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SIMULATION ANALYSIS OF NON-LINEAR BEHAVIOR OF THE DAMAGED BUILDING IN THE MEXICAN EARTHQUAKE IN SEPT. 19, 1985

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SUMMARY

Two studies are carried out to explore the reason of damaged buildings suffered with Mexico earthquake in 1985. Firstly, the non-linear analysis of a model building designed on trial is carried out in order to investigate the fundamental characteristics of Mexican buildings and the reason of damage pattern. Next, the simulation analysis of the 14 storied actual damaged building, apartment house in TLATELOLCO is performed. The major reason of severe damage of Mexican buildings is the shortage of rigidity and shear bearing capacity and the significant decrease of rigidity in upper stories.

INTRODUCTION

A number of buildings in Mexico city suffered severe damages due to the strong earthquake that occurred in western part of Mexico on September 19, 1985. Damages of the 6-15 storied reinforced concrete buildings are remarkable, and especially, the damages of upper or middle stories of the building are conspicuous, which are not observed in the past earthquakes and difficult to be predicted in Japan.

Therefore in this paper, firstly, the model buildings are designed based on both the Mexican and the Japanese Seismic Design Code in order to investigate the difference of the fundamental characteristics and the damage pattern between the Mexican building and the Japanese one. Next, the simulation analysis of the 14 storied building is carried out in order to confirm the correspondence between the analytical results and actual damage pattern.

ANALYSIS OF MODEL BUILDING

Firstly, 12 storied with three by four spans reinforced concrete buildings are designed based on both the Mexican and the Japanese Seismic Design Code. The scale of building is decided as typical ones of damaged buildings in Mexico city. The structural system of the Mexican model is adopted waffle flat slab system which is popular in Mexico city, while the Japanese model is designed as ordinary beam-column framing system. The structural members of the Mexican model are designed based on ACI standard and those of the Japanese model are designed based on AIJ Standard for structural Calculation of Reinforced Concrete Structure and ACI standard mainly. The design specifications of each model are compared in Table.1. Their framing plans and elevation are shown in Fig.1 and 2.

Analytical Model The structure of each building is idealized by beam-column framing system for the elastic analysis. The foundation is assumed to be fixed as the level of input earthquake basically, and base rocking model is also assumed for the Mexican model.

Rigidity Distribution The absolute value of the rigidity and its normalized distribution ratio for the first story are shown in Fig.3. This figure shows that the rigidity of the Mexican model is quite smaller than that of the Japanese one. The rigidity decreases markedly in upper stories in the Mexican model.

Eigenvalues Natural periods and vibration modes of both models are compared in Fig.4. The first natural period of the Mexican model is two times longer and the mode shape in upper stories is more excitably than that of the Japanese one.

Non-Linear Analysis The static step-by-step non-linear analysis is carried out to trace the behavior of the structural elements and the process from cracking to yielding condition. The damage patterns are shown in Fig.5 and the Q-δ curves of interior frame are shown in Fig.6. The results clarify that the rigidity and shear bearing capacity of the Mexican model are smaller than the Japanese one's. The damages of upper stories are more severe than those of lower stories in the Mexican model. Next, the equivalent simplified spring-mass vibration model is established by making use of the results of the static non-linear analysis. The restoring characteristic is idealized to the degrading tri-linear for the non-linear dynamic analysis. As input ground motion, S.C.T. (NS) wave on the soft soil deposit in Mexico city is adopted with maximum acceleration recorded value of 98.3gal in this analysis. The damping factors are assumed 3% for building and 5% for rocking spring for the fundamental period. Results of non-linear dynamic analysis are shown in Fig.7. The results indicate that the maximum response value in the Mexican model is quite larger than the Japanese one and the story drift and ductility ratio from middle to upper stories of the Mexican model is larger than other stories. The damage pattern in this analysis is similar to the actual damage pattern so well.

P-δ effect The story drifts of the Mexican building are too large to disregard the P-δ effect. In consideration of the P-δ effect in dynamic non-linear analysis, the story drifts increase and shear bearing capacity decreases evidently, as shown in Fig. 8.

