Study on Coulomb Stress Evolution Along Altyn Fault

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Abstract. Taking the altyn fault zone as the study area, the maxwell layered viscoelastic medium model and the PSGRN / PSCMP program were used to study the evolution of the cumulative coulomb stress over the altyn fault from 1900 to 2020, analyze the future seismic hazards of faults in the altyn fault zone. The results show that: the minfeng earthquake and changma earthquake were mainly caused by the long-term tectonic loading of the altyn fault. The wuzunxiaer S8 section and the shulehe 4 S18 south section were affected by the combined effects of the changma earthquake and long-term earthquake loading. In particular, the maximum cumulative coulomb stress of shulehe 4 S18 south section is 2.58Mpa, which is a great danger to strong earthquakes.

1 INTRODUCTIONS

The coulomb stress triggering study focuses on the relationship between tectonic stress changes and strong earthquakes. The timing of coulomb stress changes caused by pre-seismic earthquakes has a significant triggering effect on subsequent moderate and strong earthquakes[1-4]. Harris et al. [5]pointed out that the coseismic coulomb stress change caused by the 1857 Fort Tejon Ms 7.9 earthquake is positive, and has an accelerated triggering effect on all earthquakes with magnitudes above 5.5 in the California region from 1857 to 1907; Freed [6] and Pollitz [7] The trigger relationship between the 1992 Landers Ms7.3 earthquake and the 1999 Hector Mine Ms7.1 earthquake was studied. When only coseismic coulomb stress is considered, the Hector Mine earthquake occurred in the coulomb stress shadow area of the Landers earthquake, and the Landers earthquake The post-coulomb stress increased significantly in the Hector Mine area in the past 7 years. From the perspective of both coseismic and post-seismic effects, the Landers earthquake triggered the Hector Mine Ms7.1 earthquake, and the post-seismic effect played a major role; Wan Yongge and others used a viscoelastic layered medium model to calculate the Coulomb stress evolution in the northeastern region of the Qinghai-Tibet Plateau since 1920 through three aspects of effect calculations. Among the 20 earthquakes of magnitude 7 or higher in the region, 17 were calculated. The second occurred in the coulomb stress loading area[8].

This paper comprehensively considers 21 strong earthquakes in the area around the altyn fault zone, coseismic, post-earthquake coulomb stress changes, and long term tectonic loading effects in the fault zone, and examines the mutual triggering effects of strong

earthquakes around the altyn fault zone. The evolution of the cumulative coulomb stress over the fault over time is analyzed, and the future seismic hazards of each fault segment in the altyn fault zone are analyzed.

2 Models

2.1 Stratigraphic velocity structure model

According to previous literature, the formation viscosity coefficient of the study area was determined, and the regional stratum velocity structure model was established, as shown in Table 1.

Table 1.Crustal velocity structure model parameters

Serial number	Thickness /km	P speed /km·s-1	Density /g·cm-3	Viscosity /Pa·s
1	19	5.2	2.20	1.0×10 ²¹
2	5.5	5.6	2.30	2.0×10 ¹⁹
3	6.2	5.5	2.30	2.0×10 ¹⁹
4	3.2	7.8	2.40	2.0×10 ¹⁹
5	4.0	5.8	2.40	2.0×10 ¹⁹
6	14.6	7.7	2.70	6.3×10 ¹⁸
7	1000	8.2	3.30	1.0×10 ²⁰

2.2 Coseismic dislocation model

The 21 strong earthquake coseismic dislocation models in the area around the Altyn fault zone used in this paper are shown in Table 2.

