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Erosion Damage of the Rammed Earth Wall of Fujian Earth-buildings Caused by the Wind-driven Rain

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Outline

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- **Introduction**
- **Research method**
- **Case study**
- **Conclusion**

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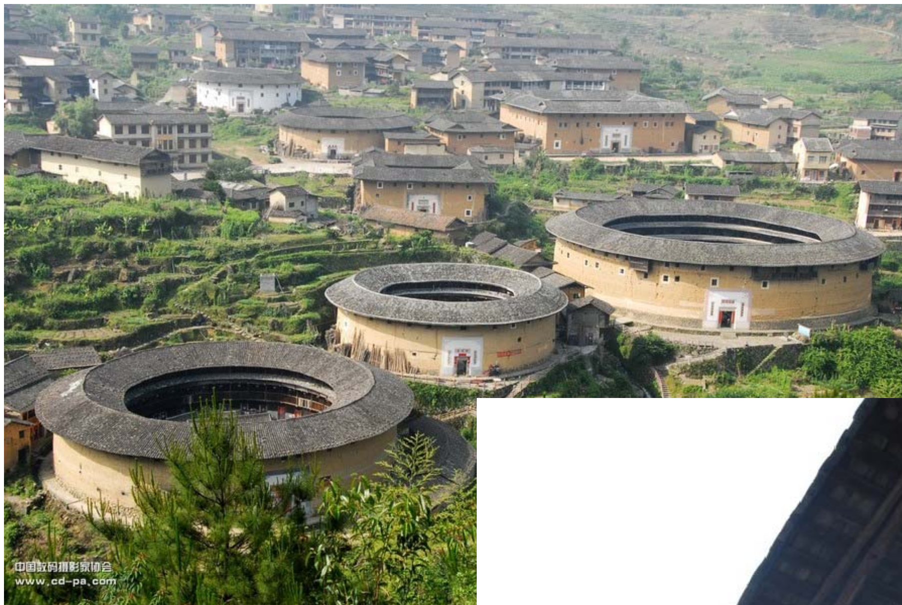
Part 1 Introduction

- Hakka earth-buildings which are listed as world cultural heritages are located in Fujian- the coastal city where typhoons with heavy rainfall occur frequently. Its salient features are rammed earth wall and big picking eaves.

Rammed earth wall and big picking eaves



Part 1 Introduction

- In order to protect these important buildings, we should avoid all the negative factors. For rammed earth structures, as we all know, the biggest natural enemy is the rain. But for the Hakka earth buildings which have big picking eaves, wind driven rain is the greatest threat.

Part 1 Introduction

- To prevent the rain damage, firstly we must understand its mechanism. There are lots of researches about material performances and bearing capacities of rammed earth in the rain at home and abroad. But the studies of erosion damage of rammed earth under severe weather conditions are seldom conducted. And this is the content we describe here: erosion damage to the Fujian rammed earth buildings caused by the wind-driven rain.

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Part 2 Research method

- The main methods we used are numerical simulation and theoretical derivation. In simple terms, we get $R_w(t)$($R_w(t)$ stands for the absorbed rainfall on the windward wall per unit time and per unit area)（mm/h）from numerical simulation and use theoretical derivation to get Δ(Δ stands for the average erosion damage by thickness)(mm).

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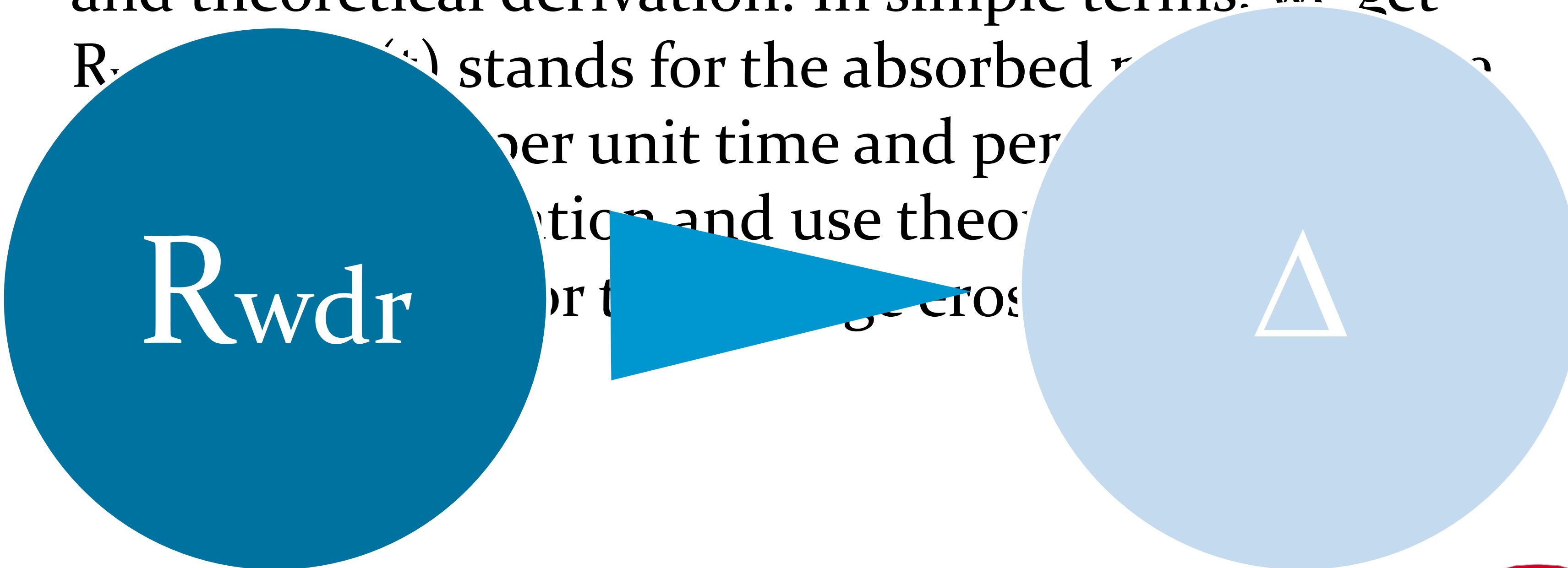

