Analytic Research for Seismic Performance for Reinforced Concrete Bridge Piers

철근콘크리트 교각의 내진거동에 관한 해석적 연구

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1. INTRODUCTION

Bridge structures are important links in the transportation system. In the event of an earthquake, it is that the integrity of the highway system be protected. Even after a very strong earthquake, it is desirable that the highway systems continue to function without disruption, as it is essential to provide lifeline linkages to hospitals, fire stations, civil defense centers, etc. In this research, therefore, the seismic behaviors of R.C piers have been evaluated through the lateral force-displacement response and curvature, strength and stiffness degradation, energy absorption capacity and equivalent viscous damping ratio, ductility, etc.

2. EXPERIMENTAL RESEARCH

The lateral force-displacement response provides in the general characteristics of hysteretic behavior of R.C pier. The cumulative curvature shows change of the flexural capacity with fluctuation of axial force. The strength and stiffness degradation shows magnitude of Baushinger and Pinching effect in the plastic hinge region. The energy absorption and equivalent viscous damping ratio show dissipation capacity on the external energy. The ductility shows resistance capacity up to the failure state on the yield state.

For these research, test specimens had been made in circular solid and hollow R.C column, being 1 to 3.4 scaled section of R.C circular pier of Hagal bridge which had been seismically designed in accordance with major provisions of seismic resistance in Korea. The details of experiment procedure and test research were shown in reference 1. Table 2.1 and Figure 2.1 are shown displacement ductility factor of all test specimen, lateral force-displacement diagram, respectively.

3. ANALYTICAL RESEARCH

This section presents the analytical theorem of the experimental results of the column tests presented in section 2. The specimens were taken as replicas of the bridge columns of the 1/3.4 scale model.

Preliminary objects of this research are as follows :

① Introduction of a reliable mathematical model of reinforced concrete bridge piers.
② Generation of lateral force displacement diagrams using the program IARCC(Inelastic Analysis of Reinforcement Concrete Columns)
③ Comparison of experimental and analytical results
④ Acquisition of analytical strength and stiffness degradation factor.
⑤ To compute the general equation of strength and stiffness degradation factor.

These results could be used in evaluate seismic performance of pre-constructed reinforced concrete piers. This general expression is helpful for evaluate the safety and serviceability of reinforced concrete bridge piers under seismic loading. The general equation is expressed with the parameter, which is considered the most influence factor of hysteretic behavior such as axial force, longitudinal steel ratio, and confinement steel ratio.

3.1 Introduction of Mathematical Model

The accurate prediction of the nonlinear behavior of reinforced concrete structure subjected to seismic

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loading requires a reliable mathematical model of reinforced concrete frame members. Based on this experimental evidence, numerous mathematical models have been proposed to simulate the hysteretic member response to cyclic loading.

In this research, the model of Roufaiel and Meyer[5] is presented, together with various enhancements. This model takes into account the finite size of the plastic regions and considers the effects of stiffness degradation, strength deterioration, shear and axial forces. This model leads to analytical response predictions, which compare very well with experimental results and therefore can be considered to be better suited for seismic response calculations than other, previously proposed models.

3.2 Material Constitutive Laws and Moment-Curvature Relationship

It is well known that concrete and reinforcing steel exhibit different behavior in tension and compression. The concrete tensile strength can be ignored under seismic loading, because most of it is lost due to cracks caused by service loads. Many researchers have idealized the stress-strain curve for plain concrete and reinforcing steel. Herein, Roufaiel and Meyers[5] refined curve has been adopted idealized stress-strain curve of concrete with some minor modification.

Stress-strain curves of steel bars used in reinforced concrete construction are typically idealized as bilinear curves. These curve for steel in compression is similar to that in tension, provided buckling is prevented. In the light of this restriction it is very rare that steel bars in compression enter the strain hardening range. In reinforced concrete members, compression bars are restrained against buckling, as long as the concrete cover has not spalled off. The accurate determination of the buckling stress is very difficult. Herein, it is assumed that the bars cannot buckle before they are strained to the point at which the concrete cover spalls off. Also, analytical primary moment-curvature relationship will be derived for a section, which includes a new definition of failure. Among the various possible failure modes, also that of buckling of the compression reinforcement is included.

