Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)

ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

UDC 624.131.1:551.243
Research article

CC BY 4.0

NATURE OF THE INFLUENCE OF TECTONIC FAULTS DEPENDING ON SOIL TYPE

Aidos K. Ibray[1], Vitaliy A. Khomyakov[1,2], Said B. Dursynov[2], Saule Zh. Jumadilova[1]*

[1]International Educational Corporation, 050043, Almaty, Kazakhstan
[2]JSC «KazNIISA», Almaty, Kazakhstan

*Corresponding author, e-mail: saule_dzhumadilova@mail.ru

ABSTRACT

Introduction. The reliability and serviceability of foundations in seismically active regions largely depend on the engineering-geological conditions of construction sites. Tectonic faults represent one of the most hazardous geological factors, since their manifestation at the ground surface may cause uneven settlements, local deformations, loss of bearing capacity, and damage to buildings and structures. This issue is especially relevant for Almaty, Kazakhstan, where active tectonics and high seismicity require a detailed assessment of fault influence on foundation soils. **Materials and Methods.** This study investigates the nature of the influence of tectonic faults on foundation soils depending on soil type. Laboratory tests were carried out using a special shear tray apparatus developed to simulate a normal-type tectonic fault by imposing controlled displacement of the movable part of the model. Three types of foundation conditions were considered: sandy soil, crushed-stone soil, and a layered crushed-stone-sand foundation with reinforcing elements. The deformation process was visually observed through the transparent front wall of the apparatus, and the parameters of fault manifestation at the ground surface were analyzed. **Results and Discussion.** The experimental results showed that soil type has a significant influence on the formation and propagation of the deformation zone. In sandy soil, the fault developed as a localized inclined shear zone with a clearly expressed deformation band, resulting in uneven surface settlement and tilting of building models. In crushed-stone soil, deformation was more diffuse and irregular due to stress transfer between coarse particles, producing a wider fault influence zone and more complex foundation movements. The measured length of the fault manifestation zone was 10 cm for sand, 22 cm for crushed stone, and 9 cm for the reinforced layered foundation, while the corresponding manifestation heights were 20 cm, 18 cm, and 17 cm. **Conclusions.** The study confirms that the influence of tectonic faults on foundation serviceability depends strongly on soil type and reinforcement conditions. The use of reinforced layered foundations can effectively reduce adverse fault effects by redistributing stresses and smoothing surface deformations. The obtained results can be used for engineering assessment, foundation design, and development of special technical conditions for construction in seismic regions and tectonic fault zones.

KEYWORDS: tectonic fault; building foundations; serviceability; geodynamic activity; seismic regions; soil reinforcement.

FOR CITATION:

Ibray A.K., Khomyakov V.A., Dursynov S.B., Jumadilova S.Zh. Nature of the influence of tectonic faults depending on soil type. Advanced Studies in Architecture and Civil Engineering. 2026; 1 (2): 25-38

© Ibray A.K., Khomyakov V.A., Dursynov S.B., Jumadilova S.Zh., 2026

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

1 INTRODUCTION

Modern urban development requires careful consideration of the engineering-geological conditions of construction sites, because the properties of foundation soils largely determine the reliability and durability of buildings and structures. Tectonic faults are of particular importance, since they form as a result of tectonic movements of the Earth's crust and exert a substantial influence on the structure, physical and mechanical properties, and stability of soils. The presence of fault zones may lead to increased fracturing of rocks, fragmentation, changes in water-related physical characteristics, and a reduction in soil bearing capacity, which directly affects the serviceability of foundations [1, 2, 4, 7].

Tectonic fault zones are often characterized by increased geodynamic activity, which may be manifested as local deformations, differential settlements, enhanced groundwater filtration, and increased seismic susceptibility of soils. In engineering and construction practice, this requires detailed investigation of the geological structure of the site, identification of fault structures, and assessment of their influence on foundation stability. Insufficient consideration of these factors may result in building deformation, structural damage, and reduced operational reliability.

This issue is especially relevant for territories with active tectonics and high seismicity. One such region is the city of Almaty, located in the zone of interaction of the mountain structures of the Northern Tien Shan. The geological structure of the city is complicated by a system of tectonic disturbances, among which the Zailiysky Fault occupies an important place. Fault structures affect the formation of engineering-geological conditions: within their limits, increased rock fragmentation, heterogeneity of soil masses, and changes in hydrogeological conditions are observed. These factors can significantly reduce the stability of foundation soils and increase the probability of uneven settlement of buildings and structures.

Under conditions of intensive urban development in Almaty, research into the influence of tectonic faults on the serviceability of foundation soils is of particular significance. A comprehensive analysis of geological and engineering-geological data makes it possible to identify patterns of soil-property changes within fault zones and to develop recommendations for improving construction reliability and safety.

Despite the existence of regulatory requirements for construction in seismic regions, the problem of assessing the direct influence of tectonic fault manifestation on foundation soils remains insufficiently studied from an experimental point of view. In most cases, the evaluation of fault zones is based mainly on geological mapping, seismic microzonation data, and general engineering-geological investigations. However, these approaches do not always make it possible to determine how the deformation zone propagates through different types of soils and how it reaches the ground surface under conditions of tectonic displacement.

