0.00298    | 0.01192     | 2.35199|

Table 3 shows the results of measurements of field discharge and the first, second, and third repetitions for each well. Input discharge (Qi) was measured using a measuring tape and stopwatch. The completed results are presented in Table 3 below.

### Table 3. Shape factor and *in situ* permeability for a porous wall of 1.0 m

| Recharge Well   | D (m) | R (m) | L (m) | H (m) | K (cm/sec) | Qi (m³/sec) | F (m)  |
|----------------|-------|-------|-------|-------|------------|-------------|--------|
| Recharge Well 1 | 0.6   | 0.3   | 1.0   | 2.0   | 0.00267    | 0.01087     | 2.03544|
|                | 0.6   | 0.3   | 1.0   | 2.0   | 0.00267    | 0.01028     | 1.92441|
|                | 0.6   | 0.3   | 1.0   | 2.0   | 0.00267    | 0.00942     | 1.76404|
| Recharge Well 2 | 0.8   | 0.4   | 1.0   | 2.0   | 0.00267    | 0.01256     | 2.35206|
|                | 0.8   | 0.4   | 1.0   | 2.0   | 0.00267    | 0.01240     | 2.32302|
|                | 0.8   | 0.4   | 1.0   | 2.0   | 0.00267    | 0.01211     | 2.26705|
| Recharge Well 3 | 1.0   | 0.5   | 1.0   | 2.0   | 0.00267    | 0.01510     | 2.82700|
|                | 1.0   | 0.5   | 1.0   | 2.0   | 0.00267    | 0.01440     | 2.69732|
|                | 1.0   | 0.5   | 1.0   | 2.0   | 0.00267    | 0.01402     | 2.62507|

Discharge outflows were calculated by dividing infiltration well volume by infiltration time. The data was used to determine the performance of the height of the porous wall of the wells in reducing the discharge of water entering the well. The following are the ratios of recharge wells with variations of 30 cm, 40 cm, and 50 cm in well radius.

The apparent difference in well trends is that the well made from concrete pipes of 0.6 m diameter had very different characteristics from the other two types of wells. By the basis of this difference, it
can be noted separately that the use of 0.6 m-diameter concrete pipes is less optimal in absorbing water compared to the other two well sizes in the study area.

Figure 2 shows that with a porous wall of L = 0.3 m, there is a decrease in recharge discharge with almost the same trends for recharge wells number 2 and number 3. The results of discharge reduction are very different from the others. The second and third measurements have almost the same value. The first measurement was taken while the condition of the wells was still new and the soil was dry and still hard, while for the second and third, the soil condition was rather soft. This affected the time it took for water to be absorbed. The time needed for well number 1 was 30 minutes in the first measurement, while the second and third were 39 minutes and 41 minutes respectively. Nearly the same process also occurred for recharge wells number 2 and number 3; in the former, well measurement took 20, 24, and 27 minutes, while the latter required almost the same times, being 20, 21, and 25 minutes.

**Figure 3.** Outflow discharge for porous walls of 0.3 m. Source: study results

Figure 3 shows that with a porous wall of L = 0.7 m, there is a decrease in recharge discharge with almost the same trends for recharge wells 2 and 3. The results of discharge reduction are very different from the others. The second and third measurements have almost the same value.

**Figure 4.** Outflow discharge for porous walls of 0.7 m. Source: study results

Figure 4 shows that recharge well number 1 takes a longer time, in contrast to recharge wells number 2 and number 3, which have larger diameters of 0.8 m and 1.0 m respectively. The results in the figure show the most ideal trends compared to the previous figures. With nearly the same values, the time period for well number 2 and well number 3 is approximately 26 to 29 minutes. The outflow
discharge for well number 2 was 0.03865 m³/minute on the first measurement but decreased further on the second and third measurements. The same occurred for recharge well number 3, which was 0.05815 m³/minute on the first measurement and decreased for the second and third measurements. This condition can occur because the effect of the diameter width is not very significant compared to the depth of the porous wall.

![Figure 5. Outflow discharge for porous walls of 1.0 m. Source: study results](image)

The research results also indicated that the velocity was influenced more by another variable. It was possible that unmeasured variable could account for some aspects of the results. From the results of the description of the design parameters that have strong and weak influences, it can be seen that the relationship between shape factors and permeability for observations with porous walls of 0.3 m has a value of determination (R²) of 0.79, F = 22.49 > F table = 5.59, and 0.03 P < 0.05 by analysis of variance. Meanwhile the relationship between shape factors and outflow discharge has a higher influence for porous walls of 1.0 m, with the value of determination (R²) being 0.80 and F = 28.69 > F table = 5.59.

4. Conclusion

The results of the experimental research contributed to the understanding of shape factor and permeability. Recharge wells collect and absorb water into the soil to increase groundwater and reduce flow.

In this research, the conclusion is that recharge well number 2, which is 0.80 m in diameter and with a porous wall of 1.0 m has the most stable discharge. This shows that the input discharge that flowed into the recharge well was absorbed into the soil optimally. Although the time needed to absorb is almost the same, it has been shown that a porous wall height of 1.0 m influences the absorption rate of all the recharge wells. Regarding shape factors and permeability, observations of 0.3 m porous walls show a value of determination (R²) of 0.79 and of 1.0 m porous walls show a value of determination (R²) of 0.80. However, from the statistical analysis results, the shape factor and outflow discharge show F = 28.69 > F table = 5.59.

It is recommended that further research is carried out for recharge wells with designs of different well diameters, applied to other flat land areas with different types of soil and coefficients of in situ permeability.

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