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SYNOPSIS : Red clay distributes widely in China, it can be classified into two kinds: swell－shrinking and non－swell－shrinking red clay.According to the strong strength and low compressibility features of the Expansive－contractive Red Clay (ECRC), it can be used as an excellent natural ground. Sometimes its swell－shrinkage property may cause crack damage to the low house which basedon the ECRC. this rupture is quite common and serious, the crack house became dangerous and had to be rebuilted.In China, the main preventive measures against the crack damage are: moisture holding, deep embedment, soil replacement method (sand cushion),sand surrouding and heat insulation,etc.

INTRODUCTION

In China, as a subkind of laterite, red clay is a special soil and it is a high plastic clay which cover over the foundation rock, it was formed by the laterization of carbonatite . Red clay distributes widely in China, it mainly distributes in the southern China, such as Guangxi, Guizhou and Yunnan etc. Red clay can be classified into two kinds: swell－shrinking and non－swell－shrinking red clay.

According to the strength and compressibility features of the ECRC ,it can be used as an excellent natural ground,but its swell－shrinkage property may cause crack damage to the house which based on the ECRC. The rupture is quite common and serious, the crack house became dangerous and had to be rebuilted. For example, in a department of Chongzuo in Guangxi, several ten thousands of square metres of low houses were damaged in different degree. In one of the serious case, 20 thousands square metres of the house were removed at a time, the economic loss was enormous. Therefore, it is most significant to make a special study of the ECRC.

In this paper, beside a brief introduction of the engineering property of the ECRC , we presented the analysis and preventive measure to the crack damage to the low house on the ECRC.

ENGINEERING PROPERTIES OF THE ECRC

1. Composition and Structure of The ECRC

Mineralogical composition of the ECRC in China is mainly kaolinite , illite and chlorite, no montmorillonite is found generally .

The chemical composition of the ECRC is obviously different from that of the typical expansive soil. The main difference is that the SiO_2 content (some are only 35 percent) and the index of SiO_2/R_2O_3 (less than 2) of the ECRC are less than that of expansive soil , and the Fe_2O_3 content (more than 13 percent) of the ECRC is more than that of expansive soil. These differences are corresponding with their difference on mineral composition.

The cation exchange capacity of the ECRC is far less than that of the expansive soil. For example , in one place of Guangxi, the cation exchange capacity of the ECRC is only 11－17 me/100g , but it is more than 30me/100g in the typical expansive soil in China, The PH value of the ECRC is about 7, the main exchangable cations are Ca^{2+} and Mg^{2+}, their content reach 30 me/100g,the Na^+ and K^+ content are extremely lower , some only 0.2me/100g.

Fine particles are the majority of all grains which the ECRC contain , and of high dispersity and non－uniformly gradation. Among of them , more than 50% are colloid that less than 2 μ, more than 60% are clay that less than 5μ. For some soil samples, more than 90% are grain that less than 1μ.

There are remarkable features in the structure of the ECRC. The particles which mainly exist as the form of aggregate are not easy to be dispersed . It is because the iron oxide and manganes oxide which remain in the soil are gelatinated in the acidic environment during the ECRC formed . Therefore, the fine particles are geled as steady aggregates of various size in the ECRC. The study of the aggregates structure of the ECRC in Guangxi Province with scanning electronic microscope indicated : there are obvious differences among the size of this aggregates, the sizes varied from 50 μ to several μ . The interior of aggregates array densely because the interior fine particles form a face－to－face struture. There is not regular array of the aggregates , so they array scatterly. Odd sand and slit distributed among the aggregates, various voids of several μ to several tens of μ formed among the aggregates, and the aggregates were geled by ferruginous oxide.

2.The Physical Properties of The ECRC

The indexs observed from the soil in its natural state indicated that the ECRC is characteristic of high moisture and low density .

a. Natural moisture content W is generally from 30% to 60%, some of them even reach 90%.

b. Natural unit weight ν is generally from 16.5 to 18.5KN/m^3, some of them only 16.0KN/m^3

c. Natural dry unit weight ν_d is generally from 13.5 to 15.0KN/m^3, some of them even only 12.8KN/m^3.

d. Natural void ratio e is at least near or equal to 1, some much more than 1.5,single even reach 2.5 . After compacted by Proctor Standard, the given optimum water content of the ECRC varied from 30% to 50% , the maximum dry unit weight varied from 13.5 to 15.0 KN/m^3 , single even less than 13.5 KN/m^3.