In this regard, laboratory modelling of fault-induced soil deformation is of particular scientific and practical importance. Such modelling makes it possible to visually observe the formation of shear zones, compare the behavior of different soil types, and determine the parameters of fault manifestation at the ground surface. The comparison of sandy, crushed-stone, and reinforced layered soil foundations allows identifying the specific features of stress redistribution and deformation development depending on the structure and mechanical properties of the soil mass.

Particular attention should be paid to the possibility of reducing the adverse effects of tectonic disturbances through the use of reinforced layered foundations. The introduction of reinforcing elements may change the trajectory of deformation propagation, reduce stress concentration, and limit the formation of pronounced surface ruptures. Therefore, the study of soil behavior in fault zones is necessary not only for

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

assessing potential hazards, but also for developing engineering measures aimed at improving the reliability and serviceability of foundations in seismically active areas.

1.1 Tectonic faults and their geological characteristics. Changes in soil properties within tectonic fault zones

Tectonic faults are important elements of the geological structure of the Earth's crust and play a significant role in the formation of engineering-geological conditions. They are zones of discontinuous deformation in rock masses that arise as a result of tectonic stresses and are accompanied by displacement of individual rock blocks relative to one another. Within such zones, the structure of the rock mass changes intensively, and areas of increased fracturing, crushing, and loosening are formed. These processes substantially modify the physical and mechanical properties of soils and rocks, directly affecting their suitability as foundations for structures [4, 7].

Fault zones have a complex internal structure and considerable heterogeneity. As a result of tectonic deformation, initially massive rocks are destroyed and transformed into various tectonic formations and weakened zones of the soil mass. Such changes may lead to reduced strength, increased deformability, and altered hydrogeological conditions. Therefore, the study of tectonic faults and their influence on soil properties is important for engineering-geological investigations and the design of construction projects.

1.2 Formation of tectonic faults

The formation of tectonic faults is associated with internal forces of the Earth and processes occurring in the Earth's crust. Under the influence of geodynamic processes, stresses accumulate in rocks due to the movement of lithospheric plates, mountain-building processes, and vertical and horizontal displacements of crustal blocks. When these stresses exceed the strength limit of rocks, failure occurs and discontinuities are formed, resulting in tectonic faults.

During tectonic deformation, individual rock blocks may move relative to one another in different directions. These movements are accompanied by the development of fractures, rock crushing, and the formation of tectonic damage zones. As a result, complex geological structures are formed in which rocks differ significantly in their physical and mechanical characteristics from the surrounding mass.

Geodynamic processes that lead to the formation of faults may occur as extension, compression, or shear of the Earth's crust. Under extension, normal faults are formed and are accompanied by subsidence of individual rock blocks. Under compression, structures associated with uplift and overthrusting of rock blocks are formed. Under shear forces, horizontal displacement of rocks occurs along the fault plane. All of these processes play an important role in the formation of the geological structure of territories and substantially affect the properties of rocks and soils.

1.3 Types of tectonic faults

Depending on the character of block displacement, several main types of tectonic faults are distinguished: normal faults, reverse faults, thrust faults, and strike-slip faults.

Normal fault (Figure 1). A fault in which one rock block moves downward relative to another due to extension of the Earth's crust.

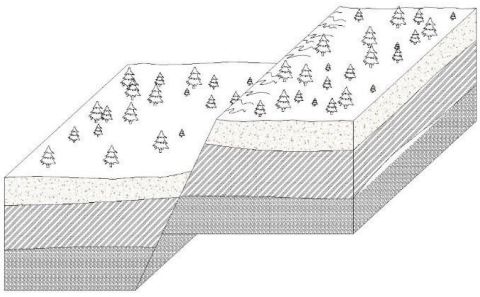


Fig. 1. Normal fault

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

Reverse fault (Figure 2). A fault in which one rock block moves upward relative to another due to compression of the Earth's crust.

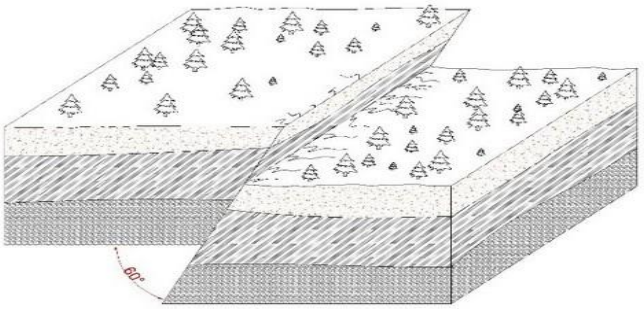


Fig. 2. Reverse fault

Thrust fault (Figure 3). A type of reverse fault with a low-angle fault plane, along which one block is pushed over another.

