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Views & Comments

International Correlation Research Program: Cross-Fault Measurement for Earthquake Prediction

Manchao He [a], Qiru Sui [a,b], Zhigang Tao [a,b]

[a] State Key Laboratory for GeoMechanics and Deep Underground Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China
[b] School of Mechanics and Civil Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China

An earthquake is one of the greatest natural disaster risks to human beings. With their unexpectedness and shockingly destructive power, earthquakes can cause major catastrophes to human society. According to the theory of plate tectonics, the lithosphere is divided into plates that move relative to each other, with most earthquakes worldwide occurring at the plates' junction. Statistically, more than 90% of natural earthquakes are due to seismogenic faults, which are caused by the relative motion of two plate blocks along the tectonic zone (i.e., surfaces of the blocks). The energy release and mechanical effects during relative motion are mainly located at the plate's contact edges. Moreover, about 80% of earthquakes with a surface wave magnitude exceeding seven are concentrated in the Pacific Rim and Eurasian seismic zones, such as China, Japan, Nepal, the Philippines, and the United States [1,2].

In March 1997, Geller et al. [3] published a paper entitled "Earthquakes cannot be predicted" in *Science*, representing the international mainstream view on earthquake prediction and forecasting. In general, the monitoring of fault activity contributes significantly to the understanding and predictability of earthquake hazards. Hanks [4] proposed a mechanical link between earthquakes and fault displacements. Therefore, monitoring fault activity is essential for predicting earthquakes. It is necessary to know the location of faults and surrounding structures before monitoring fault activity. Dong et al. [5] proposed an original method for identifying holes and complex structures, which can determine the size and strike of faults. Scuderi et al. [6] presented the seismic velocity changes in the fault creep stage before different earthquake failure modes can be used as precursors. Dong and Luo [7] proposed multiple indicators for improving fault-slip precursors by monitoring acoustic, electrical, and magnetic signals during the quiet period of earthquakes or rock bursts. The International Association of Seismology and Physics of the Earth's Interior (IASPEI) states that the criterion for a reliable earthquake precursor is that the observed anomaly must be related to stress, strain, or the immediate mechanism causing the earthquake [8]. Scientists worldwide are actively investigating earthquake occurrence mechanisms and making attempts to predict earthquakes using various apparent phenomena or parameters, such as *in situ* stress [9,10], crustal strain [11], and infrasound monitoring [12,13].

Recently, our research group has studied the similarities between two types of geological hazards—namely, earthquakes and landslides—and has shown that their nature is the same. An earthquake catastrophe process follows Newton's second law, and the force that causes the movement of two rock sides against each other is a combined force called the "Newton force" [14]. In 2008, the scientific phenomenon of a sudden Newton force drop when a landslide occurs was discovered through Newton force monitoring, and an early warning landslide physical simulation system was created and has been verified at several sites [15–18]. Manchao He's team [19] developed an indoor physical simulation system to monitor the Newton force of the Wenchuan earthquake based on the Longmenshan fault zone (LFZ) characteristics model. This model consists of a three-dimensional geological structure model of the LFZ, a negative Poisson's ratio (NPR) effect flexible measuring rod material, a piezoelectric sensing system, an automatic data acquisition and transmission device, a data reception and analysis device, an electronic display device, and a monitoring curve display system. A sudden drop in the Newton force at the fault zone when an earthquake occurs has also been found in numerous indoor experiments, as shown in Fig. 1(a) [19,20].

The double-block mechanics (DBM) model was developed based on this scientific phenomenon [20]. Unlike the classical rate and state friction law, DBM takes advantage of the measurability of artificial mechanical systems (AMSs) by inserting a special AMS into an unmeasurable natural mechanical system (NMS) to form a complex mechanical system (CMS). By directly measuring the measurable AMS, the magnitude of the unmeasurable Newton force can be indirectly calculated, thereby realizing the measurement of the Newton force. Seismogenic faults are the most sensitive regions for plate motion, and the variation in the Newton force at the fault zone can be used to scientifically characterize the actual plate motion dynamics. Curve features for cross-fault measurements extracted from the data are shown in Fig. 1(a). An active fault is a complex nonlinear process from conception to catastrophic occurrence, and the change in the fault's Newton force goes through a progressive deformation stage, an abrupt change stage, and a damage motion stage, as shown in Fig. 1(b). Hooke's

