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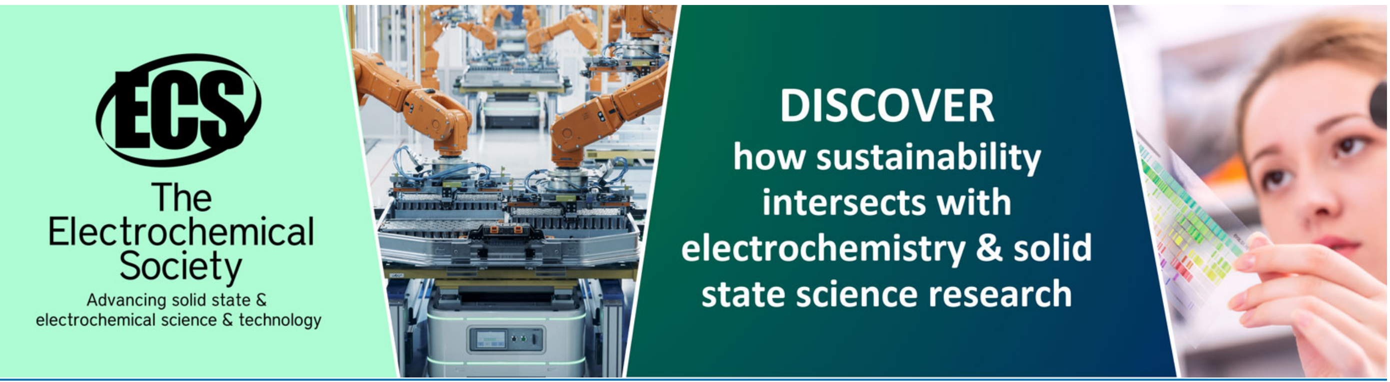

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A study on energy distribution law of frame structure across ground fissure

XIONG Zhongming[1], LIU Yixin[1*] , CHEN Xuan[1], XU Jianjian[1]

[1]Department of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi Province, 710055 China

*Corresponding author's e-mail:lyx@xauat.edu.cn

Abstract. In order to study the frame structure energy dissipation mechanism on the ground, a 3×3 span 5-story frame structure was used as the research background, and a shaking table test with a scale ratio of 1:15 was designed. Based on the prototype structure, a finite element model based on ABAQUS is established. The correctness of the finite element model is verified by experimental comparison. On this basis, the plastic energy dissipation and damping energy consumption of the structural beam and the plastic energy dissipation law of the column are analyzed. The weak part of the structure of the trans-ground fissure structure under energy conversion is found. This study provides a reference for the arrangement of energy-consuming devices in seismic design and disaster prevention and mitigation design for similar structural engineering.

1. Introduction

Xi'an is located in the ground fissure zone of the Weihe Basin. The existence of ground fissures has seriously affected the urban planning of Xi'an[1]. With the improvement of urbanization and the impact of talent introduction plans and household registration policies, the contradiction of urban land shortage is more prominent. Therefore, making full use of the land resources in the ground fissure area has become an important subject that urgently needs to be studied in urban construction. There are many studies on the dynamic response of engineering structures under ground fissure environment[2]. Huang Qiangbing et al.[3]used large-scale shaking table tests to show that the acceleration response of the ground fissure site showed a significant amplification effect; Xiong Zhongming et al.[4]used finite element software to establish the interaction between the ground fissure site and the structure with no difference between the upper and lower walls. Calculation model, quantitative analysis of frame structure acceleration, displacement and displacement angle change law;. For the research on structural energy distribution, Ye Lieping[5]summarized the relevant research results of building structures based on energy seismic design methods, and pointed out that structural damage energy dissipation mechanism control is the key to determining the cumulative energy consumption distribution of structures and realizing energy-based seismic design. From the energy point of view, based on the shaking table test of a ground fissure frame structure with a scale ratio of 1:15, a finite element model of the ground fissure structure is established, and the accuracy of the established finite element model is verified. The distribution law of plastic energy dissipation of the structure spanning ground fissures under earthquake action is analyzed. The research results provide basic data for guiding the design of shock absorption and energy dissipation for ground fissures affected areas or cross-ground fissure structures.

