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Design on the Shaking Table Test for Ground Crack Dynamic Response under Earthquake

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In this paper, according to a particular ground fissures in Xi'an city in the south of the actual stratigraphic profiles use a similar role of strong earthquakes and the theory of vibration table crack mechanical response model test for similar relation design. Find out the model of soil physical and mechanical parameters. And then, design the model soil box and the loading system. Finally, through the finite element software testing model, a numerical simulation, verify the vibration table model test the feasibility of the scheme. And we got strong earthquakes and the role of crack, acceleration, speed, displacement and shear stress response law of dynamic characteristics, etc. Do preparations for studying strong earthquakes and role of the dynamic response of crack shaking table model test. This paper sets the vibration model test design, and the finite element calculation results for the next step and strong earthquakes role of the dynamic response of crack shaking table model test study to lay the foundation. The method and the conclusion of the test, for future trials and Fen Wei basin with similar to crack period of linear across the seismic design of engineering structures provide certain theoretical support and reference value.

1. Introduction

China is one of the countries which ground fissure hazards are most serious in the world, especially in Weihe basin the phenomenon of ground fissures are most typical and the disasters caused by ground fissures are most serious (Xue et al., 2015; Smalley et al., 2016; Stojadinovic et al., 2014; Hariri-Ardebili et al., 2014). Since recorded history, there were many ground fissures occurred in Weihe Basin. With the implementation of western development strategy, large-scale urban construction, such as Xi'an city subway, Datong to Xi'an high-speed passenger rail and other projects have been unable to avoid this particular hazard, it is essential to carry out comprehensive and systematic analysis and research on the formation mechanisms of ground fissures in Weihe Basin (Caizzone et al., 2015).

Fine exploration was carried out to the typical ground fissures in Weihe basin for the first time, the basic characteristics of ground fissures were systematically studied, the formation and subtypes were divided, the formation mechanism was analysed and concluded. There are several different types, such as basin margin fault breaking mode, loess structural joints opening mode, collapsibility ground fissure mode, land subsidence ground fissure mode, basin buried fault creeping model, seismic ground fissure mode, extensional faults coupling land subsidence mode, and so on. Based on the analysis of GPS observation data and deep tectonic data, the dynamic model of continental deformation in Weihe basin was set up. Combining the finite element numerical simulation technology, the relationship between group ground fissures and continental deformation was determined. The results show that the NNW-SSE direction regional tensile stress field in Weihe basin hold a leading post in modern tectonic changing, which is the main power source of group ground fissures in Weihe Basin (He et al., 2015).

Ground fissures are Fen Wei basin of with a kind of typical geological disasters. For the moment, the causes of ground fissures in Xi'an, activity characteristic, distribution, the plague including mechanism and more thorough, also made many important results. How would expand characteristics, the vibration characteristics, to crack in the rock stress on both sides of what will change under the action of earthquake ground fissures in Xi'an. It is very important for the ground fissures in the environment of activities of the lifeline project. The role of strong earthquake fracture mechanics is a response to the research question, however, at present for the

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research of this aspect or blank. So it has certain theoretical meaning and application prospect for developing strong earthquakes in the role of the mechanical response of cracks and shaking table model test. In this paper, according to a particular ground fissures in Xi'an city in the south of the actual stratigraphic profiles use a similar role of strong earthquakes and the theory of vibration table crack mechanical response model test for similar relation design. Find out the model of soil physical and mechanical parameters. And then, design the model soil box and the loading system. Finally, through the finite element software testing model, a numerical simulation, verify the vibration table model test the feasibility of the scheme. And we got strong earthquakes and the role of crack, acceleration, speed, displacement and shear stress response law of dynamic characteristics, etc. Do preparations for studying strong earthquakes and role of the dynamic response of crack shaking table model test. This paper sets the vibration model test design, and the finite element calculation results for the next step and strong earthquakes role of the dynamic response of crack shaking table model test study to lay the foundation (Brain et al., 2014). The method and the conclusion of the test, for future trials and Fen Wei basin with similar to crack period of linear across the seismic design of engineering structures provide certain theoretical support and reference value (Guan et al., 2015).