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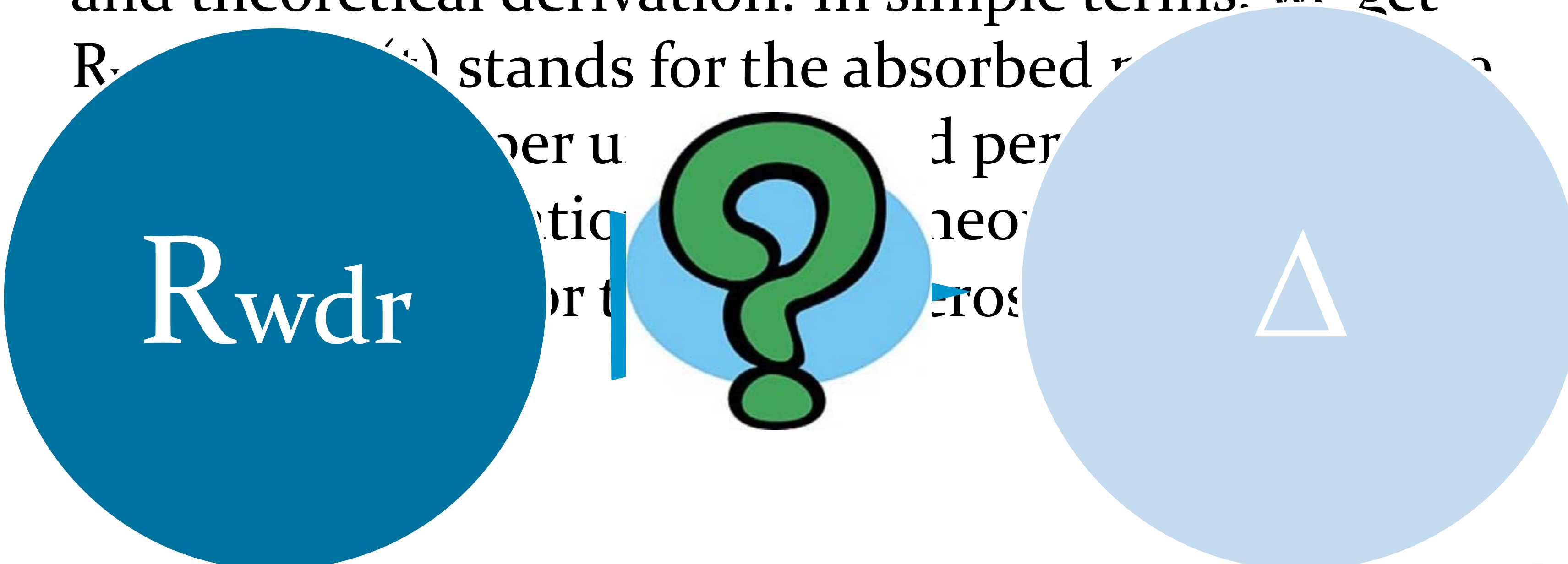

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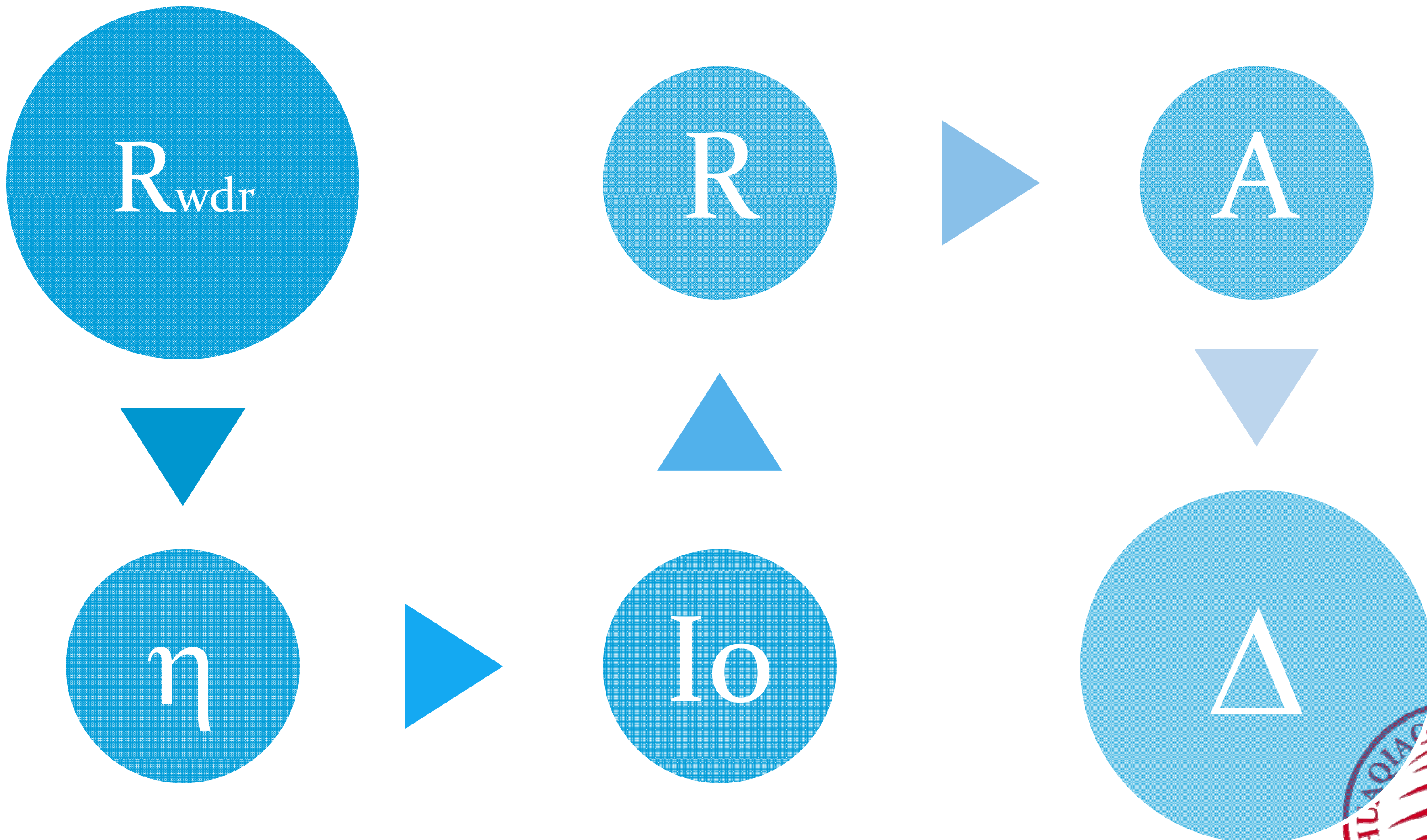