ANALYSIS OF ACTUAL DAMAGED BUILDING

Based on the field survey and the provided drawings, non-linear dynamic analysis is performed to simulate the damaged building of the type-C apartment house in TLATELOLCO. The framing plan and elevation are shown in Fig.9 and 10. The structural system in this building is waffle flat slab and infill masonry wall. This building consists of 3 units which are connected with expansion joints and each unit has 14 stories with nine by four spans as shown in Fig.11. The damage patterns of this building are shown in photo 1 and 2. Some of buildings are broken down and others are still stand, even though severe damages are occurred in structural members in every building. The pattern and the extent of damage change by every building or unit. The simulation analysis is performed to trace the non-linear behavior of these actual damaged buildings and investigated the reason of inequality in the pattern and the extent of damage.

Rigidity Distribution The absolute value of the rigidity and its normalized distirbution ratio for the first story are shown in Fig.12. The decrease of rigidity in upper stories are remarkable in the Y (transverse) direction.

Eigenvalues Results of the eigen value analysis are shown in Fig. 13. The first natural periods are 0.94sec in the X direction and 1.15sec in the Y direction.

Non-Linear Analysis The damage patterns and the Q-δ curve of X1 and X4 frame at the static step-by-step analysis are shown in Fig.14 and 15. The damages of the inner columns at every braced frame are severe in every story. Next, equivalent simplified vibration model is established in the same way as the previous study for the model building. In this analysis base-fixed model is adopted, because the rocking effect is not so significant in non-linear behavior at the model analysis. In this dynamic non-linear analysis, the skeleton curves are assumed two cases. The skeleton curves in case A are decided based on non-linear static step-by-step analysis, and in case B, the post-yielding rigidities are 10% larger than those of case A. The input earthquake and the maximum acceleration are assumed to be same as the previous study. The damping factor is assumed 3%. Results of this analysis are shown in Fig.16. Response values of upper stories in case B are larger than those of case A, and the response property corresponds to the actual damage of building. And in case A, the story drifts and the ductility ratios in lower quarter stories become larger than those of case B remarkably, therefore the story drifts increase and shear capacities decrease by the P-δ effect in lower stories. This damage pattern is similar to the collapsed building, which suggests that one of the reasons of the inequality of the building damage is due to the difference of the post-yielding rigidity (ductility of each element). First natural period of the damaged building is estimated to be 1.8sec for the Y-direction in this analysis, and this value corresponds to the predominant period, 1.65sec which is measured at the observation of microtremor in this building.

CONCLUSION

The analytical results explain the actual damage pattern of the reinforced concrete building in Mexico city successfully. Major reason of the severe damage of the Mexican buildings is the weakness of the story rigidity and the shortage of shear bearing capacity. The large story drifts are occurred because of the weakness of the rigidity, and P-δ effect increase the damage of the buildings. And the damage of upper stories is extended due to the significant decrease of the rigidity in upper stories.

Therefore in order to prevent such kind of damage, well balanced rigidity distribution will be important, especially the brick walls should be used effectively to control the story drift. And hoops should be set well to make increase the ductility of structural elements.

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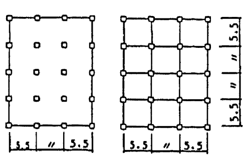
Table 1 Design Specification

			Mexico	Japan
Design Load (ton/m²)	Design of Beam·Column	Inner Column	1.40	1.07
		Outer Column	1.55	
	Seismic Design		1.30	
Concrete Strength (kg/cm²)			240	300 (7-12F) 330 (1- 6F)
Steel Bar Strength (kg/cm²)			4200 (#60 BAR)	4000 (SD 40)
Base Shear Coefficient			0.06	0.2

UNIT:m



(a) Mexico (b) Japan

Fig. 1 Framing Plan

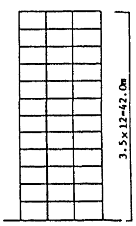


Fig. 2 Elevation

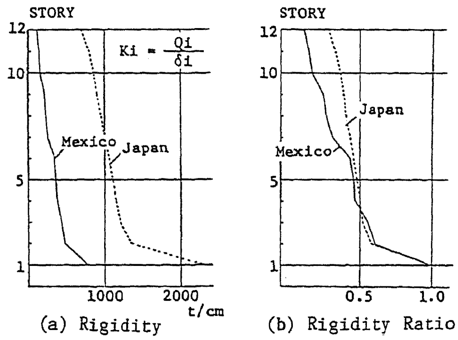


Fig. 3 Rigidity Distribution

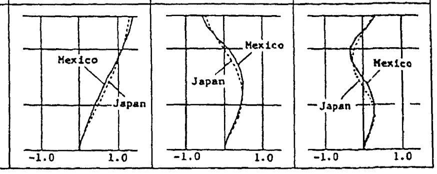
Period(sec)		1st	2nd	3rd
Mexico	Fixed	1.73	0.64	0.38
	Rocking	2.02	0.64	0.39
Japan		0.92	0.31	0.20
Mode Shape				

