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The design inquiry of liquefaction prevention of foundation using macadam wells of pressure-release and water-removal

H.Yu
Seismic Resistance Office of Xianyang, People's Republic of China

ABSTRACT,
In this paper, the author provided a theoretical basis for foundation reiforcement of buildings, using macadam wells of pressure-release and water removal, the applicable objects, fields and arranging requirements of macadam wells are proposed. The determination of distance between wells, the reinforcement depth, width as well as the special requirments for construction are also explicated.

1. INTROCTION

Along Liquefaction foundation outside of buildings, the macadam wells of pressure-release water-removal and vadose layers are laid out rationally, according to require of design, they may reduce water-removal route of liquefaction soillayer in horizontal direction, quicken vertical water-removal, the pressure of super-calm pore water is dissipated, the pressure of pore water in saturated sand layer is decreased, the foundation liquefaction would not occured. Research results indicate that, it is economic and reasonable to lay out macadam wells pressure-release and water-removal in sand foundation. In this paper, the particularity of liquefaction prevention method of building foundation that are located liquefying sand layer, is analyzed and inquired, a construction plan that is economic and reasonable, higher in reliability, convenient in construction, is given.

2. SUITABLE RANGE

The buildings that are located on I-grade terrace and river flat, theirs foundations soillayer are distributed in horizontal direction, and regular, the soil species are well-distributed, the site doesn't exist glide danger. according to the standard of aseismic design in the People's Republic of China, the building site is distinguished liquefying site, under the action of earthquakes, the ground may appears spraying weater and giving off sand from middlle to serious, when liquefation grade is middle ($5 < I_{LE} < 15$, I_{LE} is index of liquefaction) or serious ($I_{LE} > 15$), the method of macadam wells of pressure-release and water removal may be used for preventing liquefaction of the building foundation.

3. SUITABLE OBJECT

According to quantitces of statistical information [2] about liquefying foundation of Hancheng and Tangshan earthquakes in china, as for the buildings that longitudinal and transverse walls are close, such as residences, office building etc, when lower soillayes is liquefying soillayer, and the height from its top to bottom of foundation H is equal to or greater than 1, it is effective to use macadam wells of pressure-release water-removal for removing the pressure of super-calm pore water of silt and fine sand layer under the action of earthquake; but, as for spacious buildings, factory buildings, when theirs foundations are located or close to liquefying sand layer, it is not effective to use only this method, for this condition, it is nesessary to use synthetical measures, and combining structural arrangement, geologic ciditions of engineering.

4. THE BASIS OF DESIGN

Under the action of earthquakes, sand soil and silty day may be liquefied, the factors of occuring liquefaction are: (1) saturated water; (2) loose; (3) cannot drain quickly. Thus, as long as one of above-mentioned factors is changed, anti-liquefaction ability of soillayer would be changed, the settlement of liquefaction would be decreased.

Anti-liquefaction design method using macadam wells pressure-release water removal, consider that, under the action of compression stress and shear stress caused by earthquakes, bound water membrane thins or thicks, then, the stress between grains bearing by skeleton of sand soil, transfers to pore water, the stress of pore water would be increased continuously. Then, liquefying soillayer outside foundation is liquefied first, because that mrust or outside soil decrease quickly, soillayer under foundation will sink. major factors as follow:

4.1 The soillayer that is located under buildig's foundation, in the range of diffusion angle of stress, because of constrained action of additional stress, have consolidation and compaction, the void ratio and water content of foundation soil would be decreased, its bearing capacity will increase over 20 percent; it is different from outside soillayer of foundation.

4.2 According to the principle of effective stress, shear intensity of non-cohesive soil is decided by size of angle φ of internal friction, but also is direct proportion to effective normal compression stress, the effective stress is a stress in skeleton of sand soil, thus, shear intensity of soil may be given as follw:

$$f = (\sigma - u)tg\varphi \qquad (1)$$

in which:f is shear intensity of soil;

σ is total stress;

u is compression stress of pore water;

φ is angle of internal friction.

Some conclusions may be given, according to formula (1), under the action of the pressure, pore water will be vadose toward outside, the effective normal compression stress of soillayers under foundation that are located in the same harizontal plane, is greater than outside. Thus, the shear intensity, that is located under building's foundation, in the range of diffusion angle of stress, is greater outside soillayer. The shear intensity of soillayer is greater, the capacity of anti-liquefaction is higher.

4.3 Through observation and analysis for upper buildings and foundation, it is discovered that max acceleration at free-field is greater than max acceleration of built ground, theirs ratio is about 1.5 [4]. According to statistical analysis, the relationship between horizontal seismic acceleration and seismic intensity are in table 1.

Table 1. The relationship between horizontal seismic acceleration and seismic intensity

Seismic intensity	6	7	8	9
Horizontal seismic acceleration (cm / sec^2)	62.5	125	250	500

Because that seismic intensity is higher at part site, then,the saturated loose sand and silty clay of free-field around buildings, are liquefied early, the grounds appears spraying water and giving off sand, the buildings sink and incline suddenly, the walls cleave, the safety and normal use of buildings will be menaced.