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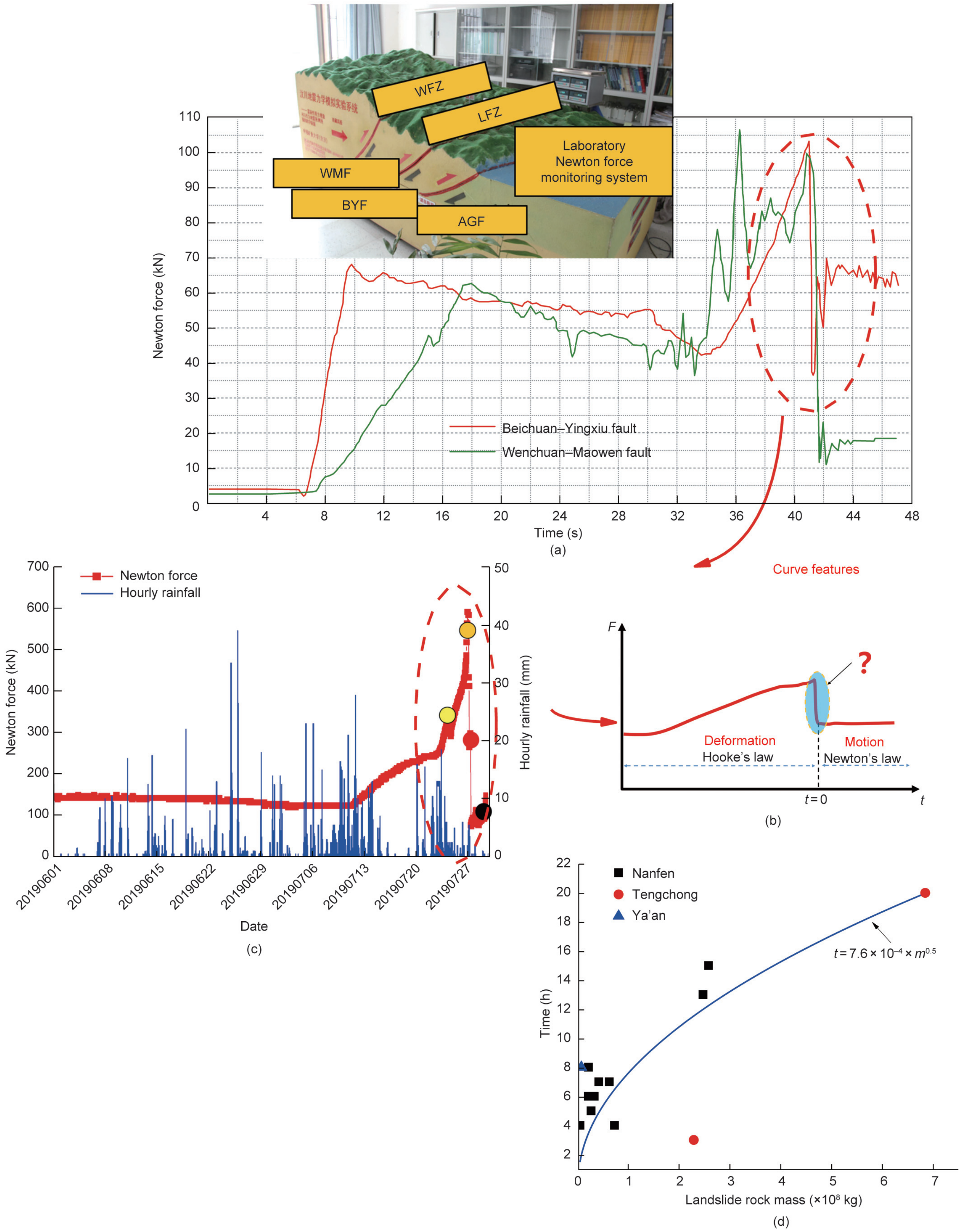

Fig. 1. Cross-fault measurements characteristics of seismogenic faults: (a) Newton force monitoring of Wenchuan earthquake physical model experiment [19,20] (WFZ: Wenchuan fault zone; WMF: Wenchuan–Maowen fault; BYF: Beichuan–Yingxiu fault; AGF: Anxian–Guanxian fault); (b) schematic diagram of Newton force change law [18]; (c) monitoring of Newton force monitoring point in slope engineering (yellow circle: yellow warning time (2019-7-24 17:07); orange circle: orange warning time (2019-7-27 04:15); red circle: red warning time (2019-7-27 14:48); and black circle: landslide time (2019-7-28 10:29)) [18]; and (d) warning time (t) with respect to the landslide rock mass (m).

law describes the relationship between elastomeric deformation and force, and simplifies the nonlinear phenomena of complex deformers in the real world. In this regard, a double-block body first undergoes Hooke's deformation in the progressive deformation stage, according to Hooke's law. In the destructive motion stage, the geological rock body breaks down and starts to move, based on Newton's laws of motion. The sudden change law, which connects Hooke's and Newton's laws of motion, is the essence of a geological body catastrophe. Based on this problem, He et al. [18] proposed a variation law of Newton forces for geological body catastrophes, thus establishing a bridge between Hooke's deformation law and Newton's laws of motion for discontinuous geological bodies. The time generation problem of Newton forces, the precursors of catastrophes, and the prediction of the time of catastrophes during the transition from Hooke's deformation law to Newton's laws of motion have essentially been solved by means of rock mechanics.