The primary moment-curvature curve relates moments to curvatures for monotonic loading. It can be idealized by three linear branches, one for the elastic loading part, one for the inelastic (strain hardening), loading part, and one for the unloading part. The details of material constitutive law and primary moment-curvature relationship are described in NCEER-87-0022 technical report.

3.3 Hysteretic Behavior of Reinforced Concrete

A number of models have been proposed in the past to represent the hysteretic behavior of RC members. In a Takeda-type model, a set of rules is specified, with which it is possible to characterize the hysteretic behavior more realistically than that with either a bilinear or degrading bilinear formulation. The model of Roufaiel and Meyer[5] utilizes such a set of rules and therefore has been adopted herein, together with certain improvements to better represent stiffness and strength degradation. It is characterized by five different kinds of branches as elastic loading and unloading, inelastic loading, inelastic unloading, inelastic reloading during closing of cracks, inelastic reloading after closing of cracks. The details of model feature shown in Fig. 3.1.

Also, the effect of shear has been investigated in this research. The coordinates of the crack-closing point(ϕ_p^+, M_p^+) can then be expressed as :

$$M_p^+ = \alpha_p M_n^+, \qquad \phi_p^+ = \alpha_p \, \phi_n^+$$

where

$$\alpha_p = \begin{cases} 0 & \text{if} \quad \frac{a}{d} \le 1.5 \\ 0.4\frac{a}{d} - 0.6 & \text{if} \quad 1.5 < \frac{a}{d} \le 4.0 \\ 1 & \text{if} \quad \frac{a}{d} > 4.0 \end{cases} \qquad \frac{a}{d}: \text{shear span ratio}$$

Above described pinching factor, α_p, is fitted for the Highway Bridge Standard Specification.

In addition to stiffness degradation, RC members experience strength deterioration under cyclic loading beyond the yield level. The rate of strength deterioration and the failure curvature depend on many factors, such as the confinement ratio, axial force, concrete strength etc. It is, therefore, suggested that strength deterioration be initiated as soon as the yield load level is exceeded, and the strength deterioration accelerates as the critical load level is reached. For this purpose, a strength drop index is proposed which defines the strength drop to be expected for a given curvature, in a single load cycle(Fig 3.2). The strength drop amount, ΔM denotes in the first subsequent load cycle for some curvature ϕ, as:

$$\Delta M = [(\phi - \phi_y)p(EI)_e + M_y - M_f]\left(\frac{\phi - \phi_y}{\phi_f - \phi_y}\right)^{\omega}$$

On the basis of selected experimental data, a value for strength deterioration factor, ω appears variable from 1 to 8.

The primary objective of this research is to predict of seismic performance for reinforced concrete bridge piers. For this purpose, the program IARCC was generated. The program IARCC consists of a main program that uses a series of subprograms to perform the detailed calculations. In this research, The Scribner's experimental data[4] and the experimental result[1] are computed by program IARCC. The test parameters such as axial force, longitudinal steel area, confinement steel area, reinforcement steel and concrete characteristics were prepared for program IARCC. And then, the suitable stiffness and strength deterioration factor are found by trial-and-error method.

The general equations of stiffness and strength deterioration are obtained as following by multi regression analysis with Scribner's test results and experimental test results.

$$\omega = 2.88 + 1.94\left(\frac{P}{A_g f_c'}\right) - 29.53\rho - 29.62\rho_s \qquad \alpha = 0.81 - 0.03\left(\frac{P}{A_g f_c'}\right) + 1.10\rho - 22.39\rho_s$$

where, A_g = area of concrete, f_c'= strength of concrete, ρ= longitudinal steel ratio, and ρ_s= confinement steel ratio. This general equation is helpful for evaluate the safety and serviceability of reinforced concrete bridge piers which is expressed with the parameter, which is considered the most influence factor of hysteretic behavior such as axial force, longitudinal steel ratio, and confinement steel ratio.

The experimental and theoretical force-displacement result is presented in Figure 3.3.

4. CONCLUSION

A reasonable analytical prediction of the hysteretic behavior of the column specimens was accomplished. The maximum lateral displacement as well as main hysteretic characteristics were successfully predicted. The summary of this research are as follows :

1) Development of Program IARCC:
2) Development of Stiffness and Strength Deterioration Factor according to main parameter:
3) The verification of general equation is successfully executed as similar strength and stiffness deterioration and equal displacement ductility factor.

