16th World Conference on Earthquake, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 3016
Registration Code: S-O1464748756

ANALYSES ON THE EFFECTIVE OF STRUCTURE MEASURES ON FRAME BEAM END FOR "STRONG COLUMN AND WEAK BEAM" FAILURE MODE

Hongliu XIA [(1)], Guang WU [(2)], Zongxin ZHENG[(3)]

(1) Associate professor, Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education,School of Civil Engineering,Chongqing University, xiahongliu@cqu.edu.cn
(2) Student, Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education,School of Civil Engineering,Chongqing University,839423566@qq.com
(3) Engineer, C&D Real Estate Corporation Limited ,289831947@qq.com

Abstract

"Strong column and weak beam" is one of the key control measures in structural seismic design. It is committed to adjusting the distribution pattern of plastic hinges of structure under rare earthquake, and the plastic hinges are expected to appear at the end of the beam, plastic hinges are avoided appearing at the end of column except the bottom column. So it is necessary to make a thorough analysis. This paper makes dynamic elastic-plastic and static analyses of three various slotting methods and general two-story (2×2) frame structures, and studies the seismic performance of each model via mechanical analysis and numerical analysis method by ABAQUS results indicate that compared with general frame, when adopting the three slotting methods proposed in this paper: little changes in the bearing capacity reserves of the structure, deformation capacity reserve increases, and the seismic performance improves; under the impact of seismic waves, the degree of damage of concrete at beam ends increases, that at column ends and joint decreases, plastic hinging appears earlier at beam ends than column ends, a higher degree of plastic hinging development appears at beam ends than column ends, which is more consistent with the "strong column-weak beam" failure mode in the code.

Key words: *frame, strong column weak beam, slotting on slab, plastic hinge distribution, static and dynamic elastic-plastic.*

1. Introduction

Seismic design ideas of Code for seismic design of buildings [1] is based on "capacity design". According to these seismic measures, such as "strong column and weak beam, strong shear weak bending, and strong joint & strong anchoring", the seismic design goals, which is "No Damage with Frequently Occurred Earthquakes, Repairable with Fortification Intensity Earthquakes and No Collapse with Rare Occurred Earthquakes" can be guided. As the key control measure in seismic design, "strong column and weak beam" has been paid much attention on by the engineers. Most of the damage phenomena of structures in Wenchuan Earthquake(2008) in China are mainly showed that hinges appear at the end of the column commonly, and the yield mechanism of "strong column and weak beam" is not realized [2~4]. After analysis something is revealed, slab reinforcement in cast in place floor involving in beam end bending is the main reason for the above phenomenon [5~8], and currently way of improving beam column factor and decreasing the axial compression ratio limit value is not sufficient to achieve [9] "strong column and weak beam". In order to weak the slab reinforcement effecting on the bending capacity of the beam, the measures of setting slit on the floor near the beam end are proposed in this paper.

Adopting software ABAQUS, firstly, 3 kinds of models by taking different measures setting slit on the floor near the beam end and the general framework model are built, and then static and dynamic elastic-plastic analysis is carried on to discuss the seismic responses of these models. Finally, the effect of the slotted structural measures on "strong column and weak beam" failure mode under rare earthquake comparatively is analyzed.

2. Finite element model and analysis parameters

2.1 Model scheme

In this paper, 4 comparative analysis models are established: model M-1 is for general framework, as shown in Fig.1, M-2 model is for model setting rectangular slit on slab, model M-3 is for model setting oblique slit on slab, model M-4 is for model setting slit on slab away from the beam a certain distance. The specific structural measures diagrams are shown in Fig.2, Fig.3, Fig.4. S in Fig.2, Fig.3 and Fig.4 is said to slit size, respective size are 100mm, 200mm, 100mm.