2. Shaking table test design

2.1.Model parameter determination
This experiment was completed by the research team at the Key Laboratory of Structure and Seismic Resistance of the Ministry of Education, Xi'an University of Architecture and Technology[6]. The experiment selected a 3×3 five-story span that crossed Xi'an ground fissure f4 (Northwest University-Northwestern Polytechnical University ground fissure). The frame structure is designed for shaking table test as a research background. The type of construction site where the frame structure is located is Class II, the designed seismic group is the first group, and the seismic class of the frame structure is Class II. Refer to the shaking table test research of Xu Weizhi et al.[7]This test uses an artificial mass model to scale the original structure and the soil at a scale of 1:15. The specific dimensions of the original structure before scaling and the model structure after scaling are shown in Table 1. Shown.

Tab 1. Model size before and after the scale

	Original structure	Model structure
total measurement	18mx15.6mx21m	1220mmx1060mmx1200mm
Side span column	400mmx500mm	27mmx33mm
Mid-span column	500mmx500mm	33mmx33mm
Board thickness	120mm	8mm
Height of each floor	3.6m	240mm
Soil	45mx22.5mx22.5m	3mx1.5mx1.5m

2.2 Making the upper frame structure and model earth box
The upper frame structure is a 3×3 five-story scaled frame structure, and the model structure plan is shown in Figure 1. This model uses M6 particulate concrete to simulate the C30 concrete in the prototype structure, and uses galvanized iron wire to simulate the steel skeleton of the original structure.

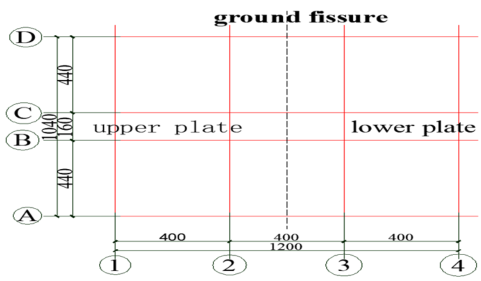


Fig 1. Layout plan of model structure

The soil used in the model is in-situ fissure site soil [8], and the model soil is configured after sieving and controlling the moisture content and density of each layer of soil. The specific control parameters are shown in Table 2.

Tab 2. Parameters of soil layers in ground fissure site

Soil layer name	Moisture content %	densityρ （g/cm3）	Shear modulusG （MPa）	Cohesion (Pa)	Internal friction angle (°)	Expansion angle (°)
loess	23.5	1.68	110.49	48000	27.6	9.2
Ancient soil	22.9	1.78	139.45	49000	27.3	9.1
Silty clay	25.2	1.90	163.34	45000	26.6	8.866667

2.3 Test loading plan and data collection
This shaking table test selects two surface waves El-Centro wave, Jiangyou wave and one bedrock wave

Cape Mendocino wave as the test seismic waves, which are loaded in seven steps along the direction perpendicular to the ground fissure, with peaks of 0.1g, 0.2g, 0.3g, 0.4 g, 0.6g, 0.8g, 1.2g. The frequency is swept with 0.05g white noise before each stage is loaded.

3. Numerical analysis based on ABAQUS software

The finite element analysis of the superstructure and the size of the soil is the size before the scale. The specific size is shown in Table 1. The upper frame structure beams and columns adopt B31 beam elements, and the floor slab adopts shell elements; the steel bars in the beams and columns are defined in keywords using the rebar command stream, and the rebar layer in the floor is inputted. The concrete constitutive of beam and column adopts the concrete UConrete02 model considering the tensile strength in the PQ-Fiber subroutine model, the slab concrete constitutive adopts the damage accumulation model in ABAQUS, and the steel adopts the ideal elastic-plastic type. The soil model uses C3D8R three-dimensional solid element simulation. The constitutive model adopts the Mohr Coulomb model, and the established finite element model of the ground fissure site and the upper frame structure is shown in Figure 2. The simulation of soil ground fissures is set as hard contact in this model, and the tangential action is simulated by the Coulomb friction model with a penalty friction coefficient, and the friction coefficient is 0.3. In order to compare the acceleration response of the finite element model and the test model, and verify the accuracy of the finite element model, the ground motion table response of three kinds of seismic waves under 0.1g and 0.4g excitation respectively is used as the seismic input, and the acceleration measurement points according to the test model The placement position of the finite element model is to monitor the acceleration of the corresponding position.

