HNSJ Humanities & Natural Sciences Journal
ISSN: (e) 2709-0833
www.hnjournal.net
Peer-Reviewed Journal
Indexed at: NSP - SJIF
Impact Factor 2022 = 4.91

RESEARCH TITLE

Evaluation of External and Internal Stability for retaining wall with sloping backfill by load resistance factor design (LRFD) method by using an excel spread sheet

NAJIA SAEED MOHAMMED. ELHAZZAR[1]

[1] Civil engineering Department ,AL Gubba, University of Derna ,Libya

Email: gegesaeedsaeed@gmail .com

HNSJ, 2023, 4(10); https://doi.org/10.53796/hnsj4109

Published at 01/10/2023 **Accepted at 19/09/2023**

Abstract

There are two stages of analysis of reinforced earth walls, namely external stability and internal stability. External stability checks assumes that the failure surface lies completely outside the reinforced soil mass and analysis of internal stability consists of evaluating the surfaces of the sliding potential within reinforced soil mass. In this paper we are going to shows potential external and internal failure mechanisms are usually considered when we design retaining walls by using Load and Resistance Factor Design (LRFD) to evaluate external and internal stability for retaining walls by an excel spreadsheet and the excel program are applied for different example by changing the propriety with the FHWA manual solutions. Also as we all know the design codes varies from country to country, In this paper we are going to be applied American Association of State Highway and Transportation Official (AASHTO) retaining Walls Design Code(ASSHTO) included the retaining walls section in their Bridge Design Manual .

Introduction

The retaining structures are composed of three components: reinforcement, soil and wall element all three parts are working together to stabilize the soil mass. We can save money, time and space by using these kinds of structure. Retaining walls applications have been used in transportation construction industrial, waterway, commercial and public structures. The most important thing when planning to design retaining walls to choose a design approach to use, selection depends on some factors such as: safety, material availability, construction difficulty, time and money. There is several design and analysis methods, in this paper we are going to use Load and Resistance Factor Design method and an excel spreadsheet used to perform analyses according to LRFD was prepared.

An example problem that was selected from (FHWA) manual is solved by using an excel spread sheet, it can be able to check internal and external stabilities for MSW very easy. All the details about the MSE wall, such as dimensions, properties of backfill and reinforcement etc are listed below.

Project requirements:

Exposed wall height ,H_e = 28 ft, Length of wall =850 ft, Design life =75 years, Precast panel unit: 5 ft wide ×5 ft tall ×0.5 ft thick, Type of reinforcement: grade 65 (F_Y = 65ksi, 1.969 in×0.157 in) [1].

Project parameters:

Reinforced backfill, $\acute{\emptyset}_r = 34^o$, γ_r =125 pcf, coefficient of uniformity,C_u = 7Retained backfill, $\acute{\emptyset}_f = 30^o$, γ_f =125 pcf, Foundation soil, $\acute{\emptyset}_{fd} = 30^o$, γ_{fd} =125 pcf [1] .

Depth of embedment and length of reinforcement:

Base on AASHTO (2007), the minimum embedment depth: d = 28/20 =1.4 ft so it is assumed that, d =2 ft. So design height of the wall H = H_e + d = 28+2 =30 ft, Length of reinforcement assumed to be L =0.8 H=24 ft [1].

Factored Bearing resistance of foundation soil:

For service limit consideration, qnf-ser =7.5 ksf, for strength limit consideration, qnf-str = 10.5ksf.

Estimation of unfactored loads:

1- Coefficient of active earth pressure**:**

$$K_a = \frac{sin^2(\acute{\emptyset}_f+\theta)}{sin^2\theta \sin(\theta-\delta)\Gamma} \qquad \textbf{(1)}$$

$\Gamma = [1 + (\frac{\sin(30+26.56)\sin(30-26.56)}{\sin(90-26.56)\sin(90-26.56)})^{1/2}]^2$ = 1.563, So K_{af} =0.537**.**

2-Vertical force**:**

Table (1) :Unfactored vertical forces and moment [1] .

