CYCLIC BEHAVIOR OF REINFORCED CONCRETE COLUMNS IN THAILAND

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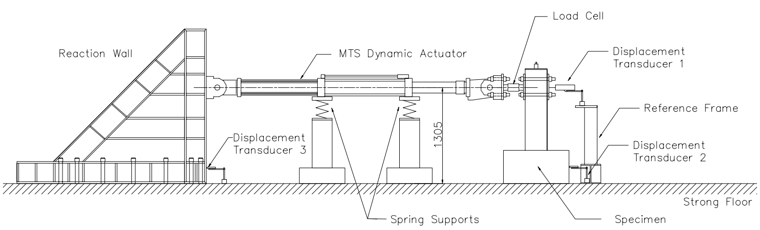
1. INTRODUCTION

Thailand has been long thought to be the country without the seismic hazard. However, recently conducted researches have revealed that the country is at a higher risk than one ever expected. From the probabilistic seismic risk map[1], it is shown that the northern and western parts of Thailand are in the moderate and moderately high risk zones, respectively. Moreover, the study indicates that Bangkok, the capital city, and the vicinity area can also suffer from the long-distance earthquake through the ‘wave trap mechanism’[2]. Due to the lack of awareness, very few buildings have been designed against the earthquake motion. Therefore, the performance against earthquake motion of these buildings is still doubtful. One way to mitigate the possible damage is to carry out the seismic evaluation so that the buildings can be retrofitted in case of not sufficient capacity. However, to carry out such a reliable evaluation, it usually requires a large amount of the database from experimental results especially the ones based on a designs and construction practices and material in the country.

This study is focused on the reinforced concrete columns in typical mid-rise frame buildings. These columns usually contain the lap splice of longitudinal reinforcement at the location just above the floor slab and a small amount transverse reinforcement satisfying the minimum requirement stipulated in the practical design code. This detailing is not satisfied with the modern seismic design principles as it can lead to brittle behavior and initiate the weak point to the overall structure. Lastly, this study also aims to introduce some structural modification to improve the seismic performance of columns.

2. INVESTIGATION OF TYPICAL DESIGN OF COLUMN IN MID-RISE BUILDINGS IN THAILAND

To ensure that the specimens will represent the typical behavior of the columns in mid-rise building in Thailand, the ‘structural index’ was introduced. A structural index was defined as the parameter that represents the behavior of the member of structure under the seismic action. An index of each member is calculated from the design configurations, for example, sectional dimension, total area of the longitudinal reinforcement of concrete and etc. The indices were calculated and collected based on the columns in many architectural and structural drawings of mid-rise reinforced concrete frame buildings in Thailand. Finally, mean values and the typical ranges of these indices were carried out as a database for designing the specimen. The structure indices used in this study are shear span ratio (a/h), normalized nominal flexural-to-shear strength ratio (M_n/aV_n), axial force ratio (P/f'_c), Longitudinal reinforcing index (ρ_l), transverse steel index ($\rho_s \sqrt{b''/s}$).



3. TEST PROGRAM

In this study, the cantilever columns were tested using quasi-static cyclic loading testing method. One end of the test column is fixed to a concrete block (base), where the deformation is negligible. This end represents the end of a column that attached to the joint. The other end, which is free to rotate in the direction of applied load, represents the position of the inflection point. The overall experimental setup is shown in Fig.1.

Test results using four column specimens are shown in the paper. The first three specimens were designed to represent the column in the low, middle and high zones in the mid-rise buildings (referred later as CLZ, CMZ and CHZ, respectively) by designing each specimen to have structural indices within the range of mean ± 1 standard deviation based on the database specified in section 2. All of them have lap splice in longitudinal reinforcement at the lowest zone of column. Based on these three specimen test results, the last specimen is modified from the low zone column specimen using the Capacity design method[3] to improve the behavior by increasing an amount of transverse reinforcement and removing the lap splice. The detail of each specimen is shown in Table 1.