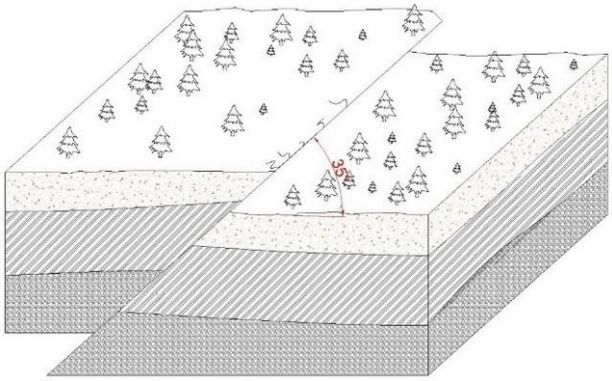


Fig. 3. Thrust fault

Strike-slip fault (Figure 4). A fault with horizontal displacement of rock blocks along the fault line under the action of shear forces.

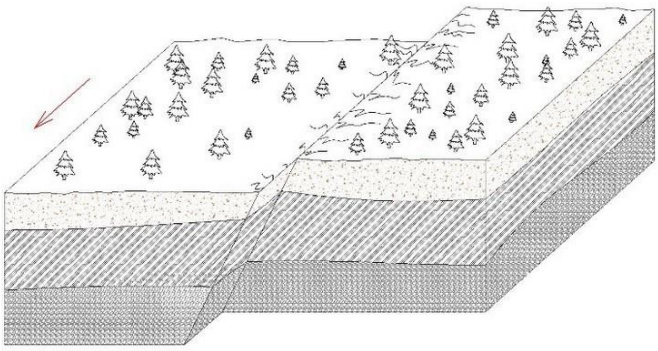


Fig. 4. Strike-slip fault.

1.4 Examples of active tectonic-fault manifestations

The tectonic normal fault that caused the strong earthquake in the city of L'Aquila is one of the most thoroughly studied examples of an active normal fault in Europe. The event,

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

known as the 2009 L'Aquila earthquake (Figure 5), occurred on 6 April 2009 at 03:32 local time and had a moment magnitude of approximately Mw 6.3 (Figure 6). The earthquake focus was located at a depth of approximately 8-10 km. More than 300 people died, thousands were injured, and tens of thousands of residents were left without housing. A significant number of residential buildings, historic structures, and infrastructure facilities were destroyed or severely damaged [15, 16].

This earthquake became one of the most destructive events in Italy in recent decades and attracted considerable attention from geologists, seismologists, and geotechnical engineers, because it made it possible to study in detail the mechanism of formation and development of a normal tectonic fault and its influence on foundation soils and the stability of buildings and structures.



Fig. 5. Damage in L'Aquila

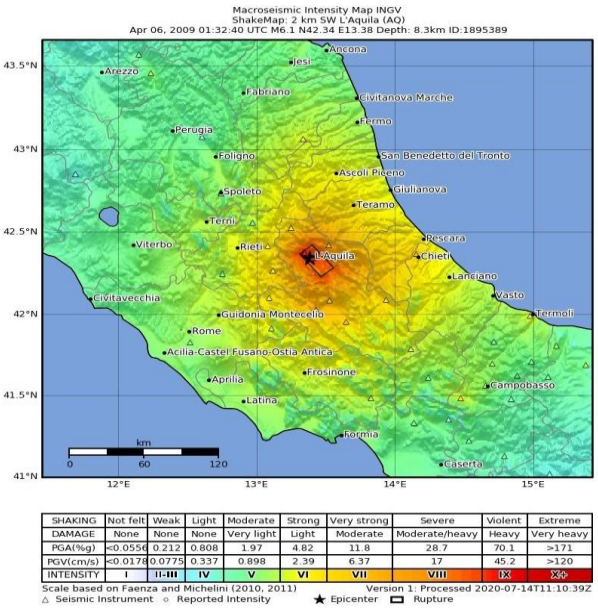


Fig. 6. L'Aquila earthquake epicenter map

Another well-known example of active fault manifestation is the 2011 Christchurch

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

earthquake (Figure 7), which occurred in Christchurch, New Zealand, on 22 February 2011 and had a moment magnitude of approximately Mw 6.2. Despite its relatively moderate magnitude, it caused severe damage to urban infrastructure and numerous casualties.

The earthquake occurred on a previously unrecognized blind fault with oblique-reverse faulting characteristics, rather than on a normal fault. The event was accompanied by significant deformation of foundation soils, severe liquefaction, lateral spreading, differential settlements, and damage to buildings and engineering infrastructure [17, 18, 19].



Fig. 7. Consequences of the Christchurch earthquake

2 METHODS AND MATERIALS

2.1 Laboratory Testing

Laboratory tests were performed at the KazGASA Academy in the Laboratory of Bases and Foundations using a special shear apparatus that simulates a normal-type tectonic fault.

The tests were aimed at studying and analyzing the influence of tectonic movements on the serviceability of foundation soils and at supplementing previously obtained data through laboratory fault modeling. Since soils serve as the foundation for any structure, their disturbance can cause deformation or destruction of buildings and structures and, in some cases, may pose a threat to human life and health. Such studies therefore have important practical value in design.

