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A NEW VIEWPOINT ON THE CAUSE FOR RESERVOIR EARTHQUAKES— A MODEL OF WEAKENED AND IMAGE FORCE

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The largest magnitude of the reservoir earthquake can reach over 6. Therefore people care very mach about this kind of earthquakes. Most of the explanation about the cause is that stress has stored greatly in the underground faults, but the faults can not be offset. After the reservoir stores water, the water will permeate into the fault, and weaken materials at both sides of the fault. It results in that the effective pressure is reduced or the frictional coefficient is decreased. Both of the effects lead to the decrease of the frictional force on the fault's surfaces, and a rapid offset can occour, which brings about reservoir earthquake. This idea seems to be a received viewpoint. But we think it is worth questioning. According to the results of simulation tests, stick-slip needs enough confinimg pressure. At the depth of several Km (1-5 km) under the ground, it is a dispute whether confining pressure is large enough to be the conditions for stick slip. In the shallow parts of crust because rock strength can support its own weight, the horizontal pressure provides the normal pressure on the vertical planes, which is the same order of magnitude with the confining pressure. Thus at the range of a few Km deep underground, the fault can produce stick slip, which is still questioned, and that water permeated into the surface of the fault will result in that the stick slip is more difficult, the earthquake can not ooccur. With the view above, we think it is quite necessary to discuss further the cause of reservoir earthquakes. This paper proposes a model of weakened and image foree.* This model is actually

* Image force is a concept in solid physics, introduced to study earthquake source by Guo Zengjian in 1979, afterwards, a series of study was made by Qin Baoyan and Rong Dailu.

another form of the combination model.In this paper, the cause of the reservoir earthquakes discussed may be divided into two parts: the cause for shallow small earthquakes and the cause for deep strong earthquakes, the two are tied to each other.But our final purpose is to predict which kind of reservoirs may induce strong earthquakes.

1.The Cause of Small Earthquakes in Reservoir Area

As is mentioned above, at the depth of a few Km, the normal pressure on fault planes can not give a definite assurance to have stick slip. So in our opinion, the cause of small earthquakes in reservoir area is that water on the segment of fault makes it creep easily, then produces stress concentration at the ends of fault and causes the fault to expand to the integral hard medium rapidly.It is not because of the slippage of the known fault itself.This means there are two imperative conditions for reservoir small earthquakes to occur: one is that in reservoir area, there must be a lot of joints or a hard rock area with many small faults; another is that water is very easy to permeate down.For example in the area of limestone and the outcrop or hidden granite, there are more earthquakes to occur. Among which, limestone is permeating condition and granite is the medium condition for earthquake occurring. It should be pointed out that hot water can have the materials on the known faults to be weak, which includes the process, both of physics and chemistry. These faults are very easy to creep and at last their ends are so expanded that earthquakes are triggered.So in reservoir area,if there is hot water under the ground,small earthquakes are easy to occur.From this,we can impute the small shallow earthquakes in reservoir area to the connexion each other of many small cracks or the fault segments in hard rocks. Actually, such a viewpoint about the cause of reservoir earthquakes is that of combination model. Among which, the small cracks can be regarded as adjustment elements, and the hard medium between the cracks is the accumulated elements.That water permeates into cracks strengthens the adjusting ability of including those of creep, stress concentration and abdication. Because, the connexion of a lot of small cracks or faults one by one, many small earthquakes are formed.This process is on and on, the mass of rock under the reservoirs can be weakened.

2.The Cause of Stromg Earthquakes in Reservoir Area

The cause of strong earthquakes in reservoir area, in our opiuon, is a combination model in three-dimentional space. Namely, the weakened area of reservoir is an adjustment element, and the creep fault hidden deeply is another adjustment element. The section between the two is a stress accumulation element, as is shown in Fig 1.

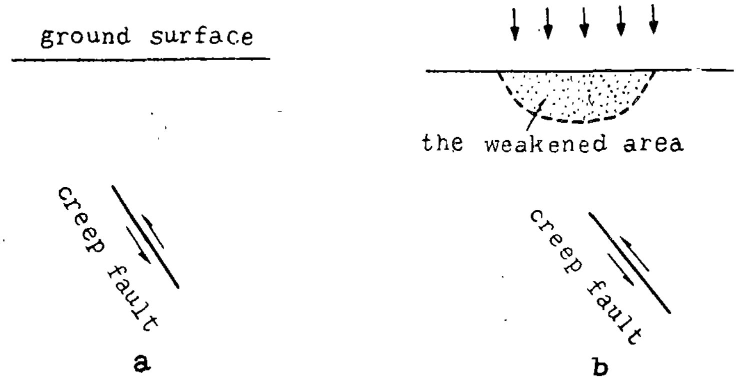

Fig. 1 a Reservoir before water storage.
Fig. 1 b Reservoir after water storage.