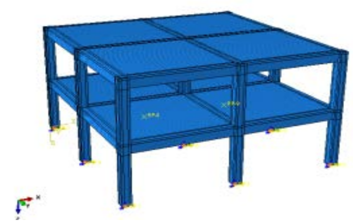


Fig.1- M-1general framework

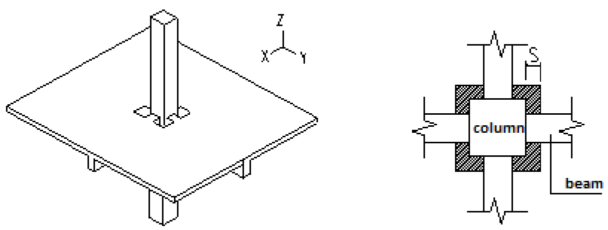


Fig.2-M-2 slotting model

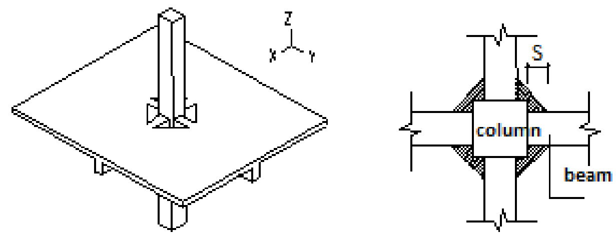


Fig.3 -M-2 slotting model

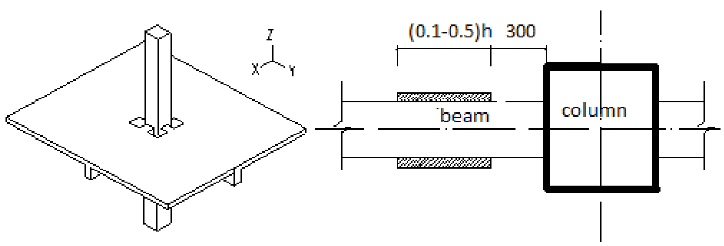


Fig.4- M-2 slotting model

The model example is taken as 2 story reinforced concrete frame structure. Structure arrangement and beam column size, reinforcement details are shown in Fig.5 and Fig.6. The concrete strength is C30, the longitudinal reinforcement in column and beam are HRB400, reinforcement in plate and beam column stirrups are HPB300. Along the direction of displacement and seismic wave input direction (X direction) the beam number are L1~L6, and the vertical cross above numbered beam number are HL1~HL6; the column number are Z1~Z9.

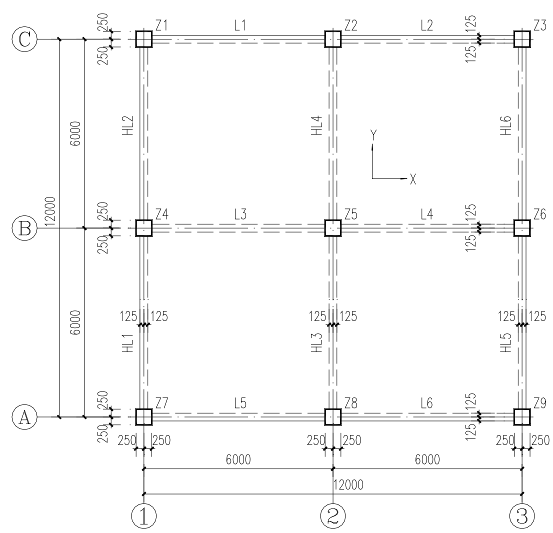
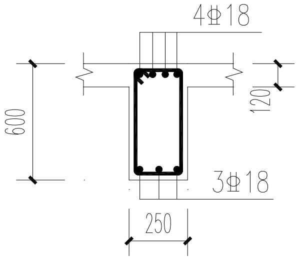
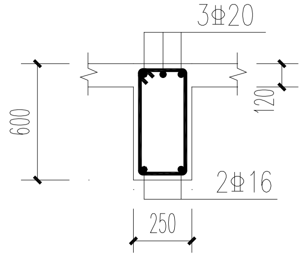


Fig.5-Layout of structure

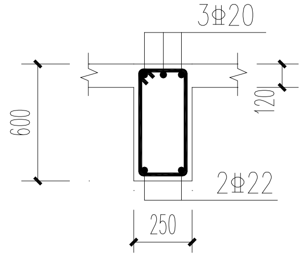
Only different ways of setting slit on the slab near the beam column nodes are taken, and then the comparative analysis on the influence on structure seismic performance is done. The influence of irregular structure arrangement and the torsion of the whole structure are not considered.



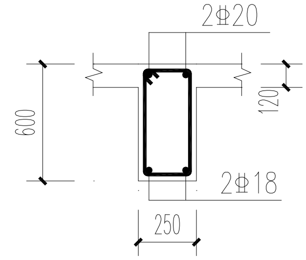
(a)First floor L3,L4 reinforcement



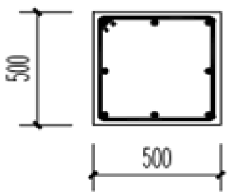
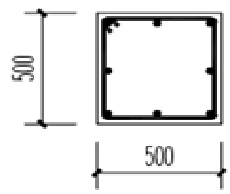
(b)First floor L1,L2,L5,L6 reinforcement



(c)Second floor L3,L4 reinforcement



(f)Second floor L1,L2,L5,L6 reinforcement

section		
number	Z1, Z3,Z7,Z9	Z2, Z4, Z5, Z6, Z8
longitudinal reinforcement	4Φ22(angle reinforcement) +4Φ18	4Φ18(angle reinforcement) +4Φ 18
stirrup	Φ8@100/200	Φ8@100/200

(e) Column reinforcement of four models

Fig.6- Reinforcement of beam and column

Load is determined by "load code for the design of building structures" [10]. Uniform wiring load on the floor frame beam is 8kN/m, uniform wiring load on the frame beam around the roof is 3.5kN/m.Seismic fortification intensity is 7 degree (0.15g), seismic grade is grade three, seismic design is grouped into the second group, the site classification is class II and reduction factor of structure period is taken as 1.0.