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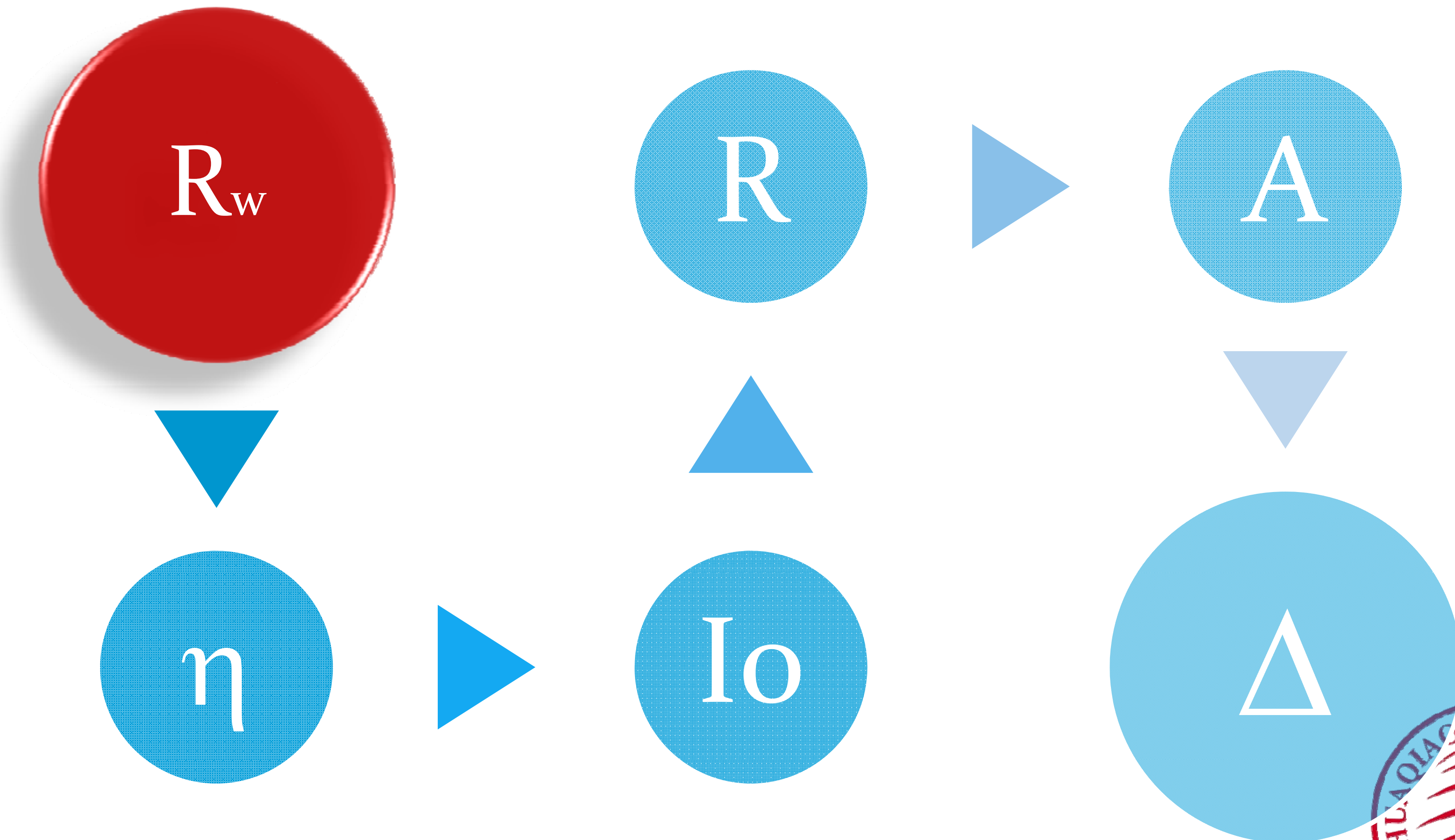
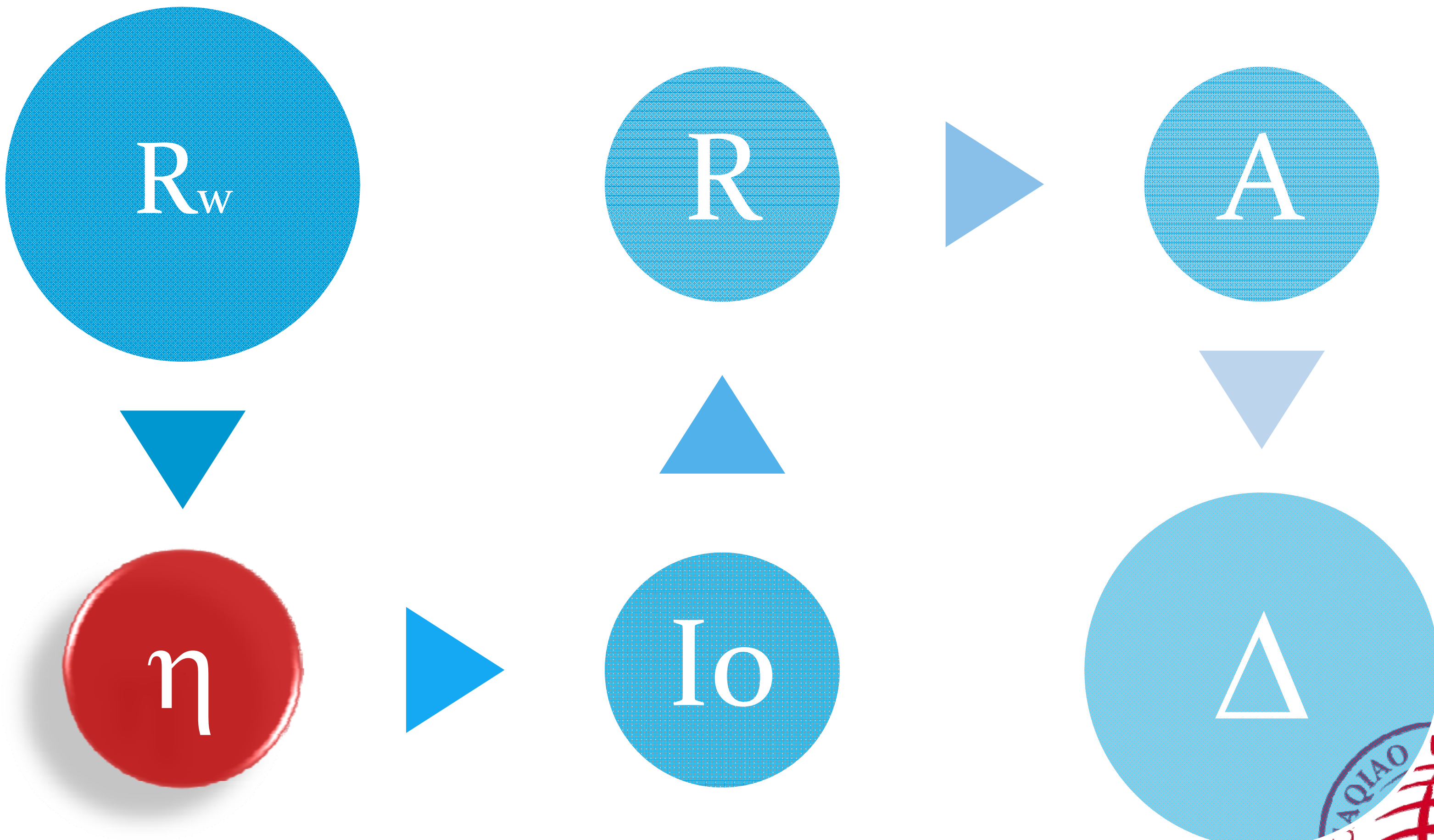


