SUMMARY AND CONCLUSIONS

Summary

Based on the experimental studies and analytical studies in this research, the summaries of studies are as follow:

Experimental Study

Test specimens were constructed by scaling down highway bridge piers. All specimens had the same dimension of 400 mm × 400 mm and effective height of 1550 mm. The longitudinal reinforcement consisted of 13 mm diameter deform bars with yield strength of 390 MPa. Tie reinforcement is of 6 mm diameter round bars with yield strength of 245. The concrete strength is in the range from 29.61 to 32.36 MPa. The tests were conducted at Kawashima laboratory of Department of civil engineering, Tokyo institute of technology.

Two parameters were studied; 1) concentric loading and eccentric loading of constant axial load with eccentricity, e/h = 0.15 2) the amount of lateral reinforcement was varied to investigate its confining effect on strength and ductility. Tie reinforcement ratios percent of specimens, ρ_s = 0.09, 0.19 and 0.37 percent. These ratios were designed based on AASHTO with non-seismic performance (specimens C1 and D1) and corresponding to 25% of the minimum total cross-section area of rectangular hoops based on AASHTO with seismic performance for zone 3 for specimens A1, A2, B1, and B2.

Each specimen was subjected to the constant axial load approximately $0.074f'_cA_g$ to $0.085f'_cA_g$ and the cyclic lateral load. The cyclic loading history was controlled by applying the lateral load to produce a step-wise displacement starting from 0.5% drift ratio and increasing the cycle of displacement with an increment of 0.5% drift ratio until final failure.

The behaviour of six bridge pier column models with different amount and arrangement of tie bars subjected to constant axial load and cyclic lateral load was studied. The cyclic loading tests and verification by fiber element analysis were conducted. The test results show the lateral force and displacement at yield, maximum lateral force and maximum displacement and the dissipation energy of the specimens. Based on Nadim, I. et. al. (1999), the maximum displacement (Δ_u) was determined when the lateral force was unloaded to 75% of maximum lateral force. When the compressive stress in core concrete on the descending branch was beyond 50% of the core concrete peak stress, crushing of core concrete and buckling of longitudinal reinforcement occurred. The column failure and Δ_u was defined when the stress of core concrete on the descending branch reached 50% of peak stress. The axial strain at 50% of f'_{cc} was used to observe Δ_u of the specimens in the experiments. For each specimen, the lateral strain in concrete core at failure is the axial strain times the Poisson ratio of 0.2. This is also the strain in the tie bars and the drift ratios can be recorded. The measure ductility factor of specimens A1, A2, B1, B2 C1, and D1 were 6, 4.2, 7.6, 5.3, 2.7 and 3.7 respectively. The fiber element inelastic analyses using computer program TDAP3 were conducted and compared with the experiment results. It can be observed that the analytical behaviour is in reasonable agreement with experimental results.

It can be found that increasing the amount of tie bars does not affect the maximum lateral load force and the yield lateral force. Increasing the amount of tie bars increases the maximum deflection and dissipation energy of the specimens. The provided cross tie significantly prevents the crushing of core concrete. The dissipation energy of specimens subjected to eccentric axial loads is not significantly different from those specimens when the axial loads were concentric. Finally, the criterion of limiting lateral strain in inner core gave satisfactory estimate of the column deflection.

Analytical Study

The analytical study on forty-two specimens simulated as cantilever bridge piers were analyzed to investigate the strength and ductility of the columns. The specimens were subjected to constant axial load and cyclic lateral load applied at the top of the columns by controlling the displacement step wisely started from 1% drift ratio until failure with an increment of 0.5% drift ratio. The number of reloading and unloading was 3 cycles in each increment step. Hysteretic behaviour responses were analyzed by TDAP3 program. The plastic hinge length of reinforced concrete members are calculated based on Paulay and Priestley (1992). For inelastic material behaviour, the stress vs. strain model of confined concrete was idealized based on Hoshikuma et al. (1997) and the stress vs. strain model of vertical reinforcement was idealized based on Menegoto and Pinto (1973). The same cross section is 400 mm × 400 mm and the compressive strength is 28 MPa. The yield strength of all reinforcement was 395 MPa (SD40 grade). The concrete strength was 28 MPa. All specimens had the same dimension of 400 mm × 400 mm. The parameters were investigated following; a) Tie reinforcement ratio, $(\rho_s, A_{sh}/sh_c)$ are 0.19%, 0.37% and 0.56%, b) Shear span ratio (l/h) 2.5, 3.5 and 4.5, c) Axial load are $0.05f'_cA_g$, $0.12f'_cA_g$ and 0.and eccentricity of e/h = 0.2 $2f'_cA_g$ with eccentricity, e/h of 0.2 , 0.3 and 0.4 and d) The vertical reinforcement ratios were 1.13 and 2.01 percent.

The results show the comparison of the drift ratio at yield and at failure, ductility and maximum moment and stress-strain behaviour of core concrete.

It was found that rectangular reinforced concrete columns with confined steel at approximately 50 % of the minimum amount required by seismic provisions may exhibit moderate ductility raging between 4 and 7 based on Wehbe et al. (1992).

Conclusions

For Thailand, bridges in the western and northern part of Thailand are located in moderate seismicity with peak ground acceleration between 0.15g and 0.225g must be considered for the amount of confinement steel provided for having ductility capacity.

Based on the experimental and analytical studies at reinforced concrete columns subjected to low axial loads ranging between $0.05f'_cA_g$ and $0.2f'_cA_g$ the conclusions as follow:

1. Tie reinforcement amount required by the AASHTO non-seismic may exhibit low ductility ranging between 1and 3.
2. To prevent the shear failure and premature bar buckling, tie reinforcement ratio at 0.40 percent, which corresponds, to approximately 50 percent of the minimum amount required by the AASHTO seismic provisions, exhibit moderate ductility being 4 for the columns with axial force level less than $0.12f_c'/A_g$. For increasing axial force level to be $0.2f_c'/A_g$, tie reinforcement ratio must be increased to 0.6 percent to obtain the ductility ratio being 3.
3. Within the range of parameter included in this research, the calculated ultimate displacement based on stress vs. strain model of core concrete proposed by Hoshikuma et al., (1997) was in reasonable agreement with experimental results.
4. When the eccentric loading applied approximately with *e/h* more than 0.2, the ductility factor was decreased rapidly.
5. For the specimens tested, increasing the amount of tie bars does not affect the maximum lateral load force and the yield lateral force whiles increasing the amount of tie bars increases ductility and dissipation energy of the specimens. The cross tie bars tend to enhance the ductility and dissipation energy and can reduce the tendency of outward exposing of tie bars and preventing crushing of core concrete. However, when there is tendency that longitudinal reinforcement will buckle between tie reinforcements (specimen C1); providing cross ties may be effective in increasing the strength and ductility of columns.

Recommendations

1. Tie reinforcement ratio, ρ_s required by the AASHTO non-seismic is not adequate for column bridge piers in Thailand which is located in the moderate seismic zone.
2. For low axial force level ranging $0.05f_c'/A_g$ to $0.2f_c'/A_g$, the minimum requirement of tie reinforcement ratio, ρ_s should be ranging 0.4 to 0.6 percent of the minimum amount required by the AASHTO seismic provisions.
3. Cross tie reinforcement must be provided adequately for enhance the seismic performance.

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