2.2 Finite element model

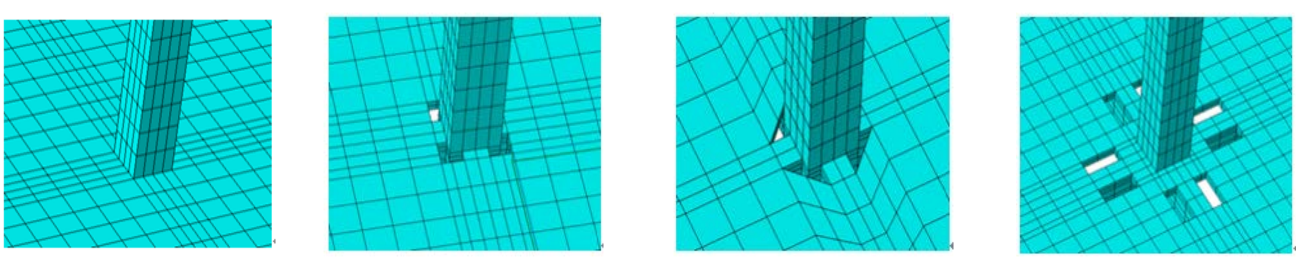
In this paper, the analysis algorithm of ABAQUS/Explicit module is used, C3D8R 3D solid element is used to simulate concrete, T3D2 truss element is used to simulate reinforcement. The steel skeleton will be embedded into concrete solid element through Embedded Function, the bond slip between the two is not considered.

For the considering of the convergence and better to simulate the seismic action of concrete tensile cracking and compressive, plastic damage model is choose as the damage model, Model PQ-fiber [11] is choose as hysteretic constitutive model of reinforcement.

Table 1- Related parameter values

ψ	ε	α_f	K_c	ν	μ
30	0.1	1.16	0.667	0.2	0.05

The whole mesh size of concrete and reinforcement is 300mm, in the beam, plate, column bending direction and the node set local species and divide mesh. Schematic diagram of each model node region is shown in Fig.7.



(a)M-1 model (b) M-2 model (c) M-3 model (d) M-4 model

Fig. 7-Nodes of each frame model

The respective static and dynamic elastic-plastic methods are used to do the analysis on the seismic behavior of the model. The analysis process is as follows.

3. Static elastic-plastic analysis

3.1 Loading mode of static elastic-plastic analysis

In this paper, loading method of the static elastic-plastic analysis is based on "pushover analysis algorithms based on multi-point displacement control" proposed by Huang Yuli [12]. The control points are established to control the displacement of the whole structure , a displacement constraint which can make each floor load distribution satisfies a constant ratio is introduced and displacement constraint equations can establish the load distribution ratio which is shown in Fig.8 and in Fig.8 p1:p2:p3:p4:p5:p6 =1:1.5:1:2:3:2

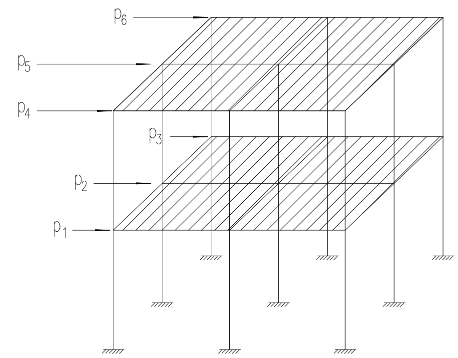


Fig.8 -Pushover load ratio distribution of each displacement control point

The model first is applied gravity load, and then the above loading method is used, and next horizontal low cyclic load is applied until the structure failed. Low cycle reciprocating loading system is shown in Table 2. Elastic stage (loading number 1,2,3) 1 times the number of cycles per displacement amplitude is count, the elastic-plastic stage (loading number 4-19) 2 times the number of cycles per displacement amplitude is count.

Table 2-Related parameter values

loading number	additional freedom displacement (unit:mm)	loading number	additional freedom displacement (unit:mm)
1	±3.6	10,11	±80
2	±7.2	12,13	±100
3	±13.1	14,15	±120
4,5	±20	16,17	±140
6,7	±40	18,19	±160
8,9	±60		

3.2 Comparative analysis of seismic performance based on hysteresis curve

Based on the static elastic-plastic analysis, the compassion and analysis of the hysteretic curves, skeleton curves, bearing capacity and deformation capacity of the four models are studied. The bearing force reserves is represented by the overstrength coefficient Ω(the ratio of structure maximum base shear and the structure seismic design force), deformation capacity is represented by the overall displacement ductility coefficient μ (0.8Pmax is corresponds to the vertex displacement and the yield displacement ratio).

From table 3 and table 4 some resuils can be drawn. Compared with M-1general framework, bearing capacity reservation of 3 other beam end slab setting slit models remains essentially same, which indicates that setting slit on slab has few effects on bearing capacity reservation.

The displacement ductility coefficient (shown in Table 4) is compared. Average displacement ductility coefficient of M-2 model is the largest. Ductility coefficient of M-3 model has improved to some extent compared with M-1 model and the displacement ductility coefficient of M-4 model has slightly reduction. Above phenomenon shows that setting slit on slab can improve the deformation capacity of the structure in a certain extent.