2. Material and method

As one of the main geological disasters in Xi'an city, ground fissures are meaning the engineering field of Xi'an city. At present, researches on the geodynamical background of the ground fissures in Xi'an city are few at present, and the relationship between the geophysical background and the geological structures in the deep is also indefinite. By using travel time data of P wave and Pn wave of earthquakes recorded by the seismic stations in Shaanxi Province and its adjacent areas, the velocities of crust in depth of 10 and 20 kilometres and the velocity image of Moho discontinuity in Weihe fault depression and its adjacent areas are determined by means of seismic tomography, the tectonic stress field in Weihe fault depression and its adjacent areas are determined by analysing the focal mechanisms of earthquakes and by inversing the main strain rate and its direction of Fenwei Basin through analysing the earthquake moment tensors, by using the broad-band digital seismic data recorded by Shaanxi digital seismic network, the distribution of Q values and the ambient shear stress field in Weihe fault depression and its adjacent areas are determined through coda wave analysing and spectra analysing, the earthquake activity is also studied in Weihe fault depression and its adjacent areas through wavelet analysis and other methods. The characteristics of ground fissures' distribution in Xi'an city and their relationship with the deep faults are also studied through the systemic analysis of the recent reconnaissance of ground fissures in Xi'an city. Under the direction of the dynamics of the regional stability theory sparkplugged by Professor Peng Jian-bing, based on the previous researches about ground fissures, combining with analysis of the results of the reconnaissance of the active faults in Xi'an city and other geophysical data, the dynamical background of the forming of Xi'an ground fissures is studied systematically, and the regional unsterilized dynamical model of the forming of Xi'an ground fissures is put forward finally. The results show that the occurrence of Xi'an ground fissures in large number is rooted in special geological environments, those are: the crust depth of the Weihe fault depression is about 10km thinner than its adjacent tectonic units such as Ordos massif and Qinling Mountains uplift, the forces from upper mantle's thermal up welling and its expanding are the dynamical sources of the tensile deformation in shallow part of the crust. The basement in Xi'an region is separated into many block structures by numerous extensional faults, so the geological structures are broken into many parts (Crack et al., 2014).

The developing space and stress conditions for the forming of ground fissures are provided by the movement of the tilted blocks and the extension of these faults. Among the faults, Kouzhen-GuanShan fault, Liquan-Heyang fault, Jinghe-Chanhe fault, Weihe fault, Lintong-Chang'an fault, Yuxia-Tieluzi fault and the northern border fault of Qingling, are the main faults controlling and influencing the formation and development of ground fissures in Xi'an city. Kouzhen-GuanShan fault, Liquan-Heyang fault, Weihe fault and Lintong-Chang'an fault are the main controlling tectonics in this region, and the ground fissures are concomitant or derived with the creeping slip of these four faults. In Quaternary period, multilevel and many-group fractures are formed in Quaternary system owing to the successive extension of Weihe basin and the coexistent extensional dislocations of these faults, and the tectonic prototypes of the tectonic fractured surface are formed then. At present, under the durative jostling northward of the Indian plate, Gansu-Qinghai land block is crushing into the FenWei region, so a successive tensile field in the direction of NNW-SSE in Xi'an region has formed. This field is just the driving force for the movement of ground fissures. The broad covering loess in this region, with collapsibility, rheology, disintegration and fracture, provides suitable slump for the forming for ground fissures. The morph-structure separated alternatively by ridges and swales provides favourable boundary conditions for the forming of ground fissures. When earthquakes occurred in Xi'an in the history, ground fissures often emerged concomitantly, these two phenomena have contemporary at a certain extent, but the ground fissures are usually coseismal or post seismic ruptures, so they are not earthquake precursor.

On the whole, in the formation of ground fissures in Xi'an city, tectonic factor is dominant, so ground fissures in Xi'an city are essentially tectonic ground fissures. The mechanisms of the formation of ground fissures in Xi'an city are listed below. The ground fissures in Xi'an city are pregnant from deep tectonic, they germinated with the extension of the Weihe fault depression, they are formed by the creeping of the faults, they are enlarged with the activity of regional tectonic stress, they are induced by earthquakes and they can be reopened and increased by over-extraction of groundwater and intense infiltration of surface water.
The algorithm can be expressed as following equation (1-8):

$$f^{(\alpha)}(x0) = \left.\frac{df(x)}{dx^{\alpha}}\right|_{x=x_0} = \lim_{\delta x\to 0}\frac{\Delta^{\alpha}(f(x)-f(x_0))}{(x-x_0)^{\alpha}} \tag{1}$$

for $0 < a \leq 1$ where

$$\Delta^{\alpha}(f(x)-f(x_0)) \cong \Gamma(1+\alpha)\lim_{x\to\infty}\Delta(f(x)-f(x_0)) \tag{2}$$

And local integral of $f(x)$ defined by Eq.3.

