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# Analysis of soil arching effect with different cross-section anti-slide pile

Zhao Bo, Zhai Yong-chao
(School of Civil Engineering and Architecture，Chongqing Jiaotong University，Chongqing 400074，China；)

**Abstract**
Although the knowledge of soil-arching effect of anti-slide pile become common, the analysis of soil-arching effect with different cross-section anti-slide pile is little. Therefore，this paper choose three typical cross-section piles (rectangular, square, circular), Then do some study about the Mechanism of mechanism, frictional arch and end bearing arch of three cross-section piles and the form of soil arch with different cross-section and the soil arch zone under same condition in order to define the best cross-section, The result show that rectangular section pile and square section pile are composed by frictional arch and end bearing arch, while circular section pile is made up by united arch, finally rectangular section pile has a more effective retaining effect than square section pile and circular section pile through compared soil arch zone with three type section piles.
**Keyword:** anti slide pile; soil arch; different cross-section; soil-pile interaction

## I. Introduction

Anti-sliding piles as aneffective Retaining structure are applied to fortify landslide or stabilize slope widely (Li H G, 2011;Pan J Z, 1980; China Railway Eryuan Engineering Group Co. Ltd, 1983). What the Mechanism of anti-sliding pile is that the stability and passive resistance of bedrock is used to offset residual sliding force and the interaction of anti-sliding pile, sliding body and bedrock make up anti-sliding mechanism of anti-sliding pile (Zhang Y L&Feng X T,2002; Dai Z H, 2002). Because of anti-sliding piles,the displacement of soil caused by earth pressure or external load is limited. The reason of this phenomenon can be explained by soil-arching effect. Soil-aching effect is shaped around pile and cause redistribution of stress in soil to achieve a new balance(JIA H L&WANG C H; 2003; LI Z C&YANG M, 2006; Wei Z A&Zhou Y K, 2010).

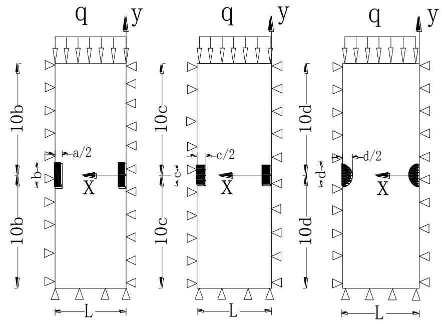
Soil-arching effect exist in piles proved by a large number of theory tests and engineering practices (TERZAGHI K, 1943; LADANYI B, 1969;WANG W L&YEN B C, 1974; Zhang JH&Xie Q, 2004) and Mechanics formula of soil-arching is solved by using Elastic mechanics (LI S J&LIAN C, 2010). Further research shows that frictional arch and end bearing arch make up the soil-arching,In later Mechanics formula of frictional arch and end bearing arch is proved and numerical simulation is applied to analysis and verify frictional arch and end bearing arch(YANG X Q &JI X M, 2014;LIN Z P&LIU Z Q, 2012). ButAbove researches mainly focus on soil-arching formation of one cross-section of pile. The analysis of soil-arching effect with different cross-section anti-slide pile is little.

Although pile distance, the properties of soil and roughness ofinterface between pile and soil have a large influence on soil arching , it is necessary for us to do research on the soil-arching of different cross-section piles under the same condition of geology and pile-soil properties. Therefore this paper is mainly to analysis Mechanical model and Mechanical mechanism of soil-arching with different cross-section anti-sliding piles under same condition. At the same time numerical models of rectangular cross-section pile, square cross-section pile and circular cross-section pile are established with flac3d to analysis the type of soil-arching and arch zone of different type cross-section pile. Confirming the best cross-section of anti-sliding pile under the same pile distance to provide reference for engineering practices and similarstudies

## II. calculation model

In this paper flac3d software is used to simplify the research object for two dimension plane strain problem, which is shown in Fig 1.unit thickness soil layer of certain depth below the surface is regarded as analysis object and unit thickness soil displacement is assumed in a horizontal direction; the pile horizontal displacement is assumed zero, namely the horizontal direction of piles is bounded, where a, b is side length of Rectangle cross-section pile's length and width, c and d is side length of square cross-section pile’s side and circle cross-section pile body's radius, The dimension parameters of model is shown in table 1. The model is used to calculate 10 times of length of pile body range behind support pile, because the soil-arching effect is no longer obvious outside 10 times of pile body range.