Fig. 4 Natural Period And Vibration Mode (Transverse Direction)

o CRACK
• YIELD

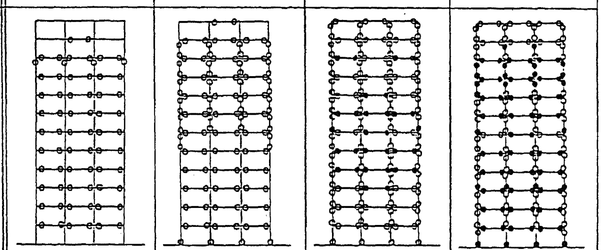
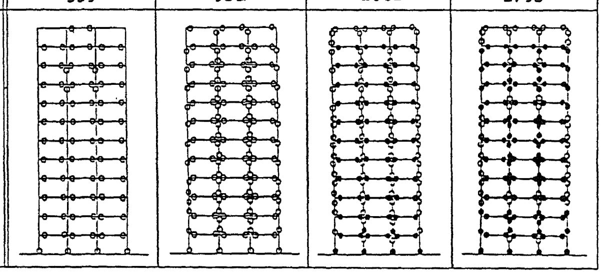
	STAGE	1	2	3	4
	CONDITION	COLUMN FIRST CRACK	DESIGN SHEAR	COLUMN FIRST YIELD	LAST STEP
MEXICO	BASE SHEAR (ton)	238	340	510	1020
	DAMAGE				
JAPAN	BASE SHEAR (ton)	559	931	2002	2793
	DAMAGE				

Fig. 5 Progressing of Cracking And Yielding of Interior Frame in Typical Stage

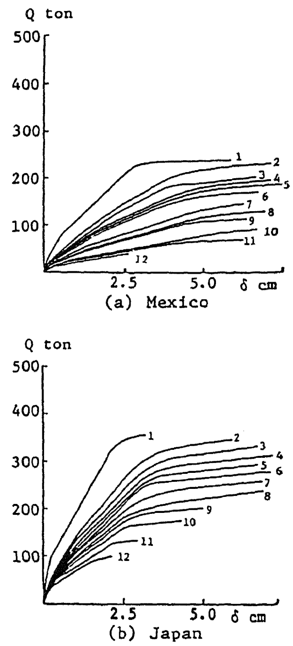


Fig. 6 Q-δ Curve of Interior Frame

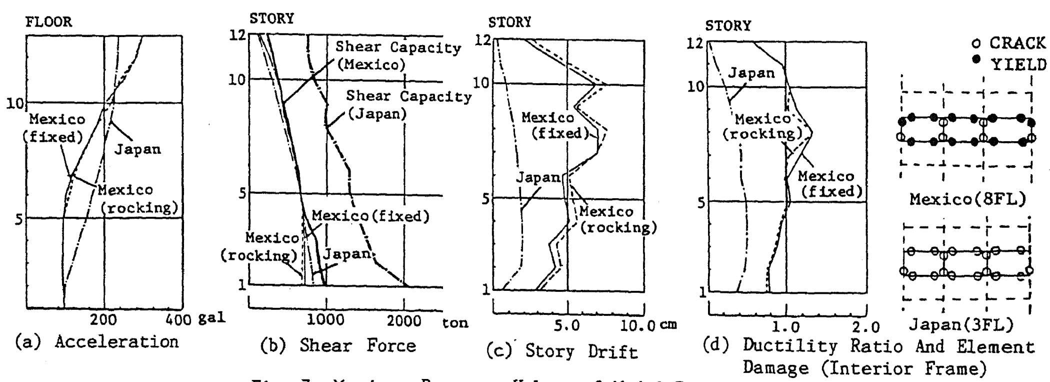
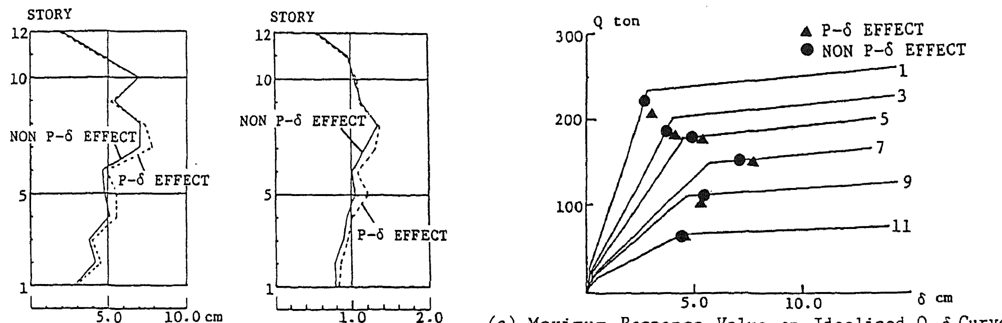