Fig. 1 a shows the situation before water is stored, and Fig. 1 b is that after water is stored. The difference between them is as follows:

(1) In Fig. 1 a, though ground surface is an adjustment element, yet its radius of curvature is infinity, no stress concentration can be produced. In Fig. 1 b, the radius of curvature of the region weakened by water in reservoir is limited, so stress concentration can be produced.

(2) As to the viewpoint of image force, whether free plane or soft medium surface makes an impact on the propagation of deep faults is determined by the distance between this surface and the ends of the fault. The distance from ground surface to the hidden fault in Fig. 1 a is greater than Fig. 1 b. So the latter is of great image force, easy to connect the two elements of adjustment and to trigger earthquakes. This is the main shock of reservoir. In the following we will have a further discussion after water is stored in reservoirs.

3. Stress Concentration Caused by the Weakened Reservoir Area

There is a very complicated situation of underground in reservoir area, so the shape of weakened area is irregular very much. We can simplify it as an hemisphere, as is shown with the dotted-line circle in Fig. 2. Before water is stored, there is no soft inclusion. So there is no stress concentration. But after water is stored, stress concentration is turned out. This value of stress concentration can be from the result of reference (1). At the different depth beneath the top of hemisphere the compression stress is shown in Fig. 3, which is paralleled to the direction of the regional pressure (the direction of X in Fig. 2). From Fig. 3, the top of the hemisphere, pressure stress has the greatest concentration, the value of

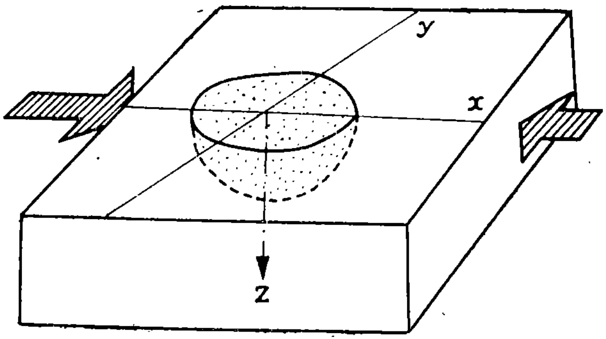

Fig. 2 The hemisphere approximation in the weakened area of reservoir.

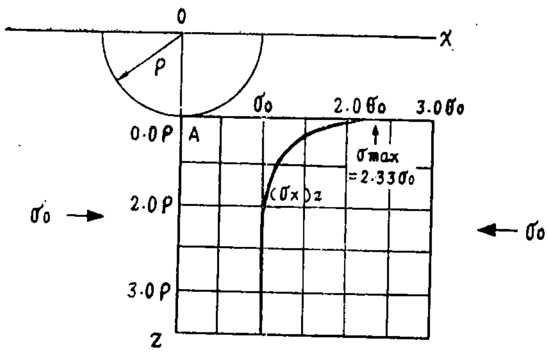

Fig. 3

which is about 3 times of the regional compression stress. From this top downwards, at the depth of 2 times of radius, stress concentration disappears. That is to say that at the depth of 2 times of radius of weakened region, stress concentration is zero. Supposing that the depth of this weakened region is 5 km, the disappearance depth of stress concentration is, of course, 10 km. As for earthquakes, shear stress value τ which we are interested in very much is:

$$\tau = \frac{1}{2} \sigma x \qquad (1)$$

This depth of shear stress concentration is as the same as that mentioned above.