Inorder to analysis mechanism of piles under same condition, the area of three type cross-section piles is equal, whose specific parameters is shown in table 2. Soil is simulated as elastic-plastic material following the mohr-coulomb law, piles are simulated as elastic material whose detail parameters are shown in Fig table 2. Interaction between pill and soil is frictional contact which are consisted by thickness triangle contact element.




(a)rectangular cross-section(b)square cross-section (c)circle cross-section
Fig1. The calculation model of different cross-section pile

Table1.Types of cross-section pile

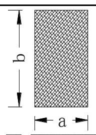
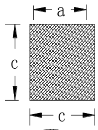
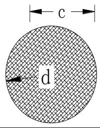
| type | Cross section type | Cross section | area($m^2$) | length/radius(m) | Perimeter(m) |
|---|---|---|---|---|---|
| 1 | rectangular |  | 1.000 | a=0.8;b=1.250 | 4.100 |
| 2 | square |  | 1.000 | C=1.000 | 4.000 |
| 3 | circular |  | 1.000 | D=1.128 | 3.550 |

Table2. Material Calculation Parameters

| type | E/MPa | Poisson | Cohesion/kPa | Friction/(°) | Dilation/(°) | tension/kpa |
|---|---|---|---|---|---|---|
| soil | 5 | 0.3 | 40 | 20 | 0 | 20 |
| pile | $3*10^4$ | 0.2 | / | / | / | / |

## III. different typeSoil Arch Mechanical Analysis

Soil arching can be divided in frictional arch and end bearing arch based on formation theory. End Bearing arch make pile body resist sliding strength directly, frictional arch works through friction force between pile and soil. Generally soil arching woks through frictional arch and end bearing arch's team work, this paper analysis mechanical state of two type soil-archings of three type cross-section anti-sliding piles Based on existing research results, the mechanical state of three types pile are shown in Fig 2-4.

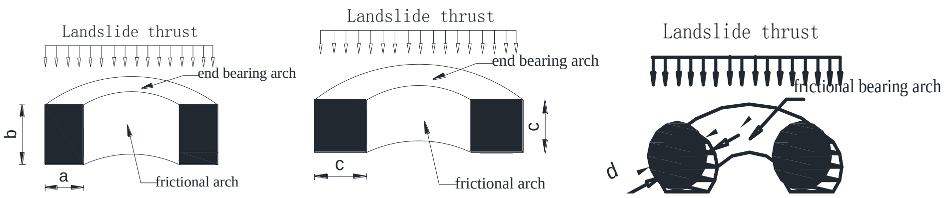



Fig2.soil arch of rectangular pileFig3.soil arch of rectangular pileFig4.soil arch of circular pile

soil arching is shaped by uneven of stress transfer and adjustment and which is the result of call its own Shear strength to resist the external force, so this phenomenoncan make soil do its best to maximize its strength. Therefore, there is no moment and shear force at the cross section of axis of arch curve no matter what type soil arching is. Only the axial stress exists at Tangential direction of arch curve, so under the same External loads p three types cross section piles' Axis formula of soil arching are :

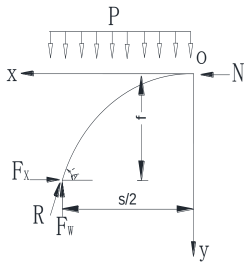



Fig5. Rational soil Arch curve

$$y = 4fx^2/s^2 \quad (1)$$

Where f is soil arch height, s is soil arch span.

According to the stressequilibrium condition, horizontal thrust at any point of axial curve,$N = ps^2/(8f)$, vertical hold is$p_x$, the component in the x direction is$F_x$, the component in the y direction is$F_y$, resultant force and its slopehas the following expression.

$$R = p\sqrt{x^2 + s^4/(64f^2)} \quad (2)$$

$$\tan(\alpha) = dy/dx = 8fx/s^2 \quad (3)$$

That is the positive-stress at archfoot section, which reaches a maximum.So, the destroy of the soil arch initially from arch springing. Then expands to the top of the arch. To ensure the safety of the arch springing,landslide thrust M at the archspringing should be less than the maximum value of pile shaft resistance N.

To ensure security of theend bearingarch, there must be $M \ll N$, in line with the formula(1-3), the friction value caused byvertical component $F_y$must be greater than The horizontal component$F_x$.

$$F_x \le F_y\eta \quad (4)$$

$\eta = \tan(\alpha) = 8fx/s^2$isthe friction coefficient between driving pile and soil.

For frictional arch,there will be skin friction on the piles shaft caused by horizontal component $F_x$ must be greater than The vertical component$F_y$ .

$$F_y \le F_x\eta \quad (5)$$

In equality (5), the meaning of properties η is as same as the equality (4).