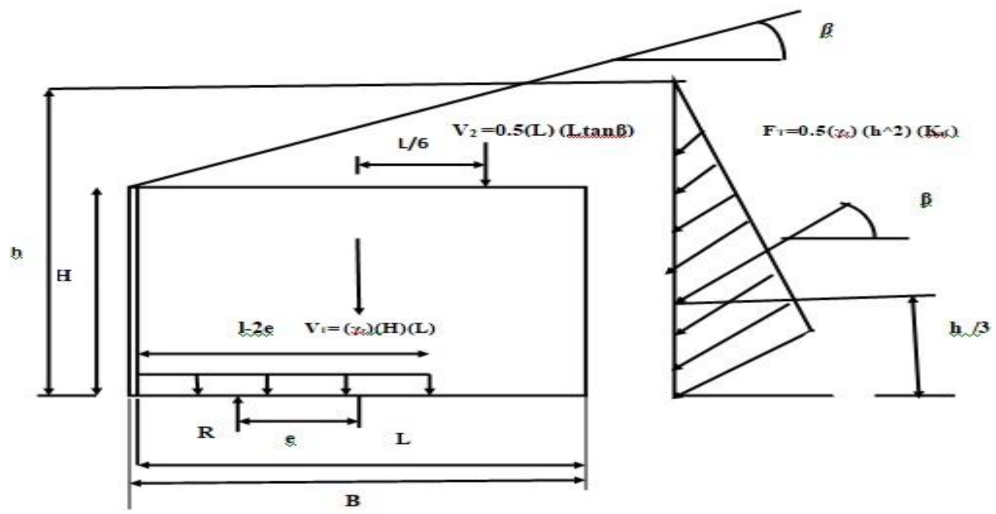
force	l(k/ft)	Moment arm(ft)	ɔment (k-ft/ft)
V_1= (γ_r)(H)(L)	**90.0**	**L/2=12**	**1080.0**
V_2 =0.5(L) (Ltanβ) (γ_f)	**18.0**	**2/3(L)**	**288.0**
F_{TV}=0.5(γ_r) (h^2) (K_{af}) (sinβ)	**26.48**	**L**	**635.44**

3-Horizontal forces:

Table (2) :Unfactored Horizontal Forces and Moment [1].

force	Valu(k/ft)	Moment ar(ft)	Moment
F_{TH} =0.5(γ_r)(h^2)(K_{af}) (cosβ)	**52.95**	**h/3=14.0**	**741.35**

Tanβ = 0.5, and h=30+24(0.5) =42 ft, the forces and moments should be multiplied by appropriate load factor and resistance factor, the figure (1) shows unfactored vertical and horizontal force [1].



The figure (1); unfactored vertical and horizontal force

❖ **Evaluate external stability of MSE walls**

The potential external failure mechanisms that are usually considered in the design of MSE walls are following.

1-Sliding Stability

The sliding may occur along the base of the wall of the MSE wall. Sliding force is the horizontal component of the thrust on the vertical plane at the back of the wall. In the sliding stability calculations, driving force general consist of the live load above the retained backfill, factored horizontal, loads due to earth, water, seismic and surcharge [2].

2- Eccentricity at base of MSE walls

In limit eccentricity calculations, the MSE wall is checked with respect to overturning. Eccentricity is defined as the ratio of summation of overturning and the resisting moments about the bottom center of the base length, to the total vertical load [2].

3- Bearing resistance

Bearing capacity in another external stability check that is performed for both strength and service limit state .The bearing capacity with respect to general shear failure can be assessed by the comparison of the factored vertical pressure at the base of the wall and the factored bearing resistance of the foundation soil. The vertical pressure due to the MSE walls is calculated as [2].

- **Evaluation of internal stability**

Internal failure can occur in two ways: the tensile forces in the inclusions become so large, namely failure by elongation or breakage of the reinforcement. And the tensile forces in the reinforcements become larger than the pullout resistance (failure by pullout) .For internal stability calculations; it is assumed that a failure surface divides the reinforced zone in active and resistance zones [2].

1. Estimation the location of the Critical Failure Surface, Variation of (K_r) and pullout resistance stress coefficients (F*):

The critical failure surface and variation of K_r and F* must be estimated depending on the type of reinforcement. For the case of inextensible steel ribbed strips, these factors are can be calculated from figure (2).