2.1 Rw

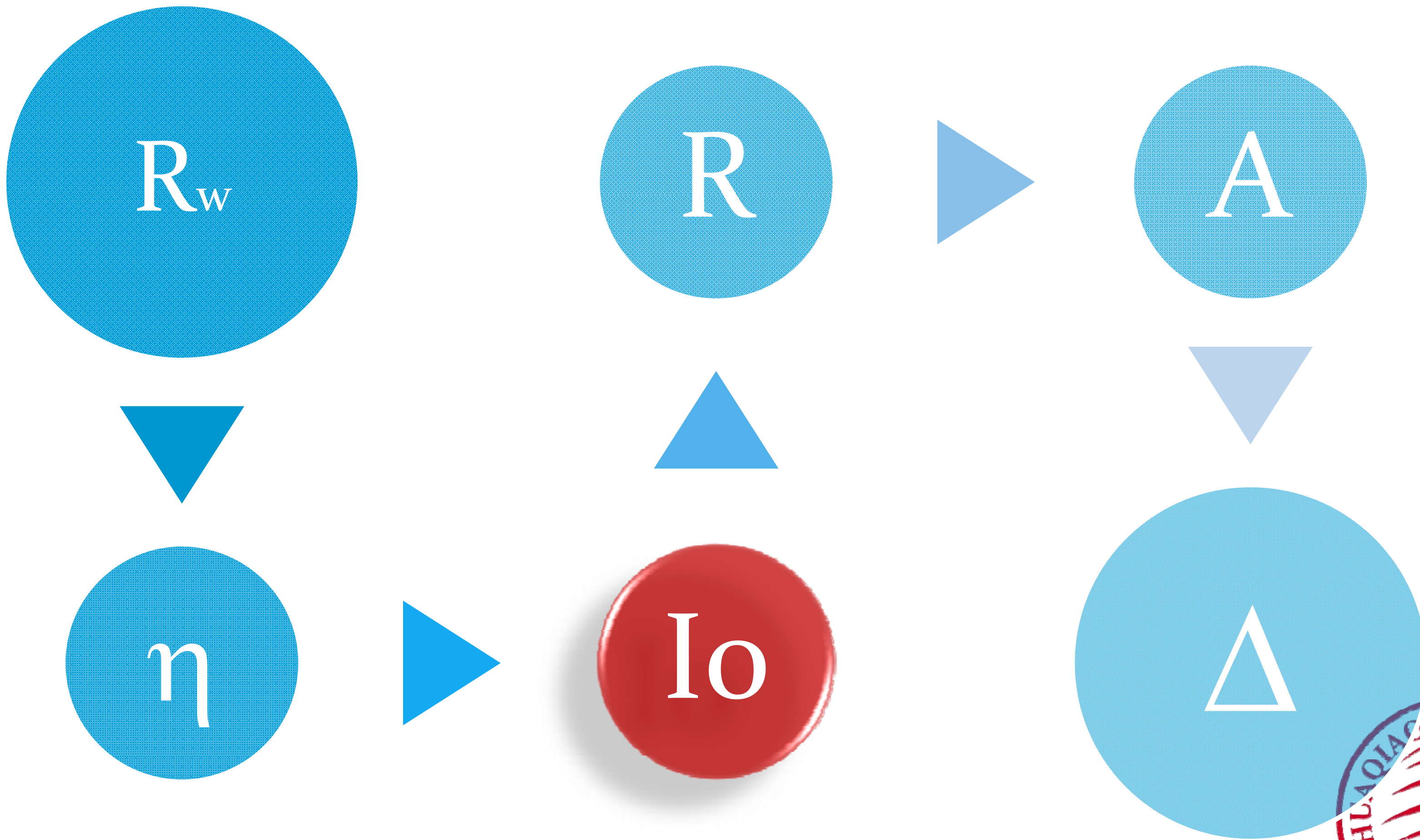
- By adding the rainfall model- the BEST model- to the wind field, and revising the rainfall value according to the initial position , the diameter distribution and the initial velocity of raindrops ,we can get different Rw under different wind speed and different rainfall from CFD（computational fluid dynamics） simulation software.

Part 2 Research method



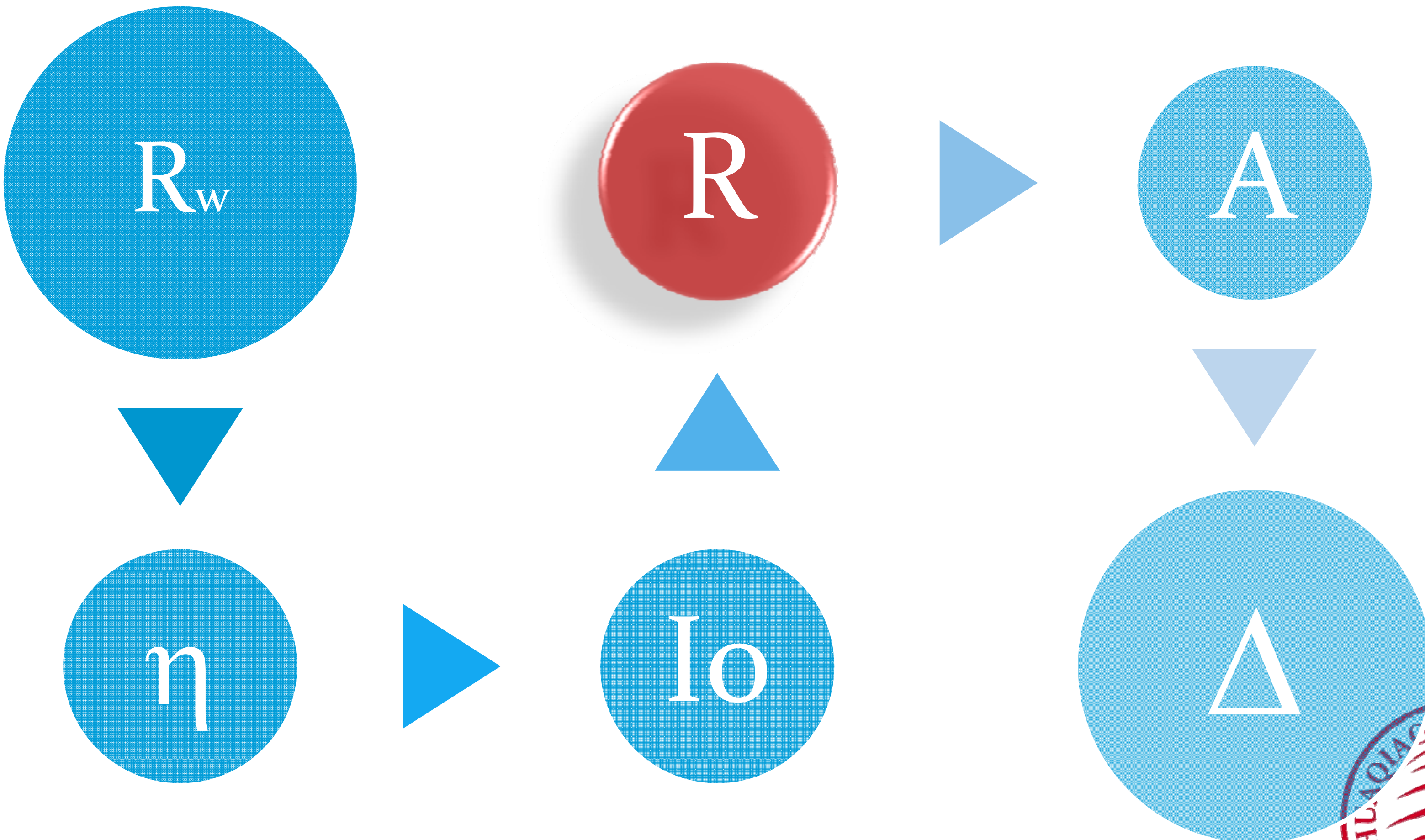
2.2 η

- In order to get the final erosion value, the erosion factor η is defined as Rw (t) / Rh (t), in which R_w (t) stands for the absorbed rainfall on the windward wall per unit time and per unit area and Rh (t) stands for the rainfall intensity when there is no wind interference (mm/h). It shows the effect to rainfall erosivity of different wind speed and different rainfall.