The purpose of the tests was to determine the zone of influence of shear faults at the ground surface depending on soil type and to assess their effect on the foundations of buildings and structures.

2.2 Description of the apparatus

To obtain more substantiated and reliable results regarding soil behavior in a tectonic fault zone, a set of laboratory tests was carried out using a tectonic-fault modeling apparatus (Figure 6). The purpose of the tests was to study the process of fault-wall formation and the nature of the propagation of the deformation zone toward the ground surface depending on soil type.

The tray apparatus has a total length of 150 cm, a width of 20 cm, and a height of 80 cm. It is constructed as a metal frame closed on three sides by 8-mm-thick metal sheets. The front side of the apparatus is made of 80-mm-thick organic glass, which enables visual observation of the deformation process in the soil mass. A coordinate grid with vertical and horizontal spacing of 5 cm is applied to the 1500 × 800 mm front face of the tray. The

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

movable part of the apparatus was displaced relative to the fixed part by up to 20 cm at an angle of 10°, making it possible to simulate the development of a normal-type tectonic fault.

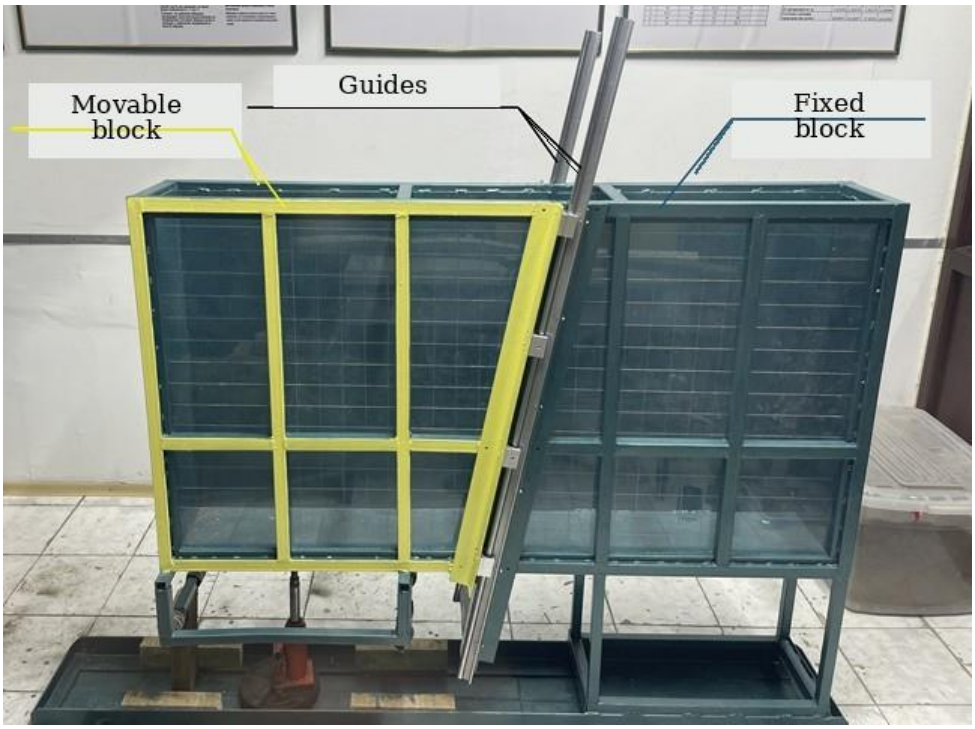


Fig. 2. Design of the geotechnical tray apparatus

3 RESULTS AND DISCUSSION

Laboratory tests were performed on sand (Figure 9) and crushed-stone soils (Figure 10). Comparison of the results made it possible to identify the specific features of fault-zone formation and the character of deformation depending on soil type.



Fig. 9. Model No. 1: sand

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)



Fig. 10. Model No. 2: crushed stone

The first test (Figure 11), performed on sand, showed that when the movable part of the apparatus was displaced, a localized inclined shear surface formed and propagated from the base of the model toward the ground surface. A wedge-shaped zone of intense deformation developed in the sand mass, accompanied by stress redistribution, soil loosening in the tensile zone, and compaction in the compression zone. These processes led to uneven surface settlement and caused tilting, rotation, and displacement of the building models located above the fault zone.