The ECRC has remarkable features in plastic property. Its limit of liquid W_L varies from 45% to 120%, the plastic limit W_P varies from 30% to 60% , the plastic index I_p varies from 17 to 65.

Distribution of the ECRC is differet from place to place on the plasticty chart,see Fig.1. The ECRC in Guangxi is mainly distributed above line A, the ECRC in Yunnan below line A, and in Guizhou it near the both side of the line A.

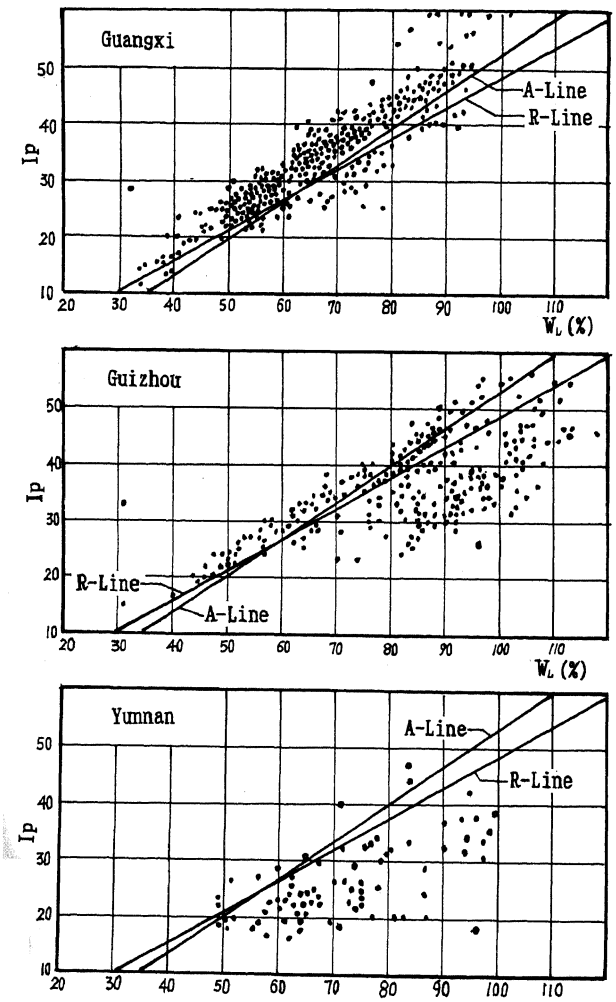

Fig 1. Distribution of Various Red Clay on Plasticty Chart

A－Line : $I_p = 0.66\ (W_L - 20)$

R－Line : $I_p = 0.534\ W_L - 6$

In China , The ECRC is defined from the red clay by adopt $I_r = W_L / W_p$ and the standard as follow :

If $I_r > 1.40 + 0.0066 W_L$ (1)

or $I_r > 0.543 W_L - 6$ (2)

The soil above the line R in the plasticty chart is called the ECRC.

Because the swell－shrinkage was decided by the soil structure to a considerable degree,the definition above is very roughly, it can only be taken as reference in the primary judgement.

Although the moisture content of the ECRC is quite high in natural state,because of the high plastic limit, the ECRC generally exist in the form of stiff, stiff plastic or plastic state.

The shrinkage limit of the ECRC W_s is generally about 20%, some reach 25% ,some even near 30% . This is very different from the typical expansive soil (for typical expansive soil, W_s is about 10%) . This is obviously because of steady aggregate structure of the ECRC.

3.The Mechanical Properties of The ECRC

The natural moisture content of the ECRC is high and its density is low (because the high void ratio) , however , owing to its steady aggregate structure , its strength is not low, and its compressibility is not high . this is somewhat different from the general concept of the clay.

The statistics show that the shear strength index of more than 100 various soil samples which in their natural states were tested with direct shear apparatus and quick shear test method were: the cohesion C within the range of 30 to 160 kPa , the internal friction angle Φ varied within the rang of 8° to 22°.

The unconfined compressive strength q_u of the soil samples which in their natural states were also high , they varied from 200 to 400 kPa .

According to the field loading test results of the ECRC , its critical edge pressure generally varied from 150 to 300 kPa , some even 800 to 900 kPa , this indicaded that this kind of the soil has very high shear strength and bearing capacity.