Table 3 -Characteristic load of hysteresis curve

Loading direction	characteristic load	M-1 (unit:kN)	M-2 (unit:kN)	M-3 (unit:kN)	M-4 (unit:kN)
positive direction	P_{max}	1413.90	1359.10	1372.30	1385.00
	P_u	1129.52	1087.28	1105.84	1100.80
	P_y	1050.50	1028.48	1045.42	981.51
	Ω	3.33	3.20	3.23	3.26
reverse direction	P_{max}	1413.70	1354.10	1359.70	1376.10
	P_u	1130.96	1067.28	1087.76	1100.88
	P_y	1077.20	1035.33	1084.86	1099.83
	Ω	3.33	3.19	3.20	3.24
average value	P_{max}	1413.80	1356.60	1366.00	1380.05
	P_u	1130.04	1085.28	1092.80	1104.04
	P_y	1063.85	1031.90	1065.14	1040.67
	Ω	3.13	3.00	3.02	3.05

Table 4 -Characteristic displacement of hysteresis curve

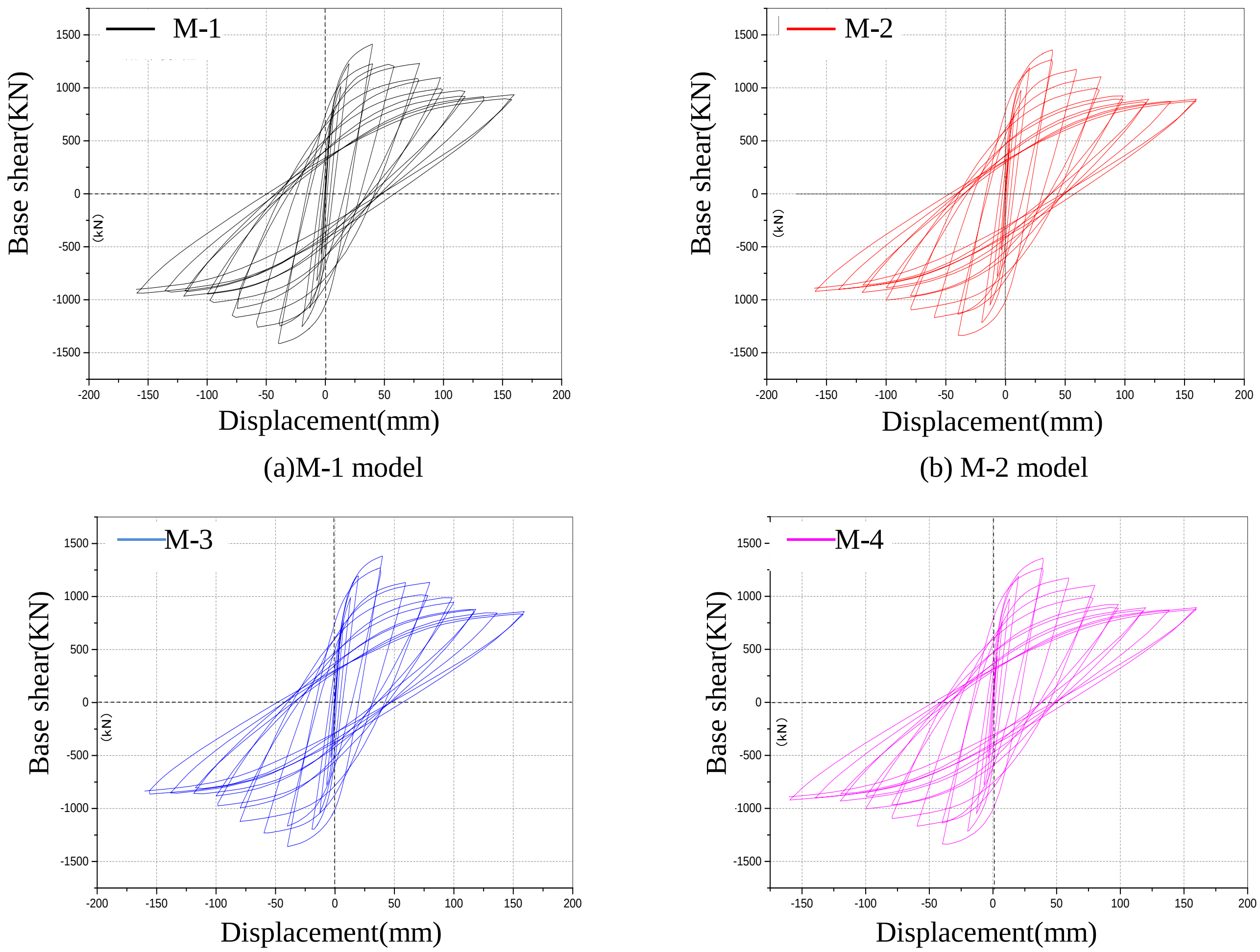
Loading direction	characteristic displacement	M-1 (unit:mm)	M-2 (unit:mm)	M-3 (unit:mm)	M-4 (unit:mm)
positive direction	Δ_{max}	39.89	39.05	39.8	38.2
	Δ_u	92.02	83.92	84.17	83.69
	Δ_y	14.34	13.61	13.01	13.36
	μ	6.42	6.17	6.47	6.26
reverse direction	Δ_{max}	38.25	39.88	40	39.1
	Δ_u	80.69	85.25	85.24	82.54
	Δ_y	14.10	12.43	14.04	15.26
	μ	5.72	6.86	6.07	5.41
average value	Δ_{max}	39.07	39.47	39.90	38.65
	Δ_u	86.35	84.58	84.70	83.11
	Δ_y	14.22	13.02	13.53	14.31
	μ	6.07	6.51	6.27	5.84