After water is stored in reservoir, with the existence of weakened region, the image force at the ends of hidden fault is made up of two terms: one is Fs, the image force caused by the ground surface and another is Fw, the image force caused by medium plane which once was weakened in reservoir area, that is:

$$F = Fs + Fw \qquad (2)$$

With the difference that the hidden faults are of strike slip and dip slip, Fs and Fw are quite different. So the formula (2)can have the two forms as follows:

When the fault is of strike slip, it is

$$F=\frac{\mu_2 D^2}{4\pi R}+\frac{\mu_1 D^2}{4\pi Y}\left(\frac{\mu_2-\mu_1}{\mu_2+\mu_1}\right) \tag{3}$$

When the fault is of dip slip, it is

$$F=\frac{\mu_2 D^2}{4(1-\mu)R}+\frac{\mu_1 D^2}{4\pi Y}\left(\frac{\mu_2-\mu_1}{\mu_2+\mu_1}\right) \tag{4}$$

In the formula, R is the distance from ground surface to the ends of the fault; r, the distance from the floor of weakened region in reservoir area; μ_2 the shear modulus of crust medium; μ_1, the shear modulus of weakened medium in reservoir; and D is the amplitude of the offset of fault. In formula (3) and (4), if $\mu_2=\mu_1$, the situation is like that there is no existence of weakened region. Thus there is only the first item to be left at both sides of the formula, that is, the ground surface brings about the image force at the ends of fault.

4. Discussion

If there is the different stiffness of medium in the deep place of underground, in the same force action, some blocks move, and some less, as is shown in Fig. 4. By so doing the slippage between layers may be brought out.

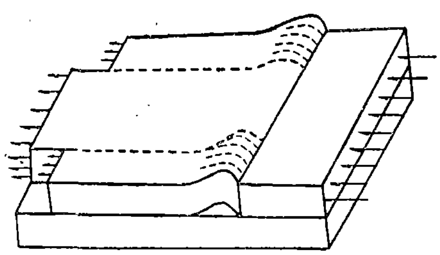

Fig. 4 The difference of transmission force with the difference of medium stiffness.

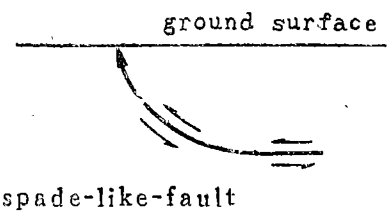

Fig. 5 The spade-like-fault created by image force.

In such a case, if the fault slipping between the layers is of an angle of elevation, the ground surface can turn out the image force and make it develop to the surface of ground, forming the spade-like-fault shown in Fig. 5 .If there is a developing fault with horizontal slip close to weakened region of reservoir, the fault may propagate upwards by the image force in Formula (3) and (4), and the earthquakes of reservoir can be triggered.Now the reservoir earthquake is of the fault with dip slip.

REFERENCE

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水库地震成因的新看法——弱化象力模式

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摘　　要

以前的水库地震成因学说大多是认为地下断层积累了较高的应力，难以错动，当水库蓄水后，水通过裂隙渗透到断层面上，从而降低了断层面上的有效正压力或摩擦系数，导致断层的快速错动形成地震。然而这个学说对解释极浅源地震是有困难的。根据模拟实验，产生粘滑要有一定的正应力，否则仅能产生稳滑。在地下几公里的深度上围压比较小，因之在这样的深度是否存在粘滑条件还值得商榷。在这种情况下，用水去帮助断层错动更没有必要了。本文作者认为水库地区坚硬介质中大量小裂缝的接通是某些水库发生大量小震的原因。水进入裂缝后可加强裂纹的蠕滑，它使裂纹端部形成应力集中，有利于诸裂纹间的接通，而不是水进入断层后使断层本身发生错动而形成地震。当大量小裂缝互相接通时，即大量水库小震发生后，水又进一步渗透到小震活动区，使这一软弱区的范围（面积和深度）进一步扩大，形成应力调整区。如果在库区下方较深处有隐伏的蠕滑断层（走滑或倾滑），这可成为水库区另一个调整单元。它们之间相对完整的介质区即为应力积累区——震源区。在区域应力场的作用下，隐伏的蠕滑断层端部有剪应力集中，另外水库弱化区下方也有应力集中，这就使两个调整单元有接通的趋势，当积累单元的应力达到极限值时，这种接通就必然产生，並形成较大水库地震。另外，水库弱化区的下界面对蠕滑断层端部还有象力作用，它也有使该断层向弱化区传播的趋势，从而导致较大的水库地震。本模式说明，如果建水库前对未来诱发的地震进行预测时，应注意库区更深部是否有隐伏断层存在。