From the compression test of various soil samples which in their natural states, the coefficient of compression a_{1-2} of pressure P from 100 to 200 kPa variedfrom 0.1 to 0.4 MPa^{-1}. According to the Chinese standard, it belong to medium or low compressibility.

4. The Swell－shrinking Property of the ECRC

In natural state , the main deformation of the ECRC is high shrinkage ratio and low swell ratio. For instance, the volume shrinkage ratio of the soil sample which in its natural state is generally higher than 6% , some even reach 20%, however, the expansion generally less than 1% to 2% , some even near zero.

The main deformation of the ECRC is shrinkage. This is owed to the no strong water affinity of mineral composition , the no high cation exchange capacity and the high natural moisture content which is nearly equal to the moisture content of the soil which has been fully expansived.

In fact , if lower its moisture content, its swell ratio increases notably, for example, the soil sample of the Laibin (Guangxi)with natural

moisture content of 49 percent (W = 49%), its volume expansion is only 0.5% ,however , its volume shrinkage δ_s reaches 26%. After having air − dried the soil sample and taken swell − shrinking test, δ_p reaches 40% while moisture content is 26.5%, see Fig.2 .

Therefore, we should not consider that the ECRC only has the property of shrinkage in any case.

The swell − shrinking of the ECRC can also be demonstrated by the fissures of the soil. There is one kind of fissure, it has smooth surface and slickenside the surface of the fissure is soaked by ferromanganese , organic matter or grey clay , this indicates the soil has swelled or shrinked repeatedly and has high swell − shrinkage . In fact , this kind of fissure can

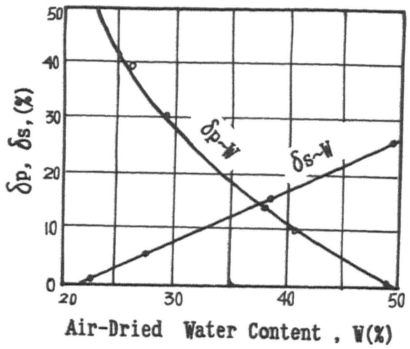

Fig 2. δp andδs of Various Air − dried Water Content

only be found in rad clay with high swell − shrinkage.

The fissure caused by shrinking is quite popular and remarkable. There are two kinds of fissure, net − shaped and lined. The former would cut soil masses into isolated soil pillars and cause engineering problem.The latter is straiht line or arc fissure , some of them are several metres long, some of them are 10 metres or even 100 metres long. The crack developed down vertically, it was several metres depth, the deepest reached 10 metres. The widest width of the ground crack is found in the ground surface , some of them reached 15 cm to 20 cm , and they became narrow from surface to underground , finally disappeared. The surface of crack was rough and uneven. In China,this kind of fissure is called ground crack. When the ground crack occurs below the foundation vertically or near the foundation parallelly, it would bring serious damage to the house.

ANALYSIS OF CRACK DAMAGE TO THE HOUSE ON THE ECRC.

The main damage to the house on the ECRC is crack damage in the wall of the low house (no more than three storeys), see Fig.4. Form of the cracks are vertical or horizontal , but oblique in most case. The width of the cracks, some reach 10 cm, some even more than 20 cm.

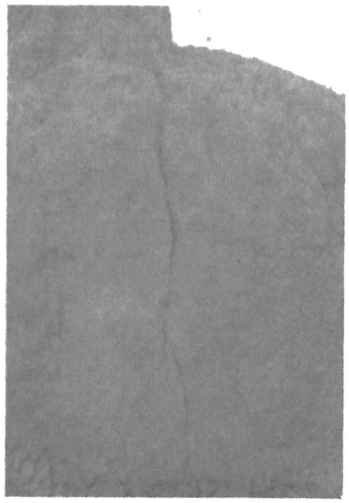

Fig 3. Cross Section of Ground Crack

Fig 4. Crack Failure of Lower Houses on The ECRC

As to the crack damage to the house on the ECRC, on one hand, it was caused by the excessive vertical swell－shrinkage , however, in the climate condition of southern China , the crack damage were generally caused by the subsidence of shrinking.