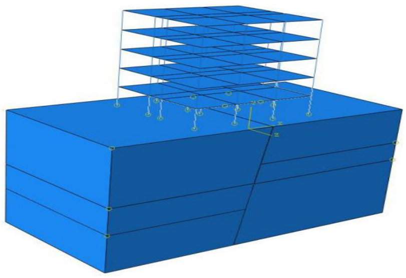
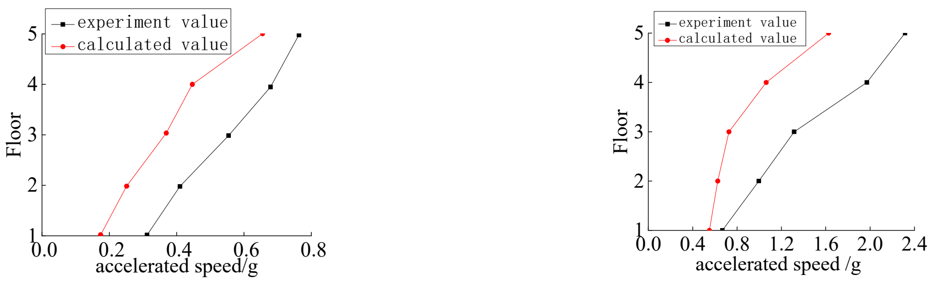


Fig 2. The whole model of the superstructure above the ground fissure

4. Comparative analysis of numerical simulation and test results

4.1 Comparative analysis of acceleration

The table response under the action of 0.1g and 0.4g El-Centro waves is used as the seismic input, and the acceleration measurement points of the test superstructure are arranged according to the acceleration measurement points of the test superstructure. The comparison is shown in Figure 3.



(a) 0.1g Countertop response (El-Centro wave) (b) 0.4g Countertop response (El-Centro wave)

Fig 3. Comparison of acceleration experimental value and simulated value under the action of EI-Centro wave

4.2 Comparison error analysis
Comparing the acceleration results obtained from the test and the numerical simulation, it is found that the simulated acceleration of each layer is consistent with the experimental acceleration. The experimental value is slightly larger than the calculated value, and the acceleration is the smallest at the bottom and the highest at the top. Because the finite element soil viscoelastic artificial boundary setting is different from the experimental soil boundary (soil box); the test model production error, and the size effect of the test plan according to the 1:15 scale ratio design causes the finite element simulation results The numerical value is slightly different from the test results, but the finite element software simulation of the dynamic response of the cross-ground fissure structure has obvious regularity, which is consistent with the change trend of the shaking table test results. It can approximate the simulation test situation and verify the correctness of the modeling calculation method in this paper. Therefore, the finite element model can be used for energy analysis of shaking table test to determine the energy distribution law of frame structures spanning ground fissures.

5. Energy analysis of ground fissure site frame structure

5.1 Energy balance expression in ABAQUS
Energy output is an important part of ABAQUS/Explicit analysis. The energy components in ABAQUS are richer, mainly including internal energy, kinetic energy, strain energy, energy input to the soil-structure system by ground motion, damping energy consumption, plastic damage energy consumption, Time-dependent energy consumption, surrounding media energy consumption, etc., these energies obey the law of conservation of energy, combined with the energy integral formula of the above formula, the simplified relationship between the energy components can be obtained as follows:

$$E_u + E_k + E_f + E_{qb} = E_w + constant$$

Where: E_u is the internal energy; E_k is the kinetic energy; E_f is the energy consumption of the model contact friction contact; E_w is the energy input to the soil-structure system by the ground motion; E_{qb} is the damping energy consumption of the surrounding medium;

5.2 Energy distribution of beam and column in ground fissure structure
In order to study the energy distribution law of the upper structural beams and columns across the ground fissure, since the ground fissure passes through the mid-span of the structure (see Figure 1), the longitudinal one-thickness frame analysis is selected, which can reflect the upper and lower beams, The difference in column energy distribution. Figure 4 shows the numbering of each layer of beams and columns in a cross frame.