4.4 The building norm of aseismic design in China stipulate, max vertical seismic acceleration may be 65 percent of max horizontal seismic acceleration. Judging from this, because that horizontal seismic acceleration increases at free-field, then, vertical seismic acceleration will increase also, the shear deformation of sand soil will be greater, the liquefying range of saturated loose sand and soft soillayer will enlarge, additional settlement will increase.

It merits attention that, liquefaction soillayer has shock-absorbing action, the seismic waves passed through liquefing soillayer, theirs high-frequency component is weakened greatly, the destruction extent of buildings that theirs periods are shorter, is lighter than non-liquefying regions, this conclusion had been confirmed by Haicheng and Tangshan earthquakes. The design plan using macadam wells of pressure-relase and water removal, has considered synthetically above-mentioned all gains and losses, this design method purports that, buildings seek shelter from serious liquefying sites, but also, the disaster of upper structure can be decreased, the settlement is controlled within admissible value, under the action of common earthquakes, the buildings can be used normally.

5. THE ARRANGING REQUIREMENTS OF MACADAM WELLS OF PRESSURE-RELEASE AND WATER-REMOVAL

The arranging requirements are determinded, according to characters of buildings and geologic conditions of engineering, and combining the thickness of liquefying sand layer, liquefaction grades, the highest water table over the years etc. The arrangement of well points will effect directly results of pressure-release and water-removal, after sand layer is liquefied, in the couse of earthquakes.

5.1 The distance from the centre of water-removal wells to outside edges of building foundations is usually 0.5 to 0.8 meters.

5.2 It is advantageous to increase diameter of ure macadam wells or to reduce the distance between wells, for draining of liquefying sand layer, through calculation and compare, to reduce the distance between wells is better than to increase the diameter of wells for dissipating pressure of pore water. the author suggests that, the diameter of wells is 25～60 centimeters ,the distance between wells is smaller than eight times of the diameter of wells.

5.3 The distance between wells should be larger than calculation value near rivers or in silt and silt soil that osmotic coefficient is smaller, else, the ideal results of pressure-release and water-removal cannot be obtained.

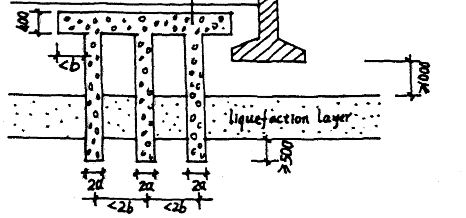

Fig 1. The signal section of macadam wells of pressure-release and water removal

6. THE DETERMINATION OF DISTANCE OF MACADAM WELLS OF PRESSURE-RELEASE AND WATER-REMOVAL

6.1 On the basis of Darcy. osmotic law, the distance of macadam wells of pressure-release and water-removal is desighed, the partial differential equations are established on condition that liquefying sand layer drain in horizontal and vertical directions at the same time. The solution of equation that is satisfied initial and boundary condition, is given, then ,calculation is made combining geologic condition of engineering and relevant data of seismic engineering, the requirements of pressure-release and water-removal are satisfied.

6.2 The select of seismic continuous time td has influence very much on the destruction extent of the structures of the sand foundation is liquidized and a structural deformation exceeds elastic limt, continuous time is a major factor of increasing its destruction extent and aggravating its deformation.

Generally speaking ,seismogenic fault is long, then, magnitude of earthquake is large, then seismic continuous time is long. Thus, seismic continuous time td is relative directly to magnitude of earthquake. The select of seismic continuous time td, may use seismic records of Tangshan earthquake in china as reference.

Table 2 The relationship between seismic record time t and magnitude M of earthquake in Tangshan earthquake

The magnitude of earthquake (M)	4.0～4.9	5.0～5.9	6.0～6.9	7.0～7.9
Seismic record time (t)	3.1	4.6	9.1	24.0

In the relevant references, seismic continous time td is total time of an earthquake that may liquedized sand foundations. Generally, at a region that design intensity is 8, td is about 20 seconds.

6.3 Drawing contour line of u / σ_0^1 within r–Z plane.

Formula (25) in reference [5] , is a theoretical formula of estimating press of pore water of sand layer set up macadam wells of pressure-release and water-removal in earthquake. In order to expound determination method of distance of wells of pressure-release and water-removal, on condition that pore water changes in earthquake, according to assuming factors, within r-Z plane, contour line of u / σ_0^1 are drawn at 10 seconds after earthquakes have happered, where, u is the press of super-calm pore water, σ_0^1 is initial effective stress, it may be seen in fig.2 that, u / σ_0^1 near the boundary of draingage is smaller, cannot liquedize. That is ta say, anti-liquefaction capability of whole sand layer is reinforced.