On the otherhand, the cause of house's cracking damage on the ECRC is the crack—— ground crack which caused by the horizontal shrinking of ground , when ground crack occurs below the foundation vetically , it produces shear force T to the base of the foundation as a tensile force and it causes the foundation broken , consequently, cracks occur in the wall which base on the foundation (see Fig.5). when the ground crack occurs near the foundation parallelly, it produce thrust force to the foundation and make the foundation moved horizontally, then the horizontal cracks occur in the wall. (see Fig.6)

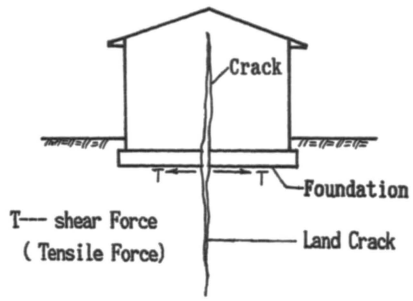

Fig 5. Ground Crack Occurs Below Foundation Vertically

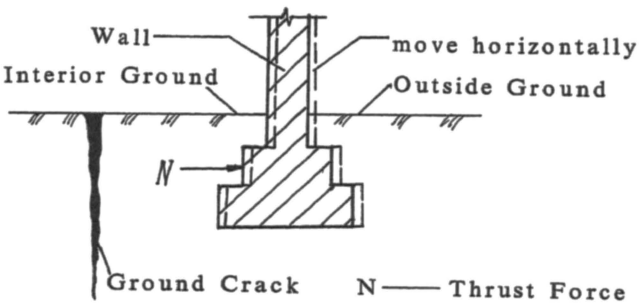

Fig 6. Ground Crack Occurs Near Foundation Parallely

The direction of ground crack is orthogonal to that of the soil water evaporation, because the direction of shrinkage stress is corresponding with that of the soil water evaporation. After house was built, moisture of foundation soil is redistributed and the theoretical isolines of moisture content are distributed along the periphery of the house. Therefore, the direction of ground crack was parallel with the wall foundation line, usually, it parallel with the longitudinal axis of the house.To the house with long span－length and few interior partition walls, ground crack usually occurs in the middle of the floor and extends along the longitudinal axis of the house(see Fig. 7).

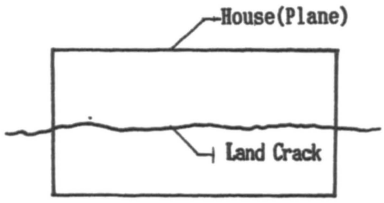

Fig 7. Ground Crack That Coincide with House Axis

Therefore, if ground crack occurs below the wall foundation , the vertical crack will inevitably occurred in this wall.

Fig.8 showed that the crack occurred in the wall and floor of a single－storey house when a ground crack occurred below this house.

Fig 8. Crack Damage To A Single－storey House Caused By Ground Crack

Fig.9 showed that the crack was occurred in the wall of a two－storey house when a ground crack occurred below this house.

Fig 9. Crack Damage To A Two－storey House Caused By Ground Crack.

The crack damage to the low house base on the ECRC is not only depend on the low or high swell-shrinkage of the ECRC, but also depend on the environmental fators as follow :

a. Climate condition —— the swell-shrinkage of Guiyang soil is higher than the Guixian soil, but the house' s crack damage of the Guiyang is less than the Guixian' s. This is because it is always rains in Guiyang , the moisture of the ground changes very gentlely all the year. However , there are remarkable rainy season and drought season in Guixian, the moisture of the ground declines rapidly in drought season.

b. Groundwater level —— the swell-shrinkage of Guixian soil is similar to that of the Litang soil. However , because of the high groundwater level that keep constantly. There is little crack damage occur to the house on Litang soil, even no crack taken place.

c. Topography and geomorphogy —— as to the house on the edge of the top of the slope or on the slopeside, the air face of the ground is large, water in the ground can be evaporated in many dirction, so the condition of moisture holding is poor . Therefore , crack damage to this house is more serious than it to the house on flat ground.

d. Ground cover —— in a farm in Wuxuan county, in front of a storehouse, there was a reinforced concrete sunning ground, the wall of this side was not damaged , but the wall of the other side was damage seriously becuse there was not any ground cover.

Therefore , while evaluating the swell-shrinkage grade of the ECRC, we should not only consider the swell-shrinkage but also the four environmental factors above.

PREVENTIVE MEASURE AGAINST THE CRACK DAMAGE TO THE LOW HOUSE ON THE ECRC.