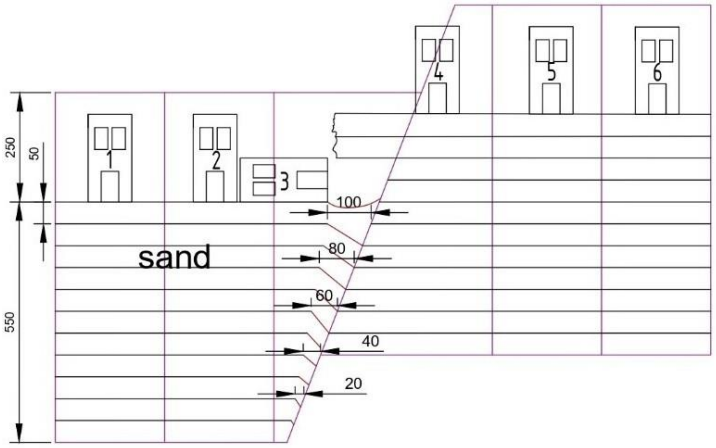


Fig. 11. Schematic diagram of the sand

In the second test (Figure 12), performed on crushed-stone soil, the deformation pattern was substantially different. In contrast to the sand mass, where a localized shear zone was observed, deformation in the crushed-stone material was more diffuse and was accompanied by the displacement of individual fragments of the soil mass. The zone of fault influence was wider than in sand, which is associated with stress transfer between the coarse particles of crushed stone. The building models experienced not only tilting but also torsional deformations caused by uneven redistribution of foundation deformations.

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

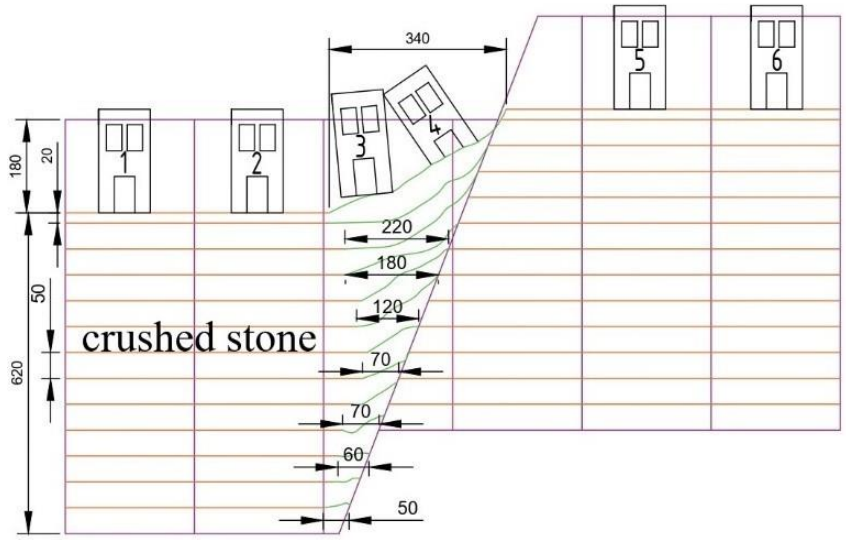
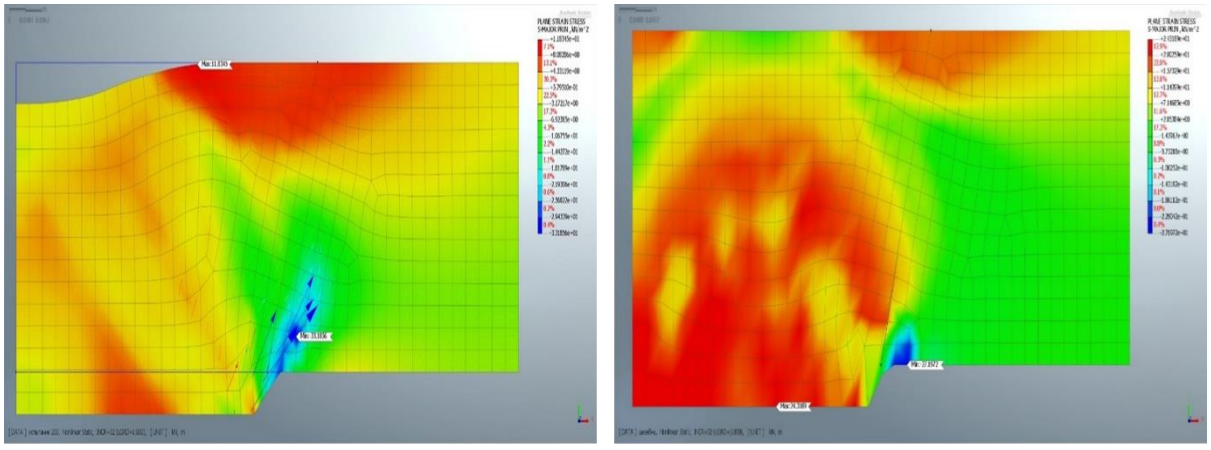


Fig. 12. Schematic diagram of the sand

The analysis of the stress distribution shows that the type of soil has a significant influence on the nature of stress redistribution during the simulation of a tectonic normal fault.

In Model No. 1 - sand, the distribution of principal stresses is more localized. The zone of maximum stress concentration is formed mainly near the fault plane and extends upward in the form of a relatively narrow inclined band. This indicates that sandy soil tends to develop a clearly expressed shear surface. The deformation process in sand is therefore more concentrated, and the influence of the fault is transmitted to the ground surface along a distinct trajectory.