(a) Serial beam number of each layer (b) Column number

Fig 4. The number of structural beam and column members

In order to facilitate the analysis of the difference in the distribution of plastic energy consumption along the height and longitudinal direction of the structure, define the energy distribution coefficient along the height λ_h and the longitudinal energy distribution coefficient λ_l as follows:

$$\lambda_h = \frac{E_{ji}}{\sum E_j} \qquad \lambda_l = \frac{E_{ij}}{\sum E_i} \tag{1}$$

In the formula, E_{ji} is the plastic energy dissipation of columns (beams) in column j (span) of the structure, and i represents the plastic energy consumption of columns (beams) in column j (span) of the structure, and i represents the 1~5 layers of the structure; $\sum E_j$ is the total plastic energy dissipation of columns (beams) in column j (span) of the structure, j represents 1~4 columns or 1~3 span beams; E_{ij} is the plastic energy dissipation of columns (beams) in the j column (span) of the i-layer structure; $\sum E_i$ is the total plastic energy dissipation of all the columns (beams) in the i-layer structure.

5.3 Distribution of plastic energy dissipation in the superstructure

Tab 3. The plastic energy dissipation of each layer beams

Number of layers	Distribution of plastic energy dissipation of each layer of beams (Jiangyou wave/El-Centro wave/bedrock wave)		
	SL	ZL	XL
First floor	446.5/67.9/643.0	15.2/8.4/38	426.6/71.4/588.7
Second floor	182.8/40.8/34.4	9.5/7.1/8.4	231.4/35.6/29.8
Third floor	509.8/201.8/40.7	11.2/7.0/8.2	433.5/69.2/35.8
Forth floor	637.1/373.2/51.8	11.7/9.4/8.2	571.9/211.1/42.8
Fifth floor	481.1/193.9/52.5	15.3/9.7/9.3	486.3/96.3/40.6

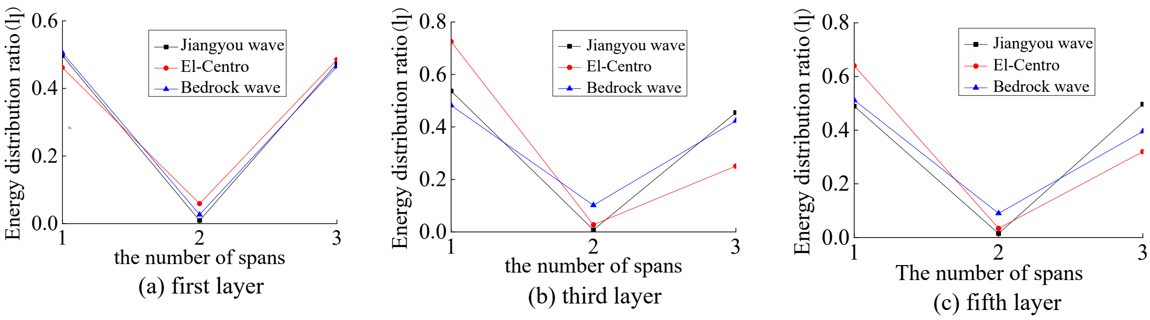


Fig 5. The plastic energy dissipation ratio of beams(λ_l)

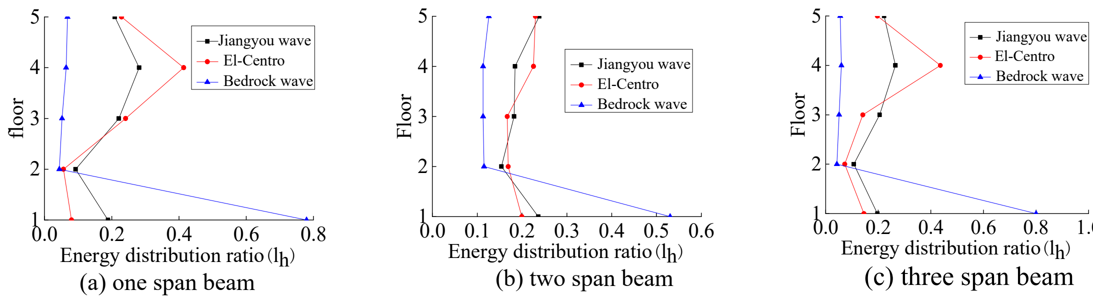


Fig 6. The plastic energy dissipation ratio of beams (λ_h)