Whether it is a landslide or an earthquake disaster, the essence of the relative motion of the two bodies is the magnitude and direction of the Newton force (i.e., the interface resultant force) acting on the fracture surface (i.e., zone) [21]. To verify the scientific validity and feasibility of Newton force monitoring, a Newton force remote monitoring and early warning system for landslide hazards has been extended to 598 monitoring points in 26 demonstration areas across China, in the mining, water conservancy engineering, and traffic engineering sectors [22]. Using indoor physical model experiments and numerous field monitoring results, four Newton force monitoring early warning levels (i.e., threshold levels) for landslide hazards—which are divided into stable, substable, near-slipping, and slipping—have been proposed based on the four color levels of blue, yellow, orange, and red [16], as shown in Table 1. Newton force monitoring of landslides is shown in Fig. 1(c), where the same curve features as in Fig. 1(b) appear in the Newton force monitoring curve of the slope. To date, 13 landslides have occurred, and the duration of the landslide warning time has ranged from 3.5 to 20 h. The analysis shows that the time of the landslide warning is positively correlated with the landslide rock mass, and that the larger the landslide scale is, the longer the landslide warning time will be, as shown in Fig. 1(d). These findings verify the variation law of Newton forces. More than a hundred lives and hundreds of millions of dollars' worth of equipment and property have been saved through the early warning system. Moreover, the successful application of Newton force monitoring to landslides has provided a basis for cross-fault measurements and earthquake prediction.

Table 1
Newton force monitoring early warning levels and early warning criteria in landslides [16].

Early warning level	Danger forecast	Level I criterion: curve slope $\frac{dF}{dt}$	Level II criterion: Newton force increment ΔF (kN)
Blue	Stable early warning	0	0
Yellow	Sub-stable early warning	> 0	20–50 Rising to yellow Newton force rise (sudden increase)
Orange	Near-slipping early warning	Turning point from > 0 to < 0	50–100 Rising to orange Newton force rise (sudden increase)
Red	Slipping early warning	< 0	> 100 Rising to red Newton force sudden drop

Newton force $F = F_n - F_0$; Newton force increment $\Delta F = F_n - F_{n-1}$; F_0 is the initial pre-stress, and F_n is the force at a certain time of the warning.

Table 2
Information on active fault monitoring points.

Name of the fault	Location	Number
Zhangjiakou Fault	Hebei	2
Fengxian Fault	Shaanxi	2
Awulale Fault	Xinjiang	2
Tan–Lu Fault	Shandong	2
Jinzhou Fault	Liaoning	1
Cheng–Hai Fault	Yunnan	1

Table 3
List of cross-fault measurements.

No.	Measuring content	Measuring parameters
1	Newton force	Static Newton force and dynamic Newton force across the fault (plane)
2	*In situ* stress	*In situ* stress across the fault plane and interior stress across the fault (plane)
3	Infrasound	Infrasound and micro-seismic evolution information across the fault (plane)
4	Fiber optic strain	Deep stress, strain, and temperature gradient across the fault (plane)
5	Crustal deformation	Crustal deformation and tectonic plate deformation across the fault
6	Other traditional parameters	*B*-value, radon anomaly, electromagnetism, and groundwater

B-value is a fixed term, a quantity that reflects the relationship between different earthquake levels and frequency.

As of 2022, ten cross-fault Newton force monitoring sites have been established on China's main seismogenic fault zones, as shown in Table 2. In 2022, the International Correlation Research Program (ICRP) on Cross-Fault Measurement for Earthquake Prediction was initiated by our research team, cosponsored by scientists from China, the United States, Japan, and others, and approved by the International Consortium on Geo-disaster Reduction (ICGdR). The ICRP is an interdisciplinary team of scientists from all over the world that aims to carry out cross-fault measurements in the world's major seismic zones under four unified principles: unified measurement content, unified measurement equipment, a unified measurement method, and a unified measurement standard. The cross-fault measurement parameters include Newton force, *in situ* stress, infrasound, fiber optic strain, and crustal deformation, as shown in Table 3. The measurement data are shared for comparison with several regions around the world. The aim is to reveal the scientific laws of plate motion destruction, achieve short-term earthquake prediction, improve the methodological and technical level of international earthquake prediction, and lay a foundation for achieving global short-term earthquake prediction. The first earthquake cross-fault monitoring data will be investigated soon.