$$
\begin{aligned}
{}_aI_b^{(\alpha)}f(t) &= \frac{1}{\Gamma(1+\alpha)}\int_a^b f(t)(dt)^{\alpha} \\
&= \frac{1}{\Gamma(1+\alpha)}\lim_{\Delta t\to 0}\sum_{j=0}^{j=N-1} f(t_j)(\Delta t_j)^{\alpha}
\end{aligned} \tag{3}
$$

The we get:

$$H_{\alpha}\{f(t)\} = \hat{f}_H^{\alpha}(x) = \frac{1}{\Gamma(1+\alpha)}\oint_R \frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha} \tag{4}$$

Where x is real and the integral is treated as a Canchy principal value, that is,

$$
\begin{aligned}
&\frac{1}{\Gamma(1+\alpha)}\oint_R \frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha} \\
&= \lim_{\varepsilon\to 0}[\frac{1}{\Gamma(1+\alpha)}\int_{-\infty}^{x-\varepsilon}\frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha} + \\
&\frac{1}{\Gamma(1+\alpha)}\int_{x+\varepsilon}^{\infty}\frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha}]
\end{aligned} \tag{5}
$$

Rewrite again Eq. (4) as

$$
\begin{aligned}
\hat{f}_H^{\alpha}(x) &= \frac{1}{\Gamma(1+\alpha)}\int_{-\infty}^{\infty}\frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha} \\
&= \frac{1}{\Gamma(1+\alpha)}\int_{-\infty}^{\infty} f(t)g(x-t)(dt)^{\alpha} = f(x)*g(x),
\end{aligned} \tag{6}
$$

$$\partial_j(C_{ijkl}\partial_k u_l + e_{kij}\partial_k\varphi) - \rho\ddot{u}_i = 0 \tag{7}$$

$$\partial_j(e_{ijkl}\partial_k u_l - \eta_{kij}\partial_k\varphi) = 0 \tag{8}$$

The linear equation can be expressed into the following simplified forms:

$$L(\nabla,\omega)f(x,\omega) = 0\text{, } L(\nabla,\omega) = T(\nabla) + \omega^2\rho\mathrm{J} \tag{9}$$

In which,

$$T(\nabla) = \begin{Vmatrix} T_{ik}(\nabla) & t_i(\nabla) \\ t_k^T(\nabla) & -\tau(\nabla) \end{Vmatrix}\text{, } \mathrm{J} = \begin{Vmatrix} \delta_{ik} & 0 \\ 0 & 0 \end{Vmatrix}\text{, } f(x,\omega) = \begin{Vmatrix} u_k(x,\omega) \\ \varphi(x,\omega) \end{Vmatrix} \tag{10}$$

Consider delay, the L can be expressed as:

$$L^0 = \begin{Vmatrix} C_{ijkl}^0 & e_{kij}^0 \\ e_{ikl}^{0T} & -\eta_{ik}^0 \end{Vmatrix} \tag{11}$$

These functions can be expressed:

$$C(\mathrm{x}) = C^0 + C^1(\mathrm{x})\text{, } e(\mathrm{x}) = e^0 + e^1(\mathrm{x})\text{, } \eta(\mathrm{x}) = \eta^0 + \eta^1(\mathrm{x})\text{, } \rho(\mathrm{x}) = \rho_0 + \rho_1(\mathrm{x}) \tag{12}$$

The value with superscript of 1 represents the difference below:

$$C^1 = C - C^0,\ e^1 = e - e^0,\ \eta^1 = \eta - \eta^0,\ \rho_1 = \rho - \rho_0 \tag{13}$$

$$f(x,\omega) = f^0(x,\omega) + \int_V \mathcal{S}(x-x')(\mathrm{L}^1 F(\mathrm{y}')$$
$$+\rho_1\omega^2 \mathbf{g}(R)\mathrm{T}_1 f(\mathrm{y}')]S(\mathrm{y}')\mathrm{dy}' \tag{14}$$

In addition, we can introduce the abbreviated formula:

$$\mathcal{g}(x,\omega) = \begin{Vmatrix} G_{ik}(x,\omega) & \gamma_i(x,\omega) \\ \gamma_k(x,\omega) & g(x,\omega) \end{Vmatrix},\quad \mathcal{S}(x,\omega) = \begin{Vmatrix} G_{ik,l}(x,\omega) & \gamma_{i,k}(x,\omega) \\ \gamma_{k,l}(x,\omega) & g_{,k}(x,\omega) \end{Vmatrix},\quad \mathcal{L}^1(x,\omega) = \begin{Vmatrix} C^1_{ijkl} & e^1_{kij} \\ e^{1T}_{kij} & -\eta^1_{ik} \end{Vmatrix},\quad \mathcal{F}(x,\omega) = \begin{Vmatrix} u_{(i,j)}(x,\omega) \\ \varphi_{,i}(x,\omega) \end{Vmatrix} \tag{15}$$