It shows that soil arch axis equation of End bearing arch,Friction arch and Frictional end bearing arch arethe same.

For rectangular sectionanti-slide pile,The End bearing arch is acting on the pile shaft andEnd bearing arch and pile shaft contact area less than Friction arch and pile shaft contact area. For circular section anti-slide pile, The End bearing arch and Friction archinteracting with each otheracting on the pileshaft.

For rectangular sectionanti-slide pile and square sectionanti-slide pile,End bearing arch and friction archboth have separate Working area, because the section sizes are different.Under the sameconditions,the strength of friction arch effectof rectangular sectionanti-slide pile is stronger than square sectionanti-slide pile. For End bearing arch, the opposite is true.For circular section anti-slide pile,soil and pile shaft contact area is limited, The End bearing arch and Friction archinteracting with each otherwill decrease the soil arch efficiency.Analyzed the effect of different cross-section of anti-slide piles on the soil arching between pilesby a real example. The effect of different cross-section of anti-slide piles on soil arching between piles.

## IV. model analysis of soil arch effect with different cross-section anti-slide piles

Utilizing FLAC3d to build models respectively,According to theintroduction of three different cross-section anti-slide pilesin chapters 2. boundary constraint and pile diameter and soilparameters, as shown in Figure 1 and table 2.pile spacing is 2.4m, landslide thrust is 10kpa, 30kpa,50kpa,70kpa and90kpa.Analyze load-bearing mechanism of different cross-section anti-slide pilesunder the effect ofdifferent load. Graph6-8 respectively showthe primary stress contournearbydifferent cross section anti-slide piles under 50kpa landslide thrust.

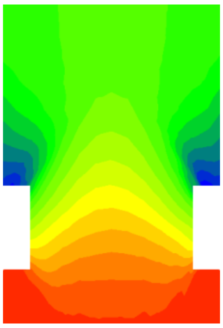


Fig6.Contour of maximum principal stress of rectangular cross-section

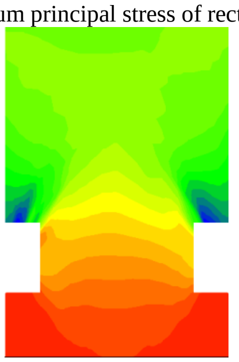


Fig7. Contour of maximum principal stress of square cross-section

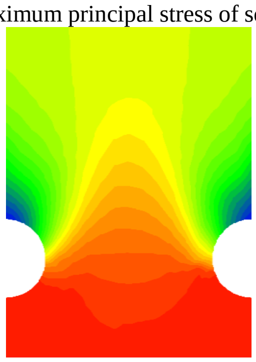
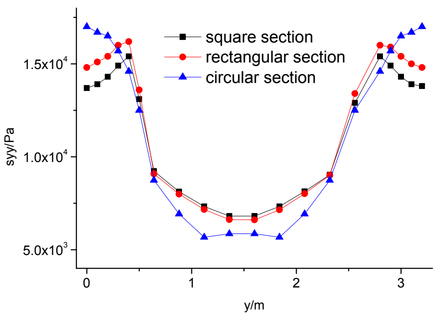


Fig8.Contour of maximum principal stress of circular cross-section

From fig6-8 it can be obtained that the soil arch mainly supports the load ofstructure throughfriction arch.The effect of the End bearing arch is not obvious. Forsquare section anti-slide pile,the endbearing arch have been formed and have been taken an important part. The effect of the friction arch is not obvious. Stress level isolinewas easy tobe observed.

Compared the soil arch effects of 3 different cross-section anti-slide piles, take y= 0.5 crosssectionbehindpiles.Measuringthe component in the y directionin this cross section under the effect of different loads shown in Figure 9-13.



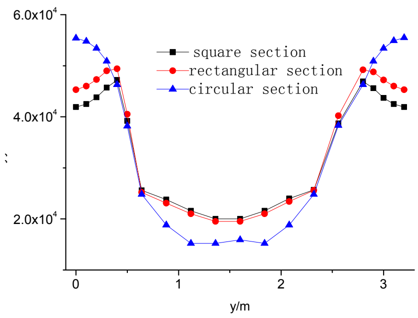
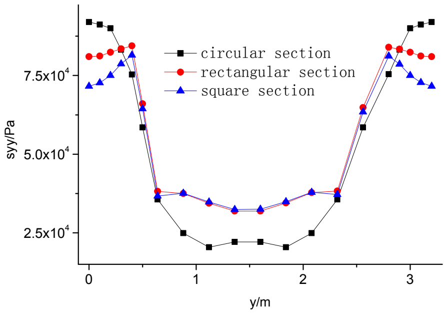