Analyzing Figures 5, 6 can be obtained: along the longitudinal direction of the structure, the longitudinal distribution ratio of the plastic energy consumption of the beams at the mid-span (crossing the ground fissure) of the structure under the action of the earthquake is the smallest, and the plastic energy consumption is the least; at the same time, the beams located at the hanging wall The proportion of

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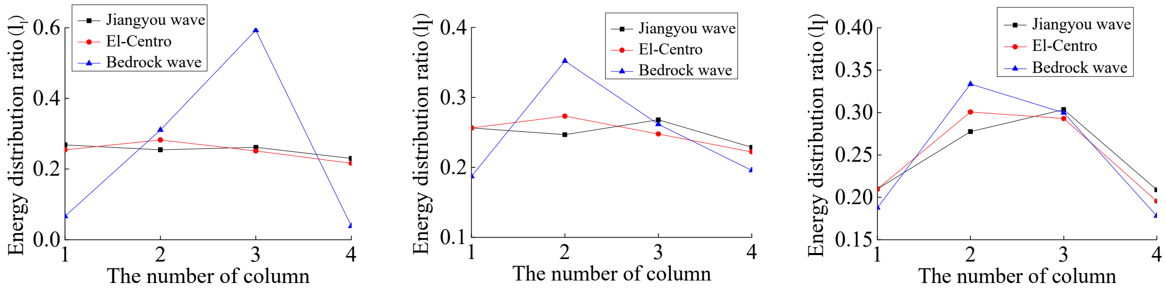
plastic energy consumption distribution is slightly larger than that of the bottom wall, which is in line with the top and bottom effect of the ground fissure site studied by previous researchers[9];

Along the height of the structure, the energy distribution of each beam at the bottom of the structure perpendicular to the direction of the ground fissure is relatively close; with the increase of floors, the difference in the proportion of plastic energy consumption in the upper and lower walls changes significantly, which is due to the increase in the height of the ground fissure site The effect of the upper and lower plates is obvious, and the nonlinear deformation of the beam at the hanging plate is more than that of the bottom plate.

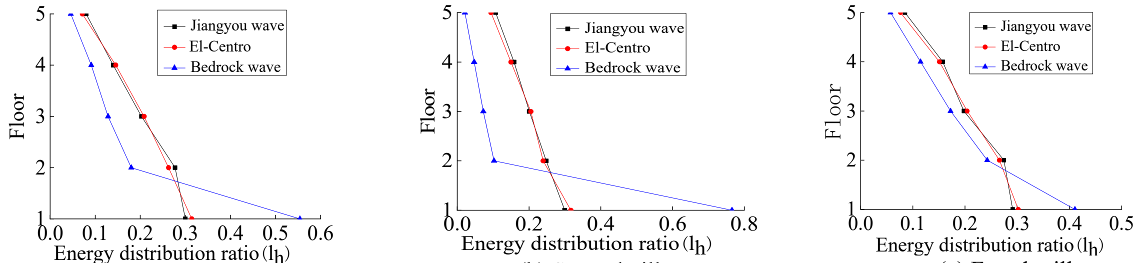
Tab 4. The plastic energy dissipation of each layer columns

Number of layers	Distribution of plastic energy dissipation of each layer of column (Jiangyou wave/El-Centro wave/bedrock wave)			
	SYZ	SJZ	XJZ	XYZ
1	253.5/95.5/75.5	246.9/106.2/356	252.9/94.5/684	222.7/81.0/43.9
2	230.0/81.0/43.9	199.1/81.5/45.8	214.2/72.5/34.4	205.7/71.6/25.9
3	172.9/63.6/17.5	166.9/68.1/32.9	181.4/61.6/24.5	153.8/55.0/18.4
4	120.8/44.4/12.3	127.6/50.7/21.0	134.6/47.5/17.1	637.1/373.2/51.8
5	63.6/21.9/6.4	84.2/31.4/11.5	91.8/30.6/10.3	63.3/20.4/6.1



(a) one layer (b) third layer (c) fifth layer

Fig 7. The plastic energy dissipation ratio of columns (λ_l)



(a)First Pillar (b) Second pillar (c) Fourth pillar

Fig 8. The plastic energy dissipation ratio of columns (λ_h)

According to the analysis of Figures 7 and 8, it can be seen that along the longitudinal direction of the structure, the energy distribution of the first and third floors of the structure is relatively close under the action of the earthquake. The plastic energy consumption of the column near the ground fissure is slightly larger than that of the column far away from the ground fissure. The distribution changes greatly, and the plastic energy consumption of the column close to the ground fissure is significantly more than that of the column far away from the ground fissure, indicating that the column is still consuming energy in the case of brittle failure of the beam.