At present, the main preventive measures againt crack damage to the house on the ECRC are as follow:

a. Moisture Holding —— because the crack damage to the house on the ECRC mainly caused by loss of the water and shrinkage of ground, so it is necessary to hold the moisture of the ground as possible. Now an effective method is to build the wide apron, its structure and size were shown in Fig.10. Generally , width of the wide apron is 2 to 3 metres , sometime it is built wider . The wide apron can hold the moisture of ground and prevent the water from entering ground , it can also keep the temperature and insulate the heat . Therefore , it can prevent ground from developing crack within the range of foundation. In addition, for holding the moisture , planting tree with excessive evapotranspiration should be controlled in the surrounding of the house .

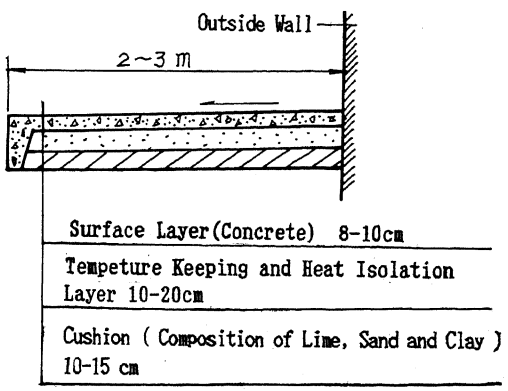

Fig 10. Structure and Size of Wide Apron.

b. Deep embedment —— because the atmospheric influence upon the deformation of subsoil decreases gradually with the increase of depth, the foundation should be embedded down to the level that the change of moisture is quite gentle . The embedded depth is generally 1.2 to 1.5 metres in the area of the ECRC . It was suggested that the deep embedment should only be buried beneath the corner of the house, becuse the air face of the foundation soil at this place is large (270°) ,moisture of the foundation soil is evaporated easily, and the crack mainly occur at the corner of the house. Taking deep embedment as the main preventive measure is able to prevent the house from crack damage successfully, but the cost of the low house will increase too much. The practice indicates that the depth of foundation can be reduced in the case of the wide apron is taken, conversely, the width of the wide apron can be increased in the case of the deep embedment is taken.

C . Soil replacement method (sand cushion) —— generally , this method is to build sand cushion beneath foundation , its thickness is about 50 cm . It acts in many aspects . The first , it can regulate the stress of foundation base and the deformation of the foundation ,thus, it can decrease the influence of non-uniform subsidence and heave of subsiol upon the building ; The second ,the ECRC inside and outside the house is separated by the sand cushion within the depth of the sand cushion to intercept the path of the capillary water and prevent the water transformation between inside and outside the house, so the moisture change of foundation soil can be decreased to prevent the ground crack from occurring and developing. The third, if ground crack occurs below foundation vertically, the wall crack caused by the foundation tensilefailure can be avoided , for sand can nottransport the shear force which produced by ground crack . In addition, it acts as adding the depth of the foundation.

d. Sand surrounding —— it was formed by filling sand in the bottom and sides of the foundation.(see Fig.11) The action of the bottom sand cushion was descriped above. The side sand surrounding can eliminate the crack damage caused by the ground crack that occurs below foundation parallelly, this is because the side sand surrounding can produce a cushioning effect, and the horizontal movement of foundation can be avoided when ground crack produces thrust force to foundation.

e. Heat insulation —— for the foundation in high temperature , the heat insulation method should be applied to prevent moisture evaporation from ground soil. The common method is to form a cushion at the bottom of the foundation with thermal insulation material like the cinde.

The moisture holding, deep embedment , sand cushion and sand surrounding above were taken comprehensively accompaning with strengthening

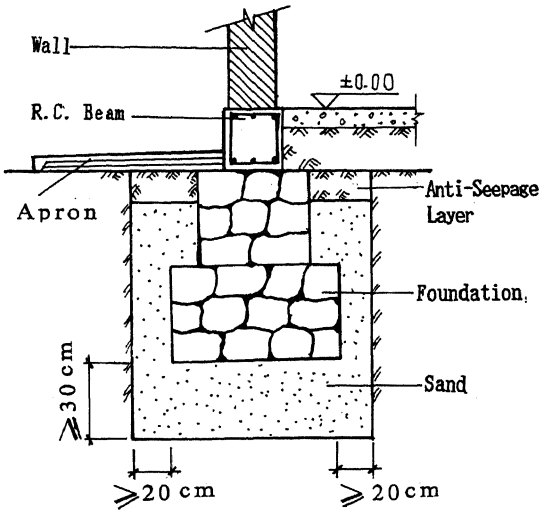

Fig11. Sand Surounding Foundation

the upper structure as supplementary measures (For example, built the reinforced concrete periphery beam to each storey of house). All measures are successful.