Rw
R
A
η
Io
Δ

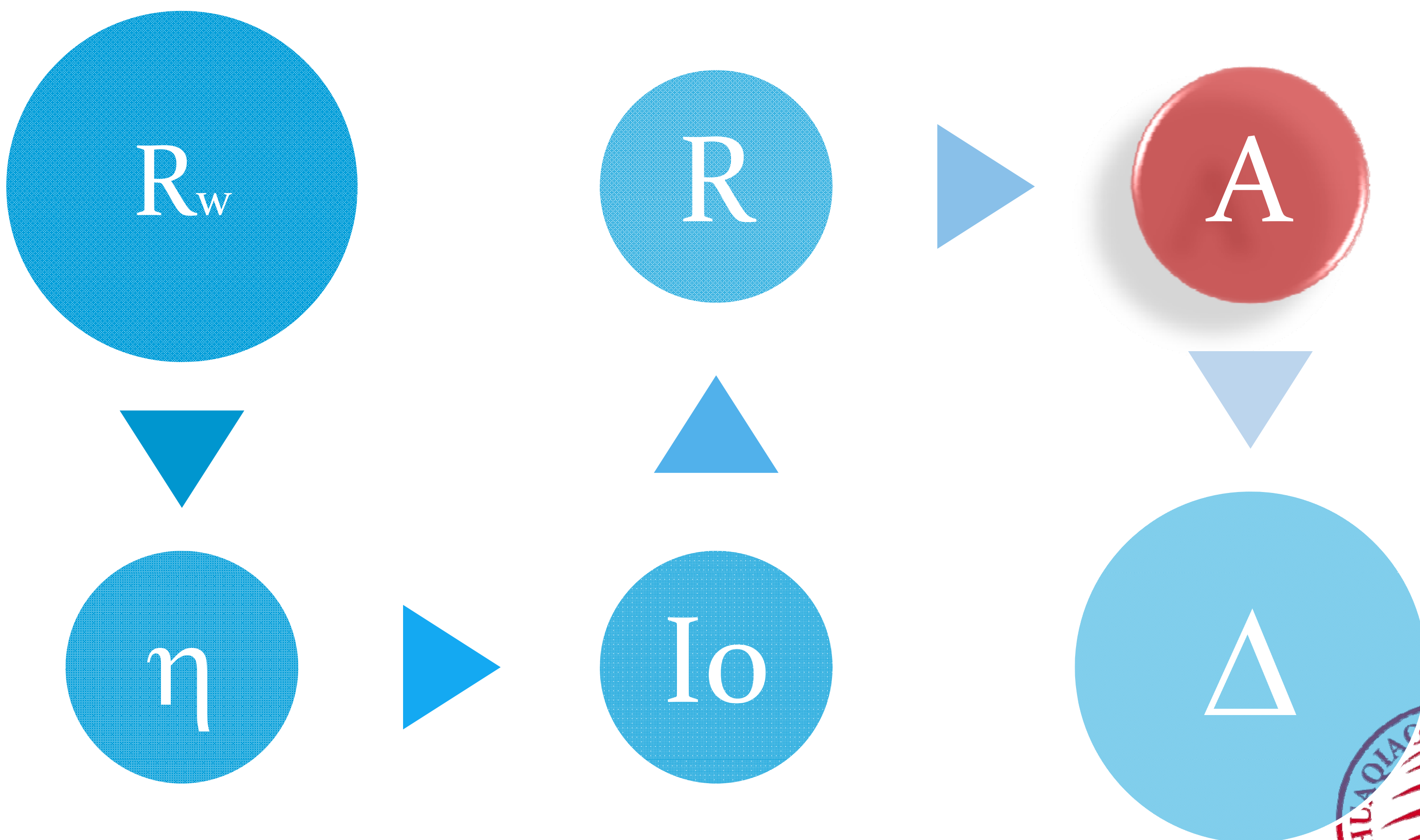
2.3 I_0

- Io is the horizontal rainfall intensity of the windward wall. According to the definition of η, Io = $\zeta \cdot \overline{\eta} \cdot I$. $\overline{\eta}$ is the average value of η, I is the vertical rain intensity and ζ is amplifying coefficient considering the uneven distribution of η on the wall. By data analysis, we value ζ as 1.25.


Rw
R
A
η
Io
Δ

2.4 R

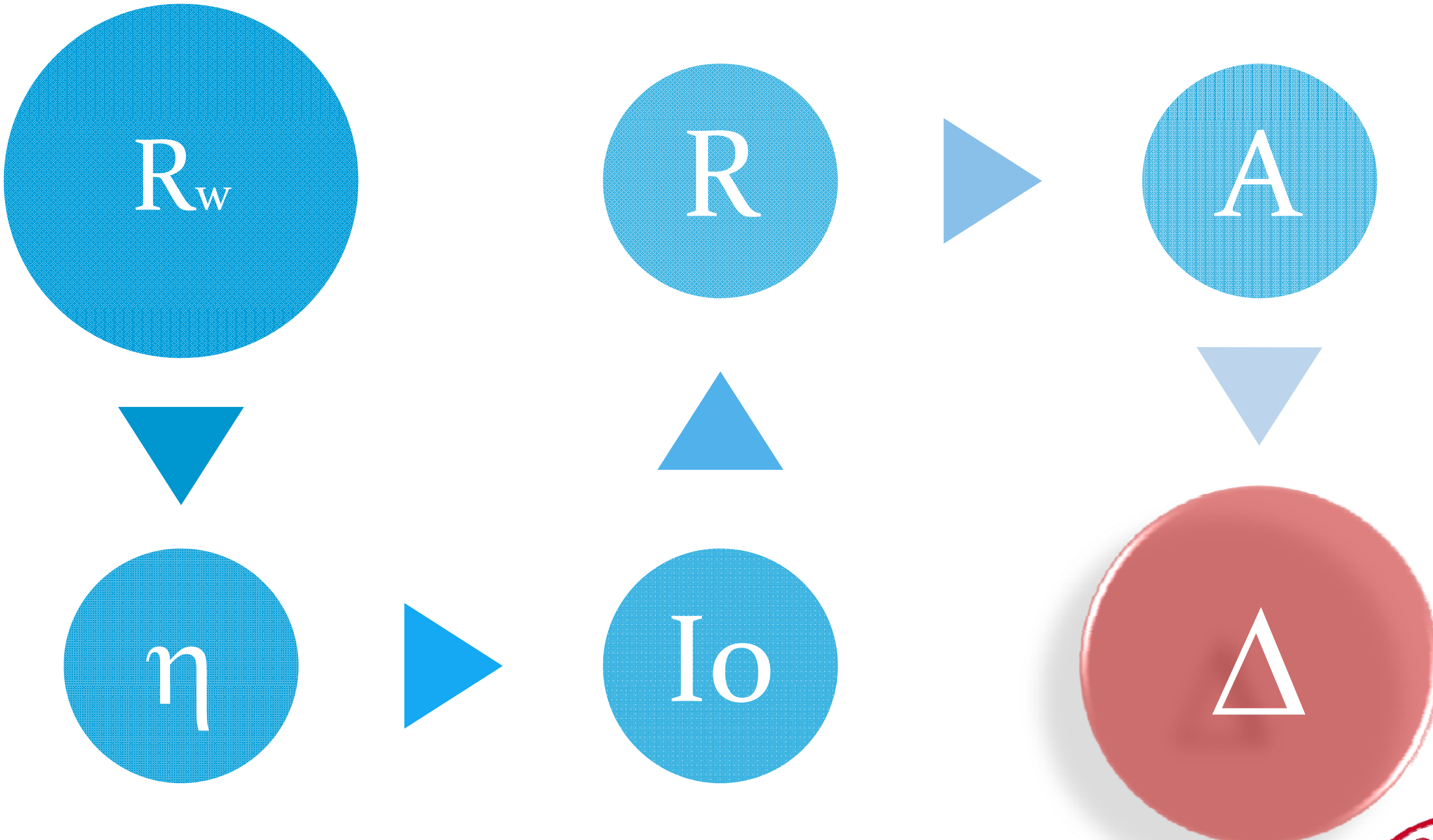
- R is the rainfall erosivity and it reflects the potential ability of soil erosion by the rainfall. The expression is $R=\Sigma E*I_0$. Considering the rainfall duration caused by typhoon is short, this paper takes half an hour of strong rainfall as calculation time. So in the above formula: R refers to the heavy rainfall erosivity($KJ \cdot mm/m^2 \cdot h$); $\sum E$ refers to the total erosion energy in half an hour of heavy rainfall ($KJ/m^2 \cdot h$);