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Table 2 Coseismic dislocation models of strong earthquakes in the Altyn fault zone

Date	Segmentation	Dislocation center position		Toward	Inclination	Sliding angle	length	SS	DS	Magnitude	position
year-month-day		Latitude /($^{\circ}$ N)	longitude/ ($^{\circ}$ E)	/($^{\circ}$)	/($^{\circ}$)	/($^{\circ}$)	/(km)	/(m)	/(m)		
1902-08-22		39.90	76.10	76.1	90	64	50	4	-1.5	8.3	Atushi
1920-12-16	I	37.00	104.21	290	88	60	23	4	-1.3	8.5	Haiyuan
	II	36.80	104.81	300	88	60	64	2.68	-1.3	8.5	
	III	36.66	105.10	305	88	60	31	4.8	0	8.5	
	IV	36.41	105.75	305	88	60	39	4.4	-2.3	8.5	
	V	36.86	105.16	305	88	60	39	3.5	-2.3	8.5	
1924-07-03		36.80	83.80	242	82	-4	57.5	1.88	0.13	7.2	Minfeng
1924-07-12		37.10	83.60	242	82	-4	57.5	1.88	0.13	7.3	Mingfeng
1927-05-23	I	38.01	101.43	300	50	60.5	97	0.85	-1.50	8.0	Gulang
	II	37.41	102.75	275	50	60.75	26	1.40	-2.50	8.0	
1931-08-10		47.10	89.80	345	75	165	170	-4	0.56	8.0	Fuyun
1932-12-25		39.70	96.70	115	79	30	116	3	-2.1	7.6	Changma
1937-01-07		35.50	97.60	290	70	15	208	3.1	0	7.5	Dulan
1950-08-15		28.38	96.68	333.5	57.5	176	250	-34.9	-2.44	8.6	Chayu
1951-11-18		31.10	91.40	310	69	180	91	-1.15	0	8.0	Bengcuo
1954-02-11		39.00	101.30	306	68	35	134.2	-2.9	-1.5	7.3	Shandan
1954-07-31		38.80	104.10	177	70	159	48.98	-1.46	-0.56	7.0	Minqin
1963-04-19		35.70	97.00	272	80	20	70	1.2	0	7.0	Dulan
1973-07-14		35.18	86.40	81	60	-35	50	1.2	0.9	7.0	Mani
1990-04-26		36.06	100.30	121	40	128	101	0	-2.6	7.0	Gonghe
1997-11-08		35.04	85.90	79	82	364.05	6.03	0.32	-0.02	7.5	Mani
2001-11-14		35.99	90.23	94.41	72	345.0	12.02	3.76	1.00	8.1	Kunlunshan
2008-03-21		35.60	81.60	219	69	-68	57.5	0.71	1.74	7.3	Yutian
2008-05-12		32.71	105.78	231	42	175	19.6	-0.02	-0.0019	8.0	Wenchuan
2014-02-12		36.05	82.91	242	78	-25.573	5	0.32	0.153	7.2	Yutian
2015-04-25		26.96	85.88	295	10	75.1493	20	0.05	-0.18	8.1	Nepal

Note: SS is the co-seismic dislocation trend sliding component, which is positive along the strike direction; DS is the co-seismic dislocation trend sliding component, which is positive along the downtilt direction.

3 Coulomb stress state of the Altyn Tagh fault zone

3.1 Coseismic and post-seismic effects of strong earthquakes on coulomb stress state in the altyn fault zone

This section comprehensively considers coseismic and post-seismic effects, and gives the coseismic and post-seismic viscous relaxation effects of the 21 strong earthquakes in and around the altyn fault zone from 19 to 2020 in the altyn fault zone the evolution of cumulative coulomb stress changes over time.

Fig.1. Coulomb stress evolution of the altyn fault zone from 1900 to 2020 caused by coseismic + postseismic

According to figure1, when co-seismic and post-seismic viscous relaxation effects are considered at the same time, the minfeng earthquake in 1924 occurred in the stress shadow area, the changma earthquake in 1932 occurred in the coulomb stress-loaded area, and strong earthquakes occurred on the altyn fault zone. The probability of occurrence in the coulomb stress loading area is also only 50%.