In Model No. 2 - crushed stone, the pattern of principal stresses is more dispersed. The stress concentration is distributed over a wider area of the soil mass. Instead of a narrow localized zone, several areas of increased stresses are observed. This is related to the coarse-grained structure of crushed stone, where stresses are transferred through contacts between individual particles. As a result, the deformation zone becomes wider and less uniform compared with sand.



a) Model No. 1: sand b) Model No. 2: crushed stone

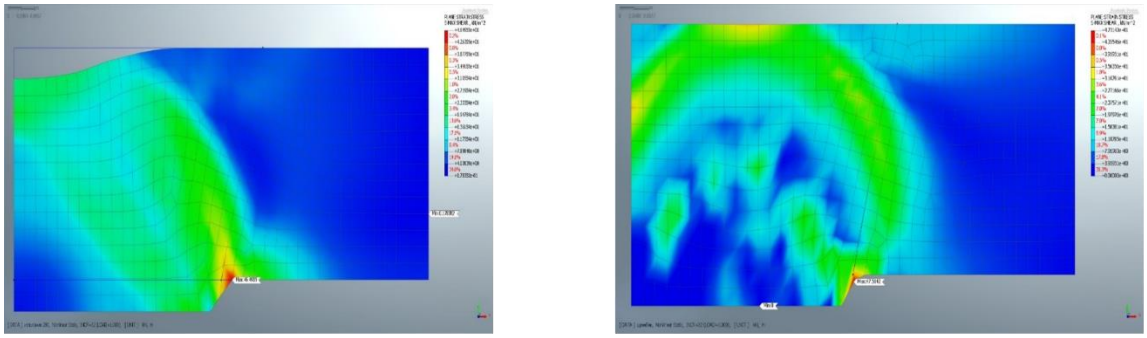
Fig. 13. Principal stresses during a tectonic normal fault

The comparison of shear stresses also confirms this difference. In sandy soil (Figure 14(a)), shear stresses are concentrated mainly along the inclined fault zone, which

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

corresponds to the formation of a distinct sliding surface. The stress field is smoother and more continuous, showing a relatively predictable mechanism of deformation propagation.

In crushed-stone soil (Figure 14(b)), shear stresses are distributed more irregularly. Local zones of increased shear stress appear in different parts of the model, especially near the lower part of the fault and within the central part of the soil mass. This indicates that deformation in crushed stone does not occur along one clearly defined surface, but develops through the displacement and rotation of individual coarse particles. Therefore, crushed-stone soil demonstrates a more complex and heterogeneous deformation mechanism.



a) Model No. 1: sand

b) Model No. 2: crushed stone

Fig. 14. Shear stresses during a tectonic fault

Thus, the results show that sand is characterized by localized stress concentration and the formation of a distinct shear zone, while crushed stone is characterized by a wider and more uneven redistribution of both principal and shear stresses. This means that in sandy soils the fault manifestation is more clearly expressed along a narrow deformation band, whereas in crushed-stone soils the influence of the fault spreads over a larger area and may cause more irregular foundation deformations, including tilting and torsional effects.

3.1 Comparative Analysis of Reinforced Layered Soil

The third test (Figure 15 (a,b,c)), performed on a layered foundation consisting of a lower crushed-stone layer and an upper sand layer with reinforcing elements, demonstrated the most favorable pattern of foundation deformation. The reinforcing elements were arranged with a spacing of 50 × 50 mm in the longitudinal and transverse directions.



a) Front view

b) Left view

c) Right view

Fig. 15. Test results for a layered soil structure (crushed stone–sand with reinforcement)

Issue No. 2 · 2026
ADVANCED STUDIES
IN ARCHITECTURE AND CIVIL ENGINEERING
(ASACE)
ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

As the deformation zone passed into the upper sand layer, partial localization of deformations was observed; however, the presence of reinforcing elements ensured stress redistribution and changed the trajectory of fault development. As a result, deformations were smoothed, and no pronounced scarp-like fault outcrop was observed at the ground surface.

The building models located within the fault influence zone experienced only moderate settlement and slight tilting without sharp distortions, indicating effective redistribution of deformations in the reinforced foundation.

Table 1 presents the obtained values, where L is the length of the fault zone at the soil surface and H is the height of the fault manifestation at the soil surface.

Table 1. Parameters of fault manifestation obtained in laboratory tests

No.	Soil type	Fault type	L, cm	H, cm
1	Sand	Normal fault	10	20
2	Crushed stone	Normal fault	22	18
3	Sand + crushed stone with reinforcement	Normal fault	9	17

3.2 Scientific Novelty Of The Study

The scientific novelty of the study lies in the experimental determination of the nature of tectonic fault manifestation at the surface of a soil mass depending on the type of foundation soil and the presence of reinforcing elements. Based on laboratory modelling of a normal tectonic fault using a special shear tray apparatus, the study identifies differences in the mechanism of deformation-zone formation in sandy and crushed-stone soils.