In these expression, $G_{ik}(x,\omega)$, $\gamma_i(x,\omega)$, $g(x,\omega)$ can be represented as:

$$\mathcal{g}(x,\omega) = \frac{1}{(2\pi)^3}\int \mathcal{g}(k,\omega)\exp(-i\mathrm{k.x})d\mathrm{k},\quad \mathcal{g}(k,\omega) = \begin{Vmatrix} G_{ik}(k,\omega) & \gamma_i(k,\omega) \\ \gamma_k^T(k,\omega) & g(k,\omega) \end{Vmatrix},\quad G_{ik} = (\Lambda_{ik} + \frac{1}{\lambda}h_i h_k^T)^{-1},$$

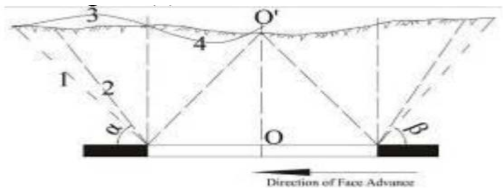
$$g = -(\lambda + h_i^T \Lambda_{ij}^{-1} h_j)^{-1},\quad \gamma_i = \frac{1}{\lambda}h_k^T G_{ki},\quad \Lambda_{ik}(k,\omega) = k_j C^0_{ijkl} k_k - \rho_0 \omega^2 \delta_{il},\quad h_i(k) = e^0_{kil} k_k k_l,\quad h_l^T = e^{0T}_{ikl} k_i k_k,$$

$$\lambda(k) = \eta^0_{ik} k_i k_k \quad \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-ik_3 x_3'} dx_3' = \delta(k_3) \tag{16}$$

Ground fissures have been the main environment geological disaster in Xi'an city. Since 1950s, 14 ground fissures have been found in Xi'an area, which has caused 4 billion Yuan's direct losses. The worse is that new fissures are coming forth and developed. As a result, the utilization of building land and urban planning and development of Xi'an city are badly restricted, and great hidden trouble is buried for city's engineering construction. So the great geo-hazard difficult problem to be solved urgently is to perform the research on genesis and disaster-causing mechanism and work out economical and effective countermeasures.
Presently, the distribution and activity characteristic of Xi'an ground fissures have been found out basically, but its genetic mechanism is immature being many different points of view and disputes on it for that there are some key basic problems being unresolved. Furthermore, the research on the countermeasures of minimizing and defending disaster is far from sufficiency because of the restriction of genesis and disaster-causing mechanism researching degree. The problems and deficiencies in the research of Xi'an ground fissures were analysed. The key problems were explored and studied by the author through large-scale and small physical experiment and numerical simulation analysis, new viewpoint on the genetic mechanism of Xi'an ground fissures were put forward. At the same time, beneficial opinion were present on the guarding against disaster of underground structure across ground fissures and the methods to evaluate the influence bandwidth of ground fissures. Finally, new appraisement on seismic effect of ground fissure site subjected to strong earthquake in Xi'an area was performed basing on further studying and re-recognizing the ground fissures. In order to perform the comparison of blasting and non-blasting related influences two sets of crack responses were recorded. The first set is the crack in the wall of the structure in order to monitor and record the changes in the crack width. The thermograph and hydrograph were set on the same location to measure and records the changes in air temperature and humidity.

3. Result and discussion

process evolving with time. The impact of mining activities will lead to the migration of all ground points after being transmitted to the ground. The imbalance migration between all ground points will result in internal deformation of soil mass and after the tensile deformation goes beyond the deforming resistance of the ground, cracks occur. The planar cracks generally occur outside the corresponding boundaries within the mining area and in front of the working face, as shown in Curve 3 in Figure 1. This area is the maximum tensile range of the underground subsidence basin. In the rear area of the working face advancement, as shown in Curve 4 in Figure 3 impacted by the mining activities, the surface soil within the region is compressed and deformed. With the progress of the mining program, the planar cracks start to close. However, as the earth surface cannot be restored to the original state and the cracks are closed to different extent, i.e. some planar cracks are not fully closed, with the final width smaller than that during the mining process, as shown in Figure 2(a); while some are over-closed, and form steps at the closing points, as shown in Figure 2(b).



