Bench Terrace Design Made Simple

Ted C. Sheng

Department of Earth Resources Colorado State University
Fort Collins, CO 80523, USA
E-mail Address: teds@lamar.colostate.edu

Abstract: Bench terraces are effective soil conservation measures used on slopelands for crop production. When world's population increases rapidly, with a rate of 77 million a year and mostly in developing countries, many slopelands are brought into cultivation where land pressures are high. In many instances in the past, however, bench terraces were built without proper design, resulting in either high construction and maintenance costs or limited use. On the other hand, some design criteria are over-complicated which hampers their application.

This paper introduces a simple but scientific design for bench terraces. The design is based on many decades of field experience in the countries of Asia and Central America. It employs a step by step approach using basic arithmetic that can be understood by field technicians, extension officers, or farmers. Based on this design, a realistic estimate of construction cost and a land use plan can be easily produced.
Keywords: bench terraces, terrace design, land treatment, conservation measures

1 Foreword

For cultivation of slopelands, bench terraces are one of the most effective measures for erosion control and crop production. With the world's population rapidly approaches 9 billion in next five decades, many of the slopelands in the developing countries will be brought into food production. In many instances in the past, bench terraces were built without scientific design, resulting in unusually high cost, maintenance difficulties, or limited use. On the other hand, some over-complicated designs have discouraged people from using them.

The present paper concentrates on the design of two major types of bench terraces: Level Bench Terraces for dry land environment and Reverse Sloped Terraces for humid regions. The principles, however, can be applicable to the other types. For instance, level bench terraces can easily be converted to paddies by simply adding a small dike on the edge for impounding water. Outward sloped terraces can be designed using similar approaches and calculations.

Using land slope and the width of the bench (flat part) as two starting points, the design proceeds step by step with basic arithmetic that can be easily understood by field workers, land users, or farmers.

2 Design basics

- Use simple arithmetic and a step-by-step approach to design.
- Design bench terraces such that the volumes of cut and fill are to be equal for minimizing construction cost.
- Design terraces according to the needs of farmers, crops, climate, and tools to be used for farming.

3 Design procedures and criteria

(1) Widths of Bench

In designing bench terraces, the width of the bench (flat part) needs to first be determined by the farmers according to crop needs, tillage tools, as well as their individual preferences. Field technicians or extension officers need to check soil depths and inform farmers that wide benches require deep soils and higher construction costs. Experience has shown that for hand cultivation 2.5 m to 5 m wide are appropriate widths whereas for mechanization 3. 5 m to 8 m are proper where depth of soil does not constitute a limit.

(2) Slopes

Slopes can be measured by using a hand level or a clinometer. In design of terraces, a representative slope or a mode slope should be obtained from the field.

If the farmer will build terraces by hand, the appropriate slope range is from 7 degrees to 25 degrees (or 12.3% to 46.6%). If machines will be used for construction, the range is from 7 degrees to 20 degrees (or 12.3% to 36.4%) according to past experience. Slopes gentler than 7 degrees may best use simple conservation measures or agronomic measures. Using machines on a slope over 20 degrees is unsafe.

(3) Vertical Intervals

After the slope and the width are determined, the Vertical Interval (*VI*) can be calculated by a simple equation. *VI* is the elevation difference between two succeeding terraces. It is essential to calculate the *VI*; it not only shows roughly the height of future terraces but also provides the basis for further designing.

The simple equation using slope and the width of the bench as the main inputs is as follows:

$$VI = (S \times Wb) / (100 - S \times U) \quad (1)$$

Where *S* is land slope in percent (%), *Wb* is the width of the bench, and *U* is the slope of the terrace riser or side slope. Use a horizontal to vertical ratio to put into the equation such as 1 for machine built terraces, 0.75 for hand-made terraces, and 0.5 for stone terraces.

Example: The *VI* of 4m-wide bench, machine-built, on 15 degree (26.8%) slope is as follows:

$$VI = (26.8 \times 4) / (100 - 26.8 \times 1) = 107.2 / 73.2 = 1.46 \text{ m}$$

To verify the validity of this simple equation, an equation used in Peru (Low & Paulet, 1967) was tested and the results were found to be the same. However, their equation is rather complicated, requiring two steps to get an answer and tangent values of two slope angles.

$$VI = 2d / (1 - \tan\alpha \tan\beta) \quad (2)$$
$$d = (Wb / 2) \tan\alpha$$

α is the slope of the land in degrees and β is the top slope angle of the riser, in degrees, in relation to a vertical line. *Wb* is the width of the bench.