For the first time within the conducted laboratory tests, a comparative modelling of the behavior of sandy, crushed-stone, and layered reinforced foundations under simulated tectonic displacement was carried out. It was established that deformations in sandy soil are more localized, forming a clearly defined inclined shear zone, whereas in crushed-stone soil the fault influence zone spreads more widely and is accompanied by a more diffuse displacement of individual particles of the soil mass.

A new result of the study is the determination of quantitative parameters of tectonic fault manifestation at the soil surface for different types of foundations. It was shown that the length of the fault manifestation zone is 10 cm for sandy soil, 22 cm for crushed-stone soil, and 9 cm for a layered sand-and-crushed-stone foundation with reinforcement. This makes it possible to assess the degree of foundation deformation hazard depending on the engineering-geological conditions of the construction site.

The scientific novelty also consists in substantiating the effectiveness of reinforced layered foundations in zones of possible tectonic disturbance manifestation. It was established that reinforcing elements contribute to stress redistribution, reduce deformation concentration, and decrease the intensity of scarp-like fault outcrop at the ground surface. The obtained results expand the understanding of the interaction between tectonic displacements and various types of foundation soils and may be used in the design of buildings and structures in seismically active regions and tectonic fault zones.

4 CONCLUSION

1. International construction practice in seismically hazardous areas confirms the significant influence of tectonic faults on the serviceability of foundation soils for buildings and structures. Ignoring, or insufficiently considering, the effects of tectonic

ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

disturbances may lead to unacceptable deformations, reduced bearing capacity of foundations, and, consequently, damage or failure of structural elements.

2. According to the requirements of SP RK 2.03-31-2020, microzonation maps of the territory of Almaty identify tectonic fault zones within which strong earthquakes may cause ruptures and seismic dislocations in soils, as well as local increases in the intensity of seismic vibrations. In accordance with Clause 4.3.7 of SP RK 2.03-31-2020, engineering investigations must verify and refine the location of zones where faults may manifest within a construction site. In addition, according to Clause 4.3.12 of the same regulatory document, for sites located in zones where faults may outcrop at the ground surface, additional corrections should be introduced for adverse factors not accounted for by microseismic zoning maps [13].

3. For this reason, experimental studies were performed in the Laboratory of Bases and Foundations of KazGASA using a special shear apparatus that simulates a normal-type tectonic fault. The laboratory tests and analytical studies made it possible to assess the condition of soils in the fault influence zone, determine the character and scale of stress redistribution, and identify the most hazardous zones of possible foundation deformation and displacement.

4. The research results show that under active geodynamic conditions, even repeated seismic actions of low and medium intensity can substantially degrade the physical and mechanical properties of soils and the operational characteristics of foundations. It was established that the pattern of deformation propagation and the parameters of the tectonic fault influence zone depend strongly on soil type and on structural measures used to reinforce the foundation. The use of reinforcing elements and layered foundations contributes to stress redistribution, reduces deformation concentration, and decreases the risk of a pronounced scarp-like fault outcrop at the ground surface.

5. The proposed simplified calculation approaches make it possible to take the influence of tectonic disturbances into account in engineering assessments and design, and to justify rational structural and planning solutions aimed at reducing the adverse effects of faults on buildings and structures.

6. Design and construction of facilities in zones where tectonic faults may manifest at the ground surface should be carried out on the basis of special technical conditions developed by specialized research organizations with consideration of experimental and theoretical research results. The obtained results allow a more substantiated assessment of the influence of active tectonic faults on construction sites when preparing special technical conditions in accordance with SP RK 2.03-31-2020, including Clauses 5.3.9, 6.2.4, and 7.4.1–7.4.2 [13]

.

REFERENCES

1. Cox, A., & Hart, R. (1989). Plate Tectonics. Translated from English by A.A. Kalashnikov and V.L. Pankov; edited by A.F. Grachev. Moscow: Mir.

2. Kocharyan, G.G. (2016). Geomechanics of Faults. Moscow: GEOS.

3. Elnashai, A.S., & Di Sarno, L. (2008). Fundamentals of Earthquake Engineering: From Source to Fragility. Chichester: John Wiley & Sons.

4. Mandl, G. (2000). Faulting in Brittle Rocks: An Introduction to the Mechanics of Tectonic Faults. Berlin: Springer.

5. Power, M.S., Rosidi, D., & Kaneshiro, J.Y. (1998). Seismic Vulnerability of Tunnels and Underground Structures Revisited. Proceedings of North American Tunneling, Newport Beach, CA. Rotterdam: Balkema, pp. 243–250.

ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

6. Kartopoltsev, A.V. (2017). [Title not specified in the source manuscript]. Tomsk: Tomsk State University of Architecture and Building Publishing House, 300 p.

7. Butenkov, A.A. (2014). Geotectonics and Geodynamics. Novocherkassk.

8. Sucuoglu, H., & Akkar, S. (2014). Basic Earthquake Engineering: From Seismology to Analysis and Design. Cham: Springer International Publishing.