Fig9.Distribution curve of $s_{yy}$ under 10KPaFig10.Distribution curve of $s_{yy}$ under 30KPa



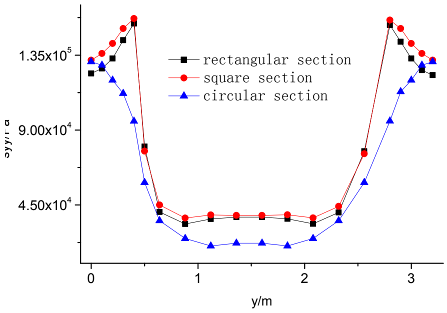




Fig11.Distribution curve of $s_{yy}$ under 50KPaFig12.Distribution curve of $s_{yy}$ under 70KPa

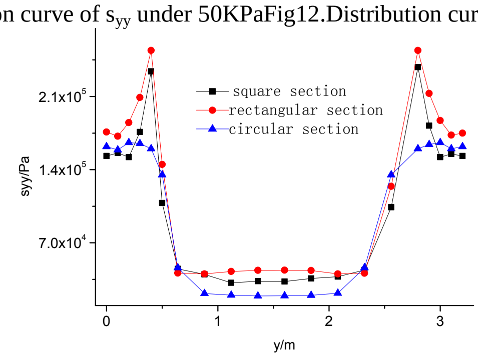



Fig13.Distribution curve of $s_{yy}$ under 90KPa

The component in the y direction. $s_{yy}$ of Soil away from the anti-slidepiles stended to stabilizing. The stressstates of circular section anti-slide pile is muchmore less than that ofrectangular sectionanti-slide pile and square sectionanti-slide pile. for circular section anti-slide pile,The stress at midlinebetweenpileswasmaximal, for rectangular sectionanti-slide pile and square sectionanti-slidepile, The stress at pile's lateral soilwas maximal, from pile's lateral to midlinebetween piles gradually reduced. More stress was distributed on the soil arch inside comparedwith the opposite. Along with theincreasing load, the load of rectangularsectionanti-slide pile and square sectionanti-slide pile increases quickly, the load of circular section anti-slide pile grew relatively slow rate. The load of rectangular sectionanti-slide pile was the biggest in the three.

α is being introduced thatdetermine the strength of soil arch effectof different cross-section anti-slide piles.

$$\alpha = (1 - q_0/q) \times 100\% \qquad (6)$$

$q_0$isfore-pile residual load, q is total load. The α of 3 different cross-section anti-slidepilesunder theeffect ofdifferent load has been calculated by monitoringthe fore-pile residual load.Which is shown in Fig 14.

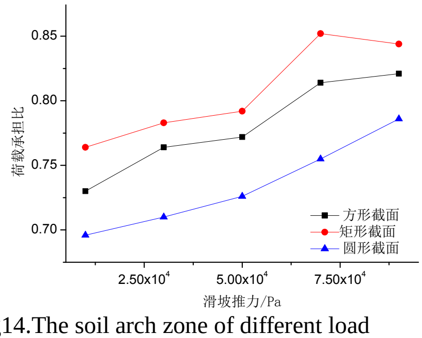



Fig14.The soil arch zone of different load

From fig.4 it can be seen that, as the valueof landslide thrust grows, α showed a tendency of increasing in the 3 different cross-section anti-slide piles. Illustrates they are performing less than optimally, Also , we can see that, α of rectangular sectionanti-slide pile was the biggest, square section anti-slide pile second, circular section anti-slide pile the lowest. The best soil arch effect of anti-slide piles is therectangular sectionanti-slide pile has the biggest α.

## V. conclusion

1 For rectangular and square cross-section piles,End bearing arch and friction arch both have separateworking area; but for circular cross-section pile,The End bearing arch and Friction archinteracting with each other. In order to keep the stability of soil arching the norm force of soil multiply the coefficient of friction Greater than or equal to shearforce of soil.

2 The analysis of theory and numerical simulation both prove the fact that：rectangular cross-section piles produce frictional arch mainly，square cross-section piles produce end bearing arch mainly， while the circular cross-section piles produce both types of soil arching.

3 Rectangular cross-section piles has a higher arch zone than another two type piles through the arch zone calculation under the same condition, this show that soil arching effect of rectangular cross-section piles is larger than others, rectangular cross-section pile has a better Retaining effect.

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