(1) Boundary of surface migration; (2) Crack surface; (3) Tensile deformation curve; (4) Compressive deformation curve; (α) Crack angle; (β) Boundary angle

Figure 1: Model of surface migration.

Figure 2: Shape of cracks. (a) Shape of planar crack; (b) Shape of stepped crack.

The role of strong earthquake fracture mechanics is a response to the research question, however, at present for the research of this aspect or blank. So it has certain theoretical meaning and application prospect for developing strong earthquakes in the role of the mechanical response of cracks and shaking table model test. In this paper, according to a particular ground fissures in Xi'an city in the south of the actual stratigraphic profiles use a similar role of strong earthquakes and the theory of vibration table crack mechanical response model test for similar relation design. Find out the model of soil physical and mechanical parameters. And then, design the model soil box and the loading system. Finally, through the finite element software testing model, a numerical simulation, verify the vibration table model test the feasibility of the scheme. And we got strong earthquakes and the role of crack, acceleration, speed, displacement and shear stress response law of dynamic characteristics, etc. Do preparations for studying strong earthquakes and role of the dynamic response of crack shaking table model test. As there are huge amounts of noise data contained in the raw point cloud data, it is imperative to conduct corresponding de-noise processing before extracting ground cracks in order to eliminate non-ground points and obtain relatively smoothed point cloud data to facilitate the detection and extraction of crack data. The flow of crack detection is shown in Figure 3. The broad covering loess in this region, with collapsibility, rheology, disintegration and fracture, provides suitable slump for the forming for ground fissures. There are several different types, such as basin margin fault breaking mode, loess structural joints opening mode, collapsibility ground fissure mode, land subsidence ground fissure mode, basin buried fault creeping model, seismic ground fissure mode, extensional faults coupling land subsidence mode, and so on. The morph-structure separated alternatively by ridges and swales provides favourable boundary conditions for the forming of ground fissures. When earthquakes occurred in Xi'an in the history, ground fissures often emerged concomitantly, these two phenomena have contemporary at a certain extent, but the ground fissures are usually coseismal or post seismic ruptures, so they are not earthquake precursor. On the whole, in the formation of ground fissures in Xi'an city, tectonic factor is dominant, so ground fissures in Xi'an city are essentially tectonic ground fissures.

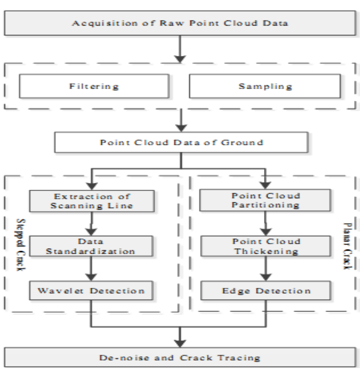


Figure 3: The cracks detection model

If there are scanning points within 4 quadrants of the window taking the zero pixels as centre, this zero pixel is within the non-crack area; if at least one of 4 quadrants of the window has no scanning points, this zero pixel is within the crack area. As the distribution of point cloud data obtained by the ground laser scanner is uneven and their density varies at different locations relative to the instrument, the thickening of ground point clouds shall be carried out block by block, and the thickening window shall be selected according to the local density of point clouds. It can be seen that the crack data contained in the point cloud may be effectively extracted by combining two crack detection methods and the crack location thus extracted is consistent with that obtained with the total station. However, impacted by the point cloud density, the cracks with smaller width cannot be extracted with the method described in this paper.

4. Conclusion

When earthquakes occurred in Xi'an in the history, ground fissures often emerged concomitantly, these two phenomena have contemporary at a certain extent, but the ground fissures are usually coseismal or post seismic ruptures, so they are not earthquake precursor. On the whole, in the formation of ground fissures in Xi'an city, tectonic factor is dominant, so ground fissures in Xi'an city are essentially tectonic ground fissures. The mechanisms of the formation of ground fissures in Xi'an city are listed below. The ground fissures in Xi'an city are pregnant from deep tectonic, they germinated with the extension of the Weihe fault depression, they are formed by the creeping of the faults, they are enlarged with the activity of regional tectonic stress, they are induced by earthquakes and they can be reopened and increased by over-extraction of groundwater and intense infiltration of surface water. Based on the analysis of GPS observation data and deep tectonic data, the dynamic model of continental deformation in Weihe basin was set up. Combining the finite element numerical simulation technology, the relationship between group ground fissures and continental deformation was determined. The results show that the NNW-SSE direction regional tensile stress field in Weihe basin hold a leading post in modern tectonic changing, which is the main power source of group ground fissures in Weihe Basin.

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