9. Gioncu, V., & Mazzolani, F.M. (2011). Earthquake Engineering for Structural Design. London: Spon Press.

10. Handy, M.R., Hirth, G., & Hovius, N. (Eds.). (2007). Tectonic Faults: Agents of Change on a Dynamic Earth. Cambridge, MA: MIT Press.

11. Plevris, V., Kremmyda, G., & Fahjan, Y. (Eds.). (2017). Performance-Based Seismic Design of Concrete Structures and Infrastructures. Hershey, PA: IGI Global.

12. Estrada, H., & Lee, L.S. (2017). Introduction to Earthquake Engineering. Boca Raton: CRC Press/Taylor & Francis Group.

13. SP RK 2.03-31-2020. Development of the Territory of the City of Almaty Taking into Account Seismic Microzoning. Code of Rules of the Republic of Kazakhstan. Astana, 2021, 61 p.

14. SP RK 2.03-30-2017*. Construction in Seismic Zones. Code of Rules of the Republic of Kazakhstan. Astana, 2017, 110 p

15. Chiarabba, C., Amato, A., Anselmi, M., Baccheschi, P., Bianchi, I., Cattaneo, M., Cecere, G., Chiaraluce, L., Ciaccio, M.G., De Gori, P., De Luca, G., Di Bona, M., Di Stefano, R., Faenza, L., Govoni, A., Improta, L., Lucente, F.P., Marchetti, A., Margheriti, L., Mele, F., Michelini, A., Monachesi, G., Moretti, M., Pastori, M., Piana Agostinetti, N., Piccinini, D., Roselli, P., Seccia, D., & Valoroso, L. (2009). The 2009 L'Aquila (central Italy) Mw 6.3 earthquake: Main shock and aftershocks. Geophysical Research Letters, 36, L18308. https://doi.org/10.1029/2009GL039627

16. Kaplan, H., Bilgin, H., Yilmaz, S., Binici, H., & Öztas, A. (2010). Structural damages of L'Aquila (Italy) earthquake. Natural Hazards and Earth System Sciences, 10, 499–507. https://doi.org/10.5194/nhess-10-499-2010

17. Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., Collett, D., Cousins, J., Cubrinovski, M., Dellow, G., Denys, P., Fielding, E., Fry, B., Gerstenberger, M., Langridge, R., Massey, C., Motagh, M., Pondard, N., McVerry, G., Ristau, J., Stirling, M., Thomas, J., Uma, S.R., & Zhao, J. (2012). The Mw 6.2 Christchurch earthquake of February 2011: Preliminary report. New Zealand Journal of Geology and Geophysics, 55(1), 67–90. https://doi.org/10.1080/00288306.2011.641182

18. Cubrinovski, M., Bradley, B., Wotherspoon, L., Green, R., Bray, J., Wood, C., Pender, M., Allen, J., Bradshaw, A., Rix, G., Taylor, M., Robinson, K., Henderson, D., Giorgini, S., Ma, K., Winkley, A., Zupan, J., O'Rourke, T., DePascale, G., & Wells, D. (2011). Geotechnical aspects of the 22 February 2011 Christchurch earthquake. Bulletin of the New Zealand Society for Earthquake Engineering, 44(4), 205–226.

19. Bray, J.D., Cubrinovski, M., Bradley, B.A., & Taylor, M. (2014). Liquefaction effects on buildings in the Central Business District of Christchurch. Earthquake Spectra, 30(1), 85–109. https://doi.org/10.1193/022113EQS043M

ISSN 3134-8475 (Print)
ISSN 3134-8483 (Online)

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ARTIFICIAL INTELLIGENCE STATEMENT

During the preparation of this manuscript, the authors used [tool name, version] solely for language editing and grammar checking. The authors reviewed and edited the output and take full responsibility for the scientific content, analyses, interpretations and conclusions of the article.

INFORMATION ABOUT THE AUTHORS

V.A. Khomyakov – Doctor of Technical Sciences, Professor at the School of Construction, KazGASA
A.K. Ibray – Master's student of the Kazakh Leading Academy of Architecture and Civil Engineering (KazGASA), International Educational Corporation, Almaty, Kazakhstan
S.B. Dursynov – Master of Engineering, Senior Engineer, Laboratory Research and Testing Sector, JSC KazNIISA
S.Zh. Jumadilova – Doctor of Philosophy in Technical Sciences, Associate Professor at the School of Construction, KazGASA

AUTHORS CONTRIBUTION

S.B. Dursynov – providing project documentation; organization of internships and practical training in construction; analysis and collection of project-related information
A.K. Ibray – development of architectural and structural solutions; preparation of the computational model; analysis of seismic-resistant design solutions; processing of research results; preparation and writing of the manuscript
V.A. Khomyakov – scientific supervision; development of the research methodology; scientific editing of the manuscript; analysis and interpretation of the obtained results; final review of the article
S.Zh. Jumadilova – providing scientific and methodological support; assisting in the analysis and interpretation of the obtained results; reviewing and editing the manuscript; contributing to the final revision of the article

The article was submitted 1 April 2026; approved after reviewing 30 May 2026; accepted for publication 10 June 2026.