Rw
R
A
η
Io
Δ

2.5 A

- Research shows that the acting force of raindrops on the rammed wall is the same to that on the soil, both display obviously splash erosion characteristics. So this paper uses the universal soil damage equation to study the erosion damage of rammed wall. $A=R \cdot K \cdot LS \cdot C \cdot P$. type: A is soil erosion loss (Kg/m2); R refers to rainfall erosivity (KJ · mm/m2 · h); K refers to the erodibility factor of soil (Kg · m2 · h/m2 · KJ · mm); LS refers to the terrain factors (slope length, slope); C refers to the covering factors; P refers to the soil conservation factor. As it for the wall ,we take C =P = LS=1.0. K shows the internal properties of soil and by calculation we take K = 0.05 Kg · m2 · h/m2 · KJ · mm.


Rw
R
A
η
Io
Δ

2.6 Δ

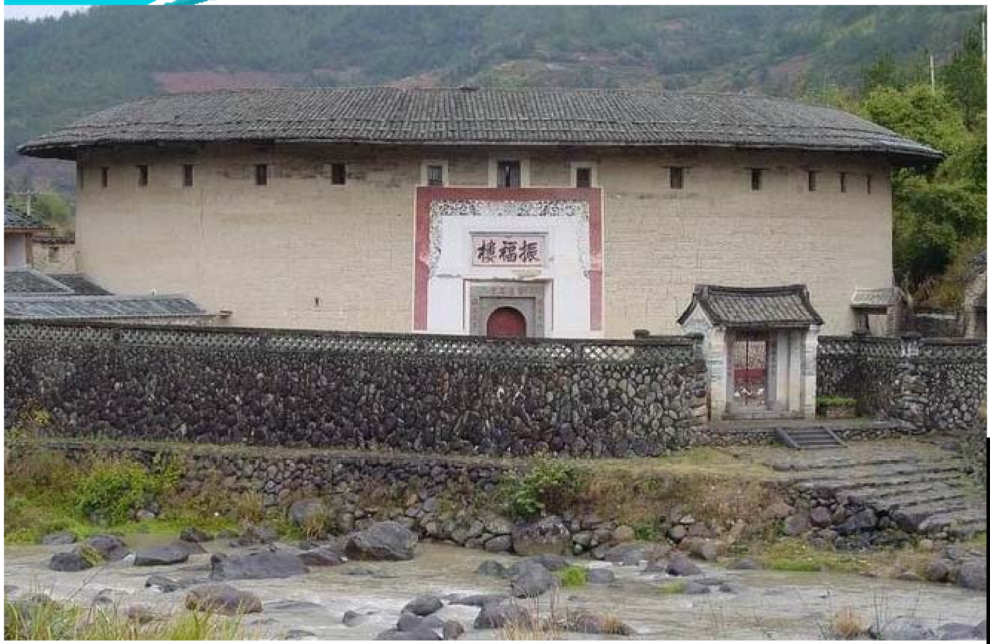
- Δ=A/ρ,Δ is the average erosion damage by thickness (mm), ρ is the wall density of earth-building. According to the material property test, we value ρ for 1.5(g/cm2)

Part 3 Case study

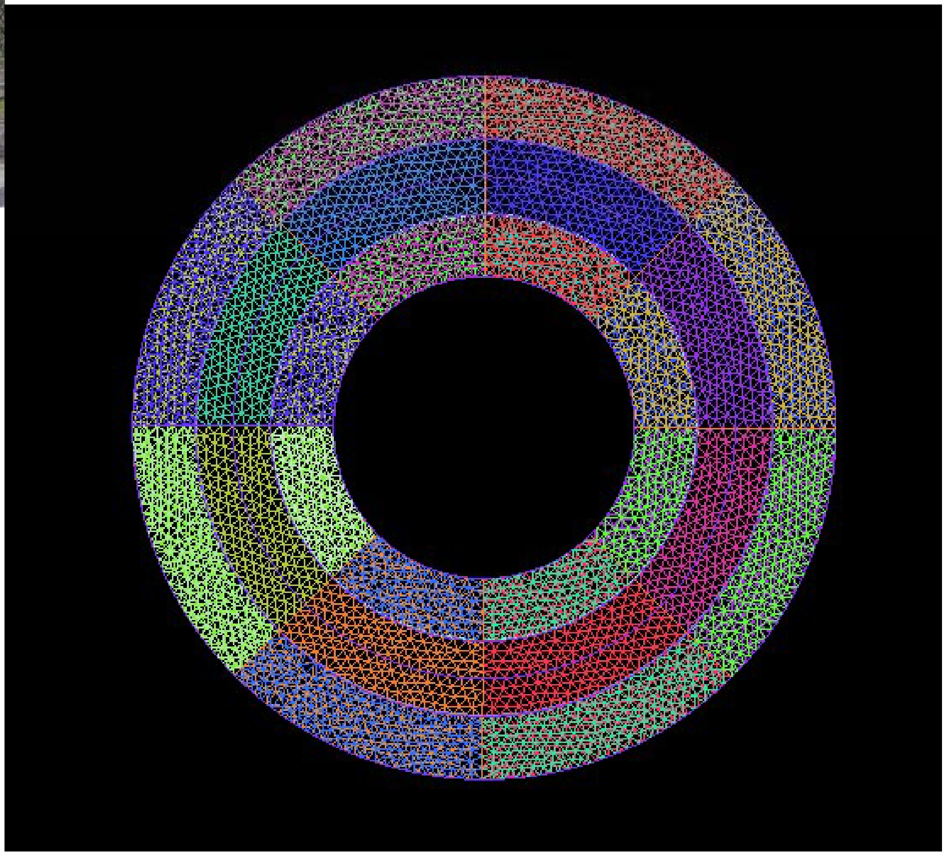
- In order to better understand the local weather characteristics of earth-buildings, this paper collected the meteorological data of a weather station in Zhangzhou. And use the relevant data when stations rainfall intensity are more than 10 mm/h and wind speed are more than 10 m/s to estimate the annual average erosion loss of rammed earth.