Fig. 7 Maximum Response Values of Model Building



(a) Story Drift (b) Ductility Ratio (Interior Frame) (c) Maximum Response Value on Idealized Q-δ Curve (Interior Frame)

Fig. 8 P-δ Effect

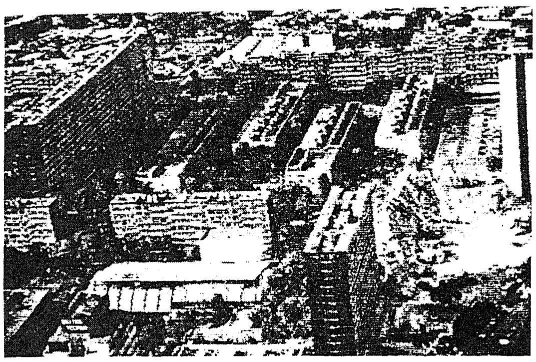


Photo 1 Overall View of TLATELOLCO

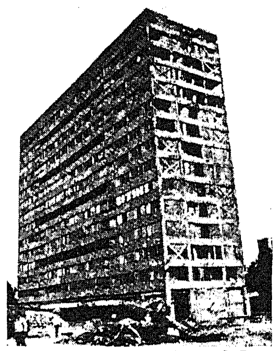
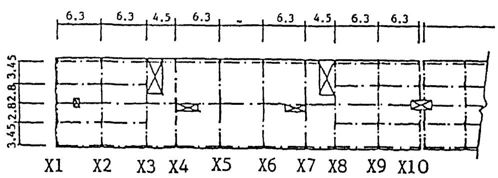
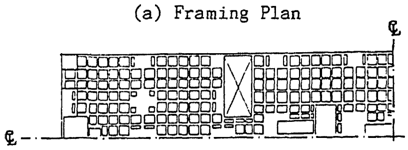


Photo 2 Damage of Type C Building



(a) Framing Plan



(b) Waffle Flat Slab (Part of)

Fig. 9 Plan of Actual Damaged Building

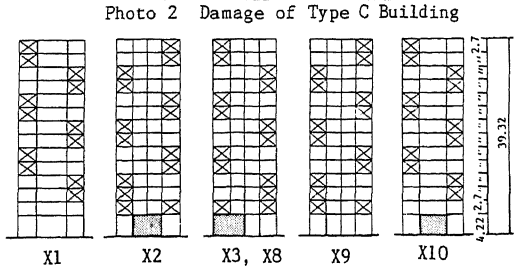


Fig. 10 Elevation

UNIT:m

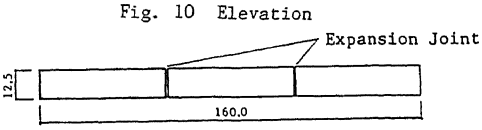
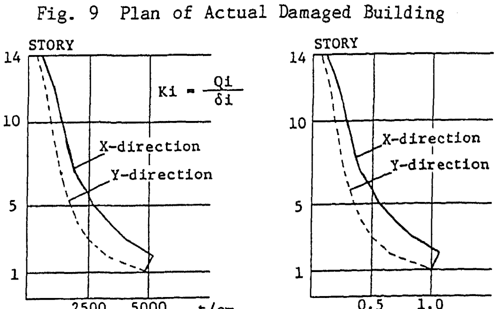


Fig. 11 Building Unit



(a) Rigidity (b) Rigidity Ratio

Fig. 12 Rigidity Distribution

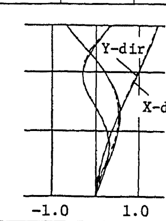
Period (sec)	1st	2nd	3rd
X-dir.	0.94	0.28	0.14
Y-dir.	1.15	0.34	0.17
Mode Shape			