4. TEST RESULTS

Specimen R1, representing CLZ, was expected to fail with the brittle shear failure mode. From the experiment, the first flexural crack was observed at just above the lap splice zone (350 mm from the base). After some cycles (drift~1.4%),

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Table 1 Detailing, structural index and test results of the column specimens (Unit: kN, mm)

Specimen	Reinforcement Detailng			Structural Index					Test Result	
	Long.	Tran.	Splice length	a/h	M_n/aV_n	$P/A_g f_c'$	ρ_t	$\rho_s\sqrt{b''/s}$	Max Load	Type of Failure
R1	24DB12	RB3@100	350	2.87	1.05	0.3	0.05	0.004	119	Diagonal shear
R2	20DB12	RB3@100	350	2.87	0.94	0.2	0.04	0.004	116	Diagonal shear
R3	10DB12	RB3@100	350	2.87	0.66	0.1	0.02	0.004	94	Lap splice failure
M4	24DB12	RB5@50	No splice	2.87	0.44	0.3	0.05	0.031	165	Flexural failure

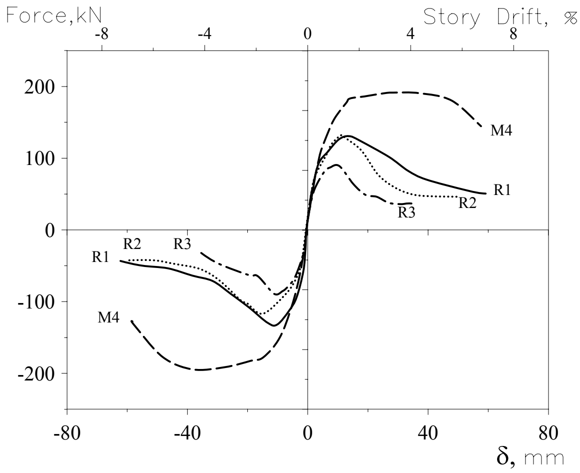

Fig. 2 Hysteretic envelope of force-displacement relationship

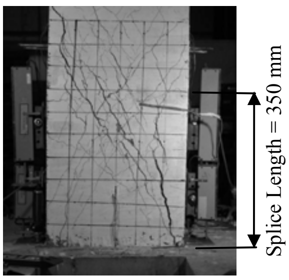

Fig. 3 Diagonal crack in specimen R1

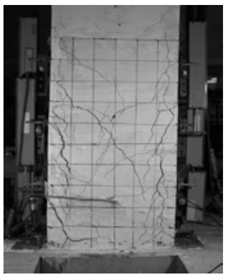

Fig. 4 Splitting crack in specimen R3

diagonal cracks were observed throughout the entire column (Fig. 3). A strain gage attached on transverse reinforcement also showed the yielding at this cycle. Simultaneously, the force-displacement relationship showed suddenly drop in the later cycles. Moreover, pinching was also clearly observed after this cycle and dissipated energy in each internal loop was very low. The above results indicated that excessive shear force was the main cause of this failure.

Specimen R2 (represent CMZ) behaved in the same way as R1. The first crack was observed just above lap splice, then diagonal cracks appeared and strength dropped. It was also noticed that some splitting cracks occurred at the peak resistance load (drift~1.4%).

Specimen R3 (represent CHZ) was expected to fail by diagonal shear failure after the yielding of longitudinal reinforcement. From the test result, specimen R3 showed flexural behavior in the first range of the test, however tensile splitting cracks were found in the subsequent cyclic before peak resistance load was reached (drift~1.1%, Fig. 4). The splitting cracks were widened after this cycle and dominated the behavior of the column specimen. Although, the diagonal cracks were also observed, they were closed after the splitting crack appeared. Therefore, it was concluded that the tensile splitting crack was the main cause of failure in this specimen.

Specimen M4, the modified specimen, was expected to have a flexural failure and ductile behavior. From the crack observation, it was shown that flexural behavior was dominated. The force-displacement relationship indicated that the resistance force can be sustained until the drift of 3.8% and also there was the better energy dissipation in each internal loop. The main cause of failure for this specimen was the reduction in the bond strength between concrete and reinforcement in the confined area of the column.

5. CONCLUSION

Test results showed all specimens, representing the existing columns in the mid-rise building in Thailand, possessed the brittle behavior. The specimen, representing the column in the low zone of building, showed diagonal failure while the other, representing the column in the high zone showed lap splice failure. Moreover, lap splice in plastic hinge zone can lead to the crack at the ends of splice, which possibly lead to a reduction of the lateral resistance. Lastly, the test result of the modified column indicated that the ductile behavior could be achieved if the amount transverse reinforcement and detailing are designed properly.

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