When co-seismic and post-seismic effects of a strong earthquake are considered at the same time, in 2020, the stress loading / unloading states at both ends of the fault zone are mainly determined by co-seismic effects. The post-seismic viscous relaxation effect changes the coulomb stress magnitude of loading / unloading. Due to the co-seismic effect of the Minfeng earthquake, the stress shadow area of the northern section of S2 to the southern section of S3 of alasyi. With time, the viscous effect of the minfeng earthquake formed a load on this area, making this stress effect the zone stress unloading amount changed from -0.53Mpa to -0.41Mpa. Due to the coseismic effect of the changma earthquake, the northern section of Shulehe 4 S18 to the stress section of Shulehe 5 S19, the viscous relaxation effect after the changma earthquake unloads the northern section of Shulehe 4 S18, and the amount of stress unloading Unloaded from -5.8Mpa to -25.8Mpa. The co-seismic coulomb stress maximum loading area in the south section of the shulehe 4, due to the post-seismic effect unloading from

2.71Mpa to 2.49Mpa, reduces the coulomb stress loading area.

For the remaining areas in the fault zone, the post-seismic viscous relaxation effect has a greater impact on the coulomb stress accumulation state than the coseismic effect. The effect of the viscous relaxation effect changed from the coulomb stress loading area to the stress shadow area.

In summary, the post-seismic viscous relaxation effect of strong earthquakes accumulates with time, which has a greater impact on the stress state of the altyn fault zone. After 120 years of cumulative loading, the change in coulomb stress after the earthquake in many areas the amount of stress change is basically the same. It is assumed that no strong earthquakes will occur in the altyn fault zone and its surroundings. The effect of post-seismic viscous relaxation on the stress state of the fault zone will exceed the coseismic effect.

3.2 Inter-seismic tectonic loading on the fault zone affects the coulomb stress state of the altyn fault zone

Based on negative dislocation theory, calculated between the shock loading configuration long lasting long-term use of slip rate fault segments, Altyn fault on the interlayer coulomb shock stress time evolution process.

Fig .2. Coulomb stress evolution of the altyn fault zone from 1900 to 2020 caused by tectonic loading

It can be seen from Figure 2 that the altyn fault zone with a length of about 1600 km has been loaded. Among them, wuzunxiaoer, suoerkuli and kushiha in the middle of the fault zone have the highest stress loading rates ($> 1.5 \text{ kPa} \cdot \text{a}^{-1}$), the overall loading rate of the western section of the fault zone is higher than that of the eastern section. The loading rate of xiaoerkule S1 to huangtuquan S7 in the western section is $1.0\text{-}1.5 \text{ kPa} \cdot \text{a}^{-1}$. The loading rate of S19 segment is the smallest ($< 1.0 \text{ kPa} \cdot \text{a}^{-1}$).

The altyn fault zone has been subjected to continuous loading for 120 years during the interseismic tectonic movement. The cumulative inter-seismic coulomb stress in the middle section has reached $0.2\text{-}0.4 \text{ Mpa}$, the cumulative inter-seismic coulomb stress in the western

section has reached $0.12\text{-}0.2 \text{ Mpa}$, and the cumulative inter-seismic coulomb stress in the eastern section It is $8 \times 10^{-2} \sim 0.15 \text{ Mpa}$. The coulomb stress loading of the entire fault zone far exceeded the trigger threshold of 0.01 MPa .

3.3 Coulomb stress evolution over time in the Algin fault zone (coseismic + post-seismic + inter-seismic)

This section calculates the evolution of Coulomb stress over time from 1900 to 2020 in the Altyn Tagh fault zone caused by co-seismic, post-seismic viscous relaxation effects and tectonic stress loading in 19 fault segments.

Fig.3. Coulomb stress evolution from 1900 to 2020 caused by co-seismic + inter-seismic + post-seismic

According to the comparison between figure3 and figure 1, it can be obtained that when three factors are considered comprehensively, before the minfeng earthquake, the cumulative loading of coulomb stress caused by the three effects is $2.4 \times 10^{-2} \text{ Mpa}$, and the coulomb stress state of the fault near the source changes. It is an obvious loading state; before the changma earthquake of 1932, the cumulative coulomb stress loading of the fault near the source was $2.6 \times 10^{-2} \text{ Mpa}$. Therefore, when considering three aspects of effects at the same time, both the 1924 minfeng earthquake and the 1932 changma earthquake occurred in the coulomb stress loading area, and the coulomb stress loading caused by the inter-seismic tectonic stress exceeded the trigger threshold, indicating that the inter-seismic tectonic stress loading is the main reason for the history of strong earthquakes on the altyn fault zone.