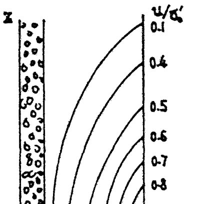

Fig 2. The distribution of contour line of u / σ_0^1 at 10 seconds after earthquakes have happened

6.4 The degree of safety of distance of macadam wells of pressure-release and water-removal

The safe coefficient determinded by design norm of foundation of china is higher. Because that an earthquake is a accidental dynamic affect, it has randomness, but also transient and reciproctation, in consideration of economic fectors of engineering construction, when foundations of built-up buildings. that are located in liquefing sites, are reinforced and designed, the safe coefficient of distance of macadam wells should be lower than static value of design, is about 1.4.

In the region that aseismic design intensity is 8, the distance of macadam wells of pressure-release and water-removal may be determinded, acconding to fig.2, in fig.2, the crossover point between contour line of u / σ_0^1 that is smaller or equal to 0.7 (safe coefficient is 1.43) and horizontal axis that shows distance of wells, is determinded first, the sand layer within value that correspond with this point, is effective range of macadam wells of pressure-release and water removal.

7. THE WIDTH AND DEPTH OF REINFORCED DESIGN OF ANTI-LIQUEFACTION OF FOUNDATION

Under the action of carthquakes, sand layer drains toward the macadam wells, but also vertical direction.Thus, the rational design should consider simultaneously drainage effects in vertical and radial directions.

If soillayer of bearing force buildings foundation is liquefying sand layear, macadam filtering water layer as a whole should be arranged on top of macadam wells; if sublayer is liquefying sand layer, macadam gullys that longitudinal and transverse directions are linked togather, should be arranged on top of macadam wells. the thickness of macadam filtering water layer is usually 30～ 40 centimeters, at suitable positions of filtering water layer, blind drains will be arranged as drainage exits.

Liquefying foundations are reinforced, using the method of macadam wells of pressure-release and water-removal ,it cannot be less than two lines in transverse direction, don't exceed 5 lines; It is the best to arrange well points according to isosleles triangle. and the distance of lines should be shorter than the distance of wells, avoid to be appear leak area of pressure-release in design. the effective width of pressure-release and water-removal of anti-liquefaction reinforced design of foundations, should be larger than 1.2~ 1.5 times thickness of liquefying sand layer. When the thickness of liquefying sand layer is larger, the width of press-release and water-removal use lower limit, otherwise, use upper width.

As for bottom elevation of macadam wells, if the foundation of sublayer is liquefying sand layer, then, it should be larger than licuefying depth about 500 millimeters; if upper foundation is silt or silt sand layer, lower foundation is middle sand. it should be larger than stable sand layer about 500 millimeters.

8. THE CONSTRUCTION METHOD AND REQUIRMENTS OF MACADAM WELLS OF PRESSURE-RELEASE AND WATER-REMOVAL

The reinforced method of liquefying foundation of buildings built-up, is different from the buildings prepared, after that liquefying soillayer is disturbed, the buildings would be effected, the pre-liquefaction would cause nonaffine settlement, walls cleave, the safety and normal use of building are effected. Thus, it is idealer to use getting hole for reinforceing liquefying foundation. In order to prevent necking-down, packing double pipes are used, packing use 20~ 40 millimeters graded macadam, layer-built packing, the thickness of each layer is about 25~ 30 centimeters back-and-forth compact. mud content of packing must be lower than 5 percent.

9. CONCLUSION

After Tangshan earthquake, China issueed an aseismic appraisal standard of industry and civil buildings, but, in the past tens years, the designers pay only attention to aseismic measures of upper structure, But, a large number of historical earthquake disaster indicate, on condition that intensity is the same, the earthquake disaster of the buildings that are located in liquefying site is lighter than non-liquefying site, the foundations failure cause settlement increase quickly, is major earthquake disaster. Thus, it is a rational and effective design method to reinforce foundations of building for prevening liquefaction.

RENFERENCES

The National standard of the People's Repubilc of China, GBJ11-89 "The Unified standard of Aseismic Design".

CHEN Shouliang, WEI Liang. 1988 "Counter Measure of Earthquake Resistance and Disaster Prevention" The Publishing House of Henan Science and Technology,

LIU Dahai, ZHONG Xigeng, YANG Chuiru, 1987 "Aseismic Design of Single and Multi-Storey Building", The Publishing House of Shaanxi Science and Technology

SHUN Gengsheng, ZHENG Datong, 1984, Soft-soil Foundation and Underground Engineering", The Publishing House of China Construction

XU Zhiying, 1989, "Aseismic liqufation Anlysis of Sand Foundation by Using Drainage Pile", Proceedings of 3rd National Conference on Earthquake Engineering.

Tin Jin University, 1978, "Foundation and Base", The Publishing House of China construction

The National Standard of the People's Republic of China, GBJ7-89 "The Unified Standard of Base and Foundation Design".