3.1 Simulated wind filed

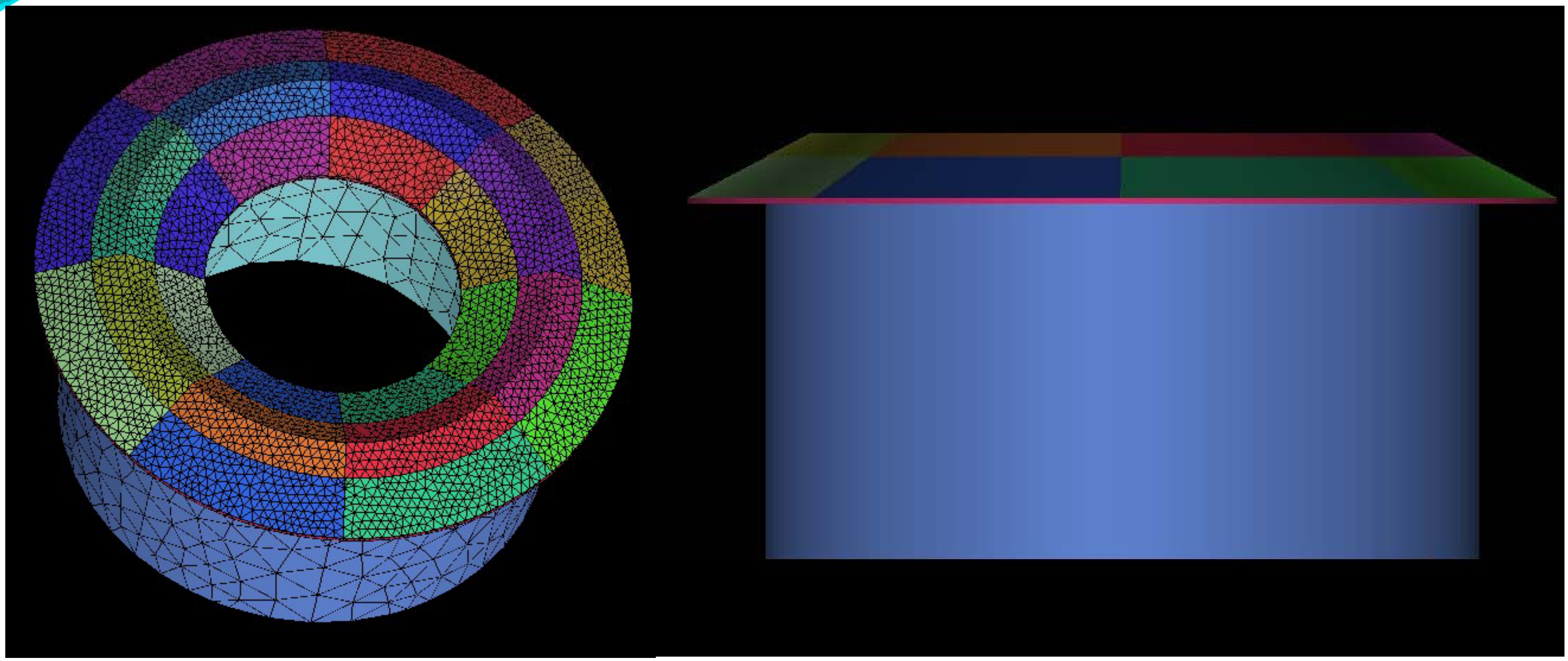
- Fujian Earth Buildings commonly have three to five layers , among which the round Earth-buildings are most commonly. So this paper is based on the most representative Hakka round Earth Building : Zhenfu building. The external diameter is 45m, while inner diameter is 30m. The outside overhanging eaves is 2.5 m while inside overhanging eaves is 2m . The roof slope angle is 25 ° and the total height is 11m,



- The planform of Zhengfu lou



- This paper use CFD(computational fluid dynamics) finite element software to divide the grid of circular Earth Building. For the convenience of numerical analysis, the windward wall and the side wall are both quartered into four parts along the horizontal and vertical direction. So there are 16 calculating faces: $\sum_{i=1}^{4} SL_i$ 、$\sum_{i=1}^{4} ML_i$ 、$\sum_{i=1}^{4} MR_i$ 、$\sum_{i=1}^{4} SR_i$, as shown in below figure.



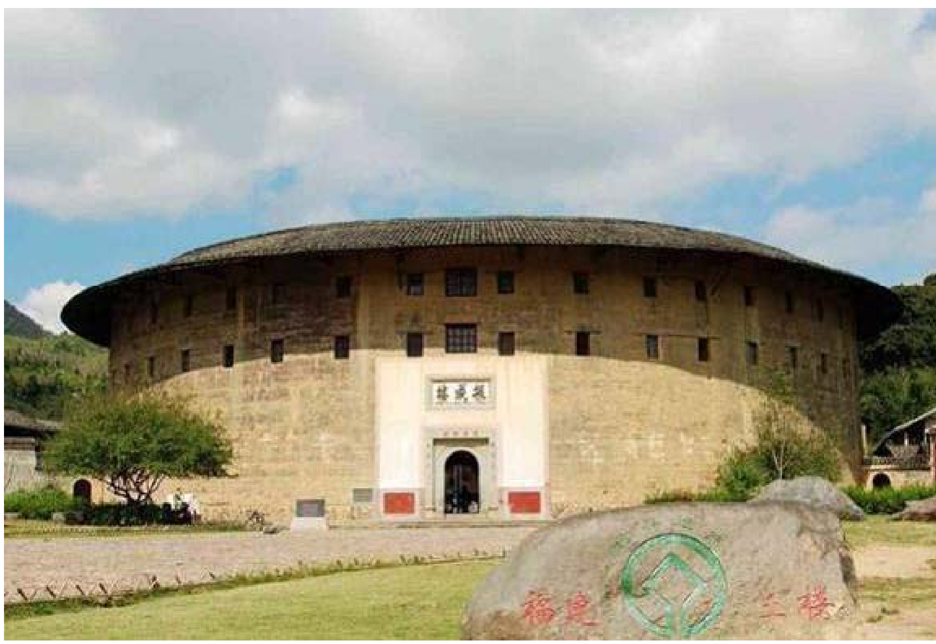
SL4	ML4	MR4	SR4
SL3	ML3	MR3	SR3
SL2	ML2	MR2	SR2
SL1	ML1	MR1	SR1