Another complicated equation using trigonometric functions was also tested and the same answer was obtained (Sheng, 1981). Consequently, it is appropriate to us Equation (1) which is simpler and easier to apply.

In Taiwan, three different equations are used for design of level, reverse sloped, and outward sloped bench terraces. (Chinese Soil and Water Conservation Society,1987). In fact, when width of bench and slope are fixed, *VI* does not change regardless of the type of bench terraces. *VI* is measured from center to center of the succeeding terraces which also marks the non-cut and non-fill point.

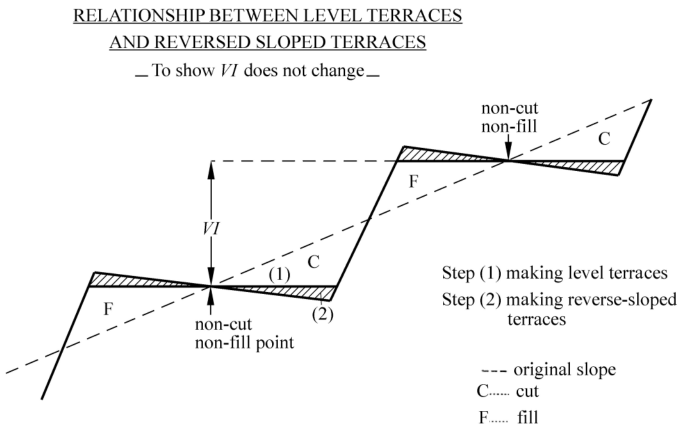


Fig.1 Same vertical interval (*VI*) between level and reverse sloped bench terraces

Fig.1 Shows that *VI* does not change between level and reverse sloped terraces. For outward sloped type, the *VI* is also the same.

(4) Heights of Riser

After *VI* is obtained it is easy to figure out the height of riser of the terraces. For level terrace, *VI* equals the height of the riser. For rice paddies, a 15 cm dike may be added to the *VI* to get the total height. For reverse sloped terraces, the *VI* needs to add a reverse height to get the total height. The reverse height can be easily calculated by the following equation:

$$RH = Wb \times 0.05 \quad (3)$$

Where *RH* is reverse height, *Wb* is width of bench, 5% is the reverse slope. A five percent (5%) reverse slope is sufficient to keep runoff away from the riser and it does not interfere with farming operation.

The height of riser (*Hr*) of reverse sloped terraces can therefore be obtained using the following equation:

$$Hr = VI + RH \quad (4)$$

Experience shows that the overall height of a riser should not exceed 1.8 m to 2 m; above that the maintenance work will become difficult.

(5) Widths of Terraces

The width of a terrace can be obtained by adding the width of the bench (*Wb*) to the width of the riser (*Wr*). *Wr* is calculated by multiplying the height of the riser to a riser slope (*U*) which has been explained in Equation (1).

$$Wr = Hr \times U \quad (5)$$

Where *Wr* is the width of the riser, *Hr* is the height of the riser, and *U* is the slope of riser giving value 1 for machine built terrace, 0.75 for hand made terrace, and 0.5 for stone made terrace. The total width of a terrace (*Wt*) is obtained as shown below:

$$Wt = Wr + Wb \quad (6)$$

(6) Lengths of Terraces

The length of a terrace is limited by the size and shape of the field and the degree of land dissection. Longer terraces will increase farming operation efficiency especially using machines for cultivation. However, too great a length in one direction in the case for drainage may cause accelerated runoff velocity and erosion. Based on past experience, 100 m in one inclined direction or 200 m in total is recommended for reverse sloped or drainage type terraces. The gradient for drainage is 0.5 % to 1 % according to soils and rainfall.

Leaner length (*L*), expressed in meters (m) in a hectare (ha), can be calculated as follows:

$$L = 10{,}000 / Wt \quad (7)$$

Where *Wt* is the width of terrace which has been explained previously.

(7) Net Area

Farmers are interested in knowing the net area for cultivation when terraces are to be built. The net area (*NA*) in a hectare (ha) can be obtained easily by multiplying leaner length (*L*) to the width of the bench (*Wb*):

$$NA = L \times Wb \quad (8)$$

Consequently, the percent of net area or percent of benches (*Pb*) in a ha can thus be obtained, as follows

$$Pb(\%) = NA / 10{,}000 \times 100 \quad (9)$$

It is important to know that on the same slope, the percent of bench or net area does not change regardless the width of the bench. In other words, building a wide bench or a narrow bench will get same percentage or flat area for cultivation, though too narrow a terrace will be impractical whereas too wide a terrace will need to cut deeper and cost more.