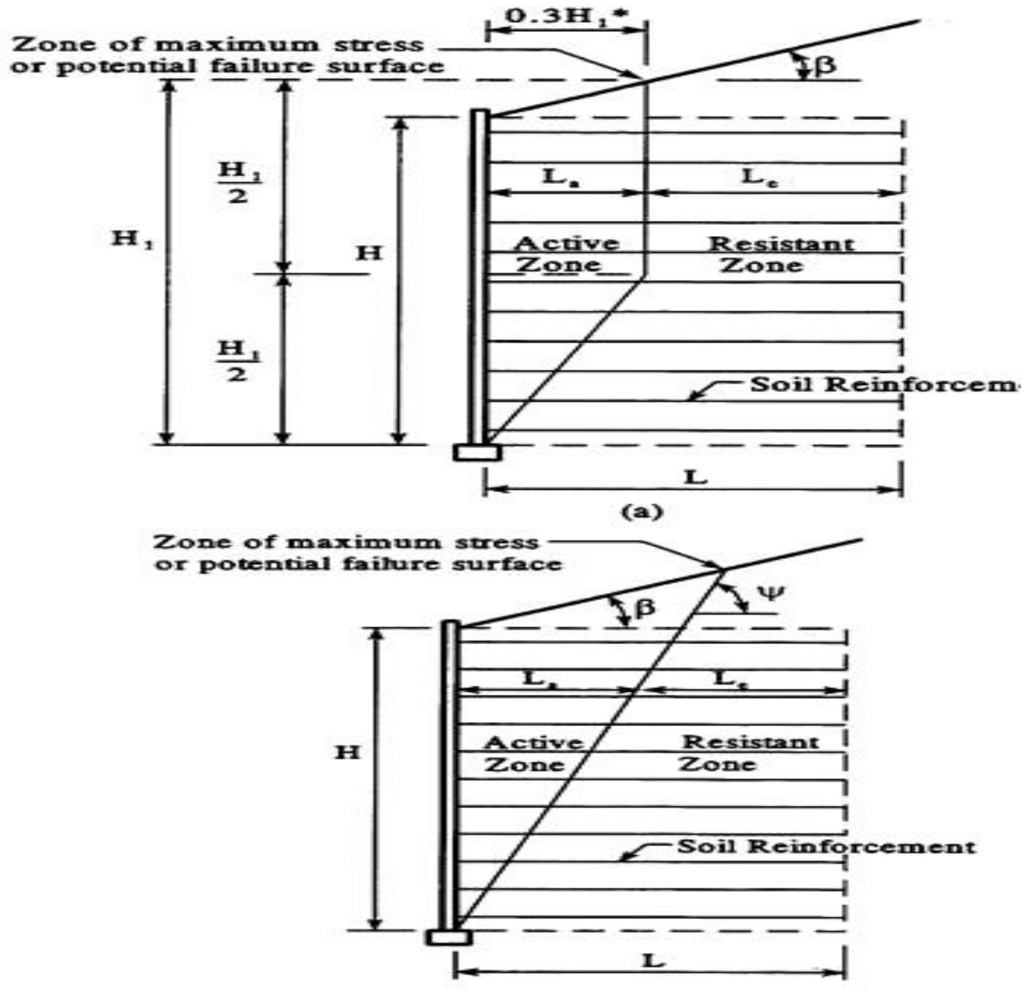


Figure (2); Location of Potential Failure Surface for Internal Stability Design of retaining Walls (a) Inextensible Reinforcements and (b) Extensible Reinforcements.

2- Establish vertical layout of soil reinforcement:

Depending on the depth Z the S_{vt} can be estimate at each level; for example at Z=9.2ft

$S_{vt} = Z^{+} - Z^{-}$

Z^{+} = 9.2+ 0.5(12.1-9.2) = 10.65ft and Z^{-} =9.2-0.5(9.2-6.3) = 7.75 ft. so S_{vt} = 10.65-7.75 = 2.9ft

3-Calculate horizontal stress (σ_H) and Maximum tension T_{max} at each reinforcement:

The horizontal stress at any given depth within the reinforced soil zone is expressed as follows: $\sigma_H = K_r [\sigma_v] + \Delta\sigma_H$ **(2)**

Where:

K_r = coefficient of lateral earth pressure in the reinforced soil zone

σ_v = factored vertical pressure at the depth of interest,

$\Delta\sigma_H$ = Supplemental factored horizontal stress due to external surcharges [2].

4-Estimation Nominal and Factored Long –Term Tensile Resistance of Soil Reinforcement:

For steel reinforcement, the corrosion affect must be considered in the design like calculation .The corrosion losses over the design life period is calculated as:

$E_c = En - E_R$ **(3)**

Where:

E_c = the thickness of the reinforcement at the end of the design life.

E_n = the nominal thickness at construction,

E_R = the thickness of metal expected to be lost by uniform corrosion during the service life of the structure.