P-Δ hysteresis curves, skeleton curves of each model under the static elastic-plastic analysis are shown in Fig.9 and Fig.10. The following results can be drown:

(1) The stiffness of each model under elastic stage is basically consistent, which showed that the stiffness of the overall structure is not significantly affected by different ways of setting slit.

(2) The peak load of each model is basically consistent, which shows that setting slit on slab had no effect on the peak load of the whole structure.

(3) The decrease stage of each model is slightly different, but the unloading stiffness is same, which shows setting slit on slab has no significant effect on the unloading stiffness of the structure.



(a)M-1 model

(b) M-2 model

(c) M-3 model

(d) M-4 model

Fig.9- Top layer P-Δ hysteretic curve of four models

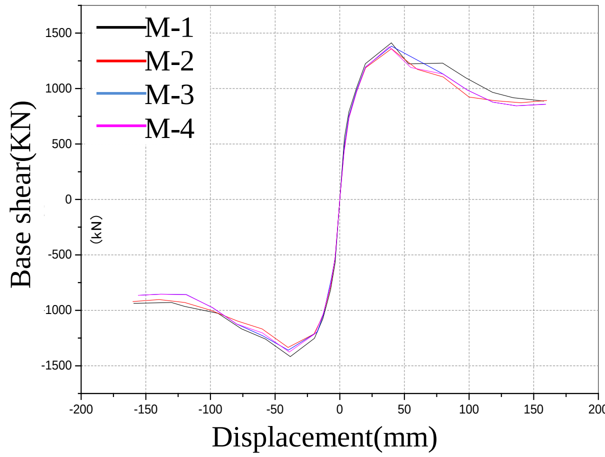
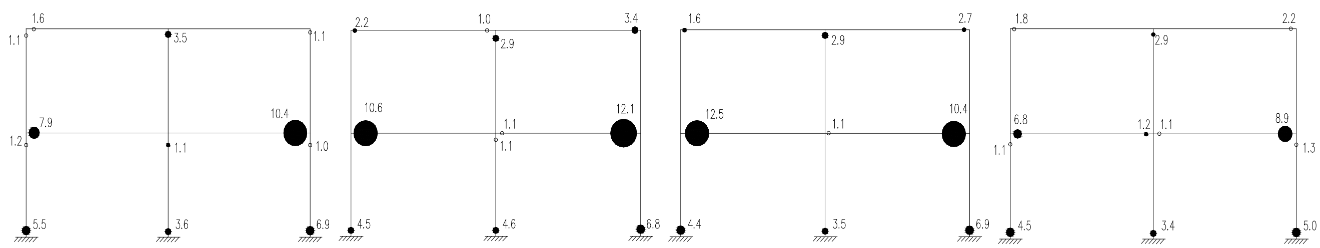


Fig.10-Skeleton curves and hysteresis curve of all models

3.3 Plastic hinges distribution model

The distribution pattern of plastic hinges reflects the position and degree of each structural members into the elastic-plastic stage, thus it can reflect the influence of different ways of setting slit on slab on the seismic performance of the structure. Because in this paper the influence of the torsion effect is not considered, the mid span of the structure bear the main load of the structure, so the distribution of the plastic hinges is mainly discussed on the mid span. Hinges distribution are drawing in Fig.11 according to the rotational degree of the end section of the members and in Fig circle say that member end section has entered a state of yield, hollow circle say one-way yield, a solid circle say bidirectional yield, the number around the circle is curvature ductility coefficient (bidirectional yield labeled absolute value larger).



(a)M-1 model (b) M-2 model (c) M-3 model (d) M-4 model

Fig.11-Plastic hinge distribution pattern of each model

3.3.1Plastic hinges distribution

Because the bottom column is fixed, so the bottoms of column of 4 examples are into the hinge model. The top and bottom column end of mid span of model M-1 are all appearing hinges and may appear layer lateral displacement mechanism, hinges of 3 models with opening floors on slab has a decline in the number and only the top and bottom end of mid column of M-2 model exist the plastic hinge at the same time, is more favorable to prevent layer lateral displacement mechanism, each layer column components in model M-3 do not exist plastic hinges on the upper and the lower ends at the same time, which can effectively prevent the collapse of the structure, while only the top end of the column of mid span of M-4 model do not enter the plastic state, there exist larger layer side shift risk. These results can be drawn from the plastic hinges distribution above, M-2 and M-3 two kind ways of setting slit on slab is more effective to prevent the occurrence of layer side shift mechanism. Compared with M-1, M-2,M-3, and M-4 models with setting slit on slab at the beam end appears more beam hinges, and is closer to expected failure modes "strong column and weak beam"

3.3.2 The hinge rate of beam and column end

The hinge rate (shown in Table 5) is calculated according to the hinge number of beam and column end of the whole space frame and the number of the whole beam and column end ratio. The data shows that: setting slit at the end of the beam with different measures, the hinge rate of the column end decreases from 47.2% to 34.7%~36.1%, the hinge rate of beam end rises from 35.4%e to 60.4%~62.5%.