Along the structure height direction, as the storey height increases, the plastic energy consumption of each column gradually decreases, except for individual floors, it basically decreases linearly. The design concept of the column-weak beam and the seismic fortification requirements of not falling in a big earthquake.

6. Conclusion

Based on the shaking table test, the finite element model of the ground fissure and the upper frame structure is established. Based on the comparison and analysis of the shaking table test and the finite element simulation acceleration response, the energy distribution problem of the upper structure across the ground fissure is studied. The distribution of plastic energy dissipation and damping energy dissipation of beams and columns along the direction of the ground fissure and the height of the structure has been studied. The study shows that:

(1) Under different seismic waves, the plastic energy consumption of the upper wall of the upper structural beam is greater than that of the footwall, and the plastic energy consumption of the beam across the ground fissure is the least. In the height direction, the energy distribution of Jiangyoubo and El-Centro is relatively consistent at the heights of each layer, and mutations occur at the second and fourth floors. The second and fourth floors have the least proportion and the fourth floor.

(2) Under the action of different seismic waves, the plastic energy consumption of the upper wall of the upper structural column member is greater than that of the foot wall. The closer the column is to the ground fissure, the greater the plastic energy consumption of the column. The energy consumption under the action of bedrock waves accounts for more than the other two waves. In the height direction, the plastic loss of the column increases with the increase of the floor height, which is consistent with the law of the increase of the floor shear force with the increase of the height under the action of the earthquake. The energy consumption of the bottom layer under the action of the bedrock wave accounts for significantly more. This is because the time history curve of the bedrock wave is relatively gentle, which makes the column concrete more plastic hysteretic energy consumption.

References:

[1] Liu N, Huang Q, Wang L. Dynamic characteristics researchof a ground fissure site at Xi’an, China [J]. Tunnelling And Underground Space Technology, 2018,82:182-190.
[2] Nina Liu, Xiaoyang Feng, Qiangbing Huang. Dynamic characteristics of a ground fissure site [J]. Earthquake Engineering & Structural Dynamics, 2019, 248: 220-229.
[3] Huang Qiangbin, Gao Huan, Liu Nina, et al. Shaking table model test on seismic response of crossing ground fissure site [J]. Journal of Geomechanics, 2018, 24(06): 785-794.
[4] Xiong Zhongming, Wang Yongwei, Chen Xuan, et al. Seismic responses of structures across ground fissure with different settlements,between hanging wall and foot wall [J]. Joural of Vibraton And Shock, 2019, 38(10): 112-118.
[5] Ye Lieping, Miao Zhiwei, Cheng Guangyu, et al. Study on the energy-based seismic design method of building structures [J]. Engineering Mechanics, 2014, 31(06): 1-12+20.
[6] XIONG Zhongming, ZHANG Chao, CHEN Xuan. Model test on ground motion parameters of site with fissures under seismic loading[J]. Rock and Soil Mechanics, 2019, 40(2):421. DOI: 10.16285/j.rsm.2017.1407
[7] Xu Weizhi, Wang Shuguang, LiuQingwei, et al. Shaking table test on vertical seismic responses of the large-span isolated structure [J]. Journal of Building Structures, 2019,: 1-14.
[8] Northwest Comprehensive Survey and Design Institute. Geotechnical Geological Prospecting Report of Tangyan Road Underground Civil Air Defense Engineering [M]. 2013, 03.
[9] Zhongming Xiong, Xuan Chen, Chao Zhang, Xiaopeng Huo, Yan Zhuge. Shaking table tests of RC frame structure across the earth fissure under earthquake [J]. The Structural Design of Tall and Special Buildings, 2018, 27(14).
[10] Abaqus Inc. Abaqus User Manual, Version 6.8, 2008.