The nominal long-term tensile strength of the reinforcement T_{al} can be estimate by following equation:

$T_{al} = F_y A_c / b$ **(4)**

$P_{tal} = F_y Ac$ **(5)**

Where:

b = the gross width of the strip, sheet or grid,

F_y = yield stress of steel,

A_c = design cross section area of the steel (A_c= bE_c) [1].

5-Estimation of Nominal and Factored Pullout Resistance of Soil: Reinforcement The pullout resistance soil reinforcement is depended on various parameters of soil reinforcement; these parameters are explained in the following equation:

$P_r = \alpha (F^*) (2b) (L_e) (\sigma_v) (\gamma_{p\text{-}EV})$ **(6)**

L_e = the length of embedment in the resisting zone

F* = Pullout resistance factor

α = Scale correction factor, (1.0 for metallic reinforcements and 0.6 to 1.0 for geosynthetic reinforcements)

σ_v = Nominal vertical stress at the reinforcement level in the resistant zone,

The factored pullout resistance as follows: $P_{rr} = ø\ Pr$ [2].

6- Number of Soil Reinforcing Strips at Each level of Reinforcement:

The number of strip reinforcement at any level related with T_{max} and P_{rr} .For tensile resistance, the number of strips (N_t) is determined as follows [2]:

$$N_t = T_{max} / T_r \qquad \textbf{(7)}$$

For pullout resistance, the number of strips(N_t) is determined as follows:

$$Nt = Tmax / P_{rr} \qquad \textbf{(8)}$$

Discussion

By using this spreadsheet we can evaluate external and internal analyses for MSE very easy and very faster, when we planning to design new retaining walls or when we check stability for MSE such example problem that was selected from (FHWA) as we know we can checked external and internal analyses with hand calculations but when we use this spreadsheet we can save time and effort.

CONCLUSION

The common design method of MSE wall depending on LRFD was used to evaluate external and internal analyses of MSE. Then, an excel spreadsheet that used to check internal and external stabilities for a given MSE wall with simple geometry was prepared. This spreadsheet is run for the example that is given in FHWA manual (2009) also evaluate external and internal analyses. And by using this spreadsheet the program run for deferent projects by changing the property such as exposed wall height. The appendix contain the calculations for evaluate external and internal analyses by excel spreadsheet.

REFERENCES

1-Berg, R.R., Christopher, B.R., Samtani. N.C. (2009). *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes-Volume II.* (FHWA-NHI-10-025).

2- Sun, C., & Graves, C. (2013). *Mechanically Stabilized Earth (MSE) Walls Design Guidance.* University of Kentucky Transportation Center.

APPENDIX

A	B	C	D	E	F	G
Requirments for project				parameters of project		
H_e	28	ft		$Ø_r$	34	degree
d	2	ft		$Ø_f$	30	degree
H	30	ft		$Ø_{fd}$	30	degree
L	24	ft		γ_r	125	pcf
tan β	0.5			γ_f	125	pcf
h	42	ft		γ_{fd}	125	pcf
cos β	0.8944			C_u	7	
sinβ	0.4472			K_{af}	0.537	
F_y	65	ksi				

I	J	K	L	M	N	O	P	Q
force and moment						load factor		
force	value of force(kft)	moment arm (ft)	moment (k-ft/ft)				EV	EH
V_1	90	12	1080			str I(max)	1.35	1.5
V_2	18	16	288			str I (min)	1	0.9
V_{TV}	26.4761406	24	635.4273744			service I	1	1
F_{TH}	52.9522812	14	741.3319368					
						resistance factor		
						$ø_s$	1	
						$ø_b$	0.65	
						$ø_t$	0.75	
						$ø_p$	0.9	

sliding resistance					
item	unit	value	str I(max)	str I (min)	ser I
F_{HT}	k/ft	52.9523	79.4284	47.6571	N/A
V_{A1}	k/ft	108	145.8	108	N/A
V_{A2}	k/ft	26.4761	39.7142	23.8285	N/A
V_{A}	k/ft	134.476	185.514	131.829	N/A
V_{NM1}	k/ft	62.3538	84.1777	62.3538	N/A
V_{NM2}	k/ft	15.28601	22.92901	13.75741	N/A
V_{NM}	k/ft	77.6398	107.107	76.1112	N/A
V_{FM1}	k/ft	62.3538	84.1777	62.3538	N/A
V_{FM2}	k/ft	15.286	22.929	13.7574	N/A
V_{FM}	k/ft	77.6398	107.107	76.1112	N/A
		$V_{FM} > H_{M}$			OK
CDR			1.348468	1.597061	
	critical valus				
	V_{F}	k/ft	85.28284		
	F_{HT}	k/ft	79.42842		
	$V_{Fmin}>F_{HTmax}$			OK	
	CDR	dim	1.073707		