Table 5- Hinge rate of column and beam under limit low cycle reciprocating loading

frame number		M-1	M-2	M-3	M-4
hinge rate	column	47.20%	34.70%	33.30%	36.10%
	beam	35.40%	62.50%	60.40%	60.40%

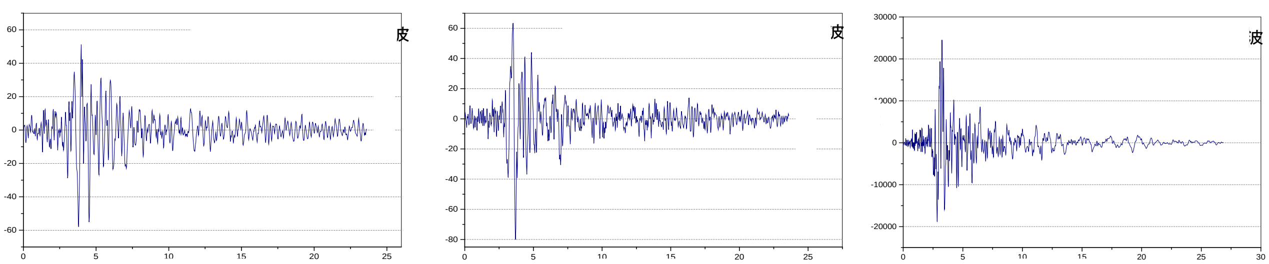
Comprehensive static elastic-plastic analysis shows that measures with setting slit on slab at the end of beams do not significantly affect the bearing capacity reservation and displacement ductility of the structure, but has a certain influence on the column hinge number, beam hinge number, hinge rotation degree of the structure, which M-2 and M-3 model is more conducive to the realization of the failure mode "strong column and weak beam".

4. Dynamic elastic-plastic analysis results

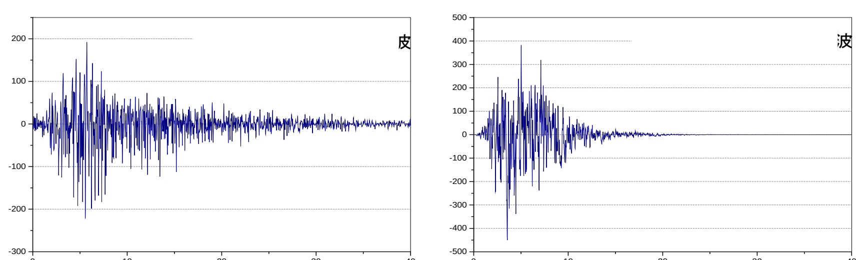
Seismic action is a dynamic procedure, the dynamic elastic plastic analysis can more accurately reflect the true structure dynamic response. 5 seismic waves are selected and then dynamic elastic plastic analysis of four numerical models is carried on and finally the maximum elastic plastic interlayer displacement angle, structural displacement ductility and plastic hinge model of the structure comparatively are analyzed.

4.1 Input selection for dynamic elastic-plastic analysis

Uncertainty of the ground motion input [13] is the most important factors causing structural seismic response randomness, according to Code for seismic design of structures[1] and dual band wave selection requirements [14], four of seismic waves and one man-made wave are selected (acceleration time history curve as shown in Fig.12).



(a)PRC00322 wave (b)PRC00317 wave (c)USA02551 wave



(d)JAP00173 wave (e)ACC1 wave

Fig.12- Seismic acceleration time history curve

Under empirical calculation, the first 10 seconds recording of the above ground motion inputs has included the peak and the main stable time, the maximum inter story displacement angle and maximum vertex displacement response peak of structure's each layer all appeared in the period, so the wave calculation time can be taken the first 10s. In order to simulate the structure into high elastic-plastic stage, the input ground motion peak amplitude is modulated to 4.5m/s^2.

4.2 Structural displacement ductility factor

The overall displacement ductility factor of the structure in the dynamic elastic plastic analysis is defined as:

$$\mu = \Delta u / \Delta y \qquad (1)$$

Δy represents the horizontal displacement of top layer of structure when components first yield, Δu represents the maximum vertex displacement of the whole process. The ductility coefficient μ reflects the deformation capacity of the structure. Table 6 shows that compared with the general framework M-1 model, displacement ductility of the 3 different setting slit model are not the same under different seismic wave input, but the overall trend shows that displacement ductility is better than M-1 model. Through average value the computed ductility coefficient of M-2 model is about 1.8 times the M-1 and average ductility coefficient of M-3 and M-4 model has less difference with M-1model can be better seen, which indicates that setting right angle slit on slab of M-2 model is more favorable to the overall ductility of structure.