11m

70.7m

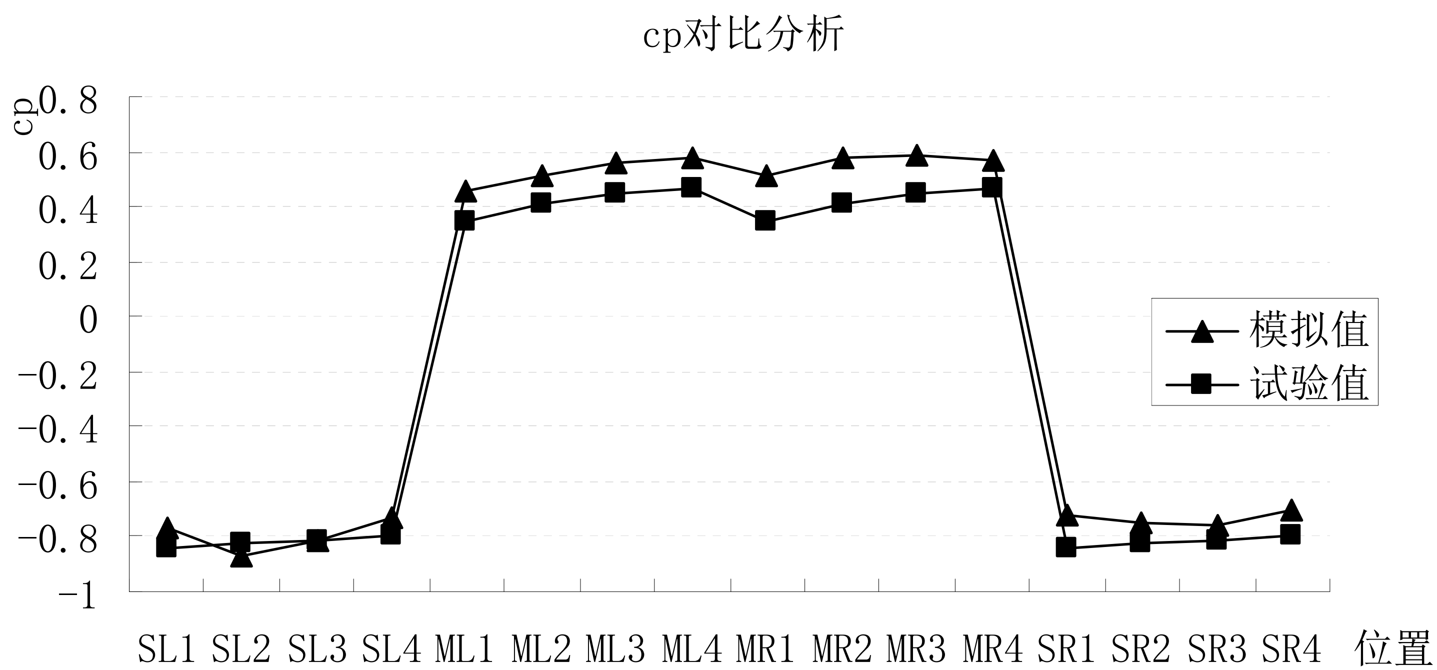
3.2 Wind tunnel test

- To verify the accuracy of the wind field by numerical simulation, we conducted a wind tunnel test. The scaled ratio of the model is 1:60. Because of the symmetry of the round earth-building, we test only 1/4 wall surface. The total number of measuring points is seventy-two, showed at the figure below.



3.2 Wind tunnel test

The comparison of wind pressure coefficients get from numerical simulation and wind tunnel test is shown in the below figure.



- From the figure we can see that wind tunnel tests results are less than that of numerical simulation, but they have a good coincidence of changing trend in general. Therefore numerical simulation result is credible, and it is feasible to use CFD simulated wind filed in the study of Hakka rammed earth Buildings.

3.3 Calculation of key variables

- According to the definition of η,we selected there kind of wind speed(10m/s,20m/s and 30m/s)and there kind of rainfall (10mm/h, 32mm/h and 64mm/h) to calculate η on the 16 wall faces.
- Table 1 η of each partition in different wind speed when rainfall is 10mm/h

areas	10m/s				20m/s				30m/s			
	SL	ML	MR	SR	SL	ML	MR	SR	SL	ML	MR	SR
4	0	0	0	0	0.05	0.21	0.27	0.18	0.22	0.55	0.67	0.19
3	0	0.2	0.18	0	0.10	0.95	0.97	0.10	0.19	1.09	1.17	0.22
2	0	0.58	0.46	0	0.24	1.14	1.24	0.30	0.37	1.39	1.30	0.34
1	0	0.52	0.52	0	0.10	1.05	1.09	0.14	0.36	1.24	1.09	0.33

- Table 2 η of each partition in different wind speed when rainfall is 32mm/h

areas	10m/s				20m/s				30m/s			
	SL	ML	MR	SR	SL	ML	MR	SR	SL	ML	MR	SR
4	0	0	0	0	0.09	0.24	0.29	0.13	0.21	0.71	0.64	0.19
3	0	0.33	0.28	0	0.15	1.02	0.98	0.11	0.15	1.18	1.24	0.19
2	0	0.58	0.50	0	0.25	1.23	1.18	0.36	0.32	1.34	1.25	0.42
1	0.10	0.59	0.54	0.08	0.11	1.01	1.05	0.19	0.35	1.15	1.18	0.36

- Table 3 ηof each partition in different wind speed when rainfall is 64mm/h

areas	10m/s				20m/s				30m/s			
	SL	ML	MR	SR	SL	ML	MR	SR	SL	ML	MR	SR
4	0	0	0	0	0.14	0.29	0.33	0.13	0.15	0.68	0.64	0.21
3	0	0.19	0.29	0	0.09	1.10	0.98	0.18	0.27	1.44	1.54	0.37
2	0.05	0.60	0.52	0.08	0.28	1.20	1.27	0.27	0.49	1.74	1.81	0.46
1	0.12	0.35	0.39	0.08	0.12	1.09	1.15	0.13	0.29	1.20	1.31	0.34

- From above data we can draw the conclusion : η values of the windward wall are much greater than those of the side wall ; the erosion damages to the side wall are almost negligible when the wind speed is 10 m/s. values of the zone 4(near the eaves) are less than the other three divisions, which shows that the large picking eaves play an important role to protect the upper wall, and the protective action become weak along with the increase of wind speed. so when the typhoons come with rainfall, the big picking eaves of earth building cannot effectively prevent rammed earth wall from rainfall erosion.

- Table4 Value of *R under* various working conditions

speed	10mm/h	32mm/h	64mm/h
10m/s	0.06	0.49	1.35
20m/s	1.09	18.12	103.96
30m/s	5.24	68.33	455.21

- From the table we can see that rainfall erosivity increase along with the wind speed and rainfall intensity. And the influence of wind speed is more apparent than that of rainfall intensity, which means the wind speed is the key factor of the erosion to rammed earth wall. The erosivity can be neglected when the wind speed and rainfall are both small, so the season rainfall have limited influence while the extreme weather is responsible for erosion damage.

- Table 5 Estimate of erosion damage of rammed earth

speed	10mm/h	32mm/h	64mm/h
10m/s	0.0051	0.015	0.043
20m/s	0.091	0.56	3.00
30m/s	0.427	2.14	14.23

- Table6 Average annual erosion damage of rammed earth wall

year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Δ	1.2	0.9	0.4	0.5	2.7	5.1	1.3	1.6	1.8	2.6

Part 4 Conclusion

- From above figure, we can see that: the annual erosion damage in the year from 2001 to 2010 years is about 0.4 mm to 2.6 mm. The erosion damage to Hakka earth-buildings from wind-driven rain is quite large. It is very necessary to put forward corresponding measures to protect the earth-buildings. And this is what we are working for.