(8) Volumes to be Cut and Filled

To build bench terraces, as mentioned previously, the volume of soil to be cut and filled has to be equal in order to minimize the cost. There should be no extra volume of soil to be disposed of or borrowed from other places. Therefore, when we calculate volumes we need only to consider one volume (cut volume) that will eventually be moved down slope to form a terrace (See Fig. 1).

Volumes can usually be obtained by multiplying an area to a length. In our case, the area is a triangle or the cross-section of the cut part (*C*). Therefore, multiplying *C* by the linear length, *L*, will obtain the volume.

For level terraces, the equation for the cross-section (*C*) is simply as follows:

$$C = (Wb \times VI) / 8 \quad (10)$$

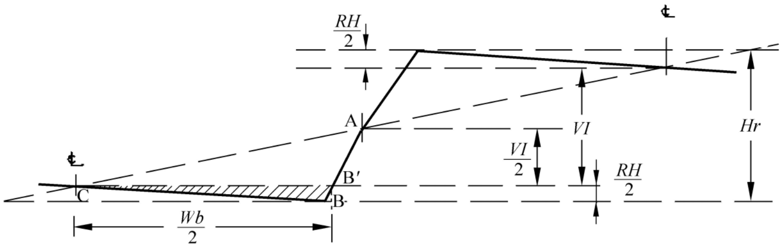
In case a small dike is needed, cross-section of the dike must be added to the above equation.

For reverse sloped terraces, the cut and fill is more and its equation is shown below:

$$C = (Wb \times Hr) / 8 \quad (11)$$

The following figure (Fig. 2) shows the calculation of the cross-section (*C*) of the reverse sloped terraces.

COMPUTATION OF CROSS-SECTIONAL AREA OF BENCH TERRACE



$$ABC = AB'C + B'BC$$

$$= \frac{\frac{Wb}{2}\times\frac{VI}{2}}{2} + \frac{\frac{Wb}{2}\times\frac{RH}{2}}{2}$$

$$= \frac{\frac{Wb\times VI}{4} + \frac{Wb\times RH}{4}}{2}$$

$$= \frac{\frac{(Wb\times VI)+(Wb\times RH)}{4}}{2}$$

$$= \frac{(Wb\times VI)+(Wb\times RH)}{8}$$

$$= \frac{Wb(VI+RH)}{8}$$

$$= \frac{Wb\times Hr}{8}$$

Fig.2 Computation of cross-sectional area of reverse sloped bench terraces

After the cross-section, *C*, is obtained, the volume to be cut and filled in a ha can be quickly calculated:

$$V = C \times L \quad (12)$$

Where *V* is the volume, *C* is the cross-section, and *L* is the linear length per ha.

(9) Depths of Cut

To find out depth of cut is essential. It is needed to compare with the soil depth measured in the field. If the measured depth is insufficient, then the width of the bench needs to be reduced to fit the depth on site (Sheng, 2000). The following equations are used to calculate the depth of cut for level terraces (Eq.13) and reverse sloped terraces (Eq.14) respectively. All the abbreviations have been explained previously.

$$(Wb/2)\ (S/100) \tag{13}$$

$$(Wb/2)\ (S/100) + RH/2 \tag{14}$$

(10) Specification Tables and Computer Software

For the convenience of field workers, a set of specific tables was produced and published (FAO,1988) for reference. Also, a special software, CONTREAT, has been produced since 1990s (Sheng, 2000).

4 Final remarks

The above-mentioned equations and calculations should be considered practical and sufficient in terrace design, bearing in mind that we are dealing with earth moving and farm work in the field. The survey, layout and construction of bench terraces are discussed in several publications (FAO, 1977; FAO, 1988; Sheng,1986).

Land slopes are usually not even and smooth. When we design terraces we need to use the mode slope or the representative slope of the site as the basis for calculation so that future terraces will produce an even width. It is important to have an even width to benefit farming operations, especially if machines are to be employed.

To design bench terraces for lasting uses, accessibility roads, waterways or irrigation installations should be considered integrally and early in the planning process.

Finally, bench terraces can be costly; they should not be built everywhere on the slope. For gentler slopes, and for semi-permanent and permanent crops, other simple conservation measures and inexpensive terrace systems can be applied (FAO, 1989; Sheng, 2000).

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