limiting eccentricity					
item	unit	value	str I (max)	str I(min)	ser I
V_{A1}	k/ft	145.8	145.8	108	N/A
V_{A2}	k/ft	39.7142109	39.7142109	23.8285	N/A
V_{A}	k/ft	185.5142109	185.5142109	131.829	N/A
M_{RA1}	k-ft/ft	1368	1846.8	1368	N/A
M_{RA2}	k-ft/ft	741.3319368	953.1410616	571.885	N/A
M_{RA}	k-ft/ft		2799.941062	1939.88	N/A
M_{OA}	k-ft/ft	741.3319368	1111.997905	667.199	N/A
M_{A}	k-ft/ft		1687.943156	1272.69	N/A
a	ft		9.098726983	9.6541	N/A
e_{L}	ft		2.901273017	2.3459	N/A
e	ft		6	6	N/A
e_{L}/l	ft		0.120886376	0.09775	N/A
the result of e_{L} in limiting value of e					
critical value					
$M_{OA\text{-}C}$	k-ft/ft	1111.997905			
$M_{RA\text{-}C}$	k-ft/ft	2321.141062			
$M_{A\text{-}C}$	k-ft/ft	1209.143156			
$V_{A\text{-}C}$	k/ft	147.7142109			
a_{nl}	ft	8.185692826			
e_{L}	ft	3.814307174	ok		
e	ft	6			
B'	ft	16.37138565			
e_{l}/l		0.158929466			
	limiting eccentricity criterial satisfied				

bearing resistance						
item	unit	value	str I(max)	str I(min)	ser I	
V_{Ab1}	k/ft	108	145.8	108	108	
V_{Ab2}	k/ft	26.4761	39.7142	23.8285	26.4761	
R	k/ft		185.514	131.829	134.476	
M_{RA1}	k/ft/ft	1368	1846.8	1368	1368	
M_{RA2}	k/ft/ft	635.427	953.141	571.885	635.427	
M_{RA}	k/ft/ft		2799.94	1939.88	2003.43	
M_{OA}	k/ft/ft	741.332	1112	667.199	741.332	
M_A	k/ft/ft		1687.94	1272.69	1262.1	
a	ft		9.09873	9.6541	9.38527	
e_L	ft		2.90127	2.3459	2.61473	
e	ft		6	6	4	ok
B'	ft		18.1975	19.3082	18.7705	
σ_v	ksf		10.1945	6.82759	7.16421	
qnf-ser	ksf		10.5	10.5	7.5	given
CRA			1.02997	1.53788	1.04687	

the result of e_l limiting value of e

critical value			
M_{OA-C}	k-ft/ft	1112	
M_{RA-C}	k-ft/ft	2321.14	
M_{A-C}	k-ft/ft	1209.14	
$\sum VC$	k/ft	147.714	
a	ft	8.18569	
e_L	ft	3.81431	
e	ft	6	
B'	ft	16.3714	
σ_{v-c}	ksf	9.02271	
q_{nf-ser}	ksf	10.5	given
limitin eccentricity satisfied			
CDR	dim	1.16373	

requrement for internal stability												
an B	0.5			K_a at Z^-=7.5	0.428		Ka at Z=0	0.481		t	0.1640833	ft
H	30	ft		K_a at Z^+=20	0.411		Ka at Z=2(	0.34		$\gamma_{P\text{-}EV}$	1	
ΔH	5.2941176	ft		σ_2	0.65625			0.125		α	1	
H_1	35.294118	ft		$\sigma_{P\text{-}EV}$	1.35		F* at z=0	2		Tr	9.7908525	k/strip
L_a	10.588235	ft		wp	5		F* at z=20	0.675				
L	24	ft		A	12.5		E_R	0.055	in			
t	0.157	in					E_C	0.102				
b	1.969	in						0.6				