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Table 2.1 Displacement Ductility Factor

Specimen	Ultimate State		Failure State		μ
	Strength (kN)	Displ. (mm)	Strength (kN)	Displ. (mm)	
CS1P1L1	185.20	66.54	-	-	7
CS1P2L1	183.80	63.34	135.55	88.75	7
CS1P2L2	167.70	64.80	117.35	77.63	6
CS2P1L1	168.28	53.60	-	-	-
CS2P2L1	185.90	43.99	131.40	75.86	6
CS2P2L2	183.75	54.39	128.65	65.60	6
CH1P1L1	232.45	43.75	171.75	76.95	7
CH1P1L2	233.95	54.55	175.20	62.83	6
CH1P2L1	231.60	49.78	184.10	69.83	7
CH1P2L2	261.20	49.60	175.15	59.83	6
CH2P1L1	249.55	43.00	156.65	66.05	6
CH2P1L2	222.65	43.75	162.55	54.53	5

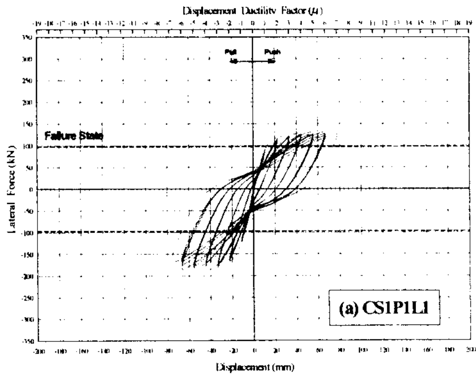


Fig. 2.1 Lateral Force-Displacement Diagram

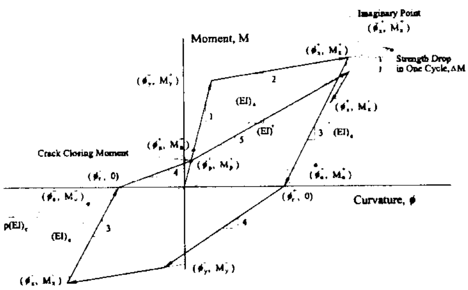


Figure 3.1 Typical Crack Closing Moment and Strength Deterioration

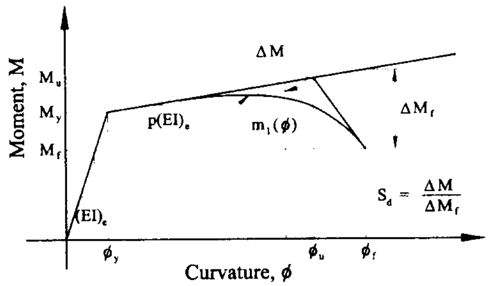
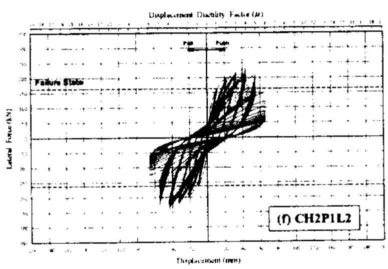
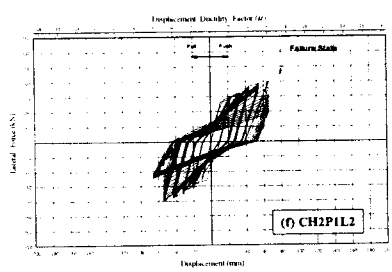


Figure 3.2 Strength Deterioration Curve



(a) Experimental Result



(b) IARCC Result

Figure 3.3 Comparison of Experimental and Analytical Result

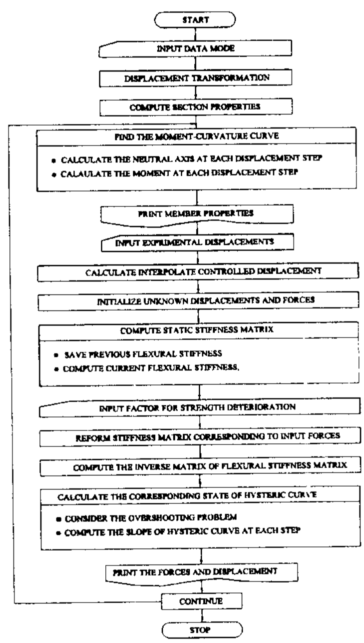


Figure 3.1 The Flowchart of Program IARCC