The coulomb stress change caused by interseismic structural loading is smaller than the coulomb stress change caused by the strong earthquake that occurred on the altyn fault zone, but it acts on the fault segment for a long time. After years of accumulation, the stress values of the coulomb stress loading area caused by the minfeng earthquake and the changma earthquake were further enhanced, while the range of the stress shadow area and the stress unloading value were reduced. For the middle section of the fault zone, the change in coulomb stress caused by tectonic loading between earthquakes is

much greater than the co-seismic and post-seismic coulomb stress changes in these earthquakes.

It can be seen from fig. 3 that the stress shadow zone of the fault zone still exists, mainly distributed in two locations of the fault zone. The first shadow zone is located in the north section of kuyake S2, alasayi S3, and andierhe S4 in the southwest edge of the fault zone. This amount of stress unloading in this shadow area is $-0.2 \sim -0.59 \text{ Mpa}$. The second shadow area is located in the north section of Shulehe 4 S18 section to Shulehe 5 S19 section. The stress unloading capacity of this shadow area is $-0.08 \sim -25.6 \text{ Mpa}$.

The rest of the fault zone is the Coulomb stress loading area, and all loading areas exceed the trigger threshold. Among them, the wuzunxiaoer S8 segment has a loading of 0.3 to 0.5 Mpa , which is mainly due to the long-term loading of the interseismic structure. The maximum loading area of the fault zone is the southern section of Shulehe 4 S18. The stress loading in this area is $0.5 \sim 2.5 \text{ Mpa}$, which is mainly due to the combined effects of the changma earthquake and long-term loading between earthquakes. In summary, the cumulative stress of the S8 segment of wuzunxiaoer and the southern segment of shulehe4 S18 is relatively high. Among them, the maximum cumulative coulomb stress of the southern segment of Shulehe4 S18 is 2.58 Mpa , which is of great risk of strong earthquakes and needs to be focused.

4 CONCLUSIONS

This article takes the altyn fault zone as the study area, comprehensively considers 21 strong earthquake data from the altyn fault zone and its surrounding areas, and uses the PSGRN / PSCMP program to simulate and study the cumulative coulomb stress change on the altyn fault from 1900 to 2020. Over time, the future seismic hazards of each fault section of the altyn fault zone are analyzed. This article mainly draws the following conclusions:

(1) Taking into account the coseismic and post-seismic viscoelastic relaxation effects of 21 strong earthquakes in the altyn fault zone and its surrounding areas since 1910, and the inter-seismic tectonic loading effect of 19 fault segments to calculate the change of Coulomb stress with time in altyn fault. The results show that the minfeng earthquake and the changma earthquake were mainly caused by the long-term tectonic loading of the Altyn fault zone. The change in coulomb stress caused by inter-seismic tectonic loading is relatively small compared to the coulomb stress change caused by strong earthquakes that occur on the altyn fault zone, but it acts on the fault segment for a long time. After years of accumulation, it becomes the main influencing factors of stress accumulation state in most areas of the altyn fault zone.

(2) The results of coulomb stress evolution from 1900 to 2020 show that under the influence of long-term structural loading between earthquakes, the cumulative Coulomb stresses in most sections of the fault zone are under loading. Section S8 of Wuzunxiaer and southern of Shulehe4 S18 is affected by the combined effects of the changma earthquake and long-term earthquake loading, and the cumulative stress is relatively high. Especially, the maximum cumulative Coulomb stress of the south section of Shulehe4 is 2.58Mpa, which poses a high risk of strong earthquakes.

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