Table 6-Overall displacement ductility of structure

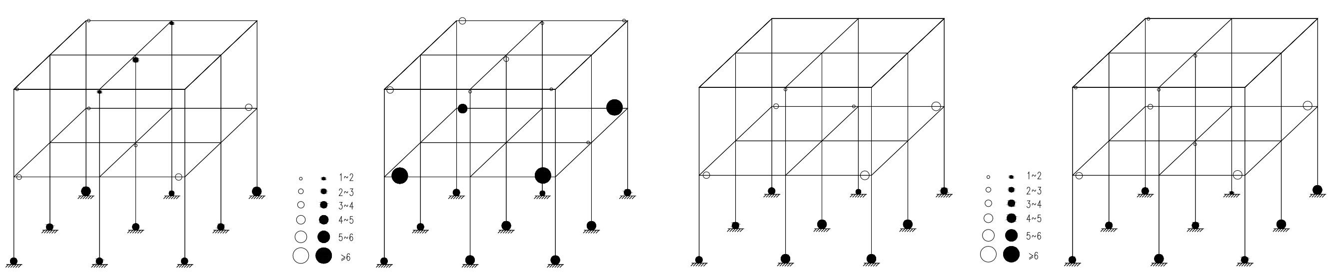
Inputs	M-1	M-2	M-3	M-4
	μ_Δ	μ_Δ	μ_Δ	μ_Δ
PRC00322	6.26	6.70	4.09	4.81
PRC00317	3.23	3.16	4.07	3.18
USA02551	2.08	3.18	1.54	1.42
JAP00173	1.86	3.46	1.28	1.28
ACC1	1.50	5.81	3.42	2.21
average value	2.42	4.33	2.63	2.28

4.3 Plastic hinge distribution model

The plastic hinge distribution is given under the example of seismic wave PRC00322 input, and the analysis of the hinge distribution plastic pattern , the order of the plastic hinge and the failure model are carried on.

4.3.1 Distribution pattern of plastic hinge

The plastic hinge distribution pattern is shown in Fig.13.



(a)M-1 model (b) M-2 model (c)M-3 model (d)M-4 model

Fig.13-Plastic hinge distribution pattern under PRC00322 seismic wave

Comparative analysis of the structure plastic hinge distribution of Fig. 19 shows: after opening floors on slab, the number of column hinges decreased, the development degree of plastic hinge reduces, and the part of the column hinges changes from a bidirectional hinge into a one-way hinge; beam hinge number increases significantly, the development degree of plastic hinge increases, while the original beam end out hinge position plastic rotation increases and part of the beam hinges changes from a one-way hinge into a bidirectional hinge. The M-2 model beam hinges appears more bidirectional beam plastic hinges, part of the column hinge changes from a bidirectional hinges into one-way hinges, has obviously control effect on the structure of the plastic hinge distribution pattern, is more conducive to guide the failure mode of "strong column and weak beam"

4.3.2 Sequence of plastic hinges

Table 7-Time and position of first hinges in each model under seismic action

Inputs	M-1		M-2		M-3		M-4	
	time	position	time	position	time	position	time	position
PRC00322	3.76s	"FL" Z2,Z3,Z5,Z6,Z8,Z9 "B"	2.98s	"FL" L5 "L"	3.62s	"SL" L6 "R"	3.14s	"FL" L2 "R"
PRC00317	3.46s	"FL" Z2,Z8 "B"	3.20s	"FL" L2,L6 "R"	3.44s	"FL" Z2 "B"	3.44s	"FL" Z2,Z8 "B"
USA02551	2.90s	"FL" Z2,Z5,Z8 "B"	2.87s	"FL" L2 "R"	2.92s	"FL" L6 "R" Z5,Z6 "B"	2.93s	"FL" L6 "R",Z2,Z5 "B"
JAP00173	4.62s	"FL" Z2,Z3,Z4,Z5,Z7,Z8 "B"	2.30s	"FL" L2,L6 "R"	4.64s	"FL" L1 "R",L5 "R"	4.66s	"FL" Z7 "B"
ACC1	3.64s	"FL" L2,L6 "R",Z1,Z2,Z4,Z5,Z7, Z8 "B"	2.38s	"FL" L2, L6 "R"	3.58s	"FL" L2, L6 "R"	3.60s	"FL" L2 "R",L6 "R"

Notes: "FL" is for "first floor", "SL" is for "second floor","L" is for "left" , "R" is for "right", "B" is for "bottom".