Fig. 13 Natural Period And Vibration Mode (Y Direction)

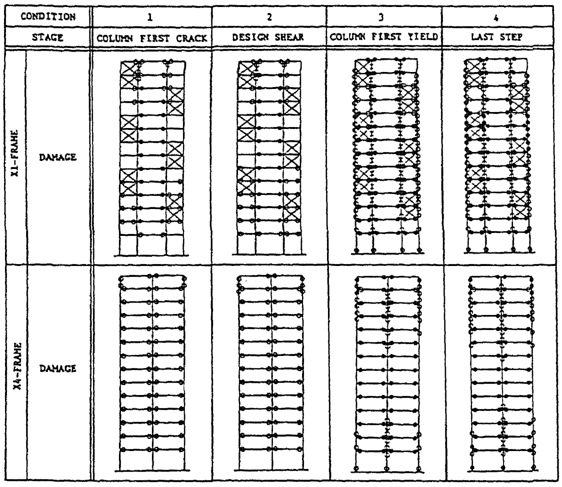


Fig. 14 Progressing of Cracking and Yielding in Typical Stage

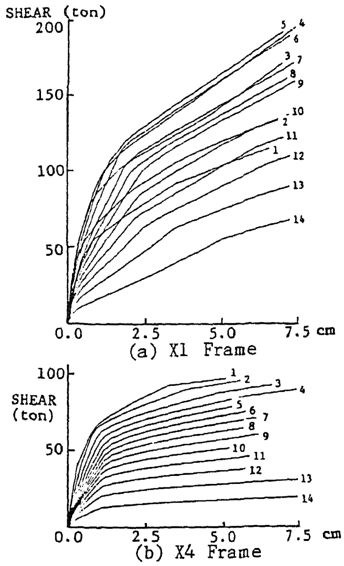


Fig. 15 Q-δ Curve

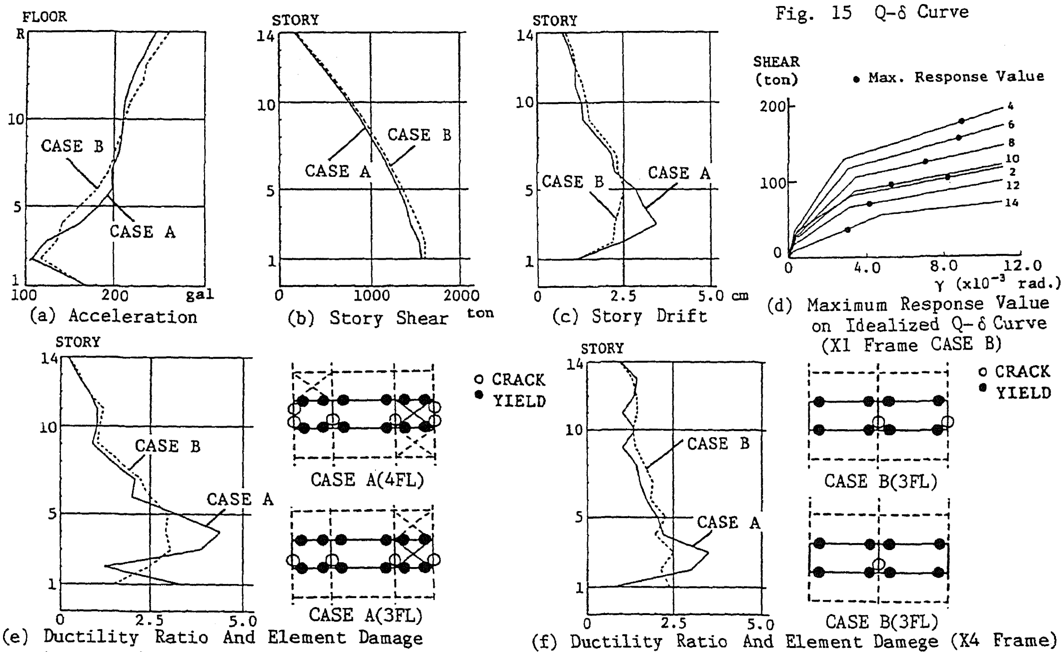


Fig. 16 Maximum Response Values of Actual Building

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