References

[1] Seismological Society of China. Earthquakes and earthquake hazards common sense [Internet]. Beijing: Seismological Society of China; [cited 2022 Dec 15]. Available from: http://www.ssoc.org.cn/Detail.html?id=40&contentId=107. Chinese.

[2] Engdahl ER, Villaseñor A. Global seismicity: 1900–1999. In: Lee WHK, Kanamori H, Jennings PC, Kisslinger C, editors. International handbook of earthquake and engineering seismology, part A. San Diego: Academic Press; 2002. p. 665–90.

[3] Geller RJ, Jackson DD, Kagan YY, Mulargia F. Earthquakes cannot be predicted. Science 1997;275(5306):1616.

[4] Hanks TC. Small earthquakes, tectonic forces. Science 1992;256(5062):1430–2.

[5] Dong LJ, Tong XJ, Hu QC, Tao Q. Empty region identification method and experimental verification for the two-dimensional complex structure. Int J Rock Mech Min Sci 2021;147:104885.

[6] Scuderi MM, Marone C, Tinti E, Di Stefano G, Collettini C. Precursory changes in seismic velocity for the spectrum of earthquake failure modes. Nat Geosci 2016;9(9):695–700.

[7] Dong LJ, Luo QM. Investigations and new insights on earthquake mechanics from fault slip experiments. Earth Sci Rev 2022;228:204019.

[8] Jordan TH, Chen YT, Gasparini P, Madariaga R, Main I, Marzocchi W, et al. Operational earthquake forecasting: state of knowledge and guidelines for utilization. Ann Geophys 2011;54:315–91.

[9] Hickman S, Zoback M. Stress orientations and magnitudes in the SAFOD pilot hole. Geophys Res Lett 2004;31(15):31.

[10] Lockner DA, Morrow C, Moore D, Hickman S. Low strength of deep San Andreas fault gouge from SAFOD core. Nature 2011;472(7341):82–5.

[11] Ozawa S, Nishimura T, Suito H, Kobayashi T, Tobita M, Imakiire T. Coseismic and postseismic slip of the 2011 magnitude-9 Tohoku-Oki earthquake. Nature 2011;475(7356):373–6.

[12] Campus P, Christie DR. Worldwide observations of infrasonic waves. In: Le Pichon A, Blanc E, Hauchecorne A, editors. Infrasound monitoring for atmospheric studies. Berlin: Springer; 2010.

[13] Che IY, Park J, Kim TS, Hayward C, Stump B. On the use of a dense network of seismo-acoustic arrays for near-regional environmental monitoring. In: Le Pichon A, Blanc E, Hauchecorne A, editors. Infrasound monitoring for atmospheric studies. Berlin: Springer; 2019. p. 409–48.

[14] He MC. Real-time remote monitoring and forecasting system for geological disasters of landslides and its engineering application. Chin J Rock Mech Eng 2009;8:1081–90. Chinese.

[15] Tao ZG, Zhang B, He MC. Research on mechanism and monitoring and early-warning technology of landslide in Luoshan mining area. Chin J Rock Mech Eng 2011;30:2931–7. Chinese.

[16] Tao ZG, Li HP, Sun GL, Yin LJ, Zhang XL. Development of monitoring and early warning system for landslides based on constant resistance and large deformation anchor cable and its application. Rock Soil Mech 2015;36(10):3032–40. Chinese.

[17] Tao ZG, Zhang HJ, Peng YY, Zhao S, He MC. Frame structure and engineering applications of multi-source system cloud service platform for landslide monitoring. Chin J Rock Mech Eng 2017;36:1649–58. Chinese.

[18] He MC, Ren SL, Tao ZG. Remote monitoring and forecasting system of Newton force for landslide geological hazards and its engineering application. Chin J Rock Mech Eng 2021;40:2161–72. Chinese.

[19] He MC, Wang Y, Tao ZG. A new early-warning prediction system for monitoring shear force of fault plane in the active fault. J Rock Mech Geotech 2010;2(3):223–31.

[20] He MC, Tao ZG, Gong WL. Geo-disaster prediction with double-block mechanics based on Newton force measurement. Geomech Geophys Geo 2017;3(2):107–19.

[21] He MC. Research on the double-block mechanics based on Newton force measurement. Chin J Rock Mech Eng 2016;35(11):2161–73. Chinese.

[22] He MC, Ren SL, Tao ZG. Cross-fault Newton force measurement for earthquake prediction. Rock Mech Bull 2022;1(1):100006.