For example,the soil in the WuXuan town of Guangxi in China is the strong ECRC, and the ground crack there developed extremely well . The crack damage to several tens of low houses (6-9 metres wide , 30-60 metres long) have occurred constantly since they were built in 1950 ' s and 1960 ' s, all single－storey and two－storey houses have almost occurred crack . Though some measures (excavating the ditch around buildings for storaging water,embedding deep and strengthening foundation , widening wall body, constructing the reinforced concret－eslab under foundation , adding the reinforced codcrete periphery beam and footing beam) were taken respectively at that time, the renovation of the house had been taken constantly, and the failure had occurred constantly . In 1970 ' s , for single－storey houses,the sand surrounding foundation(shown in Fig.12)was taken;for two－storey houses,the sand cushion and sand sur－rounding foundation(shown in Fig.13) were taken. Since then , no crack damage to the houses have occurred.

The examples above indicated: at present ,in China,the preventive measures against the crack damage to the houses on the ECRC are effective.

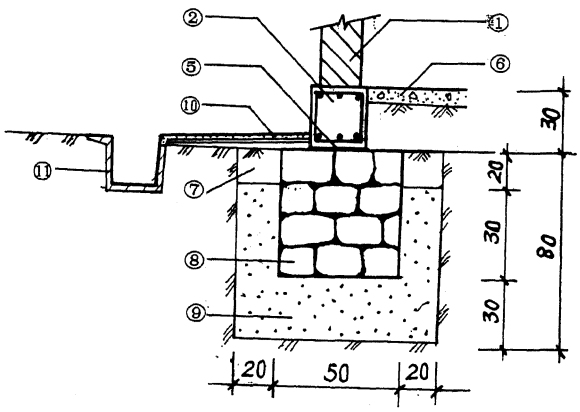

Fig 12. Sand Surrounding Foundation For Single-storey House

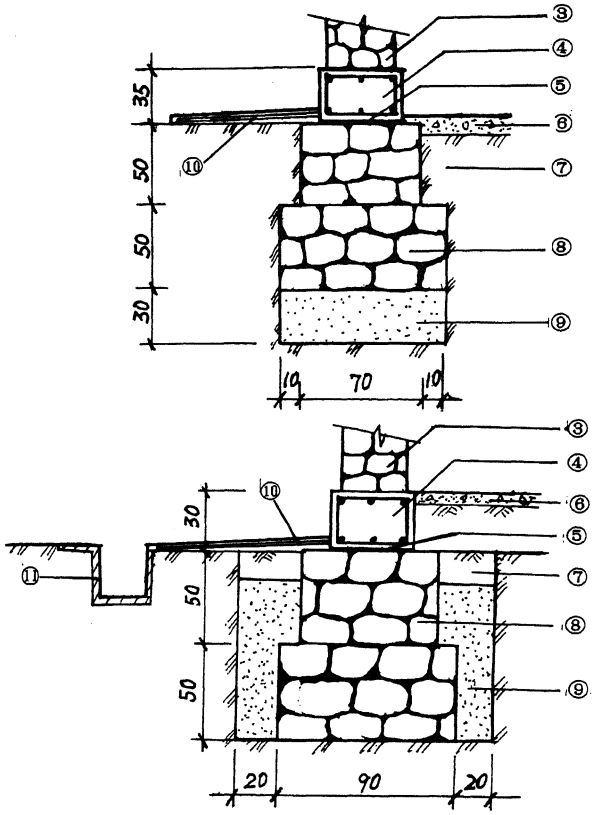

Fig 13. Sand Cushion and Sand Surrounding Foundation For Two－storey House

① —— Outside Wall
② —— 30 × 30 cm² R·C Ground Beam, Contain 4Φ16 reinforcing bar
③ —— 40cm thick rubble wall
④ —— 45 × 30cm² R·C ground bean, contain 6Φ16 reinforcing bar
⑤ —— asphalt felt
⑥ —— floor inside house
⑦ —— compacted fill
⑧ —— foundation
⑨ —— sand
⑩ —— apron
⑪ —— open ditch

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