The dynamic elastic plastic analysis for the first time hinges appearing and position of the hinge is given in Table7, from the data in the table the following conclusions can be drawn: the first time appearing column hinges of general framework model M-1 under earthquake wave input is at the bottom of the column, while M-2 and M-3, M-4 model most first appears beam hinges, among them model M-2 in all 5 seismic waves first appears beam hinges which shows that this kind of measure setting slit is effective to guide the implementation of "strong column and weak beam" failure mode.

4.3.3 Comparison of the hinge rate of structural members

The statistical results of the hinge rate of the beam column member under the input of the PRC00322 wave (seismic wave peak value 4.5m/s^2) is given in Table 8. The results shows that the hinge rate of the column decreased and the hinge rate of the beam of the M-2, M-3 and M-4 models increases under the dynamic elastic plastic analysis.

Table 8- Hinge rate of column and beam under PRC00322 seismic wave

frame number		M-1	M-2	M-3	M-4
hinge rate	column	34.70%	26.40%	26.40%	29.20%
	beam	12.50%	27.10%	12.50%	12.50%

Dynamic elastic-plastic analysis shows that, compared with the general framework M-1model, the measure of setting slit on slab can make the rate of the column hinge reduce, the rate of the beam hinge increase under the earthquake action. M-2 model shows firstly early appearing beam hinge under seismic wave input and under multiple seismic wave input calculation the average displacement ductility coefficient of the overall structure also is bigger than the general framework and other measures, so M-2 model is more conducive to achieve "strong column and weak beam" failure mode for the frame structure.

5. Conclusions

In this paper, the comparative static and dynamic elastic-plastic analysis is used to study on structure measures which are 3 setting slit on slab of two-story space framework model and a general framework model. Influence of different setting slit measures on the seismic performance and failure modes of the overall structure are comparatived. The results are shown as follows:

(1)Structure bearing capacity and stiffness: Static elastic-plastic analysis shows, characteristic loads of four models remained basically same, capacity is basically unchanged. The initial elastic stiffness remained same, unloading stiffness are similar too.

(2)Structural displacement ductility: Static elastic-plastic analysis shows that compared with the general framework M-1, structure ductility coefficient of setting rectangular slit on slab model (model M-2) will be increased to a certain extent. The ductility capacity of the whole structure will also develop.

(3)The plastic hinge model of the structure: Static and dynamic elastic-plastic analysis shows that, the mearsures of setting slit cause the number and the development degree of column hinge reduce, and the number and the development degree of beam hinges increase. M-2 model measure makes beam hinges appear before column hinges, and is the more effective method to achieve "strong column and weak beam" failure mode.

6. Acknowledgements

This research was sponsored by the Natural Science Foundation of China (Project No. 51578093) .

7. References

[1] Code for seismic design of buildings GB50011-2010(2010). Beijing: *China Building Industry Press.*

[2] Ye Lieping, Qu Zhe, Ma Qianli, Lin Xuchuan, Lu Xinzheng, Pan Peng(2008): Study on ensuring the strong column-weak beam mechanism for RC frames based on the damage analysis in the Wenchuan earthquake. *Building structure.*(11),52-69

[3] Wang Wei, Xue Jianyang, Zhang Hongmei, ZhouYing,Xie Qifang1, Li Fangyuan(2009):Seismic design and lessons learnt from the earthquake disaster of frame structures in5.12 Wenchuan earthquake. *World Earthquake Engineering*(4)

[4] Wang Yayong(2008): Lessons learnt from building damages in the Wenchuan earthquake---seismic concept design of buildings. *Journal of Building Structures*.29(4)

[5] Ye Lieping , Ma Qianli , Miao Zhiwei(2012): Study on weak beam-strong column design method of RC frame structures. *Engineering Mechaincs*.12(12)

[6] Wang Suguo, Han Xiao-lei, Ji Jing(2009): The effect of slabs on the failure mode of Reinforced Concrete frame structures. Journal of Civil, *Architectural & Environmental Engineering*.(1).66-71

[7] U.S.-Japan research(1988): Seismic design implications. *Journal of Structural Engineering*, ASCE. 114(9).2000-2016.

[8] Wight B B C J K. Experimental investigation on seismic behavior of eccentric reinforced concrete beam-column-slab connections(2008). *Aci Structural Journal*, 105(2):154-162.

[9] Yang Hong, Zhu Zhenhua, BaiShaoliang.(2011): An evaluation of the effectiveness of the Chinese strong column weak beam measure under b-i directional horizontal seismic excitations. *China Civil Engineering Journal*(1).58-64

[10] Load code for the design of building structuresGB5009-2012,(2012).Beijing: *China building industry press*

[11] Pang Peng(2013) .Tsinghua University

[12] Huang Yuli, Lu Xinzheng,Ye Lieping, Shi Wei.(2011): A pushover analysis algorithm based on multiple point constraints. *Engineering Mechaincs* (2).18-23

[13] Powell G H,Row D G. (1976).Influence of analysis and design assumptions on computed inelastic response of moderately tall frame, Berkeley:University of California,

[14] Yang Pu, Li Yingming, Lai Ming.(2000): A new method for selecting inputting waves for time-history analysis. *China Civil Engineering Journal*, 33(6).