level	Z(ft)	Z(-) ft	Z(+) ft	Zp-ave	Svt (ft)	ka -	ka +	$\sigma_{v\text{-}soil(z\text{-})}$
1	1.25	0	2.5	9.89705882	2.5	0.481	0.463375	0
2	3.75	2.5	5	12.3970588	2.5	0.46338	0.44575	0.3125
3	6.25	5	7.5	14.8970588	2.5	0.44575	0.428125	0.625
4	8.75	7.5	10	17.3970588	2.5	0.42813	0.4105	0.9375
5	11.25	10	12.5	19.8970588	2.5	0.4105	0.392875	1.25
6	13.75	12.5	15	22.3970588	2.5	0.39288	0.37525	1.5625
7	16.25	15	17.5	24.8970588	2.5	0.37525	0.357625	1.875
8	18.75	17.5	20	27.3970588	2.5	0.35763	0.34	2.1875
9	21.25	20	22.5	29.8970588	2.5	0.34	0.34	2.5
10	23.75	22.5	25	32.3970588	2.5	0.34	0.34	2.8125
11	26.25	25	27.5	34.8970588	2.5	0.34	0.34	3.125
12	28.75	27.5	30	46.0441176	2.5	0.34	0.34	3.4375

$\sigma_{v\text{-soil (z+)}}$	$\sigma_{H\text{-soil(z-)}}$	$\sigma_{H\text{-soil (z+)}}$	$\sigma_{H\text{-soil}}$	H-surcharge (z)	H-surcharge (z+)
0.3125	0	0.19548633	0.097743164	0.426135938	0.410521289
0.625	0.19548633	0.37610156	0.285793945	0.410521289	0.394906641
0.9375	0.37610156	0.5418457	0.458973633	0.394906641	0.394906641
1.25	0.5418457	0.69271875	0.617282227	0.379291992	0.363677344
1.5625	0.69271875	0.8287207	0.760719727	0.363677344	0.348062695
1.875	0.8287207	0.94985156	0.889286133	0.348062695	0.332448047
2.1875	0.94985156	1.05611133	1.002981445	0.332448047	0.316833398
2.5	1.05611133	1.1475	1.101805664	0.316833398	0.30121875
2.8125	1.1475	1.2909375	1.21921875	0.30121875	0.30121875
3.125	1.2909375	1.434375	1.36265625	0.30121875	0.30121875
3.4375	1.434375	1.5778125	1.50609375	0.30121875	0.30121875
3.75	1.5778125	1.72125	1.64953125	0.30121875	0.30121875

A_{trib}	Tmax	F*	L_e	$Z_{p\text{-ave}}$	$\sigma_v(\gamma_{P\text{-EV}})$
12.5	6.45089722	1.9171875	13.411765	9.897058824	1.237132353
12.5	8.60634888	1.7515625	13.411765	12.39705882	1.549632353
12.5	10.6735034	1.5859375	13.411765	14.89705882	1.862132353
12.5	12.3595862	1.4203125	13.411765	17.39705882	2.174632353
12.5	13.9573718	1.2546875	13.411765	19.89705882	2.487132353
12.5	15.3692688	1.0890625	14.25	22.39705882	2.799632353
12.5	16.5952771	0.9234375	15.75	24.89705882	3.112132353
12.5	17.6353967	0.7578125	17.25	27.39705882	3.424632353
12.5	19.0054688	0.657	18.75	29.89705882	3.737132353
12.5	20.7984375	0.675	20.25	32.39705882	4.049632353
12.5	22.5914063	0.675	21.75	34.89705882	4.362132353
12.5	24.384375	0.675	23.25	37.39705882	4.674632353

Pr	Prr	$T_{n(\phi_s)}$	N_p	N_t	N_q	S_h
10.439054	9.40	9.7908525	0.68662003	0.658869819	2	2.5
11.9463354	10.75	9.7908525	0.80046387	0.879019358	2	2.5
12.9980141	11.70	9.7908525	0.91240463	1.090150568	2	2.5
13.5940901	12.23	9.7908525	1.0102091	1.262360574	2	2.5
13.7345634	12.36	9.7908525	1.12913607	1.425552252	2	2.5
14.2581486	12.83	9.7908525	1.19769865	1.569757976	2	2.5
14.8539032	13.37	9.7908525	1.24137047	1.694977746	2	2.5
14.6912681	13.2221413	9.7908525	1.33377766	1.801211562	2	2.5
15.1077429	13.60	9.7908525	1.39777249	1.941145447	2	2.5
18.1651448	16.35	9.7908525	1.27218226	2.124272376	3	1.666667
21.0163038	18.91	9.7908525	1.19438521	2.307399305	3	1.666667
24.0751309	21.67	9.7908525	1.12538329	2.490526234	3	1.666667